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A field guide to the Late Pleistocene coral reef deposits of Treasure Beach, Jamaica

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ABSTRACT. The Falmouth Formation, deposited during the Last Interglacial Warm Period, is the youngest of a series of raised terraces that form part of the Coastal Group in Jamaica. The similarity in species composition to modern coral reefs makes it a useful fossil analog for long-term changes in reef systems. While the outcrops of the Falmouth Formation along the north coast of Jamaica have been extensively documented, relatively less work has been conducted on the exposures along the south-western coastline. This guide covers eight stops along the stretch of coastline from Great Bay to south of Fort Charles, Treasure Beach. Eight facies (TB1–TB8) were identified along the traverse. They indicate a range of reef environments from the more distal crest to proximal patch reefs and lagoons. The eastern outcrops (Sites 1–3) show a distinct two-tiered structure interpreted as progradation whereas the more western outcrops (Sites 4–8) show a conformable retrogradation pattern.

Keywords: Treasure Beach, Late Pleistocene, coral reefs.

1. INTRODUCTION

The geological history of Jamaica can be succinctly summarized in four phases: 1) the Cretaceous Great Arc subduction volcanism, 2) Paleocene to early Eocene rifting, 3) mid-Eocene to mid-Miocene carbonate deposition, and 4) mid-Miocene uplift (**Draper, 1998**). The last of these phases results in the deposition of the Coastal Group shaped by regional tectonics and global fluctuations in sea level.

The Falmouth Formation (**Figure 1**), the youngest member of the Coastal Group, was first described by **Hill** (**1899**) as "white chalky marl, usually friable but frequently indurated. In this are preserved numerous mollusks and fragments of reef-building corals." A more comprehensive description of the formation was undertaken by

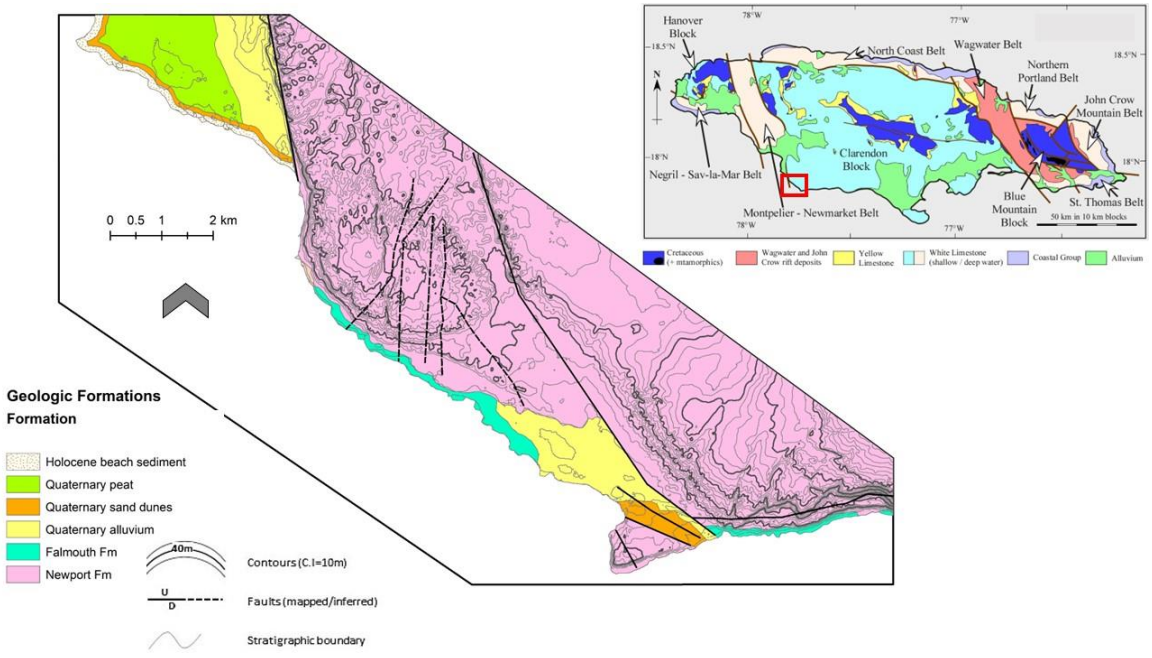

Figure 1. Geological map of the southern St. Elizabeth (adapted from Benford et al., 2014 which was redrawn from Wright, 1975). The location of the area is shown in the geological map of Jamaica reproduced with permission from Mitchell and Edwards (2016).

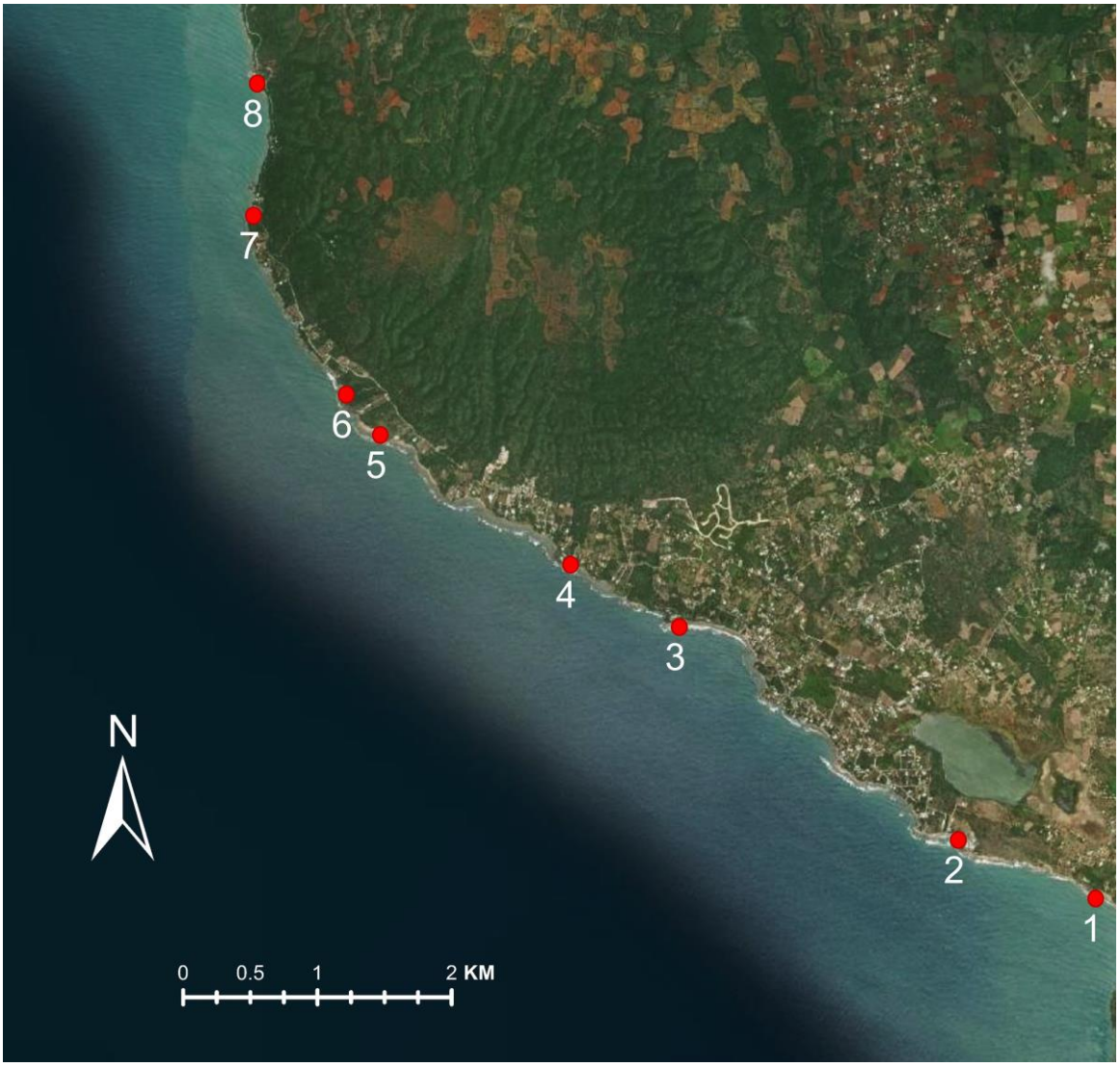

Figure 2. Stops along the coastline of Treasure Beach. The traverse runs from Great Bay to Fort Charles Beach. Sites: 1, Great Bay; 2, Tranquility Bay; 3, Frenchman's Bay; 4, Pelican Villa; 5, Black Spring Point; 6, Natural History Museum/Treasure Beach Turtle Group; 7, 0.4 km North of Dream Away Beach; 8, 0.5 km South of Fort Charles Beach.

Cant (**1971**) and **Burne and Cant** (**1972**) who, via U-Th absolute dating, determined the time of deposition to be during the Last Interglacial Period.

The Falmouth Fm provides particular insight into the Quaternary tectonics of Jamaica (**Horsfield, 1975**; **Skrivanek et al., 2017**) as well as long-term patterns of coral reef zonation and environmental response (**Boss and Liddell, 1987**; **Perry, 2000**). While much of the research into the Falmouth Fm. has been conducted along Jamaica's northern coastline (**Liddell et al., 1984**), there remains a paucity of information about the southwestern coastline. **Hendry and Head** (**1985**) provide the first published attempt to describe the Quaternary deposits along the southwest coastline near Great Pedro Bluff. **Maharaj** (**1996**, **2000**) further provides a depositional model of the overlying units deposited during the Last Glacial Period and early Holocene. A series of strike-slip fault splays are also proposed to run orthogonally to the Treasure Beach fault parallel to the coastline (**Maharaj, 2000**).

This field guide was adapted following a successful trip by the Geological Society of Jamaica to Treasure Beach, St. Elizabeth on the 15th April 2023. The Late Pleistocene coral reef exposures along this stretch of coastline are exceptionally well-preserved and show a wide array of geometries and growth fabrics that have been interpreted using the classic reef descriptions of **Goreau** (**1959**). It is anticipated that this guide will serve as a useful foundation and encouragement for future work in the area.

2. Methods and Descriptors

Outcrops are described using the terminology of **Embry and Klovan** (**1971**) and **Insalaco** (**1998**) based on the growth fabric. **Cairns** (**1982**) can be consulted for further information on field identification of coral species. Relative abundance of coral species is noted using the terms dominant (>75%), abundant (51–74%), frequent (26–50%), infrequent (11–25%), and rare (1–10%).

3. Localities

The traverse is approximately 9 km along the Late Pleistocene fossil reef exposures spanning the coastline from Billy's Bay in the northwest to Great Bay in the southeast (**Figure 2**). Attempts were made to locate suitably well-preserved Falmouth Fm. exposures west of Great Pedro Bluff. However, all exposures here are almost entirely covered by lithified beach rock or too degraded to discern any coral species or growth fabric. Sea cliffs of the Falmouth Fm. exposures along the study area ranged from 1.7 m to 10 m above present sea level (APSL). Seaward of these cliffs is bordered by a continuous wave-cut platform. Landward of the Falmouth Fm. exposures is both a modern and lithified dune system. The lateral growth fabric of the corals is often obscured by coarse-grained quartz beach-rock with low-angle cross-bedding.

Stop 1: Great Bay

GPS: 17° 52' 2.7156" N, 77° 44' 33.5652" W

This is the easternmost site of the traverse and can be located by driving to the end of Great Bay Road near the access point to the beach. From this point, there is a five-minute walk northwest along the beach to the first outcrop at the headland.

The upper tier reef unit consists of large in-situ stands of *Acropora palmata* corals approximately 1.1 m high. The stands immediately at the edge of the shoreline (**Figure 3B**) have a mono-specific coral composition and an open framework. Landward exposures show a mixed coral composition with *A. palmata* remaining the dominant frame builder and abundant *Siderastrea radians*. Unlike the *A. palmata* stands immediately along the shoreline, these landward stands are heavily encrusted by up to 30 cm of microbialites and crustose coralline algae. The interstitial space between the fronds of the landward-most exposure of encrusted *A. palmata* is heavily occluded by quartz-rich, coarse-grained sand cemented to form friable beach rock shown in **Figure 3D**. *Aliger gigas* and bivalves can be observed "floating" within the beach rock matrix. The lower tier of the exposure is heavily degraded consisting of *A. palmata* rubble and planate massive coral heads of *Psuedodiploria strigosa* shown in **Figures 3A** and **C**.

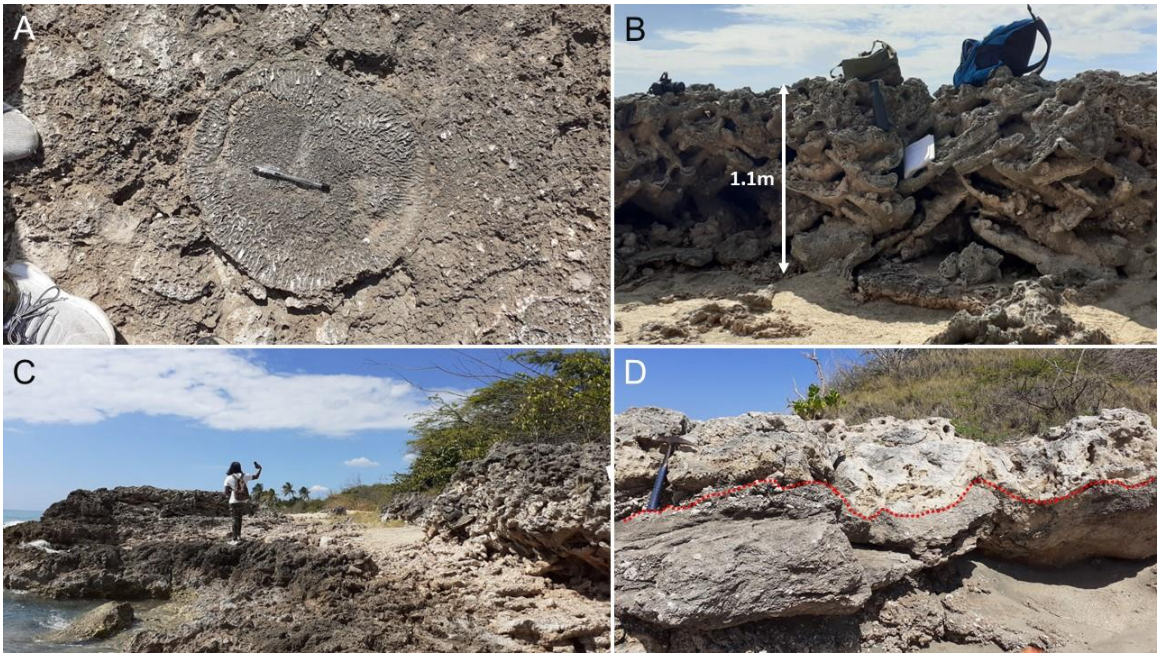

Figure 3. A, eroded planed head of *P. strigosa* at base of *A. palmata* stands. B, in-situ *A. palmata* stands approximately 1.1 m tall. C, organization of two *A. palmata* stands and intervening planed surface of rubble and *P. strigosa* coral heads. D, heavily encrusted *A. palmata* framestone overlain by siliciclastic beach rock. (Hammer = 33 cm).

Figure 4. A, 1.3 m tall patch reef at the top of the in-situ *A. palmata* sequence shown in D. B, thin "coral carpet" of fragments of *P. furcata* and *P. porites* encrusted by *S. radians*. C, view of Tranquility Bay showing east direction. Note the differences in elevation between east and west headlands. D, eastern headland of Tranquility Bay showing a vertical change from in-situ *A. palmata* stands to patch reef systems.

Site 2: Tranquility Bay
GPS: (West) 17° 52' 10" N, 77° 45' 03" W
(East) 17° 52' 10" N, 77° 45' 01" W

Stop 2 is located by walking along the coastline westward from Stop 1 for approximately 1 km. Two exposures can be observed on either side of the small bay, Tranquility Bay East and West (**Figure 4C**), both show a two-tiered reef growth structure. The lower tier on both east and west exposures consists of dominant in-situ *A. palmata* approximately 1.1 m tall and infrequent *Siderastrea* sp. The eastern headland of the bay is approximately 2.4 m (**Figure 4D**) high of which 1.1 m can be accounted for by the lower tier and 1.3 m by the upper tier. The upper tier of the eastern headland consists of patch reefs approximately 1.3 m high dominated by *Colpophyllia natans* and *P. strigosa* (**Figure 4A**).

The western headland shows a lower elevation of approximately 1.1 m with a similar lower-tier coral composition. However, the upper tier consists of a thin (approximately 10 cm thick) "coral carpet" of abundant *Porites porites*, *Porites furcata*, and *S. radians* (**Figure 4B**). The coral composition of the upper tier is responsible for the difference in elevation between the eastern and western headlands of Tranquility Bay as seen in **Figure 4C**.

Stop 3: Frenchman's Bay
GPS: 17° 53' 4.8948" N, 77° 46' 13.944" W

Return to the parking spot at the end of Great Bay and drive to the corner of Mair Rd. and Great Bay Rd. Turn left and proceed southwards until the end of the road then turn right. The beach can be accessed through the Waikiki Guest House. A small trail is also found opposite the Treasure Beach Inn and Bar. Walk west along the beach until the headland.

The western headland of Frenchman's Bay also exhibits a two-tiered structure similar to Great Bay and Tranquility Bay with a similar height of 2 m APSL. The lower tier is mixed in composition with *A. palmata* being dominant at the base grading to mixed framestone then hemispherical coral framestone at the top. The top of the lower tier is dominated by *Pseudodiploria* sp. coral heads notably all approximately 40 cm in height (**Figure 5A**). The upper tier consists of instances of planation of the *Pseudodiploria* sp. coral heads and recolonization of the surface by *S. radians* (**Figure 5B**).

Stop 4: Pelican Villa, Billy's Bay
GPS: 17° 53' 20.1912" N, 77° 46' 43.2768" W

Return to the parking spot and continue westward along Fort Charles Rd. to Billy's Bay Beach. The beach can be accessed through a trail next to Villa Elegance and Destiny Villa. Once on the beach, turn right and walk east until the headland. The coastal exposure behind Pelican Villa is 3 m high. The lowest unit is approximately 1 m thick and consists of isolated basal hemispherical *Pseudodiploria* sp. coral heads within medium to coarse-grained bioclastic sand (**Figure 6A**). This is overlain by an upper unit of platestone and rudstone composed of branched calcareous coralline agal tubes, and sparse *Acropora cervicornis* (**Figure 6B**) grading into in-situ and ex-situ *A. palmata*. The lower and upper units are conformable and separated by an indistinct surface.

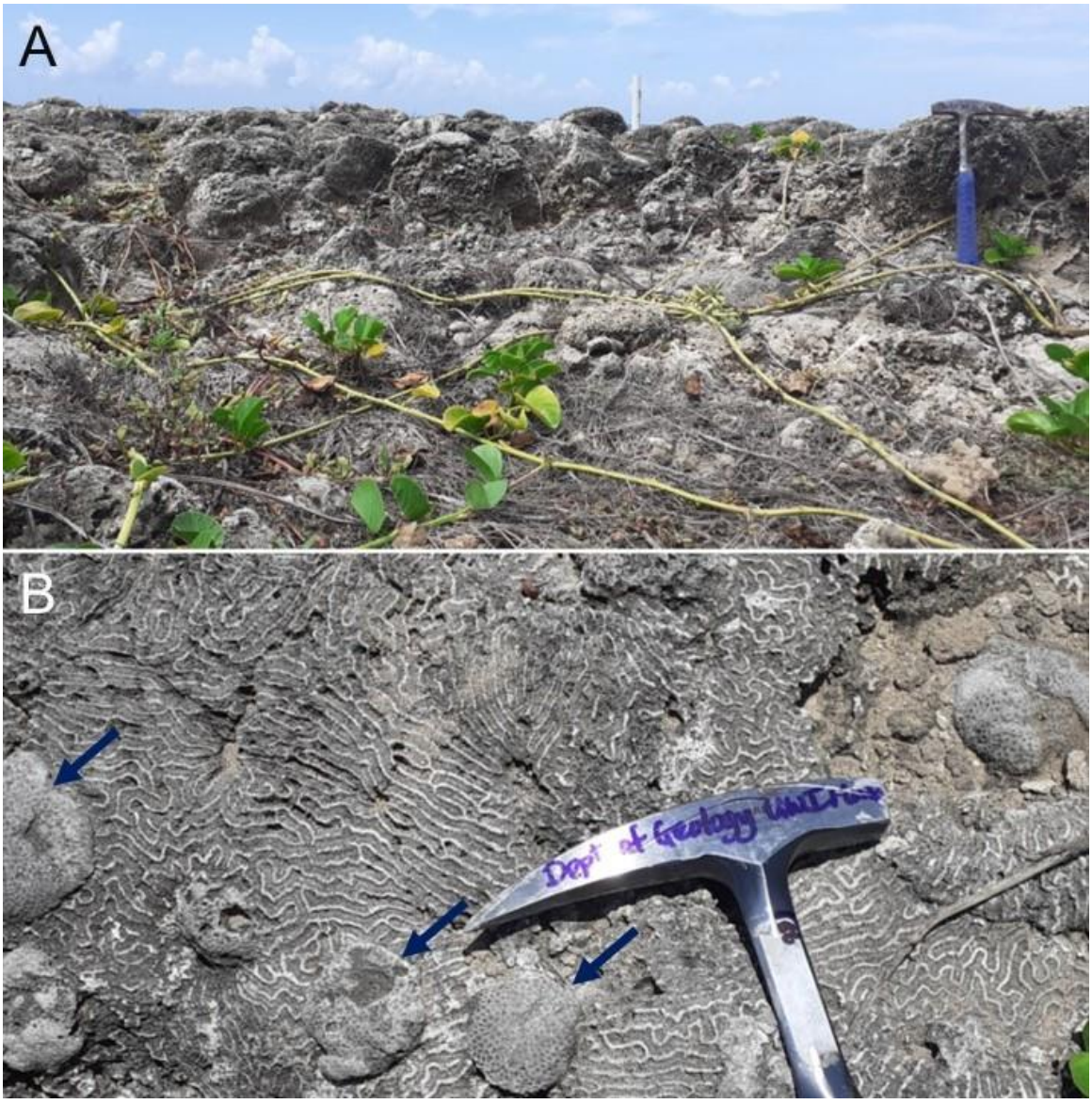

Figure 5. A, hemispherical coral heads at the top of the outcrop at Frenchman's Bay. B, eroded head of *P. strigosa* recolonized by *S. radians* indicated by blue arrows. Hammer is 33 cm.

Stop 5: Black Spring Point

GPS: (East) 17° 53' 52.7928" N, 77° 47' 32.3412" W
and 17° 53' 48.39" N, 77° 47'25.62" W
(West) 17° 53' 46.8564" N, 77° 47' 23.4816" W

Return to parking and continue westward along Fort Charles Rd for approximately 1.57 km. There is a wide access road on the left-hand side (likely an incomplete construction project). Drive to the end of the access road and enter the beach. Outcrops for Black Spring Point (BSP) East can be observed along the cliff face while walking approximately 500 m southeast (turn left once entering the beach). BSP West can be observed along the cliff face walking 100 m northwest (turn right once entering the beach) from the access point.

Outcrops near Black Spring Point exhibit a range of facies geometry. A major elevation difference can be observed at this site compared to Sites 1-4. These exposures are over 8 m high. Two distinct traceable units are present. A lower unit ranges from 1-4 m in thickness and consists of bioturbated carbonate sand with sparse isolated corals such as *Eusmilia fastigiata*, *C. natans*, and *Pseudodiploria* sp. The upper unit is a mixed framework of *A. palmata* clasts with a wide range of states of surface preservation and encrustation, in-situ *A. palmata*, massive coral species, and branched coral species such as *A. cervicornis*. Interstitial sediment between coral clasts can also be observed within this unit.

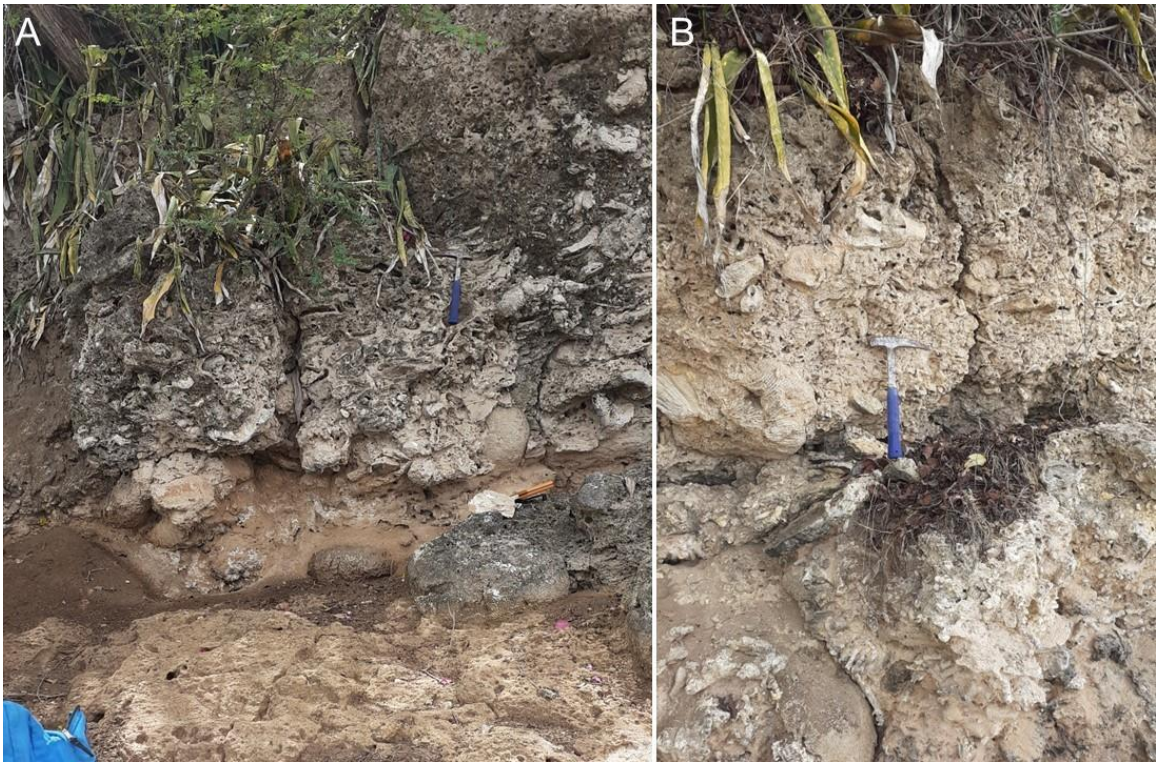

Figure 6. Pelican Villa, Billy's Bay A, indistinct surface of basal massive hemispherical corals within carbonate sand. This is overlain by coral rudstone containing *A. palmata* clasts. B, thicket of *A. cervicornis*, calcareous algal tubes and *A. palmata* rubble.

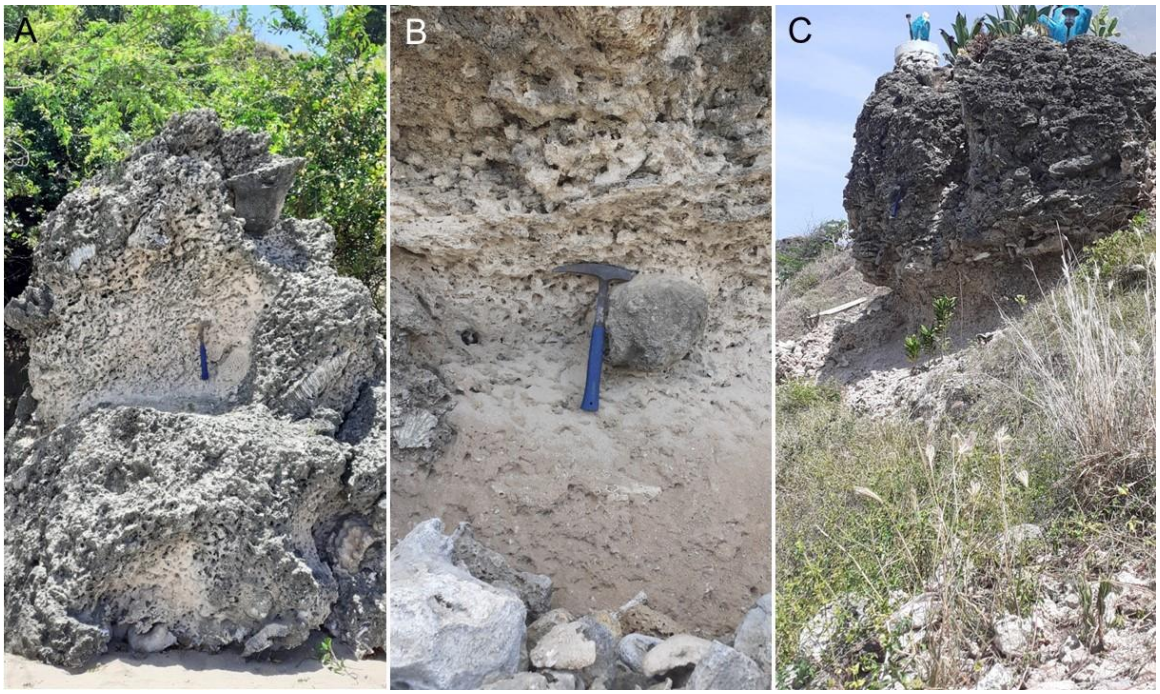

Figure 7. Black Spring Point. A, detached block of Falmouth outcrop consisting of lagoon sands and overturned coral heads. B, lower unit of lagoon sand with isolated branched and massive corals. C, upper unit of coral framework underlain by discontinuous lagoon sediment east of Black Spring Point.

The boundary between the lower and upper units is sharp with a thin transition (<8 cm) to cross-laminated coarse-grained sands at the top of the lower unit (**Figures 7-8**).

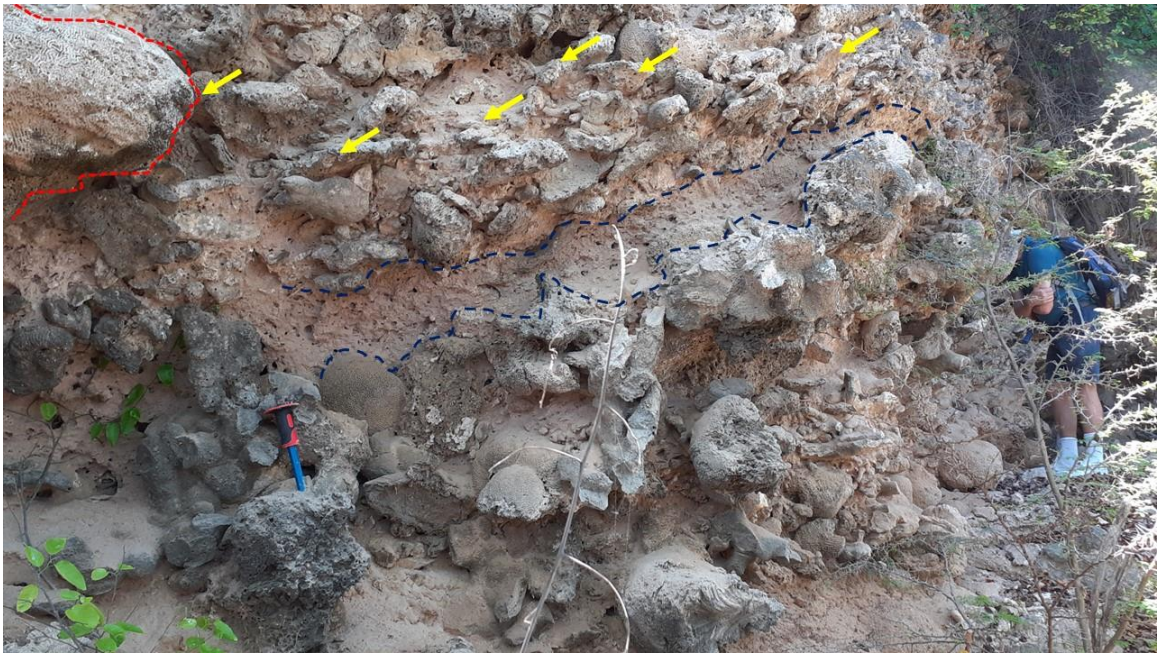

Figure 8. BSP East. *A. palmata* clasts showing landward (southward) imbrication, indicated by yellow arrows, onlap an in-situ massive coral head (dotted red line). A discontinuous lens of bioclastic sand within the dense rubble growth fabric is indicated by the blue lines.

Figure 9. BSP West. Sharp boundary between the lower and upper units. Note the interstitial sediment between the clasts of the coral framework in the upper unit.

The BSP West exposure is approximately 10 m tall based on measurements taken from scaled field photographs (**Figure 9**). The thickness of the lower unit increases to 4 m with small (≤20 cm) sparse branching corals within the medium to coarse-grained bioclastic sand matrix. There is a sharp boundary at the base of the overlying unit. The upper unit is similar in composition to that of BSP East with a notable exception being the direction of imbrication of the *A. palmata* clasts, unlike BSP East, these clasts are imbricated seaward towards the south.

Figure 10. Billy's Bay Natural History Museum. A, *O. annularis* colony in the upper 2 m of the outcrop showing several instances of partial mortality with yellow arrows indicating surfaces of sediment smothering and blue arrows indicating new direction of growth. B, spherical *O. annularis* colony approximately 0.4 m tall capped by branching calcareous algae. C, *D. stokesii* coral within a loose growth fabric.

Stop 6: Billy's Bay Natural History Museum

GPS: 17° 54' 2.232" N, 77° 47' 34.9116" W

Stop 6 can be accessed by continuing to walk westward along the coast for approximately 150 m then walking landwards to the cliff face. Alternatively, the site can be accessed through the back of the Billy's Bay Natural History Museum run by the Treasure Beach Turtle Group.

The exposure behind the Natural History Museum/Treasure Beach Turtle Group is approximately 8 m tall with the lower 3 m covered by the modern beach. The outcrop is dominated by hemispherical coral framestone with abundant *Orbicella annularis*, frequent *Dichocoenia stokesii*, and rare *Orbicella faveolata* (**Figure 10C**).

The colony form of *O. annularis* at the base of the exposure is spherical with relatively equal growth in all directions with a height of 0.5–1.5 m (**Figure 10B**). The framestone at the base of the outcrop is capped by a 0.5 m thick lens of branching calcareous algal tubes. There is a gradual upward transition to a loose domestone growth fabric at approximately 2 m from the base with *O. annularis* colonies having a more pronounced vertical growth component compared to the basal colonies. There are several instances of partial mortality of the colonies above 2 m where the corals show clear abrupt changes in the direction of growth (**Figure 10A**).

Stop 7: North of Dream Beach

GPS: 17° 54' 37.7784" N, 77° 47' 56.4792" W

Continue driving along Fort Charles Rd for 1.3 km from the Natural History Museum (approximately 0.4 km north of Dream Beach). Stop 7 can be accessed via an empty lot of land just north of The Cove and just south of Great Escape Villa. This locality shows the Falmouth Formation overlying undifferentiated White Limestone, mapped as the Newport Formation in **Benford et al. (2014)**, bounded by an unconformity (**Figure 11**). The Falmouth Formation is composed of a dense growth fabric of hemispherical coral framestone dominated by *Pseudodiploria* sp. Colony sizes range from 30 cm to 50 cm. The underlying White Limestone platform is heavily bored by bivalves of unknown species with boreholes up to 2 cm in diameter.

Stop 8: South of Fort Charles

GPS: 17° 55' 10′7652" N, 77° 47' 54.3264" W

The final stop is located approximately 1.2 km north of the previous stop at the headland at the corner of Starve Gut Bay. A concrete trigonometric station can be seen at the tip of the cliff. Turn right after walking onto the beach.

This is the most westward site of the Treasure Beach traverse and consists primarily of floatstone with sparse massive corals dominated by

Figure 11. North of Dream Beach. A, the broken yellow line highlights the unconformity between the upper Falmouth Formation and the lower undifferentiated White Limestone. B, massive corals overlying the disconformity C, bivalve borings within the lower White Limestone unit approximately 2 cm in diameter.

Figure 12. Outcrop near the headland south of Fort Charles composed primarily of floatstone with isolated massive corals.

Pseudodiploria sp. and *S. radians* within a bioturbated carbonate sand matrix (**Figure 12**). Rhizocretions are also present in the uppermost unit of the exposure. A thin (thickness ≈ 0.5 m) discontinuous unit of domestone and mixstone is noted at approximately 1 m APSL. The growth

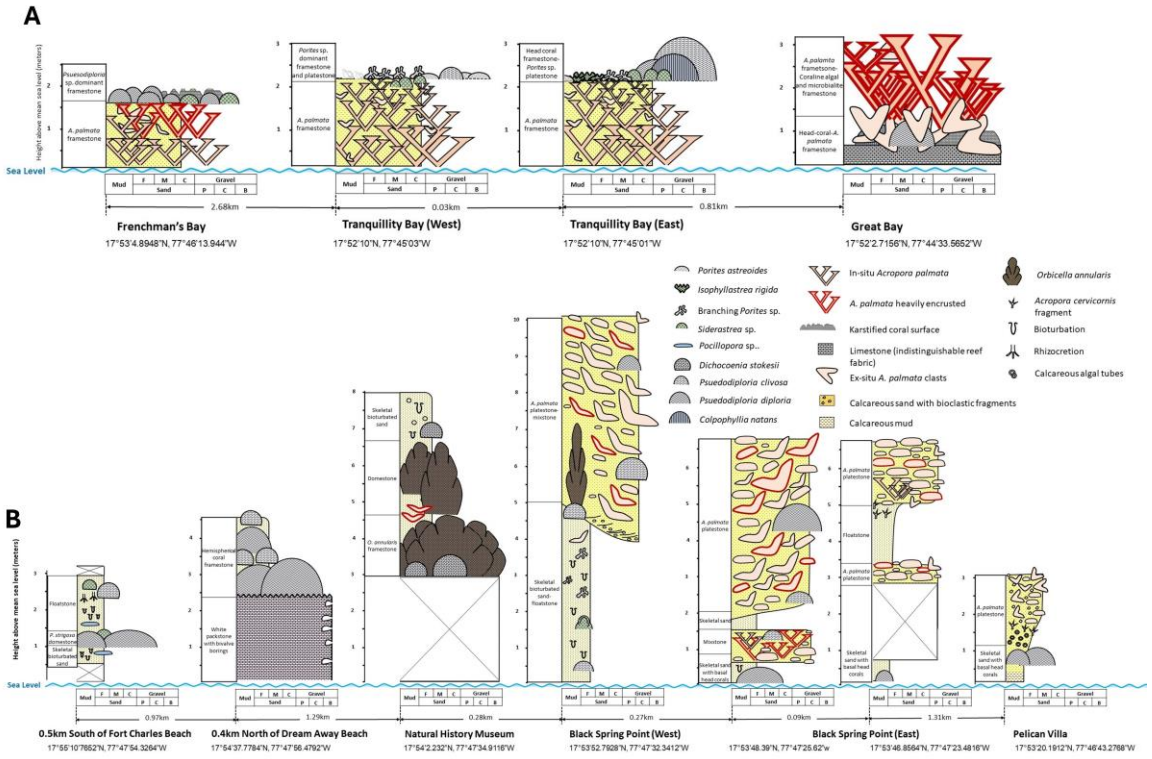

Figure 13. Stratigraphic logs of representative sections described along the traverse. A, outcrops east of Frenchman's Bay to Great Bay. B, outcrops west of Pelican Villa near Billy's Bay to the final stop south of Fort Charles Beach. [Follow for a larger version]

fabric is loose and consists of abundant *Pseudodiploria* sp. and *C. natans*, infrequent *D. stokesii*, and rare *Pocillopora palmata*.

4. INTERPRETATION

The growth fabric and coral assemblages found along the traverse imply a range of paleo-zonations ranging from distal crest to more proximal lagoon environments. A total of eight facies (TB1-TB8) were identified – each associated with specific environmental conditions (**Table 1**). There is a notable trend from distal to proximal facies travelling northwest along the traverse.

The eastern sections of Treasure Beach (Stops 1 to 3) (**Figure 13A**) show a distinct two-tiered architecture with the lower unit consisting of a crest and rubble ridge assemblage associated with high hydrodynamic activity. Comparatively, the upper unit consists of an assemblage associated with relatively low hydrodynamic activity and high sediment tolerance. The transition from the lower to the upper unit implies the crest facies becoming rapidly restricted and increasingly stressed by sedimentation. This suggests a progradation of the reef resulting in a crest further offshore restricting the hydrodynamic activity behind it. Reef progradation has also been documented in the Neogene outcrops of Bonaire (**Laya et al., 2018**) attributed to limited accommodation space.

Vertical changes in accommodation space can also be interpreted in these outcrops. The lower tiers – TB1, TB3, and TB4 – are all associated with limited accommodation space; TB4 observed at the headland of Frenchman's Bay being the most obvious example of this. The different height ranges of the upper units imply varying degrees of limitation by accommodation space following the restriction of the lower unit. The increasing dominance of lagoon and back-reef facies (TB5–TB8) heading northwest is likely the result of coastline orientation as well as the trend of the paleo-crest. The thickness of these facies reflects the lagoon depth landward of the crest and nearing the shoreline. A wide range of outcrop heights can be observed along the traverse ranging from 2 m to >8 m. **Skrivanek et al. (2017)** inferred subsidence along the traverse from Great Bay to the headland at Frenchman's Bay assuming an interglacial sea level maximum of +6 m APSL. These further corroborate the assertion by **Maharaj (2000)** of a fault splay system from the proposed Treasure Beach Fault.

Table 1. Biofacies (TB1-TB8), interpretation, and paleo-zonation identified along the Late Pleistocene coral reef outcrops in Treasure Beach, St. Elizabeth. Height intervals match with Figure 13.

Facies	*Description*	*Localities*	*Height intervals (m)*	*Interpretation*	*Reef zonation*
TB1	Planated hemispherical coral heads and taphonomically degraded *A. palmata* rubble.	Great Bay	0 – 1.6	High wave energy with little to no accommodation space for coral growth near sea level resulting in the planation of the coral heads.	Reef flat
TB2	Large 1m tall in-situ stands of *A. palmata* framestone moderately to heavy continuous encrustation. The coral framework is open with no interstitial sediment between branches.	Great Bay	1.6 – 2.0	High wave energy within 5 m of the sea surface. In-situ and abundant *A. palmata* suggests sufficient accommodation space for growth with low sediment input.	Upper Palmata/ Breaker Zone
TB3	In-situ and ex-situ *A. palamta* framestone with intra-clastic medium-grained carbonate sand.	Tranquility Bay	0 – 2.0	Infiltration of *A. palmata* framework by intra-clastic sediment suggests the seaward extension of the lagoon.	
TB4	Framestone and mixstone dominated by in-situ *A. palmata* with infrequent to rare *P. astreoides*, *Siderastrea* sp., and *Pseudodiploria* sp. Mixtone gradually transitions upwards to framestone dominated by *Pseudodiploria* sp. colonies all approximated 40 cm tall with instances of erosion of coral head.	Frenchman's Bay	0 – 1.8	Sediment-tolerant species such as *Siderastrea* sp. and *P. astreoides* suggest an environment landward of the flat. **Goreau (1959)** suggests a depth of 2-3 m associated with this species composition. The 40 cm height of most *Pseudodiploria* sp. colonies implies limited accommodation space and growth nearly approaching sea level. A similar occurrence has been documented by **Goreau (1959)** at South Cay, Jamaica.	Rear zone
TB5	Imbricated mixstone and platestone dominated by *A. plamata* with a ride range of surface preservation states. Discontinuous lenses of floatstone with rare *A. cervicornis* are also observed within this facies. Fine to medium-grained interstitial bioclastic sediment is also present between clasts.	Pelican Villa BSP East BSP West	1.5 – 3.0 0.7 – 6.5 5.0 – 10.0	Various states of surface preservation of coral clasts imply that rubble was sourced from living, recently dead, or long-dead colonies. This may also imply that clasts were buried by sediment relatively quickly. Interruptions in clast deposition give way to the deposition of the floatstone lenses. Imbrication implies a sloping surface influencing the orientation of the coral clasts. Onlapping of massive corals has been observed by **Blanchon et al. (2017)** in the back reef along a modern fringing reef in Punta Maroma, in the Yucatan Peninsula following storm events.	Reef crest
TB6	Hemispehrical coral framestone dominated by colonies ranging in height up to 2 m tall. of *Pseudodiploria* sp., *O. annularis*, *C. natans*. *P. astreoides* and *D. stokesii* may also be observed.	Tranquility Bay Natural History Museum	2.0 – 3.3 3.0 – 6.5	Size ranges of colonies imply accommodation space was not a limiting factor at the time of growth. Sediment tolerant species such as *P. astroides* and *D. stokesii* are typically found in lagoon settings. The lack of any *A. palmata* rubble corroborates this assertion.	Lagoonal patch reefs
TB7	Thin unit (<10 cm) of *Porites* sp. dominated branched framestone. Small knobs of *S. radians* are also observed with a height of 5 cm.	Tranquility Bay Frenchman's Bay	2.0 – 2.1 negligible	The thickness of this facies implies relatively little time between initiation and mortality. All species are associated with sediment tolerance and the branching forms with low wave energy.	Back reef
TB8	Floatstone composed of bioclastic med-coarse-grained sand. Burrows and rhizocretions observed.	Pelican Villa BSP West Natural History Museum South of Fort Charles	0 – 1.2 0 – 5.0 6.5 – 8.0 0.5 – 3.0	High rate of sedimentation and smothering of small coral colonies within a protected, low wave energy environment.	Lagoon

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