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Coastal change and evolution at Negril, Jamaica: a geological perspective

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ABSTRACT. Rocks of the Yellow Limestone and White Limestone groups underlying the present coastal platform and morass at Negril resulted from accumulation of sediment generated by marine organisms commencing over 40 million years ago. Elevation above sea-level occurred within the last ten million years. Over the last 3 million years, the platform was down-faulted to its present elevation relative to hills bordering its southern and eastern margins. During lower sea-levels over the last 1.5 million years, the precursors to present river systems encroached on and eroded the platform, and developed submarine valleys offshore. Cliff and undercut features, popular diving locations, were created at the shelf edge, when higher still-stands of sea level occurred. 18,000 years ago sea-level began to rise from about 120 m below present until by 8,000 years ago the sea encroached onto the platform. This encouraged growth of shallow marine organisms, producing carbonate skeletons. Their disintegration produced sand along the seaward-facing platform edge. Behind more elevated parts of the platform conditions favoured establishment of wetland leading to formation of peat deposits. Sand accumulated to form an extended beach system across what is now Long Bay and Bloody Bay. By 2,000 years ago, during rising sea level, the beach system had retreated to a position along the western margin of the Great Morass. Subsequently the rate of rise diminished and biogenic sand accumulation was rapid enough to allow beach-widening towards the ocean, resulting in the modern barrier beach. Present shoreline retreat is a recent phenomenon, coinciding in time with accelerating global sea-level rise, major alterations to the wetland drainage and the development of a high density tourist industry.

Key words: Negril, Jamaica, beach erosion, White Limestone, geological history, development, morass elevation.

1. INTRODUCTION

Negril lies at the western end of the island of Jamaica (**Figure 1**). The geological history of the Negril region extends back for some 40 million years and has involved a complex sequence of sedimentary and erosional processes and tectonic movements leading to the shape of the present landscape. In this respect the analysis of coastal change on millennial timescales provides a striking counterpoint to recent, short term beach erosion at Negril.

The study region contains six physiographic units (**Figure 1**). They are: 1) a region of rugged hills here called the Springfield Hills, made up of karst limestone lying east of the Great Morass; 2) Negril Hill, an upland region of somewhat less rugged limestone bordering the southern end of the morass; 3) the Great Morass itself, an extensive wetland, underlain by limestone, some 21 km^2 in extent, lying between the hills and the coast; 4) the two narrow coastal barrier beach systems of Long Bay and Bloody Bay, composed of white carbonate sand and separated by a limestone promontory; 5) a submerged coastal platform (island shelf) extending 1-2 km offshore and terminating at about 10 m depth at the top of a drowned cliff line, the uppermost of several breaks in 6) the island slope, leading down to the ocean floor at depths exceeding 2000 m. Several submarine valleys have been cut into the island slope.

2. GEOLOGICAL SETTING

For a detailed discussion of the geological evolution of the Negril region reference should be made to the paper by Hendry (1987). The following notes summarise the picture.

The island of Jamaica is situated on the northern edge of the Caribbean Plate abutting the southern edge of the North American Plate (Hendry 1987). Because these plates have been moving past each other and grinding against each other for millions of years the rocks forming the island have suffered

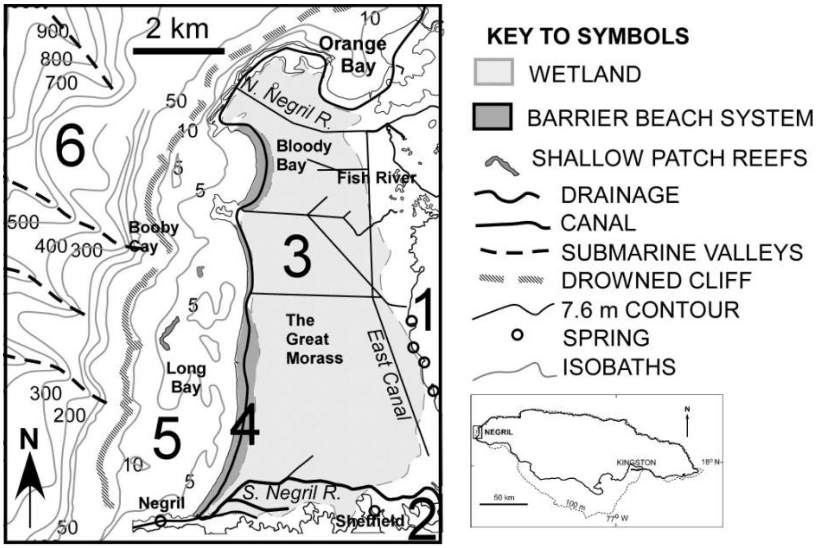

Figure 1. Negril, western Jamaica, showing main physical features. As described in the text, 1, Springfield Hills; 2, Negril Hill; 3, Great Morass; 4, barrier beach system; 5, island platform or shelf; 6, island slope with submarine valleys. Isobath in metres below sea-level

more or less continuous fracturing over a long period and have been broken up into a series of structural blocks, separated by faults. Geologically, the differing landscapes developed by these physiographic units over time are due to their being situated on three different blocks which have moved up and down relative to one another. The Springfield Hills form a structural block, here called the Springfield Hills block (SHB), while units 3, 4 and 5 of **Figure 1**, comprising the Great Morass, beaches and island shelf, are here called the Negril Morass block (NMB). Both these blocks form part of the regional Hanover Block of Hendry (1987, figs. 2 and 4). The rocks forming the hills consist of elements of the Yellow Limestone and White Limestone groups (Mitchell, 2004). The same suite of limestones probably underlies the Great Morass and they are found cropping out along the coast, at Point Pen between Long Bay and Bloody Bay (Hendry 1987, fig. 3). These limestones were deposited within a shallow marine environment during the Eocene Epoch, some 40 million years ago.

Negril Hill forms part of a block, here named the Negril Hill Block (NHB) within the Negril-Savanna-la-Mar structural Belt of Hendry (1987, fig. 4). In contrast to the rocks of the SHB and NMB the limestones of the NHB consist mainly of the chalky Montpelier Formation of the White Limestone Group, deposited, on the evidence of the microfossils it contains, in a deeper water environment, probably several hundred metres deeper than that of the other two blocks. The microfossils also indicate this deposition took place during the Miocene Epoch up until about 10 to 15 million years ago. Negril Hill is capped on its southern side by a stepped series of raised marine terrace limestones (Cant 1973), containing corals and other shallow water fossils of Pleistocene age, ranging from about 2 million to 120,000 years old. These provide evidence for the transformation of the Negril Hill area from a deep ocean environment through progressive emergence to its present elevation, involving uplift of the rocks of hundreds of metres.

Over the past 3 million years, continued uplift of the Negril region was accompanied by earth movements which resulted in progressive down-faulting of the NMB relative to the other two limestone hill blocks (Hendry 1987). This has meant that while the NHB developed raised marine terraces along its southern side as it was progressively elevated above sea level, any similar terraces that may have developed on the NMB are now submerged (Hendry, 1987). In fact the drowned cliff and undercut features bordering the sea-ward margin of the shelf at Long Bay, providing popular diving locations, are similar to those of the modern cliff terminating Negril Hill along the Westend coast, and suggest that it too was originally created as a cliff above sea-level. The fact that the drowned cliff appears to be of comparatively recent formation, and is now submerged, indicates that local earth movements are continuing through the present day and that the fault zone separating the Great Morass from Negril Hill is probably still active. Thus, while the Negril region has been comparatively free of seismic disturbances in recent times, one cannot rule out the occurrence of even severe earthquakes in the future.

3. RECENT GEOLOGICAL HISTORY

Over the past 1.5 million years, the successive

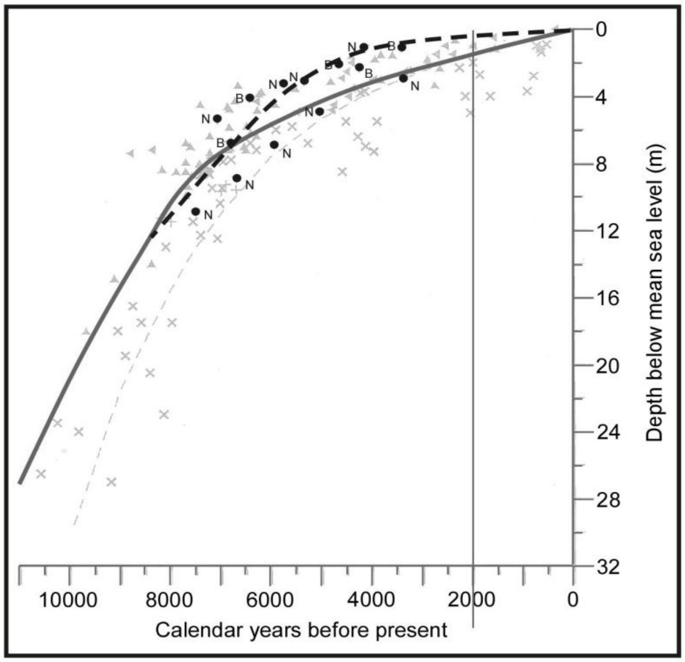

Figure 2. Sea-level rise curve for the Caribbean. Solid line, Caribbean curve of Toscano and McIntyre (2003), dashed line, curve of Digerfeldt and Hendry (1987). Grey symbols, data points of Toscano and McIntyre; Solid black symbols, data on mangrove peat from Digerfeldt and Hendry as plotted by Toscano and McIntyre. Vertical line at 2000 BP indicates possible date when widening and progradation of the beach barrier commenced.

formation and then melting of the several vast ice sheets of the Pleistocene Ice Age resulted in sea-level being successively lowered and raised by as much as 120 m in magnitude. During low sea-level stands the precursors to present river systems encroached on and eroded the NMB and platform, leaving meandering valleys now either sediment-filled or visible under-water. The submarine valleys cut into the island slope (**Figure 1**) probably mark the exits of this drainage to the ocean. As the bedrock of the NMB is limestone, some of this drainage may have been underground through cavern systems.

Around 18,000 years ago, with the melting of the last ice sheets, sea-level began to rise from about 120 m below present (**Figure 2**). By 8,000 years ago it had reached 12 m below present, flooding the platform edge. This environment encouraged growth of shallow marine organisms, producing carbonate skeletons. Their disintegration produced sand along the seaward platform area. Behind more elevated parts of the platform in hollows and flooded river valleys conditions favoured establishment of wetland conditions, leading to the formation of peat deposits (**Figure 3**). Hendry and Digerfeldt (1989) provided a detailed account of the palaeoenvironments of the wetland over the past 8000 years.

Marine sand accumulated to form an extended beach system across what is now Long Bay and Bloody Bay. By about 2,000 years ago, during rising sea level, the beach system had retreated to its present position along the western margin of the Great Morass. Subsequently, the diminishing rate of sea-level rise and the increasing rate of sand accumulation along the ocean side, facing a widening shelf initiated shoreline progradation. Beaches widened towards the ocean, leading to formation of beach ridges and the barrier system seen today. Radiocarbon dates obtained during an earlier study of the Negril region (DOGG 2002) and youngest dates from the underlying peat deposits (Hendry and Digerfeldt 1989) suggest that transgression of the barrier beach system onto the morass reached its maximum extent some 2000 years ago, since when beach accretion has dominated the shoreline until very recent times (**Figure 4**). Details of such accretion there and at other locations around Jamaica await further studies. Within the past 2000 years sea-level was more or less stable until the 18th century, with fluctuations probably not exceeding 30 cm (Kemp and Benjamin, 2009; Morhange et al., 2001, Grinsted et al., 2009), providing conditions favourable for beach accretion, assuming positive sediment budgets. The last authors have indicated a global sea-level maximum at about 1150 AD followed by a minimum at about 1730 AD. Since then the present trend of sea-level rise, associated with Global Warming, has been in place (Richardson et al. 2009)

Coincident with barrier widening the drainage system over the wetland region evolved to reach the pattern shown in **Figure 5**. The earliest maps giving a more or less accurate picture of the morass, before anthropogenic interference occurred, are those of Robertson (1804, see **Figure 5**) and Sawkins and Brown (1865). The drainage of the southern part of the morass was via the South Negril River, sourced

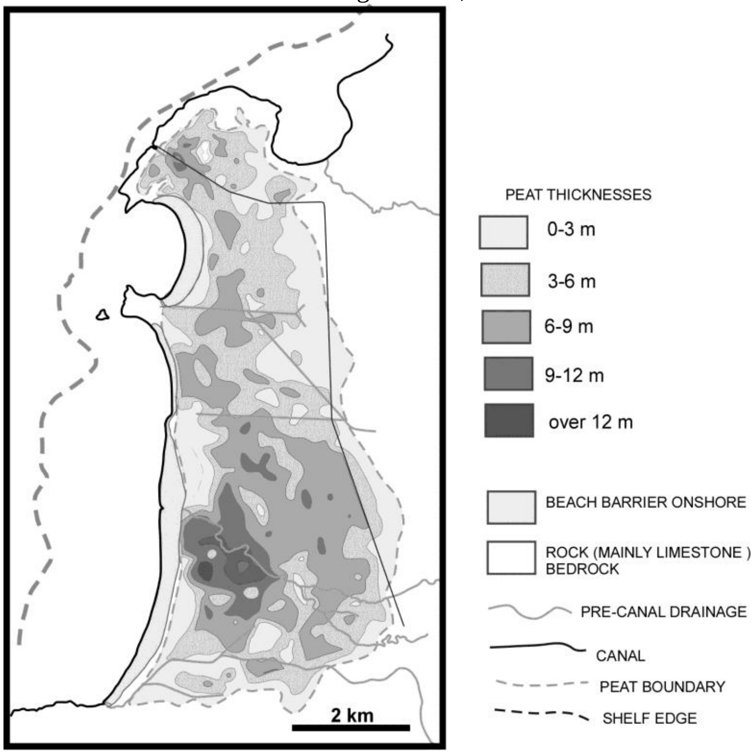

Figure 3. Peat thicknesses in the Great Morass, modified from Hendry and Digerfeldt 1989.

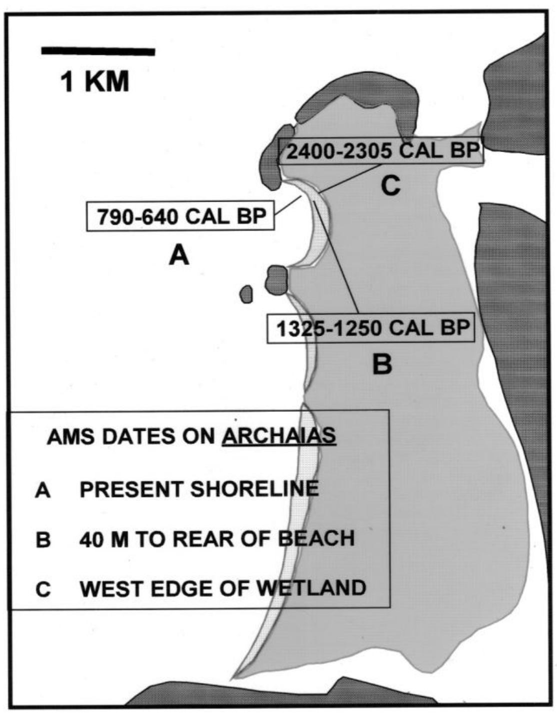

Figure 4. Map showing location of samples used for radiocarbon dating (modified from DOGG 2002).

from outside the morass and carrying appreciable quantities of sediment in flood times. The mainly sediment-free Middle River was sourced from springs at Springfield along the eastern boundary of the morass, while the North Negril River was sourced from within the morass itself.

The Fish and Orange Rivers both exited separately into Orange Bay (**Figure 5**). The broad features and history of Bloody Bay and Orange Bay are similar to that of Long Bay. The existence of an exit through the reef on the northern side of Bloody Bay, together with offshore bathymetry indicating a depression or valley in this area suggests that there was substantial late Pleistocene and/or early Holocene drainage from the morass to the sea at that locality. At Orange Bay deep channels through the reef indicate a similar history of drainage extending back into the Pleistocene (**Figure 6** and Hendry 1982).

Since the early 19th century man has increasingly influenced the wetland and beach environments. Drainage ditches cut in the later 19th and earlier 20th centuries modified the natural drainage in the north-central part of the morass to the pattern seen in **Figure 7**, diverting much of the flow from the morass into Long and Bloody Bays and reducing the North Negril River to a minor discharge through the exit now used by the North Canal. The Fish River is marked as a seasonal stream on the 1:50,000 Imperial topographic Sheet A of the 1940s. Both it and the Orange River still emptied into Orange Bay.

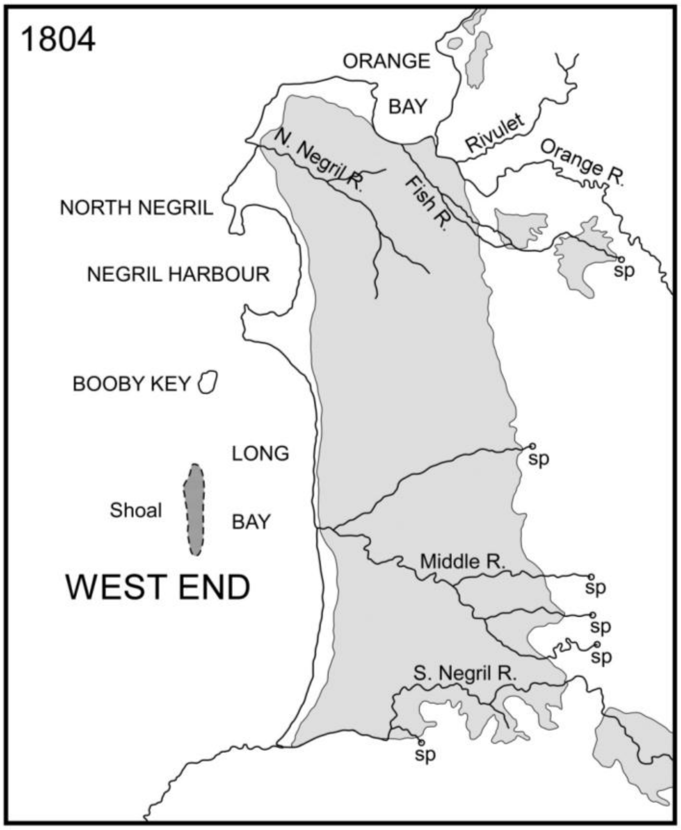

Figure 5. Map of Negril showing drainage features at the beginning of the 19th century. Grey areas, morass; sp, spring. Redrawn from James Robertson, 1804. Names are as given on Robertson's map. Note the use of the name West End for the whole of the southern part of Long Bay.

Figure 6. Aerial photograph of Orange Bay showing the well-developed system of channels through the reef across the bay entrance (from the February 1953 aerial survey; Film 7, photo 048). North is towards the top of the photo. Distance across the bay entrance is 1 km.

The construction of the East Canal in the 1950s effectively cut off the water supply to the Middle River drainage, while the North Canal (North Negril R. on **Figure 1**) diverted the flow of the Orange and Fish Rivers from Orange Bay into the former channel of the North Negril River (**Figure 1**). However, as late as 1980 this area was still dominated by freshwater sawgrass vegetation.

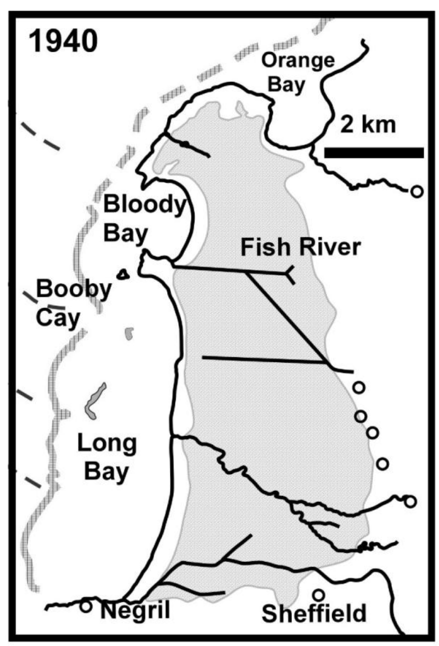

Figure 7. Map showing drainage features as they appeared in 1940. Redrawn from the 1:50,000 topographic map Imperial Series, Sheet A, based on the 1940-1941 aerial survey. Circles mark springs.

4. CONCLUSIONS

The morass environment will become increasingly affected by sea-level rise (SLR). There is little information on whether or not the growth of morass vegetation is such that wetland floor elevations can keep up with SLR. It is clear that over the long term it can do so (Hendry and Digerfeldt, 1989), However the accelerated SLR in modern times (Richardson et al., 2009, p.8) may exceed the capacity of the morass floor to keep up. The water-logged parts of the morass are likely to become increasingly saline and drained areas underlain by peat will continue to undergo subsidence to meet the rising water table. This process has already been encouraged by the excavation of the now derelict and partly saline East Canal, diverting most of the supplies of fresh water from the springs along the eastern hills that formerly fed the Middle River (DOGG 2002; Robinson 1999). Because the East Canal is tidal, the salinities in the morass are high, and have been for many years (Haggstrom, 1983). During the dry season, the evapotranspiration from the morass itself is higher than the rainfall, i.e. there is a deficit. This is made up by inflow (partially saline, and shallow groundwater) from the surrounding canal system (Haggstrom, 1982) and probably through seepage from the sea through the barrier beach. This deficit may become more acute in the future (Taylor et al., 2007), and coupled with rising sea-level, may lead to an increase in waterlogged areas.

These problems were recognized in the 1970s and 1980s when the last detailed assessment was carried out in connection with the Petroleum Corporation of Jamaica's peat fuel programme. A workshop held in 2001 (CWIP, 2001) concluded that little had changed in twenty years over the major part of the morass, but some strategic planning directions were identified. As recently as 2010 the main problems outlined by Bjork, Haggstrom and others thirty years ago and by stakeholders in 2001were reiterated in a study supported by the United Nations Environment Programme (UNEP, 2010).

The present situation of substantial shoreline retreat is probably a recent development, perhaps even post-1950. It appears to have coincided in time with major alterations to the wetland drainage and the development of a high density tourist industry along the ocean edge (Robinson et al., 2012, this volume). Linking cause and effect in the production, movement and capture of sediment along the shoreline on recent time scales, and presently observed erosion, is the subject of other papers in this volume, as are possible future changes in shoreline position and characteristics (Smith and Morin, 2012, this volume; Robinson et al., 2012, this volume).

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