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INTRODUCTION

A subaerial terrace system extends intermittently around the western end of St. Croix, between the town of Frederiksted in the west to Cane Bay in the north (Fig. 1). The terrace is highly variable in both its elevation and depositional fabric. The abundance of corals, some apparently in growth position, strongly supports a marine origin for this feature. Its elevation above present sea level implies either 1) a marine highstand at the time of deposition, 2) subsequent uplift, or 3) some combination of both.

The following pages describe the lithologic character of this terrace system, and discusses its possible origin and depositional history. The project was started as a WIL class project (under the supervision of the senior author) in the summer of 1985 when 3 holes were drilled in the terrace and the nearshore pavement beyond. Three other class projects in the summer and fall of 1988 added 8 additional cores. Since then, a field program to measure and sample detailed sections in coastal exposures has been conducted.

The results reported here are only preliminary in nature. Also, our comments are confined primarily to the west shore, as core data along the north coast are not yet adequate to address how the northern . terrace relates to the one discussed below. Nevertheless, it is hoped that this information will provide a useful glimpse into the depositional history of an important geologic feature on the island.

DESCRIPTION

Gross Lithology in Core and Outcrop

In the initial coring survey, five basic rock types were identified (Fig. 2a). These include a fine grainstone (Type 1), a medium-coarse grainstone (Type 2), a medium-coarse grainstone with widely scattered granules, usually coral (Type 3), a fossil-rich rudstone with the coarser clasts (generally 10-15 mm across) comprising more than 50% of the rock (Type 4), and a fossil-rich rudstone with larger clasts typically exceeding 25-50 mm (Type 5). A variation of Type 4 and 5 rocks contains abundant terrigenous fragments from the nearby Caledonia Formation. These five lithologic types can be distinguished in outcrop with relative ease. Large-scale sedimentary structures enhanced by weathering are useful in discriminating between facies in outcrop. Cross-

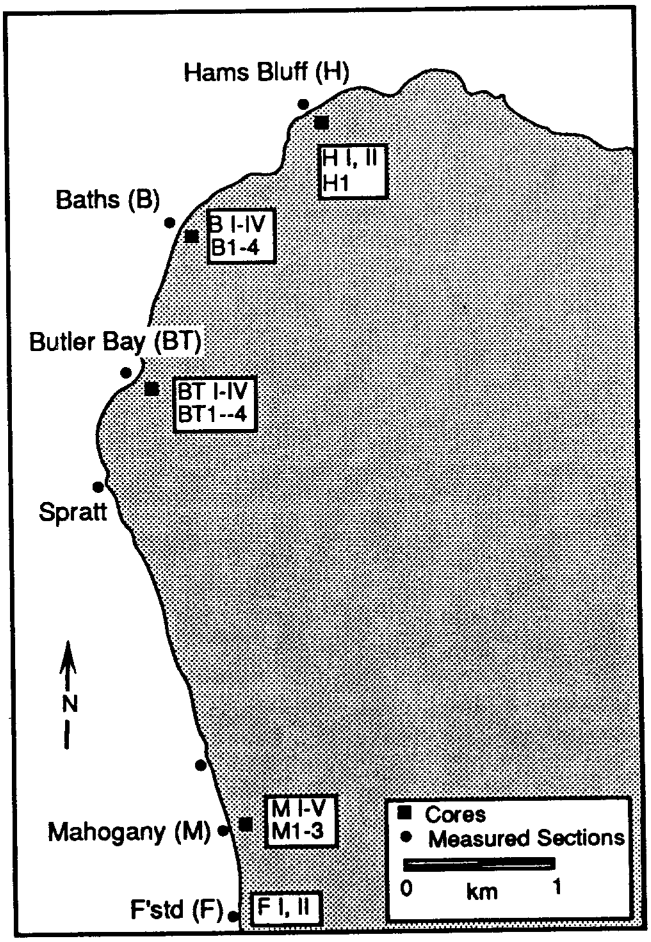


Figure 1. Map showing the location of measured sections and cores along the west coast of St. Croix.

bedding is a prominant feature in the uppermost rock units exposed at many sites. Weathering also enhances the detail on numerous fossils that occur throughout the area.

Stratigraphy

Stratigraphic units - Logs for the I I cores and 18 measured sections are included in Figures 3 and 4. Arabic numbers (i.e. M-1, M-2, etc.) are used to designate cores. Roman numerals (i.e. B-I, II, etc.) are used for the measured sections. Three sedimentary facies were identified and are described below. They are designated, from top to bottom, A, B and C.

At most localities, the uppermost section (unit "A") consists of a medium-coarse grainstone (rock type 2). Where not pitted by dissolution, grains appear moderately rounded. At outcrop scale, this unit usually exhibits large-scale cross-bedding. In thin section, the dominant sedimentary constituents (Table 1) include fairly well-rounded coral fragments, cryptocrystalline grains, red algae, and forams (Fig. 2c). The condition of the allochems and the relative abundances of voids and groundmass vary greatly within the unit. Some samples have very little cement and contain moldic voids. Many allochems display evidence of dissolution, in the form of worn skeletal fabrics (Fig. 2c), and a few coral fragments

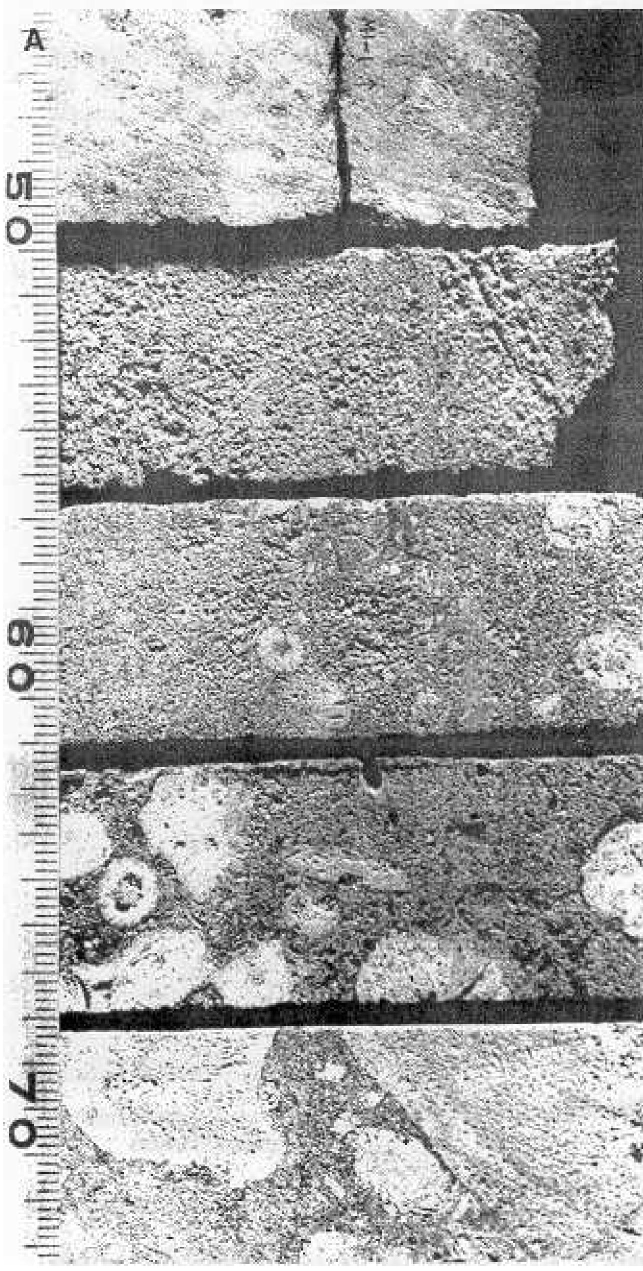
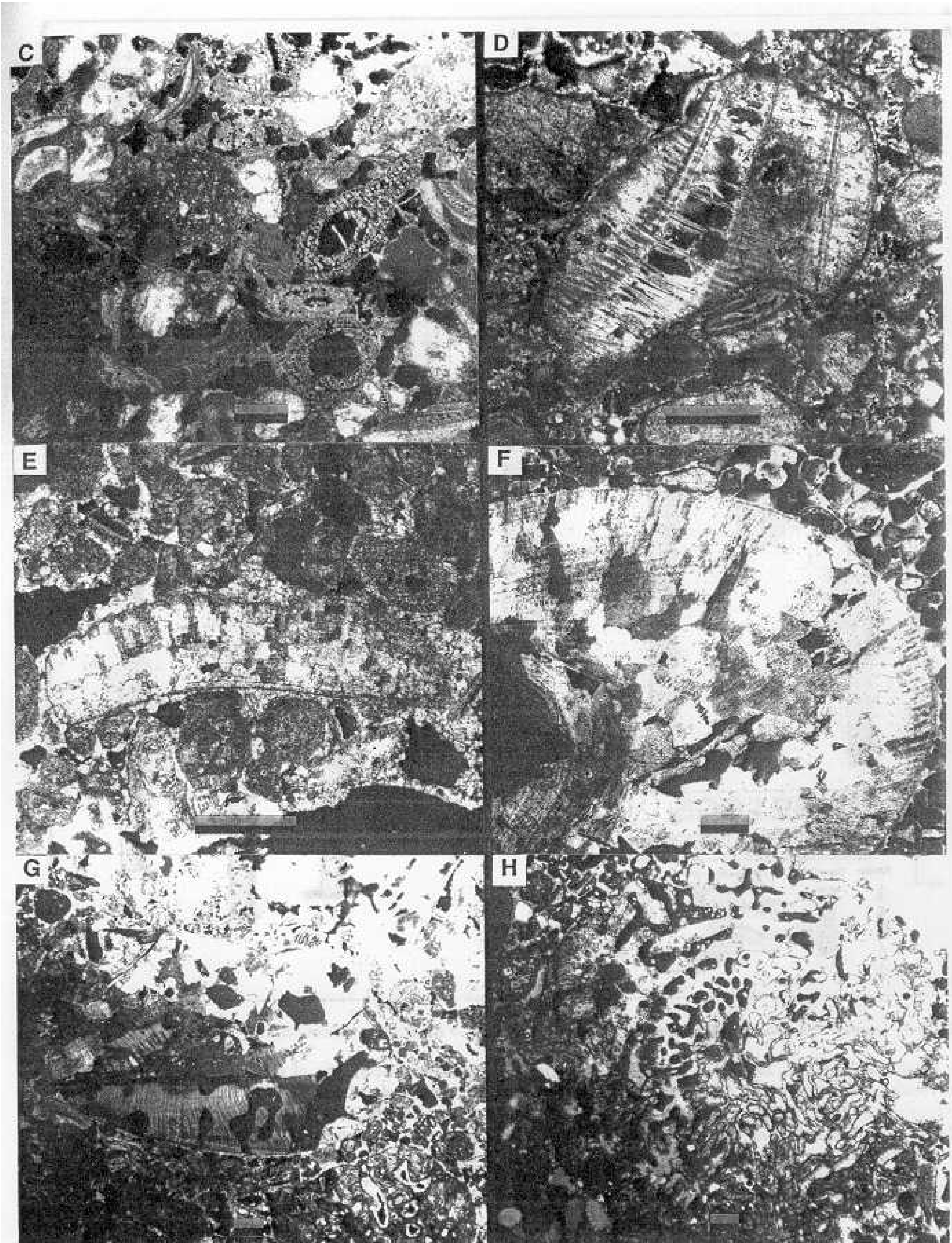


Figure 2. A. Five *rock types recognized in cores and measured* sections. *Rock Type 1 is at the top; Rock Type 5 is* at the *bottom. B. Measured section BT-1 at Butler Bay. The more* massive *unit at the top is from the* beach *(Unit A). The cross-bedded* unit *below* is *interpreted as beachface deposits. At this site, A.* cervicornis-rich *Unit "B" is missing (see* section in Figure 3). *The contact between facies A and B was bared on increased coral content near* the base *of the section. C. Sample B4-2: Skeletal fabrics of benthic forams dissolved by undersaturated waters. Scale 500μ; cross polarized. D. Sample MI-11: Nearly dissolved out skeletal fabric of* mollusc *fragment* highlighting *cross lamellar microstructure. Scale* 500μ; *cross-polarized. E. Sample* Af/-26: *Mollusc fragment that has been recrystallized to pseudospar. Scale 500μ; cross-polarized. F. Sample MI -I6: Mollusc fragment* which *has been neomorphically recrystallized and then partially dissolved. Scale 500μ; cross-polarized. G . Sample M1-26: Partially recrystallized mollusc fragment* which *displays worn skeletal fabric and has micrite-Jilled, non-skeletal fabric voids. Scale 500μ; cross-polarized. H. Sample M1-26:* Acropora cervicornis *fragment (cross. section) which has undergone partial dissolution leaving skeletal pore-shaped "blebs" of micrite. Scale* 500μ; *plain light.*


C
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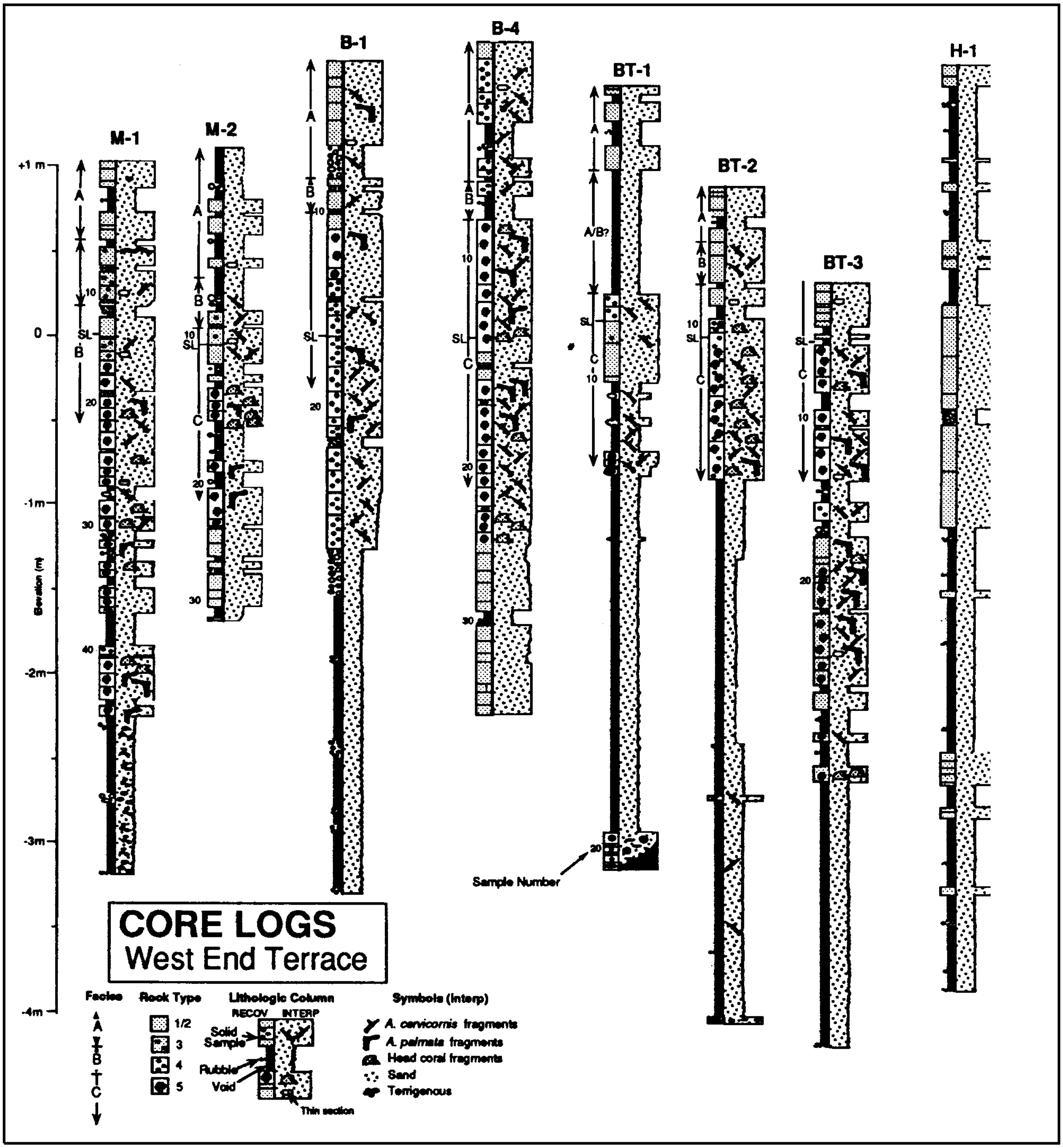

Figure 3. Logs of cores from the West End. M = Mahogany Road; B = Baths; BT = Butler Bay; H = Hams Bluff.

in these cement-free samples have been partially recrystalized to pseudospar. Other samples from unit A display abundant miniscus cement (Fig. 2d), show relatively little dissolution, and contain no evidence of recrystalization.

Beneath the cross-bedded grainstone, a coral-rich zone (unit "B"; rock types 3 and 4) often occurs. In hand specimen, the matrix of this rudstone appears similar to the grainstone of unit "A". In thin section, the dominant constituents include coral and mollusc fragments, along with encrusting forams. The allochems are generally degraded, and a relatively large number of grains (19.7%) display evidence of dissolution or worn fabric. This unit shows little cementation, and only a very small amount

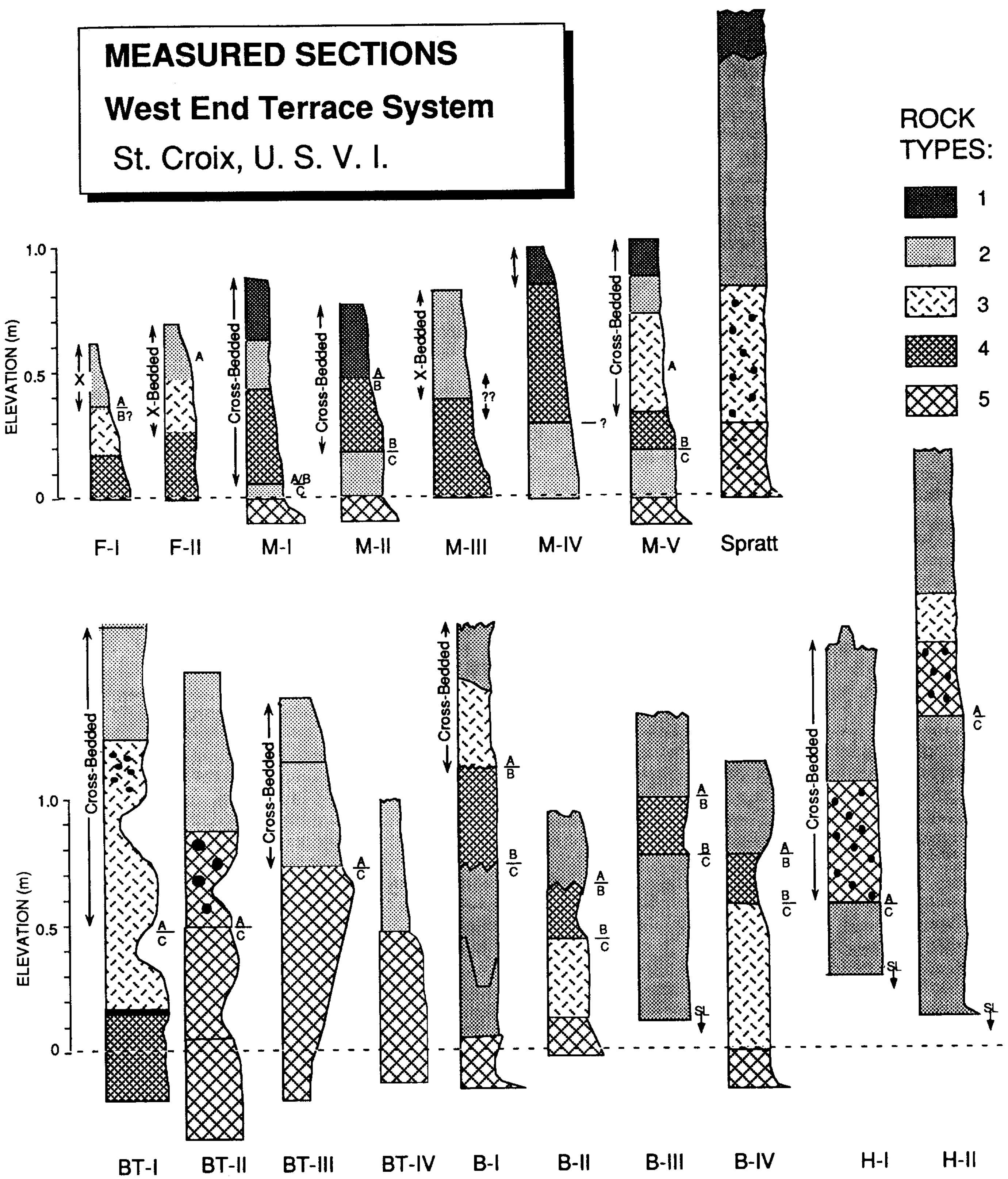

Figure 4. Measured sections from the West End terrace system. Sprats = Spratt Hall section; F = Frederiksted near the fort. Facies and rock types are shown.

of microspar between particles. No recrystallization of skeletal material was quantified in the point counts. Voids occur mainly between particles, but there is also a great deal of moldic void space. Widespread dissolution dominates the facies, evidenced by worn skeletal fabrics, moldic porosity and a paucity of cement. This unit displays numerous good examples of nearly dissolved skeletal fabric (e.g. Fig 2d). The larger allochems are dominantly fragments of the branching coral *Acropora cervicornis,* typically oriented in an onshore-offshore alignment. Where seen, this unit is usually cross-bedded (Figs. 2b), although in some instances this is not apparent.

The lowest ("C") unit is highly variable, but is usually a coral-rich or molluscan rudstone (rock types 4 and 5). Some of the corals are demonstrably in place, but most are toppled over or detrital. Common corals include *Acropora palmata, A. cervicornis, Montastrea annularis, Diploria* sp. and *Porites astreoides.* Coral abundance can exceed 50%. Where *A. cervicornis* is an important component of the coarse fraction (e.g. rock type 4), the coral sticks are not usually oriented as in the upper "B" unit.

In places, pebbles and cobbles from the Caledonia Formation can also be important components. Also, this unit can be comprised primarily of Type 2 grainstones, similar to those comprising Unit "A" (e.g. sections M-II, M-V; B-III in Figure 4). In the field, differentiation between upper (Unit "A") and lower (Unit "C") grainstones can be accomplished only by tracing them laterally in outcrop. Figure 5 is a series of photographs all taken at the same elevation near one another at the Baths (Fig. 1), and illustrates the lateral heterogeneity of unit "C".

In thin section, the dominant constituents of Unit C are coral and cryptocrystalline allochems. In some samples, red algae and mollusc fragments are also important (Table 1). The coral occurs as sand-size fragments as well as gravel-size clasts. The larger coral fragments may have sparry calcite cement or micrite infill of skeletal-fabric pores, and they are often encrusted by red algae, vermetid gastropods and encrusting forams. Allochems are generally degraded, microbored and often partly to mostly dissolved or recrystallized. Cement occurs as microspar at grain contacts, or it assumes a patchy meniscus-like distribution, consisting of microspar to orthospar that bridges several grains. It is not altogether clear whether this pattern reflects localized precipitation or dissolution of a wider-spread cement. Cement is also located within skeletal-grain fabrics, especially in corals and forams, as microspar and void-filling orthospar. Syntaxial overgrowths of echinoderms and forams are also present.

Dissolution is apparent in all Unit C thin sections, evidenced by non-fabric interparticle voids, moldic voids, worn skeletal fabrics and truncated patches of void-filling, interparticle orthospar. Many skeletal allochems, especially corals and molluscs, have been partly to completely recrystallized to pseudospar (Fig. 2e,f). Some samples display several stages of alteration; in sample M1-26, a partially recrystallized mollusc fragment displays worn skeletal fabric, and has micrite-filled, non-skeletal fabric voids (Fig. 2g). It also contains a mostly recrystallized *A. cervicornis* fragment which has partially dissolved, leaving pore-shaped masses of micrite surrounded by moldic voids (Fig. 2h).

Stratigraphic sequence - In general, these units occur in one of three sequences. The most common sequence contains all three facies (the "cross-bedded grainstone-rudstone" sequence; Fig. 6). The grainstones of unit "A" and the coral-rich rudstones of unit "B" exhibit well-developed cross-bedding. The lower "C" unit is separated from the upper lithologies by an abrupt contact, and is typically a coral or mollusc-rich rudstone. At the "Baths" site, the upper unit is exposed in two pits excavated by the Knights of Malta in the 1700's (Fig. 7). Near these pits, the three-dimensional geometry of unit "B" can be observed, and it appears to pinch out in a seaward direction over a distance of a few meters (Fig. 7).

There are two variants to this most-often observed sequence. At some localities (e.g. sections BT-III and IV; Fig. 4), the "B" unit is missing, and the upper grainstone sits directly atop the lower, coral-rich facies ("Cross-bedded Grainstone" of Figure 6). At other localities (e.g. Hams Bluff and Spratt Hall; Figs. 1 and 4), the upper unit contains a significant proportion of terrigenous pebbles and small cobbles, often oriented along what appear to be cross-bedding planes (the "Caledonia Pebble" sequence of Figure 6).

Chronostratigraphy - A single potassium-argon date from an unmodified conch shell near the upper boundary of unit "C" at the "Baths" yielded an age of 125,000 years (Lynton Land, written comm.). A mollusc shell from unit "A" in core B-1 at the "Baths" (Fig. 8) yielded a radiocarbon date of >31,000 ybp, and is assumed to be radiocarbon "dead". A sample of *A. palmata* from core B-2, located 25 m offshore from the Baths, was radiocarbon-dated at 29,600 ± 550 ybp. The sample contained modem marine cements, however, and this date is considered a minimum. Inasmuch as the last time sea level reached the level of the sample in core B-2 was during the Sangamon highstand, it is assumed that this sample is contemporaneous with the other two for which dates are presently available.

At this time, the temporal framework of these deposits is poorly defined, and additional information is necessary to better differentiate events recorded in the cores and measured sections. For the purpose of discussion below, it is assumed that the two radiocarbon-dated samples were deposited during the 125,000 ybp time frame indicated by the K-Ar sample from unit "C". While this seems to be a reasonable assumption, the very limited data base should be kept in mind throughout the ensuing discussion.

Table 1. Point-count data for thin sections from West End core sample thin sections. Totals for each category, void, groundmass and allochems, are represented by percentages relative to a total of 300 points counted per thin section. subcategories, such as constituent allochems, are percentages normalized to total allochems. BP = between particles; WPF = within particle fabric; WPNF = within-particle, non fabric; MO = moldic; cryptoxl = cryptocrystalline; matrix = particles < 0.10 mm.

SAMPLE NO.	ELEV (m-sl)	FACIES	VOID				GROUND-MASS			ALLOCHEMS							
			TOTAL	BP	WPF	WPNF & MO	TOTAL	CEMENT	MATRIX	TOTAL	CORAL	RED ALGAE	MOLLUSC	FORAM	CRYPTOXL	NON-CaCO3	OTHER
B4-2	+1.35	A	28	66.8	15.4	17.9	6	23.3	76.6	66.1	41.9	18.2	8.6	19.7	5.6	0	6
BI-5	+1.2	A	11.6	92.2	2.6	2.6	30.8	63	37	57.7	27.7	10.4	10.4	12.9	29.5	0.5	9.1
M2-5	+0.5	A	29.6	98	1	1	6.0	5	95	64.4	63.7	2.6	8.9	6.3	16	0	2.5
M1-11	+0.28	B	27	61.9	12.2	25.9	10.7	6.5	93.5	62.2	45.5	4.8	23.6	19.8	3.2	0	3.1
BT3-2	+0.25	C	27.7	90.3	9.7	0	4.6	28.3	71.8	67.6	53.7	12.3	7	17.3	7.8	0	1.9
BT2-9	+0.23	C	36.3	91.7	1.9	6.3	7.3	54.8	45.2	56.4	20.7	6.6	11.2	12.4	45.6	0.5	3.5
M2-10	@SL	C	22.6	5.8	45.6	48.7	13.2	34.9	65.2	64	66.7	1.6	15.6	10.3	4.2	0	1.6
M1-16	-0.10	C	24	94.6	0	4.2	13.3	64.7	35.3	62.7	21.9	4.8	8	8.5	55.3	0	1.5
BT3-13	-0.83	C	21	91.9	3.3	4.8	15.6	48.7	51.3	63.4	50	20.5	6.8	14.2	5.8	0	2.7
M1-26	-0.85	C	21.3	56.3	0	43.7	29.1	72.2	27.8	49.7	61	1.4	15.5	0	20.7	0	1.4
BT3-22	-1.85	C	24	20.8	4.2	75	53.7	5.6	94.4	22.4	40.2	26.8	3.1	8.9	16.5	1.3	4.5
B4-37	-2.0	C	29.7	32.7	0	67.3	36.3	5.5	94.5	33.9	43.4	15.6	3.8	1.8	34.5	0	0.9

FACIES INTERPRETATIONS

Units "A" and "B" are interpreted as deposits from a beach environment. Higher in the section, sediment laminations slope uniformly in a seaward direction, similar to the pattern seen in modern mid-beach deposits. The coral-rich "B" unit typically contains bidirectional cross-laminations more characteristic of the lower beach just below still-water level. The greater abundance of small coral fragments in the lower unit is interpreted to reflect size sorting between the surf zone and the area of beach runup. The pinching out of the "B" unit at the "Baths" (Fig. 7) is also consistent with this interpretation. On most exposed beaches around St. Croix today, a narrow zone of coarse pebbles can be found just below still-water level (i.e. near the beach "step"). This material is gradually accumulated as it moves onshore but cannot be transported up onto the beach face by ambient wave conditions. Because it is also not deposited further offshore, the coarse material is concentrated in a relatively narrow band near the base of the beach slope.

Elsewhere in the Caribbean, similar cross-laminations have been interpreted as fossil dunes (for a summary, see McKee and Ward, 1983). It is unlikely that the cross-bedding seen in units "A" and "B" is related to fossil dunes, however. Both modern dune sands and their ancient counterparts are typically fine-grained (McKee and Ward, 1983) and very well sorted (Ball, 1967; Ward and Brady, 1973). The sediments within the terraces on St. Croix are much coarser-grained and are typically poorly sorted. It is difficult to envision eolian processes depositing the sediments on the west end of St. Croix.

The lower "C" unit is interpreted as a nearshore pavement-reef similar to the one occurring seaward of the elevated terrace today. Based on the radiocarbon date from offshore core B-2, most of the nearshore pavement fronting the elevated terrace seems to be contemporaneous with unit "C" from the cores and measured sections on shore. Samples recovered from holes B-2 and B-3 (Fig. 8) are generally reworked and cemented corals that are very similar to the larger allochems of the "type 5" rudstones. The reason for the vuggy porosity in the offshore cores relative to their landward counterparts is not understood at this time.

As discussed above, the character of unit "C" varies laterally from site to site and vertically within a single core. The present reef community seaward of the terrace is similarly variable. Over short distances, benthic cover is dominated by branching corals, head corals, loose sand

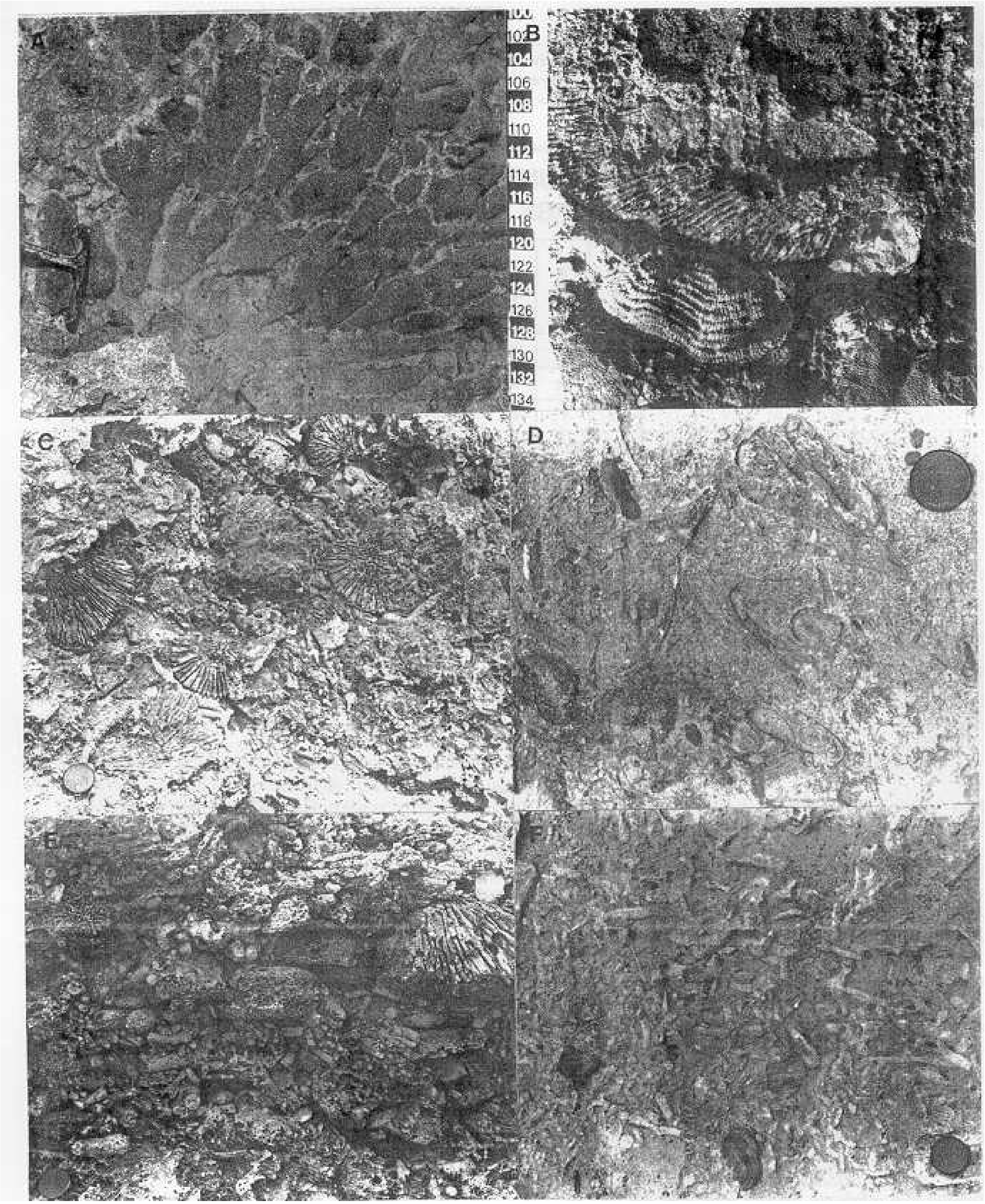

Figure 5. Photographs of unit C near the Baths illustrating its lithologic variability A. Large colony of knobby M. annularis. *Hammer for scale. B. Overturned colonies of* M. annularis *and S.* siderea. *Sacle in centimeters. C. Mixed assemblage of head corals in a rudstone matrix. Lens cap for scale in this* and *following photos. D. Concentration of mollusc shells* (Strombus). *E. Mixed head-coral and A. cervicornis debris. F. A. cervicornis rubble in a reef channel (?).*

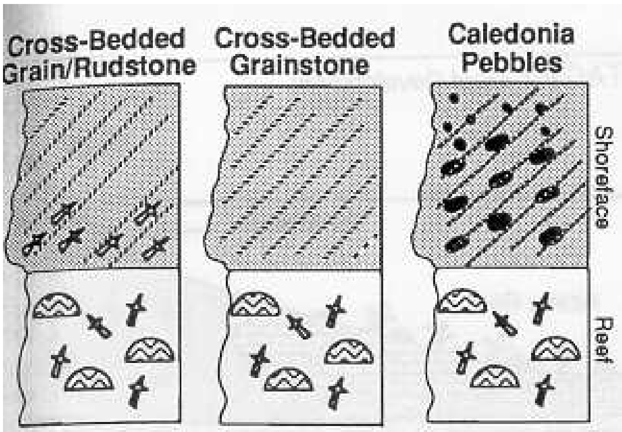

Figure 6. Three "typical" sequences found in the cores and measured sections.

or hard, bioeroded pavement. These environments have likely shifted over time, and this migration is probably responsible for the lateral and vertical variability seen within unit "C".

Depositional History

The one reliable date from Unit "C" indicates deposition at around 125,000 ybp. This would correspond with the Sangamon highstand of approximately +5m. The radiocarbon date from beneath the nearshore hardground implies pre-Holocene deposition, likely contemporaneous with that of unit "C" on shore. Unit "C" and most of the nearshore pavement were probably deposited during the latter stages of the Sangammon sea-level rise in a reef-like setting (Fig. 9A). Based on the amount of coral found in the cores (Fig. 3) and on the surface of the terrace (Fig. 5), coral cover was probably higher than on the present offshore pavement. The dominant coral species included A. *cervicornis, A. palmata, Montastrea annularis, Diploria* sp. and half a dozen other head corals.

A well-developed molluscan community was also present, and contributed significantly to the fossil record. The dominant molluscs include *Strombus* sp. and *Cittarium* sp. In some instances, these have produced pockets of nearly 100% molluscan material (Fig. 5d).

At some point, stabilization of sea level limited upward accretion of the nearshore reef. Carbonate production on the shelf continued to supply sediment to the adjacent beach which gradually prograded over the nearshore pavement (Fig. 9B). Where present, the "B" unit represents the lower part of the beach and the immediate nearshore zone. Coral fragments in the "B" unit were likely derived from a nearshore community of active A. *cervicornis* and washed inshore to the base of the beach face. The greater importance of terrigenous clasts in the upper units probably reflects the influx of detritus washed out of the upland Caledonia Formation during heavy rains, a process which continues today.

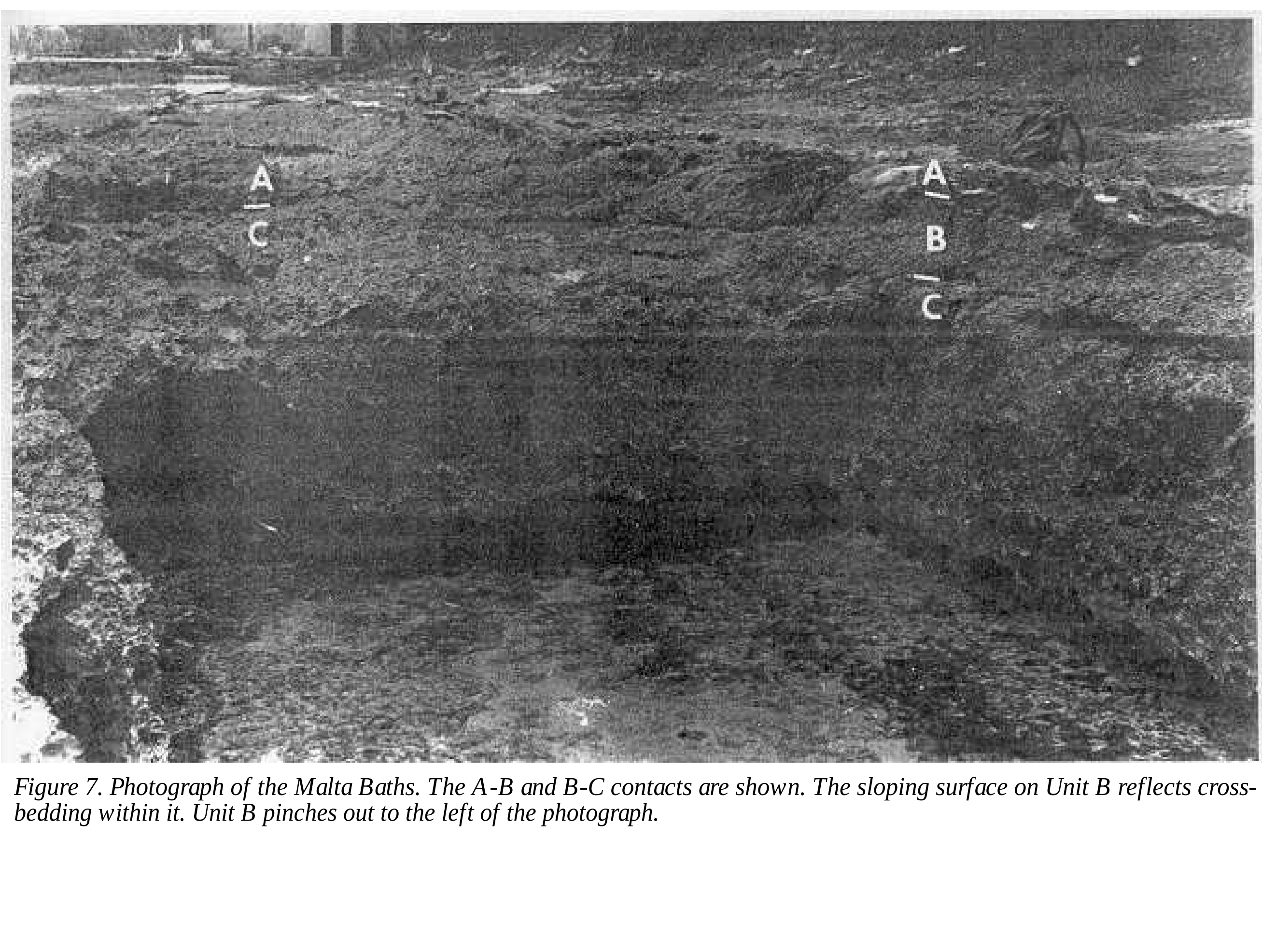

Figure 7. Photograph of the Malta Baths. The A-B and B-C contacts are shown. The sloping surface on Unit B reflects cross-bedding within it. Unit B pinches out to the left of the photograph.

From the limited chronostratrigraphic information offshore, it appears that most of the material beneath the present hardground is pre-Holocene in age. This implies that, during Holocene time, bioerosion on the existing pavement has matched or exceeded carbonate production by the sparse benthic community that presently exists (i.e. there has been no net accretion). An unanswered question in this regard is why the Pleistocene reef community was apparently better developed than the one existing today.

Another problem relates to the temporal framework of the present hardground. The one sample from beneath the hardground predates the Holocene. Off the "Baths", this hardground is continuous and very flat. Few holes can be found penetrating its surface. Yet lead fishing sinkers were recovered in the offshore cores. Inasmuch as there is no conceivable way for such artifacts to easily get through the present surface, the development of a continuous crust must be a fairly recent event. The environmental conditions responsible for this phenomenon are presently uncertain.

TECTONIC IMPLICATIONS

Most discussions of the geologic history of St. Croix (e.g. Multer *et al.,* 1977; Gerhard *et al.,* 1978) have concluded that tectonic activity on the island has been largely dormant since Miocene time. Data from the West-End terrace imply, however, that this activity continued at least through the Pleistocene and is likely still occurring. The contact between the upper beach facies and the lower reefal facies generally slopes in a southerly direction (Fig. 10). While there is variability in the elevation of the contact in the measured sections and core holes at each site, there is little overlap between sites and a definite southerly dip can be discerned. While this amounts to less than one degree, the uniform 1.24 m drop in the inferred contact between the upper ("A" and "B") and lower ("C") units over a distance of approximately 5 km cannot be adequately explained by depositional processes alone.

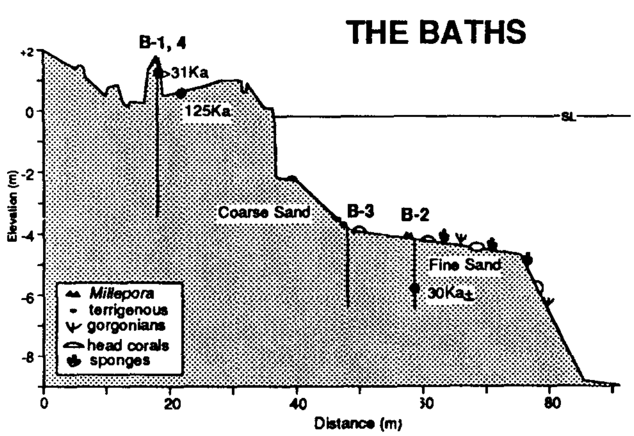

Figure 8. Cross section near the Baths. The locations of cores and three dated samples are shown.

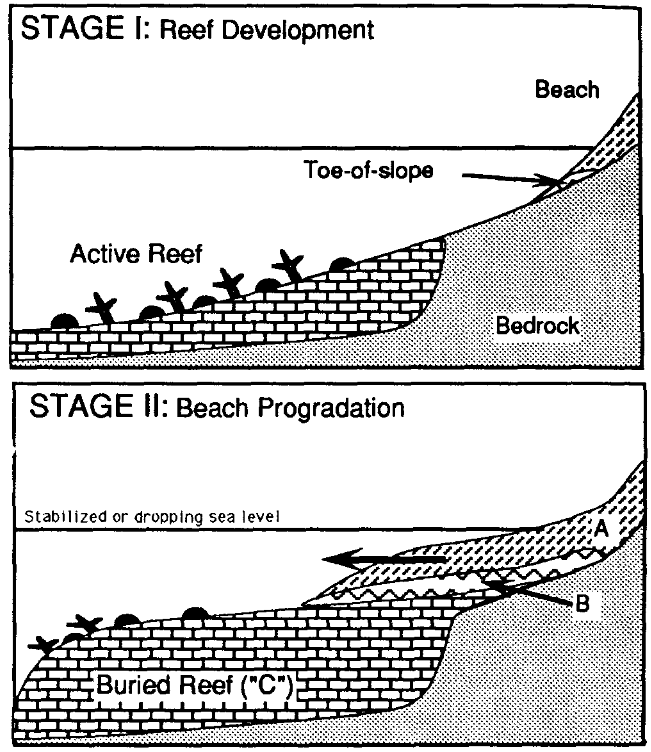

Figure 9. Stylized diagrams illustrating deposition of the reef (Facies Unit C) and later progradation of the beach (Facies Unit A-B).

It is proposed that this represents southerly tectonic tilting since the rock units of the West-End terrace system were originally deposited 125,000 years ago.

Recent investigations support this idea. Gill and Hubbard (1985) and Gill *et al* (this volume) reported faulting along the south-central coast of the island that displaced strata of Pliocene age. Based on seismic data, Holcombe a al. (in press) describe southern tilting in rocks off the west coast of St. Croix. Despite earlier conclusions that St. Croix has been tectonically quiet for the past 20-30 million years, the southward dip in the contact between the upper beach units (A and B) and the lower reefal unit (C), along with recent findings by other investigators paints a picture of continual tectonic activity through to the present.

WHERE TO GO

The best exposures of the West End terrace system occur near the measured sections located in Figure 1. These are all easily accessible from the road north of Frederiksted. The upper, cross-bedded units are well-exposed along the southern side of Butler Bay and in a few elevated blocks around the "Malta Baths". The reefal facies is easiest to see and most diverse near the "Baths". Excellent examples of well-preserved corals and molluscs can be examined in plan view anywhere along the exposed terrace surface. The rock pools excavated by the Knights

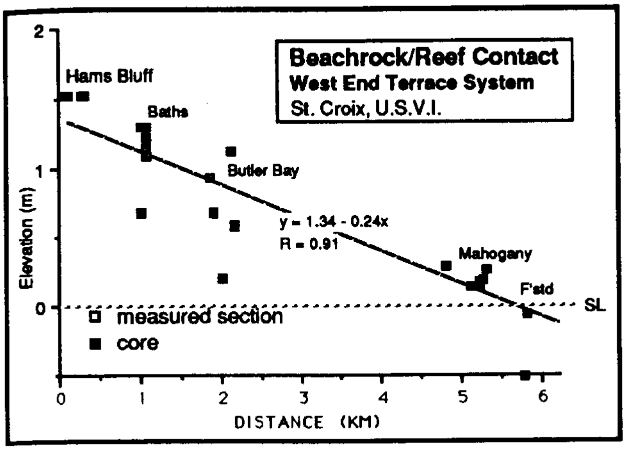

Figure 10. Elevations of the contact between facies A-B and C at Hams Bluff, the Baths, Butler Bay, Mahogany Road and Frederiksted. The contact dips southward (confidence limit > 0.90).

of Malta (Fig. 7) provide a "block-diagram" view of all three stratigraphic units discussed above.

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