

Field guide to the geology and geomorphology of the Tertiary limestones of the Central Inlier and Cockpit Country

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ABSTRACT. The geology and geomorphology of the rocks of the Yellow Limestone and White Limestone Groups on the northern margin of the Central Inlier of central Jamaica are described. The Yellow Limestone Group consists of limestones (Stettin and Chapelton Formations) and clastic rocks (Guys Hill Formation). The limestones of the Yellow Limestone Group give rise to doline karst, with low residual hills, with the dolines locally amalgamated to form uvalas in the Stettin Formation. The Guys Hill Formation forms to gently gullied topography with shallowly incised stream systems of moderate drainage density. The overlying White Limestone Group is represented by the Troy Formation and consists of dolostones and crystalline limestones. The geomorphology is represented by cockpit and tower karst, with intervening prominent enclosed depressions. Detailed descriptions of eleven localities, representing a two-day field excursion, are given to illustrate the important geological and geomorphological aspects of this area.

1. INTRODUCTION

ROCKS of the Yellow Limestone and White Limestone groups crop out around the perimeter of the Central Inlier (McFarlane, 1977; Mitchell, in press a, b). They consist of clastic sedimentary rocks (sandstones, mudstones and conglomerates), impure limestones and pure carbonates (limestones and dolostones). These rocks are exposed over much of Jamaica, and are responsible for the development of classic karstic topography, some of which is particularly well displayed in Cockpit Country (e.g., Sweeting, 1958). The rocks of the Central Inlier have been described in a wide variety of publications. Details of the Cretaceous succession can be found in Mitchell (1999, 2000, 2002, in press a) and Mitchell and Blissett (1999, 2001). The rocks belonging to the Yellow Limestone and White Limestone groups have been described by Robinson (1996), Robinson and Mitchell (1999) and Mitchell (in press b). The geomorphology of the limestones of Jamaica has been discussed by Sweeting (1958, 1972), Versey (1972) and Miller (in press). Other general descriptions of the karst of the island were given by Doerr and Hoy (1957) and Urqhart (1958), while a recent summary was presented by Draper and Fincham (1997).

This field trip will look at the various rock types present in the Yellow Limestone and White Limestone groups, and explore how the geomorphology relates to the different rock types present. The itinerary is split into two days, with an

overnight stay in Mandeville. We begin with brief descriptions of the various lithologies found in and around the Central Inlier together with the characteristic landforms developed on these lithologies.

2. GEOLOGY AND GEOMORPHOLOGY IN AND AROUND THE CENTRAL INLIER

2.1. Cretaceous-?Paleocene Succession

Geology. The Cretaceous succession in the Central Inlier consists of a variety of clastic and volcanoclastic sedimentary rocks, together with subordinate limestones and igneous rocks. These rocks are well-exposed in many areas, but are not the major subject of this trip. The succession is summarised in Table 1, and has been well-described elsewhere (e.g., Coates, 1968; Mitchell, 1999, 2000, in press a; Mitchell and Blissett, 1999, 2001).

Geomorphology. The rocks of the Cretaceous-Paleocene succession give rise to spectacular scenery characterised by strongly incised river valleys belonging to the Rio Minho and its tributaries and intervening steep ridges. The indurated character of the rocks supports steep-sided valleys, with valley evolution controlled by incision, valley steepening and landslide processes. Earle (1991) discussed the extent and significance of landslides in the Rio Minho watershed. According to Ahmad (1995), these successions have

Table 1. Geological succession of Cretaceous-Tertiary rocks in the Central Inlier

UNIT		AGE	
Troy Formation		Middle Eocene	
Yellow Limestone Group	Chapelton Formation	Middle Eocene	
	Guys Hill Formation		
	Stettin Formation		
	Freemans Hall Formation		
<i>Sub-Yellow Limestone Unconformity</i>			
Kellits Synthem	Summerfield Group	Waterworks Formation	Upper Maastrichtian
		Mahoe River Formation	
		Peckham Formation	
		Green River Formation	
	Guinea Corn Formation		
	Thomas River Formation		
	Slippery Rock Formation		
<i>Sub-Slippery Rock Unconformity</i>			
Crofts Hill Synthem	Dawburn Content Formation	Upper Santonian to Lower Campanian	
	Back River Formation		
	Peters Hill Formation		
<i>Sub-Peters Hill Unconformity</i>			
Arthurs Seat Formation		?Lower Cretaceous	

experienced some of the most damaging rainfall-induced ‘debris flows’ on the island, one of the consequences of which is accelerated soil erosion.

2.2. Yellow Limestone Group

The Yellow Limestone Group consists of three formations, the Stettin Formation, the Guys Hill Formation and the Chapelton Formation (Robinson and Mitchell, 1999). These are briefly described below.

2.2.1. Stettin Formation

Geology. The Stettin Formation is represented by foraminiferal- and mollusc-bearing limestones that may be as much as 100 m thick or more in the west, but show rapid thinning to the east, and are locally absent (Fig. 1). The succession contains many different lithologies, including hard, cemented foraminiferal grainstones, nodular packstones, wackestones, fenestral micrites and thin seams of claystone and marlstone. The limestones of the formation commonly show well-developed bedding, with beds ranging in thickness from a few centimetres up to several metres. The base is locally represented by sandstones and conglomerates for which the name Freemans Hall beds has been used (e.g., Robinson, 1996).

Geomorphology. The Stettin Formation gives rise to a subdued karstic topography. Dolines (or sink holes) are well-developed and between these are rounded, low residual hills. Within the Stettin Formation, the dolines are relatively shallow and broadly conical in shape with rounded floors. Sweeting (1958) was the first worker to describe the dolines in the “lower limestone beds” of the Yellow Limestone Group as “relatively small (about 50-150 feet [15-46 m] in diameter) and shallow, with slumped sides”. In some areas the dolines have coalesced to form more complex uvalas, with more than one topographic low point, but with no extensive flat areas to their floors. Uvalas commonly form due to the intersection of at least two dolines, which seems to be the case for the features in the Stettin Formation, though in some instances smaller dolines may have formed within larger ones. Some of the uvalas show a pronounced orientation, though others are more lobate in plan. Elsewhere (e.g., Jennings, 1985), uvalas with pronounced orientation are often elongated along strike, with a chain of depressions along the same trend. The uvalas in the Stettin Formation occur either where the bedding is horizontal or are elongated in the direction of the dip of the beds.

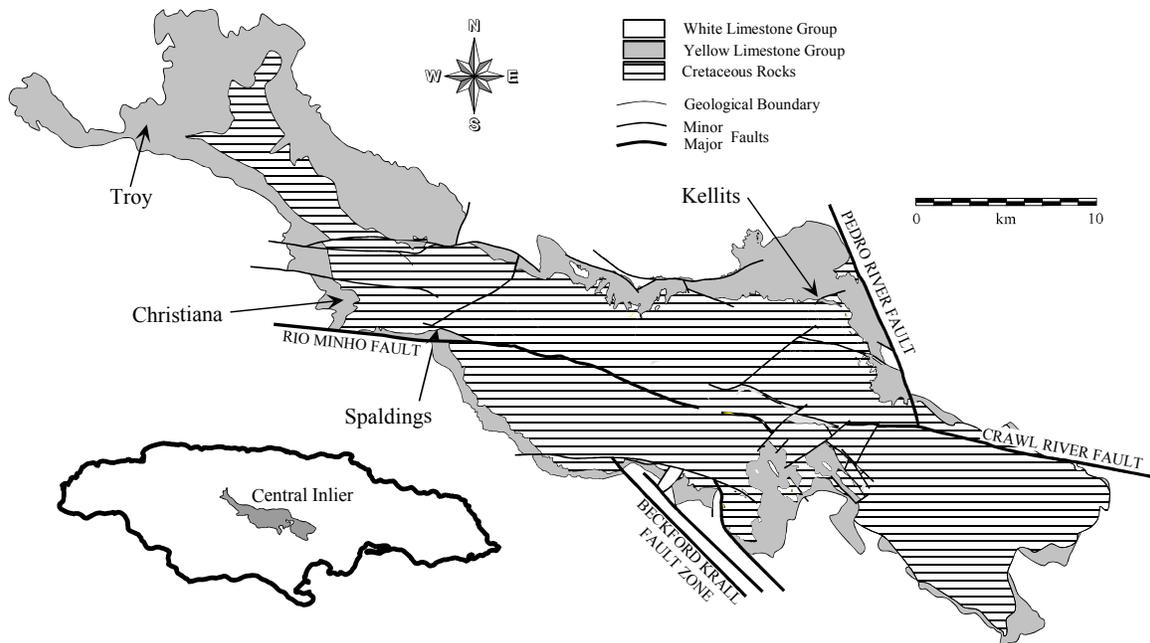


Figure 1. Simplified geology of the Central Inlier, showing Cretaceous rocks and Yellow and White Limestone Groups

2.2.2. Guys Hill Formation

Geology. This is the middle division of the Yellow Limestone Group in the Central Inlier, and is represented by mudstones, sandstones, conglomerates and minor limestones (Robinson, 1996; Robinson and Mitchell, 1999). The formation ranges in thickness from 50 m to 350 m. The succession is more sandy and conglomeratic towards the east, and more clay-dominated with minor limestones towards the west. In general, the rocks of the Guys Hill Formation are weakly indurated, however, at least one sandstone unit in the western part of the inlier is more strongly indurated and forms a marked topographic feature around the town of Litchfield.

Geomorphology. The Guys Hill Formation gives rise to gently gullied topography with shallowly incised stream systems of moderate drainage density. The gullies are short, but well-developed and reach up to third order drainage systems. The landscape of the Guys Hill Formation is also subject to mass wasting and the general topography is replete with surface features produced by soil creep and other slow mass movement processes. Where the Guys Hill Formation abuts the underlying Stettin Formation, the gullies and drainage networks form short, centripetal drainage systems where the surface stream disappears in sinkholes developed within the lower limestone.

2.2.3. Chapelton Formation

Geology. The Chapelton Formation is the upper limestone division of the Yellow Limestone Group and consists of foraminiferal, molluscan and echinoidal limestones (Robinson, 1996; Robinson and Mitchell, 1999). The limestones range from medium bedded (10 to 80 cm) up to thickly bedded and unbedded units. The formation ranges in thickness from about 50 m to 200 m.

Geomorphology. Sweeting (1958) described the geomorphology of the “upper limestone beds” of the Yellow Limestone Group as doline karst where the “dolines are large and often steep-sided, sometimes being over 400 feet [123 m] in diameter and they may be 100 feet [31 m] deep”. We agree with this general description of the geomorphology of the Chapelton Formation which gives rise to karstic landforms characterised by medium-scale enclosed depressions and rounded residual hills. The enclosed depressions are deeper than on the Stettin Formation and are steeper cone shaped features. Where the Chapelton Formation abuts the White Limestone Group, and especially where it makes a conformable contact with the overlying Troy Formation, the landscape is characterised by deep and steep-sided dolines interspersed with Troy Formation outliers forming well-developed towers. The overall morphology of the dolines on the Chapelton Formation suggests compound origins, in that they are partly the result of solution, but their steep-sided nature may also indicate collapse

mechanisms, probably related to well developed cave systems within the Chapelton Formation (e.g., Wadge and Draper, 1977).

2.3. White Limestone Group

The lithostratigraphy of the White Limestone Group has recently been revised by Mitchell (in press b), and the geomorphology by Miller (in press). The shallow water limestones of the Clarendon Block contain four formations: Troy, Swanswick, Somerset and Moneague. The rocks considered in this field trip form part of the Troy Formation.

2.3.1. Troy Formation

Geology. The Troy Formation consists of pink, grey, brown and off-white limestones and dolostones. The bedding is locally very regular, with beds ranging from a few tens of cm up to a metre or two. Elsewhere, the Troy Formation appears largely unbedded. The limestones are composed of calcium carbonate (calcite, aragonite having been replaced by calcite). The dolostones do not react (other than for veins and calcite-filled vugs) when dilute HCl is applied. The limestones range from micritic limestones to coarse, crystalline rocks that preserve the textures of the sucrosic dolostones. The latter are sucrosic dolostones that have subsequently been dedolomitized (replacement of dolomite by calcite). The dolostones range from dolomicrites (very fine-grained dolostone in which the grains cannot be resolved with a hand lens or microscope) to coarse sucrosic dolostones that have textures resembling that of granulated sugar. The dolomicrites and micritic limestones commonly contain irregular fenestrae, which are pores up to 5 mm in diameter formed by desiccation and shrinkage or air and gas bubble formation (Shinn, 1968; Tucker and Wright, 1990). Fossils are absent in the Troy Formation of the Central Inlier, other than for cavities resembling the larger foraminiferan *Cushmania* that are filled with calcite.

Geomorphology. The Troy Formation forms spectacular karst scenery, including cockpit karst (kegelkarst), tower karst and deep dolines or sinkholes. The White Limestone Group has also been significantly block faulted (Lewis and Draper, 1990; Draper, 1998), leading to a 'horst and graben-type' landscape with well-developed poljes or interior valleys. The Troy Formation tends to support rugged karst terrain due to the fact that it has been dolomitised and is therefore harder,

denser and more resistant to erosion. It has also been case hardened in many places which allows for the development of upstanding landforms. The most common karst terrain type on the Troy Formation is cockpit karst (kegelkarst) (Sweeting, 1958; Versey, 1972), which forms a rugged topography of broadly conical hills and enclosed depressions of equal prominence. The cockpit depressions are polygonal or star-shaped and they are mostly contiguous, with a clear divide or col between each depression. The depressions reach up to 200 m deep and 1 km in diameter. The intervening conical hills are up to 100 m high and have a range of diameters which may exceed 1 km. All of the cockpits are marked by a vertical shaft in the lowest part of the depression (Smith *et al.*, 1972).

Karst towers are also common within the Troy Formation, especially where it is in conformable contact with the underlying Chapelton Formation, though tower karst may also occur where the Troy is in faulted contact with older Formations in the Yellow Limestone Group. The towers within the Troy Formation are steep-sided residual limestone hills of similar height to the conical hills of cockpit karst and with slopes up to 60-90°, surrounded by an alluvial plain or older rocks with less rugged topography. Some of the towers have planar tops, while others are more conical and with pointed summits. Towers which are surrounded by alluvium are often solutionally undermined and characterised by pronounced basal notches, foot-caves and a ring of sinkholes around the tower base. Other towers within the Troy Formation, which are not being undermined by solution, often have more gently sloping (25-30°) colluviated foot-slopes, these normally occur above regional groundwater or perched-groundwater tables and are not surrounded by alluvium.

Block-faulting has also led to the development of interior valleys or poljes, which are common within the Troy Formation limestones, but are also associated with other limestones within the White Limestone Group. Most poljes in Jamaica are strongly structurally controlled and represent down-faulted blocks. Poljes are at least 400 m across, though most in the Troy Formation are at least 1 km wide, and commonly have a flat or gently undulating floor within alluvium. They are associated with surface streams which flow across the floor of the polje and usually disappear at the margin into sinkholes (ponors). Poljes are also characterised by a distinct, steeply-sloping boundary rim, which forms an abrupt break of slope with the polje floor. The poljes in Jamaica have been summarised by Versey (1972), while more detailed work has been undertaken in specific

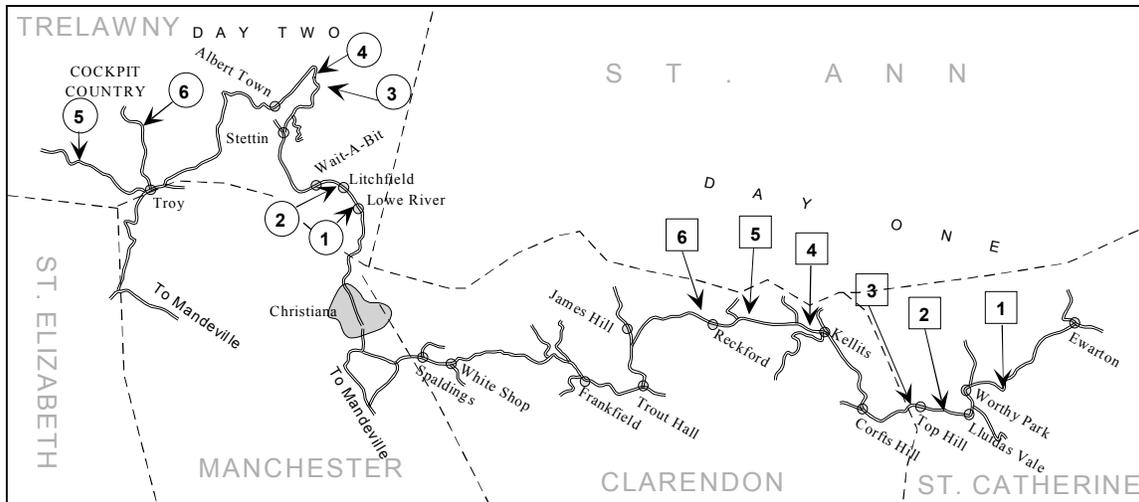


Figure 2. Distribution of stops for days 1 and 2 related to the road network in the parishes of St. Catherine, St. Ann and Trelawny

localities including Lluidas Vale, which is partly developed in the Troy Formation (Landmann, 1990).

ITINERARY: DAY 1

Drive out of Kingston, along the A1 past Spanish Town and through Bog Walk and Linstead (Fig. 2). On the approach to Ewarton, take the left turn to Lluidas Vale. We will pass through scenery developed in the White Limestone. The first stop is at the sign for Worthy Park where there are excellent views across Lluidas Vale.

Stop 1. Lluidas Vale, St. Catherine. This occurs on a west-facing fault scarp above Lluidas Vale polje. The polje occurs in Troy Formation limestones displaced by NE-SW trending faults to produce large-scale fault blocks which are important controls on the geomorphology of the area. A more recent alluvial and limestone debris cover occurs within the vale, whereas the steeply sloping rim of the polje to the west, north and east is within Troy Formation limestones. To the south and southwest of the vale, rocks of the Yellow Limestone Group crop out, while further south older Cretaceous volcanic and sedimentary strata, comprising the Arthurs Seat Formation are exposed. Here the geomorphology is different, with processes dominated by mass movements and surface water erosion forming typically dissected terrain. A number of northwards flowing surface streams rise in this area and extend into Lluidas Vale forming the Murmuring Brook and Rio Cobre stream systems. Lluidas Vale polje is developed within a downfaulted block of Tertiary White

Limestone and it has a strong structural control through NW-SE trending faults. The floor of the vale also appears to be structurally controlled in that a series of down-faulted limestone blocks are present and overlain by a sequence of limestone rubble, bauxitic soils and alluvium which extends to over 30 m thickness. Lluidas Vale is a Rand- or Border-Polje (sensu Ford and Williams, 1989) in that it is not surrounded on all sides by limestone but bordered to the south by volcanic and clastic sedimentary strata of the Central Inlier in the Juan de Bolas Mountains. The latter is the source of the Rio Cobre and Murmuring Brook which flow northwards towards the vale. The Rio Cobre flows north through the centre of the vale, but turns abruptly southeastwards and flows a short distance along the fault scarp before sinking. In the polje, the river and Murmuring Brook are both ephemeral streams flowing only after rainfall. The north and northwest border of the vale is marked by well-developed cockpit karst. A number of small alluvial fans occur on this part of the vale in heavy clay soils representing the residue of limestone dissolution (Landmann, 1990). Much lighter alluvial soils occur on the eastern and southern part of the vale due to more frequent flooding. The western margin of the vale is marked by a less steep slope containing dolines and small conical hills grading to tower karst towards the polje.

The Rio Cobre sink occurs at the contact of the polje floor and side slope and is therefore a classic ponor feature (a depression/sink at the border of a polje) in a full blind-valley. The Rio Cobre stream network within the vale is an ephemeral feature and for the most part dry and clogged with bamboo. At this locality a number of small cave systems, the Worthy Park Caves, occur on the slope above the

main river sink and possibly represent former elevated ponors. A detailed description of the Worthy Park Caves was given by Fincham (1997).

From stop 1, descend down into Lluidas Vale and drive through the town of the same name. Stop 2 is situated on the edge of the vale.

Stop 2. Dodd's Valley, St. Catherine. Well-developed tower karst surrounded by a flat alluvial floor can be seen in Dodd's Valley on the western side of the Lluidas Vale polje. Tower karst (Turm Karst) comprises oversteepened limestone hills, often with basal notches which may be the product of laterally directed solution. A flat-topped tower near to the road at this locality contains a well-developed basal notch, which may be exposed, at least in part, by soil erosion. A second tower in this general area has a well developed system of foot caves and basal stream sinks. The foot caves have a strong bedding plane and joint control, in that both horizontal and vertical conduits are developed in response to weathering along bedding planes and joints, respectively. The towers in this area also display case-hardening phenomena, where the surface limestones are coated with secondary reprecipitated calcite. Slightly upslope from this locality is a second group of towers that show no evidence of lateral undercutting. Their basal slopes are shallower and represent a blocky limestone talus debris.

Leaving Stop 2, the road climbs back up the White Limestone towards Top Hill. At Top Hill (Stop 3) and on the road descending the hill on the far side of Top Hill, there are excellent views into the Central Inlier.

Stop 3. Top Hill views. From Top Hill, extensive views across the eastern end of the Central Inlier are visible. This end of the inlier is characterised by igneous and volcanoclastic rocks that give rise to rugged mountains with steep-sided valleys.

Continue down the Hill and through Crofts Hill and Kellits. This road is cut in the sandstones of the Guys Hill Formation and there are many small exposures by the roadside. Between Crofts Hill and Kellits there are views to the south over the deeply incised valley of Pindars River. On passing through Kellits the Stettin Formation becomes well-developed and typical Stettin-type karstic scenery is developed (Stop 4).

Stop 4. Elongate enclosed depressions west of Kellits. West of Kellits the Stettin Limestone is almost horizontal. It gives rise to large (up to

1 km²) north-south, elongated, enclosed depressions.

Most of the depressions in the area are uvalas, with more than one topographic low point within the depression, though their floors are not flat. The depressions form relatively subdued topography where the negative relief elements dominate the landscape. Most of the depressions have only gentle to moderate side slopes, such that the landscape is rolling in character. The uvalas in this area are considered to be solutional in origin, though minor collapse may also have occurred.

As we pass further to the west, other depressions are also developed. Around Sandy River, there are many roadside exposures in the Stettin Limestone, and this is the type area for many of the larger foraminifers from the Stettin Formation. We will stop at a typical exposure of the Stettin Formation just before Sandy River (Stop 5).

Stop 5. Stettin Limestone at Sandy River. About 4 m of nodular limestone is present here. These limestones have a nodular texture, with hard cemented limestone layers or nodules surrounded by soft mudstones. Macrofossils (bivalves) can be seen in life position in these rocks. The Stettin Limestone was deposited in a shallow marine setting during the early Middle Eocene; it represents the first transgression (flooding) of central Jamaica since the Cretaceous.

Drive on through Sandy River to Reckford Square, a small track leads off about 200 m to the west of the square down to the fields (Stop 6).

Stop 6. Geomorphology at Reckford. The path leads down into a large amphitheatre-like bowl. On the rim, small 'islands' of white limestone can be seen to the north of a major fault that cuts out the Chapelton Formation. The main amphitheatre is formed of the gullied slopes of the Guys Hill Formation which run down to a series of smaller and larger sink holes in the Stettin Formation. Several of these sinkholes have small streams sinking into them.

From Stop 6 continue along the road until the main road from James Hill to Trout Hall is reached. Then follow the road to Trout Hall, on through Frankfield to the Astra or Mandeville Hotel in Mandeville.

ITINERARY: DAY 2

Drive from the hotel through Christiana and on towards Lowe River. A small quarry on the right

hand side of the road behind the fenced in truck packing area exposes the Chapelton Formation.

Stop 1. Chapelton Limestone at Lowe River.

This stop is a good example of why the Yellow Limestone was so named by Sawkins in 1869. Here we can see a yellow weathering impure fossiliferous limestone. The hill above the scarp is entirely composed of the limestones of the Chapelton Formation. The echinoid *Fibularia* occurs abundantly at this locality. This species is particularly rare and until this locality was discovered, only 30 specimens of *Fibularia* had ever been recovered from the Chapelton Formation. The low biodiversity and marly lithology of this site suggests a restricted shallow-marine environment. Other echinoids are also present as well as very rare shark teeth.

From Lowe River drive on towards Wait-A-Bit. Extensive views across the steep slopes of the Guys Hill Formation are available. The classic Litchfield section in the Guys Hill Formation is a road cut on the road.

Stop 2. Guys Hill Formation at Litchfield. The roadside exposure represents a 12 m interval in the upper part of the Guys Hill Formation, the total thickness being about 286 m in this area. This exposure is quite spectacular and contains a considerable amount of information. This exposure is faulted. On the south side of the fault (towards Lowe River), approximately 8 m of the succession is exposed. The lowermost unit is best exposed on the other side of the road, and comprises a thick, laminated mudrock. Above this mudrock is a unit of heterolithics, consisting of interbedded sandstones and mudstones in beds less than 6 cm thick. Heterolithics suggest alternating energy conditions with muds deposited during quiet water periods. The overlying sandstone units show cross-bedding and ripple cross-lamination. These structures indicate migration of bedforms (dunes and ripples). Large-scale (macroform), curved (sigmoidal) erosion surfaces are present and represent the migration of large bedforms. This indicates that periods of active migration of these large bedforms alternated with periods of relative calm, indicated by bioturbation (disturbance of the sediments by organisms), mud drapes and thin intervening mudstones. As energy conditions increased, the mudstones were torn up and deposited with coarser, sand-sized sediments along accretion surfaces (mudstone rip up clasts). These sedimentary structures and lithologies suggest that this succession represents a tidal sand wave complex. On the other side of the fault, the upper

part of the previous succession is repeated at the base.

There are good examples of growth faults in this exposure (the main fault is probably also a growth fault, but this cannot be proved). The largest of these clearly displaces the sandstone-mudstone boundary, but does not affect the overlying limestones or lignitic shale horizon. The failure plane is curved, showing slippage towards the northwest. Slippage along the fault created about 30 cm of space, resulting in a commensurate thickening of the upper beds on the slipped side. The development of growth faults corresponds with a transition in the lithology from sandstones to more calcareous facies, possibly associated with increased water depth. The calcareous shale above the sandstones contains septarian concretions, whereas above are two thin limestones with abundant oysters. Finally, this exposure contains a lignitic shale near the top containing abundant plant material; it forms a useful marker band across the Central Inlier. Plant traces may also be found in the mudstones at lower levels. This suggests that this shallow marine locality was relatively close to an Eocene land mass.

From Litchfield, drive through Wait-A-Bit and on towards Stettin. This is the type area for the Stettin Formation and many exposures of the Stettin Formation are visible. Take the right turn down towards the river and follow the road to the west. The road passes across a major fault throwing Stettin Formation against the White Limestone. Quashies River Sink is in the White Limestone and accessed by a small trail from the road. Watch out for ticks/grass lice!

Stop 3. Quashies River Sink, Freeman's Hall, Trelawny. Quashies River is a large stream draining about 10 km² of the north-west part of the Central Inlier. The stream rises on the Black Grounds near Wait-A-Bit and flows north to sink about 3 km south of Ulster Spring near to Freemans Hall.

In 1965, there was an attempt to establish the Quashies River sink rising using 30 kg of fluoresceine dye by the Karst Hydrological Expedition to Jamaica from Huddersfield, England (Livesey, 1966). Although the test was unsuccessful, it showed that the two largest caves in the area, Quashies River Cave and Bristol Cave, both contain sections of an underground river. A further test from the Quashies River Sink using dyed Lycopodium (Club Moss) spores gave a positive trace to Dornock Head Rising in seven days, for a sink-rising distance of some 12 km (Brown and Ford, 1968, 1973). Dornock Head is

situated north of Stewart Town, St. Ann and forms the headwaters of the Rio Bueno.

The Quashies River Sink is a large and impressive collapse feature, some 37 m deep. The river enters the sinkhole through a gorge down cascades on the south side of the collapse. It then flows northwards along the floor of the collapse and enters a large arched cave entrance to the north of the sinkhole. The entrance is about 6 m high and 15 to 20 m wide. The cave contains a number of cascades and waterfalls up to 30 m high, beyond which is a muddy passage with deep water which ends in a sump. There is also a set of dry passages, called the Balcony Series, on the west side of the sinkhole. A more detailed description of Quashies River Cave appears in Fincham (1997).

Return to the road and pass along to the west. A small stream (Stop 4) has well developed tufa deposits.

Stop 4. Tufa in stream. Tufa is a limestone which is precipitated from running water. River water running over the calcareous sedimentary rocks of the White Limestone has become supersaturated with respect to CaCO_3 . In small waterfalls, turbulence drives off CO_2 and this coupled with biochemical activity of plants (e.g., mosses) leads to the precipitation of tufa. Tufa (or travertine) is widespread in numerous waterfalls in Jamaica and commonly preserves impressions of the plants on which it has grown.

Continue along the road, turning left twice and pass up into Albert Town. From Albert Town drive on to Troy. Pass through Troy and take the right turn up the hill (the road is not good).

Stop 5. Heading view over Cockpit Country. Cockpit Country is famous worldwide for its spectacular karst topography, it being the type area for a tropical limestone terrain termed cockpit karst (kegelkarst). Cockpit karst comprises steep sided, polygonal shaped depressions up to 1 km in diameter; and conical hills, some of which are elongate and asymmetrical, 30-130 m high and up to 1 km diameter, displaying an array of slope forms from small steps and ledges to major cliffs. The cockpits tend to be contiguous, with a clear divide between each depression and occasional cone asymmetry developed due to localized dip increases, or localized case hardening. In the area viewed from Heading, three principal classes of cockpit karst can be recognized based on the shape and size of the conical hills (Miller, 1998). These are cockpits with conical hills, cockpits

with small asymmetric hills and cockpits with larger conical hills and limestone ridges. It is inferred that these differences in cockpit karst are a result of the weathering of different stratigraphic units within the White Limestone Group, but this still requires further testing.

Around the margins of Cockpit Country, cockpits often give way to glades, pocket valleys and poljes, due to lateral planation of the limestones rather than vertically directed solution. Such features are best seen on the northern flanks of Cockpit Country, though tower karst does occur in the Heading and Troy area, where they represent small White Limestone outcrops surrounded by Chapelton Formation limestones of the Yellow Limestone Group. In the Heading area, doline karst is the predominant landform on the Chapelton Formation.

The regional pattern of subterranean water movement within the Cockpit Country is northwards, but for the most part individual cockpit depressions are hydrologically relict, the only surface flow being associated with depressions containing a soil infill. Streamflow in this area is confined to the Hector's River which sinks to the west of Troy, it reappears to the south for a short distance as the Coffee River, sinks at Coffee River Cave to re-emerge at Oxford as the One-Eye River. The One-Eye River sinks at Wallingford Sink and rises again in the Nassau Valley, where it forms a part of the Black River drainage basin.

Return to Troy, and take the left turn in the middle of the town towards the Troy Windsor Trail.

Stop 6. Tyre, Troy-Windsor Trail. This is a trail across Cockpit Country. Here the limestones at the boundary between the Yellow and White Limestone Groups can be seen. The Chapelton Formation at the top of the Yellow Limestone Group consists of thinly bedded limestones and marls with scattered fossils. In contrast, the base of the White Limestone is represented by the Troy Formation, which consists of hard thickly bedded to massive dolostones and recrystallized limestones. The dolostones have a coarse sugary texture and do not react with dilute HCl. In the Tyre and Troy-Windsor trail area, the dominant karst landforms are towers surrounded by dolines, which are oval or circular enclosed depressions. The towers are developed on Troy Formation dolostones, while the dolines occur in underlying Chapelton Formation limestones.

Acknowledgements. *We thank Sherene James and Thomas Stemann for making comments on the original paper.*

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Revised version received: February 25th 2003
Accepted: February 28th 2003