Mitchell, S. F., Ramsook, R., Coutou, R. and Fisher, J. 2011. Lithostratigraphy and age of the St. Ann's Great River Inlier, northern Jamaica. *Caribbean Journal of Earth Science*, Volume **42**, 1-16. © Geological Society of Jamaica.

Lithostratigraphy and age of the St. Ann's Great River Inlier, northern Jamaica

SIMON F. MITCHELL, RYAN RAMSOOK, RICHARD COUTOU AND JASON FISHER

Department of Geography and Geology, The University of the West Indies, Mona, Kingston 7, Jamaica.
Email: simon.mitchell@uwimona.edu.jm or barrettia2000@yahoo.co.uk

ABSTRACT. The geology of the St. Ann's Great River Inlier is revised. A new map of the inlier showing the faults is presented as a base to understand the succession. The lithostratigraphy is described and eight formations are recognised: Windsor Formation (Coniacian: 230+ m thick), Clamstead Formation (Santonian, divided into five members: Lower Clamstead Mudstones; Lower Clamstead Sandstones; Middle Clamstead Mudstones; Upper Clamstead Sandstones; Upper Clamstead Mudstones: 403 m thick), Liberty Hall Formation (Late Santonian and Middle Campanian separated by a major fault: 60+ m thick); Drax Hall Formation (Middle Campanian: 63 m thick); Cascade Formation (Middle-Late Campanian: 180 m thick); Lime Hall Formation (Late Campanian: 14 m thick); St. Ann's Great River Formation (Late Campanian: 14 m thick); and New Ground Formation (Early to Middle Eocene: 290 m thick). The age assignments of the various formations are discussed based on previous and new fossil records.

Key words: St. Ann's Great River Inlier, Jamaica, Cretaceous, Stratigraphy.

1. INTRODUCTION

The small Cretaceous inlier exposed along St. Ann's Great River (**Figure 1**) in northern Jamaica contains a succession of predominantly clastic rocks. This sequence is important for understanding Cretaceous stratigraphy in the Antillean Region because it yields ammonites, inoceramids and planktic foraminifers in a relatively continuous succession. Sohl (1979, p. XXXXI.2) went as far as to say *"stratigraphic continuity and occurrence of both mollusks and foraminifera make this one of the most important sequences in the Antilles for establishing a detailed biostratigraphy of the Caribbean Province"*. In this paper a revision of the stratigraphy of the inlier is presented together with a new geological map as a base for future work on the biostratigraphy.

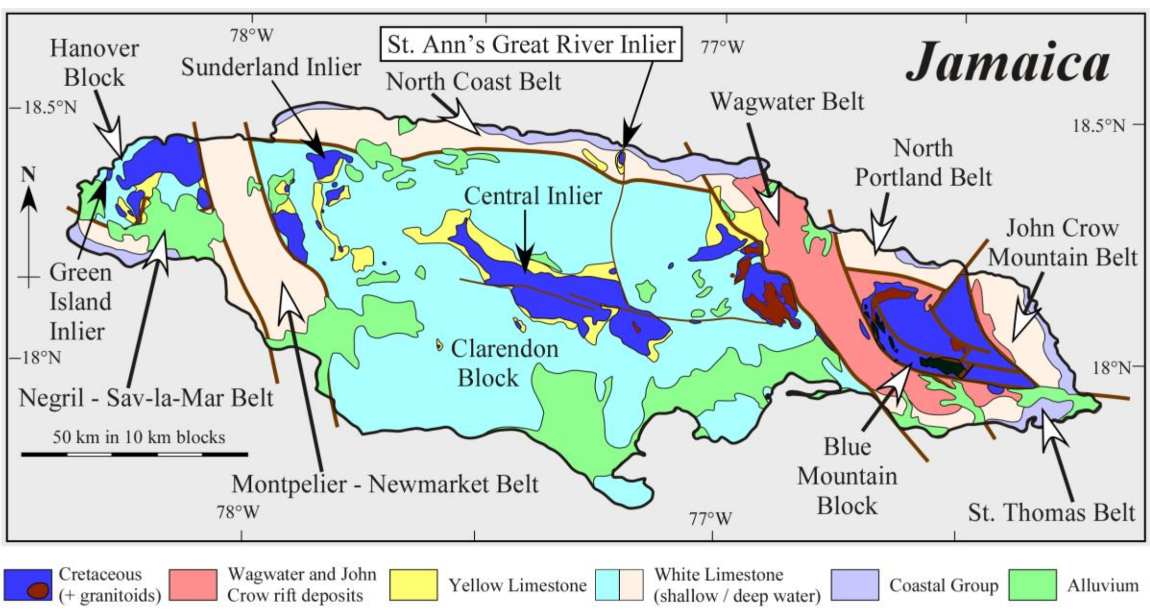

Figure 1. Figure 1. Location of St. Ann's Great River Inlier, northern Jamaica, and its relationship to the Paleogene block and belt structure.

2, PREVIOUS STUDIES

Sawkins (1869, p. 199) in his report of the 10th of May, 1866, stated that *"the Great St. Ann's River* ... [and its tributaries] ... *have cut through a portion of the upper conglomerates of the trappean series and expose some of the superincumbent black shales to the east of Liberty Hill"*. The exposures do not appear on the Sawkins and Brown 'Geological map of Jamaica' of 1865 that was published in Sawkins (1869) nor on the Hill map of 1898 (Hill 1899), which is largely a copy of the Sawkins and Brown map. The Sawkins and Brown map was produced in 1865, before the geological mapping of Jamaica was completed, probably to coincide with the legislature imposed termination of the geological survey of Jamaica at the end of 1865 (Colonial Office Records, The National Archives, Kew, London). Sawkins, however, managed to obtain an extension to complete the surveying, including St. Ann, but the Sawkins and Brown map of 1865 was never revised. The trappean exposures in St. Ann are, however, shown on the geological map of St. Ann, dated 1866, that was completed for the survey of that parish (manuscript copy in the Institute of Jamaica) and this was presumably the map that was referred to by Matley (1924a) as showing these exposures.

Matley (1924a), during his survey of water resources in Jamaica, discovered the existence of a gas seep in the Windsor Spring, a spring that had been reported by Sawkins (1869), and measured the gas to be 98.34% methane and 1.66% carbon dioxide. At that time, Matley regarded the clastic rocks exposed in the river valley to the south as of early Eocene age, suggesting that Cretaceous rocks might exist at depth. Subsequently, he discovered a Cretaceous limestone in the sequence at the southern end of the inlier (Matley, 1924b) containing rudists (*Radiolites cancellatus* Whitfield and *Radiolites nicholasi* Whitfield) which Trechmann, in a personal communication to Matley, thought were probably of Maastrichtian age. Matley suggested that the bulk of the succession exposed in the inlier was either below the limestone or separated from it by a fault. Matley made a hurried geological survey of the inlier before he left Jamaica (Matley, 1925). Matley's (1925, p. 14) description is reproduced here: *"The strata of the inlier occupy a length of 2¼ miles from north to south along the floor of the valley with a width not exceeding ¾ mile. The general structure is an anticline, the principle axis of which trends nearly north to south, but in the northern part there are dips to the east, so that there is some evidence that the inlier may be a dome. Unfortunately I had not the time to examine the east and west boundaries of the inlier. There does not appear, however, to be room on the sides of the valley for all the strata of the inlier to be exposed, and the higher beds must be either faulted out or covered unconformably by the Montpelier Limestone. The northern end of the anticline is ruptured by a fault that runs in a north-north-easterly direction through the mineral spring and brings down the Montpelier Limestone against the lower beds of the inlier."* The northern limb of the anticline *"exposes only the lower sandstones and conglomerates of the inlier"* with *"dips NNE at 20º up to 60º"*. The southern limb exposes, from the base upwards, *"thick sandstones and conglomerates with some shaly partings and beds of flaggy grits, above which comes a few feet of clays followed by pebbly sandstone. These graduate upward into blue clays and shales with rare bands of sandstone. In one place I saw a few marine fossils (small Pholadomyas) which are apparently of Cretaceous age. Unsurveyed rocks, about ⅜ mile across their strike succeed; then, at the point where the tributary from Dawson Town joins the main river, clays are again seen with occasional bands of pebbly sandstone, followed by a thick group of sandstones and conglomerates over which the river rushes in a series of cascades. Pebbles up to 24 inches in diameter were seen in these conglomerates. They continue as far as the bridge that crosses the river at the confluence with the Fonthill tributary. Then comes a bed of shaly Rudist Limestone with a matrix of yellow marl. It has a superficial resemblance to a bed of Yellow Limestone, but contains* Radiolites cancellatus, *Whitf. and* R. (Lapeirousia) Nicholasi *Whitf., so that it is evidently of Cretaceous age. A few feet of clay succeeds, then a bed of nodular limestone, followed by more blue clays in which I found an abundant marine fauna. Dr. C. T. Trechmann F.G.S. who was then in Jamaica kindly examined the specimens (as well as the rudists from the limestone) and identified the following:-* Pecten (Janira) quinquecostatus, Pholadomya *(a species also found at Providence, parish of Portland),* Turritella *sp.,* Cardium, Cerithium *spp.,* Solarium *(?) sp.,* Amauropsis *& other Naticoids*, Dentalium, Volutilites *(?),* Plicatula *sp., Corals, 2 spp., Echinoid fragments. Dr. Trechmann considers the horizon represented is highest Cretaceous (Maastrichtian). The clays pass up into conglomerates, in one bed of which the pebbles consist entirely of hard fresh black basalt with a resinous lusture."*

Trechmann (1927) recorded over 1,400 ft of section in the inlier, puts thicknesses on Matley's units, recognized that *Barrettia* occurred in the

Table 1. Succession in St. Ann's Great River as given by Trechmann (1927, pp. 30-31).

		Thickness in feet
1.	Tertiary white marls passing up into white limestone	?
	Unconformity ?	
2.	Conglomerates containing numerous limestone pebbles. Richmond or basal Eocene.	?
	Unconformity.	
3.	Grey and black shales becoming calcareous towards the base. Fossils plentiful; *Neithea quadricostata*, *Plicatula* cf. *andersoni*, *Pholadomya jamaicensis*, *Gosaria* sp., *Glauconia matleyi*, *Apporrhais* sp., *Cerithium* cf. *libycum*, and other forms. The gastropods occur mostly in calcareous shales a few feet above the limestone.	About 40
4.	Clayey limestone with fragments of Rudistae.	10
5.	Grey and pink nodular limestone containing complete and broken specimens of *Biradiolites cancellatus* and *B. subcancellatus*, *Barrettia monilifera*, and a large specimen of *Laperiousia nicholasi*.	12
6.	Massive conglomerate with many igneous and a few limestone pebbles.	50 (?)
7.	Grey and blackish shales and shaley sandstones. A bed of small *Corbula* occurs in these shales about 800 feet below the Rudist limestone and below this is a bed with *Turitella cardenasensis*, *Neithea subcompacta*, *Natica* sp., *Ostrea* sp., *Echinoderm* spines, etc. About 1,000 feet below the limestone a specimen of *Inoceramus* cf. *balticus* was collected by Mr. J. V. Harrison.	over 1,000
8.	Grey nodular shales with calcareous bands, no fossils seen.	300 (?)
9.	Thick conglomerates and sandstones, base not seen	?

Table 2. History and relationship of lithostratigraphic schemes used for the rocks exposed in the Cretaceous to Early Eocene of St. Ann's Great River Inlier (Fm, Formation; Mbr, Member; Congl., Conglomerate). Ages apply to this study.

Jamaican Stanolind 1956	Chubb, 1955, 1958, 1960, 1963	Meyerhoff and Kreig 1977	Jiang and Robinson1987	Herein		
				Formation	m	Age
New Grounds Formation	Conglomerates	New Ground Congl.	New Ground Fm	New Ground Fm	(290)	Late Campanian
	Diozoptyxis Shale	"Diozoptyxis" Shale	St Ann's Great River Fm	St Ann's Great River Fm	48	
Lime Hall Limestone	Barrettia Limestone	Barrettia Limestone (Lime Hall Limestone)	Lime Hall Mbr	Lime Hall Fm	28	
Great River Formation	Cascade Fm	Cascade Congl.	Cascade Fm	Cascade Fm	180	Middle Campanian
		Actaeonella Beds		Drax Hall Fm	63	
				Liberty Hall Fm	60++	Faulted
Windsor Formation	Inoceramus Beds (Series)	Inoceramus Shales	Windsor Fm	Clamstead Fm	403	Santonian
	Windsor Shale	Windsor Formation		Windsor Fm	230+	Coniacian

Rudist Limestone, and described various fossils from the sequence. Trechmann's description is worth repeating here (**Table 1**) because it has formed the basis of many subsequent reports, both on the succession and about the age of the sequence. Trechmann (1936, p. 253) collected an ammonite from the *"lowest known fossiliferous shales, some 800 ft below a Barrettia limestone"* that was identified as *Nowakites* aff. *paillettei* (d'Orbigny) by L. F. Spath (in Trechmann, 1936) and attributed to the Upper Coniacian or Lower Santonian. Subsequently this specimen has been identified as a Santonian *Nowakites* of the *paillettei* group by J. W. Kennedy (written communication in Sohl, 1979, p. XXXI.3) and as *Nowakites lemarchandi* (Grossouvre) which ranges from Early Coniacian to Late Santonian (Wiedmann and Schmidt, 1993).

Oil exploration began in Jamaica in 1955 by Canadian Base Metals, with chairman Franklin D. Roosevelt, and the initial target was the Windsor gas seep, but because access could not be gained, the Geological Survey recommended a site at West Negril, but the site selected was 5 km to the east of this because there was easy access to the road and to a water supply (Wright, 1996; Exploration Division PCJ, 1982). Various unpublished oil company reports applied formation names to the various successions in the Cretaceous of Jamaica and some of these names have subsequently become established in the published literature. The Jamaican Stanolind Oil Company (1956) used the following names for the Cretaceous succession exposed in St. Ann's Great River (**Table 2**): Windsor Formation, Great River Conglomerate, Lime Hall Limestone and New Grounds Formation.

Table 3. Planktic foraminifers from the 'Inoceramus Shales' of St. Ann's Great River

Position	Assemblage from Esker (1969) & revised Assemblage [square brackets] from Pessagno (1979)
Upper part	**Late Santonian**: *Marginotruncana renzi renzi* (Gandolfi), *M. renzi angusticarinata* (Gandolfi), '*M. sigali* (Reichel)' [=*M. augusticarenata* (Gandolfi) according to Pessagno, 1979], *M. coronata* (Bolli), *Heterohelix reussi* (Cushmann), *Globigerinelloides asper* (Ehrenberg), *Gublerina deflaensis* (Sigal), *Planoglobulina glabrata* (Cushman), *Rosita fornicata* (Plummer), *Globotruncana linneiana* (d'Orbigny), *Guembelitria* sp. cf. *G. cretacea*.
Middle part	**Middle Santonian:** *Marginotruncana renzi renzi* (Gandolfi), *M. renzi angusticarinata* (Gandolfi), '*M. sigali* (Reichel)' [=*M. augusticarenata* (Gandolfi)], common *M. coronata* (Bolli), *Dicarinella concavata* (Brotzen), common *Gublerina decoratissima* (de Klasz), *Heterohelix reussi* (Cushmann), *Hedbergella* sp., *Globigerinelloides asper* (Ehrenberg), *Gublerina deflaensis* (Sigal).
Lower part	**Early/Middle Santonian**: *Praeglobotruncana algeriana* Caron, *Marginotruncana renzi renzi* (Gandolfi), *M. renzi angusticarinata* (Gandolfi), '*M. sigali* (Reichel)' [=*M. augusticarenata* (Gandolfi)], *M. coronata* (Bolli), *Dicarinella* sp. cf. *concavata primitiva* (Dalbiez), *D. concavata* (Brotzen), *Gublerina decoratissima* (de Klasz), *Heterohelix reussi* (Cushmann), *Hedbergella* sp.

Chubb (1955, 1958, 1960; in Zans et al., 1963) progressively revised his interpretation of the succession exposed in St. Ann's Great River. In 1955, a four-fold division was recognised broadly following Trechmann's description: 1,400 to 2,500 ft of shales and conglomerates (placed in the Cenomanian) of the Inoceramus Shales or Series (Zans 1953; Chubb, 1955) below the Barrettia Limestone; the Barrettia Limestone (Turonian); 40 ft of shales (Turonian) above the Barrettia Limestone (which Chubb called the Diozoptyxis Shales in 1955); and a *'considerable thickness of conglomerates and shales'* above. The Inoceramus Series of St. Ann was placed in the Cenomanian based on Chubb's own identification of *Inoceramus crippsi* Mantell, whereas the Diozoptyxis Shales were named after *Glauconia matleyi* which was transferred to that genus. The interpretation of the section changed considerably after Zans (1954, p. 2) recognised a fault in the shale-conglomerate sequence to the south of Windsor (Chubb, 1958, 1960; in Zans et al., 1963). This fault (our fault F2) was interpreted to separate Campanian rocks to the north, from a southerly dipping Turonian to Campanian sequence to the south. The southern succession began with the Turonian-Coniacian Inoceramus Shales, containing *Inoceramus deformis* Meek, Trechmann's *Nowakites paillettei* and Turonian or Turonian-Coniacian planktic foraminifers (identified by Paul Bronimann of the Esso Standard Oil Company in Havana, Cuba); followed by an unnamed thick conglomerate; the Barrettia limestone (?Santonian); and the Diozoptyxis Shale (Campanian). The conglomerates above the Diozoptyxis Shale were now referred to as the New Ground Conglomerate (Chubb, 1960) and tentatively assigned to the Campanian. The name Windsor Shale was used for the succession to the north of the fault (Chubb, 1960).

Greiner (1965, fig. 6) published a map of the succession in St. Ann's Great River and placed a fault about two fifths of the way along the river section at the point where the dip in the beds swings from broadly eastwards to broadly southwards (our fault F4). Esker (1969) described planktic foraminifers from the Cretaceous succession in St. Ann's Great River collected to the south of this fault, but his ages were different from those assigned to the succession by Bronimann. Esker (1969) reported three assemblages of planktic foraminifers from the Inoceramus Shales and suggested a Late Coniacian to Late Santonian age (**Table 3**). However, Pessagno (1979) noted that the presence of *M. concavata*, and to a lesser degree *Gublerina decoratissima* indicated that all three assemblages were of Santonian age. Esker (1969) also listed sparse foraminifer faunas from 'a few feet of organic rich shales' (probably from the base of the Drax Hall Formation of this study) above the Inoceramus Shales and from a shale within the New Ground Conglomerate that indicated Campanian and Early-Middle Eocene ages, respectively.

The Inoceramus Shales have yielded various specimens of inoceramid bivalves that were discussed in a series of papers by Kauffman (1966, 1969, 1979). An inoceramid collected from float by H. L. Hawkins has been the cause of much controversy; it was identified as *I. inconstans* Woods by Chubb (1955, p. 191), *I. deformis* Meek by Chubb (1958) and *I.* cf. *deformis* by Chubb (1960). Kauffman (1979, XXX.7) suggested instead that this was a specimen of *Cordiceramus mulleri* (Petrascheck) of late Santonian or early Campanian age. Equally, the specimens indentified as *I. crippsi* Mantell from the Inoceramus Shales by Chubb (1955, p.191) were identified as *C. mulleri* and *Cataceramus (Endocostea) balticus* (Boehm) by Kauffman (1979, p. XXX.6-7). Kauffman (1966) also made 'tentative field identifications' of the late

Campanian *Inoceramus proximus subcircularis* Meek and Hayden in grey shales in the upper part of the Inoceramus Shales. Thus, Kauffman concluded that all the inoceramids collected from the Inoceramus Shales suggest a late Santonian or early Campanian age.

Meyerhoff and Kreig (1977) summarised the results collected to date, including unpublished details of the St. Ann's Great River succession collected by Norman Sohl and their figure 16 is reproduced here (**Figure 2**). Norman Sohl estimated that the Windsor Formation was 700 to 850 ft thick, and collected ammonites (*Peroniceras* cf. *moureti* Grossouvre, *Gauthiericeras* cf. *bajuvaricum* (Redtenbacher), *Baculites* cf. *yokoyamai* Tokunaga & Shimizu and *Neocrioceras* sp.) and inoceramids (*Cremnoceramus waltersdorfensis hannovrensis* (Heinz) and *Mytiloides fiegei* (Tröger)) from the base of the formation that indicate an Early Coniacian age (Sohl, 1979; Kauffman, 1979). The Inoceramus Shales (1,300 to 2,200 ft thick) are shown as beginning at the fault between the third and fourth fording (Meyerhoff and Kreig, 1977, fig. 16). However, this fault (our fault F2) is significantly to the north of the fault (our fault F4) shown by Greiner (1965) and Esker (1969) which lies to the south of the first fording. The age ranges for the Inoceramus Shales indicated by Meyerhoff and Kreig (1977) are based on the planktic foraminifers studied by Esker and the inoceramids identified by Kauffman. The planktic foraminifers are shown as being collected to the north of the first river fording, yet Esker's (1969, p. 210) description indicates they were collected above the "basal volcanic boulder conglomerate" to the south of the first fording." Thus the formainifers and inoceramids were collected from about the same interval and the species identified indicate that the Inoceramus Shales are of Santonian age. The Actaeonella Beds (237 – 440 ft thick) consist of a lower unit of conglomerate and an upper unit of shales; they are succeeded by the Cascade Conglomerate (600 – 800 ft thick). The Barrettia Limestone, or Lime Hall Limestone, is 10-20 ft thick and was correlated with the 'late' Campanian Stapleton and Green Island Formations of western Jamaica. The succession is completed by the Diozoptyxis Shale (80-100 ft thick) and the New Ground Conglomerate (more than 951 ft thick). In the same year, the name St. Ann's Great River Formation, presumably after usage by Norman Sohl, first appeared on the 1:250,000 geological map of Jamaica (McFarlane, 1977).

Jiang and Robinson (1987) briefly described the succession in the St. Ann's Great River Inlier. They recognised three formations: the Windsor Formation at the base (Lower Coniacian to Lower Campanian), the Cascade Formation in the Middle (Upper part of lower Campanian), and introduced the name St Ann's Great River Formation for the top part of the succession. The St Ann's Great River Formation included the Barrettia or Lime Hall Limestone and the overlying (Diozoptyxis) shales, and was attributed to the Middle and Upper Campanian. Verdenius (1993) studied the calcareous nannofossils from St. Ann's Great River, but his samples cannot be related to the measured sections described here.

3. Methodology

In order to understand the succession in St. Ann's Great River, a detailed geological map is required. This was difficult to create before because of the lack of a detailed base map that accurately shows the course of the river. The 1:12,500 series topographic map produced by the Jamaican Survey Division shows only the general course of the river, not the details of its bends, because in the aerial photographs there is extensive tree cover across the whole valley. This lack of detail has rendered previous maps of the inlier unreliable because some of the major bends in the river are not even included on this 1:12,500 scale map.

For this study a GPS (geographical positioning system) unit was used to create a base map onto which the geological data could be plotted. The course of the river and road and the positions of fords (fordings) were recorded. Following the basic topographical information, the geology was recorded. This methodology allowed the construction of a detailed geological map that showed individual units, the strike and dip of beds, and the various faults that were identified.

Following geological mapping, the stratigraphy in each fault block was measured. This allowed a composite section for the inlier to be created. Fossils were also collected during and subsequent to the logging exercise, but a detailed discussion of all the fossils would take up too much space here. Further reports detailing the various fossil groups collected from the inlier will be presented elsewhere. This paper concentrates on establishing a sound lithostratigraphical base and reviews the general age assignment of the various lithostratigraphic units.

4. Lithostratigraphy

The detailed geological map for St. Ann's Great River (**Figure 3**) shows that the structure is fault

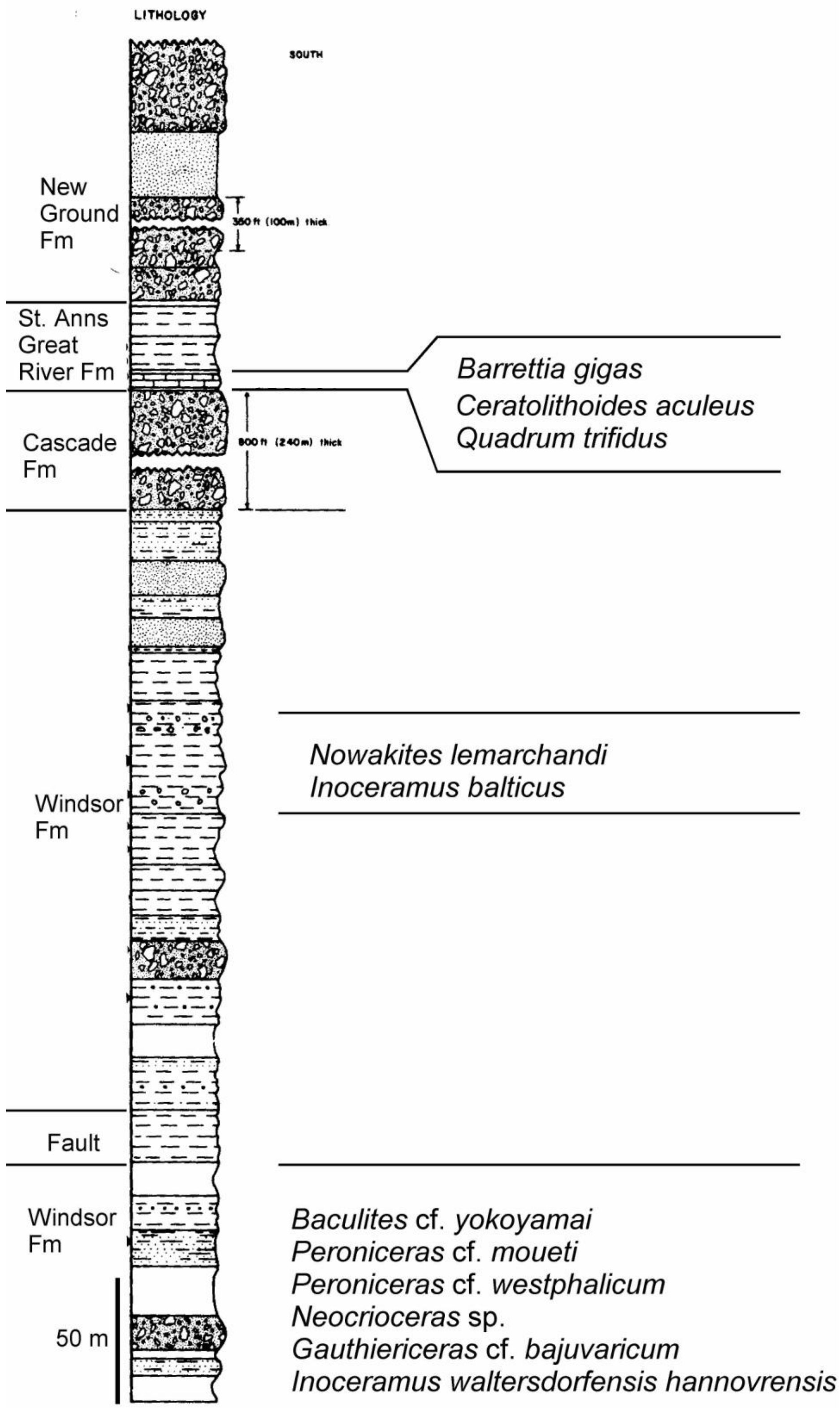

Figure 2. Columnar section along St. Ann's Great River as given by Meyerhoff and Kreig (1977) as modified from an unpublished report by Norman Sohl. Reproduced from Meyerhoff and Kreig (1977, Figure 16) with permission.

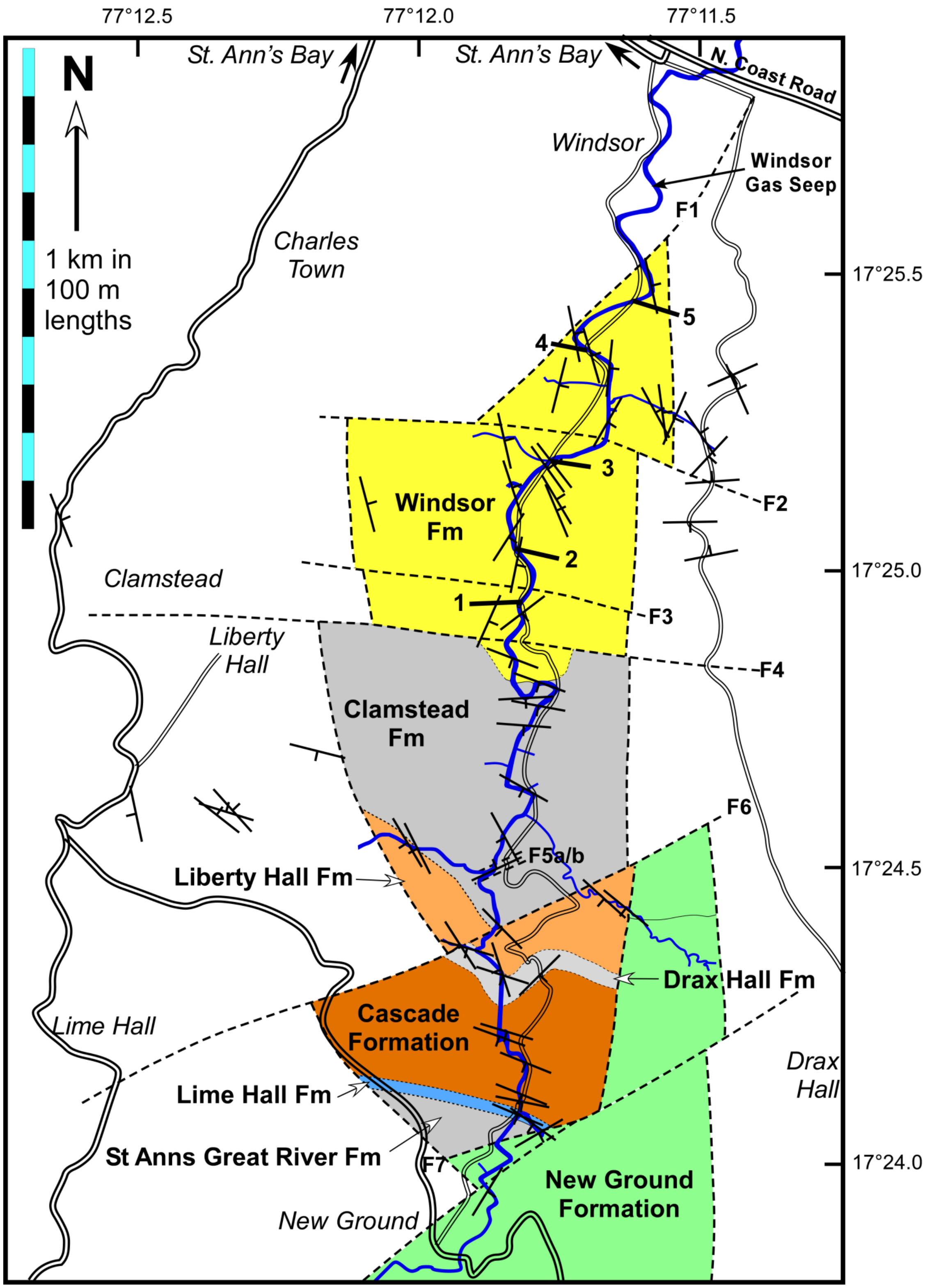

Figure 3. Simplified geological map of St. Ann's Great River Inlier (Yellow Limestone and White Limestone uncoloured). Stratigraphic boundaries shown by fine dashed lines, faults by thick dashed lines. St Ann's Great River and its tributaries shown by blue (solid) lines. Drivable roads shown by thick double lines, tracks by thin double lines. Fords (Fordings) are numbered 1 to 5; the main faults that cross the river are labelled F1 to F7. Latitudes and longitudes from GPS measurements.

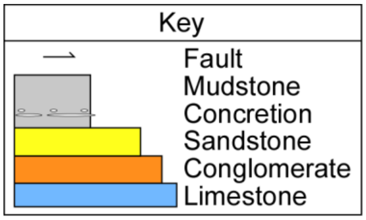

Figure 4. Key to symbols used

bounded and not an anticline as tentatively suggested by Matley (1925a, b). Furthermore, there are more faults present than has previously been mapped. These faults separate fault bounded blocks with moderately consistent internal dips. A pronounced change in the dip direction of the rocks in the river occurs associated with the major fault (F3 in **Figure 3**) a little upstream of fording number 1; north of this fault, dips are generally towards the east, whereas to the south of this fault, dips are towards the south. There are several faults (faults F1-F3 in **Figure 3**) in the northern part of the section (within the Windsor Formation), a fault (F5 in **Figure 3**) in the central part of the inlier (within the Liberty Hall Formation), and a fault (F6 in **Figure 3**) at the southern end of the inlier (separating the Cretaceous rocks from the Eocene conglomerates). At the southern end of the inlier, the Eocene rocks also dip towards the south, but with a smaller amount of dip than the Cretaceous rocks. It is probable, therefore, that the Lower Eocene conglomerates overlie the Cretaceous rocks unconformably, as originally suggested by Trechmann (1927), but due to the faulted contacts this cannot be proved.

The revised lithostratigraphy presented here recognizes six Cretaceous formations (Windsor, Clamstead, Liberty Hall, Drax Hall, Cascade, St. Ann's Great River) and one Eocene formation (New Ground Formation). In addition, a number of marker beds have been identified (and are also described) either because they have a distinctive lithology and are easily recognizable in the field, or because they yield common or biostratigraphically important fossil assemblages.

Windsor Formation

Introduction. The name Windsor Shales was introduced in an unpublished report by the Jamaican Stanolind Oil Company in 1956, and its first published usage is by Chubb (1960) for the succession between the fault (our fault F2) and the Windsor Spring. The name Windsor Shale or Windsor Formation has been widely used subsequently and is retained here for the succession of siltstones, sandstone and conglomerates below the Inoceramus Shales in the St. Ann's Great River Inlier. The base of the formation is not seen.

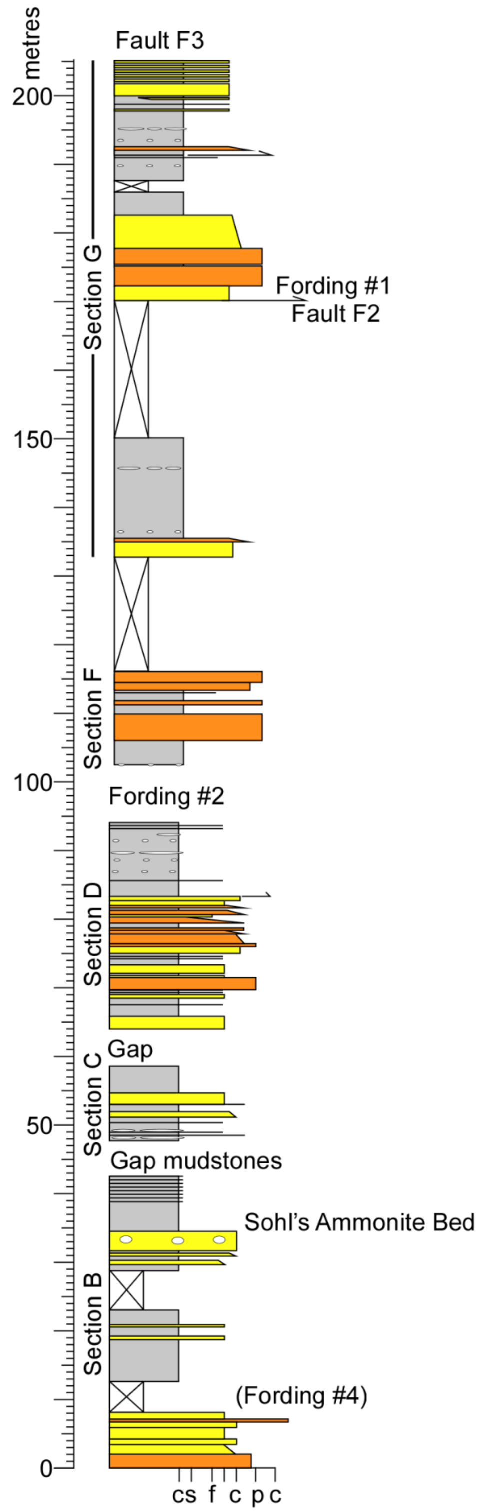

Figure 5. Stratigraphy of the Windsor Formation to the north of the fault immediately south of the First Fording. Sections are arranged in order along the river from fording #4 to fault #4.

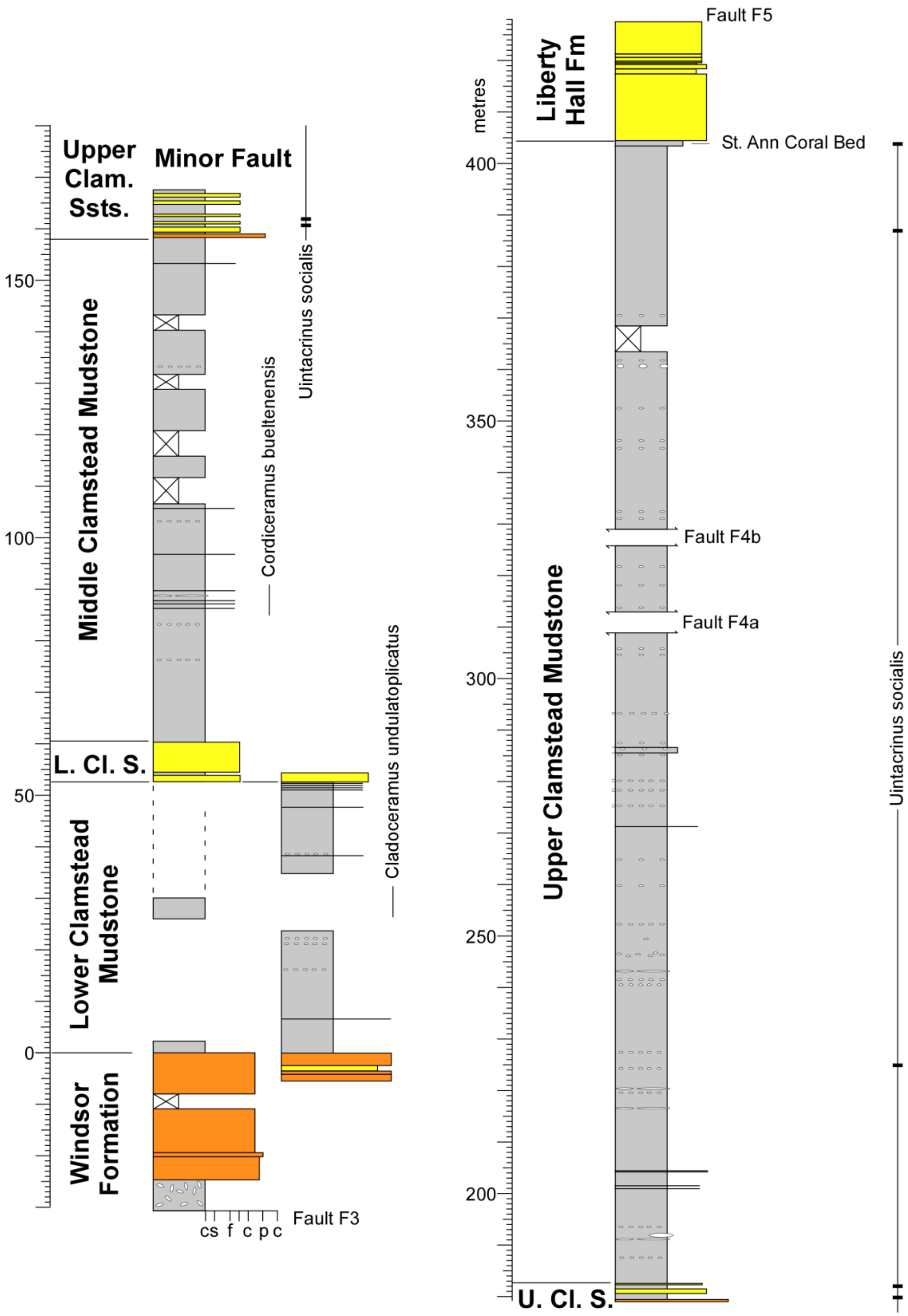

Figure 6. Stratigraphy and distribution of selected macrofossils for the top of the Windsor Formation, the Clamstead Formation and the base of the Liberty Hall Formation in the St. Ann's Great River Inlier.

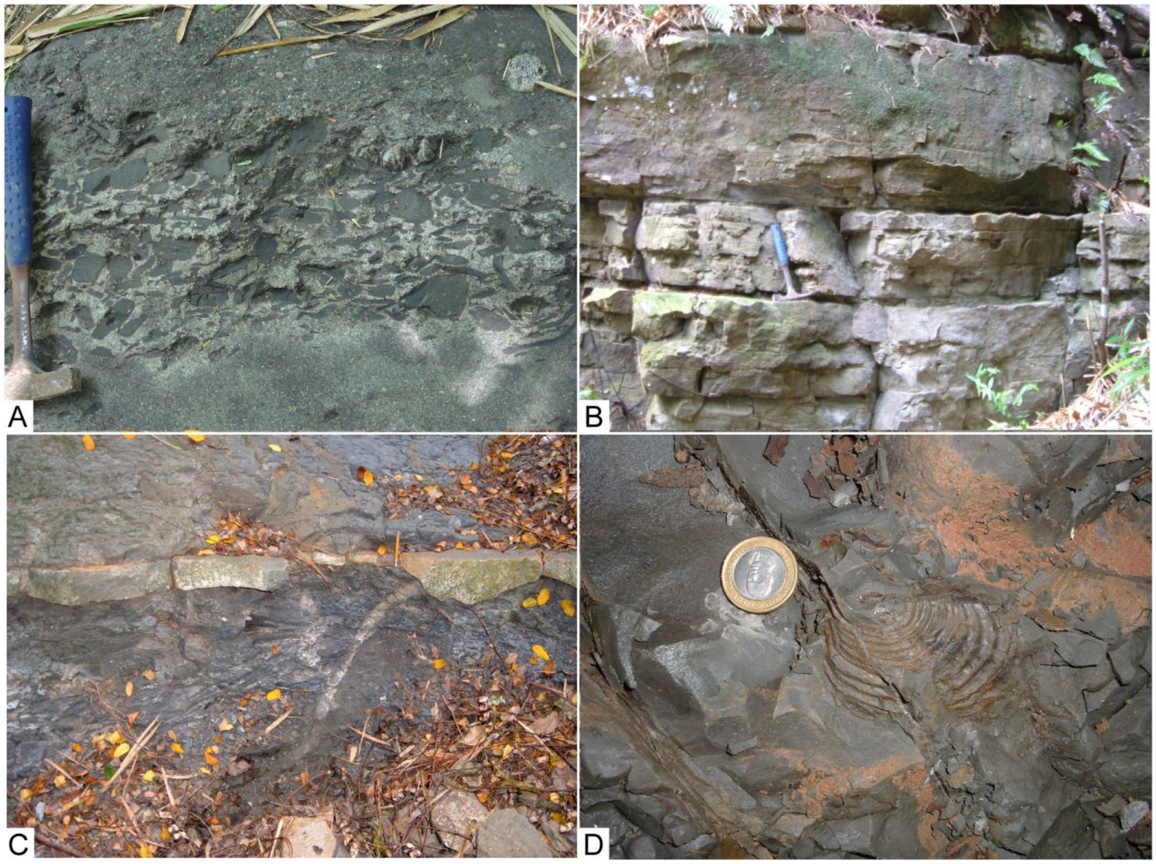

Figure 7. A, Pebble conglomerate with sandstone matrix, upper part of Windsor Formation about 25 m below Clamstead Formation. B, Bedded sandstones with ripple form sets (middle), Windsor Formation (sandstone to north of fault F4). C, Upper Clamstead Sandstones, channelled sandstone in mudstones at top of member (note burrow descending from channelled level). D, Upper Clamstead Mudstones with a specimen of *Cordiceramus*.

Description. The Windsor Formation consists of alternating units of sandstones/conglomerates and shales/siltstones. The conglomerates are clast- and matrix-supported and contain pebble to cobble-sized clasts; bedding ranges from a few tens of centimetres up to several metres. The conglomerate beds occur in relatively thick packages. Clasts are dominated by well-rounded fine-grained volcanics, with rarer limestones; mudstone rip-up clasts are abundant. At least four units of conglomerate/sandstone are present in the Windsor Formation (**Figure 4-6**). The third unit of sandstones contains symmetrical (wave) ripples (**Figure 7**). The complete thickness of the Windsor Formation cannot be determined because the base is unexposed and the succession is cut by a least two faults. A measured minimum thickness of 230 m has been measured (**Figures 4-6**).

Sohl's Ammonite Bed. A single fossil-yielding level in the lower part of the formation is called Sohl's Ammonite Bed after Norman Sohl who discovered it in 1971. The location of the bed was given by Sohl (1979, p. XXXI.2) as *"a shale bed in the upper-middle part of the Windsor Shale at a river bend about 100 yards above ford number four"*. The deep bend is obvious in the river course and recent collections from this level have yielded *Peroniceras*, *Baculites* and *Cremnoceramus*.

Type section. The type section of the Windsor Formation is here selected to be the continuous outcrops to the south of Windsor that contain Sohl's Ammonite Bed.

Palaeontology and age. Sohl's Ammonite Bed in the lower part of the Windsor Formation contains a Lower Coniacian ammonite-inoceramid association (Sohl, 1979; Kauffman, 1979). The ammonites include: *Peroniceras* cf. *moureti*, *Gauthiericeras* cf. *bajuvaricum*, *Baculites* cf. *yokoyamai* and *Neocrioceras* sp.; the inoceramids: *Cremnoceramus waltersdorfensis hannovrensis* and *Mytiloides fiegei*. Age diagnostic macrofossils have not been collected from the middle or upper part of the formation, although (transported) shallow-water gastropods, including an undescribed species of *Otostoma*, are common in several of the higher conglomerate beds.

Clamstead Formation (new name)

Origin of name. This name, taken from Clamstead which is situated a short distance north of Liberty Hall, is introduced here for the Inoceramus Shales of Chubb (1955, 1958, 1960; in Zans et al., 1963). The first part of the name (clam) is particularly appropriate for a unit that was known as the Inoceramus Shales.

Description. The Clamstead Formation is a thick monotonous succession of siltstones, with only a few thin layers of sandstone and numerous layers of grey calcareous concretions. It is divided into five successive units (members) here.

Lower Clamstead Mudstones. This is a thick monotonous series of mudstones. The only marker beds are: a single layer of pebbles near the base of the unit, occasional layers of calcareous concretions, and a few thin, discontinuous sandstones towards the top of the formation. It has a thickness of about 53 m.

Lower Clamstead Sandstones. This is a unit consisting of thin to medium bedded sandstones that are separated by thin mudstones. Some of the sandstones have thin lags at their bases, sometimes including inoceramids. The exposure of the unit is repeated along the river due to a large meander. This unit is about 8 m thick.

Middle Clamstead Mudstones. This is a thick monotonous series of mudstones. The only marker beds are a few cm thick sandstone beds and occasional layers of calcareous concretions. It has a thickness of about 97 m.

Upper Clamstead Sandstones. This unit consists of medium beds of sandstone and pebble conglomerates alternating with mudstones. The unit forms a prominent strike section where the river has followed a series of mudstones above strongly cemented pebble sandstones near the top of the member. The thickness of the member is difficult to determine due to poor exposure in its middle part and some minor faulting, but a thickness of about 25 m is probably close.

Upper Clamstead Mudstones. This is a thick monotonous series of mudstones and siltstones. The only marker beds are occasional layers of calcareous concretions. The thickness is at least 220 m, but the succession is interrupted by some faults (probably associated with a minor fold) of unknown throw.

Type Locality. The type section extends from above the last thick conglomerate layer of the Windsor Formation (south of the first fording) to the St Ann's Coral Bed at the base of the overlying Liberty Hall Formation at the lower waterfall.

Palaeontology and age. Macrofossils are common at many levels within the section, but full taxonomic treatments have yet to be completed. *Cladoceramus undulatopicatus* (Roemer) occurs in the Lower Clamstead Mudstones, and *Cordiceramus bueltenensis* (Seitz) occurs in the Middle Clamstead Mudstones, indicating the Lower and Middle Santonian respectively. *Uintacrinus socialis* Grinnell (Mitchell, 2009) appears near the base of the Upper Clamstead Sandstones, and ranges up to the St. Ann's Coral Bed at the base of the overlying Liberty Hall Formation; a cumulative thickness of about 245 m, probably the greatest thickness for this zone known anywhere in the World.

Trechmann (1927) listed the gastropods *Nerita subcompacta* Trechmann, *Lunatia* cf. *larteti* Böhm, *Turritella* aff. *cardenasensis* Böse, *Rostellaria* spp. and *Volutilithes* sp., and the bivalves *Ostrea* cf. *delettrei* Coquand and *Corbula* cf. *parsura* Stolley from the upper part of the Upper Clamstead Sandstones of this report. Sohl (1998) also described several gastropods from the same level.

The foraminiferal assemblages described by Esker (1969) as revised by Pessagno (1979) agree with the new macrofaunal data indicating a Santonian age. This is consistent with ages derived from the ammonite collected by Trechmann (1927) and most of the inoceramid assemblages in museum collections discussed by Kauffman (1966, 1969, 1979). The record of the upper Campanian *Inoceramus proximus subcircularis* by Kauffman (1979) is now considered erroneous.

Liberty Hall Formation (new name)

Introduction. The name Liberty Hall Formation, after Liberty Hall situated to the northwest of the river section, is introduced here for the succession of thick units of siltstones alternating with thick sandstones with minor conglomerates that occurs above the Clamstead Formation. The base of the formation is marked by the St. Ann's Coral Bed at the base of the thick sandstone exposed on the western side of the lower waterfall, whereas the top of the section is seen in the eastern side of the same waterfall. The waterfall itself runs along a significant fault that cuts out much of the formation.

Description. The formation consists of sandstones and conglomerates, generally in medium to thick beds. A single marker bed at the base of the formation is named the St. Ann's Great River Coral

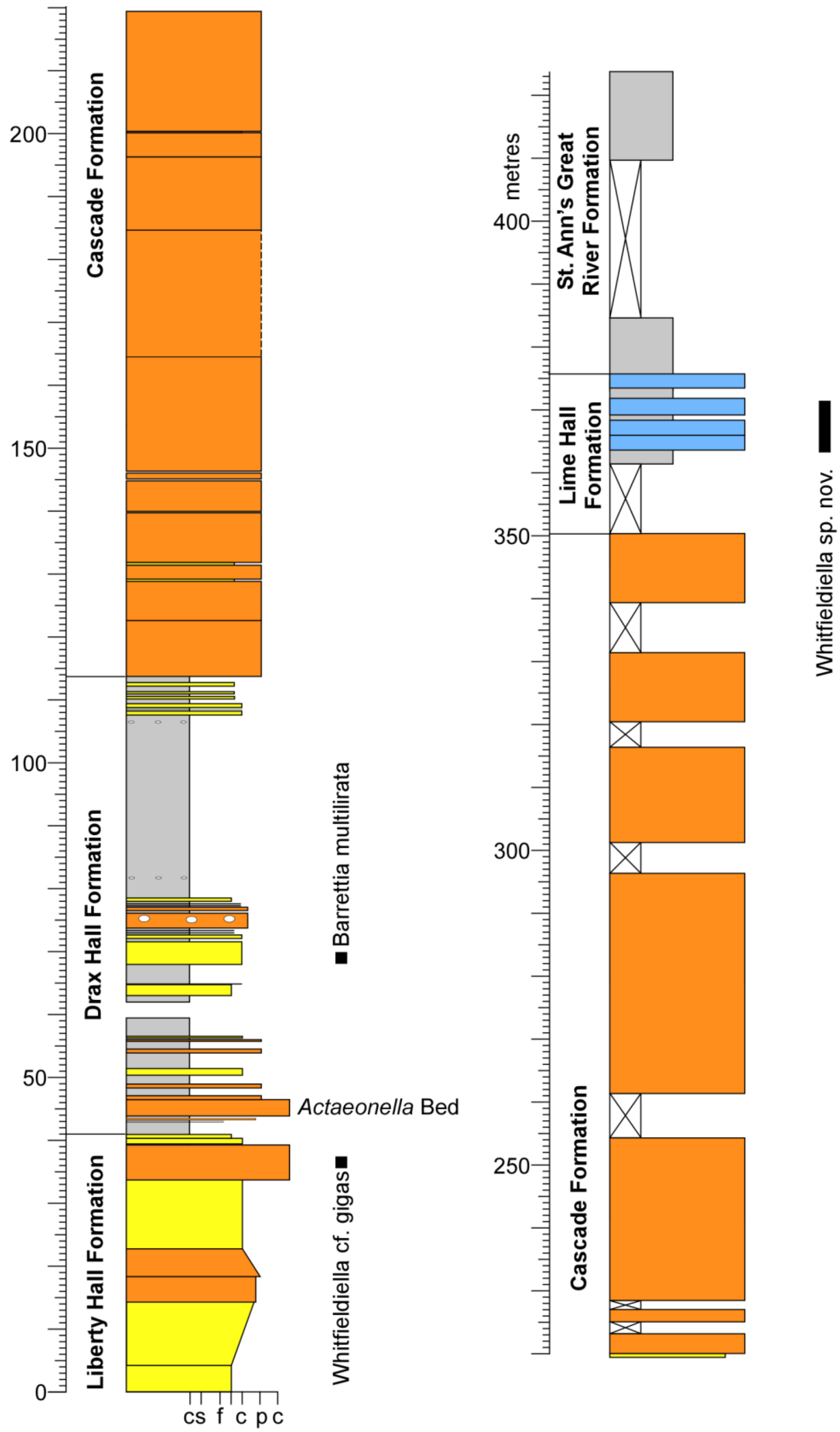

Figure 8. Stratigraphy and distribution of selected rudist bivalves for the Liberty Hall (top), Drax Hall, Cascade, Lime Hall and St. Ann's Great River Formation in the St. Ann's Great River Inlier.

Bed. The formation is at least 60 m thick, although the presence of a major fault that must cut out a significant amount of section, maybe several kilometres when compared to western Jamaica, means that its actual thickness cannot be determined.

St. Ann's Coral Bed. The name St. Ann's Coral Bed appears on specimens preserved in the University of the West Indies Geology Museum. This is a sandy siltstone that yields abundant fossils including corals, inoceramids and ammonites.

Type section. The type section for the formation is taken at the lower waterfall on St. Ann's Great River where the bottom and top of the formation are exposed.

Palaeontology and age. The St. Ann's Coral Bed yields a rich fossil assemblage including corals, ammonites, inoceramids, gastropods, rudist (*Barrettia* sp. nov.) and other bivalves, and also marks the last occurrence of the late Santonian crinoid *Uintacrinus socialis*.

Reworked rudists, *Whitfieldiella* cf. *gigas* (Chubb) occur in a conglomerate in the upper part of the formation suggesting a mid Campanian age (Mitchell 2010).

Drax Hall Formation (new name)

Introduction. The name Drax Hall Formation is introduced here for a thick unit of shales and mainly weakly cemented sandstones that occurs between the two waterfalls on St Ann's Great River. The name is taken from the Drax Hall Estate to the east of St. Ann's Great River.

Description. The Drax Hall Formation consists of a series of grey siltstones that contain uncemented sandstones and pebbly limestones in the lower part. The shales are dark grey and are characterised by a high proportion of siltstone beds. The formation can be divided into three parts: a basal unit of siltstones and sandstones with common fossils; a middle unit of monotonous siltstones, and a thin upper unit of siltstones with thin sandstones (**Figure 8**). The formation is 63 m thick, although it is cut by one fault that possibly cuts out some of the section.

Actaeonella Bed. The name Actaeonella Beds was first used by Meyerhoff and Kreig (1977). The name is retained here, in the singular, for a bed consisting of a pebbly limestone that contains scattered fossils including large specimens of the gastropod *Actaeonella*.

Type locality. The type locality is exposed in the river between the two waterfalls on St. Ann's Great River.

Palaeontology and age. Gastropods are common in the lower part of the Drax Hall Formation; these include turritellids that occur in the shales both below and above the Actaeonella Bed, and poorly preserved specimens of a large species of *Actaeonella* in the bed itself. A single well preserved specimen of *Barrettia multilirata* Whitfield was collected from a gritty sandstone above the Actaeonella Bed (**Figure 8**) indicating a correlation with the Stapleton and Green Island formations of western Jamaica. This occurrence indicates that the correlation of the Lime Hall Limestone that occurs much higher in the succession with these two limestones of western Jamaica (Meyerhoff and Kreig, 1977) is erroneous.

Esker (1969) recorded the following planktic foraminfers from *"a few feet of highly organic black shale"* within the Drax Hall Formation: *Rosita fornicata* (Plummer), *Globotruncana arca* (Cushman), *G. bulloides* Vogler, *G. orientalis* El-Nagger, *G.* cf. *linneiana* (d'Orbigny), *Globotruncanita* cf. *stuartiformis* (de Lapparent) and *G. elevata* (Brotzen), with a few reworked *Marginotruncana renzi* (Gandolfi). These forms would appear to indicate a Campanian age above the disappearance of *Marginotruncana*, if *M. renzei* is reworked, which is consistent with the evidence provided by the rudist bivalves. Verdenius (1993) recorded *Quadrum trifidum* (Stradner) from below the Lime Hall Limestone (presumably within the Drax Hall Formation), which is consistent with the age assignment from the rudist bivalves.

Cascade Formation

Introduction. The name Cascade Formation, after the Cascade at the upper waterfall in St. Ann's Great River, was introduced by Chubb in 1958, where the name is listed against the log, for the unit called the Great River Formation in unpublished oil company reports (e.g., Jamaican Stanolind Oil Company, 1956).

Description. The formation is about 180 m thick and consists of thick beds with pebble- to cobble-sized clasts set in a sandstone matrix; intercalated are a few thin beds of sandstone and siltstone. The pebble- to cobble-sized clasts consist predominately of volcanic material (andesites and porphyritic lavas), but also include some fine-grained limestones. Rare reworked examples of the rudist *Durania* sp. are present.

Type Section. The type section, nominated here in the absence of a previous designation, is in the bed of St. Ann's Great River immediately below the upper waterfall (the Cascade).

Palaeontology and Age. No indigenous fossils are present in the formation, and it is assigned a Campanian age on the basis of the ages of the underlying and overlying units.

Lime Hall Formation

Introduction. The name was first used in unpublished oil company reports (Jamaican Stanolind Oil Company, 1956) and was first published by Meyerhoff and Kreig (1977).

Description. The formation consists of a lower portion of siltstones, estimated to be about 14 m thick, but with only the top few metres exposed; and an upper 14 m thick unit of alternating limestone/muddy limestone and siltstones, reminiscent of the cycles seen in the Guinea Corn Formation (Mitchell, 2002).

Type Section. The type section, nominated here in the absence of a previous designation, is in the small tributary that joins St. Ann's Great River just above the bridge on the parochial road.

Palaeontology and age. Rudist bivalves are common in the Lime Hall Limestone. Although the multiple fold hippuritids have previously been referred to as *Barrettia monilifera* by Trechmann (1927) and *Barrettia gigas* by Chubb (1971), they actually belong to an undescribed form of *Whitfieldiella* and do not help with age determination. The presence of *Barrettia multilirata* in the Drax Hall Formation, some 400 m below the Lime Hall Limestone, indicates that the Lime Hall Limestone should not be correlated with the Green Island and Stapleton Formations of western Jamaica, but represents a younger level.

Larger foraminifers of the Lime Hall Limestone are dominated by specimens of *Sulcopeculina*. This assemblage lacks *Pseudorbitoides* and is therefore probably of late Late Campanian age above the extinction level of *Pseudorbitoides* (Mitchell and Ramsook, 2009). The nannofossil *Ceratolithoides aculeus* (Stradner) was reported from two samples collected from the Lime Hall Limestone and indicates zone CC20 or younger (Jiang and Robinson, 1987, p. 31), consistent with the foraminiferal evidence.

St. Ann's Great River Formation

Introduction. The name St. Ann's Great River Formation first appeared on the 1:250,000 Geological Survey map of Jamaica, presumably after an unpublished name used by Sohl in 1976, and is equivalent to the 'Diozoptyxis' Shale of Chubb (1955). Jiang and Robinson (1987) also gave a brief description of it.

Description. The formation consists of dark grey silty shales with common shallow water fossils. There are no obvious marker beds. The formation has a thickness of 48 m, but is terminated at the top by a fault (fault F7 in **Figure 3**).

Type locality. The type locality of the St. Ann's Great River Formation is exposed in the bed and banks of St. Ann's Great River above the small bridge on the old parochial road.

Palaeontology and age. Fossils are abundant and Trechmann (1927) described the gastropods *Solarium* sp., *'Glauconia' matleyi* Trechmann, *Vermetes* cf. *libycus* Quaas, *Cerithium* cf. *libycum* Wanner, *Rostellaria (Calyptrophorus)* sp., *Aporrhais* sp., *Gosavia* sp. and *Lyria* sp., and the bivalves *Amusium*? cf. *membranaceum* Nilsson, *Neithea quadricostata* Sowerby, *Plicatula* cf. *andersoni* Newton, *P.* cf. *urticosa* Morton, *Pholadomya jamaicensis* Trechmann and *Cytherea* sp. *'Glauconia' matleyi* was erroneously transferred to the nerinellid genus *Diozoptyxis* (Chubb, 1955; Sohl, 1998), and the name Diozoptyxis Shale was applied to the unit that yielded it. None of these forms has any biostratigraphic value, and a late Campanian age is inferred based on the suggested age of the underlying Lime Hall Formation.

New Ground Formation

Introduction. The St. Ann's Great River Formation is in faulted contact with grey to brown conglomerates about 50 m upstream of the bridge on the parochial road. These were called the New Grounds Formation in unpublished oil company reports (Jamaican Stanolind Oil Company, 1956). Subsequently, Sohl resurrected the name in an unpublished report in 1976 and it was first published as 'New Ground Conglomerate' by Chubb (1960).

Description. The formation consists of pebble conglomerates in thick to very thick beds. Within the formation, a thin unit of pyritous mudstones is present. The thickness of the formation has not been determined in this study, but Sohl (reported in Meyerhoff and Kreig, 1977) indicated a thickness of 290 m.

Type locality. The type locality is situated in St. Ann's Great River, south of Fault F6.

Palaeontology and age. Esker (1969) reported the planktic foraminifers *Morozovella* (now *Globorotalia*) *aragonensis* (Nuttal) (zones P7-P11), *M.* (now *Globorotalia*) *prolata* (Bolli), *Acarina* (now *Truncorotalia*) *soldadoensis* (Bronnimann) (latest Paleocene to top middle Eocene) and *Pseudohastigerina wilcoxensis* (Cushman and Ponton) (zone P6-P11) from a blue argillaceous sandstone within the New Ground Conglomerate which indicate a late Early to early Middle Eocene age (Toumarkine and Luterbacher, 1985).

Acknowledgements. *We thank Beverley Lashley of the UWI Science Library for finding the old and difficult references. Mr. Ian Brown and Dr. Gavin Gunter made valuable comments on the original manuscript which are greatly appreciated. Dr. Gavin Gunter (Petroleum Corporation of Jamaica) gave permission to reproduce Figure 2.*

REFERENCES

Chubb, L.J. 1955. The Cretaceous succession in Jamaica. *Geological Magazine*, **92**, 177-195.

Chubb, L.J. 1958. The Cretaceous inlier of St Ann's Great River. *Geonotes*, **1**, 148-152.

Chubb, L.J. 1960. Correlation of the Jamaican Cretaceous. *Geonotes*, **3**, 85-97.

Chubb, L.J. 1971. Rudists of Jamaica. *Palaeontographica Americana*, **7**, 161-257.

Esker III, G.C. 1969. Planktonic foraminifera from St. Ann's Great River Valley, Jamaica. *Micropaleontology*, **15**, 210-220.

Exploration Division, PCJ, 1982. *Petroleum Exploration Onshore Jamaica. Review for Inter-American Development Bank.* Petroleum Corporation of Jamaica.

Greiner, H.R. 1965. *The oil and gas potential of Jamaica. Geological Survey Department, Jamaica. Bulletin* No. **5**, 1-24.

Hill, R.T. 1899. The geology and physical geography of Jamaica: a study of a type of Antillean development. *Bulletin of the Museum of Comparative Zoölogy at Harvard College in Cambridge*, **34**, 1-256.

Jamaican Stanolind Oil Company, 1956. *Jamaica Stanolind Geological Report No. 10. Geology of the St. Ann's Bay Inlier*, 1-8, Jamaican Stanolind Oil Company, Kingston, Jamaica.

Jiang, M.-J. and Robinson, E. 1987. Calcareous nannofossils and larger foraminifera in Jamaican rocks of Cretaceous to early Eocene age. *In* **R. Ahmad (Ed.)**, *Proceedings of a workshop on the status of Jamaican geology. Special Issue* (No. **10**) 1987, 24-51, Geological Society of Jamaica. Signart Printing House, Kingston, Jamaica.

Kauffman E.G. 1966. Notes on Cretaceous Inoceramidae (Bivalvia) of Jamaica. *The Journal of the Geological Society of Jamaica*, **8**, 32-40.

Kauffman E.G. 1969. The Upper Crctaceous Inoceramus of Puerto Rico. *In* **J.B. Saunders (Ed.)**, *Transactions of the 4th Caribbean Geological Conference, Port of Spain, Trinidad and Tobago, 28 March-12 April 1965*, 203-218 (dated 1968, distributed 1969).

Kauffman E.G. 1979. Middle Cretaceous bivalve zones and stage implications in the Antillean Subprovince, Caribbean Province. *In* **R.A. Reyment and G. Thomel (Eds.)**, *Evenements de la partie moyenne du Cretace (Mid-Cretaceous events) Uppsala 1975 – Nice 1976 Reports sur la biostratigraphie des regions cles (reports on the biostratigraphy of key areas), Annales de Museum d'Histoire Naturelle de Nice*, **4** (1976), XXX.1-10, Centre d'Etudes Méditerranéennes, Museum d'Histoire Naturelle, Nice, France.

Matley, C.A. 1924a. Report on a mineral spring at Windsor, St. Ann, and on the possibility of the occurrence of petroleum in its neighbourhood. *Supplement to the Jamaica Gazette*, Sept. **25**, 1924, 396-398.

Matley, C.A. 1924b. Further report on the possibility of the occurrence of petroleum deposits in the valley of St. Ann's Great River. *Supplement to the Jamaica Gazette*, Sept. **25**, 1924, 398.

Matley, C.A. 1925. Report on the strata in the valley of St. Ann's Great River, Parish of St. Ann, Jamaica. *Supplement to the Jamaica Gazette*, Thursday, January 1, 1825, **XLVIII No. 3**, 13-15.

McFarlane, N. (Compiler), 1977. *1:250,000 Jamaica, Geology*, Mines and Geology Division, Ministry of Mining and Natural Resources, Jamaica.

Meyerhoff, A.A. and Krieg, E.A. 1977. *Petroleum potential of Jamaica*, 1-131, Ministry of Mining and Natural Resources, Kingston, Jamaica.

Mitchell, S.F. 2002. Palaeoecology of corals and rudists in mixed volcaniclastic-carbonate small-scale rhythms (Upper Cretaceous, Jamaica). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **186**, 237-259.

Mitchell, S.F. 2009. The Cretaceous crinoid *Uintacrinus socialis* from Jamaica and its significance for global correlation. *Geological Magazine*, **146**, 937-940.

Mitchell, S.F. 2010. Revision of three large species of Barrettia from Jamaica. *Caribbean Journal of Earth Science*, **41**, 1-16.

Mitchell, S.F. and Ramsook, R. 2009. Rudist bivalve assemblages from the Back Rio Grande Formation (Campanian, Cretaceous) of Jamaica and their stratigraphical significance. *Cretaceous Research*, **30**, 307–321.

Pessagno Jr, E.A. 1979. Middle Cretaceous planktonic foraminiferal biostratigraphy of the Antillean-Caribbean region and eastern Mexico notes on the ammonites of eastern Mexico. *In* **R.A. Reyment and G. Thomel (Eds.)**, *Evenements de la partie moyenne du Cretace (Mid-Cretaceous events) Uppsala 1975 – Nice 1976 Reports sur la biostratigraphie des regions cles (reports on the biostratigraphy of key areas), Annales de Museum d'Histoire Naturelle de Nice*, **4** (1976), XXVIII.1-9, Centre d'Etudes Méditerranéennes, Museum d'Histoire Naturelle, Nice, France.

Sawkins, J.G. 1869. *Reports on the geology of Jamaica or, part II of the West Indian survey. Memoirs of the Geological Survey*, i-vi, 1-339, Longmans, Green and Co., London.

Sohl, N.F. 1979. Notes on middle Cretaceous macrofossils from the Greater Antilles. *In* **R.A. Reyment and G. Thomel (Eds.)**, *Evenements de la partie moyenne du Cretace (Mid-Cretaceous events) Uppsala 1975 – Nice 1976 Reports sur la biostratigraphie des regions cles (reports on the biostratigraphy of key areas), Annales de Museum d'Histoire Naturelle de Nice*, **4** (1976), XXXI.1-6, Centre d'Etudes Méditerranéennes, Museum d'Histoire Naturelle, Nice, France.

Sohl, N.F. 1998. Upper Cretaceous trochacean gastropods from Puerto Rico and Jamaica. *Palaeontographica Americana*, **60**, 109 pp.

Toumarkine, M. and Luterbacher, H.P. 1985. Paleocene and Eocene planktonic foraminifera. *In* **H.M. Bolli, J.B. Saunders and K. Perch–Nielsen (Eds.)**, *Plankton Stratigraphy*, Cambridge Earth Science series, 87–154.

Trechmann, C.T. 1927. The Cretaceous shales of Jamaica. *Geological Magazine*, **64**, 27-42.

Trechmann, C.T. 1936. The Basal Complex question in Jamaica. *Geological Magazine*, **73**, 251-267.

Verdenius, J.G. 1993. Late Cretaceous calcareous nannoplankton zonation of Jamaica. *In* **R.M. Wright and E. Robinson (Eds.)**, *Biostratigraphy of Jamaica*. *Geological Society of America Memoir* **182**, 1-17, Boulder, Colorado.

Wiedmann, J. and Schmidt, W. 1993. Upper Cretaceous ammonites from Jamaica and their stratigraphic and paleogeographic implications. *In* **R.M. Wright and E. Robinson (Eds)**, *Biostratigraphy of Jamaica, Geological Society of Jamaica Memoir*, **182**, 77-91, Boulder, Colorado.

Wright, R. 1996. *Jamaica's Energy: old prospects, new resources*, 266 pp., Petroleum Corporation of Jamaica, Kingston, Jamaica.

Zans, V.A. 1953. The eastern half of St. Ann (Sheet F). *In* **Zans, V.A.** *Annual report of the Geological Survey Department for the financial year 1951-1952*, 10 pp., Government Printers, Duke Street, Kingston, Jamaica.

Zans, V.A. 1954. Sheet F, Stratigraphy, Upper Cretaceous. *Annual Report of the Geological Survey Department, 1952-1953*, Government Printers, Duke Street, Kingston, Jamaica.

Zans, V.A., Chubb, L.J., Versey, H.R., Williams, J.B., Robinson, E and Cooke, D.L. 1963. *Synopsis of the geology of Jamaica an explanation of the 1958 provisional geological map of Jamaica. Bulletin* No. **4**, Geological Survey Department, Jamaica, 1-72, Government Printer, Duke Street, Kingston. [Dated on front cover and title page 1962, Printers imprint at bottom of front page is 1963,]

Revised manuscript accepted: 3rd March 2011