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Geology of the Maastrichtian (Upper Cretaceous) succession of the Jerusalem Mountain Inlier in western Jamaica

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ABSTRACT. The geology of the Jerusalem Mountain Inlier is revised based on geological mapping. Five Cretaceous formations are recognized: Mint Formation (new name); Thicket River Formation; Belleisle Formation (new name); Jerusalem Formation; Masemure Formation. The Mint Formation is introduced for what has previously been called the Moreland Formation. Descriptions of the formations and locations of the type sections are indicated. In terms of structure, the inlier shows only gentle folding and does not represent an anticline as previously interpreted.

Keywords: Jamaica, Cretaceous, Jerusalem Mountain Inlier, Maastrichtian, lithostratigraphy.

1. INTRODUCTION

The Cretaceous rocks of Jamaica are exposed as a series of inliers across the island that now crop out within a Cenozoic block and trough structure (**Hose and Versey, 1957**) (**Figure 1**). In the Hanover Block of western Jamaica there are four Cretaceous inliers: the Lucea (Hanover) Inlier, the Grange Inlier, the Green Island Inlier and the Jerusalem Mountain Inlier. The large Lucea Inlier exposes a thick Santonian to Campanian predominantly sedimentary sequence of at least 5 km thickness, but there is no universally accepted lithostratigraphic scheme (**Grippi, 1980**; **Schmidt, 1988**; **Donovan et al., 2006**). The Green Island Inlier is a small inlier to the west of the Lucea Inlier and is famous for its rudist bivalves, particularly large specimens of the hippuritids *Barrettia* and *Whitfieldiella* (**Whitfield, 1897**; **Trechmann, 1924**; **Chubb, 1955, 1971**; **Mitchell, 2010**; **Mitchell and James-Williamson, 2015**). The lithostratigraphy of the Grange Inlier was described in detail by **Fisher and Mitchell** (**2012**). A formal lithostratigraphy for the Jerusalem Mountain Inlier is proposed in this paper and the structure of the inlier is briefly described.

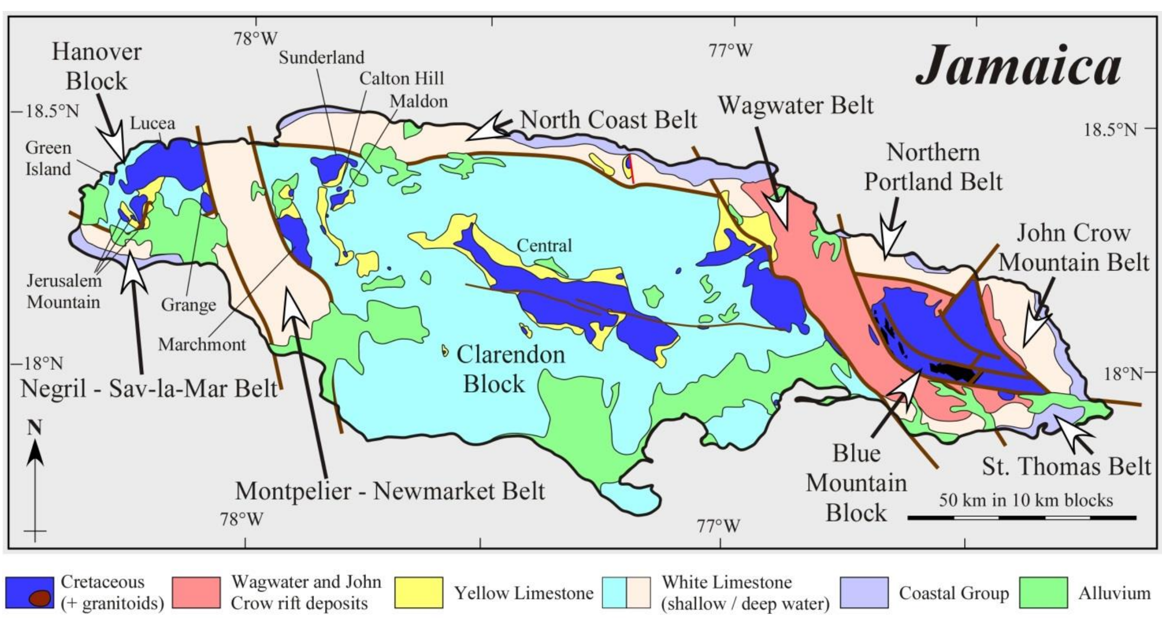


Figure 1. Cretaceous inliers of Jamaica related to the Cenozoic block and trough structure

2. History of Research

The presence of Cretaceous limestones in western Jamaica around the community of Jerusalem Mountain was first demonstrated by Charles Barrington Brown during the first geological survey of Jamaica (**Sawkins, 1869**). **Hill** (**1899**, p. 49) described the section and recognised limestones containing Alectryonate oysters, *Caprinella* and gigantic *Caprina*s. **Trechmann** (**1924**) drew attention to the succession at Jerusalem Mountain suggesting that the boundary with the surrounding Tertiary rocks may be faulted and suggested an anticlinal structure. He provided a section and suggested that this might be the highest Cretaceous limestone in Jamaica.

Kozary (**1956**), in an unpublished report, introduced a lithostratigraphic scheme for much of the Cretaceous and lower Tertiary rocks of Jamaica including the Jerusalem Mountain Inlier. Four formations were recognised. The Moreland Formation consisted of sandstones, siltstones and pebble conglomerates; the Thicket River Formation consisted of 'reefal' limestone; the Jerusalem Formation consisted of calcarenites and calcilutites separated by silty sands and clays; and the Masemure Formation consisted of sandstones, siltstones and shales. The names employed by **Kozary** (**1956**) have gradually found their way into the geological literature. The Masemure Formation was first mentioned by **Eva** (**1976a, b**), the Moreland Formation was included by **McFarlane** (**1977**) on the 1:250,000 scale geological map of Jamaica, and **Jiang and Robinson** (**1987**) used the terms Thicket River and Jerusalem members. **Jiang and Robinson** (**1987**) placed the Thicket River and Jerusalem members within the Jerusalem Mountain Formation (the Jerusalem beds of **Hill, 1899**).

The rudist bivalves in the Jerusalem Mountain Inlier have also received a lot of attention. **Trechmann** (**1924**) recorded a series of species, whereas **Johnson and Kauffman** (**1996**, p. 252) gave generalized sections of the Maastrichtian rocks in Jerusalem Mountain. They stated that it was the *"most complete, well-dated section of the rudistid reef and framework extinction known from the Caribbean province."* Subsequent work on the rudist bivalves from the inlier includes that of **Chubb** (**1971**) and **Mitchell** (**2013a**).

Strontium isotope dating of the Cretaceous limestones in Jamaica (**Steuber et al., 2002**, using a timescale where the top of the Maastrichtian was at 65 Ma) changed the interpretation of the Maastrichtian succession in Jamaica. This work showed that the limestone successions in the Central Inlier and the Maldon Inlier were late late Maastrichtian in age (65.78 - 66.68 Ma), but that the rudist-bearing limestones at Jerusalem Mountain were of early late Maastrichtian age (69.05 - 69.12 Ma).

Gavin Gunter (**2005**) mapped and described the geology of Jerusalem Mountain as part of his Ph.D. thesis. However, structural complications prevented him from coming up with an unambiguous interpretation of the structure and stratigraphy of the inlier.

3. Lithostratigraphy

The rocks of the Jerusalem Mountain Inlier were mapped by us at four different times between 2010 and 2013 with a total of 12 days being spent in the field. Both the geology of the inlier as well as the geology of the surrounding areas were considered, particularly as regards the faults passing into, or forming the margins of, the inlier, and extensive collections of fossils were made. The geology is presented in **Figure 2** and five formations are recognized here. The name Moreland Formation is

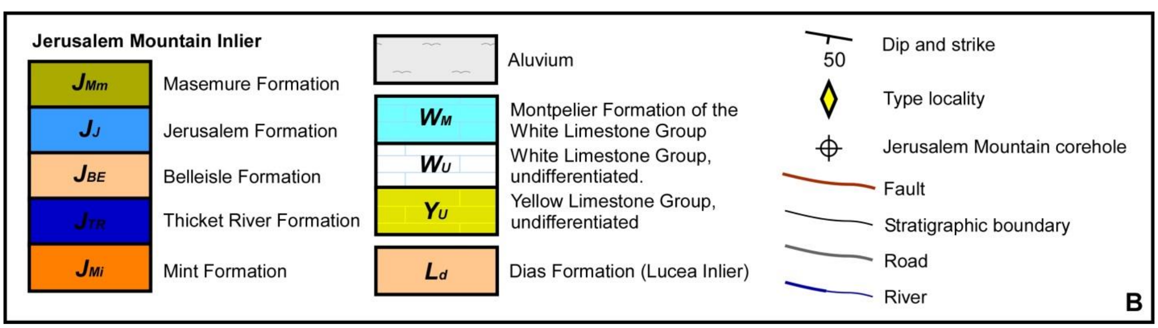
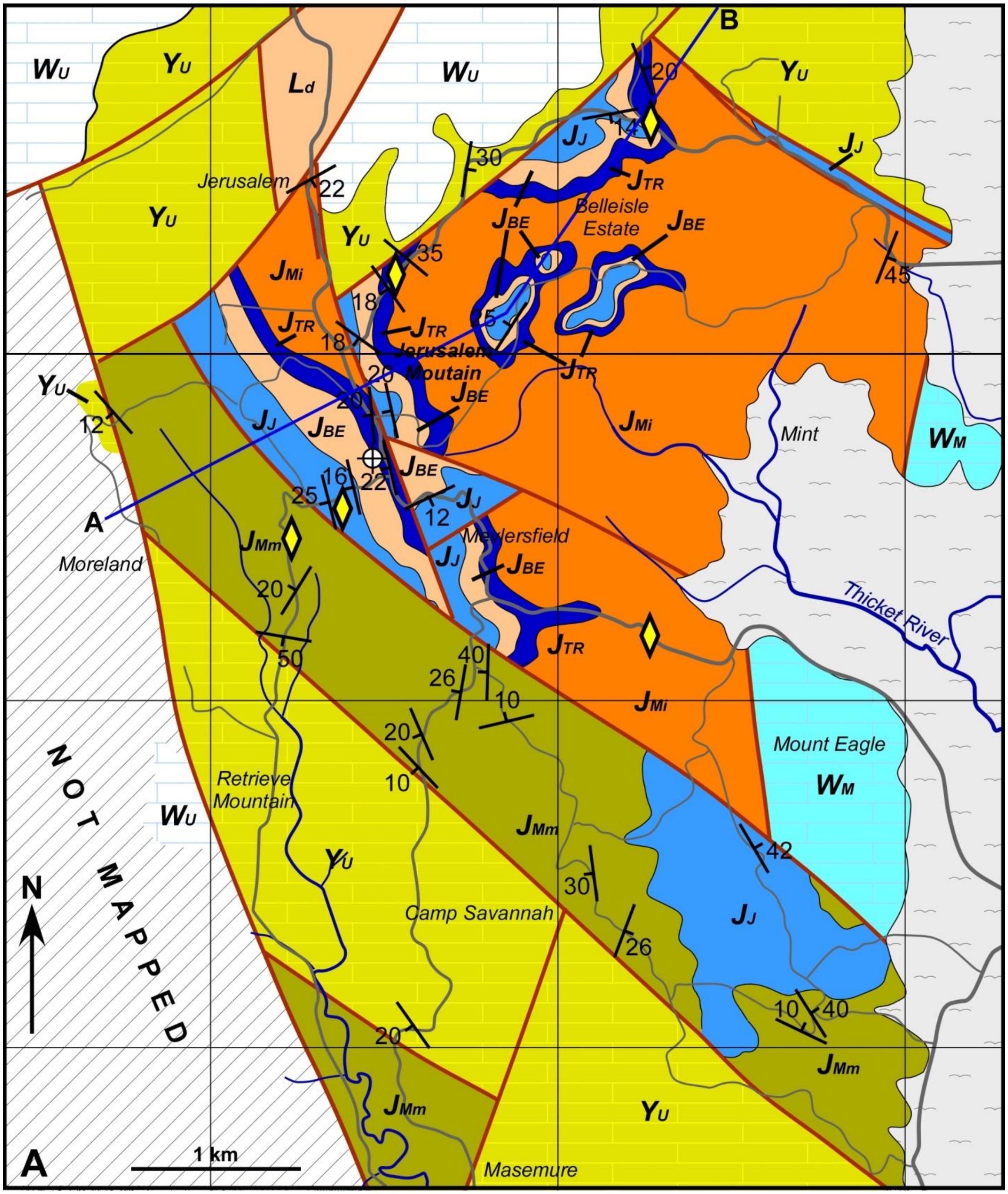


Figure 2 (and facing page). Geological map of the Jerusalem Mountain Inlier based on field mapping undertaken by us. Terminology follows Mitchell (2015), with Letter indicating inlier of group (J, Jerusalem Mountain Inlier; L, Lucea Inlier; Y, Yellow Limestone Group; W, White Limestone Group), and letters indicating formation. The unmapped area to the west consists of rocks belonging to the Yellow Limestone and White Limestone groups but boundaries between units were not mapped in this area and cannot be shown on the geological map. Figure 2A (above), key to symbols used, and Figure 2B (facing), geological map.



inappropriate because the formation does not crop out close to the hill with that name. Since the Thicket River and Jerusalem formations are separated by a distinct unit of siltstones (named the Belleisle Formation here), and all three are mappable, there is no reason to maintain a Jerusalem Mountain Formation with Thicket River and Jerusalem members. Following the original descriptions of **Kozary** (**1956**) the Thicket River and Jerusalem are given the rank of formation in this paper. Although **Hill** (**1899**) used the term Jerusalem Beds for these rudist-bearing limestones, we believe that only confusion can come from using this term for the rudist-bearing limestones which have now been established as the Thicket River Member/Formation.

Below we describe the formations found in the Jerusalem Mountain Inlier. For other units consult the following: Lucea Inlier (**Grippi, 1980**), White Limestone (**Mitchell, 2013c**).

3.1. Mint Formation (new name)

Introduction. The Mint Formation represents the oldest formation exposed in the Jerusalem Mountain Inlier. The name Moreland Formation has been used by **McFarlane** (**1977**), **Jiang and Robinson** (**1987**), **Robinson** (**1994**), **Sohl** (**1998**) and **Bateson and Samuels** (**2008**) for this formation. Moreland is a mountain situated to the west of the Jerusalem Mountain Inlier and is nowhere close to exposures of the so-called Moreland Formation. We therefore rename this unit the Mint Formation herein.

Description. The formation consists of a series of red or brownish sandstones and pebble conglomerates. The conglomerates are clast supported and contain rounded pebbles of igneous rock (andesites and basalts) and are set in a sandstone matrix. Thin units of red or brown sandstone are also present.

Type Section. The type section is selected along the road from Mount Eagle to Jerusalem Mountain to the southwest of Mint; here typical features of the formation can be seen.

Palaeontology and age. The formation has not yielded any fossils. It underlies the Thicket River Formation and is therefore older than that formation.

Thickness. A minimum estimate of the thickness of the formation cannot be given as the base is not exposed. The exposed section has a minimum thickness of 80-120 m.

Discussion. The Mint Formation underlies the limestones that carry the *Titanosarcolites* rudist assemblage. It finds a direct comparison with the Shepherds Hall Formation of the Sunderland Inlier (**Chubb, 1958**), the Slippery Rock Formation of the Central Inlier (**Mitchell and Blissett, 2001**; **Mitchell, 2013b**) and the Strawberry Formation of the Grange Inlier (**Fisher and Mitchell, 2012**). These formations all represent the basal transgressive unit at the base of the Kellits Synthem (**Mitchell, 2003, 2006**).

Thicket River Formation Jiang and Robinson (1987) adapted from Kozary (1956).

Introduction. The name Thicket River Formation is retained here for the rudist-bearing limestone in the Jerusalem Mountain Inlier. The name has been employed by **Jiang and Robinson** (**1987**), **Hazel and Kamiya** (**1993**), **Robinson** (**1994**) and **Sohl** (**1998**). **Hill** (**1899**) called the rudist-bearing limestone in this area the Jerusalem Beds, but to avoid confusion this term is not reapplied to the rudist-bearing beds that **Kozary** (**1956**) called the Thicket River Formation.

Description. This formation consists of a succession of interbedded mudstones, siltstones and limestones. The mudstones frequently contain calcareous nodules and the limestones are generally impure. The whole sequence is highly fossiliferous with numerous rudist bivalves, gastropods, and corals.

Type Section. The selected type section is along the road south of Jerusalem Mountain in the upper catchment of the Thicket River (**Figure 2**). The whole thickness is exposed.

Palaeontology and age. Rudist bivalves are abundant and include: *Bournonia cancellata* (Whitfield), *Biradiolites jamaiacensis* Trechmann, *Trechmanites rudissimus* (Trechmann), *Titanosarcolites* sp., *Thyrastylon chubbi* Alencaster, *Caribbea muellerreidi* (Vermunt), *Antillocaprinia occidentalis* Whitfield, *Chiapasella* sp., *Plagioptychus jamaicensis* (Whitfield), *Plagioptychus zansi* Chubb, and *Rudocaprina* sp. This is a typical Titanosarcolites limestone rudist assemblage. Strontium isotope ratios from well-preserved shells of *Plagioptychus jamaicensis* indicate a mid-Maastrichtian (69.05 - 69.12 Ma) age (**Steuber et al., 2002**).

Thickness. The estimated thickness from cross sections is of the order of 20 m.

Discussion. The majority of the formation was penetrated in Petroleum Corporation of Jamaica (PCJ) Jerusalem Mountain Corehole #1 (see **Figure 2** for location of borehole). This corehole shows alternations of impure limestones and siltstones and passes down into the Mint Formation below.

Belleisle Formation (new formation)

Introduction. The name Belleisle Formation is introduced for a unit of siltstones that separates the Thicket River Formation from the Jerusalem Formation.

Description. The formation consists of grey siltstones and shales and contains occasional layers of small (10 cm by 3 cm) calcareous concretions.

Type Section. The formation has a poor outcrop and the best available section is on the road north-east from Jerusalem Mountain (**Figure 2**).

Palaeontology and age. No age diagnostic fossils have been recorded from the unit.

Thickness. Although poorly exposed, cross sections indicate a thickness of about 15 m for the unit.

Discussion. This formation is introduced here because it separates the lower rudist-bearing limestones (Thicket River Formation) from the upper oyster-bearing limestones (Jerusalem Formation) in the Jerusalem Mountain Inlier.

Jerusalem Formation Jiang and Robinson (1987) adapted from Kozary (1956)

Introduction. The name Jerusalem Formation is retained for the oyster-bearing limestone in the Jerusalem Mountain Inlier. It has formally been called the Alectryonia {sic – Alectryonaria) Limestone (**Trechmann, 1922**; **Hose, 1950**; **Zans et al., 1956**) and the Ostrea (Alectryonia) Limestone (**Chubb, 1955**).

Description. The Jerusalem Formation consists of pale grey, dense, bedded, bioclastic limestones. They are typically represented by grainstones and have well developed stylolites. Thin siltstones are interbedded with the limestone in some localities. Higher parts of the limestone are less fossiliferous and more micritic.

Type Section. The best available section at the present time is 200-400 m along road from Jerusalem Mountain towards Moreland (**Figure 2**) where the lower part of the formation is exposed.

Palaeontology and age. The most conspicuous fossils are large oysters, the *Alectryonaria* of **Trechmann, 1922**. Similar oysters occur at a few levels within the Guinea Corn Formation suggesting that this is a distinctive facies in the Maastrichtian of Jamaica.

Thickness. Due to faulting, there is no locality where the complete thickness of the Jerusalem Formation can be seen. The lower part is well exposed around Jerusalem Mountain itself where (based on cross sections) up to 50 m are present. In the fault block to the south at Camp Savannah the upper 30-40 m of the formation are exposed. The estimated thickness is probably in the order of 60 m.

Discussion. This formation was originally considered the youngest Cretaceous unit in Jamaica (**Trechman, 1924**; **Johnson and Kauffman, 1996**), but following the strontium isotope dating of rudist bivalves in the Thicket River Member (**Steuber et al., 2002**) the Jerusalem Formation is best placed within the mid-Maastrichtian age. The lack of rudist bivalves must have been due to conditions on the sea floor making the environment unsuitable for them. Similar oyster bearing limestones occur at several layers in the succession in the Central Inlier.

Masemure Formation Eva (1976a, b) adapted from Kozary (1956)

Introduction. The name has been widely applied to the red sandstone succession that forms the highest unit in the Jerusalem Mountain Inlier (e.g., **Eva, 1976a, b**; **Coates, 1977**; **McFarlane, 1977**; **Meyerhoff and Krieg, 1977**; **Rodrigues, 1983**; **Draper, 1987**; **Jiang and Robinson, 1987**; **Hazel and Kamiya, 1993**; **Robinson, 1994**; **Sohl, 1998**; **Mitchell, 2004**; **Bateson and Samuels, 2008a**).

Description. Massive red mudstones and sandstones above the highest limestone of the Jerusalem Formation. In general, medium-grained sandstone predominates. Sedimentary structures are rare but include ripple-cross lamination, and laminated (sandstone-mudstone) heterolithics. The interbedded shales and sandstones and cross-lamination suggest deposition on a clastic tidal flat to supratidal flat.

Type Section. The type section selected is along the road from Jerusalem Mountain to Moreland (**Figure 2**). The formation is also exposed in a fault bounded block near Masemure, but currently only poor exposures are available in this area.

Palaeontology and age. No fossils have been collected from the unit in the Jerusalem Mountain Inlier. The Content #1 hydrocarbon exploration well penetrated a red sandstone sequence beneath the rocks of the Yellow Limestone Group (**Meyerhoff and Kreig, 1977**) which may be an equivalent.

Thickness. The top of the unit is not exposed, but available exposures suggest a thickness in excess of 120 m.

Discussion. The Masemure Formation represents a return to tidal flat clastics and records a regression following the deposition of the Thicket River-Belleisle-Jerusalem succession. Younger rocks are not found at the surface in the Hanover Block, but may have been penetrated within the Negril Spots #1 and West Negril #1 hydrocarbon exploration wells, although the correlation between wells and surface outcrops is very problematic (**Meyerhoff and Kreig, 1977**). We regard the Masemure Formation as a direct equivalent of the Thomas River Formation of the Central Inlier (**Mitchell and Blissett, 2001**; **Mitchell, 2013b**).

4. Structural Geology

Trechman (**1924**) suggested that the Cretaceous rocks of Jerusalem Mountain might be fault-bounded and also showed an anticlinal structure. Our mapping clearly shows that the inlier is fault bounded and we do not see a passage from the Cretaceous into the Paleogene. Faults are dominated by a NNW-SSE to NW-SE set and a less prominent WSW-ENE set (**Figure 2**). These are relatively typical fault orientations for Jamaica with the NW-SE set corresponding to reverse faults and the WSW-ENE corresponding to normal faults related to transpression across the E-W northern Caribbean Plate boundary during the late Miocene to Recent (e.g., **Benford et al., 2015**).

A plot of bedding data for the Cretaceous rocks (**Figure 3**) shows a dispersed single cluster indicating a regional dip towards the SW. The NE-SW elongation of the cluster suggests minor NW-SE folding, but this is not clear from the distribution of strike bars shown on **Figure 2**. The cross section across the Jerusalem Mountain Inlier (**Figure 4**) shows a general south-easterly dip towards the southwest, but undulating low amplitude folds to the northeast. We do not believe there is significant folding in the Jerusalem Mountain Inlier.

5. Discussion

The succession seen in the Jerusalem Mountain Inlier fills a gap in the understanding of the development of the *Titanosarcolites*-bearing rudist assemblages of central and western Jamaica. The succession begins with red bed pebble conglomerates and sandstones (Mint Formation) formed within a fluvial-deltaic environment and forming the lowest unit within the Kellits Synthem (**Mitchell, 2003, 2006**). The subsequent transgression introduced fully marine conditions in the Jerusalem Mountain Inlier with the establishment of a rich rudist bivalve assemblage. This transgression can be traced to the east through the Kennsington Formation of the Sunderland Inlier into the lower part of the Thomas River Formation of the Central Inlier (**Mitchell, 2013b**). A regression is represented by the passage from the Jerusalem Formation to the Masemure Formation with the establishment of tidal flat sandstones. The main rudist limestones seen in the Calton Hill, Maldon and Central Inliers (as well as those in the Marchmont Inlier) represent a second transgression with carbonate sedimentation persisting until the end of the Maastrichtian, but are not developed in the Jerusalem Mountain Inlier.

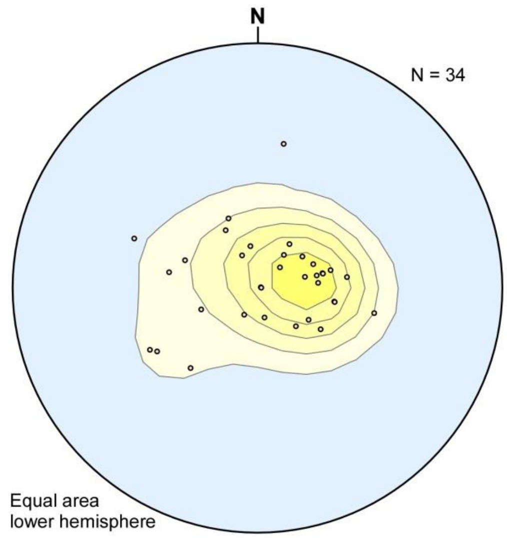


Figure 3. Equal area stereonet for Cretaceous rock's bedding in the Jerusalem Mountain Inlier. Note overall regional south-westerly dip with a few points indicating gentle folding. Clusters to fold limbs poorly defined. Density calculation by cosine sums, cosine exponent = 20, and contour intervals = 10.

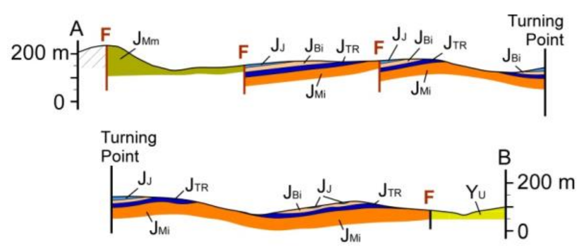


Figure 4. NE-SW cross-section across the Jerusalem Mountain Inlier (see Figure 2B for location of section line). Note lack of overall anticlinal structure but presence of presumably small-scale folding. No vertical exaggeration.

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