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Lithostratigraphy of the Cretaceous succession in the Benbow Inlier, Jamaica

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ABSTRACT. The lithostratigraphy of the Cretaceous rocks of the Benbow Inlier is described based on new geological mapping. The succession is some 6,500 m thick and includes rocks ranging in age from Valanginian or Hauterivian to Cenomanian or Turonian. Ages are determined based on previous macrofossil and nanofossil reports and the relationships between units. The Devils Racecourse Group (changed rank) contains nine formations (from the base up): Cistern Formation (new name: 1,600 m of lavas); Redwood Formation (new name: 510 m of conglomerates with minor lava); Jubilee Formation (equivalent to the Bonnett, Copper and Phillipsburg limestones: 100-375 m of limestones interbedded with clastics and minor lavas); Boozy Ridge Formation (new name: 510 m of shales, sandstones and conglomerates with minor lava); Benbow Formation (changed rank: 400 m of limestones); Ragville Formation (new name: 280 m of pillow lavas); Burtons Formation (new name: 10 m of limestones); Golden Grove Formation (new name: 430 m of pillow lavas); and Airy Mount Formation (new name: 350 m of conglomerates). The Devils Racecourse Group is succeeded by the Seafield Formation (changed rank: 320 m of limestones and interbeded shales, sandstones and conglomerates), Rio Nuevo Formation (1,150 m of shales with minor sandstones and conglomerates) and the Tiber Formation (600 m of conglomerates and lavas).

Key words: ***Jamaica; Cretaceous stratigraphy; lithostratigraphy; Devils Racecourse Group.***

1. INTRODUCTION

The Benbow Inlier of central Jamaica is situated on the north-eastern margin of the Clarendon Block (**Figure 1**) and contains the only fossiliferous pre-Albian arc succession known in the Greater Antilles. It is therefore extremely important in understanding the early evolution of the Great Arc

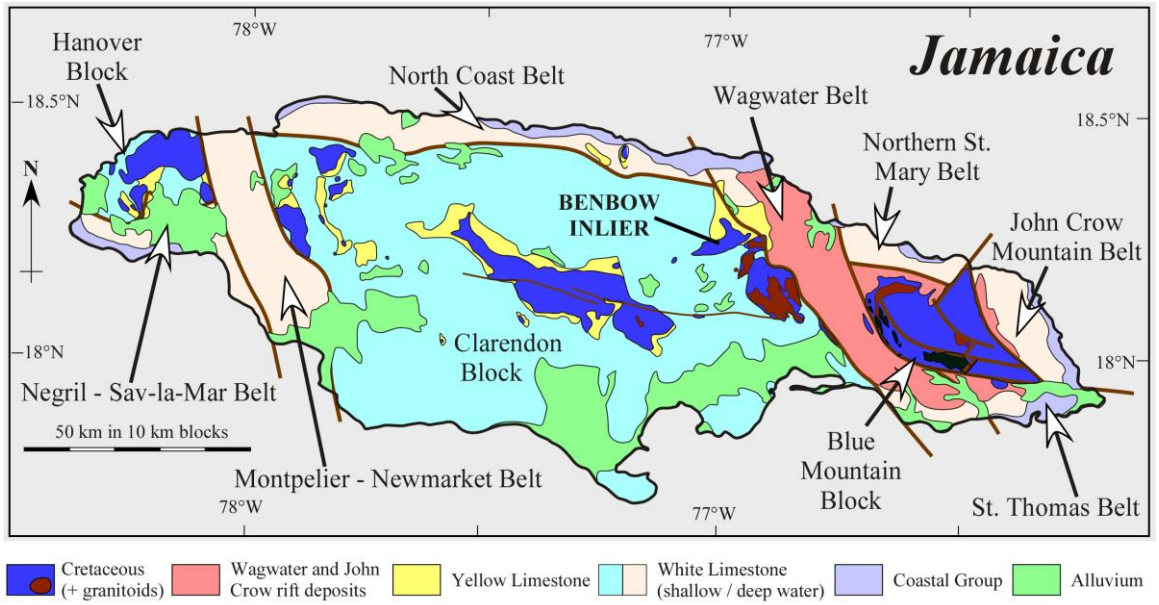

Figure 1. Simplified geological map of Jamaica showing the locations of the Cretaceous inliers (dark blue/black) and their relationships to the late Neognere block and trough structure. The Benbow Inlier is Location of the Benbow Inlier is located on the NE part of the Clarendon Block. The other large inliers in the Clarendon Block are the Above Rocks and Central inliers.

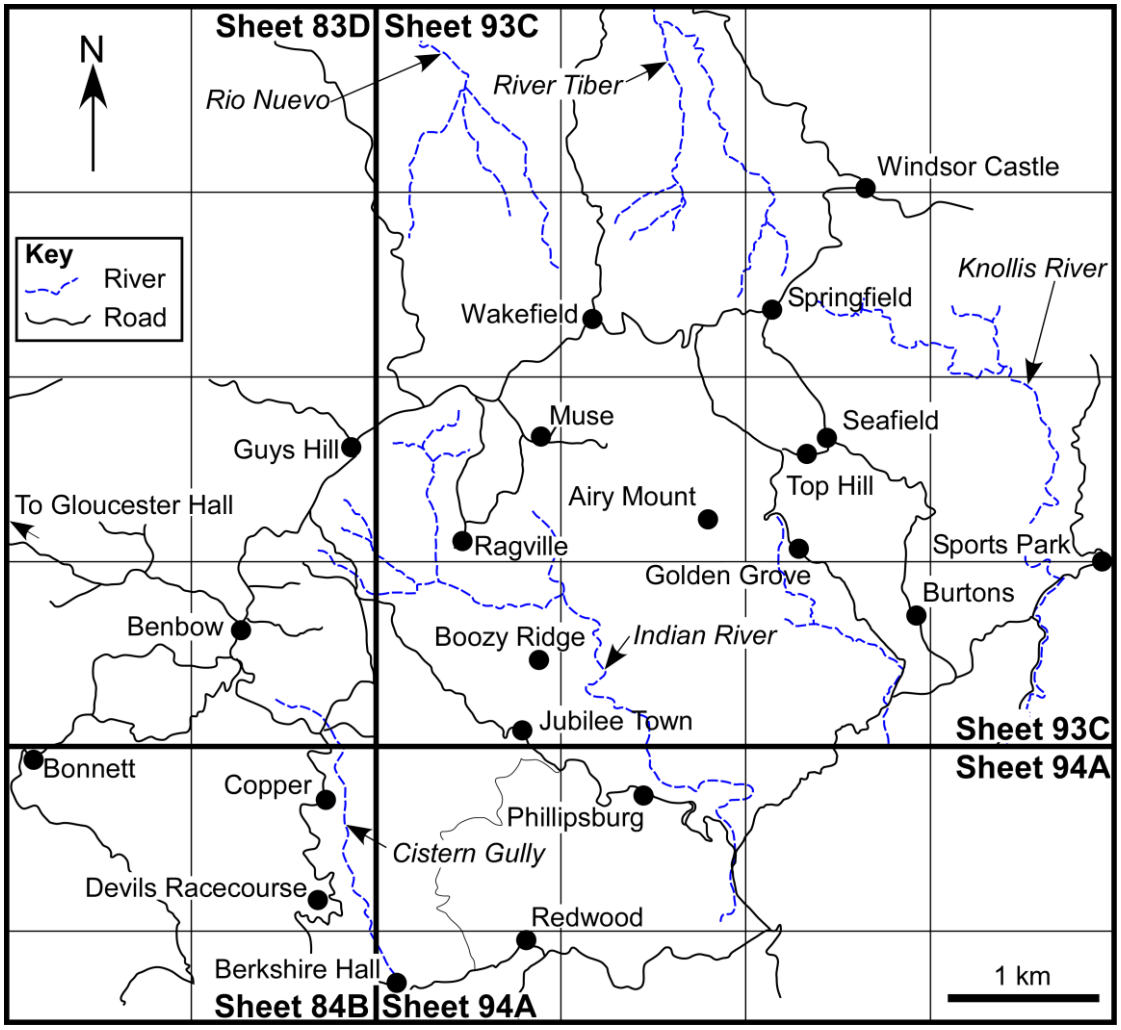

Figure 2. Geographic names used in the text. Taken from the 1:2,500 Survey map series: sheets 83D, 84B, 93C and 94A.

of the Caribbean (cf. Pindell and Kennan, 2002, 2009). The last revision of the lithostratigraphic nomenclature for the inlier was introduced by Burke et al. (1969) in a paper that was read at the Fourth Caribbean Geological Conference in Trinidad in 1965. A renewed interest in the rocks of the Benbow Inlier has come from the recognition of various rudist bivalves (Skelton and Masse, 1998; Pantoja-Alor et al., 2004), a need to understand the geological evolution of Jamaica (Mitchell, 2003, 2006) and because of recent studies on the major, minor and isotope geochemistry of the igneous rocks (Hastie et al., 2007, 2008).

In this paper we introduce a revised lithostratigraphic interpretation of the inlier based on new geological mapping. About 30 field days were spent mapping the main areas of the inlier using the Jamaican Survey Department 1:12,500 series topographic maps (sheets 83D, 84B, 93C and 94A) as base. In this paper we illustrate the new map and describe the revised lithostratigraphic scheme. The terminology used here follows that proposed in the International Stratigraphic Guide (Murphy and Salvador, 1999). The geographic names used in this report are shown on **Figure 2**.

2. THE NEW GEOLOGICAL MAP OF THE BENBOW INLIER

The new geological map of the Benbow Inlier is shown in **Figure 3**. We recognise thirteen formations within the inlier, with the lower nine formations comprising the Devils Racecourse Group. The inlier is relatively simple structurally; the entire succession exhibits a general NW-SE strike with beds dipping towards the northeast. Although the dip direction is relatively uniform, a series of faults makes the interpretation of the

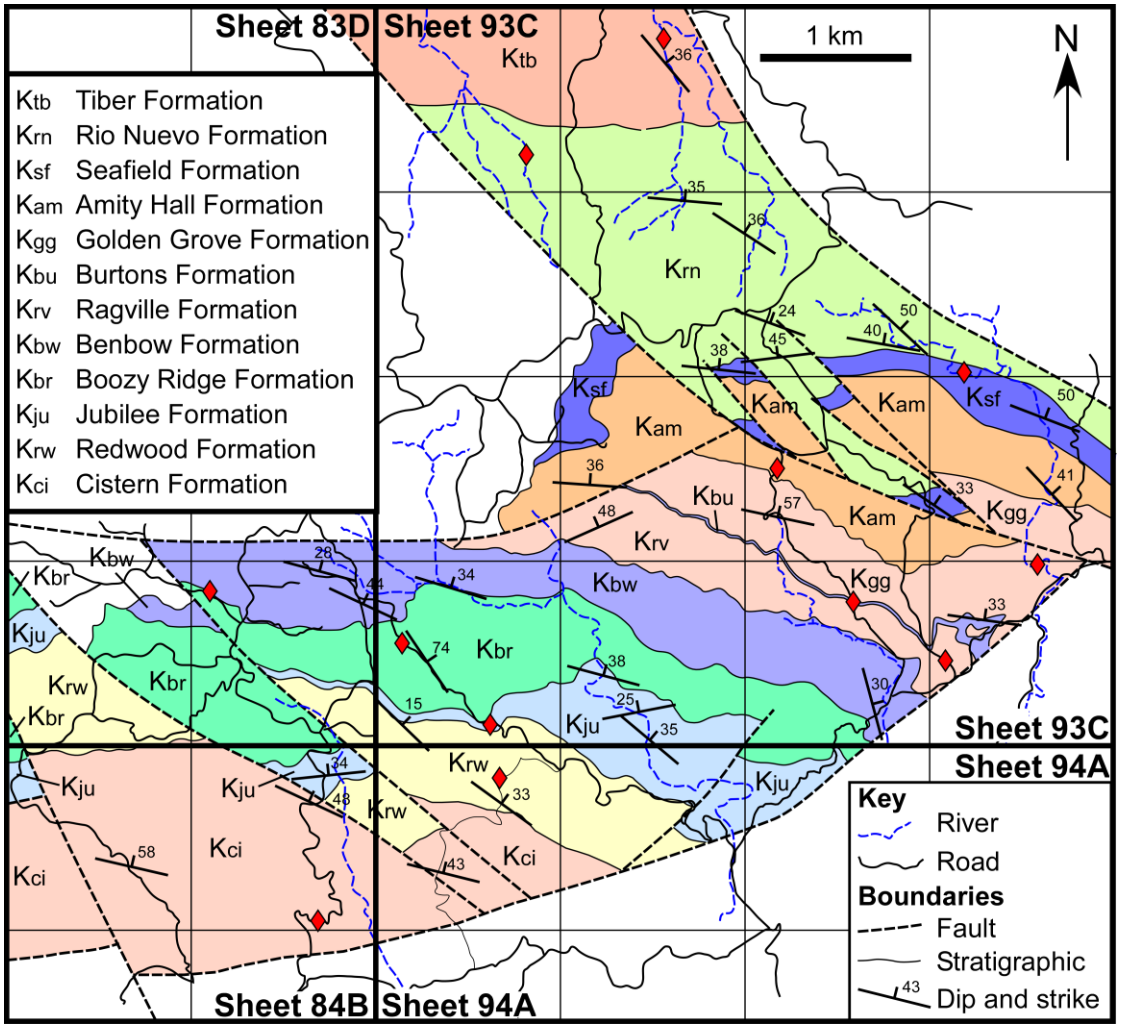

Figure 3. Geological map of the Benbow Inlier covering parts of 1:12,500 sheets 83D, 84B, 93C and 94A. Grids from the 1:12,500 map series. Rocks younger than the Cretaceous are uncoloured. Type sections are shown with a diamond symbol.

succession, particularly the number of limestones, more difficult. **Table 1** illustrates the various published lithostratigraphic schemes for the inlier and a comparison with our revised scheme. We recognise three limestones in the Devils Racecourse Group, the Jubilee, Benbow and Burtons limestones that can be differentiated, not only because they are intercalated with different lithological units, but because they contain age-diagnostic fossils. We show that the many (Copper, Jubilee, Bonnett and Phillipsburg) limestone members previously recognised in the middle part of the Devils Racecourse Formation contain the same fauna and are the same age; we explain their geographical distribution by block faulting (**Figure 3**). The Seafield Formation lies within a significant fault zone that has made the interpretation of this part of the stratigraphy difficult (Burke et al., 1969). However, given the biostratigraphic data, we believe that our interpretation of this part of the succession is at least reasonable.

3. LITHOSTRATIGRAPHY

The Cretaceous succession in the Benbow Inlier ranges in age from Valanginian or Hauterivian to late Cenomanian or early Turonian (**Figure 3**) and is represented by some 6,500 m of section. We describe the formations in order below starting with the oldest.

3.1. Devils Racecourse Group (changed rank)

The Devils Racecourse Formation of Burke et al. (1969) is elevated here to the level of group, and the constituent previously described members, where appropriate, are raised to formation status.

Table 1. Comparison of lithostratigraphic schemes for the Benbow Inlier. Correspondence between columns is not implied below the Benbow Member/Formation. Limestone-dominated units are shaded.

Burke et al. 1969	Robinson 1994	Herein		Thickness	Age based on fossils
Tiber Formation	Tiber Formation	Tiber Formation		600 m	
Rio Nuevo Formation	Rio Nuevo Formation	Rio Nuevo Formation		1,150 m	Middle Albian to Late Cenomanian
Seafield Member	Seafield Formation	Seafield Formation		320 m	Lower Albian
Devils Racecourse Formation	Devils Racecourse Formation	Devils Racecourse Group	Airy Mount Formation	350 m	Airy Mount Formation
			Golden Grove Form.	430 m	
			Burtons Formation	8 m	Late Barremian-Early Aptian?
			Ragville Formation	280 m	
Benbow Member	Benbow Member		Benbow Formation	400 m	Barremian
			Boozy Ridge Form.	510 m	
Jubilee Member	Jubilee Member		Jubilee Formation	100-375 m	Hauterivian
Copper Member	Copper/Bonnett Mbr.		Redwood Formation	510 m	
Phillipsburg Member			Cistern Formation	1,600 m	

3.2. Cistern Formation (New Name)

Introduction. The Cistern Formation is introduced here to represent the oldest lithological unit belonging to the Devils Racecourse Group. This unit is exposed in the southern part of the Inlier, along the southern end of the Devils Racecourse main road, and northwest of Berkshire Hall. The exposure extends eastwards across the Cistern Gully, from which the name is derived. This unit was previously described as the lower unit of the Devils Racecourse Formation (Burke et al., 1969; Roobol, 1972).

Description. The Cistern Formation consists of some 1,600 m (calculated from the map) of basaltic andesites and dacites/rhyolites with a few thin intercalated tuffs. Petrographic examination of the lavas (**Figure 4A**) reveals an abundance of quartz and plagioclase feldspar. Both quartz and feldspar crystals occur as phenocrysts surrounded by a groundmass of chlorite, calcite, epidote, a few opaque minerals and smaller crystals of quartz and feldspar. The plagioclase phenocrysts have irregular boundaries and show evidence of growth twinning, some are broken by microfaults (**Figure 4A**) whereas others show moderately developed micro-boudinage structures. In plane-polarized light, thin sections show a prominent brown colour resulting from iron oxidation. The deformation features observed are typical of retrograde deformation associated with hydrothermal alteration, or to zeolite facies metamorphism. The lavas have an island arc tholeiite (IAT) composition (Hastie et al., 2007, 2008). A few porphyritic dykes are present with plagioclase feldspar being the dominant phenocryst phase.

Type Locality. The type locality for this formation is situated along the lower Devils Racecourse main road, approximately 375 m west of Berkshire Hall. Although significantly weathered, exposures of quartz-rich igneous rocks with barite mineralization can be observed at this locality.

Age. There is no direct age indication for this formation other than it is older that the overlying Redwood Formation. A Valanginian or early Hauterivian age is tentatively suggested on this basis.

Boundaries. The Cistern Formation is faulted against limestones of the Cenozoic Moneague Formation to the south of the Benbow Inlier.

3.3. Redwood Formation (New Name)

Introduction. The Redwood Formation is introduced here for the thick unit of conglomerates and sandstones that immediately overlies the Cistern Formation. Exposures of this formation can be seen along the minor road from Jubilee Town to the community of Redwood, from which the name is derived. Burke et al. (1969) recognized a sequence of volcaniclastic material forming the top of the lower Devils Racecourse Formation that is herein defined as the Redwood Formation.

Description. The Redwood Formation consists of some 510 m (calculated from the map) of fairly well-cemented pebble conglomerates and tuffs. Occasional thin beds of tuffaceous sandstones are

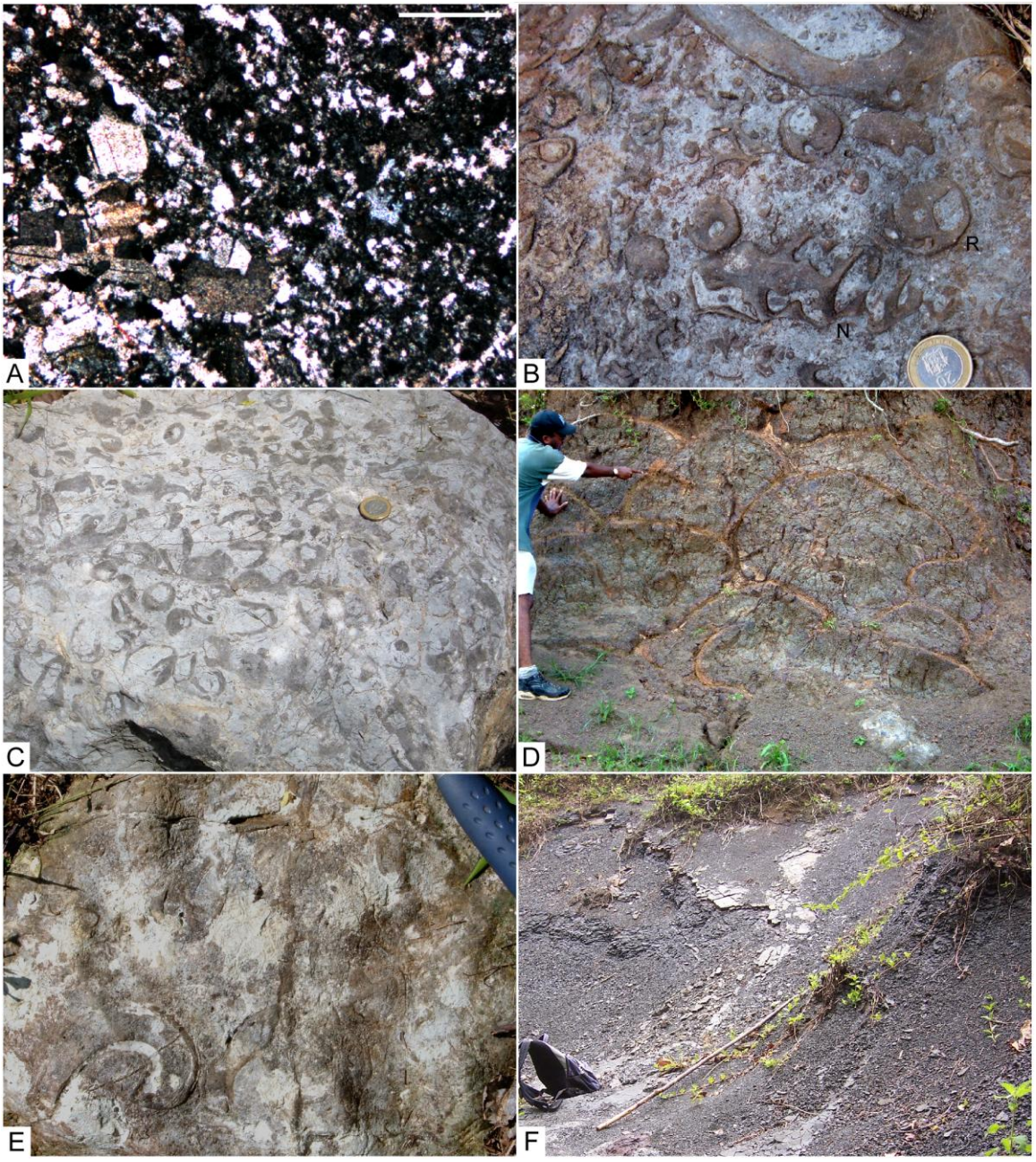

Figure 4. A: Photomicrograph showing plagioclase phenocrysts in an altered lava from the Cistern Formation from the Devils Racecourse road west of Berkshire Hill (scale bar = 5 mm). B: A limestone block from the Jubilee Formation at the Jubilee Seventh Day Adventist Church showing the rudist (R) *Retha tulae* (Felix) and a nerineid gastropod (N); coin is 22 mm in diameter. C: Benbow Formation with abundant *Amphitriscoelus primaevus* Pantoja-Alor, Skelton & Masse immediately south of the bridge over the river south of Burtons; coin is 22 mm in diameter. D: Pillow lavas in the Golden Grove Member at Golden Grove. E: The rudist *Coalcomana ramosa* (Boehm) in the Seafield Formation to the NE of Seafield. F: Shales of the Rio Nuevo Formation in the Rio Nuevo in the northern part of the inlier.

common. Conglomerate clasts are predominantly rounded to sub-rounded andesitic rock fragments indicating transport in a fluvial environment not far from the sediment source. At least one lava flow is present near the top of this formation and its contact with the conglomerates can be observed where the fine-grained chilled margin of the flow is seen. No fossils have been recovered from this unit.

Type Locality. The type locality for this unit is chosen as the exposure by a small waterfall along the minor road located approximately 600 m east of Copper. Exposures along the Devils Racecourse main road show only the base of the formation and these are very weathered, however, individual beds can be sufficiently distinguished to allow for orientation measurements.

Age. There is no direct age indication for this formation other than it is older the overlying Jubilee Formation. A Valanginian or early Hauterivian age is tentatively suggested on this basis.

Boundaries. The Redwood Formation is interpreted to have conformable boundaries with the underlying Cistern Formation and the overlying Jubilee Formation from geological mapping.

3.4. Jubilee Formation (changed rank)

Introduction. The Jubilee Formation represents the lower carbonate unit within the Devils Racecourse Group. Exposures of this formation can be observed along the Devils Racecourse main road north of the district of Copper and also along the minor road heading southeast from Benbow towards Jubilee Town. Chubb (1960) first referred to this unit as the Jubilee Limestone, and later provided a brief description (Chubb in Zans et al., 1963) where reference was made to the presence of the rudist *Pachytraga*. Burke et al. (1969) subsequently defined this unit as a limestone member of the Devils Racecourse Formation. Since then, the unit has been referred to as the Jubilee Member (Arden, 1975; Sohl, 1978; Meyerhoff and Krieg, 1977) the Jubilee Limestone (Chubb, 1971; Green, 1972; Wright, 1974; Coates, 1977; Jiang and Robinson, 1987; Robinson, 1994) the Bonnett Limestone (Chubb, 1960; Wright, 1974), the Bonnett-Copper Limestone (Chubb, 1971), the Copper Limestone (Burke et al., 1969; Robinson et al., 1972; Coates, 1977; Jiang and Robinson, 1987; Robinson, 1994) and the Phillipsburg Limestone (Chubb, 1960; Burke et al., 1969: Chubb, 1971; Sohl, 1978). These limestones were previously considered as separate units, although Burke et al. (1969) acknowledged possible similarities between the Copper and Phillipsburg Limestones. Detailed mapping has revealed that these four limestones represent a single formation containing the same rudist species that has been displaced by faulting. The oldest available name, the Jubilee Formation, is used for this formation here.

Description. The Jubilee Formation consists of some 100-375 m (determined from the map) of compact, very hard, dark to medium grey limestones interbedded with mudstones and volcanically derived sandstones and conglomerates. A single lava flow is present near the base of the formation on the Devils Racecourse road and in Indian River. Limestone beds are generally massive and bedding is poorly developed. The limestones range from micrites and biomicrites at lower levels to wackestones and packstones at higher levels. The macrofossil assemblage is dominated by the rudist *Retha tulae* (Felix) (**Figure 4B**), which appears to be restricted mainly to the uppermost beds (Skelton and Masse, 1998). Exposures at the type locality show abundant specimens of *R. tulae* in growth position. A similar, or even the same, bed with abundant *R. tulae* can be seen at the type section for the Copper Limestone of Burke et al. (1969). These rocks are hard and well indurated making sampling nearly impossible. Fossils can however be examined on weathered surfaces. Other forms include abundant and relatively diverse nerineid gastropods, colonial corals (Löser et al., 2009), foraminifers (Vila et al., 1986; Skelton and Masse, 1998) and alage (Vila et al., 1986).

Type Locality. The type locality for the Jubilee Formation can be found just east of Jubilee Town along the road heading northeast towards Benbow. The formation is well-exposed with abundant specimens of *R. tulae*, many of which are preserved in growth position.

Age. The foraminifers (*Coscinophragma* sp., *Miliola* sp., *Nautiloculina* sp., *Lithocodium aggregatum* Elliot, *Daxia* cf. *minuta* Laug & Peybernes and *Vercorsella* sp.) and algae (*Acicularia* sp. A) indicate a Hauterivian age (Vila et al., 1986; Skelton and Masse, 1998).

Boundaries. The Jubilee Formation rests conformably on the conglomerates and tuffs of the Redwood Formation.

Remarks. Previous estimates for the thickness of the Jubilee Formation were given by Burke et al. (1969) at 100 m and Robinson et al. (1972) at 100 m. Both estimates were proposed based on exposures at the type locality. To the south and southeast of the type locality the formation appears to increase in thickness up to 375 m. This thickness increase appears to be due to lateral facies variations, with limestones entering at lower levels than seen at the type locality, rather than faulting.

3.5. Boozy Ridge Formation (New Name)

Introduction. The name Boozy Ridge Formation is introduced here for the thick sequence of shales, sandstones and conglomerates that directly overlie

the Jubilee Formation. This unit is exposed along the road joining Jubilee Town to Benbow and along sections of Boozy Ridge, north of Jubilee Town. This formation was previously considered as part of the middle unit of the Devils Racecourse Formation of Burke et al. (1969) and identified as the sequence exposed between the Copper (=Jubilee) and Benbow limestones.

Description. The 510-m-thick (calculated from the map) Boozy Ridge Formation consists predominantly of a thick sequence of shales, sandstones and conglomerates, but also includes a lava flow near its base. The shales are thinly bedded and extensively weathered which makes sampling at outcrop difficult. Bedding is also recognized in the sandstones which are pebbly in some places. The conglomerates are mostly dark red to reddish-brown and are generally clast supported. They are poorly sorted with clast sizes ranging from pebbles to boulders. Clasts are mainly volcanic and basalts appear to be the dominant type. A small felsite dyke intrudes the formation near its base.

Type Locality. The type locality for the Boozy Ridge Formation is chosen as the exposure situated approximately 1.2 km northwest of Jubilee Town along the road to Benbow. The exposure is extensively weathered, however, all the lithologies associated with this unit can be observed at this locality.

Age. No fossils have been recovered from the formation, and it is either of late Hauterivian or early Barremian age.

Boundaries. This unit lies conformably above the Jubilee Formation and extends across the entire inlier.

3.6. Benbow Formation

Introduction. The Benbow Formation represents the thickest limestone unit in the Devils Racecourse Group. Previously referred to as the Benbow Limestone, the youngest limestone member of the Devils Racecourse Formation (Burke et al., 1969), this unit is now raised to formation status. This unit was first reported as the Benbow Limestone by Matley and Raw (1942) for the compact dark blue-grey limestone exposed around the district of Benbow. Although it was originally recorded as a Cretaceous limestone by Sawkins (1869), Matley and Raw (1942) incorrectly designated it to the Eocene, a mistake repeated by Hose and Versey (1957). Chubb (1960) confirmed its Cretaceous age based on the rudist and gastropod fauna. A further description of the rudist fauna was given by Chubb in Zans et al. (1963). Burke et al. (1969) considered this the uppermost limestone member of the Devils Racecourse Formation, and the unit has been referred to as the Benbow Limestone since then (Chubb, 1971; Robinson et al., 1972; Sohl, 1978; Jiang and Robinson, 1987; Robinson, 1994; Skelton and Masse, 1998).

Description. The Benbow Formation consists of 400 m (calculated from the map) of very hard, compact dark blue-grey biomicrite, rich in rudists, gastropods and corals, with smaller numbers of chondrodonts and columnar stromatolites. Exposures are for the most part unyielding to rock hammers, and as such, macrofossils can only be studied on weathered surfaces. The rudist fauna includes *Retha tulae* in the lower part, and *Amphitriscoelus primaevus* Pantoja-Alor, Skelton & Masse (**Figure 4C**) in the upper part. Other rudists include *Toucasia* sp. Gastropods (*Diozoptyxis renauxiana* (d'Orbigny), *D.* cf. *coquandiana* (d'Orbigny), *Archimedea gigantea* (d'Hombre-Firmas) and *Nerinea galatea* Coquand) are found in association with the rudists (gastropod identifications by Norman Sohl in Khudoley and Meyerhoff, 1971). *Chondrodonta* is abundant and appears to be confined to the upper part of the formation. Benthic foraminifers and algae are abundant in the Benbow Formation (Pisot et al., 1986; Vila et al., 1986; Skelton and Masse, 1998).

Type Locality. Due to the large outcrop area of the Benbow Formation, numerous exposures are easily accessible, although no single outcrop shows all of the characteristics of this unit. The type locality is designated as the exposure situated to the northwest of Benbow, approximately 300 m along the road from Benbow to Gloucester Hall. Here, the Benbow Formation is exposed in massive thick beds with abundant specimens of *Amphitriscoelus primaevus*, chondrodonts and corals.

Age. Benthic foraminifers (*Choffatella decipiens* Schlumberger, *Neotrocholina friburgensis* (Guillaume and Reichel), *Citaella* sp., *Cuneolina tenuis* Velic-Gusic, *Pseudocyclammina hedbergi* Maync and *Miliola* sp.: Pisot et al., 1986; Vila et al., 1986; Skelton and Masse, 1998) and algae (*Salpingoporella katzeri* Conrad & Radoicic, *Salpingoporella melitae* Radoicic, *Hetersporella lemmensis* Bremier, *Salpingoporella appenninica* De Castro and *Actinoporella* sp.: Pisot et al., 1986; Vila et al., 1986) are common in the Benbow Formation and indicate an age range from Early to Late Barremian. The rudist *Retha tulae* has an age range of Hauterivian (herein) to early Barremian (Skelton and Masse, 1998) whereas *Amphitriscoelus primaevus* Pantoja-Alor, Skelton & Masse is of late

Barremian age (Pantoja-Alor, Skelton & Masse, 2004).

Boundaries. The Benbow Formation rests conformably on the conglomerates, sandstones and shales of the Boozy Ridge Formation. Near to the western end of the Inlier, the Benbow Formation is in faulted contact with limestones of the Cenozoic White Limestone Group.

3.7. Ragville Formation (New Name)

Introduction. The name Ragville Formation is introduced here for a 280-m-thick (calculated from the map) pile of pillow lavas with associated volcaniclastic sediments that rest on top of the limestones of the Benbow Formation. This unit is exposed across much of the inlier from just west of Burtons towards the district of Ragville from which its name is derived. This formation was previously included in the Upper Devils Racecourse Formation (Burke et al., 1969; Roobol, 1972; Robinson, 1994).

Description. The Ragville Formation consists of mafic lava flows associated with thin layers of volcaniclastic sediments at the base and top of the flows. The lava flows were deposited under water as indicated by pillow structures which can be observed in almost all the exposures. The lavas are predominantly fine-grained vesicular basalts with some vesicles filled in by calcite. Other samples show a slight porphyritic texture. Petrographic analysis of these lavas reveals an abundance of plagioclase feldspar (40-50%) mostly as small (<1 mm), elongated crystals forming most of the groundmass with very few larger crystals as phenocrysts. Other minerals include chlorite (25-30%), calcite (10%), minor traces of epidote and a few mafic minerals. There is an obvious rusty-brown colouration of the thin sections indicating the presence of iron oxides as the products of alteration by hydrothermal fluids. The composition of these lavas ranges from basalts to basaltic andesites and geochemical studies indicate a calc-alkaline chemistry (Hastie et al., 2007, 2008). The volcaniclastic layers at the base and top of the unit consist of weathered conglomerates and sandstones, and locally contain clasts of limestone.

Type Locality. The type locality of the Ragville Formation is situated along the main road from Burtons to Golden Grove, about 200 m along the road above the fording west of Burtons. This exposure extends for approximately 500 m and the basalts of this unit can be observed showing both porphyritic and vesicular textures. Pillow structures are poorly defined at this locality, however, they are quite prominent in the bed of the Indian River just west of Airy Mount.

Age. From its stratigraphic position, the Ragville Formation is of either late Barremian or early Aptian age.

Boundaries. The Ragville Formation conformably overlies the Benbow Formation and the contact at the base can be clearly observed at the type locality. This unit is also in conformable contact with the Burtons Formation which immediately overlies it.

Remarks. Roobol (1972) estimated a thickness of 300 m for the pillow lavas forming much of the upper part of the Devils Racecourse Formation of Burke et al. (1969). This would include both the Ragville and Golden Grove formations.

3.8. Burtons Formation (New Name)

Introduction. The Burtons Formation is introduced here for the thin limestone unit that lies above the Ragville Formation. This unit extends across much of the inlier from Burtons towards Guys Hill. This unit was not previously recognized as a separate unit, and was previously attributed to the Benbow Formation (Burke et al., 1969; McFarlane, 1977).

Description. The Burtons Formation consists of 8 m of hard dark grey micritic limestone. Exposures are relatively poor except at the type locality. Fossils are scarce and are limited to rudists, tentatively identified as *Retha munieri* (Matheron).

Type Locality. The type locality for the Burtons Formation can be found as an exposure situated along the main road southeast of Golden Grove about 150 m south of the Postal Agency. This is the best exposure of the Burtons Formation where the limestone is bedded and has a gentle dip to the northeast.

Age. If the identification of *Retha munieri* is correct, this species would suggest a late Barremian or Early Aptian age (Skelton and Masse, 1998).

Boundaries. At the type locality, the lower boundary of the Burtons Formation can be seen in contact with basaltic lavas of the Ragville Formation while the upper boundary can be seen in contact with volcaniclastic sandstones appearing at the base of the Golden Grove Formation.

Remarks. Although the Burtons Formation is relatively thin, its position well above the Benbow Formation may mean that it is the local expression of the Early Aptian limestone that yields *Amphitriscoelus waryingi* Harris & Hodson in Trinidad (Harris and Hodson, 1922) and Mexico (Alencáster and Pantoja Alor, 1996).

3.9. Golden Grove Formation (new name)

Introduction. The name Golden Grove Formation is introduced for the uppermost unit of pillow lavas which rests on top of the Burtons Formation, and the highest unit of the Devils Racecourse Group. Like the Ragville and Burtons Formations, this unit extends across much of the inlier. The Golden Grove Formation was previously considered as part of the thick pile of pillow lavas comprising the upper Devils Racecourse Formation (Burke, et al., 1969; Roobol, 1972; Robinson, 1994). This unit represents the second pile of pillow lavas and rests on top of the Burtons Formation.

Description. The Golden Grove Formation is lithologically similar to the Ragville Formation, but is distinguished from it because it overlies the Burtons Formation, whereas the Ragville Formation underlies the Burtons Formation. It consists of a 430-m-thick (calculated from the map) pile of mafic lavas, basalts and basaltic andeistes, with very pronounced pillow structures (**Figure 4D**) indicating submarine extrusions. Geochemical studies indicate a calc-alkaline chemistry similar to that of the Ragville Formation (Hastie et al., 2007, 2008). Thin layers of volcaniclastic sediments form part of this unit at the base and top of the lava flows. The lavas appear as weathered porphyritic basalts with most of the original textures retained. At the top of the flows, the lavas are extensively weathered and fractured but the pillow structures have been retained. Petrographic analysis of these lavas shows phenocrysts of plagioclase feldspar (15%) and olivine (15%) set in a groundmass of quartz, opaque sulphide or oxide minerals and smaller lath-like crystals of plagioclase feldspar. Quite a few of the plagioclase crystals display zoning and show alteration to chlorite around the edges, while others have been almost completely altered. There is a noticeable rusty-brown colouration of the thin section which indicates hydrothermal alteration to produce iron oxides.

Type Locality. The type locality for the Golden Grove Formation is situated on the east bank of the Knollis River west of Sports Park, approximately 750 m northwest along the river from the road bridge. Fresh exposures of well-developed pillow lavas can be observed. Along the main road from Golden Grove to Top Hill, weathered exposures of the lavas with pillow structures are well exposed (**Figure 4D**).

Age. Based on its stratigraphic position, the Golden Grove Formation is either of late Aptian or early Albian age.

Boundaries. The Golden Grove Formation rests conformably on top of the Burtons Formation.

3.10. Airy Mount Formation (New Name)

Introduction. The Airy Mount Formation is introduced for the conglomerates in the upper part of the Devils Racecourse Group. This unit is exposed mostly in the north-eastern part of the inlier along the main road from Burtons to Top Hill. The exposures extend across much of the inlier from Richmond Hill in the east towards the area north of Airy Mount from which the name is derived. Burke et al. (1969) recognized this unit as part of the Upper Devils Racecourse Formation which comprised conglomerates with volcanic clasts.

Description. The Airy Mount Formation consists of 350 m (calculated from the map) of pebble conglomerates with minor pebbly sandstones. The conglomerates are greyish-brown, poorly- to moderately-sorted and are matrix supported. Pebbles are for the most part well-rounded with scattered angular pebbles. Pebbles are derived from igneous rocks together with a small variety of other rock types. There are a few isolated boulder-sized clasts of porphyritic igneous rocks. No fossils were observed.

Type Locality. The type locality for the Airy Mount Formation can be seen along the main road from Golden Grove to Top Hill. At this locality, the sharp contact between the conglomerates of the Airy Mount Formation and the pillow lavas of the underlying Golden Grove Formation can be clearly observed. A fairly well cemented exposure of the conglomerates can be observed at this locality and the various lithologies of the clasts can be studied in detail.

Age. There are no fossils and the unit is placed in the late Aptian or early Albian on stratigraphic grounds.

Boundaries. The base of the Airy Mount Formation is exposed at the type locality where it rests, probably conformably, on the top of the Golden Grove Formation.

3.11. Seafield Formation

Introduction. The Seafield Formation is named for the uppermost limestone unit exposed in the Benbow Inlier. It immediately overlies the Airy Mount Formation and is exposed north of Pear Tree Grove. Detailed mapping has shown that this unit can be traced across much of the northern portions of the inlier and is therefore raised to formation status. The Seafield Formation was first named as the Seafield Limestone by Chubb (1960) for the

youngest limestone exposed in the Benbow Inlier. It was later described by Chubb in Zans et al. (1963). Burke et al. (1969) and Robinson et al. (1972) referred to this unit as the Seafield Limestone Member belonging to the Rio Nuevo Formation. Subsequent authors have retained the name with member status (Sohl, 1978; Woodley and Robinson, 1977; Jiang and Robinson, 1987; Robinson, 1994). Here, the name will be retained, but elevated to formation status and separated from the overlying Rio Nuevo Formation.

Description. The Seafield Formation consists of a 320-m-thick sequence (calculated from the map, but with extensive faulting) of limestones interbedded with mudstones, shales and conglomerates. Conglomerates are coarse-grained with limestone clasts up to 40 cm in diameter. Sandstones are poorly sorted and appear pebbly in some exposures. Mudstones appear lignitic and are generally laminated. Two limestones have been tentatively distinguished, but have similar characteristics and may represent the same unit duplicated by faulting. The limestones are light greyish-brown, coarse-grained and composed of bioclastic material including rudists, rudist fragments, corals, gastropods and echinoid spines. The rudist fauna includes *Coalcomana ramosa* (Boehm) (**Figure 4E**), *Caprinuloidea perfecta* Palmer, *C. multitubifera* Palmer, *Eoradiolites* sp., and *Toucasia* sp. No microfossil analysis of this limestone was carried out however Jiang and Robinson (1987) reported the benthic foraminifer *Mesorbitolina texana* (Roemer) as *'Orbitolina oculata'*. Limestone blocks presumably derived from the Seafield Formation found loose in the Rio Nuevo river bed contain *Texicaprina*.

Type Locality. The best exposures of the Seafield Formation can be seen along the banks of the upper tributaries of the Knollis River east-southeast of Springfield. The unit is well exposed for several hundred metres along the river and all the lithologies can be observed. This locality is chosen as the type locality for the Seafield Formation. Other exposures are found along the main road from Springfield to Top Hill.

Age. The *Coalcomana-Caprinuloidea* rudist assemblage is widespread in the early Albian across the American region being found in Puerto Rico (Skelton, 1996), the Dominican Republic (Myczyński and Itturalde-Vinent, 2005), Cuba (Thiadens, 1936), Mexico (Boehm, 1898; Alencáster and Pantoja Alor, 1986) and Texas (Scott, 2002). The presence of *Texicaprina* in loose limestone blocks suggests that the Seafield Formation may extend up into the middle Albian (Scott, 2002).

Boundaries. The Seafield Formation has conformable contacts with the Airy Mount Formation below and the Rio Nuevo Formation above. However, extensive faulting makes the interpretation of the succession, as well as the determination of the thickness of the formation difficult.

3.12. Rio Nuevo Formation

Introduction. The Rio Nuevo Formation represents a thick sequence of sedimentary rocks overlying the Seafield Formation. This unit is exposed mostly to the northeast of Guys Hill and extends westwards across the Rio Nuevo River Valley. This formation was first named the Rio Nuevo Mudstone by Greiner (1965) in reference to a paper by Burke et al. read at the Caribbean Geological Conference in Trinidad in 1965, but appearing in publication only in 1969 (Mitchell, 2009a). This name was retained by subsequent authors (Robinson et al., 1972; Roobol, 1972; Arden, 1975; Sohl, 1978; Jackson and Smith, 1979; Jiang and Robinson, 1987; Robinson, 1994). Burke et al. (1969) included the Seafield Limestone as a member in the lower part of the Rio Nuevo Formation; we however note that limestones only occur in an interval below the main occurrence of shales and that the Seafield and Rio Nuevo are best treated as separate formations.

Description. The Rio Nuevo Formation comprises at least 1,150 m (calculated from the map, but with extensive faulting in the lower part) of dark grey shales (**Figure 4F**) with minor amounts of conglomerates and tuffaceous sandstones. Sandstones vary in grain size from fine to medium grained with some layers of coarse sands in the lower parts of the formation. They are poorly sorted and the clasts appear to be derived from volcanic rocks. Shales dominate in the upper part of the formation.

Age. Macrofossils are rare although the rudist *Texicaprina* (=*Sabinia vivari* (Palmer) and =*Sphaerucaprina seafieldensis* Chubb as reported by Chubb, 1971) occurs at the base of the formation. Calcareous nannofossils, recovered from the top of the formation, include *Cylindralithus asymmetricus* Bukry, *Corollithion achylosum* (Stover), *C. exiguum* Stradner, *Microrhabdulus decoratus* Deflandre, *M. belgiicus* Hay & Towe, *Lithraphidites acutus* Verbeek & Manivit, *L. moratus* Stover, *Eprolithus (Lithastrinas) floralis* (Stradner) and a questionable *Quadrum gartneri* Prins & Perch-Nielsen as one assemblage (Jiang and Robinson, 1987). Another assemblage collected near the top includes *Eiffellithus turriseiffelii* (Deflandre), *E. (L.) floralis*, *Lithastrinas moratus*

Stover, *Vagalapilla (Vekshinella) matalosa* (Stover) and a possible *Q. gartneri*. Although *Q. gartneri* indicates the Late Cenomanian to Middle Turonian (Sissingh, 1977), its uncertain presence limits the age of the top of the Rio Nuevo Formation to the Middle to Late Cenomanian based on the occurrence of *Lithraphidites acutus* (Perch-Nielsen, 1989).

Type Locality. The type locality for the Rio Nuevo Formation can be found along the banks of the Rio Nuevo. Extensive exposures of the shale sequence with well-developed bedding can be observed at this locality.

Boundaries. The Rio Nuevo Formation has conformable contacts with both the overlying Tiber Formation and the underlying Seafield Formation.

3.13. Tiber Formation

Introduction. The youngest lithostratigraphic unit exposed in the Benbow Inlier is the Tiber Formation, a 600 m sequence (calculated from the map) of conglomerates and associated lava flows overlying the Rio Nuevo Formation. The unit is exposed in the northern sections of the inlier with most exposures confined to the banks of the Tiber River. This unit was first named the Tiber Conglomerate by Greiner (1965) in reference to a paper being prepared by Burke et al. It was formally named as the Tiber Formation by Burke et al. (1969) to whom we attribute authorship. Its name and lithostratigraphic status have been used consistently by successive authors and is retained.

Description. The Tiber Formation consists of coarse-grained conglomerates with associated minor lava flows. The conglomerates are poorly-sorted, clast-supported and comprise sub-rounded to sub-angular clasts derived from andesites and clastic rocks. Bedding is poorly developed in the exposures.

Type Locality. The type section for the Tiber Formation is located in the bed of the Tiber River. Extensive exposures of the conglomerates with well-developed bedding can be seen in the bed of the river.

Age. No fossils have been collected from the Tiber Formation. On stratigraphic grounds it is either late Cenomanian or early Turonian in age.

Boundaries. This formation lies conformably above the Rio Nuevo Formation. The upper boundary of this unit is an unconformity at the base of the Paleogene succession.

4. DISCUSSION

The Benbow Inlier clearly contains an important sequence of arc rocks intercalated with limestones containing rich assemblages of gastropods and rudist bivalves. This demonstrates that Jamaica formed part of a volcanic arc system from at least as early as the Hauterivian, and probably from the Valanginian onwards and has a continuous sequence extending up into the Albian or Cenomanian. This contrasts with current models for the Great Arc of the Caribbean (Pindell and Kennan, 2009) where the arc either undergoes a polarity reversal or is initiated in the Aptian, yet there is no obvious unconformity in the Benbow succession. The great thickness of the succession in the Benbow Inlier (c. 6.5 km) might suggest that this forms part of an accretionary subduction complex; yet similar great thicknesses of stratigraphic succession are seen in the Santonian, Campanian and Maastrichtian elsewhere in Jamaica (e.g., Mitchell and Blissett, 2001; Mitchell, 2009b), where there is no evidence of thrusts. It seems that the very thick stratigraphic sequences in Jamaica developed because there was sufficient accommodation space and extensive supplies of sediments and volcanics generated from the arc.

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