Palaeokarstic surfaces in the Upper Cretaceous limestones of central Jamaica

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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 Paleocene 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 volcanioclastic, braided-delta complex (Mitchell, 2000; Mitchell & Blissett, 2001). Although there have been extensive studies of the paleontology 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;
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 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
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 pockmarked with small pits that form a nodular, mammillated 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 morphology (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.
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.

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.

### Table 1

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<th>Length (L)</th>
<th>Width (W)</th>
<th>Depth (D)</th>
<th>Mean diameter MD=(L+W)/2</th>
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<th>Elongation =L/W</th>
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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 Bogli (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. 4. Relationship between (A) elongation (length versus width) and (B) mean diameter versus depth of palaeokarstic depressions on surface 2.
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 CO₂ 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y 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 & Kaufman (1996) sug-
gested 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 palaeo-
karst 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 transgres-
sion, palaeokarstic surfaces may be expected to become
destroyed by marine erosion or affected by bioerosion,
particularly where wave energy is high. The palaeo-
karstic 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 trans-
gressions 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 CO₂ 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 pro-
duced 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 sedi-
mentary 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 in 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.

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References


