Caribbean Journal of Earth Science, **38** (**2005**), 21-33.

The geology of Barbados: a field guide

STEPHEN K. DONOVAN[1] (including a joint contribution with DAVID A.T. HARPER[2])

[1]*Department of Palaeontology, Nationaal Natuurhistorisch Museum, Postbus 9517, NL-2300 RA Leiden, The Netherlands*
[2]*Geological Museum, University of Copenhagen, Öster Voldgade 5-7, DK-1350 Copenhagen K, Denmark*

1. INTRODUCTION

These excursions are presented both to introduce the stratigraphy, structure and geological history of Barbados, and to act as a starting point for any geologist intending to investigate the island. Barbados is a small island, shaped like a contorted teardrop, and about 34 km long by 24 km at its widest. The visitor to the island who is intending to undertake fieldwork is recommended to hire a car. The only other reliable forms of transport are bus or taxi. While cheap, buses tend to stick to the main routes, particularly in the country, although the size of the island means that localities are rarely more than a few km from a bus stop. If money is no object, a taxi driver will be happy to drop you at a site in the morning and collect you at a pre-arranged time.

Large-scale road maps are available free or at low cost from many hotels, service stations and bookshops on the island. Wilder (1999, p. 171) noted that there are 1,300 km (800 miles) of paved roads in Barbados, so there are many potential places for getting lost! The 1:50,000 geological map of Barbados (Poole and Barker, 1983) may be obtained from Edward Stanford Ltd., 12/14 Long Acre, London, WC2E 9LP, England, who will also be able to supply relevant topographic sheets. There are many tourist guides to the island, such as Ali (1996) and Wilder (1999). Other recent geological guidebooks, published to coincide with major geological conferences in Barbados, include Anon (1986, 2002), although these are not widely available. The account of the island's geology by Machel (1999) is available from the Barbados Museum and Historical Society, The Garrison, St. Michael, Barbados.

2. GEOLOGICAL HISTORY

The Barbados Ridge, including the island of Barbados, is comprised of over 4 km of Tertiary strata overlying at least 20 km of relatively low density sediments and sedimentary rocks that lie over the subduction zone of the South American Plate under-riding the Caribbean Plate (Westbrook *et al.*, 1973). This represents an accretionary prism, indicated by the presence of an arcuate, north-south negative gravity anomaly. This negative anomaly is parallel to the positive gravity anomaly of the Lesser Antilles volcanic arc. The exposed core of the Barbados Ridge consists of deformed turbidites, volcanogenic strata, olistostromic blocks, conglomerates, and possible mud volcanoes and deltaic deposits. Barbados is one of the few places in the world where an active accretionary prism is subaerially exposed (Speed, 1994, 2002).

With the exception of some volcanic ash bands, the rock succession in Barbados is entirely sedimentary in origin, demonstrating its geological independence from the volcanic arc of the Lesser Antilles. Eighty five per cent of the exposed rocks are Pleistocene reef limestones. The remaining 15 per cent are Tertiary sedimentary rocks of marine origin which crop out in a triangular region in northeast Barbados called the

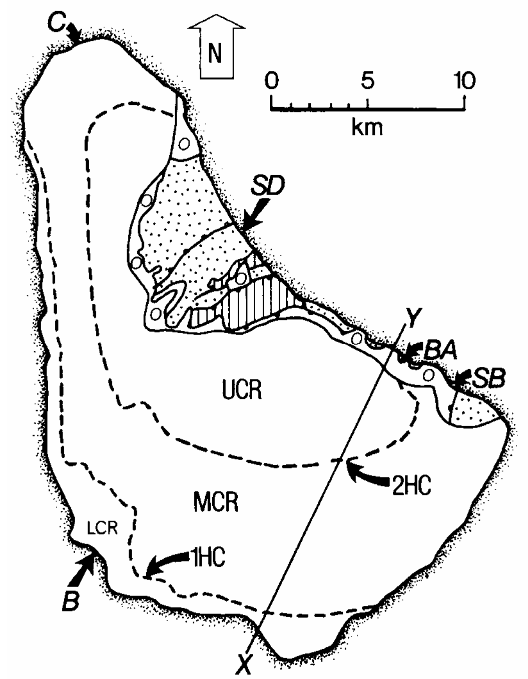

Figure 1. Simplified geological map of Barbados (redrawn and modified after Speed *et al.*, 1991, fig. 2). Key to tectono- and lithostratigraphic units: open stipple, basal complex; vertical ruling, diapiric melange; O, Oceanic nappes; UCR, Upper Coral Rock; MCR, Middle Coral Rock; LCR, Lower Coral Rock. The First High Cliff (1HC) separates the LCR and MCR; the Second High Cliff (2HC) separates the MCR and UCR. Key to place names: B, Bridgetown; BA, Bath; C, Cluffs; SB, Skeete's Bay; SD, Scotland District.

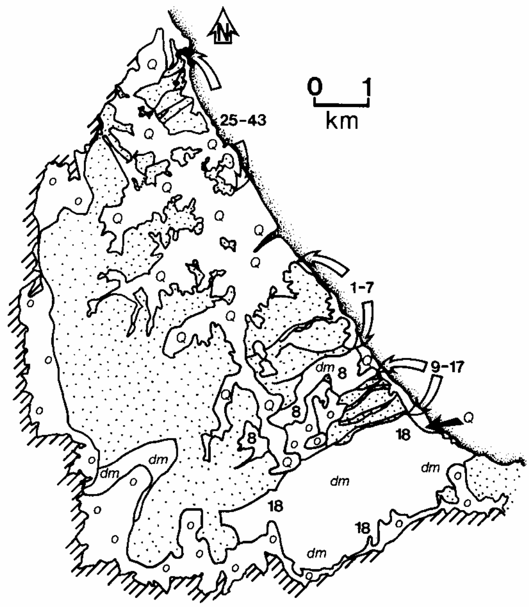

Figure 2. Geological map of the Scotland District of Barbados (redrawn and considerably simplified after Jansma and Speed, 1988, fig. 1; Speed, 2002, fig. 9). Key: open stipple, basal complex; dm, diapiric melange; o, Oceanic nappes; Q, fluvial, alluvial, dunal and other non-reefal Quaternary deposits of the Scotland District; oblique lines, Coral Rock; 1-7, 8, 9-17, 18, 25-43, fault packets (not all packets nor boundaries between packets shown); dense stipple, coastline. Packets 8 and 18 in diapiric melange.

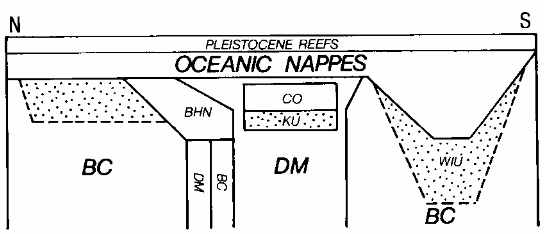

Figure 3. Tectonostratigraphic stacking diagram of a north-south section through Barbados, showing the relationships between tectonic and lithologic units (redrawn and simplified after Speed, 1988, fig. 2; 1994, fig. 10.6). Uncertain contacts (stratigraphic or tectonic?) dashed; all other contacts tectonic part from the stratigraphic contact at the base of the Pleistocene reefs. Key: BC, basal complex; BHN, Bissex Hill Nappe; CO, Cattlewash Oceanics; DM, diapiric melange; KU, Kingsley Unit; WIU, Woodbourne Intermediate Unit; prism cover stippled. Individual fault-bounded packets within the basal complex not indicated.

Scotland District, over an area of 40 km^2 (Figs 1, 2). Traditionally, the sedimentary succession of Barbados was interpreted as an autochthonous sequence, formed in the location where they are at present found (see, for example, Jukes-Browne and Harrison, 1891, 1892; Trechmann, 1925; Senn, 1940; Barker and McFarlane, 1980; Poole and Barker, 1982, 1983), but it is now considered to be comprised of Tertiary allochthonous units overlain by a Pleistocene authochthonous cap.

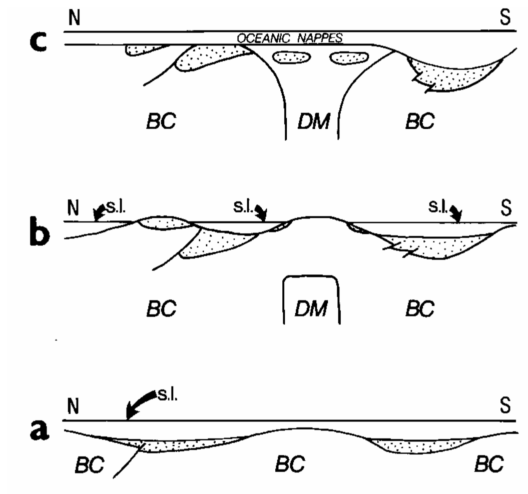

Figure 4. Schematic serial north-south cross-sections through Barbados during the Neogene (redrawn after Speed, 1994, fig. 10.8; 2002, fig. 6), showing structural evolution during progressive late stage deformation. (a) Early Miocene. (b) Late Miocene. (c) Pliocene. Note particularly the axial diapirism of the central anticline, the progressive subsidence of the southern syncline (= Woodbourne Trough) and subaerial exposure by the Pliocene. Key: BC, basal complex; DM, diapiric melange; prism cover stippled; s.l., sea level.

Speed and co-workers (Speed and Larue, 1982; Speed *et al.*, 1986, 1991; Speed, 1988, 1994, 2002; Torrini *et al.*, 1985; Torrini, 1988; and references therein) have reinterpreted the units of deformed Tertiary rock in the Scotland District. They are considered to show a structural complexity indicating that they are considerably displaced with respect to each other, that is, they are allochthonous (Figs 3, 4). It is therefore necessary to recognise these separate structural units ('packets') in order to determine their true relationships. Speed (1988) suggested a seven phase evolution of Barbados, prior to the deposition of the autochthonous Pleistocene reefs.

1. The accretion of a basal complex by the end of the Eocene. This basal complex is an amalgam of fault-bounded packets of sedimentary rocks at least 4.5 km thick and probably accreted by scraping sediment from the Lesser Antilles Accretionary Prism in the late Eocene. It consists of deep-water siliciclastic sedimentary rocks of turbiditic origin (=Scotland Group) and hemipelagic, radiolarian-rich clays.

2. The deposition of three sedimentary facies of the `Oceanic Group' occurred from the middle Eocene onwards.

Facies I (Oceanic Nappes): These were deposited in the forearc basin in the Eocene to middle Miocene, receiving no terrigenous input, but including distal debris from the volcanic arc.

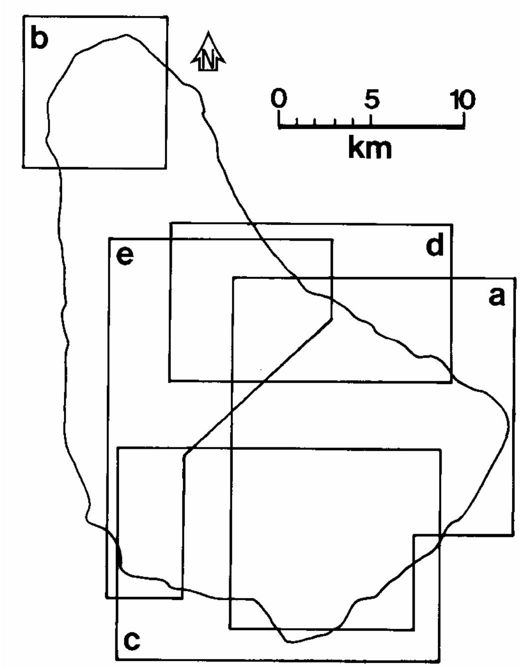

Figure 5. Relative positions of field excursions described in the text. (a) Southeast Barbados (Fig. 6). (b) North Barbados (Fig. 7). (c) South Barbados (Fig. 8). (d) Scotland District (Fig. 11). (e) Central Barbados (Fig. 12).

Facies II (Bissex Oceanics): Middle to late Eocene in age. Lithologically similar to Facies I, but with minor beds of quartz sandstones and channelized volcaniclastics.

Facies III (Cattlewash Oceanics): Forming a diapiric melange near Cattlewash (=Joe's River Beds).

3. Deposition of a (so far) unrecognised older prism cover (that is, those sedimentary rocks deposited on the basal complex after the basal complex has accreted), and a younger prism cover including the T and Woodbourne Intermediate Unit.

4. Tectonic transport of Oceanic Facies II in the middle Miocene or earlier, deformation occurring before being covered by the Bissex Hill Formation.

5. Mud diapirism in the late Miocene and later, with debris of diapiric origin occurring in the Kingsley unit of the younger prism cover.

6. Thrusting of Oceanics.

Facies I (Oceanic Nappes) thrusted above the Miocene Woodborne Intermediate Unit.

Facies II (Bissex) thrusted above the Miocene Bissex Intermediate Unit.

Facies III (Cattlewash) thrusted over the late Miocene Kingsley Unit.

7. Uplift of the structural high of the accretionary prism, centred at or near Barbados, in the early Miocene, possibly due to a decrease in the rate of subduction (Westbrook *et al.*, 1973).

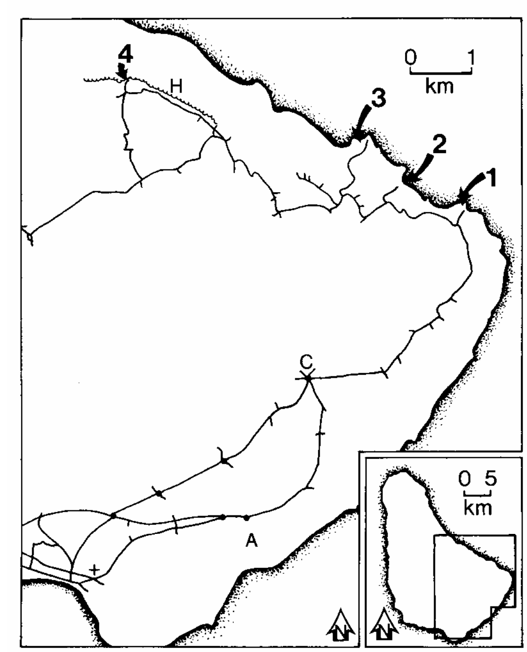

Figure 6. Locality map showing the positions of Christ Church Cemetery (+) and Stops 1-4 in southeastern and eastern Barbados. Only those roads relevant to this excursion are indicated. This figure should be used in conjunction with the geological map of Poole and Barker (1983) and any tourist road map. Key: A, Grantley Adams International Airport; C, Six Cross Roads; H, Hackleton's Cliff; 1, Ragged Point (Stop 1); 2, Skeete's Bay (Stop 2); 3, Conset Point (Stop 3); 4, viewpoint on Hackleton's Cliff (Stop 4); coastline stippled. Inset outline map of Barbados shows extent of main map; approximate extent of Tertiary outcrop stippled.

3. ITINERARIES

The areas visited by the excursions outlined below are shown in Figure 5. All itineraries commence from the Bridgetown area. The first itinerary is a shortened version of Donovan and Harper (2002).

4. COASTAL GEOLOGY OF SOUTHEAST BARBADOS

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Trechmann's grave. Figure 6 illustrates the relative positions of the localities to be visited on this excursion, which pay particular attention to sites originally described by Dr. C. T. Trechmann (1885-1964) (Donovan and Harper, 2002; Donovan, 2003). On the way to Stop 1 a detour may be taken to visit C.T. Trechmann's grave and pay due respect. On 20th February, 1964, a death notice in the 'Stop Press' of The Advocate announced "*On 18th February, 1964, Dr. CHARLES TAYLOR TRECHMANN of Durham, England. The funeral will take place at Christ Church*

Cemetery at 4.30 p.m. today where friends are asked to meet." Trechmann is buried in Christ Church Cemetery, not in the adjacent cemetery of Christ Church Parish Church.

Stop 1: Ragged Point Lighthouse. About 9.1 km from Six Cross Roads, parish of St. Philip. Turn right at the 'Lighthouse' sign and park at end of road (do not enter the property on the right) (approximately GR 59º 25' 58" W 13º 9' 39" N). Although not visible from this position, this stop is close to the angular unconformity between the Scotland Beds and overlying Coral Rock. The unconformity is best seen from the impressive sea cliffs on the south side of the bay (Deebles Point; see Trechmann, 1933). However, first stop on this side of Spring Bay in order that the lithology of the Scotland Beds can be observed at close hand, which unfortunately means that the unconformity per se is obscured. If the path is not in a perilous condition, a descent to beach level can be made to observe the unconformable contact. The Coral Rock will be examined further at close quarters at Stops 2 and 3.

The Scotland Beds exposed on Ragged Point range from unfossiliferous quartzose sandstones to gritstones showing some honeycomb weathering. Massive iron-rich carbonate(?) nodules are rare. These beds are underlain by shales (Trechmann, 1933, p. 43). Trechmann (1925, p. 486) published a measured section of the Scotland beds at this locality, totalling 157 feet (about 50 m) in thickness, the overlying limestones varying up to a maximum of 100 feet (about 30 m) (Trechmann, 1933, p. 25). Fissures in the limestone have yielded bones of iguana and a rodent (Trechmann, 1937, pp. 357-358). Trechmann's research on the age of the Scotland Beds and his ideas on the significance of basal Coral Rock are discussed above.

The brachiopod *Tichosina* sp. cf. *T. bartletti* (Dall) occurs in the basal Coral Rock at this locality. This is a large, biconvex, globose terebratulide with a functional pedicle which would have lived associated with large patches of substrate. Our knowledge of both living (Asgaard and Stentoft, 1984) and Pleistocene *Tichosina* in the Caribbean region (Harper *et al*., 1995; Harper, 2002; Harper and Donovan, 2002) suggests an outer shelf or upper slope setting, a deduction at variance with Trechmann's gastropod data which suggested a shallower water origin (1933, p. 27; see also Jung, 1968). The *Tichosina*-bearing horizon is seen at beach level in the limestone cliffs on the south side of the bay west of Deebles Point.

To the west and northwest, Skeete's Bay (Stop 2) is marked by the obvious cream-coloured building, and Conset Point (Stop 3) forms a far headland. The differences in coastline geometry can easily be related to the presence of either Coral Rock (vertically jointed cliffs with obvious bedding) or Tertiary deposits (low cliffs and easily accessible sandy bays) (Patel, 1995).

If time is available, it is informative to visit Deebles Point, to the southeast of Ragged Point. The contrast in coastal morphology between the Tertiary and Quaternary deposits is even more starkly apparent from this viewpoint. Care must be taken in approaching the cliff edge, as the drop is vertical due to joint control (see Scheidegger, 1976, for discussion of the distribution of joints in the limestones of Barbados). Walking to Deebles Point across the fields, many limestone exposures are apparent with a fauna dominated by colonial scleractinian corals. Humphrey and Matthews (1986, p. 98) discussed the sedimentation and diagenesis of the limestones of the Ragged Point area and provided a schematic diagram of the environments of deposition at Deebles Point.

Stop 2: Northwest side of Skeete's Bay. About 3.4 km from Stop 1. There is a signpost at the Skeete's Bay turnoff. Obtain permission to park by the cream-coloured building with the green roof (EDF/Barbados Government Fisheries Building). Scramble down onto the beach to the left (northwest) over the limestone armouring, then scramble over the local limestone to see the exposure.

Stop 2 is the northwest side of Skeete's Bay, Whitehaven, parish of St. Philip (approximately 59º 27' 00" W 13º 10' 00" N), figured and discussed briefly by Trechmann (1937, p. 346), who considered it "a good collecting ground for the basal fauna." It is a coastal exposure of the basal Middle Coral Rock (484,000 -127,000 years old; Poole and Barker, 1983) that rests unconformably on the Tertiary Scotland Beds and Oceanic Group (Trechmann, 1937, p. 344, text-fig. 3); the basal position perhaps suggests it to be Middle Pleistocene. The fauna includes benthic foraminifers such as *Amphistegina*, platy agariciid scleractinian corals, bryozoans, terebratulid brachiopods (Harper and Donovan, 2002), benthic molluscs (Trechmann, 1937), asteroids and echinoids (Donovan, 2000), the clionid sponge boring *Entobia* isp. in some molluscs and scleractinians, and rarer pteropods, crab claws, and arcoscalpellid barnacle plates. The lithology, fauna and style of preservation of the fossils in the Middle Coral Rock at this locality are similar to parts of the Lower Pleistocene Manchioneal Formation of Jamaica (Donovan *et al*., 2002), deposited in a deeper water, fore reef setting.

Stop 3: Conset Point. From Stop 2, drive via Blades Hill College Savanna no. 2 road. The distance between Stops 2 and 3 is about 4.6 km. Walk down the track towards the coast, then turn left on the coastal footpath. Veer off left into Conset's Cutting, formerly part of the Barbados Railway (Horsford, 2001, pp. 32-33) (approximately 59º 27' 37" W 13º 10' 46" N). This limestone cutting is up to 3 m high. Bedded limestones are exposed in the cutting, with more massive limestones apparent further along the track (=stratigraphically lower, as bedding is dipping more or less towards south). Grainstones at the entrance to the cutting are cross-bedded on the right side. These limestones contain common, *in situ* colonial scleractinian corals; the limestones are finer grained and more massive lower down the section, where there are also colonial scleractinians, oysters and gastropods. Locally there are skeletal packstones and grainstones. Stops 2 and 3 are both in the Middle Coral Rock, but there is considerable contrast in the faunas. Unlike the basal beds (=deep water) seen at Stop 2, the presence of autochthonous(?) scleractinian corals at Stop 3 indicates that these beds were deposited within the photic zone and are more similar to those seen at Deebles Point (Stop 1).

It is the basal Coral Rock at Conset Point that was proposed to be Oligocene by Spencer (1902; Harrison, 1907; Trechmann, 1933, p. 24). Although Trechmann agreed with Harrison's assessment of the incorrectness of this determination, he did identify within this cutting three species of pectinid bivalve that he considered to be pre-Pleistocene (1933, p. 27; 1937, pp. 345-346).

Stop 4: Hackleton's Cliff. Follow the road signs to the viewpoint at Hackleton's Cliff, overlooking Bathsheba, a driving distance of about 11.8 km. This elevated spot gives a fine view into the Scotland District, being perched near the highest point of the Upper Coral Rock and the supposed edge of Trechmann's thrusted sheet of limestone (1933, p. 20) (approximately 59º 32' 36" W 13º 11' 51" N).

5. NORTH BARBADOS

Stop 1: Arawak Cement Quarry. Drive north from the Bridgetown area on Highway 1, the main west (or leeward) coast road, which is situated on the Lower Coral Rock and overlying superficial deposits; the First High Cliff and the Middle Coral Rock are close by in the east. This coast has been developed for tourism and has neither the magnificent sea cliffs of the east coast nor the impressive Atlantic breakers. To the west, two submerged barrier reefs, at 22 and 70 m water depth, are separated from the coast by a submerged wave cut terrace (MacIntyre, 1967). The shallower of these two reefs is still active. To the north of Speightstown, Highway 1B turns inland at Littlegood Harbour, then north again near Colleton. In the Checker Hall area, parish of Lucy, take the left turn at the crossroads and proceed to the cement plant (approximately 59º 38' 47" W 13º 17' 6" N; Fig. 7).

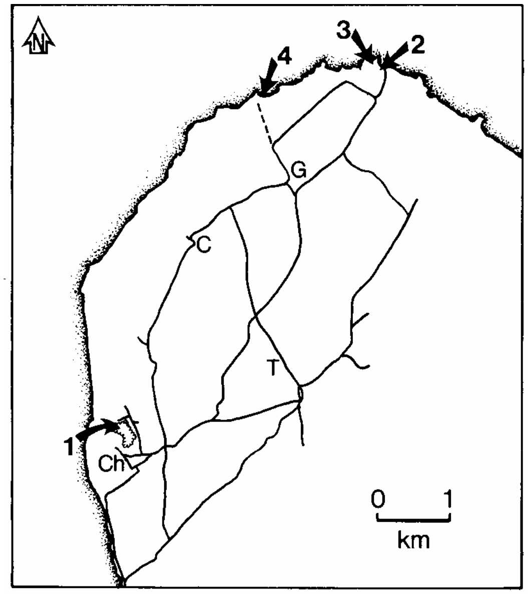

Figure 7. Locality map showing the positions of Stops 1-4 in north Barbados. Only those roads relevant to this excursion are indicated (including the track to Stop 4). This figure should be used in conjunction with the geological map of Poole and Barker (1983) and any tourist road map. Key: C, Content; Ch, Checker Hall; G, Greenidge; T, Trents; 1, Arawak Cement Quarry (Stop 1); 2, Animal Flower Cave, North Point (Stop 2); 3, limestone cliffs west of North Point (Stop 3); 4, Cluff's Bay (Stop 4); coastline stippled.

The Arawak Cement Quarry was opened in 1984. It is situated close to the west coast (providing loading facilities for ships) and is the most important working quarry on the island. Permission from the owners is required if it is to be visited. Limestone from the quarry, mixed with clay from Greenland, situated about 15 km away, is used in the manufacture of cement on site (Gordon *et al*., 1986, pp. 123-125).

The limestones are well lithified Lower Coral Rock, that is, Upper Pleistocene. Large colonies of the scleractinian *Montastraea annularis* (Ellis and Solander) are the main fossil component at this locality, some of which preserve borings. Extant *M. annularis* occurs from 2 to 40 m water depth, although its optimum is 7 to 22 m (Wood and Wood, 2000, p. 44) and is an important framework builder in Caribbean reefs (Woodley and Robinson, 1977, pp. 22-23). Sandier lithologies contain larger benthic foraminifers. Rare and unusual components of the fauna include the brachiopod *Argyrotheca* sp. cf. *A. barettiana* (Davidson) and the large heart urchin *Meoma ventricosa* (Lamarck) (Donovan and Jones, 1994).

Stop 2: Animal Flower Cave, North Point. Return to the main Highway 1B, and continue north and then northeast through Broomfield and Content. Follow signs to the Animal Flower Cave, north of Flatfield.

The Animal Flower Cave (59º 36' 50" W 13º 19'

51” N; Fig. 7) is situated close to the most northern point on Barbados. It is a public show-cave that has been visited since before the mid-19th century. Access is provided via a staircase through a blowhole. The animal ‘flowers’ are live invertebrates such as sea anemones and a tube-dwelling worm, the seafeather *Sabellastarte magnifica* (Shaw), that live in a rock pool (The Carpet Room) (Ali, 1996, pp. 222-223). The caves open on the ocean and are the safest way to view the Atlantic from within the rugged cliffs of north Barbados. The caves are dissolved in the Middle Coral Rock and are floored by a distinctive surface within the limestones.

Stop 3: Limestone cliffs. A walk along the cliffs to the west of North Point, until the wire fence of enclosed farm land is reached, provides dramatic views of the vertical cliffs of the Middle Coral Rock. The distinctive surface that floors the Animal Floor Cave is easily seen, as are other caves, gullies and blow holes. Access to the cliffs is not possible due to their vertical, joint-controlled morphology; do not be tempted to try, even where there is an inviting bench formed by the bedding surface. Instead, examine the Pleistocene reef limestone that is abundantly exposed underfoot. The most prominent fossils in both the cliffs and on the cliff tops are colonial scleractinian corals.

Stop 4: Cluff’s Bay. Drive along the track nearest the coast until the track to Cluffs Bay is reached on the right. Walk along this track to Cluff’s Bay. Care must be taken at this locality (approximately 59º 37’ 48” W 13º 19’ 38” N; Fig. 7), with narrow ledges perched at the unconformity between the Miocene Oceanics and the basal Middle Coral Rock. This locality was described by Trechmann (1937, p. 344), who presented a measured lithological section.

Trechmann (1937, p. 349) listed a fauna of benthic molluscs, pteropods and brachiopods from this locality that is much less diverse than that from Whitehaven (=northwest side of Skeete’s Bay; see above), although this may be, in part, the result of the easier access at the former locality. The most notable difference is, perhaps, the presence of three species of pteropods at Cluff’s Bay, but none at Whitehaven, possibly indicating a deeper water, more open marine setting. The large terebratulid brachiopod found at this locality is *Tichosina* sp. cf. *T. bartletti* (Dall) (Harper, 2002).

6. BRIDGETOWN AND THE SOUTH COAST

Stop 1. The Barbados Museum. The Barbados Museum and Historical Society was founded in 1933. Its museum occupies St. Ann’s Garrison, a 19th century British military prison. It is situated in the parish of St. Michael, southeast of the central part of

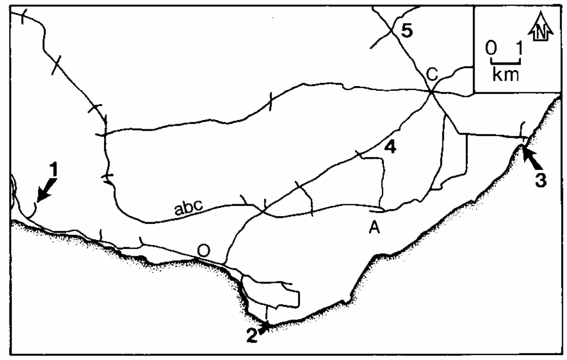

Figure 8. Locality map showing the positions of Stops 1-5 on or near the south coast of Barbados. Only those roads relevant to this excursion are indicated. This figure should be used in conjunction with the geological map of Poole and Barker (1983) and any tourist road map. Key: A, Grantley Adams International Airport; abc, ABC Highway; C, Six Cross Roads; O, Oistines; 1, the Barbados Museum, Bridgetown (Stop 1); 2, South Point Lighthouse (Stop 2); 3, Foul Bay (Stop 3); 4, Woodbourne Oilfield (Stop 4); 5, Chapel Quarry (Stop 5); coastline stippled.

Bridgetown, behind the Garrison Savannah race-track. (Note that, at the time of writing, the current pamphlet advertising the Museum has a map which incorrectly shows its position as Kendal Point, several kilometres to the east!) The Museum has displays covering many aspects of Barbadian history and life, including natural history, prehistory and maps. The library is an important research resource, containing 5,000 books, monographs and articles on the culture and natural history of the island.

Stop 2: South Point Lighthouse. From the Barbados Museum, drive east through Hastings, Worthing and the Dover area. Stay close to the coast in following signs through Miami Beach and Atlantic Shores. Park near South Point Lighthouse (59º 31’ 47” W 13º 02’ 38” N; Fig. 8).

Two sea cliffs cut in reefal limestones, one ancient, one modern, are exposed in the South Point area. South Point is within the outcrop area of the Lower Coral Rock (Poole and Barker, 1983). South Point Lighthouse is situated on limestones of an *Acropora palmata* (Lamarck) sedimentary facies dated as being 125,000 years old (Humphrey and Matthews, 1986, p. 97). The colonial scleractinian coral *A. palmata* is commonly found in shallow water, high energy reefal environments at the present day down to 16 m water depth (Woodley and Robinson, 1977, p. 22; Wood and Wood, 2000, p. 42). On the shore, modern sea cliffs are formed of younger limestones dated as 82,000 years in age (Humphrey and Matthews, 1986, p. 97). These old sea cliffs were thus cut between 125,000 and 82,000 years ago, attesting to the rapid rate of uplift of the island, considered to have been 300 mm per

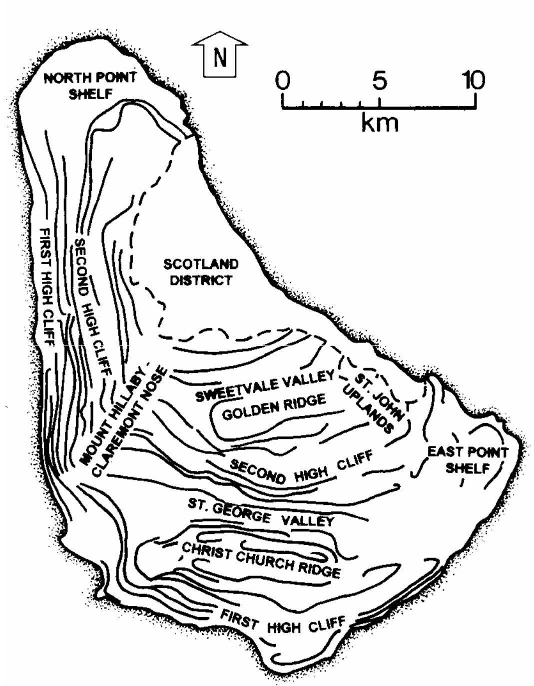

Figure 9. Surface morphology of the limestone areas of Barbados (redrawn after Mesolella *et al.*, 1969, fig. 2). Reef terraces shown as continuous lines; erosional escarpment at edge of Scotland District shown as dashed line.

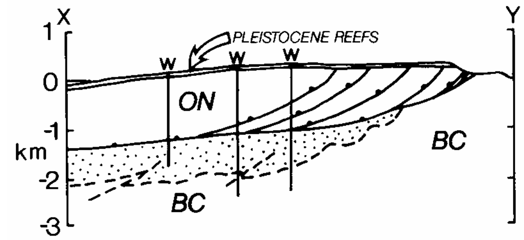

Figure 10. Cross section X-Y (southwest-northeast) across the Woodbourne Trough oil field (redrawn after Speed *et al.*, 1991, fig. 2 pars) (for line of section, see Fig. 1). Key: BC, basal complex; stipple, prism cover; ON, Oceanic nappes; w, oil wells.

thousand years for the past 700,000 years (Humphrey and Matthews, 1986, p. 87).

The limestones forming the modern sea cliffs are in an *Acropora cervicornis* (Lamarck) sedimentary facies. *A. cervicornis* is a colonial scleractinian coral commonly found in shallow water, high energy reefal environments at the present day down to 40 m (Wood and Wood, 2000, p. 42). A notable feature of the limestones in this area is the preservation of scleractinian corals in their original aragonitic state. This is explained by Humphrey and Matthews (1986, p. 97) by both the low annual rainfall in this area and "*... a local high in the Tertiary aquiclude [that] shields the area from subsurface flow of fresh water phreatic lense*." That is, extensive water flow within the limestone from higher points of the island to the coast is blocked in this area due to the limestone being draped over an elevated portion of the underlying Tertiary deposits, the water having to take an alternative route when it couldn't flow uphill. The local high is represented at the surface by the Christ Church Ridge, an east-west elongate hill (Fig. 9).

Stop 3: Foul Bay. Return along the coast road in a northwesterly direction. At Oistins turn right and drive northeast to join the ABC Highway; just north of Oistins the road climbs the First High Cliff and onto the Middle Coral Rock. Follow the ABC Highway to the Grantley Adams International Airport and then follow minor roads through St. Martin's and Rices. Do not turn left towards Crane, but drive straight on, then turn left and park near the coast at Foul Bay (59º 26' 02" W 13º 05' 58" N; Fig. 8).

The limestone cliffs on the coast are part of the Middle Coral Rock (Poole and Barker, 1983). Humphrey and Matthews (1986, pp. 97-98) considered these limestones to be of the same age as those in the old sea cliff beneath South Point Lighthouse (Stop 2, above), but to represent an *A. cervicornis* sedimentary facies. Although this is an area of low rainfall, there is a high phreatic flow of fresh water through the limestones from the area of the St. George Valley, between the Christ Church Ridge and the Second High Cliff (Fig. 9). This fresh water has acted to dissolve scleractinian corals and other aragonitic fossils such as gastropods. The matrix has recrystallized to a well-lithified, low magnesium calcite.

Stop 4: Woodbourne Oilfield. Return towards the Grantley Adams International Airport. Take the ABC highway west, soon turning left towards Fairview and St. Patrick's. At St. Patrick's turn right (northeast) on the H6 Highway. A little further on the highway, in the Woodbourne area, is found to be passing through fields of sugar cane with nodding donkey unmanned oil wells. Stop and examine one of these servants of the oil industry at close quarters (found at approximately 59º 29' W 13º 06' N; Fig. 8).

The following account is based mainly on those of Gordon *et al.* (1986, pp. 112-113), Speed *et al.* (1991) and Barker *et al.* (2002, pp. 101-102) (Fig. 10). The Woodbourne Oilfield of the Woodbourne Trough, a northeast-southwest trending depression in the subterranean surface of the basal complex, is the main oil producing area of Barbados. It was discovered in 1966 and is currently being exploited by the Barbados National Oil Company. Of over 280 wells that have been drilled, about 90 are flowing or pumping at any time in the Woodbourne area of the parishes of Christ Church and St. Philip. Currently, average daily production is about 1,200 barrels of oil per day; total production has been over nine million barrels. Oil is refined at the Mobil Oil refinery at Graves End, parish of St. Michael.

The source rocks are thought to be organic-rich mudrocks of the basal complex that have been buried to over 7 km, the minimum depth for thermal maturation. This unusually high depth of burial is because accretionary prisms have low geothermal gradients, about one third of the global average (Speed *et al.*, 1991, p. 338). Reservoir rocks are folded and thrusted quartz sandstones of the basal complex and the overlying Woodbourne Intermediate Unit (Fig. 3; southern basin in Fig. 4). Cap rocks are mudrocks and marlstones(?) of the basal complex and Woodbourne Intermediate Unit, and the relatively undeformed Oceanic Nappes (Fig. 10). The current reservoirs probably evolved during deformation in the late Neogene (Fig. 4).

Stop 5: Chapel Quarry. Continue on the H6 Highway to Six Cross Roads and then turn northwest (second exit from roundabout) towards St. Philip's Church and Church Village, within site of the Second High Cliff. The Chapel Quarry is to the east of the angle formed between this road and the H4B Highway (approximately 59º 29' 15" W 13º 8' 8" N; Fig. 8). Permission from the owners is required if Chapel Quarry is to be visited.

The Chapel Quarry produces cut limestone blocks, unlike the Arawak Cement Quarry (see above). Its limestones are "*... well graded, good, soft quality and not with a great deal of cementation or recrystallisation which tend to make the rock too hard*" (Gordon *et al.*, 1986, p. 114; Barker *et al.*, 2002, p. 106). Blocks are produced in various sizes. They are used in building construction (including foundations), as a decorative facing stone, and for walls and ground sills. Exposure to the atmosphere leads to discolouration due to fungal growth, although blocks may be treated chemically as a preventative measure (Gordon *et al.*, 1986, p. 114).

7. SCOTLAND DISTRICT

Those wishing to examine the succession and structure of the Scotland District in considerably more detail than outlined below are referred to Speed (2002). This is complimented by the study of the geomorphology by Patel (1995).

Stop 1: Chalky Mount. Take Highway H2 northeast from the Bridgetown area, the road climbing onto the Upper Coral Rock. Note signs for Harrisons Caves and Welchman Hall Gully, but do not be tempted by their delights just yet (see central Barbados, below). Northeast of this area the scenery changes

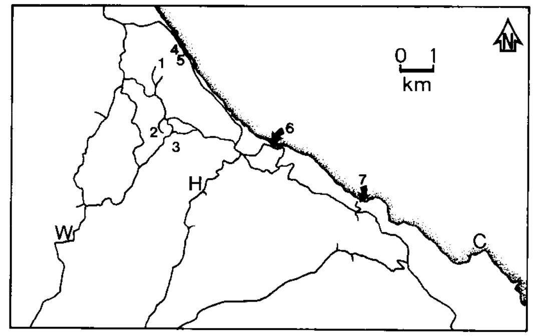

Figure 11. Locality map showing the positions of Stops 1-7 in the Scotland District of Barbados. Only those roads relevant to this excursion are indicated. This figure should be used in conjunction with the geological map of Poole and Barker (1983) and any tourist road map. Key: C, Conset Point; H, Horse Hill; W, Welchman Hall; 1, Chalky Mount (Stop 1); 2, Bissex Hill (Stop 2); 3, Coconut Grove (Stop 3); 4, exposures on East Coast Road (Stop 4); 5, oil seep (Stop 5); 6, Bathsheba (Stop 6); Bath Cliff (Stop 7); coastline stippled.

dramatically as the road leaves the internally drained plateau of Pleistocene limestones and enters the Scotland District. Follow signs to Chalky Mount Potteries on the right and then left. Follow the left fork and park at the end (approximately 59º 33' 15" W 13º 13' 55" N; Fig. 11). This is locality 1 of Speed (2002, pp. 19, 26, figs 10, 12).

Despite its name, Chalky Mount is not on chalks. It lies within the outcrop of the Upper Scotland Formation *sensu* Poole and Barker (1983) (=basal complex). This area provides the best exposures of siliciclastic rocks, mainly turbidites, of the basal complex in the Scotland District. The sandstones, siltstones and mudstones within this sedimentary packet, with a total thickness of about 600 m, were probably deposited in a basal plane - outer fan setting in the middle Eocene (Speed *et al.*, 1986, pp. 13-17; Speed, 2002, p. 19).

Walk uphill bearing N70ºE on the track on sandstones dipping to the south. This ridge is part of an anticlinal fold, with north-dipping limb exposed across the gully to the north. At the crest of the hill examine the quartz sandstone succession, interpreted as part of an inner fan channel fill (Speed, 2002, p. 26). The trace fossils that are so plentiful at some horizons are suggestive of a turbidite succession.

Stop 2: Bissex Hill. Drive back along the Chalky Mount ridge, past the fork, but left at the junction. Follow the road south towards Bissex Hill. Follow the road that curves around the west side of the hill and park near the end (approximately 59º 33' 12" W 13º 12' 51" N; Fig. 11).

The rocks of the Bissex Hill nappe, including the Bissex Hill Formation sensu Poole and Barker (1983), are structurally higher than the basal complex, but beneath the Oceanic nappes (Fig. 3). They consist of the Eocene Bissex Oceanics overlain by Lower Miocene(?) micrites and the Lower to Middle Miocene Bissex Hill Formation (Speed, 1988, pp. 29:7-29:8, 2002, pp. 34-37). This succession rests on a thrust fault over the Miocene Bissex Intermediate Unit that forms part of the prism cover (Fig. 3).

Although exposures are, at best, poor, boulders of the Lower to Middle Miocene Bissex Hill Formation are scattered at the roadside. These are globigerinid foraminiferal sandstones with common spines of regular echinoids. Other fossils that have been found in this part of the succession include solitary scleractinian corals, fish teeth and isocrinid crinoids (Speed, 1988, p. 29:8; Donovan and Veltkamp, 2001, p. 731).

Stop 3: Coconut Grove (Joe's River Formation). Return north on this road, taking the first right turn and right again. Drive south and southwest, joining the Saddleback Road from the left. Park at the side of the road on the left about 150 m past the Parks Road turning on the right (approximately 59º 33' 3" W 13º 12' 33" N; Fig. 11). Descend the track to the southeast for a few hundred metres, veering left at a fork. Stop at the top of an exposed slope. This is site 6 of Speed (2002, pp. 55-58).

This hillside (Coconut Grove) represents part of a dyke-like diapiric melange derived from mudrocks of the basal complex and is part of the largest surface expression of any Barbadian diapir (Speed, 2002, p. 55). The diapir is emplaced into the basal complex. It is comprised of (Speed, 2002, p. 58):

matrix – very coarse- and fine-grained sand, clay, organics (probably mainly bitumen).

green mudstone granules – up to a few cm in diameter, mainly pure, less commonly sandy, yet without an identifiable source unit in the basal complex.

lithic blocks – 1 cm to 25 m in diameter, clay ironstone, calcitized radstone, quartz sandstone with a calcite or bitumen cement, chert. The latter lacks an identifiable source unit in the basal complex.

fossils – mainly foraminifers and benthic molluscs (Kugler *et al*., 1984), and trace fossils such as *Ophiomorpha* isp. The fauna is considered indicative of an ancient cold seep community (Little, 2001; Gill *et al*., 2002).

Stop 4: East Coast Road near Barclays Park. Turn your vehicle around and return as you came until the fork to the east of Bissex Hill, where the right fork is taken east towards the coast. Turn left (northeast then northwest) along the east coast road. Drive past Barclays Park and park by the monument on the right which commemorates the opening of the road by H.M. Queen Elizabeth II (Fig. 11). The succession exposed on the opposite side of the road includes many impressive sedimentary structures within a vertically orientated sequence within the basal complex, which provide evidence for way-up and palaeoenvironment.

The most impressive sedimentary structures in this sequence are spherical diagenetic nodules up to *circa* 1 m in diameter. A thin conglomerate bed exposed about 100-200 m below the section with giant nodules has yielded clasts bored by clionid sponges (*Entobia* isp.). Trechmann's (1925) estimate of the age of the basal complex (=Scotland Beds) relied on fossil molluscs collected from conglomerates such as this one. He probably visited the localities that Hill (1899, p. 176) used in comparing the age of the Scotland Beds with the Paleogene Richmond Formation of Jamaica (Donovan, 2003). The only other macrofossils in this part of the succession are indeterminate carbonised plant fragments preserved parallel to bedding in sandstone units.

Stop 5: Oil seep. From the conglomerate bed at Stop 4, walk over the low slopes to the south, slowly diverging from the highway. Careful searching will reveal an oil seep at the surface, a rare surface expression of the hydrocarbon resources of the island.

Stop 6: Limestone 'mushrooms' at Bathsheba. Drive southeast, back past Barclays Park and Cattlewash. Turn off the highway to Bathsheba and park near the coast, in view of the large fallen limestone boulders (approximately 59º 31' 12" W 13º 12' 35" N; Fig. 11). Walk down to the beach.

These limestone boulders, some as big as a house, are presumably derived from the face of the Hackleton's Cliffs to the south west. A cliff on a rocky coastline presents one face to the sea and will develop a sea level or intertidal notch at its base. The tidal range in the Caribbean is less than one metre, which is reflected by the height of the notches in these fallen boulders. However, unlike a cliff, these boulders present all sides to the sea and have developed a notch through 360º, hence their distinctive shapes like a group of top-heavy limestone mushrooms. The notch is typically deep, the well-lithified limestones not collapsing until the 'stalk' of the mushroom is slender. The notch is not formed by the erosive action of the sea *per se*, but rather by the feeding action of herbivorous invertebrates scraping algae from the limestone. Typical eroders would be the radulae of chitons and gastropods, and the Aristotle's lantern of regular echinoids (Bromley, 1975). At low tide it is apparent that the notch is floored by a horizontal platform that is the remnant of the base of the boulder (Wilder, 1999, photograph on pp. 254-255).

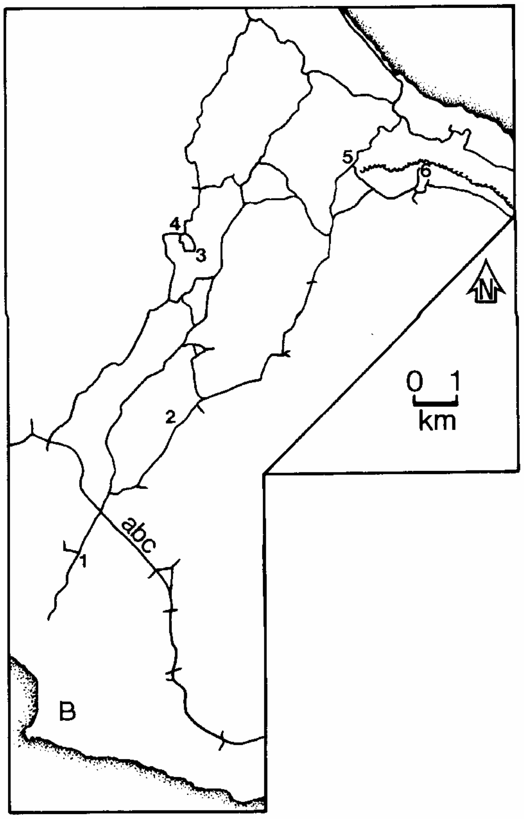

Figure 12. Locality map showing the positions of Stops 1-6 in central Barbados. Only those roads relevant to this excursion are indicated. This figure should be used in conjunction with the geological map of Poole and Barker (1983) and any tourist road map. Key: abc, ABC Highway; B, Bridgetown; 1, Waterford district (Stop 1); 2, Dayrells (Stop 2); 3, Harrison's Cave (Stop 3); 4, Welchman Hall Gully (Stop 4); 5, Horse Hill (Stop 5); 6, Hackleton's Cliff (Stop 6); coastline stippled.

Stop 7: Bath Cliff. Drive back to the East Coast Road and continue southeast. After about 6 km take the turn on the left to Bath Beach. Turn right at the bottom and park. Walk a short distance along the coast to the Bath Cliffs (approximately 59º 29' 46" W 13º 11' 42" N; Fig. 11). This is site 8 of Speed (2002, pp. 62-68).

The Bath Cliff section forms part of an Oceanic nappe. It is impressive to see, albeit steep and difficult to access, providing a particularly complete section across the Eocene/Oligocene boundary interval (Saunders *et al.*, 1984) in an area of structural complexity (Torrini *et al.*, 1985). It is one of the most complete and well-studied sections through this part of the geological succession in the tropical western Atlantic, and a rare example of a continuous section in deep water lithofacies across the Eocene/Oligocene boundary, making it particularly important for international correlation. It consists of a sequence of "... *pelagic rocks (indurated oozes, pelagites) [that] vary from totally noncalcareous to highly calcareous, the end members being radiolarian indurated oozes ... and nannofossil marly chalks ...*" (Saunders *et al.*, 1984, pp. 391, 393) associated with interbedded volcanic ashes. Rate of sedimentation was estimated as 27.1 mmy^{-1} (Saunders *et al.*, 1984, p. 394), which is considered to be atypically high when compared with coeval deposits laid down in deep water settings. Palaeobathymetry is estimated to have been between 2,800 and 4,800 m.

Walk further along the beach towards the southeast end of the bay. A petroleum seep occurs at beach level, just below the embankment of the closed railway line.

8. CENTRAL BARBADOS

Stop 1: Waterford District, near Codrington Agricultural Station. From the ABC Highway, turn southwest towards Bridgetown on Highway 3. In the area of the turnoff towards Codrington Agricultural Station (on the right), parish of St. Michael, examine the road cutting, starting at the southwest corner and walking northeast (approximately 59º 36' 8" W 13º 6' 49" N; Fig. 12).

This is Stop 6 of Humphrey and Matthews (1986, p. 101), in the Middle Coral Rock just above the First High Cliff and dated at 194,000 years old. The succession shows a range of reef-related biolithofacies. The lowermost part of the cutting exposes an *Acropora cervicornis* facies with caliche crusts. The staghorn coral, *A. cervicornis* (Lamarck), is succeeded by the elkhorn coral, *Acropora palmata* (Lamarck), that occurs in a reef crest facies in association with encrusting red algae. The interstitial sediment is locally poorly cemented. A change to a sandy backreef lagoonal facies with *Montastraea annularis* is, in turn, succeeded by branching coralline algae and *Porites porites* (Pallas), the clubbed finger coral.

Stop 2: Dayrells Reef Tract, northeast of Hothersal Turning. Retrace the route northeast to the ABC Highway, which is crossed. Follow Highway H3, which involves taking a right fork at Hothersal Turning and a left at the turning for St. George's Church. The section at Dayrells, parish of St. Michael, is a further road cutting (approximately 59º 34' 52" W 13º 8' 20" N; Fig. 12). Examine it by starting at the southwest corner and walking northeast.

This is Stop 5 of Humphrey and Matthews (1986, p. 100), in the Middle Coral Rock just below the Second High Cliff and dated at 320,000 years old. Fore reef deposits in the southwest part of the cutting are, unusually for the Coral Rock, through a *Montastraea annularis* buttress zone. This is associated with an *Acropora palmata* reef crest facies in which a subaerial exposure surface is discernable.

Stop 3: Harrison's Cave. Continue northeast on Highway H3, but a little over 1 km further on take the left turn towards Applewhaites. At the end of this road turn left at the T-junction and within 300 m turn right towards Proutes. About 500 m further on on the left take the Hopewell turning. The road is somewhat winding. Turn right (almost due north) towards Holy Innocent's Church and Sturges. Both Harrisons Cave and Welchman Hall Gully (Stop 4), in the parish of St. Thomas, are signposted and close to each other. Follow the minor road to Harrisons Cave and park (approximately 59º 34' 29" W 13º 10' 54" N; Fig. 12).

Harrison's Cave is the most impressive cave known in Barbados and has been developed as a major tourist attraction since the mid-1970s. The cave is developed within the outcrop of the Upper Coral Rock (Poole and Barker, 1983), only about 1 km to the south of the edge of the Scotland District and close to the highest point of the island, Mount Hillaby (340 m; Gordon et al., 1986, p. 116). The limestone in this area varies between 52 and 66 m in thickness (Anon, undated, p. 12). The tour of the caves is by the so-called 'tram,' a series of carriages hauled by a battery electric vehicle along a roadway that follows the former course of underground streams that are now diverted (Ali, 1996, p. 222).

Stop 4: Welchman Hall Gully. Return to the main Highway H2 and follow signs to nearby Welchman Hall Gully (Fig. 12).

This gully, over 1 km in length, is a collapse feature in the Upper Coral Rock and has been developed as a botanical garden by the Barbados National Trust. The geologist will appreciate the range of limestone solution and precipitation features seen along the walls of the gully, allowing examination in daylight of structures seen underground at the previous stop. Features include a prominent dripstone pillar about 1.25 m in diameter, formed by the union of a stalactite and its associated stalagmite.

Stop 5: Horse Hill. From Welchman Hall Gully, travel northeast on Highway H2 and then turn right (southeast) on the Highway H3A to Blackmans and Coffee Gully. At this point turn left (north to northeast) on Highway H3. The exposure at Horse Hill, parish of St. Joseph, is northwest of St. Joseph's Girls School, and about midway between District F Police Station and Bowling Alley (approximately 59º 32' 33" W 13º 11' 43" N; Fig. 12).

This locality is a road cutting, high sided on both sides of the road, which runs northeast and downhill in the Upper Coral Rock. A rubbly *Porites*? biofacies at the top of the hill trends down into *in situ*, close packed coral heads further down the hill and rubble beds at the bottom. Donovan and Veale (1996) described the shallow water, irregular echinoids *Echinoneus cyclostomus* Leske and *Brissus* sp. cf. *B. unicolor* (Leske) from this locality.

This stop is within the outcrop area of the Upper Coral Rock (Poole and Barker, 1983), above the Second High Cliff. Radtke *et al*. (1988, appendix 1) obtained electron spin resonance dates from aragonitic corals in a traverse across the Second High Cliff to the south of the present study area. These vary from 310,000 to 642,000 years, in broad agreement with the dates obtained by He/U dating (Bender *et al*., 1979). Whatever the precise age of the Highway 3 specimens, they seem certain to be greater than 250,000 years old (Mesolella *et al*., 1969); the quoted dates fall in the range of the Middle Pleistocene (Harland *et al*., 1990, fig. 3.17).

Stop 6: Hackleton's Cliffs. Turn around and travel back up onto the central limestone upland. Turn left towards Malvern on the road at the top of Hackleton's Cliff. Follow the road signs to the viewpoint at Hackleton's Cliff, overlooking Bathsheba (approximately 59º 32' 36" W 13º 11' 51" N; Fig. 12). This viewpoint was visited during the first excursion herein (see above), but there is no finer place to take a last look at the geology of Barbados.

Acknowledgements. This field guide is dedicated to the memory of the late Dr. Roy Blackman, who helped in the quest for Trechmann's grave, but who died while the first draft of this guide was being written. My research on the geology and palaeontology of Barbados has been supported by funding from the National Geographic Society grant #5722-96, The University of the West Indies, Mona and the Nationaal Natuurhistorisch Museum Leiden, which I am pleased to acknowledge. I thank the many geologists who have discussed the complexities of the geology of Barbados with me over the years, notably Trevor Jackson, John Saunders, the late Bob Speed and Rudolf Torrini. S.K.D. and D.A.T.H. thank Mrs Betty Carillo-Shannon (Librarian, Barbados Museum) and Miss Yvonne Norville (Librarian, Barbados Advocate) for their invaluable assistance in helping them to locate Trechmann's grave. Dr. Thomas A. Stemann (University of the West Indies, Mona) is thanked for his constructive review.

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Revised manuscript received:3rd October, 2004
Accepted: 10th October, 2004