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QUATERNARY SEDIMENTATION IN THE LAKE ST. LUCIA AREA

A PROGRESS REPORT

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INTRODUCTION

Lake St. Lucia is a large saline lagoon on the Zululand coastal plain. It is separated from the Indian Ocean by a compound barrier, the basal portions of which consist of calcareous sandstones bearing raised marine cut terraces. These are surmounted by semi-consolidated sandstones and the loose sands of the high coastal dunes, which attain elevations of 180 metres.

The lagoon comprises two north-south trending bodies of water, False Bay and Lake St. Lucia proper, with a connecting strait known as Hells Gate (Fig. 1). The total surface area fluctuates between 225 and 420 km^2 depending upon lake level. This is in turn determined by the relative intensity of inflow and evaporation, varying from a position some 1.1 metres above mean sea level following floods to below sea-level during times of drought. Fresh water is contributed largely by the Nyalazi, Hluhluwe, Mzenene and Mkuze Rivers, with a combined annual discharge of 452×10^5 m^3. The Narrows, a shallow winding channel, is the only outlet, extending 21 km to St. Lucia Estuary. The occasional negative gradient accompanying low lake levels creates reverse flow of sea water up the Narrows into the Lake. Prior to its artificial diversion in 1952 the Umfolozi River, with a discharge greater than the total freshwater inflow into the Lake, flowed into the Estuary. It now enters the sea 1.5 km south of its former outlet. Tidal amplitudes of up to 106 metres in the Estuary are totally absorbed within the Narrows. Rapid wind induced changes in Lake level are common however.

False Bay and the western shores of Lake St. Lucia are incised into Cretaceous strata. The gentle seaward dip exposes progressively younger stages from the Neocomian of the upstream Mzenene to the easternmost exposure at such localities as The Coves and Charters Creek which probably span the Mesozoic - Cenozoic boundary into the Paleocene.

These rocks are sporadically overlain at an elevation of 10 metres by Upper Tertiary coquina ("pecten bed") and sandstone. Above these are the unconsolidated red, brown and grey sand deposits which mantle the coastal plain. The most conspicuous topographic features are north-south oriented dune ridges, the larger of which are composed of red sand. To the west of the Lake these commonly have a boulder bed at the base.

In False Bay there are fossiliferous late Pleistocene deposits with a fauna indicative of unrestricted marine conditions. These must have accumulated prior to the development of a continuous seaward barrier. At a later stage the barrier was more substantial and had a profound influence on the nature and rate of sedimentation. It is the purpose of this paper to outline the salient sedimentary and geomorphic characteristics of the barrier and lagoon and to relate these to the processes involved in their development. It is apparent from the outset that the dominant factor has been eustatic changes in sea level.

Most of the data were obtained from the study of surface exposures and shallow auger samples. Important information concerning the sediments beneath the Lake bed was provided by seven continuous cores. These were obtained during the latter half of 1973 through the efforts of Mr. T. Blok in charge of St. Lucia Reclamation, and extend from the sediment-water interface to Cretaceous bedrock at a maximum depth of over 30 metres. Foraminifera, ostracods, diatoms and a variety of macrofossils have been set aside for specialist examination.

CALCAREOUS SANDSTONES OF THE BARRIER

Several distinct stratigraphic units are exposed along the seaward side of the barrier, but the sandstones do not

outcrop on the landward margin. Certain units are correlative with outcrops in the Durban area described by a number of authors including Krige (1932), King and Maud (1965), McCarthy (1967) and Maud (1968).

UNIT 1

The oldest deposits of the barrier consist of fine to medium-grained sandstone which is best exposed at First Rocks and Bats Cave (Fig. 1). This is probably equivalent to the "Bluff Beds" of Krige (1932) or the "first aeolianite" of Maud (1968). It extends from an unknown depth below sea level to a maximum observed elevation of 8 metres. The higher parts have been subjected to considerable karst weathering.

Large-scale cross-bedding is a characteristic feature. Dips range from 8 to 36 degrees and are variable in azimuth, although a strong westerly component is evident in most outcrops (Fig. 2). Foreset laminae commonly display evidence of minor slumping prior to lithification. In thin section the rock is seen to consist predominantly of well sorted subangular to rounded quartz grains with diagenetically altered shell fragments and a sparite cement.

These attributes together support the interpretation by Belderson (1961) and McCarthy (1967) of an aeolian origin for the equivalent formation in Natal. Sand was presumably piled up as coastal dunes during a stage of eustatically lowered sea level. Ample sand would have been available from a belt of emergent continental shelf several km wide. Present day prevailing wind directions are from the northeast and southwest, flowing roughly parallel to the shoreline. During glaciations however, temperative contrasts between land and sea would have been increased, thus leading to a higher frequency of strong onshore winds.

This accounts for the high proportion of landward inclined foresets in unit 1.

At certain localities, such as Bats Cave, these aeolian sandstones are truncated by a flat, horizontal erosion surface at between 4 and 5 metres above sea level. Elsewhere they are preserved to a height of 8 metres or else eroded to a lower level, frequently below present sea level.

UNIT 2

The undulating erosive surface on unit 1 is overlain between spring low tide level, or possibly lower, and an elevation of up to 5 metres by coarser grained sandstone, which is conglomeratic in part. These rocks, here referred to as unit 2, are subdivisible into two distinct facies on the basis of differences in sedimentary structures, and to a lesser extent, on lithology.

The first type consists of low-angle, eastward-inclined planar foresets of medium to coarse-grained sandstone with small discoidal and blade-shaped pebbles composed largely of lydianite. Well defined parallel lamination dips seaward at between 4 and 10 degrees. Microscopic examination reveals that these sandstones are less perfectly sorted than the aeolian deposits. They contain up to 10 percent feldspar, a variety of mollusc and echinoderm fragments, plus forminifera and algae. These deposits strongly resemble the upper foreshore of modern beadies. The preponderance of flattened pebbles of small size (less than 3 cm maximum diameter) was a product of size-shaping sorting processes that operate in the swash zone, and the eastward dipping stratification records the successive profiles of a prograding beach. Local discontinuities mark changes in the beach profile.

The second facies occurs at a lower level (Generally below metres) but is gradational into the upper foreshore beds. It

is trough cross-bedded sandstone, very similar in lithology to the beach deposits, but differing in the shape of the pebbles. Both flat and equant shapes are represented, and many are almost perfect spheres. Furthermore, the maximum size is slightly larger, some pebbles attaining diameters of 15 cm.

Whereas discoidal and blade-shaped pebbles are selectively cast up on a beach, shape sorting results in a larger proportion of equant pebbles being concentrated below low tide level. Thus it appears that these trough cross-bedded sandstones originated in a lower foreshore environment.

Measurement of trough axis azimuths (Fig.) reveals that the currents which deposited these sands flowed in directions which were roughly parallel or perpendicular to the existing shoreline. Since the late-Pleistocene shoreline trend was undoubtedly very similar, these were therefore longshore currents. Modern day patterns along certain sections of the Natal and Zululand coasts are very similar. Both northward and southward flowing currents are observed at different times. The off-shore directed cross-beds possibly reflect rip current effects such as can be observed today with parallel wave incidence.

The upper foreshore facies of unit 2 extend to a maximum elevation of between 3.5 and 5 metres where they are levelled by the same erosion surface that locally truncates the older aeolian deposits of unit 1. Thus the high water level corresponding to the deposition of these beach sands must have been a little more than 5 metres above present sea-level. A poorly preserved 8 metre surface at Bats Cave possibly corresponds to this level. Deposition must therefore have coincided with an interglacial higher sea-level which succeeded the low stand during which the aeolian sandstones (unit 1) accumulated.

During the ensuing marine retreat, probably related to an

interstadial of short duration, these shoreline deposits were lithified, and together with the older sandstones, subjected to karst weathering. Renewed advance of the sea above its present level planed both aeolian and beach deposits along a seaward sloping surface between 5.3 and 3.4 metres.

UNIT 3

A thin veneer of coarse pebble conglomerate mantles this younger wave planed surface, filling in both karst depressions and potholes produced by marine abrasion. The thickness of this unit is therefore highly variable, ranging from a few centimetres to 2 metres. The inclusions consist of locally eroded clasts of calcareous sandstone together with a variety of extrabasinal pebbles. A discoidal shape predominates. Some of the inclusions are of boulder dimensions, the largest encountered measuring 65 cm in diameter. The mean diameter is approximately four times greater than that of the pebbles in unit 2. Compositionally quartzite pebbles are most numerous followed by lydianite and gneiss. Large numbers of oysters and other abraded mollusc fragments are present locally. It is possible that some are preserved in situ in potholes where they lived.

Unit 3 is ascribed to transgressive shoreline processes which characteristically deposited coarse shingle. The fact that the coarsest material is preserved in fossilised potholes suggests that these were the tools responsible for the scouring of the potholes, some of which are distinctly underent. This vigorous action broke off blocks of the older sandstone which were later incorporated in the sandy matrix.

The superabundance of pebbles derived from the hinterland suggests that in addition to the Umfolozi other large rivers may have been providing this material, with outlets further north. There is however a northward decrease in the maximum dimension of

these inclusions (Table 1) suggesting that the competence of the Umfolozi considerably exceeded other rivers in the area. Larger pebbles are encountered to the north of the Umfolozi than to the south, indicating that beach drift patterns were the same as they are today.

Maximum high water mark corresponding to this episode was a little above 5 metres above present sea level. This interstatial was thus considerably lower than the previous.

UNIT 4

An aeolian sandstone very similar in sedimentary composition, texture and structures to unit 1 overlies a 4.4 metre high pebble veneered eroded surface at Bats Cave. The foresets are inclined westward at angles of 35 degrees. This sandstone was apparently not deposited to any great thickness, extending to an elevation of only 10 metres. Nevertheless, the karst and decalcified upper portions suggest that some of the overlying sands were derived by leading of the sparite cement in unit 4.

The limited distribution and thickness of this deposit suggests accumulation during a brief and minor lowering of sea-level related to a stadial. A narrow belt of exposed sand would have been subjected to deflation, and the sand accumulated against the older deposits of the barrier.

UNIT 5

Evidence for at least one further rise in sea-level above the present shoreline comes from a second generation of potholes incised through unit 3 and commonly extending into unit 2. These potholes differ from the older variety associated with unit 3 in the development of outflow channels produced by seaward runoff and in the character of the fill, which consists largely of oysters.

The oysters occur most abundantly within 1.5 metres of modern spring high water mark. Many adhere to the sides or to one another in living position and there are few reworked fragments. Potholes at elevations of up to 4.5 metres contain reworked oysters and discoidal pebbles.

CORAL BEDS OF FALSE BAY

The only other consolidated Quaternary deposits, apart from hardpans, are highly fossiliferous limestones which crop out at three localities on the western margins of False Bay (Fig. 1). The same unit occurs intermittently along a shallowly submerged shelf bordering these outcrops, and at three isolated localities within False Bay and Hells Gate, where they extend to within a few cm of the surface.

These rocks overlie an uneven eastward dipping surface eroded on Cretaceous siltstones (Fig.). They extend to a maximum observed elevation of 3.2 metres a.s.l. The upper surface has probably been lowered by solution weathering, as evidenced by a karst surface.

Fossils include a variety of corals, many of which are colonial scleractinians preserved in growth position. Small brachiopods are common. Of the molluscs, oysters and five varieties of pecten are abundant. Practically all are disarticulated, and the valves have no preferred disposition. Gastropods, although occurring in a variety of shapes and sizes, are less numerous. Also present are crab remains, sponge and echinoderm fragments, and the chirriped Balanus. Trace fossils are mainly large (1 - 4 cm diameter) branching dominantly vertical forms which include Thalassinoides and Ophiomorpha, a calianassid burrow.

Thin section examination reveals that the bulk of the allochems

consist of broken mollusc fragments, foraminifera and red algae, with a variable proportion of lithoclasts, mainly quartz with a little feldspar. According to Folk's (19) classification this rock is a biosparite, a well sorted, moderately high energy deposit, with a calcite cement. Spherical to discoidal pebbles of rhyolite, basalt, jasper, chert and lydianite are abundant in the lower parts of the exposures, decreasing upward in size and number.

These deposits have been dated radiometrically as older than 50,000 years (U.C.L.A. No. 1830). Their lithology and faunal content point to a relatively unrestricted, high energy shallow marine situation in close proximity to the shore. Sea-level was at least 3 metres above the present, and the water temperature possibly a few degrees warmer. It appears therefore that False Bay was at this time a marine embayment with Hells Gate opening directly to the sea. This would have been contemporaneous with one of the stages of levelling of the barrier sandstones to seaward. These would have resembled some of the shallowly submerged "reefs" off the present day Natal coast, e.g. Aliwal Shoal and Glenton Reef. Living corals were restricted to areas of free circulation in the vicinity of Hells Gate, and have not been encountered as fossils in those areas of False Bay which would have been very sheltered or periodically diluted by fresh water inflow. The Hluhluwe River probably discharged to the west of its present position near the Picnic Point outcrop. It is possibly significant that fossil molluscs and brachiopods are particularly abundant at Picnic Point, whereas the greatest abundance of large <u>in situ</u> corals is at Listers Point, well removed from any former river outlet and opposite Hells Gate.

SANDS OF THE COASTAL PLAIN

Several distinct varieties of unconsolidated sand mantle the coastal plain. Prominent N-S trending dune ridges consist largely of homogeneous red sand, but are commonly coarser towards the base. Six dune cordons, decreasing in age from west to east, have been

mapped by Davies (1974).

A thick basal boulder bed occurs in the lowermost parts of the western cordons, e.g. at Bushlands Halt. This is replaced eastward by scattered pebbles and pebble bands at all elevations. A kilometre inland from Fanies Island Rest Camp pebbly very coarse-grained sand attains a maximum thickness of 8 m. Heavy mineral laminae, containing up to 60 percent zircon, rutile, magnetite, garnet and ilmenite, occur interlayered with quartz, sand, which itself displays textural banding. Pebbly coarse-grained beds 1-15 cm thick alternate with finer material in approximately the same proportion. These layers commonly display opposed (herringbone) cross-lamination. The pebbles are discoidal and of physically resistant varieties, mainly vein quartz and quartzite. Further south near Charters Creek and in the Makakatana plantation area are similar deposits displaying low angle cross-bedding of variable azimuth, but with prominent westward dips.

These deposits are interpreted as of estuarine or shore zone origin, with indications of tidal reversal in flow. Marked westward cross-bedding inclinations preclude a normal fluviatile origin. The moderately mature composition and texture, and the predominantly discoidal pebble shape suggest energetic processes with shape-sorting on beaches or estuarine shoals.

The homogeneous red sand, which in most dune ridges overlies the boulder and pebble bearing deposits, has a median diameter in the fine-grained sand range with little regional variation. It has a maximum thickness of 50 m to the west of False Bay. Subangular to rounded quartz grains make up between 70 and 95 percent. The heavy mineral content decreases eastward from a maximum of 8 percent near Bushlands. In most samples clays constitute between 6 and 18 percent, occasionally higher. These appear to have originated by the kaolinisation of feldspar, which is almost entirely absent.

The innermost dune ridge which passes through Hluhluwe village is considered by Davies (1974) to be related to a very high early

Pleistocene sea-level. The dune bases become progressively lower eastward, and the ridges are steeper and more continuous. Davies cites this as evidence of decreasing antiquity, a conclusion which is supported by variations in the soil profile. Indurated ferruginous hardpans, a product of advanced podsolisation, are well developed in the west. Although present 5 km inland from St. Lucia Estuary this layer has not been recognised seaward of the lake.

The dune ridges are attributed to aeolian processes concommitant with marine regressions, and together with the coarser estuarine or beach deposits at the base constitute a transgressive-regressive couplet.

Very fine-grained whitish sand is intermittently exposed in a dune ridge adjacent to the western shores of Lake St. Lucia and The Narrows. It rests on the Cretaceous at an elevation of 7 - 12 m and varies between 3 and 9 m in thickness. It is abruptly overlain by pebbly coarse-grained sands.

Over 90 percent of the sand is quartz with about 8 percent calcite. It is well sorted, and unlike other sands in the area displays marked skewness. This in combination with other textural and compositional attributes is suggestive of deposition by wind. An absence of internal structures and the weathering characteristics, which resemble loess, support this hypothesis.

The coastal plain is veneered with coversands which are generally between 0.5 and 3 m thick. Some have undoubtedly been derived by leaching of red sands. This is evidenced by tongues of white sand which extend down into the red sand. There has nevertheless been local redistribution of these sands, probably during Holocene times. Ventifacts have been recovered from a quarry to the west of Fanies Island, and scattered wind faceted pebbles occur elsewhere in the uppermost pale sands.

Near Charters Creek a discontinuous thin layer of reworked hardpan is encountered between the red sand and overlying light grey sand. The gravel layer confirms that the upper sands are not simply the leached counterpart of the red sands but are substantially younger. This is further supported by marked textural contrasts. The median grain size of the coversands coincides almost exactly with the homogeneous red sands, but they are better sorted, with slight skewness. This attests to considerable aeolian reworking.

Low dunes and hummocky topography are present over much of the eastern half of the coastal plain. These are quite distinct from the larger red sand ridges from which they have been derived in places by deflation. A north-south alignment is once more evident but is less consistent. Augering reveals that these dunes consist entirely of coversands.

COASTAL DUNES

Practically continuous high coastal dunes extend from Mtunzini northward into Mozambique. They consist of light coloured almost pure quartz sand with local concentrations of heavy minerals. Grain size analysis reveals a normal distribution with a median diameter in the medium sand range.

In places the coastal dunes overlap landward onto the youngest red sand cordon, which they clearly postdate. Dune peaks attain an elevation of 188 m to the south of St. Lucia Estuary. From the estuary and First Rocks to the north they are low and insignificant. Beyond First Rocks two lines of high dunes are separated by a narrow depression. Between the southern end of Lake Bangazi and Mbotsheni are seven peaks which exceed 150 m.

Deep augering reveals an increasing percentage of heavy minerals, but the absence of a core of older consolidated deposits. The sands have been weakly calcified in places. Nor is there any

evidence of the lignite-bearing Port Durnford Formation except to the south of St. Lucia Estuary. Excavation of the seaward dune flanks reveals multidirectional cross-bedding. Occasional cross-bedding on a large scale, in sets 10 m thick, is reflected in places by patterns in the vegetation growing on the flanks (Tankard, per. comm.). This, together with the topography of the dune crests suggests that winds from the northeast and southwest have been equally effective. Both northward and southward inclined slip faces are apparent.

An origin related to a lowered sea-level is indicated by the present narrow beach, and the dominance of destructive processes which are effectively reducing the average elevation of the dunes. Northeasterly winds in particular have produced parabolic blowouts which cause local destruction of vegetation and thus accelerate deflation. Certain dune crests are actually growing in elevation (C.J. Ward, per. comm.) but this appears to be exceptional.

As with the older aeolian deposits sand would have been carried landward across the exposed sandflat. The pre-existing ridge of older cemented sands more or less coincident with the existing shoreline would have localised accumulation as an almost continuous dune belt, broken only by river outlets. The sand would have been stabilised by vegetation during the subsequent climatic amelioration. Further limited accretion of wind-blown sand along the seaward margins has..

LAKE ST. LUCIA SEDIMENTS

A coring programme conducted by the Roads Department of the Natal Provincial Administration established that sediment thicknesses are considerably greater than previously suspected. Seven continuous cores, extending from the sediment-water interface to Cretaceous bedrock, were obtained from the following sites:-

Location of Site	Sediment Depth to Bedrock
Norther False Bay	31 metres
Southern False Bay	14
Hells Gate	32
South of Bird Island	12
Southern Selleys Lake	11
Catalina Bay	8
The Narrows	15

Each core was sampled at small intervals, and the foraminiferal content is being studied by Prof. F. Phleger of Scripps Institution for Oceanography. Larger organisms, mainly molluscs, have been set aside for specialist examination. Particle size analysis proved extremely difficult in a number of samples, which were too fine even for settling analysis. The current approach is to resort to centrifuge methods in these cases. Carbon 14 analysis of selected samples is being conducted by Dr. Vogel of the Natural Isotopes Division of the C.S.I.R., and the following dates have been obtained thus far:-

Location of Site	Depth of Sample	Age
Northern False Bay	31 metres	15,000 years
Hells Gate	32	6,000
Southern Selleys Lake	10	3,700
The Narrows	7.6	3,300
	$\pm$14	42,000

Comparison of grain-size data from the various cores reveals no discernable pattern apart from a basal layer of sand (Selleys Lake and south of Bird Island) or reworked Cretaceous overlain by silt and mud with shell layers. The sand contains broken marine shells, is very uniform in texture and composition, and is probably beach or estuarine. Oysters are present in the reworked Cretaceous silt, indicating marine or brackish conditions. Associated bivalves are thick shelled and disarticulated, and include waterworn fragments indicative of high energy processes.

This relatively coarse grained basal layer is thickest in Lake St. Lucia proper, being very thin in Hells Gate and False Bay. It is overlain by silty clay containing occasional thin layers of shells

or sand. Both bivalves and gastropods are common and are predominantly small, thin shelled delicate forms. Certain cores, such as Hells Gate, are more or less constant in sedimentology and macrofaunal content above the coarser base. Carbonaceous mud, consisting on average of about 86 percent clay and quartz of clay dimensions, 10 percent carbonate and 4 percent carbon. There is a marked upward increase in foraminiferal content, mainly Ammonia. There are also scattered sand-size quartz grains with a red oxide coating which are most abundant in the lower half of the Lake sediments. These appear to have been blown in from the red sand cordons.

Detailed scatter diagrams of quantitative size data from the southern False Bay core reveal differences from bottom to top (van Heerden, 1974). The basal sediments are interpreted on this basis as an estuarine deposit, which is overlain by lagoonal muds.