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Timing and implications of Late Cretaceous tectonic and sedimentary events in Jamaica

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ABSTRACT

The Cretaceous succession in Jamaica can be divided into sedimentary packages bounded by major unconformities (synthems). On the base of biostratigraphy and ages derived from strontium isotope ratios, these unconformities have been dated as Early Santonian, Late Campanian-Early Maastrichtian and Early Eocene. Each unconformity is also characterised by the widespread deposition of shallow water limestones, and a further shallow limestone depositional event occurred in the late Middle Campanian. Some unconformities can be related to known tectonic events (based on either Burke-type or Pindell-type models) that affected the Caribbean region. The Early Santonian event is widespread and occurred shortly after the creation of the Caribbean Large Igneous Province. The late Middle Campanian shallow water limestone event could correlate to the reversal of the Great Arc of the Caribbean in Burke-type models, but is unrepresented in Pindell-type models. The Late Campanian-Early Maastrichtian unconformity is related to the first collision of the Caribbean Plate with North America in both Burke-type and Pindell-type models. The Early Eocene event is associated with the onset of rifting that controlled Tertiary depositional patterns across Jamaica.

KEYWORDS **Cretaceous. Tertiary. Uncorfomities. Caribbean Plate. Jamaica. Stratigraphy.**

INTRODUCTION

Mobilistic models for the evolution of the Caribbean involving Pacific origins for the Caribbean Plate and Caribbean Large Igneous Province (CLIP) fall into two groups: Pindell-type and Burke-type models (Burke, 1988; Pindell and Barrett, 1990; Pindell, 1994; Pindell and Kennan, 2001; Kerr et al., 2004). Pindell-type models have a westward facing arc in the early Cretaceous, which became east-facing in the Aptian allowing the Caribbean Plate to move between the Americas and colliding with them from Early Maastrichtian to Eocene time. Burke-type models have a westward facing arc in the pre-Campanian, the emplacement of the CLIP in the Turonian to Coniacian, the collision of the CLIP in the Campanian with the arc causing arc reversal and allowing the Caribbean Plate to be pulled between the Americas, and a Late Campanian-Eocene collision between the Caribbean and North and South American Plates.

Changes in tectonic stress regimes and tectonic events profoundly affect sedimentation within sedimentary basins in island arc systems (Vail et al., 1991; Busby and Ingersoll, 1995). Consequently, the events that have occurred during the evolution of the Caribbean should have left a significant imprint on the sedimentary successions. Mitchell (2004) described the geology of central Jamaica and established a succession of tectono-sedimentary packages in Central Jamaica using well-constrained age assignments (Kauffman, 1966; Jiang and Robinson, 1987; Jiang, 1993; Wiedmann and Schmidt, 1993; Underwood and Mitchell, 2000).

This paper represents a revision of Mitchell (2004) and incorporates the strontium isotopic data of Steuber et al. (2002) and new biostratigraphic data. It extends the tectonically controlled sedimentary packages recognized in central Jamaica to western and eastern Jamaica, recognizes new events, compares the succession in Jamaica with successions in Cuba, Hispaniola and Puerto Rico, and discusses how these events might relate to the Pindell and Burke models.

GEOLOGICAL SETTING

The geological evolution of Jamaica has been divided into four basic stages by Draper (1987). The Cretaceous was characterized by island arc volcanism associated with the extrusion of lavas and the deposition of volcaniclastic sedimentary rocks and thin limestones. In Paleocene-Early Eocene time, Jamaica was the area of extensive intra-arc rifting. From Middle Eocene to Middle Miocene time, Jamaica formed part of an extensive carbonate platform complex that extended across the Nicaragua Rise. Renewed uplift began in the Late Miocene and continues to this day; this has resulted in the rapid uplift of the Blue Mountains and the exhumation of numerous inliers exposing the Cretaceous succession on the island.

The Cretaceous-Paleocene rocks referred to in this paper are exposed in the Blue Mountains, Clarendon and Hanover Blocks (Fig. 1). The succession on the Clarendon Block (particularly the Central Inlier) has been best studied and forms the ‘type’ succession of this report. The succession was divided into packages (synthems, Fig. 2) bounded by angular unconformities (Mitchell, 2004). This stratigraphic subdivision allows the recognition of distinct depositional episodes, separated by important tectonic events that shaped the sedimentary basins of Jamaica. The volcanic basement and synthems are briefly discussed below (details can be found in the references cited).

STRATIGRAPHY

Older Volcanic Succession

In the Central Inlier, the Arthurs Seat Formation consists of a thick succession of volcanic and sedimentary rocks (Mitchell, 2004). The lower part consists of a sequence of tholeiitic andesitic flows and associated dyke rocks (Jackson, 1987; Mitchell, 2004); the upper part, very-poorly-sorted, unbedded conglomerates associated with rare graded/laminated sandstones and porphyritic basalts and andesites with calc-alkaline affinities (Jackson, 1987; Mitchell, 2004). This succession was intruded by various dykes, and in the east by the Ginger Ridge Granodiorite (Porter, 1970, 1972) giving a K-Ar isochron age of 85 ± 9 Ma (Turonian to Middle Campanian, Lewis et al., 1972). The succession was interpreted to have formed in a subaerial, proximal volcaniclastic apron close to an active volcanic centre (Mitchell, 2004).

In the nearby Benbow Inlier, a 9 km thick succession of lavas, volcaniclastic sediments, shales and limestones is developed (Burke et al., 1968), with rudist-bivalves indicating a Barremian to Late Albian age range. The uppermost part of the succession has yielded a Turonian nannofloral assemblage (Jiang and Robinson, 1987). Tholeiitic lavas in the lower part of the section are regarded as part of the tholeiitic island arc (or PIA) suite, whereas the overlying Albian to Turonian rocks have a calc-alkaline island arc suite (Jackson, 1987).

The oldest dated rocks exposed along the southern side of the Grand Ridge of the Blue Mountains consist of basalts and gabbros of the Bath-Dunrobin Formation (Wadge et al., 1982). These consist of typical MORB basalts and have been interpreted as a dismembered ophiolite complex (Wadge et al., 1982; Jackson, 1987). Cherts interbedded with the basalts indicate a Turonian-Coniacian age (Montgomery and Pessagno, 1999), the same as the CLIP fragments found in Hispaniola and drilled in DSDP wells (Kerr et al., 2004).

Crofts Synthem

In the Central Inlier, the Crofts Synthem has a basal angular unconformity, and consists of the Peters Hill, Back River and Dawburn Content formations (Mitchell, 2004). The Peters Hill Formation consists of up to 25 m of limestone and is succeeded by the Back River Formation represented by a coarsening upwards succession of mudstones passing upwards into thickly bedded sandstones. A thin unit of cross-bedded sandy limestones is present at the top. The overlying Dawburn Content Formation is a succession of graded, turbiditic sandstones and intervening shales. The Peters Hill Limestone contains a prolific Santonian rudist fauna, whereas the overlying Back River Formation contains inoceramids and planktic foraminifers indicating the Upper Santonian-Lower Campanian (Kauffman, 1966; van Dommelen, 1971). The Crofts Hill Synthem has been intruded by a few basaltic sills and andesitic dykes.

In the Stapleton Inlier (Fig. 2), the Crofts Synthem is represented by a conglomerate-shale-limestone sequence. The Johns Hall Conglomerate has yielded probable Early Campanian gastropods (Sohl, 1967), whereas the overlying deep-water Sunderland and Newmans Hall Shales have yielded Early and Middle Campanian nannofossils (Jiang, 1993). The Stapleton Limestone, represents a widespread shallow-water phase yielding a rudist fauna included *Barrettia gigas* Chubb (Chubb, 1971) and is of late Middle Campanian age (Jiang, 1993). The overlying Shephards Hall Formation is also of Campanian age (Jiang, 1993).

In the parish of Hanover, a thick Santonian-Middle Campanian section is present within the Lucea, Grange, and Green Island Inliers (Chubb, 1955; Grippi, 1980; Grippi and Burke, 1980; Schmidt, 1988). The most complete Santonian-Middle Campanian succession is seen in the central block of the Lucea Inlier (Grippi, 1980; Jiang and Robinson, 1987). Here a deep-water turbiditic Santonian (and possibly older) succession is present, and is cut by a submarine channel-fill. This is overlain by a lenticular limestone (the Clifton Limestone yielding a late Santonian rudist assemblage), and a Santonian-Lower Campanian deep-water shale-conglomerate sequence (Jiang and Robinson, 1987). The Green Island Limestone of the Green Island Inlier is the local expression of the widespread late Middle Campanian shallow-water *Barrettia gigas* limestone.

Late Cretaceous Unconformity

In the Central Inlier, the unconformity at the base of the Kellits Synthem truncates the Arthurs Seat Formation, Crofts Hill Synthem, and an east-west, high-angle thrust fault at the top of the Crofts Hill Synthem (Mitchell, 2004).

Kellits Synthem

The Kellits Synthem is well-developed across the Cornwall-Middlesex Block and represents a major transgressive-regressive cycle (Mitchell and Blissett, 2001; Mitchell, 2004). It is exposed at outcrop in the Central, St. James, Marchmont and Jerusalem Mountain Inliers.

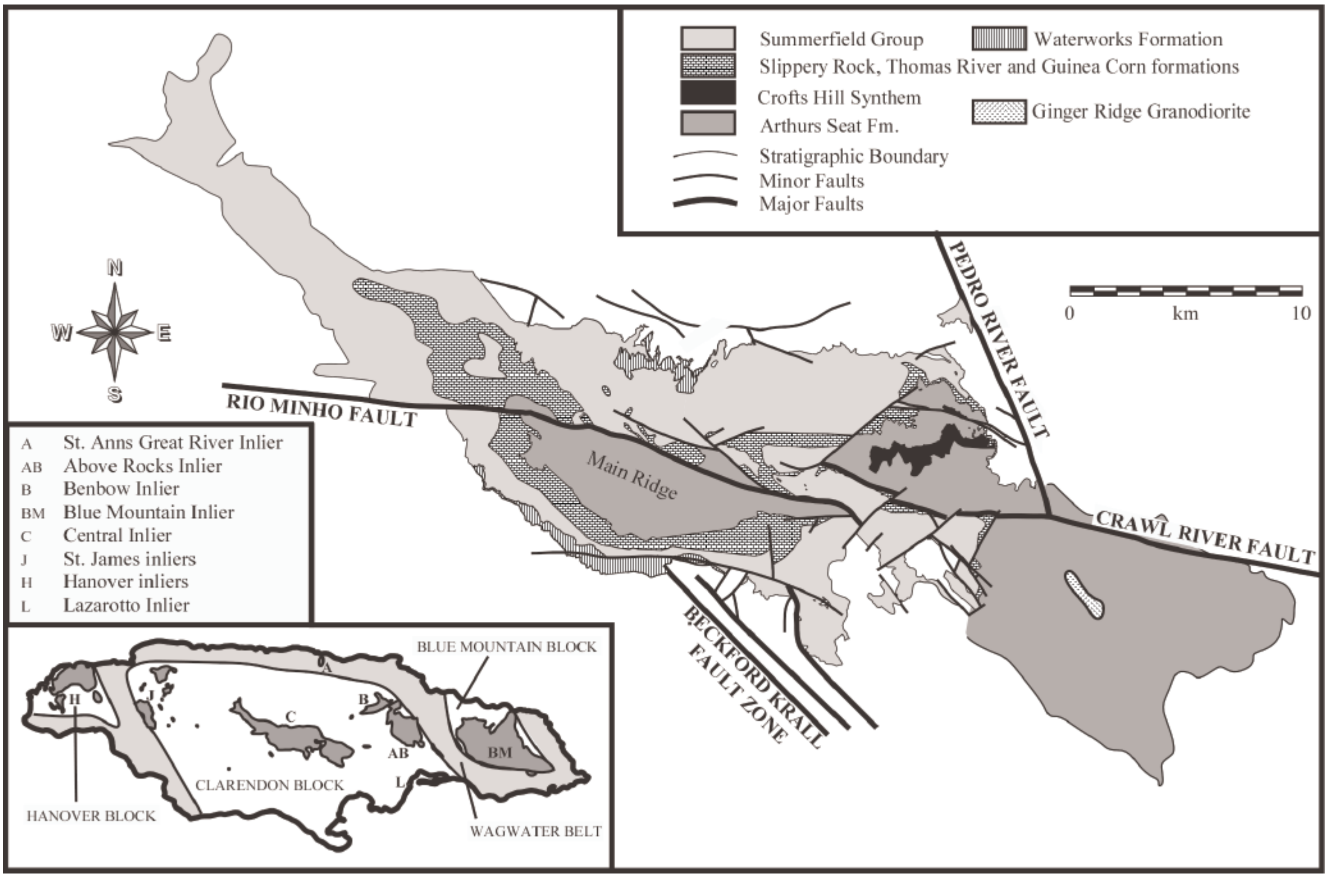

FIGURE 1 | **Geological sketch of the Central Inlier showing major litholofical and structural characteristics. Inset: Tertiary structural blocks of Jamaica showing the location of the Central Inlier (C) in the Clarendon Block. See further explanation in the text.**

The succession in the Central Inlier has been extensively described before (Mitchell, 1999; Mitchell and Blissett, 2001; Mitchell, 2004). The basal Slippery Rock Formation (150 to 175 m thick) consists of red, brown or grey pebble conglomerates in poorly-defined beds up to several m thick. The conglomerate beds have sharp, erosive bases, may have tabular and trough-cross bedding; some show nodular calcretes at the top. The amalgamated conglomerate beds pass upwards into discrete conglomerate beds alternating with poorly-sorted, pebbly sandstones and red siltstones with nodular and pelloidal calcretes. In the western part of the inlier, the Slippery Rock Formation is succeeded by the Thomas River Formation. This consists of up to 175 m of red and grey mudstones. At the base is a thin sandy limestone with oysters. The red mudstones are unfossiliferous, but contain thin horizons of nodular calcrete. The grey mudstones contain thin beds of flaser, wavy and lenticular bedded sandstone showing bidirectional palaeocurrents. A few thin, widely spaced marine limestones are present and contain a rudist-coral fauna. The grey mudstones yield a mixed marine–freshwater fanua (gastropods and bivalves) and flora (charophytes, Kumar and Grambast-Fessard, 1984; Kumar and Oliver, 1984). The Guinea Corn Formation is up to 250 m thick and rests on the Thomas River Formation in the west, the Slippery Rock Formation in the middle, but is absent in the eastern parts of the inlier. The formation consists of rudist-bearing limestones (Coates, 1965, 1977; Kauffman and Sohl, 1974; Mitchell, 1999, 2002) alternating with fossiliferous siltstones and mudstones forming rhythms (Mitchell, 2002). Rudist bivalves are abundant in the limestones, and include *Titanosarcolites*, *Praebarrettia*, *Bournonia*, *Biradiolites*, *Chiapasella*, *Antillocaprina* and *Thyrastylon* (Trechmann, 1924; Chubb, 1971; Kauffman and Sohl, 1974; Mitchell, 1999, 2002; Mitchell and Gunter, 2002). The limestones thin to the northeast and mudstones become more prominent. Fossiliferous siltstones are interbedded with the limestone in the lower part of the succession. In the upper part of the succession, mudstones with graded sandstones, similar to the sandstones in the overlying Green River Formation, are present (Mitchell, 1999). A late Maastrichtian age is indicated by the fauna (Underwood and Mitchell, 2000) and ages derived from strontium isotope values (Steuber et al., 2002). The Guinea Corn Formation (or Slippery Rock Formation where the Guinea Corn Formation is missing) is succeeded by the Summerfield Group consisting of a shallowing-upwards succession of marine to terrestrial volcaniclastic sedimentary rocks (Mitchell, 2000; Mitchell and Blissett, 2001). The lower part consists of mudstones with normally graded sandstones (Green River Formation – 60 m thick) that pass up into massive sandstones (Peckham Formation – 150 m thick). The overlying Mahoe River Formation (210 m thick) consists of thickly-bedded, pebble and boulder conglomerates with rounded clasts that have well-developed imbrication. The top of the group is represented by up to 150 m of dacitic ignimbrites of the Waterworks Formation. Mitchell (2000) interpreted this shallowing-upwards succession as a progradational volcaniclastic braid-delta, associated with a newly emergent volcanic centre. A single fission track age from apatites from the Waterworks Formation indicates the earliest Eocene (55.3 ± 2.8 Ma, Ahmad et al., 1987).

In the parish of St. James, the Kellits Synthem is exposed in the Kennsington, Calton Hill, Maldon and several smaller inliers (Gunter and Mitchell, 2005). The succession consists of thick interbedded rudist-bearing limestones and shallow-marine mudstones. The Maldon and Vaughansfield Formations correlate with the D Beds and top F Beds in the Central Inlier (Mitchell and Gunter, 2002; Gunter and Mitchell, 2005); the Calton Hill Limestone possibly equivalent to the B or MC beds. The marine mudstones are succeeded by marine (?and terrestrial) sandstones and conglomerates, which are the lateral equivalent of the Summerfield Group.

The succession in the Jerusalem Mountain Inlier consists of a lower unit of limestones (Jerusalem Mountain Formation) and an upper unit of red beds (Masemure Formation) (Jiang and Robinson, 1987). The Jerusalem Mountain Formation, previously regarded as the youngest fossiliferous Cretaceous deposit in Jamaica, is now known to be of early Late Maastrichtian age (Steuber et al., 2002). The Masemure Formation is probably a lateral equivalent of the Thomas River Formation.

The Kellits Synthem is overlain unconfomably by the deposits of the Yellow Limestone Group (late Early Eocene to Middle Eocene) across central and western Jamaica (Robinson and Mitchell, 1999).

DISCUSSION

The Cretaceous stratigraphy of Jamaica can be divided into distinct sedimentary packages separated by angular unconformities. The oldest rocks consist of a volcanic arc succession in central and western Jamaica (Lower and lower Upper Cretaceous) and an ophiolite suite (Turonian-Coniacian – either part of the CLIP, or a back/fore-arc spreading centre) in the Blue Mountains. Similar mafic-ultramafic suites associated with basalts of Turonian to Coniacian age occur in eastern Cuba and have been interpreted as part of an extensional back-arc basin succession (Iturralde-Vinent et al., this volume; Proenza et al., this volume). Evidence for the Pindell-type model arc polarity reversal was inferred because of the change from primitive island arc tholeiites to calc-alkaline volcanics during the Aptian of the Benbow inlier (Pindell and Kennan, 2001).

An important Santonian event is recognized with the widespread development of shallow-water limestones with rudist assemblages. These appear either intercalated in deep-water deposits (e.g., Clifton Limestone of the Hanover Block) or as transgressive deposits (Peters Hill Formation of the Central Inlier). This Santonian carbonate phase finds parallels elsewhere in the Caribbean, the Cotui Limestone of Puerto Rico (Skelton, 1996) and the Loma Yucatán Limestone and other localities of Cuba (Rojas et al., 1995). This event has been interpreted as one of several interruptions in the arc's magmatic activity, associated with deformation, uplift and subaereal erosion; followed by general subsidence and resume of magmatic activity usually with a different geochemistry (Iturralde-Vinent, 1994; Kerr et al., 1999).

A widespread shallow-water limestone phase is also developed in the upper part of the Crofts Synthem of Western Jamaica. This limestone contains the *Barrettia gigas* rudist assemblages and is dated on calcareous nan-

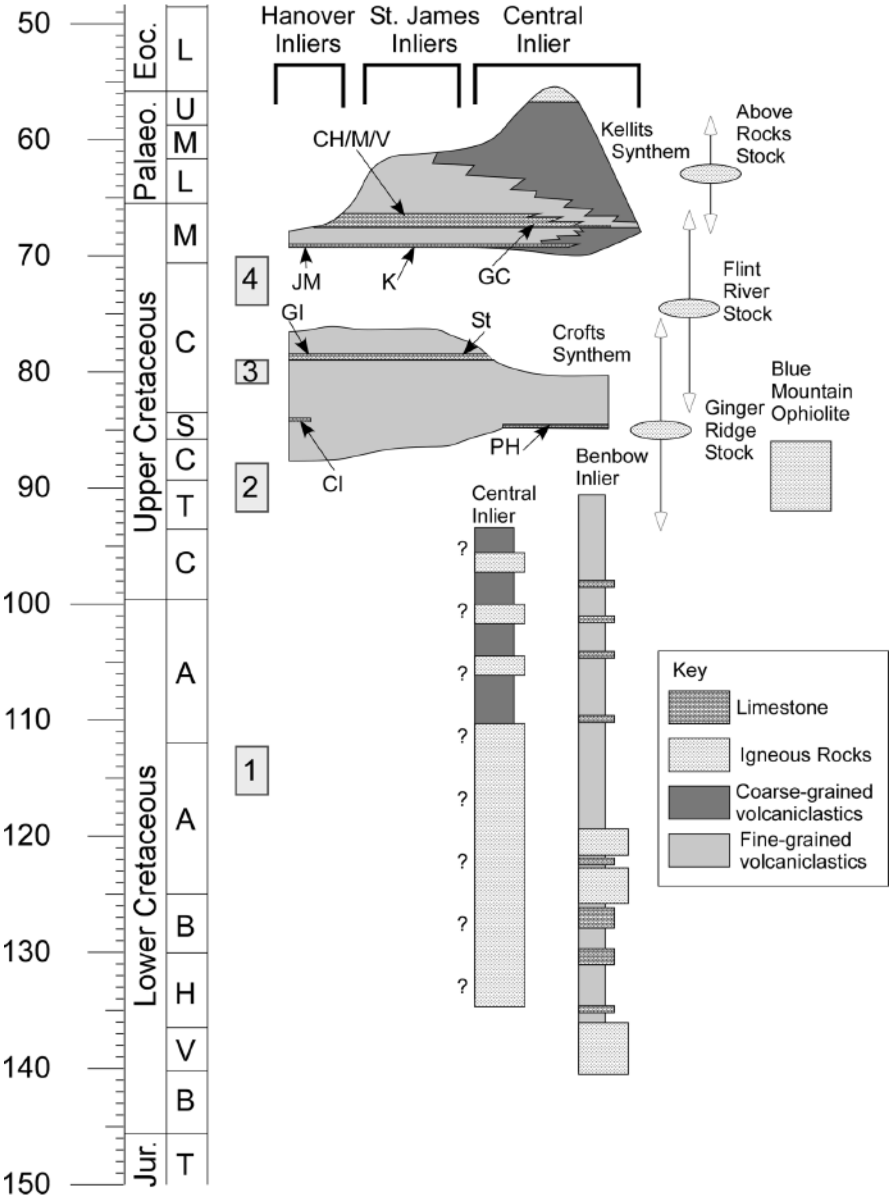

FIGURE 2 **Simplified stratigraphy of the Cretaceous of Jamaica. Timescale in Ma after Gradstein et al., 2004. Events: 1: Arc reversal – Pindell-model; 2: formation of CLIP; 3: arc reversal – Burke model; 4: collision of Caribbean plate with North America. Limestone units: GC: Guinea Corn; K: Kensington; CH/M/V: Carlton Hill, Maldon and Vaughansfield; GI: Green Island; St: Stapleton; CI: Clifton; PH: Peters Hill.**

nofossils as late Middle Campanian. In Cuba, Rojas et al. (1995) report two Campanian-Maastrichtian *Barrettia* associations: a lower (Campanian) *Barrettia monilifera* limestone unit (Loma de Caballeros, and other localities); and an upper *Barrettia-Titanosarcolites* association. A revision of the species and lineages of *Barrettia* and *Titanosarcolites* is needed to resolve the detailed correlations between Cuba and Jamaica. The shallow-water limestone event of Jamaica could relate to the arc polarity reversal of the Burke-type models.

The unconformity at the base of the Kellits Synthem is well developed in Central Jamaica and is well-constrained to the Early Maastrichtian based on ages derived from Sr-isotope values in the overlying limestones of the Kellits Synthem (Steuber et al., 2002). Mitchell (2004) attributed this unconformity and the associated thrusting to the collision between the Caribbean Plate (Nicaragua Rise) and the North American Plate (Maya/Yucatàn Block). Both Burke- and Pindell-type models recognize this event.

CONCLUSIONS

The sedimentary successions preserved in the Cretaceous rocks of Jamaica record important changes in depositional styles that are related to changes in regional/local stress regimes and/or tectonic events. The Early Maastrichtian collision of the Caribbean Plate with the North American Plate is recorded by thrusting and an important unconformity. Earlier unconformities and/or shallow water limestone deposits occur and have direct equivalents in other parts of the Caribbean. These events have been interpreted as interruptions of the arc's magmatic activity due to tectonic events (multiarc hypothesis of Iturralde-Vinent, 1994; Kerr et al., 1999). Further detailed studies dating and tracing these events across the Caribbean are needed to determine their value in reconstructing the tectonic plate history.

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