Landscapes of The Bahamas and Their Unexplained Relationship to Sea Level Change

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Abstract

Field and expert airphoto interpretation work in ten of the Bahama Islands between Florida and Cuba over a three year period revealed the origin of the low lying, tree covered landscape features which are closely related to Pleistocene sea level change and differing sedimentary regimes. Maps at 1:25 000 scale of dunary landscapes identified by their limestone type, now fossilized) were produced in detail for one Atlantic marginal or windward island (Cat Island, 70 kms long). A second island (the largest island in the Bahamas, Andros) built mainly of depositional shallow marine limestone types on a broad shallow bank, was investigated for agricultural purposes. There, a key area was mapped in detail to illuminate the relationship between depositional limestone types in an energy related environment and the usefulness of the land (its agricultural capability) once sea level had fallen and the sediments were exposed to subaerial diagenesis and differential weathering. The latter etched out different ground surfaces which are diagnostic. This work was undertaken for the Bahamas Government and has scarcely appeared in academic literature. In view of current interest in sea level change, it seems doubly important to bring it out of the dusty storeroom.

Keywords: sea level change; airphoto interpretation; Bahamas marsh and dune landscapes; juvenile limestone karst

Introduction

The Bahama Islands north of Cuba and southeast of Florida are isolated by currents and very deep water from terrigenous (land derived) sediment and built purely from limestone. They occupy parts of the shallow waters called the Bahama Banks. In some islands their windward coasts face onto deep Atlantic water while in others (for example Little Abaco) their windward coast faces water of less depth; or as at Andros are protected from the full reach of Atlantic waves. Normally the lee shore coasts face onto the shallow Bahama Banks. Google Maps offers a good depiction.

The islands can be divided on the basis of their position on the shallow Bahama Banks and hence their relationship to the energy of the Atlantic. They can also be divided on the basis of climate, groundwater, vegetation, landform and surface deposits. A clear distinction that has historically been made is based on vegetation: between the ‘Pine Islands’ (Andros, New Providence, Grand Bahama and the Abacos - Great and Little) which are mainly covered in slow growing Bahamian Pine (now in regeneration after clear felling) and the remainder of the islands, called the ‘Coppice Islands’ so called on account of their hardwood vegetation, now largely reduced to thicket form.

This paper emphasises in its dual content (Cat Island and Andros) the difference between Coppice Islands which are characterised by a fringe of dune formation brought about by onshore westerly winds and waves and Pine Islands which associate with broad shallow bank areas and associated shallow intertidal marsh habitats where the marginal dunes are of less significance or absent. A better descriptor for most of the Coppice Islands might be Atlantic Windward Islands and that is what is used in this paper.

The Bahamas may be further sub divided into a number of groups on the basis of rainfall. Long Island, North and Central Acklins and Mayaguana form a group with a wetter climate of 30-40 inches annual rainfall, whilst Mangrove Cay, South Andros, Eleuthera, Cat Island and San Salvador receive over 40 inches. These island groupings based on rainfall also have differences in vegetation, soil, cementation of late deposited lime sands, surface deposit and different capabilities for ground water replenishment.

For the geologist, the fact that the ground/rock surface typical of flat areas of the pine islands are not repeated in the Atlantic Windward islands is a valuable distinction; similarly notable is the presence of large areas of uncemented surface deposits in South Acklins (an Atlantic Windward [coppice] Island and Inagua. The last named is a semi arid island of sparse vegetation cover with a saline shallow depression. It occupies a large bank area with minor east coast dunes.

Though the islands are built of limestone, there is great variety between limestone types (geologically referred to as lithofacies). This depends on the energy of the depositional environment, where muddy deposits indicate low energy and sandy (or coarser) deposits higher energy. It also depends on the characteristic components whether that is lime mud, pellets of mud produced by feeding organisms, shallow water oolitic sand or particles derived from shell, coral or other lagoonal sources (bioclastic grains). Differences in depositional environment (hence by extension lithofacies) are best understood as corresponding with differences in the much more familiar terrestrial natural habitats.

Geographic descriptions based on ‘hill, mountain, plateau valley and plain’ do not work in the Bahamas where the maximum relief between high and low land is only 206 ft and there is no channelled surface runoff. Within islands, it is reasonable to define hilly and flat sub regions and identify steep and less steep slopes. Also to identify saline and hypersaline ponds and wetter and drier places close to sea level, and a variety of ridge forms of littoral, marine and dunary (eolian) origin. Most of these are notably lithified, that is their component sand grains have become self cemented into rock under the influence of sea spray, rain or groundwater. A large part of the ‘land’ at the margins of the Pine Islands (Andros most especially so) is intertidal marsh and has characteristic habitats as will be illustrated for Shroud Cay. This intertidal marsh zone later may be abandoned by the sea and harden into self cemented rock surfaces. This is what has happened in the study area of North Andros.

The significance of the 1969-1974 surveys at the time.

The survey undertaken from 1969 -74 was to establish the useability of land in both islands for agriculture. Alternatively the ground/geology problems that might be encountered in any engineering development. This latter was the principal focus in Cat Island. The land quality work, forest inventory and vegetation mapping was accompanied by a major drilling and ground water sampling programme and establishment of survey levelling benchmarks through out. Ten islands were surveyed in detail, three others were reported on.

In Cat Island agriculture has traditionally taken the form of cut and burn shifting agriculture (excepting historically – the 18th Century - when parts were parcelled up for a short period of estate cotton growing). Most of the land lies beneath dense ‘bush’ much showing the scars of cut and burn farming.

Before the 1950s Andros had lain undisturbed as slow growing climax pine forest with understory of poison wood, other shrubs, bracken, grasses, palmettos in high water table areas, very rare cycads, orchids and other species. It was then clear felled (excepting mother seed trees) on licence from the Bahamas Government to an American company Owens Illinois. Small areas around Owens Town were affected by a sawn timber operation and a second by an unsuccessful Colonial Development Corporation rice growing project at Twin Lakes.

The location of the islands which form part of this paper is given in Fig. 1.

Generalities on Method

Shallow Banks ('Pine') Islands and Atlantic Windward ('Coppice') Islands were compared over a three and a half year period of residence and field work on the thirteen main islands. Different methods were employed for each of the two island types. Excepting water resources, and soils no laboratory work was undertaken nor in the geomorphology was any detailed scrutiny given to rock face (stratigraphic) sections. The latter are key to many geologic studies - see for example Hearty (1998).

Method: The North Andros Study Area

Though Andros was examined in aerial photography (at 1:10,000 scale greyscale with a 6 inch lens) the key to the analysis here was ground survey sampling. Access to and positioning of observations was facilitated by a rectangular network of logging tracks (clear felling was in process at the time). These tracks provided a framework for three levels of survey, the first more general of the whole of North Andros (1238 field observations plus helicopter reconnaissance of Mangrove Cay); the second focused on about 2000 hectares (of land identified by the USAID programme (with the Bahamas Government) for arable agriculture; the third a more detailed sampling of the same agricultural development area amounting to about 440 sites (about one site for every four and a half hectares). Agriculture (replacing pine forest) became a strong focus in part of Andros.

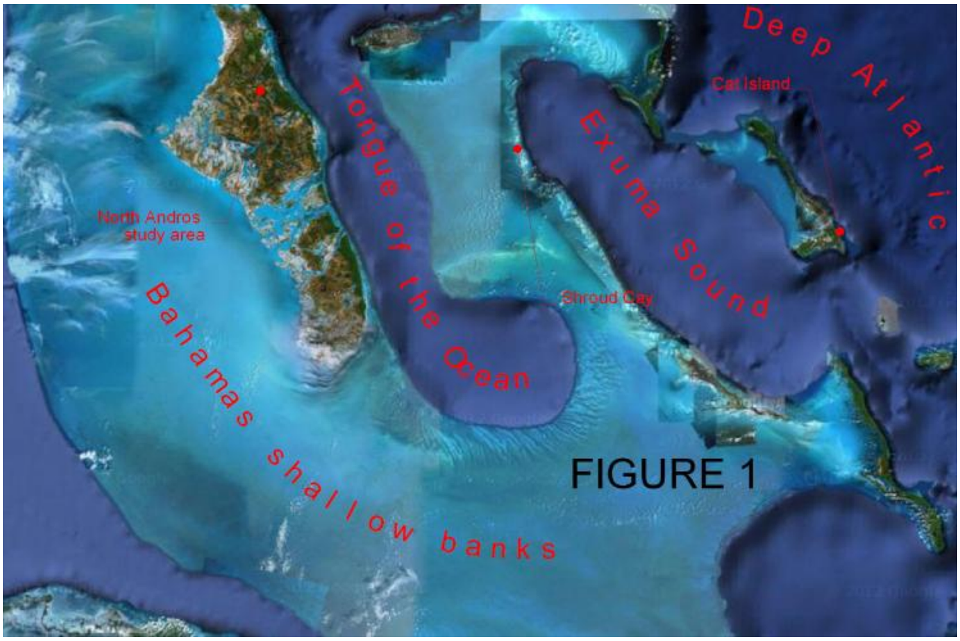
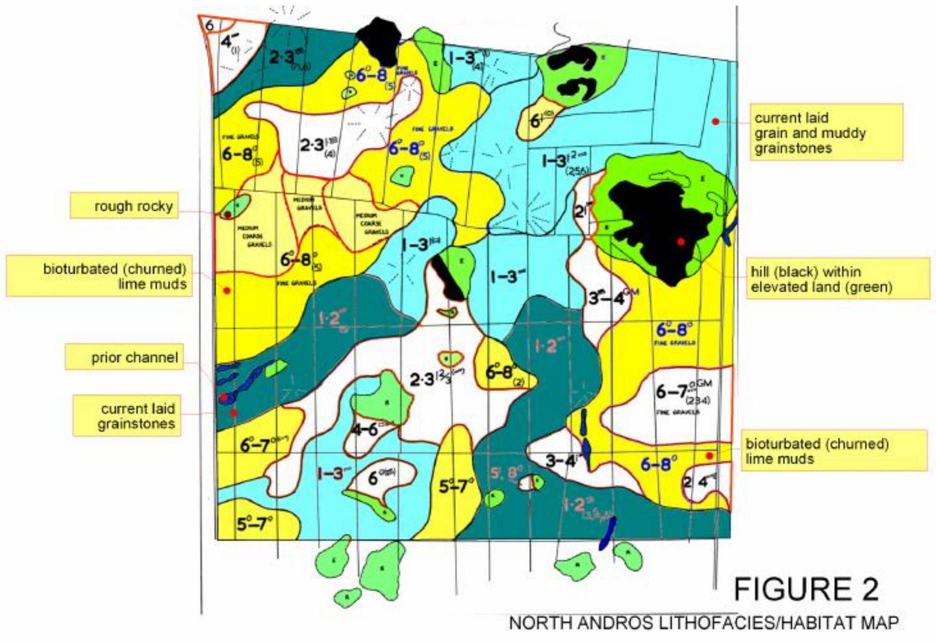


Fig. 1. Location map

In the final and detailed Andros survey the chosen method required the author to walk in 45m from the track; to then walk 45m out at right angles and to record by examination of at least 10 hand specimens, the identity of fresh broken samples of limestone. A number of other observations were made regarding surface, hardness presence or absence of 'castles', sedimentary structure and soil content, The qualities observed were recorded as an index fraction of six variables. In some cases (where the lithofacies was clearly understood by inspection) the sampling was abbreviated. The limestone rock characteristic was described in a series: from wholly muddy to wholly grainy; whether with burrows or whether bio-turbated (churned) by the paleo population including both 'in mud' dwellers, surface vegetation and wading birds (at the time of deposition); whether thinly, coarsely or massively bedded by wave oscillation or current action or speculatively, the prior site of mangrove growth. A measure of soil penetration, volume of 'dead rock' (ie rock that would have to be wind rowed), and rock fragility was also recorded. All of these were seen to have a direct relationshsip to 'ploughability' in land preparation. A tabulated distillation of the types encountered is presented in Fig. 3. A set of 15 characteristic ground surfaces (see Fig.4) was drawn up to illustrate each of the types.



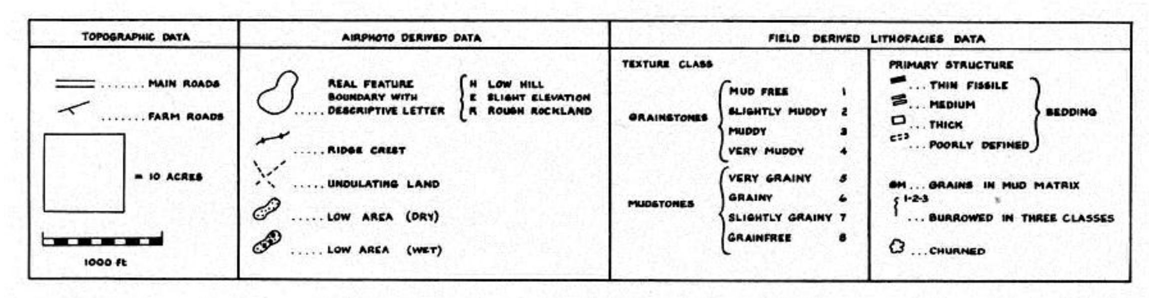


Fig. 2a: Key to Andros Mapping

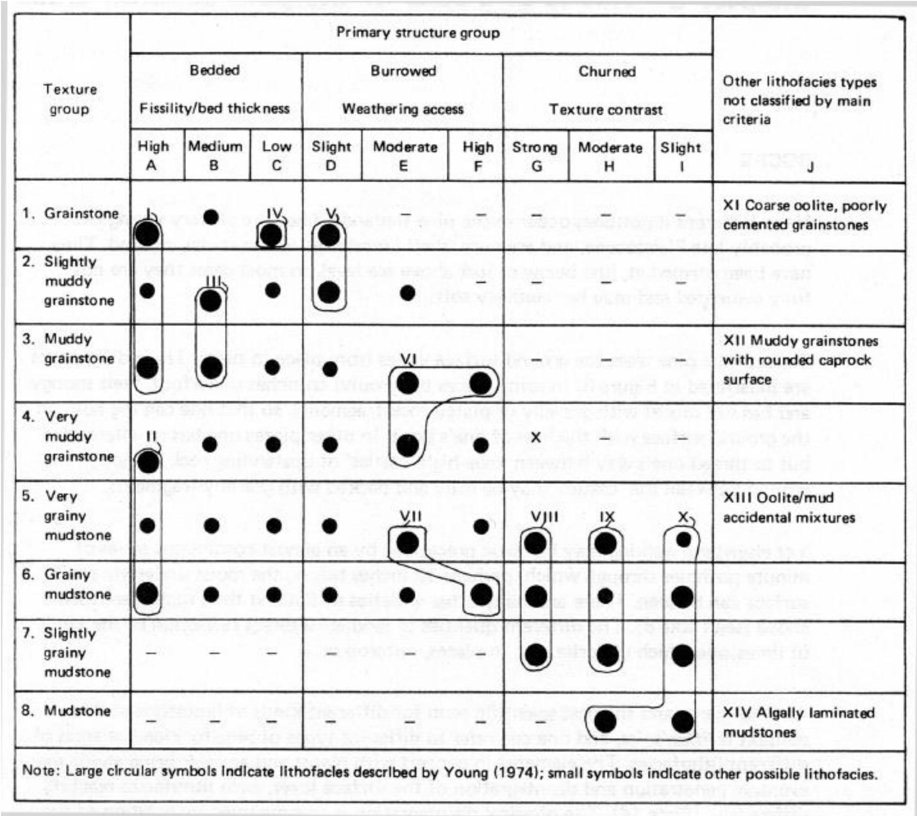
The mapping of Andros (as a whole) and of the USAID programme area – which later became BARTAD (the Bahamas Agricultural Research Training and Development Area) - began as a routine mapping of land capability especially for development of potentially arable land from the corroded (karstified) rock surface. As it progressed to the detailed survey it was clear that, from the observed surface of limestone rockland (which in common usage had always been referred to as a single surface type called 'Pine Barrens'), a paleo-habitat map emerged. This was cryptic and invisible without detailed survey lying as it did beneath pine forest and shrub understory. It was also apparent that this related to the prior environments of deposition. It was at one and the same time a geological lithofacies map and a 'prior intertidal marshland habitat map'. This distribution of lithofacies (limestone types relating to particular energy environments) is compared here with the habitat distribution (see Figures 5 and 6) in Shroud Cay a modern tidal and intertidal marsh. Shroud Cay is seen as a modern day example of the prior environment of the North Andros Study area. This is further explained later in the text.

Fig. 2b: Andros Oblique Oblique

Outcome: North Andros Study Area: An early stage of juvenile karst.

Karst, the landscape of weathered limestone is widely studied. Jennings J.N. (1971). The literature offers many examples of major karst features dolines, solution pits, caverns, towers, limestone pavements etc., etc. Also referred to in the most texts is microkarst or 'Minor solution sculpture' (Jennings). As far as this author has researched none of the microkarst features resemble those found on Andros where karst processes have affected a varied pattern of recently emerged, recently lithified limestones.

The very nature of the ground surface beneath the pine forest cover (see Fig.4) offers a significant view of this juvenile karst formation on a recently emergent limestone land surface. The karst surface is accompanied by minor volumes of yellow brown or darker brown soils which vary in amount from 'barely any' to 'a considerable volume'. Depending on the lithofacies, soil penetrates into (or sits on) the surface, ranging from 'no penetration' 1-2cms on 'cap rock' to more than 100cms in strongly burrowed or fine bedded deposits. This had and has a great significance to the use of such land for arable preparation and subsequent agronomic performance. The study grouped many intergrades into fifteen characteristic ground surfaces of juvenile karst (see Fig. 3). These characteristic surfaces are shown (see below) to relate to the prior sedimentary environment.



Texture group	Primary structure group									Other lithofacies types not classified by main criteria
	Bedded Fissility/bed thickness			Burrowed Weathering access			Churned Texture contrast			
	High A	Medium B	Low C	Slight D	Moderate E	High F	Strong G	Moderate H	Slight I	J
1. Grainstone	I ●	•	IV ●	V ●	–	–	–	–	–	XI Coarse oolite, poorly cemented grainstones
2. Slightly muddy grainstone	•	III ●	•	●	•	–	–	–	–	
3. Muddy grainstone	●	●	•	•	VI ●	●	–	–	–	XII Muddy grainstones with rounded caprock surface
4. Very muddy grainstone	II ●	•	•	•	●	•	x	–	–	
5. Very grainy mudstone	•	•	•	•	VII ●	•	VIII ●	IX ●	X •	XIII Oolite/mud accidental mixtures
6. Grainy mudstone	●	•	•	•	•	●	●	•	●	
7. Slightly grainy mudstone	–	–	–	–	–	–	●	●	●	
8. Mudstone	–	–	–	–	–	–	–	●	●	XIV Algally laminated mudstones

Note: Large circular symbols indicate lithofacies described by Young (1974); small symbols indicate other possible lithofacies.

Fig. 3: Andros lithofacies tabulated sharpened

It is also significant that this wide variety of juvenile karst is not seen on flat land areas of Cat Island nor in any of the coppice islands studied. It appears to be confined to the pine islands (Abaco, Grand Bahama, Andros, New Providence). It may relate to surface age (ie juvenile) or to the effect of a high fresh water table, or to the influence of the pine forest vegetation.

Outcome: The prior sedimentary environment of the North Andros Study Area

What was also apparent was that the BARTAD study area, North Andros, contains landform surfaces of two ages the older ones having stood clear of later sedimentation acting to control it. These are shown in the BARTAD lithofacies map (Fig. 2) and its key/legend Fig.2A where the earlier landform is identified by E – slight elevation, R- rough rockland and H- low hill Also that the most recent emerged land surface (the major part of the North Andros study area) was previously intertidal/supratidal marsh and associated marine elements. For this comparison I refer to the Habitat Map of Shroud Cay in the Exumas (see Fig. 6) and explanation in the following paragraph.

Shroud Cay is of comparable size to the North Andros Study Area (BARTAD) and forms a near perfect comparative model of habitat (*vide* Shroud Cay) and sedimentary lithofacies (*vide* Andros). The west-east width of Shroud Cay between prominent coastal points is 2.4 km while the width of the North Andros Study Area between the main N/S logging haulage and the so named Queens Highway is 3.1km. Shroud Cay first came to the author's attention as a sedimentary model, during repeated flights along the Exuma Cays while travelling from George Town, Exuma to Nassau.

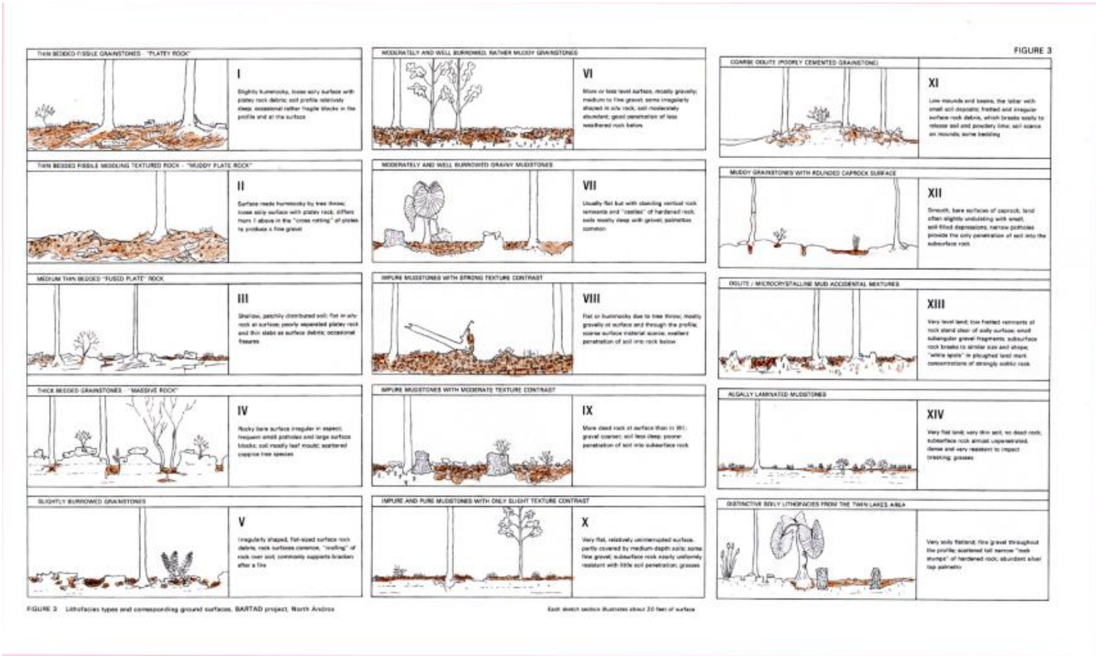


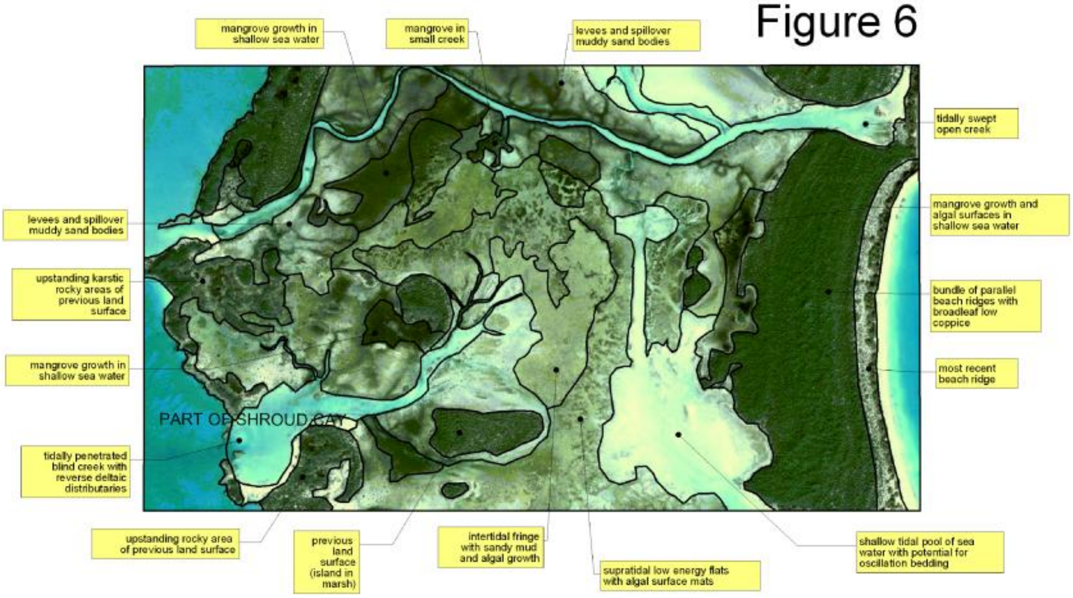
Fig. 4: Andros Karst Surfaces - Surfaces Andros

Fig. 5: Shroud cay location of marsh

The North Andros Study Area compared with Shroud Cay

Shroud Cay (part of the Exuma chain of cays) is mapped here (Fig. 6) using the Google Earth image supported by 1:36,000 scale grey scale infra red aerial photography (dated May 1967) the latter viewed stereoscopically.

Figure 6



What stands out in Shroud Cay is the distinction between high, medium and low energy environments of deposition which include: a tidally swept open creek; a tidally penetrated blind creek with reverse deltaic distributaries; a tidally affected area – a shallow tidal pool of sea water - with little current velocity but potential for oscillation bedding; channel overbank deposits (levees) which are augmented by twice monthly spring tides and by exceptional storm surges, and low energy intertidal areas dominated by organisms and acting as feed sites where mud becomes pelleted; supra tidal mud surfaces dominated by algal growth; sites of mangrove growth in shallow water and upstanding rock areas of a previous land surface which now form islands within the marsh. The whole of Shroud Cay is protected from the deep water of the Exuma Sound by a bundle of parallel beach ridges, now fossil and lithified and carrying a low broadleafed vegetation cover. This sedimentary/habitat model finds many parallels in the North West Andros study by Shinn et al (1969) and Ginsburg et al 1973.

The connection then with the North Andros study area is that it can safely be assumed that North Andros was built up on the same sedimentary model as Shroud Cay but is now emergent, the sea level having fallen by about 2 or 3 metres. It (the North Andros Study Area) is dry land and carries natural pine forest and has a microkarstic surface which relates directly to the lithofacies of the comparable wet marsh habitats of Shroud Cay. Beneath the surface at variable but small depth (about 1.5 metres) lies a freshwater (Ghyben Herzburg) lens which hydrostatically sits supported on saltwater a little above sea level and moves up and down with the tide.

Method: Cat Island

Airphoto interpretation using stereoscopic viewing of 1:10,000 scale greyscale photography and x3 magnifying binoculars was the key to the mapping of Cat Island. This was followed by traverses along drivable tracks across the short width of the island and throughout. The ground survey focused on the ground surface, the vegetation and any characteristic morphologies, soil if any and small scale karst features. These were related to hand specimens under a 10x lens. The hilly areas were also categorised and mapped by slope value with steeper slopes being a valuable indication of dune slip fronts. This was done using the aerial photography, taking advantage of the tendency for slope exaggeration in the specific (wide angle 6 inch lens) aerial photography used. Interestingly, the patterns of traditional cut and burn farming in part defined different lithofacies types or at least bared the land surface so that the ground surface might be seen. Some lithofacies based land types were sought after, some avoided.

A caveat

The author acknowledges that the lithologies recorded in the map of Cat Island are based on only 400 sampling points about half of which specifically recorded lithology. Others recorded surface rock, vegetation, soil distribution, small depressions (banana holes) and large caves ('culander land'). The morphology and dune units identified in stereo airphoto interpretation held these observations together and offered a landscape scale view. Further ground survey would benefit the study.

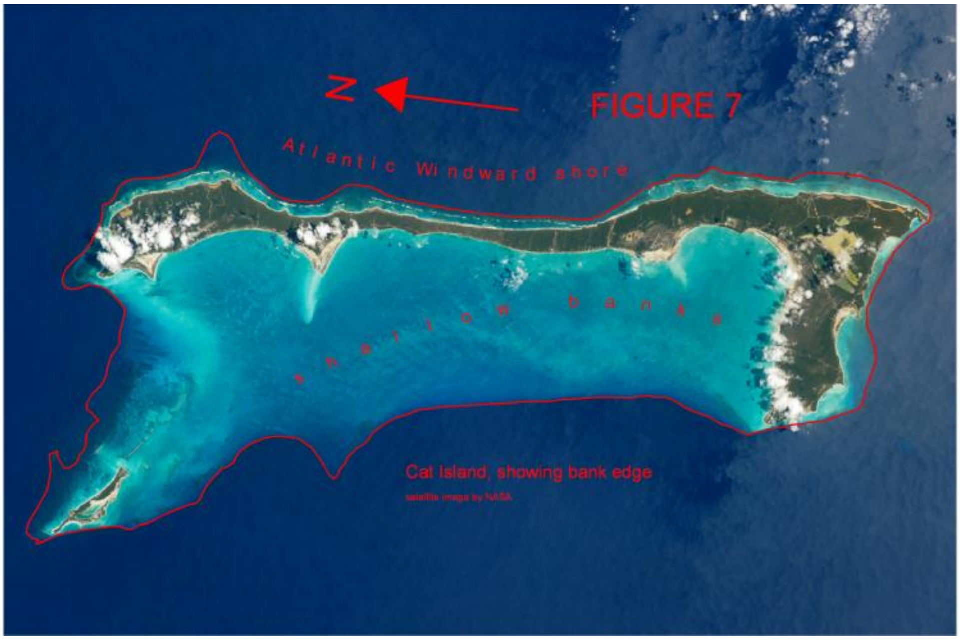
As the Cat Island survey progressed it became apparent that the patterns of landform and sedimentation related to different sea level stands of the Pleistocene and Holocene periods and the author took a decision early on to map the different fossilised (lithified) dunes in detail. The author was not aware at the time (1971) of any research to support this. It was done not as academic research in its own right but as the by-product of land capability mapping. Subsequent papers, Carew and Milroie (1997), Hearty (1998), have examined the dunary successions in detail but for a number of restricted areas of outcrop in other islands (Eleuthera New Providence San Salvador, Lee Stocking Island in the Exuma Chain) and have drawn interesting conclusions regarding sea levels.

Outcome, Cat Island: the very different Cat Island sedimentary model

The NASA image of Cat Island is presented as Fig. 7. The margin of the Cat Island shallow bank to which it forms an elevated rim is indicated by a red line which holds to what the celebrated Andros diver Archie Forfar referred to as 'the drop off' where the bank descends abruptly to great depth. A large part of the perimeter of the Cat Island Bank terminates abruptly in this way at about 10 metres depth, but where it *slopes* down (rather than plunges), the sea floor may in places be seen through the clear water to an estimated 20 metres. These latter areas have been included within the red line. The Atlantic Ocean side of Cat Island faces roughly east north east and lies across the formative winds.

Cat Island is a coppice covered island of low relief with few identifiable landform elements. It rises to 205ft above sea level which happens to be the highest point in the Bahamas. That said it is low and appears at first inspection to have few interpretable features save for distinctive sandy coastal beach spits and ridges (the recent sands along the coastal edge), level low, flat - though sometimes faintly ridged - land in the west and numerous shallow ponds. Some of these ponds are less and some more saline. Extreme hypersalinity is associated with elongate shallow ponds which stand impounded between sandy coastal deposits and the inland areas. They are the habitat of gelatinous red algal mats and this can be seen on the NASA image.

A reconnaissance visit straightway showed a clear difference between distinctive denser limestones associated with red aluminous lateritic soils, (as analysed at the University of the West Indies by Ahmad and Jones (1969)), of the type which elsewhere may have been referred to as terra rossa paleosols. These stood in contrast to less hard limestones with shallow brown immature lateritic soils and even less soil rich land (lithosols/protosols) and bare rock. Hearty (1998) proposes that limestone soils in Eleuthera redden with age and has used this observation to date paleosols between dune units. Source material may also be a factor in soil colour.



What emerged from the airphoto interpretation was as shown on Fig. 8 an extract map of dunes sequences in south Cat Island. This interpretation was based on the vegetation cover and the morphology of the low hill land. It particularly made use of steep and less steep slopes which appeared to correspond with dune front slip faces. The present day active, uncemented and lightly cemented coastal dunes suggested the (obvious) model: that the principal process of land formation at this high energy Atlantic edge of the Bank was dune formation.

Examination of the map (Fig. 8) which is part of the map at 1:25 000 scale in six sheets of the whole island, displays as many as six consecutive lines of dunes each suggesting a separate period of dune formation. Also clear is that these vary between (1) the furthest west, near pure oolitic deposits - these are of the kind precipitated on the seafloor of shallow banks, then exposed for a period to formational winds. These winds swept up accumulated deposits of sand into dunes and moved them across a sensibly level platform surface. And (2) detrital mixtures of coral algal and shell fragments (bioclastic grains) together with peloidal grains (faecal pellets) and (3) uncemented Holocene/Recent dunes with associated beaches and some flat sands.

This succession of dune phases in Cat Island can be interpreted in the way that they are arranged (their position) on the Bank and by their distance from the abrupt Bank edge, the latter offering an indication of the potential width of lagoonal offshore (the sediment production area). They also relate one to the other: a later dune may ramp up (to give stratigraphic superposition - Carew and Myroie (1997) record that wind blown sand may be deposited 30 metres above the shore and may bury earlier dune forms and preserve older dunes - or may fill in gaps in an earlier dune, or lie downwind (eg the new dune fails to reach as far onto the Bank as its predecessor dune) or be obstructed by the remnant of an earlier 'wasted' limestone mass which may or may not be of dune origin. Retrospectively some of these non dune masses are seen as marine plumes forced tidally through island gaps.

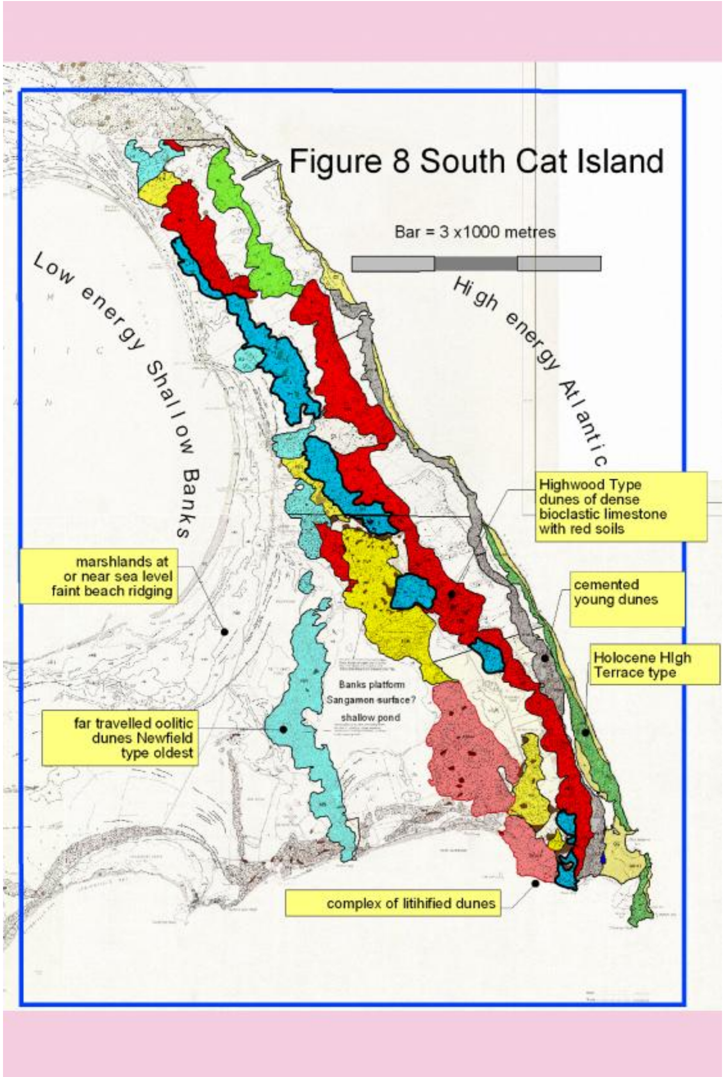


Figure 8 South Cat Island

It also appeared (though more detailed lithological work is required) that the sedimentary composition of dune masses may (logically) vary along the depositional strike, which is the long axis of the island. To explain the latter: though of the same age adjacent dune masses will predictably comprise different lithologies dependent on the available grains in their different source areas. This variation is recorded in the map legend as the table of 'Dune units on the Map' (see Fig. 9). The map cautiously adopts a selection of local names (eg Dolphin Hill, Newfield, Highwood etc) to identify the dune masses. These are described in more detail in the map legend.

The most mobile deposit mapped in Cat Island is that comprising small oolitic grains which themselves are spherical and move readily. Such a dune is exemplified by the Newfield Type, among the oldest which displays complexity both of outline and internal slope and counter slope. It appears to have preceeded all other visible dune units and perhaps lies on a marine and intertidal low level surface which Carew and Milroie (1997) have suggested is of Sangamon (Pleistocene) age. It may be of interest to note that the depositional strike of this dune lies north and south and thus not across the modern prevailing wind and not to the same direction of later dunes.

DUNE UNITS ON THE MAP

DUNE UNIT	MAP SYMBOL	LIMESTONE CHARACTERISTICS	LAND FORM	RELATIVE AGE
DOLPHIN HEAD TYPE	DH	Very well cemented,	A straight hard narrow low ridge with short but steep slopes, rising to 50 feet from a flat base.	Oldest unit recognised.
NEWFIELD TYPE	ND	fine grained oolite.	Aligned steep very rough low hills, rising to 175 feet from a flat base; many solution pipes.	Contemporary with DH or younger.
DOVEDALE and KELLY HILL TYPE	D/KH	Partly recrystallised medium grained sediment containing skeletal grains, pellets and oolites.	Both broadly based hills, rising to maximum of 100 feet, and smaller hills; slopes relatively smooth, no major slope breaks.	Contemporary with or possibly older than M/R but younger than ND.
MOUNT VIEW and RED HILL TYPE	M/R	Much recrystallised fine grained sediment containing mostly skeletal grains.	As above, but maximum height of 150 feet, slopes exceptionally smooth and rounded; soil bodies found in mid-slope positions.	Younger than ND.
SANDFLY HILL TYPE	SH	Moderately cemented medium grained	Complex indefinite gently sloping hilly land, adjacent to and usually lower than the Highwood type.	Younger than M/R.
HIGHWOOD TYPE	HD	sediment comprising oolites and faecal pellets, with some skeletal grains.	Distinctive dune shape, characteristic dune front, crestal alignment and back slope; often ramped up on older dunes to give a maximum height of 207 feet.	Younger than SH, perhaps of same general phase.
BENNETT'S HARBOUR TYPE	BHR	Compact medium grained sediment containing pellets, skeletal grains and some oolites, in a fine grained non-crystalline matrix.	Elevated tracts at 20-30 feet, mostly flat but with several chains of low arcuate hills marking weak dune fronts.	Older than WHR.
ARID "CACTUS" LAND TYPE	AL	Well cemented fine and medium fine oolite, with some shell fragments.	Elevated broadly arched land overlooking ocean; long back slope nearly to sea level; dune front slope not developed; fissured.	Older than SB; younger than BHR.
NANNY HILL TYPE	NH	Moderately well cemented, rather porous, uniform medium grained oolite.	Simple near-symmetrical ridges rising to 25-100 feet from a flat base; derivation mostly from south shore.	Older than WHR.
SMITH BAY TYPE	SB	Soft poorly cemented medium grained sediment. Perhaps lumps (Illing) or coated skeletal grains.	Steep high very distinctive dune units rising to 125-160 feet, with steep dune front slopes and long uniform moderately steep back slopes.	Possibly contemporary with WHR or perhaps older.
WARREN'S HARBOUR TYPE	WHR	Compact medium to coarse grained very shelly sediment with many whole shells.	Narrow low 10-20 feet deposit adjacent to coastal Holocene; small dune front slope; may have transverse channels.	Youngest Pleistocene unit recognised.
HOLOCENE HIGH TERRACE TYPE	HT	Loose and semi-lithified shelly and oolitic sands.	Stable part lithified often steep sand dunes up to 50 feet high. (Mapping unit also includes some beach ridge forms).	Holocene i.e. younger than 10,500 years before present.

OTHER UNITS SHOWN ON THE MAP

UNIT	MAP SYMBOL	LIMESTONE CHARACTERISTICS	LAND FORM	RELATIVE AGE
OTHER HOLOCENE SANDS	OS	Loose and semi-lithified shelly and oolitic sands.	Beach ridges and areas of flat sandy land.	Later Holocene.
VERY CAVEY "CULANDER" LAND	CL	Well cemented fine oolites.	Land of various slope categories riddled by large 10 feet wide or larger collapse caverns.	Not confined to any one age.

Fig. 9

Showing less travel are those dunes of bioclastic and peloidal origin. They were perhaps less mobile (sluggish movers); and these may have been blocked in their progress downwind by pre-existing dunes, by the contemporary growth close to the shore of vegetation (dune fixation before cementation) by light early cementation or perhaps by being blocked high ground water areas which arrested their forward movement - the latter developing into shallow hypersaline ponds which the dunes impounded.

The bioclastic (or coralgal) dune most readily recognised is that named Mountview and Red Hill type. It is dense, recrystallised, not limey on impact, shows bioclastic grains and rises to 150ft above sea level with exceptionally smooth and rounded slopes and with red aluminous lateritic soils found both mid slope and in slope base positions.

Examination of present day literature

At the time of the field surveys leading to the information in this paper there had been little published about Bahamian onshore geology or landform. An exception was the paper by Shinn et al. (1969) which sees wet areas of West Andros as a model for petroleum stratigraphers and an example of dolomite formation. A study by Land et al. (1967) on the dune and other landforms of Bermuda proved of value as did a generalised study of intertidal deposits for example Ginsburg et al. (1973). There was much more information on offshore (Banks) carbonate sedimentation environments and lithology in the widest sense. This offered information of commercial importance to petroleum geologists and has been augmented by later studies.

Since the present study was made (as reports and maps to the Bahamas Government 1969 to 1974 and then to 1977) there has been a widening of research regarding onshore geology. Much of this has focused on the small island of San Salvador where there is a privately funded research and field studies station (the Gerace Research Station, identified as part of the University of the Bahamas). Other research has investigated sites of limited extent on Eleuthera, New Providence and Exuma. A list of publications at 1997 is listed in Carew and Mylroie (1997).

The findings outlined here are supported or illumined by information from the papers cited. The findings themselves may offer important supportive information at landscape level. This paper which is principally based on a resource survey, does not claim nor is competent, to make any detailed evaluation of the work of others.

Commentary regarding the North Andros Study Area as an example of prior sedimentation on part of a Shallow Banks island, the following:

- Shroud Cay accords closely or can be explained by the tidal flat environment recorded in Shinn et al. (1969) who however never overtly regarded their study area as habitat. Shroud Cay comprises two visible phases of sea level, one of contemporary (Holocene) deposition functioning around a second which comprise a number of eroded land mass limestone areas of an earlier part submerged land surface.
- The Andros study area (which bears close comparison with Shroud Cay) is a juvenile karst based on tidal flat deposits now lithified and mostly sitting 1-2 metres above present fresh water table which approximates to sea level. Within it are small areas of prior karst surface making low hills, rocks and elevated area. These prior surfaces appear to have controlled to some extent later phase of marsh deposition in the same manner as currently such prior surfaces do in Shroud Cay. Prior surfaces also speak of even earlier phases of deposition.
- It is generally accepted that the Bahamas platform has been subject to minimal tectonic subsidence and this relative land/sealevel change is discounted in the discussions read.
- It has been suggested, see for example Carew and Mylroie (1997), that the surface lowering by dissolution of the limestone is in the order of a few metres per 100,000 years. Accordingly, the surface of the Andros Study area will have been lowered (weathered down) from its lithified tidal flat origins. It is tempting to equate the degree of lowering with the height of the hardened 'rock castles' as seen in Lithofacies type IX (see Figures 3 and 4) which rarely achieved 60 cms. The actual process of lowering is complex and lithofacies dependent.

Commentary regarding Cat Island as example of a dune built Atlantic Windward island, the following:

- The number of phases of sea level change is proposed by Hearty (1998) as *"at least six broad interglacial sea-level cycles (10^5 year cycles) combining several intervals of prolonged platform emergence (10^4 being 20,000 - 40,000 year cycles)* and *'minor ecological or eustatic oscillations' (10^3 year cycles) indicated by protosols"*…..and [he adds]
- "*Stage 5 is indeed complex. Three major depositional phases are recognized: two oolitic complexes associated with significant sea level oscillations within substage 5e (authorities are quoted), and a final substage 5a event separated from substage 5e by a reddish paleosol. Extensive skeletal eolianite ridges were deposited throughout the [Atlantic] windward Bahama Islands".* This would support the mapping observations given in this paper which define at least six dune phases..
- Bioclastic deposits relate to transgressive periods in which there was a larger lagoonal area supplying bioclastic materials. The width of this lagoon varies along the Cat Island shore as can be observed in the NASA image. It is/was wider in earlier times when the onshore land was not 'crowded' by existing dunes.
- That observations within cuttings [on Eleuthera] show superposition (stacking) of dune units separated vertically by paleosols.
- Carew and Mylroie (1997) also say *"sequential eolian deposits are often situated lateral to one another – not necessarily atop one another, as is the more common situation among other sediment facies."*
- Also that at times of high sea level - Carew and Mylroie (1997) suggest sea level surpassed its present datum by up to 6 metres and flooded the shallow banks. This they date to the Sangamon or last interglacial about 125ka BP. The shallow banks at that time acted as *"a carbonate factory [which] produces abundant sediment; and relatively unvegetated dunes form and prograde landward as sea level continues to rise to its acme".* These unvegetated dunes principally comprising oolites would be swept up into dunes from the then emergent surface. They appear to correspond most clearly to this paper's Newfield type. These appear to be the joint oldest of the dune sequence and seen as landforms which may have moved across an unimpeded platform.To the airphoto interpreter/geomorphologist they show a sense of 'fossilised movement.'

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