Field Trip 2: Selected geological sites in the parishes of western St Andrew and St Thomas

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The understanding of the geology of Jamaica has significantly advanced in recent years with revisions of the stratigraphy (e.g., Mitchell, 2003, 2006, 2013a, 2013b; Mitchell et al., 2001; James-Williamson and Mitchell, 2012), the igneous rocks (Hastie et al., 2008, 2010) and metamorphic rocks (e.g., Abbott et al., 2013; West et al., 2014). Although many details remain to be published, an outline of the geological history of Jamaica is described below based on these references and will be published in detail elsewhere.

Different parts of Jamaica evolved in different parts of the Caribbean plate-arc system. The eastern Blue Mountains (Bath area and Rio Grande Valley) are represented by plateau basalts that were produced by a mantle plume over the Galapagos Islands hotspot during the late Turonian-early Coniacian (88-91 Ma). The sequence consists of a basement of plateau basalts (Bath Volcanics) overlain by a sedimentary (Cross Pass Shales; Back Rio Grande Limestone, Rio Grande Limestone, Providence Shales) and a series of back-arc lavas (Bellevue Volcanics). Rudists from the limestones (Mitchell and Ramsook, 2009) share more in common with faunas from Costa Rica, than with those from the rest of Jamaica and other areas of the Greater Antilles. The Cretaceous rocks from the rest of Jamaica were formed in an island arc setting and consist of volcanic rocks (basalts, andesites and dacites) and a suite of clastic and carbonate sedimentary rocks. The volcanics were initially formed from the subduction of typical oceanic crust, and subsequently by the subduction of the CLIP. Metamorphic rocks in the western Blue Mountains were formed in a subduction zone setting; they include amphibolites (Westphalia Schists, Green Bay Schists) with arc derived protoliths and Greenschists/Blueshists (Mt. Hibernia Schists) with CLIP protoliths.

The two contrasting areas of Cretaceous rocks that would form ProtoJamaica were brought together by strike-slip faulting along NE-SW orientated faults initiated during the collision of the northeastwardly moving Caribbean Plate with the Yucatan Block at the end of the Campanian (producing an unconformity at the base of the Kellits Synthem). Uplift related to these faults saw the rapid return of the metamorphic rocks to the surface and releasing bends resulted in the development of rift basins (John Crow Mountains Rift, Wagwater Rift). The rifts were filled with thick sedimentary successions and volcanics (Halberstadt Volcanics, Newcastle Volcanics) derived from the CLIP as it was thrust under Jamaica.

Following the collision of the Caribbean Plate (Cuba) with the Bahamas Block in the late Early Eocene, ProtoJamaica was established, the Caribbean Plate took on an eastwardly motion relative to the North American Plate, and an unconformity was formed beneath the rocks of the Yellow Limestone Group. With a change in plate motions, new stress regimes resulted in extension along the Nicaraguan Rise with the formation of a block and trough topography. Shallow water platform carbonates (Yellow Limestone and White Limestone groups) developed over the blocks and deep-water chalks were deposited in the troughs from the mid Eocene to the mid Miocene). Tectonic episodes affected Jamaica throughout the deposition of the limestones, with notable unconformities at the base of the Troy and Somerset formations, as well as within the Oligocene.

With the collision of the leading edge of the Caribbean Plate (Dominica Republic) with the Bahamas in the Eocene, thrust stacks developed progressively across Hispaniola during the Oligocene-early Miocene and renewed tectonic deformation was transferred to Jamaica during the mid-Miocene. This deformation was associated with a restraining bend (Plantain Garden-Blue Mountain Fault) and saw the progressive development of flower structures in the Blue Mountains (James-Williamson et al., 2014). As uplift took place, the Coastal Group was deposited around the margin of Jamaica. The Coastal Group is represented by mixed clastics (derived from the uplift of the Blue Mountains and Wagwater Belt) and carbonates (formed from marine organisms, such as, corals, foraminifers, molluscs and algae) and is particularly well developed in the coastal areas of Portland and St. Thomas. These mixed clastic and carbonate deposits formed in a range of environments and provide a window into the geologic development of this portion of Jamaica. The area also can boast of some world class fossil sites that document the major changes in Caribbean marine biota during the Late Neogene through Recent.

The stratigraphy of the Coastal Group of St Thomas includes four formations (August Town, Layton, Old Pera and Port Morant formations), each composed of mixed clastic and carbonate sediments. The Mio-Pliocene Layton Formation was deposited in deeper marine upper bathyal conditions and is made up chiefly of marlstones with some sandstones, conglomerates and occasional shell beds. The other units, the August Town Formation (late Miocene), the Old Pera Formation (early Pleistocene) and the Port Morant Formation (late Pleistocene), all contain sandstones and conglomerates along with localized fringing reefs and coral patches exposed along the coast from Port Morant westward to Morant Bay. In St. Andrew, the Coastal Group is represented by the August Town Formation overlain by the Harbour View Formation.

This Field Guide indicates some of the features of the evolution of the geology of eastern Jamaica. Stops are identified using GPS locations.

Stop 1. Harbour View Formation, Palms Apartments (GPS: N 17° 56.892', W 076° 41.940')

This locality is located just off the south coast road between Harbour View and Bull Bay and is situated about 500 m to the west of the bridge over the Cave River. Access is by a narrow road (GPS: N 17° 56.833', W 076° 41.951') immediately on the west of the Palms Apartments. The hillside has been excavated for the foundations of a house, but the house was never constructed. The section shows well-stratified, granule-pebble conglomerates and associated minor coarse-grained sandstones of the Harbour View Formation dipping at about 60° to the south. The conglomerates display imbrication indicating bidirectional currents (waves), and marine trace fossils (*Taenidium* isp.). On the western side of the exposure there are two successive erosively-based beach units which are deposited against ancient cliff lines cut into the Harbour View Formation). The older (lower) beach unit dips at about 10° to the south and shows landward-directed imbrication of boulders (**Figure 4**). The younger (upper) beach unit is subhorizontal and largely inaccessible. On the far southwestern extremity of the exposure, the lower beach bed is displaced by a small southerly dipping reverse fault (back-thrust). This locality shows synsedimentary deformation causing progressive southward tilting (development of footwall synclines) of the units and cutting of erosional marine terraces and deposition of cobble/boulder beaches as the Harbour View Formation were uplifted by thrust faults propagating to the south of the Wagwater Fault.

Figure 4. Unconformity showing boulder conglomerates (beach) overlying steeply dipping marine pebble conglomerates. Book for scale.

Stop 2. Bath Volcanics, Bridge at Bath (GPS N 17° 56.850', W 076° 21.624')

This location is located on the road from Port Morant to Bath and is situated immediately to the north of the new bridge over the Plantain Garden River just by the sign for Bath. Here, the Plantain Garden River runs along the course of the Plantain Garden Fault. This is an east-west, left lateral (sinistral), strike-slip fault with a lateral displacement of maybe 10 km. To the south of the fault there is a small Cretaceous inlier, the Sunning Hill Inlier, surround by an Eocene-Miocene clastic (Richmond Formation) and carbonate (Yellow Limestone and White Limestone groups) succession. To the north of the river are the Bath Formation (lavas with subsidiary cherts and mudstones) and the Cross Pass Shales (a deep-water turbiditic succession of probable Coniacian-Santonian age.

The Bath Formation is largely comprised of basaltic lavas, sometimes showing pillow structures, with minor chert and thin units of clastic mudstone. The lavas have typical immobile and trace element compositions that indicate that they were formed as a part of the Caribbean Large Igneous Complex (CLIP). The CLIP was produced over the Galapagos Island hotspot when the head of a mantle plume reached the ocean crust. It is this large volume of basaltic lavas that have caused the abnormally thick (c. 14 km) oceanic crust under the Caribbean Plate. The Bath lavas exposed at the bridge over the Plantain Garden River appear to show pillows; however, these are not pillows, but the cores of joint-defined blocks that have suffered extensive weathering. Fluids have broken down the basalt progressively from joint in thin layers forming a typical example of onion skin weathering

(**Figure 5**). A close look at the basalts reveals a complete lack of vesicles indicating extrusion of the lavas at great water depths where the high pressure kept the gasses dissolved in the magma.

Along the old road to the west, on the northern side of the Plantain Garden River are exposed a series of clastic mudstones that are most easily studied in a series of fallen blocks. The rocks consist of red or brown fine-grained clastic mudstones with no apparent structure. Nearby, these rocks have yielded late Turonian and early Coniacian radiolarians. The basalts and particularly the mudstones contain numerous thin calcite veins.

Figure 5. Bath Volcanics at Stop 2 showing onion-skin weathering.

Stop 3. Thornton Volcanics, Sunning Hill (GPS: N 17° 57.267', W 076° 24.584')

This locality lies within the Sunning Hill Inlier on the road from Sunning Hill to Whitehall. The best way to locate the exposure is using the GPS location as there are few markers along this road. The Sunning Hill Inlier contains a deepening-upwards succession that consists of, in ascending order: the Thornton Volcanics, red-bed conglomerates and sandstones, a thin limestone (Bon Hill Limestone) and a thick sequence of shales and sandstones. Fossils in the Cretaceous sequence (ammonites, inoceramid bivalves, rudist bivalves and nereinid gastropods) indicate an early Campanian age, and the Thornton Volcanics are therefore either of latest Santonian or, more likely, early Campanian age.

This locality shows a road cutting in very hard basaltic andesites that show well developed pillow structures (**Figure 6**). Individual pillows are separated by thin layers of sediments suggesting eruption into the uppermost part of a marine sedimentary pile. Basalts (not seen on this trip) higher in the sequence do not show pillows suggesting that the eruption was initially underwater, but built up to be subaerial. Immobile and trace element analyses indicate that these basaltic andesites are typical island arc volcanics, and therefore contrast markedly with the Bath Volcanics only 3-4 km to the east. Even allowing for movement along the Plantain Garden Fault, the Bath and Thornton volcanics could not have formed in such close proximity. The Bath Volcanics were formed within the central part of the Caribbean Plate, whereas the Thornton Volcanics formed in an island arc on the edge of the Caribbean Plate, with maybe 1,000-1,500 km separating the original sites of formation. Subsequently the two sets of volcanics have been juxtapositioned by tectonic processes as the Caribbean Plate collided with the North American Plate.

Figure 6. Pillow lavas in the Thornton Formation at Stop 3. Hammer (lower centre) for scale.

Stop 4. Mt Hibernia Schists, East Arm of the Morant River (GPS: N 17° 58.304', W 076° 28.861')

This locality is situated where the East Arm of the Morant River exits from the Blue Mountains Inlier to the north of the trace of the Plantain Garden Fault. The section extends from the alluvium upstream along the river to the old hydroelectric dam know as Reggae Falls. Formerly, the alluvium on the west bank of the river immediately to the south of the first bedrock outcrop showed fault movements within the alluvium similar to the fault seen cutting the lower beach bed in the Harbour View Formation at Locality 1.

To the north of the alluvium, the first rocks that are encountered are a series of weathered basaltic lavas. These rocks occur on both sides of the river and contain abundant vesicles. The presence of vesicles indicates extrusion into shallow water and indicates that they are island arc rocks potentially similar to the Thornton Volcanics.

The basalts are in faulted contact (the fault is represented by a gully on the western side of the river) with the greenschists of the Mt. Hibernia Schists which extend from this fault up to and beyond the dam forming Reggae Falls. The greenschists contain a mineral assemblage including: epidote and actinolite, together with chlorite, quartz, albite and clinopyroxene. A foliation is developed dipping gently towards the S/SW. The hill to the northwest on the western side of the East Arm of Morant River is called Union Hill, and contains the outcrops of the blueschists in the Mt. Hibernia schists. Immobile and trace element data from the blueschists indicates that they are derived from a protolith of the Bath Volcanics. This demonstrates that the CLIP was subducted towards the end of the Cretaceous beneath Jamaica.

Stop 5. Bowden Shell Bed (GPS: N17° 53' 23.76" W76° 18' 52.62")

This locality along the road from Port Morant to Bowden Marina just before the turn up the hill to Old Pera is one of the most famous fossil sites in the entire Caribbean. Having first come to light in the mid 19th century, it has been the focus of considerable work ever since (see Donovan 1998 for a review). Although the main shell bed itself is found in an exposure not more 8-10 m long and 2-3 m thick, it contains hundreds of species of molluscs, corals, and other marine invertebrates. The fauna represent a mixture of shallow marine and terrestrial forms transported down slope into a deeper marine setting.

A thick section of the outcrop was trenched and described by Pickerill et al. (1998). More recent work has re-cleared a broad section of the outcrop (**Figure 7**) allowing access to the main body of the shell bed close to road level as well as further uphill through much of the Pickerill et al. (1998) section.

Stop 6. East end of Fisherman's Bay, St. Thomas, Port Morant Formation (GPS: N17° 51' 37.72", W76° 20' 58.96")

Turning off the main south coast road (A4) at Prospect heading toward the coast on Crescent Rd. the track ends in an exposure of a low reef terrace in the Late Pleistocene Port Morant Formation. This represents the most westerly exposure of extensive pure carbonate reef facies in this unit. Here one can walk among excellent exposures of coral in growth position.

Figure 7. Bowden Shell Bed, late Pliocene, Bowden Member, Layton Formation. This image was taken in June 2009 after it had been cleared with a backhoe. A large channel fill is exposed to the right of the geologist and bedded units are exposed to the left.

At this site (**Figure 8**), there is a mixed coral fauna with considerable growth of more fragile thin branched species suggesting this developed in a more protected area behind a wave exposed reef crest. Common massive corals seen here include *Orbicella* and *Pseudodiploria* growing among abundant branched *Acropora* and *Porites*. These are all essentially identical to key species that inhabit the modern Caribbean. It should be noted, however, that this Late Pleistocene reef is more extensive and shows denser coral cover than any modern near shore reefs in this area.

Figure 8. Reef terrace in the late Pleistocene Port Morant Formation at Stop 2. Thin branched *Porites furcata* shown in centre of photo; thick branched *Acropora palmata* seen at lower left

Stop 7. Oxford Road Coastline, Old Pera Formation (GPS: N17° 52' 7.70" W76° 21' 44.02")

At the intersection of Oxford Road with the A4, a path leads to impressive coastal exposures of the early Pleistocene, Old Pera Formation consisting chiefly of coarse conglomerates and sandstones dipping slightly to the south. At various intervals, corals colonized the substrate and are seen in place growing up through cobble rich sediment to form small coral mounds and thickets, some with colonies over a metre across. At the eastern end of the outcrop just visible at sea level, large in place massive species form a coral rich limestone.

Given the rather strenuous environment represented at this site, coral diversity here is understandably low. However, like all early Pleistocene coral faunas of the Caribbean, this site shows a mixture of extant and extinct species. Plio-Pleistocene coral communities in the Caribbean were ~50% more diverse than at present and a major extinction event hit reefs sometime after the deposition of the Old Pera Formation. At this stop extant species of *Pseudodiploria*, *Porites* encrust cobbles as well as transported fragments of extant *Acropora*. The dominant in place branching coral (**Figure 9**), however, is *Stylophora monticulosa*, an extinct species whose closest relative is living today in the Pacific.

Figure 9. Coral in growth position within coarse conglomerates of the early Pleistocene Old Pera Formation, Stop 3. Branching coral at centre top is *Stylophora monticulosa*, a species extinct in the Caribbean.

Stop 8. Lyssons, Golden Shore Hotel, August Town Formation (GPS: N17° 52' 27.61" W76° 22' 42.24")

Turning off the A4 down Winward Road toward the Golden Shore Hotel, brings one to a coastal outcrop of the late Miocene August Town Formation. At this site, a fringing reef system developed with a base of small corals colonizing coarse conglomerates and grading upward into densely packed coral growth fabric 2-3 metres thick and exposed across more than 60 m of coastline. Until recently the impressive outcrop, (**Figure 10**) showed a clear transition from the more clastic rich back reef grading into purer carbonate and coral dominated reef core. Unfortunately, the epidemic of sea wall building that has affected much of this stretch of coastline destroyed some of this outcrop.

Still, some of the succession from conglomerate to reef is accessible and the main body of the reef tract is well exposed. Coral diversity here is low but almost completely distinct from that of the Old Pera Formation. Only 2 minor species in this reef are extant, most of the others go extinct during a period of significant taxonomic turnover in the Caribbean Plio-Pleistocene. The principal branching species is again *Stylophora monticulosa*. This reflects the dominance of *Stylophora* before the origination of the key elkhorn and staghorn species of *Acropora* that structure modern reefs in the Caribbean region.

Figure 10. Reef developed on coarse clastics in the late Miocene August Town Formation at Lyssons.

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