CRETACEOUS RESEARCH

Cretaceous Research 00 (2003) 1–10

# Palaeokarstic surfaces in the Upper Cretaceous limestones of central Jamaica

David J. Miller*, Simon F. Mitchell

*Department of Geography and Geology, University of the West Indies, Mona 7, Kingston Jamaica*

Accepted 10 February 2003

## Abstract

Two prominent pitted surfaces in rhythmic, late Maastrichtian, rudist-bearing limestones in central Jamaica are described. The lower surface is pock-marked with small pits that form a nodular, mamillated surface. The pits are roughly circular to gently elliptical in plan view. They vary in diameter from 5–170 mm and in depth from 5–90 mm, and are orientated perpendicular to bedding. This surface is buried beneath a lignite-rich siltstone bed. The upper surface contains microkarren phenomena represented by small cylindrical potholes up to 40 mm in diameter and 30 mm deep. These surfaces are interpreted as palaeokarstic because the pits are: (1) perpendicular to bedding and not the present land surface; (2) infilled with very poorly sorted siltstone, and (3) overlain by lignitic shales indicating terrestrial influx. The presence of two palaeokarstic surfaces in late Maastrichtian limestones suggests short-period cycles in relative sea level, consistent with glacial-eustatic driving mechanisms.

*Keywords:* Maastrichtian; limestones; palaeokarst; rudists; Jamaica.

## 1. Introduction

Palaeokarst can be defined as ‘fossil’ karst, a remnant from a previous period of karstification, and characterised by the presence of ancient, buried surfaces and deposits. It is distinguished from relict karst, which originated within the present phase of karstification, and although the geomorphic processes which formed the terrain are no longer operative, the karst is still being modified by contemporary processes. Palaeokarst is, therefore, buried and inert, and although it can include karst of interstratal and hypogene origin (Ford & Williams, 1989), most documented palaeokarsts are surficial, epikarstic phenomena and cavernous features (Bosak et al., 1990). Palaeokarst occurs across the same range of spatial scales as does active karst, from small-scale solution sculpturing to surface features with tens to hundreds of metres of relief (Ford & Williams, 1989). At the small extreme, one of the most common types of palaeokarst is solution pitted exposure surfaces capping shallow-water limestones forming cycles or rhythms, where the carbonates were briefly exposed to vadose diagenesis and karren pitting before re-submergence and burial by new carbonate deposition (Ford & Williams, 1989).

The Late Cretaceous (Maastrichtian) to early Palaeocene succession in the Central Inlier (central Jamaica: Fig. 1) is represented by the Kellits Synthem (Mitchell, in press). This shows a transgressive-regressive cycle of probable Caribbean-wide tectonic significance (Mitchell & Blissett, 2001; Mitchell, in press). The transgressive succession begins with braided-stream type conglomerates, passes up through tidal flat sandstones-mudstones and into thick rudist-bearing limestones (Mitchell, 1999; Mitchell & Blissett, 2001; Mitchell, in press). The regressive succession consists of a volcaniclastic, braid-delta complex (Mitchell, 2000; Mitchell & Blissett, 2001). Although there have been extensive studies of the palaeontology of the limestone of the Kellits Synthem (e.g., Whitfield, 1897; Trechmann, 1924; Chubb, 1971; Coates, 1977; Jiang & Robinson, 1977; Sohl & Kollman, 1985; Donovan, 1993; Hazel & Kamiya, 1993; Krijnen et al., 1993: Sandy et al., 1997; Mitchell, 2002a,b;

---

* Corresponding author. Dr D. J. Miller.
*E-mail address:* smitchell@cwjamaica.com (D.J. Miller).

0195-6671/03/$ - see front matter © 2003 Published by Elsevier Science Ltd.
doi:10.1016/S0195-6671(03)00032-6

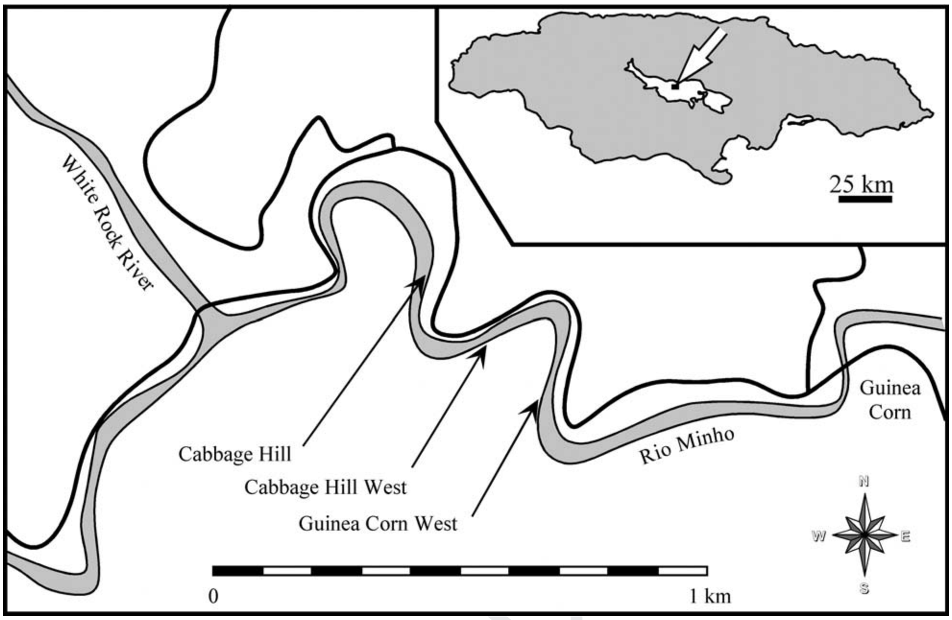

Fig. 1. Distribution of sections studied in the Central Inlier of central Jamaica. Rocks shown as black lines, rivers as grey lines, localities arrowed. The inset map shows the localities of the Central Inlier (unshaded) and the position of the main map (black box).

Mitchell & Gunter, 2002), there have been few studies of the sedimentology. In this paper we document two recently discovered palaeokarstic surfaces within the Guinea Corn Formation.

## 2. Rhythms in the upper Guinea Corn Formation

The Guinea Corn Formation was deposited on a shallow shelf/platform adjacent to an active andesitic volcanic complex (Mitchell, 2002a,b). These shallow water limestones can be traced some 100 km across central and western Jamaica. The succession in central Jamaica consists of some 200 m of shallow-water, rudist-bearing limestones and intervening mudstones and sandstones that are arranged into rhythms (Mitchell, 1999, 2002b). The rudist bearing limestones have recently been dated as Late Maastrichtian (Steuber et al., 2002). The rhythms in the upper 50 m, or so, of the Guinea Corn Formation consist of a lower siltstone or calcareous siltstone unit, and an upper limestone unit (Mitchell, 1999, 2002b). The siltstone unit is usually relatively thin, yields few fossils, and may contain a large proportion of lignite fragments. Generally, it has a rather abrupt contact with the underlying limestone at the top of the previous rhythm. The limestone portion of each rhythm can usually be divided into two: a lower part that contains relatively common rudists [*Titanosarcolites giganteus* (Whitfield), *Biradiolites jamaicensis* Trechmann, and *Thyrastylon* sp.] together with abundant larger benthic foraminifera [*Chubbina jamaicensis* Robinson and *Kathina jamaicensis* (Jarvis and Cushman)]; and an upper part in which rudists are rare, while the same species of benthic foraminifera remain abundant. In this paper we consider the succession of rhythms in the upper part of the Guinea Corn Formation that were labelled F5 to G5 by Mitchell (1999).

### 2.1. Rhythm F5

Rhythms in the F Beds of the Guinea Corn Formation are characterised by a relatively thin siltstone/sandstone lower division (typically 20–100 cm thick) and a thick upper limestone division (typically 80–300 cm thick) (Mitchell, 1999). Rhythm F5 is the uppermost rhythm of the F Beds. Its basal contact with rhythm F4 is relatively abrupt (surface 1 in Fig. 2) and shows no palaeokarstic features. The limestone contains a low diversity of rudist bivalves together with the benthic foraminifera *K. jamaicensis* and *C. jamaicensis* (Fig. 2).

### 2.2. Rhythms G1–G4

These four rhythms can easily be traced between exposures in the Guinea Corn Formation (Fig. 2). The correlation of rhythms is aided by the distinctive nature of rhythm G3, a grey limestone (the other rhythms comprise white limestones) containing abundant white larger benthic foraminifera and common steinkerns of gastropods.

The base of rhythm G1 is particularly noteworthy as it consists of a prominent irregular surface overlain locally by a lignite-rich mudstone unit (=surface 2 in Fig. 2). No rootlets are present beneath the lignitic shale. At Cabbage Hill, the surface occurs on the upper

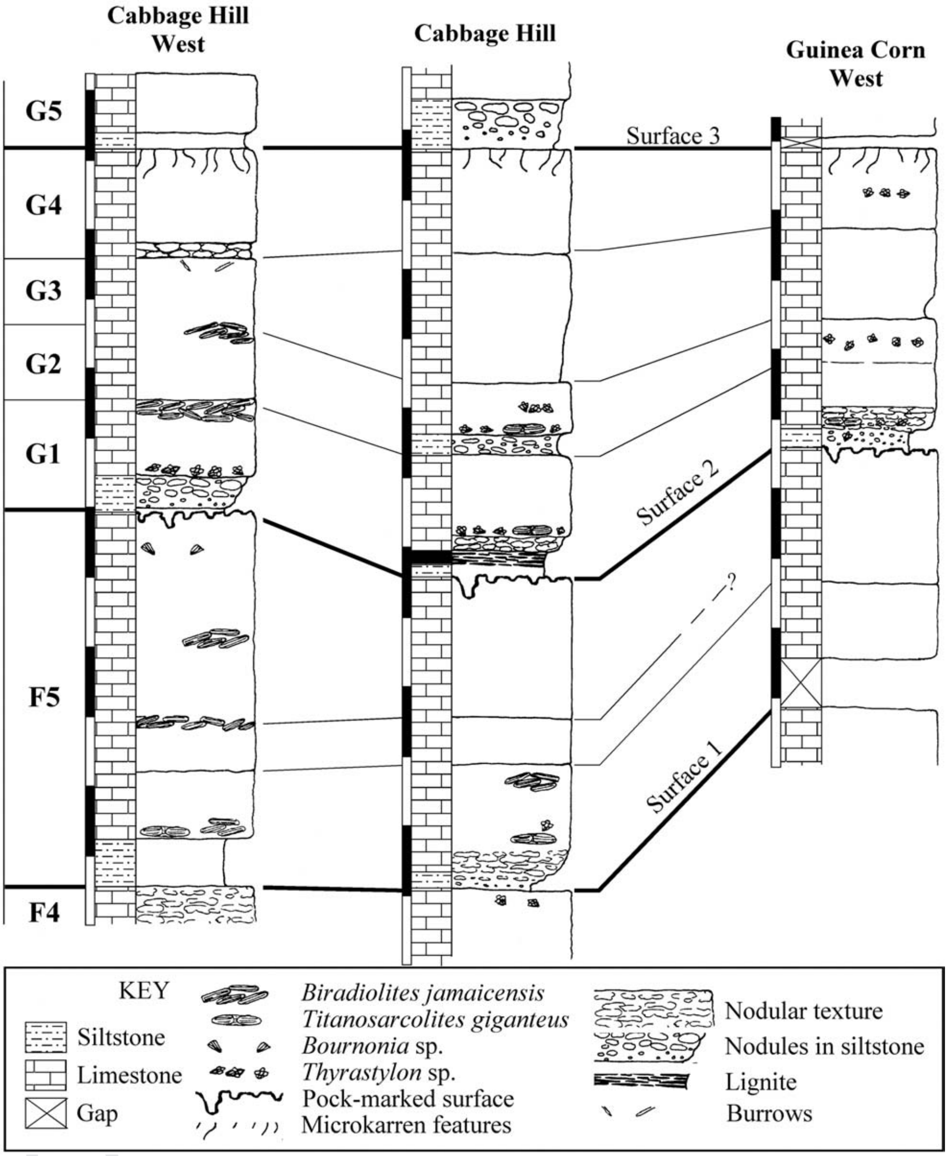

Fig. 2. Graphic logs showing three sections through rhythms F4 to G5 of the Guinea Corn Formation (rhythm numbers after Mitchell, 1999), at the three localities shown in Fig. 1, using the base of rhythm G5 as datum. Graphic logs show weathering profiles. Rudist abundance recorded as seen in the field. Surfaces 1–3 (2–3 are palaeokarstic) are described in detail in the text. Scale bars in metre intervals.

bedding plane of the steeply dipping (c. 70 degrees), fairly massive uppermost-limestone bed of rhythm F5, and displays a small-scale joint pattern normal to bedding (Fig. 3A). The joint pattern has been opened up slightly by solutional weathering, forming a rubbly and nodular texture that extends beneath the surface to a depth of 41 cm. Distinct honeycomb weathering patterns, similar to spitzkarren, with a predominant orientation normal to bedding, can also be detected to a similar depth; these are partly infilled with the sandy mudstones of the overlying bed. The surface is pock-marked with small pits that form a nodular, mamillated surface (Fig. 3B). Most of the pits are roughly circular to gently elliptical in plan view, although a few are more irregular. The pits vary in diameter from 5–170 mm and in depth from 5–90 mm, and are orientated perpendicular to the overlying bedding surface. The features can be divided into two predominant types based on morphometry (Table 1). The most common karren features are pits and pans, which are roughly circular to oval in plan view, with bowl-shaped floors, 45–170 mm in diameter and 25–90 mm deep. The larger pits commonly have steep boundary walls that slope convexly inwards towards the rounded floor of the pit, making them convexo-concave in profile (Fig. 3C). Some of the larger pits are partly infilled with sediment similar to the overlying bed, while others are devoid of any infill. A few of the pits have flattened floors and the bounding slopes have been steepened by undercutting, forming a distinct break of slope between pit floor and side slope,

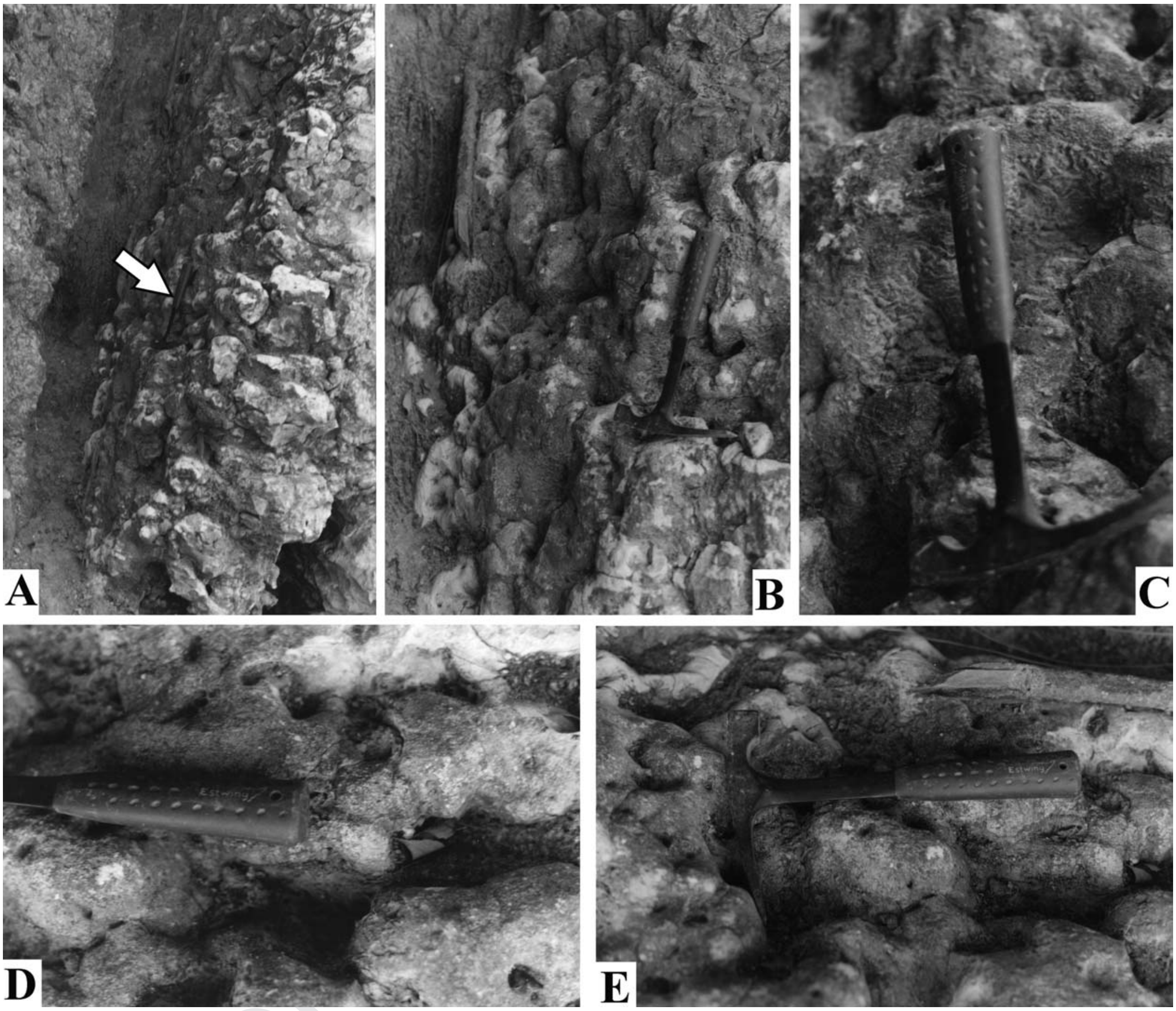

Fig. 3. Photographs of palaeokarstic surface 2 in the Guinea Corn Formation, Jamaica. A, palaeokarstic surface at Cabbage Hill, surface 2, cycle G1–4, showing steeply dipping nature of the cycle, with overlying sedimentary rocks with abundant lignite. The surface is clearly nodular and mamillated in appearance, with the development of an open joint normal to the palaeokarstic surface. A larger pothole appears at the base of the exposure. Hammer (arrowed) is 28 cm long. B, detail of the palaeokarstic surface at Cabbage Hill, surface 2, clearly showing pitted and uneven surface with larger pits and smaller pock-marks. C, larger bowl-shaped pits on the palaeokarstic surface, showing steep, convex, bounding slopes and rounded pit floors. Some of the pit floors are partly infilled with sedimentary rocks. D, solution pans with steep boundary slopes having been over-deepened and undercut to form small basal notches. The floors of some of the pans are partly infilled with sedimentary rocks. E, larger solution pits with intervening rain splash pits; the latter are superimposed on the positive relief elements of the surface. The smaller rainpits do not develop on the bounding slopes or floors of the larger solution pits and pans.

leading to a more distinct pan shape. Indeed, a few of the pits have over-steepened, almost undercut boundary slopes that form a small basal notch at the junction between the pit floor and the bounding wall (Fig. 3D). The larger pits are clustered and a few are aligned. Some of the larger pits are elongated, although there is no common orientation pattern.

The surface at the base of rhythm G1 also contains a few smaller pits and pock-marks, which are superimposed upon, and restricted to, the upstanding relief elements of the surface, forming small imprints in areas between the larger pits (Fig. 3E). They do not occur within the larger pits themselves. These smaller features are also circular to oval in plan, but predominantly tubular to cylindrical rather than bowl-shaped in bed-normal orientation. Some of the smaller pits are tapered. They are less common and more isolated than the larger pits, and range from 5 to 40 mm in diameter and up to 30 mm deep. Most of the smaller pock-marks are devoid of a sedimentary infill (i.e., it has been removed by weathering).

The basal G1 surface at Cabbage Hill exposes 27 measurable pits of varying size and their overall morphometric properties are given in Table 1. The larger pits have a tendency to be slightly more elongated, and have shallower depth/diameter and width/depth ratios compared to the smaller features, reflecting the bowl-shaped cross-sections of the larger pits, compared to the tubular and cylindrical form of the smaller pits. Fig. 4 shows that there is a distinct relationship between length-to-width and depth-to-diameter parameters of the pits. Relationships between other parameters show no distinct correlations.

Two larger and deeper potholes also occur on the surface with an orientation normal to bedding. The largest pothole occurs towards the base of the exposure (Fig. 3A) and extends through the body of the limestone bed forming a small ‘lighthole’. The pothole is 84 cm deep and 20 cm wide. It is broadly cylindrical in shape and circular in plan with no apparent elongation. The interior surface of the pothole is scalloped and marked by small flutes, suggesting vertical water movements down the feature. The joint pattern is better developed and has a more open appearance in the immediate vicinity of the pothole compared to the remainder of the bed, suggesting that the origin of the feature was controlled by enhanced solution along more common lines of weakness. A second larger, broadly circular, cylinder-shaped pothole also occurs towards the base of the exposure. This measures 24.5 cm in diameter and is 23 cm deep, and is partly infilled with sediment from the overlying bed.

Table 1
Morphometric properties of the palaeokarstic surface at Cabbage Hill, Surface 2, Rhythm G1–4 (measurements in mm)

| Classification | Length (L) | Width (W) | Depth (D) | Mean diameter MD=(L+W)/2 | Depth/Diameter =D/MD | Elongation =L/W | Width/Depth =W/D |
|---|---|---|---|---|---|---|---|
| Small pit | 5 | 5 | 10 | 5 | 2.00 | 1.00 | 0.50 |
| Small pit | 15 | 10 | 10 | 12.5 | 0.80 | 1.50 | 1.00 |
| Small pit | 20 | 15 | 15 | 17.5 | 0.86 | 1.33 | 1.00 |
| Small pit | 25 | 25 | 20 | 25 | 0.80 | 1.00 | 1.25 |
| Small pit | 30 | 30 | 25 | 30 | 0.83 | 1.00 | 1.20 |
| Small pit | 35 | 30 | 30 | 32.5 | 0.92 | 1.17 | 1.00 |
| Small pit | 35 | 25 | 20 | 30 | 0.67 | 1.40 | 1.25 |
| Small pit | 40 | 25 | 20 | 32.5 | 0.62 | 1.60 | 1.25 |
| Small pit | 45 | 15 | 25 | 30 | 0.83 | 3.00 | 0.60 |
| Small pit | 45 | 35 | 30 | 40 | 0.75 | 1.29 | 1.17 |
| Mean | 29.5 | 21.5 | 20.5 | 25.5 | 0.9 | 1.4 | 1.0 |
| Std dev. | 13.2 | 9.7 | 7.2 | 10.7 | 0.4 | 0.6 | 0.3 |
| Large pit | 50 | 35 | 30 | 42.5 | 0.71 | 1.43 | 1.17 |
| Large pit | 50 | 45 | 35 | 47.5 | 0.74 | 1.11 | 1.29 |
| Large pit | 50 | 35 | 25 | 42.5 | 0.59 | 1.43 | 1.40 |
| Large pit | 55 | 35 | 30 | 45 | 0.67 | 1.57 | 1.17 |
| Large pit | 60 | 55 | 30 | 57.5 | 0.52 | 1.09 | 1.83 |
| Large pit | 65 | 50 | 25 | 57.5 | 0.43 | 1.30 | 2.00 |
| Large pit | 75 | 45 | 35 | 60 | 0.58 | 1.67 | 1.29 |
| Large pit | 80 | 65 | 40 | 72.5 | 0.55 | 1.23 | 1.63 |
| Large pit | 85 | 80 | 70 | 82.5 | 0.85 | 1.06 | 1.14 |
| Large pit | 100 | 65 | 60 | 82.5 | 0.73 | 1.54 | 1.08 |
| Large pit | 105 | 75 | 50 | 90 | 0.56 | 1.40 | 1.50 |
| Large pit | 110 | 70 | 45 | 90 | 0.50 | 1.57 | 1.56 |
| Large pit | 115 | 60 | 45 | 87.5 | 0.51 | 1.92 | 1.33 |
| Large pit | 120 | 85 | 45 | 102.5 | 0.44 | 1.41 | 1.89 |
| Large pit | 150 | 45 | 40 | 97.5 | 0.41 | 3.33 | 1.13 |
| Large pit | 150 | 75 | 60 | 112.5 | 0.53 | 2.00 | 1.25 |
| Large pit | 240 | 100 | 90 | 170 | 0.53 | 2.40 | 1.11 |
| Mean | 97.6 | 60.0 | 44.4 | 78.8 | 0.6 | 1.6 | 1.4 |
| Std dev. | 49.3 | 19.2 | 17.4 | 32.4 | 0.1 | 0.6 | 0.3 |

The sedimentary rock overlying and infilling the features of the top surface of F5 consists of very poorly sorted, sandy siltstone. The sand grade material includes highly weathered andesitic lithic fragments and crystals. This poorly sorted, sandy siltstone is overlain by a 30 cm-thick lignite bed. The lignite consists of flattened fragments of wood; rootlets are absent. Neither marine nor terrestrial body fossils have been recovered from the lignite bed, only plant remains. The lignite bed is overlain by a nodular limestone that contains the benthic foraminifers *C. jamaicensis* and *K. jamaicensis.*

Surface 2 is also well developed at the two other locations exposing this part of the Guinea Corn Formation (Fig. 2). The surface in each case shows similar characteristics to those seen at Cabbage Hill.

### 2.3. Rhythm G5

Rhythm G5 marks a thick limestone in the Guinea Corn Formation and rests on a prominent, distinctive surface (surface 3 in Fig. 2). At Cabbage Hill, this surface is pock-marked and highly irregular, although it is much less nodular and mamillated in appearance

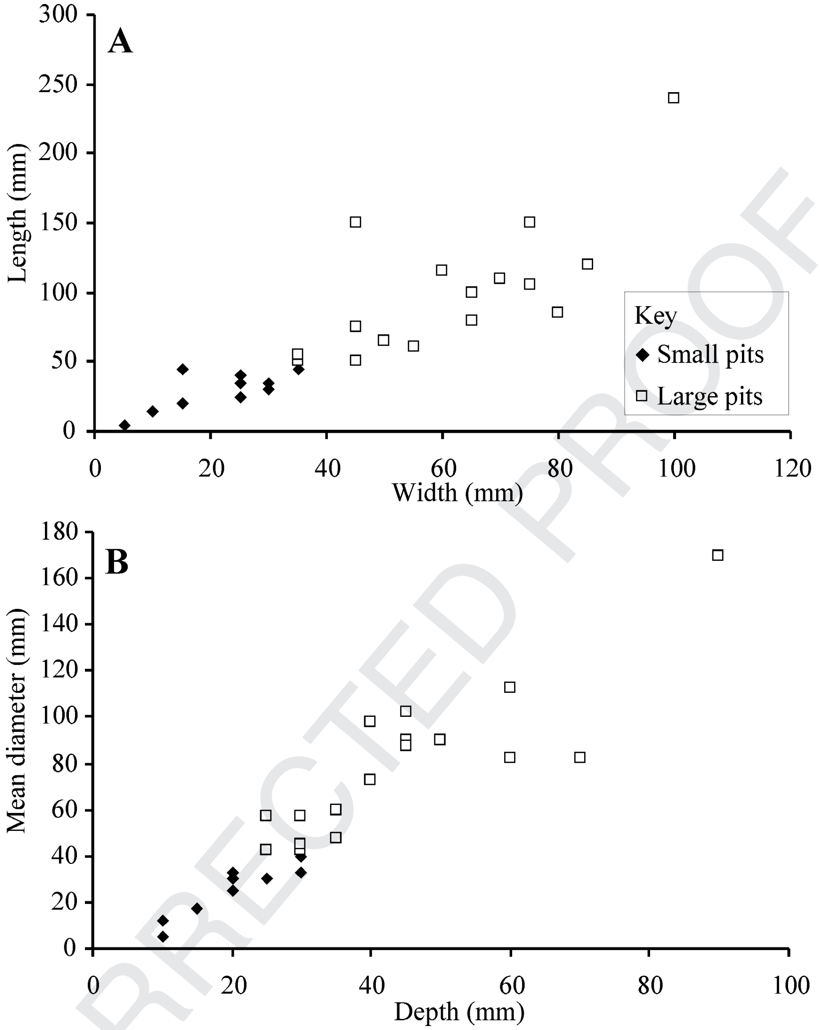

Fig. 4. Relationship between (A) elongation (length versus width) and (B) mean diameter versus depth of palaeokarstic depressions on surface 2.

compared to surface 2. The distinctive features of the surface are microkarren phenomena represented by small cylindrical potholes up to 40 mm in diameter and 30 mm deep (Fig. 5A). These are similar to the rain-splash pits identified on surface 2. Two larger pits on surface 3 are about 90 mm in diameter and 45 mm deep. As with surface 2, dissolution extends into the body of the limestone bed producing a lensoid, open-joint appearance (Fig. 5B). The bedding in this rhythm is also steeply dipping and the palaeokarstic surface is normal to the steeply-inclined bedding.

Surface 3 is recognisable in all three sections of the Guinea Corn Formation studied (Fig. 2). In each case, the surface is overlain by a prominent limestone.

## 3. Interpretation of the surfaces

The microtopography of palaeokarstic surface 2 comprises two principal karren types based on size, both of which would be described as circular plan forms in the classification of Ford & Williams (1989), or as etched forms resulting from solutional attack in the types described by White (1988). Some of the larger features are solution pits, while others with detrital infill and flat floors with over-steepened and undercut bounding slopes are solution pans (solution basins); the latter were termed ‘kamenitza’ by Bögli (1960). Solution pits, together with karren shafts, are the most widespread active karren forms on both bare limestone surfaces and beneath a soil cover (Ford & Williams, 1989). In active karst environments, solution pans occur principally on bare or slightly vegetated rock, where they are a major karren form (Trudgill, 1985). These forms appear to be rare or absent beneath a soil cover, as solution pans develop where pools and ponds of water collect on the surface due to partial armouring of the pan floor by organic detritus or soil. This inhibits seepage into the limestone and focuses solution around the perimeter of the pan, over-steepening and undercutting its boundary slopes. In contemporary environments, solution pans

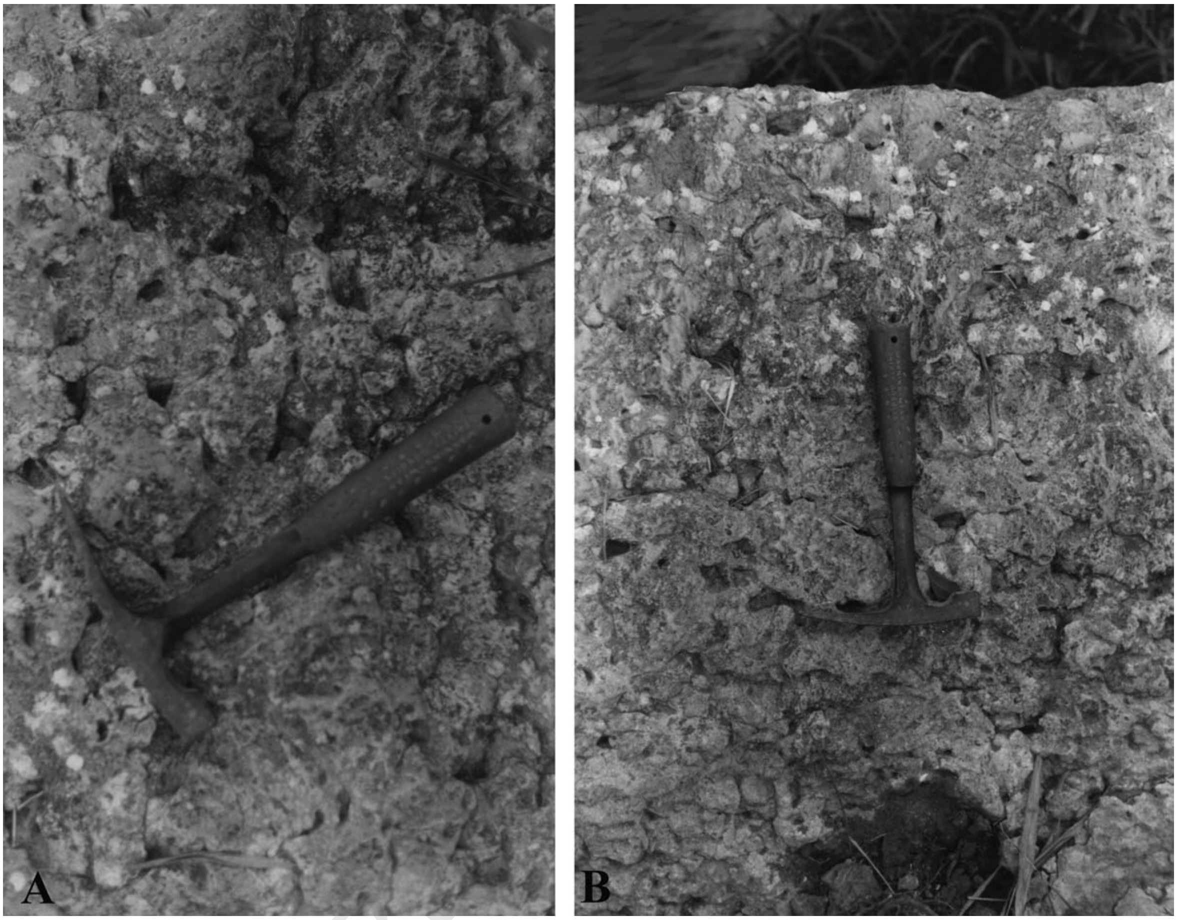

Fig. 5. A, mottled and pitted palaeokarstic surface 3 from cycle G5. The surface pitting is generally restricted to small pock marks. B, section of cycle immediately below the palaeokarstic surface. The limestone below the surface has been karstified to form an open lensoid fissure pattern.

and basins only occur on rock surfaces that are horizontal, such that water may collect in small pools and basins.

The smaller features recognised on surface 2 are also classified as pits in the terminology of Ford & Williams (1989), although some of the very small pits could alternatively be termed ‘rainpits’ *sensu* Jennings (1985). Rainpits are usually less than 30 mm in diameter and 20 mm deep, often occurring in fields or singly when they are formed by leaf drip (Jennings, 1985). Such solution features in modern environments are also considered to result from biogenic weathering, through the biochemical activity of cyanobacteria releasing $CO_2$ at night (Danin & Garty, 1983).

The larger potholes associated with surface 2 are analogous to modern-day karren shafts (Ford & Williams, 1989), which are short ‘caves’ up to 2–3 m deep and 1 m wide. Most have a structural guide and are formed by surface drainage into the epikarst.

Consequently, we ascribe the larger pits to dissolution associated with pools of water lying on the surface, since some of them are flat-floored solution pans, which, as indicated earlier, only occur on bare surfaces in contemporary environments. The morphometry of the larger pits would suggest that, as solution progressed, they became larger, wider and deeper. Pools of standing water in the floor of the pits would also have led to solutional undercutting and over-steepening of their bounding slopes. We attribute the development of the small pock-marks to rain splash processes, suggesting a bare or lightly vegetated surface, either devoid of, or with an incomplete soil cover. The smaller pits are more isolated features, which may suggest that they formed from persistent at-a-point leaf drips and throughfall off vegetation onto a relatively soluble substrate. The two deeper potholes on surface 2 are attributed to more significant vadose water movements by strong surface drainage into the epikarst along more exploitable lines of weakness, suggesting at least partial induration and the development of a joint pattern. The solution scalloping and fluting on the interior walls of the potholes would also suggest the general lack of a soil cover on the exposure surface during the karstification phase.

The environmental setting of the surface at the time of karstification was one of a relatively soft substrate, possibly lightly vegetated, where small pits, with ephemeral or permanent pools and puddles, developed by solution. Smaller pits developed on the surface by rain-splash processes in areas between the pools. The surface was sufficiently elevated to produce meteoric water movements from the surface through the vadose zone to the epikarst. The exposure of the carbonates to fresh-water led to meteoric diagenesis, when they became stabilised to low magnesium carbonates and sufficiently cemented to promote pitting of the surface. The dominance of solution over cementation in the formation of these surfaces suggests a humid tropical environment (Tucker & Wright, 1990).

Surface 2 at Cabbage Hill is overlain by a lignite rich siltstone. This deposit indicates high fluxes of land-derived terrestrial plant material. Such a scenario is consistent with transgressive flooding of a karstic terrain and the development of eutrophic conditions in shallow-water marine lagoonal areas (cf. Mitchell, 2002b).

## 4. Implications of exposure surfaces in the Guinea Corn Formation

Palaeokarstic surfaces have not previously been recorded from the Upper Cretaceous limestones of the Caribbean region. Johnson & Kauffman (1996) suggested that a brief period of emergence may have been responsible for the development of a hardground in the *Titanosarcolites* limestones of the Jerusalem Mountain Inlier of western Jamaica; however, no palaeokarst was developed and submarine cementation seems more probable.

The existence of palaeokarstic surfaces in the Guinea Corn Formation capping offshore rudist-rich limestones implies uplift and not simply shoreline progradation. The tops of cycles generated through progradation of the shoreline do not display evidence of prolonged exposure, but are of fairly low relief and affected by saline or brackish water, which would preclude the generation of significant vadose alteration (Wright, 1994), in which case the cycle would not exhibit evidence of vadose meteoric overprinting in the form of karst solution features (Strasser, 1991). Small-scale palaeokarst of the nature described within the Guinea Corn Formation is best preserved where the karst processes are overwhelmed by rapid deposition, especially by terrigenous sediments or volcanic ash, succeeded by prolonged subsidence (Ford & Williams, 1989). Where palaeokarst is buried by a succeeding marine transgression, palaeokarstic surfaces may be expected to become destroyed by marine erosion or affected by bioerosion, particularly where wave energy is high. The palaeokarstic surfaces may, therefore, have been inundated by transgression in a low energy environment, though they are more likely to have become buried relatively rapidly by estuarine organic and reworked volcanic sediments, forming the overlying beds.

The presence of two palaeokarstic surfaces suggests that there were at least two falls in sea level that exposed the limestones to karstification, and subsequently transgressions that allowed limestone deposition to resume. The lack of palaeokarstic surfaces capping other rhythms in the Guinea Corn Formation may be explained by transgressive erosion removing evidence of exposure, different water depths for different parts of the formation (i.e., relative falls in sea level were unable to expose the limestones), or by different degrees of relative sea level fall (sea-level falls were too small to expose the limestones). Small eustatic changes in sea level have been widely suggested as the cause of variations in stratal geometry in many Cretaceous successions (e.g., Haq et al., 1988; Plint, 1996). The Cretaceous is generally interpreted to have been a time of greenhouse climatic conditions with high atmospheric $CO_2$ levels (Crowley & Berner, 2001; Wilson et al., 2002). Yet despite this, the wide recognition of small-scale sea-level fluctuations has been interpreted to be due to the waxing and waning of small ice caps (e.g., Gale et al., 2002). Small-scale waxing and waning of these ice caps could have produced minor oscillations of sea level that would be necessary to produce the palaeokarst in the Guinea Corn Formation.

## 5. Conclusions

The origin of pock marks and pits on the top surfaces of sedimentary rhythms in the Guinea Corn Formation are interpreted as penecontemporaneous with the sedimentary succession. The karren features are considered to be palaeokarst for three reasons:

1 The pits and pots are perpendicular to bedding rather than to the present land surface. They are developed at the base of a rhythm that is steeply dipping, and there is a lack of any obvious asymmetry to their development. On a steeply-dipping bedding plane surface any later karren development along lines of weakness would be expected to produce asymmetric forms in both cross-section and plan, but this is not the case. Such a surface would also tend to develop hydrodynamically-controlled, linear karren features formed by sheet- or channel-flow, rather than the circular to oval etched forms that occur.

2 Some of the pock marks and small pots are infilled with very poorly sorted siltstone, which forms the base of the overlying rhythm. Also, the top 40 cm of the bed below the palaeokarstic surface in rhythm G1 is weathered into a honeycomb structure similar to spitzkarren, with an orientation normal to bedding and partly infilled with sedimentary rock from the overlying bed.

3 The surface was briefly exposed to vadose diagenesis and karren pitting followed by re-submergence and deposition of new carbonate above it. Thus, the surface fits into the definition of palaeokarst in that it was buried subsequent to a karstification phase which produced the small-scale solution features. It is also unrelated to any contemporary karst processes modifying the exposures today.

The palaeokarst in the Guinea Corn Formation suggests short periods of sea-level fall followed by sea-level rise. Such sea-level cycles have been suggested elsewhere and attributed to possible waxing and waning of small ice caps during the Late Cretaceous.

## Acknowledgements

We thank Donovan Blissett and Fatima Patel for help in the field. Stephen Donovan and Paul Wright made valuable comments that greatly improved the original manuscript.

## References

Bögli, A., 1960. Kalklosung ünd Karrenbildung. Z. Geomorphol. Suppl. 2, 4–21.

Bosak, P., Ford, D.C., Glazek, J., Horacek, J., 1990. *Paleokarst – a systematic and regional view*. Elsevier, Amsterdam, 725 pp.

Chubb, L.J., 1971. Rudists of Jamaica. Palaeontogr. Am. 7, (45) 161–257.

Coates, A.G., 1977. Jamaican coral-rudist frameworks and their geologic setting. Reefs and related carbonates – ecology and sedimentology. Am. Assoc. Petrol. Geol. Stud. Geol. 4, 83–91.

Crowley, T.J., Berner, R.A., 2001. CO2 and climate change. Science 292, 870–872.

Danin, A., Garty, J., 1983. Distribution of cyanobacteria and lichens on hillsides in the Negev Highlands and their impact on biogenic weathering. Z. Geomorphol. 27, 423–444.

Donovan, S.K., 1993. Jamaican Cretaceous Echinoidea, In: Wright, R.M., Robinson, E. (Eds.), Biostratigraphy of Jamaica*, Geol. Soc. Am. Mem., 182,* pp. 93–103.

Ford, D.C., Williams, P.W., 1989. *Karst geomorphology and hydrology*. Unwin Hyman, London, xv+601 pp.

Gale, A.S., Hardenbol, H., Hathway, B., et al., 2002. Global correlation of Cenomanian (Upper Cretaceous) sequences: evidence for Milankovitch control on sea level. Geology 30, 291–294.

Haq, B.H., Hardenbol, J., Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change, In: Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., et al., (Eds.), Sea level changes – an integrated approach, SEPM Spec. Publ., 42, pp. 71–108.

Hazel, J.E., Kamiya, T., 1993. Ostracod biostratigraphy of the Titanosarcolites-bearing limestones and related sequences of Jamaica, In: Wright, R.M., Robinson, E. (Eds.), Biostratigraphy of Jamaica*,* Geol. Soc. Am. Mem., 182, pp. 65–76.

Jennings, J.N., 1985. *Karst Geomorphology*. Basil Blackwell, Oxford, x+293 pp.

Jiang, M.-J., Robinson, E., 1977. Calcareous nannofossils and larger foraminifera in Jamaican rocks of Cretaceous to early Eocene age. In Ahmad, R. (ed.), Proceedings of a workshop on the status of Jamaican geology, Kingston, March 1984. Geological Society of Jamaica, Special Issue, pp. 24–51.

Johnson, C.C., Kauffman, E.K., 1996. Maastrichtian extinction patterns of Caribbean province rudists, In: MacLeod, N., Keller, G. (Eds.), Cretaceous-Tertiary mass extinctions: biotic and environmental changes, Norton and Company, New York, London, pp. 231–272.

Krijnen, J.P., MacGillavry, H.J., van Dommelen, H., 1993. Review of upper Cretaceous orbitoid larger foraminifera from Jamaica, West Indies, and their connection with rudist assemblages, In: Wright, R.M., Robinson, E. (Eds.), Biostratigraphy of Jamaica*,* Geol. Soc. Am. Mem., 182, pp. 29–63.

Mitchell, S.F., 1999. Stratigraphy of the Guinea Corn Formation (Upper Cretaceous) at its type locality between Guinea Corn and Grantham (northern Clarendon, Jamaica). J. Geol. Soc. Jamaica 33, 1–12.

Mitchell, S.F., 2000. Facies analysis of a Cretaceous–Paleocene volcaniclastic braid-delta. Geological Society of Trinidad and Tobago and Society of Petroleum Engineers (GSTT 2000 SPE) Conference, July 10–14, 2000, Hilton Hotel, Port-of-Spain, Trinidad. Conference Proceedings CD Rom, SS03, 1–9.

Mitchell, S.F., 2002a. The fauna of Jamaican Cretaceous reefs. In: Jackson, T.A. (ed.), Caribbean geology into the third millennium. Transactions of the Fifteenth Caribbean Geological Conference, June 29–July 2, Kingston, Jamaica, 1998. UWI Press, Kingston, 131–138.

Mitchell, S.F., 2002b. Palaeoecology of corals and rudists in mixed volcaniclastic-carbonate small-scale rhythms (Upper Cretaceous, Jamaica). Palaeogeogr., Palaeoclimatol., Palaeoecol. 186, 237–259.

Mitchell, S.F., In press. Sedimentology and tectonic evolution of the Cretaceous rocks of central Jamaica: relationships to the plate tectonic evolution of the Caribbean. In: Bartolini, C., Burke, K., Buffler (eds), *Mexico and the Caribbean region: plate tectonics, basin formation and hydrocarbon habitats*. American Association of Petroleum Geologists, Memoir.

Mitchell, S.F., Blissett, D., 2001. Lithostratigraphy of the late Cretaceous to?Paleocene succession in the western part of the Central Inlier of Jamaica. Carib. J. Earth Sci. 35, 19–31.

Mitchell, S.F., Gunter, G.C., 2002. Biostratigraphy and taxonomy of the rudist Chiapasella in the Titanosarcolites Limestones (Maastrichtian) of Jamaica. Cret. Res. 23, 473–487.

Plint, A.G., 1996. Marine and nonmarine systems tracts in fourth-order sequences in the Early–Middle Cenomanian, Dunvegan Alloformation, northeastern British Columbia, Canada, In: Howell, J.A., Aiken, J.F. (Eds.), High resolution sequence stratigraphy: innovations and applications*,* Geol. Soc. Spec. Publ., 104, pp. 159–191.

Sandy, M.R., Harper, D.A.T., Donovan, S.K., et al., 1997. A late Cretaceous brachiopod from Jamaica, its significance for Mesozoic brachiopod palaeobiogeography and evolution. Proc. Geol. Assoc. 108, 201–207.

Sohl, N.F., Kollman, H.A., 1985. Cretaceous actaeonellid gastropods from the Western Hemisphere. US Geol. Surv. Prof. Pap. 1304, 1–104.

Steuber, T., Mitchell, S.F., Buhl, D., et al., 2002. Catastrophic extinction of Caribbean rudist bivalves at the Cretaceous-Tertiary boundary. Geology 30, 999–1002.

Strasser, A., 1991. Lagoonal-peritidal sequences in carbonate environments: autocyclic and allocyclic processes, In: Einsele, G., Ricken, W., Seilacher, A. (Eds.), Cycles and events in stratigraphy, Springer-Verlag, Berlin, pp. 709–721.

Trechmann, C.T., 1924. The Cretaceous limestones of Jamaica and their Mollusca. Geol. Mag. 61, 385–410.

Trudgill, S., 1985. *Limestone Geomorphology*. Longman, London, x+196 pp.

Tucker, M.E., Wright, V.P., 1990. *Carbonate Sedimentology*. Blackwell Scientific, Oxford.

White, W.B., 1988. *Geomorphology and Hydrology of Karst Terrains*. Oxford University Press, Oxford, ix+464 pp.

Whitfield, R.P., 1897. Descriptions of species of Rudistae from the Cretaceous rocks of Jamaica. Bull. Am. Mus. Nat. Hist. 9, 185–196.

Wilson, P.A., Norris, R.D., Cooper, M.J., 2002. Testing the Cretaceous greenhouse hypothesis using glassy foraminifera calcite from the core of the Turonian tropics on Demerara Rise. Geology 30, 607–610.

Wright, V.P., 1994. Paleosols in shallow marine carbonate sequences. Earth Sci. Rev. 35, 367–395.