ST LUCIA RESEARCH – VOLUME I

AN ASSESSMENT OF PAST AND PRESENT GEOMORPHOLOGICAL AND SEDIMENTARY PROCESSES OPERATIVE IN THE ST LUCIA ESTUARY AND ENVIRONS

By
I. Ll. van Heerden and D. H. Swart

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CSIR RESEARCH REPORT 569

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SCOPE

Flooding as a result of "Cyclone Domoina" in late January 1984 obliterated all protection works in the mouth of the St Lucia system and flushed the mouths of the Mfolozi and St Lucia estuaries wide open, thereby depositing vast quantities of debris and sediment out to sea. In addition the dredger used to maintain the St Lucia mouth was also washed out to sea, where it sank.

At the SCADCO meeting of 2 March 1984 remedial measures were discussed. Dr I.Ll. van Heerden, then of the Environmental Services Group of Specialist Offshore Services (SOS), now head, Marine Geoscience Division of the National Research Institute for Oceanology (NRIO), and Dr D.H. Swart, head of the Sediment Dynamics Division of the NRIO of the CSIR, were asked to prepare proposals to study the estuarine and coastal processes in the St Lucia area. The results of such studies were to serve as a basis for the redesign of the St Lucia mouth.

This report, written by Dr I. van Heerden and Dr D. Swart, discusses -

- the results of the monitoring of the system subsequent to Domoina;
- a refraction study to serve as input for the calculation of the longshore transport potential of the waves in the area; and
- recommendations for the improvement of the St Lucia and Mfolozi mouths.

Specialist Offshore Surveys performed most of the field work and were involved in the initial data reduction.

F P ANDERSON
CHIEF DIRECTOR

Stellenbosch
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1. INTRODUCTION

1.1 General

Cyclone Domoina passed over the midlands of Zululand on 30 January 1984 and struck St Lucia early on the morning of 31 January (Figure 1). Floods resulting from the storm severely damaged farmland on the Mfolozi Flats and forced considerable changes in the Mfolozi and St Lucia Estuaries (Figure 1) (Van Heerden, 1984). As a result, studies were initiated in February 1984 to determine the responses of the various systems to the storm and to formulate a management plan for the St Lucia Estuary that would have a strong process-response approach. An important part of the work involved deciphering the natural long-term processes.

1.2 Study Area

The Mfolozi Flats lie between Mtubatuba and the coast and form the coastal plain or receiving basin (Figure 1) of the Mfolozi River (Van Heerden, 1985). This is the largest fluvial coastal plain in South Africa and biological productivity is high. In the past the flats were composed of wetlands that supported large numbers of wild animals and wildfowl, while the Mfolozi Estuary was very productive in terms of fish, oysters, shrimp and other such organisms. At present the natural productivity of the area is negligible as it has been replaced by extensive sugar cane plantations.

At the seaward extremity of the Mfolozi Flats is the St Lucia Estuary/Lake system (Figure 1). The Mfolozi and St Lucia Estuaries are closely interrelated, having shared a common mouth until man's intervention in the 1950s. St Lucia is the largest estuarine system in Africa (Cameron-Dow, 1974; Wallace, 1975) and the most productive along the eastern seaboard of South Africa. In addition to the great variety of animals within their confines, the St Lucia Estuary and Lake are the breeding grounds for large numbers of hippopotami and crocodiles. The St Lucia/Mfolozi systems are often quoted as being one of the richest areas in Africa where avifauna is concerned. St Lucia village at the mouth of the estuary is an important sport-fishing holiday resort.

1.3 Manuscript Format

This report will firstly describe the study methods and the forcing functions operative in the study area and then the results of the fieldwork. The discussion will view the dominant processess chronologically, that is, those operative prior to the initiation of the draining of the Mfolozi Flats in 1927; from 1927 up to the time cyclone Domoina struck; and then the readjustments following Domoina. The management options for the St Lucia Estuary will be discussed last.

Part II contains all the appendices and is of a more technical nature.

2. METHODS

Fieldwork was started on 6 February 1984 and continued until 16 June 1985, although most of the fieldwork was performed between 1 June and 1 October 1984. This was supplemented by a detailed literature review and numerical computations.

2.1 Synoptic Monitoring of Coastal Processes

Aerial photography of the coast from Mapelane Rocks to First Rocks (see Figure 1) was carried out at low tide on the following days:

Date	Water level*
12.02.1984	+ 0,21
04.04.1984	- 0,18
01.06.84	- 0,88
17.06.84	- 0,72
29.06.84	- 0,79
14.07.84	- 0,83
02.08.84	- 0,80
23.11.1984	- 0,93
08.03.1985	+ 0,03
20.05.1985	- 0,86

* As determined from South African Navy (SAN) tidal charts, in metres with mean sea level as datum.

Weather data and swell characteristics were obtained from various agencies to be utilized in determining synoptic change in forcing functions.

2.2 Nearshore Bathymetric and Side Scan Sonar Surveys

The survey area extended from Mapelane Rocks to 2 km north of the St Lucia Estuary mouth. Survey lines, which started at the outer edge of the surf zone, were 200 m apart and orientated east-west. Lines extended to at least the 20 m isobath.

A Trisponder position-fixing system was utilized. This micro-wave equipment involves setting up "remote" transmitters on land and a "master" transmitter/receiver on the boat (Figure 2). The two-way travel time for a signal from the master to each remote and back again is converted into ranges by the Trisponder 540 DDMU (Digital Distance Measuring Unit). This is then conveyed to an Autocarta II hydrographic survey unit. The latter is a mini-computer programmed to calculate co-ordinates and supply track guidance. The system supplies accuracies of about 0,5 m in range measurement and allows boat travel directly along survey lines.

An echo-sounder was utilized to obtain continuous bathymetric information along survey lines. Tidal corrections were made using standard techniques. Vertical depth accuracies are estimated to be of the order of 0,20 m.

Side-scan sonar data were collected on a Klein 521 system utilizing a 100 kHz fish. Basically the side-scan sonar system consists of three units: a transducer, which forms the underwater unit and is better known as the "fish", a steel wire reinforced cable acting as transmission and tow cable simultaneously, and a dual channel recorder (Figure 3).

The fish consists of a streamlined, hydrodynamically-balanced body about 1 m long and two sets of transducers that scan the seabed on either side. The dual channel recorder contains most of the electronics as well as the graphics mechanism. The transducer sends out short sonar pulses of 0,1 milliseconds duration and returning signals are amplified in the recorder and fed, in the form of variable currents, to the helix electrodes that sweep out from the centre of the recording drum. The current passes through the recording paper to the printer blade-electrode and from there to earth. The current passing through the paper produces marks of varied intensity that are proportional to the strength of the incoming signals, thus reflecting the nature of the seabed. The recorded image is termed a "sonograph" and, in a sense, is remotely similar to a continuous high-altitude aerial photograph (Figure 4).

2.3 Beach Profile Measurements

In August 1984, 23 profiles were measured between Mapelane Rocks and a point 2 km north of the St Lucia mouth. The landward limit of each was established by Trisponder and/or theodolite (resection and dogleg) and was marked by a wooden stake. Profiles were then measured with a survey staff and theodolite during spring low tides. Lines generally extended to waist depth in the surf zone, the presence of sharks precluding the extension of profiles any deeper.

A total of seventy-five (75) sediment samples were collected along the profiles during August 1984. The median diameter was obtained through the use of a settling tube. Settling velocities were converted into an equivalent sieve median diameter utilizing the curves of Fromme (1977). An additional 10 samples were collected from the beach between Mapelane and 4 km north of the St Lucia mouth during March 1985.

2.4 Time-series Bathymetric Survey of Lower Reaches of St Lucia Estuary

On 16 June, 27 August and 12 September 1984 echo-sounder doglegs were run in a zigzag fashion across the lower 4 km of the estuary. Position-fixing control was obtained through the use of the Trisponder system. Thirteen to 14 km of survey track were run during each survey, with position fixes approximately every 50 m along the track. Continuous echo-sounder traces were collected. In addition the side-scan sonar was towed along the length of the channel during each survey. In June 1985 simple verification depth soundings were made in the lower 2,5 km of the estuary.

Bathymetric profiles were also run in the Mfolozi Estuary in mid-June and mid-September 1984 and in June 1985.

2.5 Literature Review

Aerial photography dating back to 1937 was obtained from Trig. Survey, Mowbray, Cape Town. This was combined with maps and survey charts of the area produced since 1884 to determine plan-view changes in the morphology of the Mfolozi Flats and Mfolozi and St Lucia Estuaries. Historical records dating back to 1576 were examined, as were published and unpublished scientific reports. From the above data sources it was hoped to gain an insight into marine and fluvial processes that operated prior to cyclone Domoina.

2.6 Wave Refraction

Wave data measured in the nearshore area at Richards Bay by Waverider and clinometer in the period January to September 1984 were converted to deep-sea wave data by refraction techniques. It seems reasonable to assume that the deep-sea wave climate depicted by this data set is similar to that at St Lucia.

Wave direction frequencies were obtained from historical Voluntary Observing Merchant Ships (VOS) data held at NRIO (Swart and Serdyn, unpubl.) covering the period 1961 to 1979. In the $1^{\circ} \times 1^{\circ}$ square opposite St Lucia (28°-29° latitude, 32°-33° longitude) 6 056 data points exist.

The wave heights and periods shown in Table 1 are visual estimates and according to Nicholson (pers. com.) related to instrument (Waverider) values as follows:

$$H_{mo} = 1,0 + 0,8\ H_{VOS} \qquad ...(1)$$

$$T_p = 6,0\ T_{VOS}^{0,4} \qquad ...(2)$$

where

H_{mo} = spectral estimate of significant wave height
T_p = spectral peak period
H_{VOS}, T_{VOS} = visual estimates of wave height and period

Wave refraction computations were performed utilizing the equations and techniques discussed by Crowley (1985).

3. ENVIRONMENTAL INFLUENCES AFFECTING ESTUARINE SEDIMENTATION

A number of important physical forces operate in the study area and the mean condition of each component of each system represents a balance between these forces. However, forcing functions affected either directly or indirectly by atmospheric circulation patterns can dramatically change the equilibrium situation.

3.1 Climate and Rainfall

Situated between latitudes 27°S and 31°S, Natal has a subtropical coastal and temperate inland climate. Thunderstorms and mid-latitude cyclonic activity contribute to the weather pattern, the former predominantly in summer (October through to March), the latter in winter (April through to September). Precipitation is the most important climatic variable in this context because of its influence on stream flow and sediment load capacity.

The average annual rainfall in Natal is approximately 850 mm. However, this amount is distributed unevenly over the province. Precipitation above the mean value occurs along the entire coastline and in the Drakensberg escarpment zone. Along the southern Zululand coast annual precipitation exceeds 1 250 mm and is associated with almost daily thunderstorms during the summer months. The often intense nature of the rainfall leads to rapid overland flow and to frequent peaks in the stream hydrographs. Winter rainfall, associated with depressions and troughs moving north-east along the coast, is more widespread and not as intense. Nevertheless, when these disturbances are blocked by anticyclonic activity off the Natal coast, continued widespread rainfall may cause extensive flooding further inland. Precipitation totals also vary significantly from year to year, causing great variability in streamflows, especially in the drier portions of Zululand where a succession of low-flow years may have a profound effect on the physical and ecological characteristics of Lake St Lucia.

3.2 Tropical Cyclones

A cyclone is any atmospheric system in which the barometric pressure diminishes progressively to a minimum value at the centre and towards which winds blow spirally inward from all sides, resulting in a lifting of the air and eventually in clouds and precipitation (Dunn and Miller, 1964). Circulation is clockwise and the system overspreads an approximate circular or elliptical area of at least 80 km, generally several hundred, and often over 1 600 km in diameter. Tropical cyclones are essentially rotating cyclones of the tropical oceans and when well developed are vast whirlwinds of extraordinary violence.

Data from South Africa, Madagascar, Mauritius and Reunion revealed that since 1927 approximately 10 tropical cyclones were generated every year in the tropical regions of the Indian Ocean (Dunn, 1984). Of these, four originated in the Mozambique Channel. Since 1950 ten cyclones have caused significant rainfall (in excess of 100 mm) over Natal (Kovacs, 1985), albeit only Domoina traversed South Africa.

Although it is not possible to speculate on the repetition of a Domoina-size event, the tracks of the 10 cyclones observed over the last 35 years suggest that a real possibility exists of a similar event (in terms of penetration and residence) taking place within a few decades (Dunn, 1984). In March 1925 up to 1 200 mm of rain fell in nine days in the Mfolozi catchment (Kovacs, 1985). The ensuing floods were apparently larger than those associated with Domoina (Table 2), although the origin of the storm is not documented but was most likely a tropical cyclone. The above-mentioned review reveals that Domoina-magnitude rains (more than 600 mm) are not rare in the Mfolozi catchment.

3.3 River Floods

Extreme rainfall events, which lead to large river floods, are one of the most important physical phenomena influencing the coastal zone. Heavy precipitation and attendant erosion within the river drainage basin increase both the carrying capacity of the river and the amount of transportable sediment. Steep gradients, erodible soils and unwise land-use practices combine to produce high sediment yields that eventually find their way to the coast where deposition occurs, sometimes forcing considerable environmental change.

The Mfolozi River has a catchment of approximately 10 000 km^2. The average annual run-off appears to be between 393 × 10^6 m^3 (Kovacs, 1985) and 887 × 10^6 m^3 (Perry, in prep.). Perry (in prep.) has derived the simulated monthly run-off (Table 2) of the Mfolozi River from October 1921 to September 1975, based upon HRU 9/81 data (Pitman et al., 1981). Review and characterization of this data reveal that during the above-mentioned 55-year period there were 20 single months when the run-off was approximately equal to the average annual run-off (400 - 900 × 10^6 m^3) and four single months when the run-off was much larger. The data presented in Table 2, although only simulated run-offs, reveal three important features of Mfolozi run-off; firstly, that it is very erratic in nature; secondly, that large floods are fairly common (24 in 55 years); and thirdly, that floods can occur at any time of the year.

Quantitative examples of peak flood discharges are 15 000 to 22 000 m^3 s^{-1} in March 1925, 8 500 m^3 s^{-1} in July 1963 and 16 000 m^3 s^{-1} during Domoina in January 1984.

3.4 Meteorological Forcing

Coastal winds and especially the longshore components of such winds play an important part in the sea level and current variations in the shallower shelf region adjacent to a coastline (Niiller, 1975). Of particular importance are the "coastal lows" that form on the west coast with the approach of a suitable leader front (Figure 5) and then propagate around the Southern African coastline.

Dramatic changes in the wind regime can occur along the Natal coast during the passage of such a low. Thus it is common for the wind to change from north-easterly to south-westerly in a matter of minutes, with the total wind velocity change being up to 20 m/s and more. The prevailing winds are spread fairly evenly over the 12 months of the year and are almost equally divided in frequency (Figure 6) (Weather Bureau, 1960; Orme, 1973).

3.5 Ocean Swells

The most important marine physical force along this section of the coast is the wave climate. Although the south-easterly swells produced in the "roaring forties" become deflected and progressively weakened before reaching the Natal coast, wave processes force most sediment movement. The two most important characteristics of waves in terms of beach and spit responses are angle of swell approach and wave height. For 87 per cent of a two-year period - March 1971 to February 1973 (CSIR, 1973) the ocean swell along the Natal coast varied from 1 m to 3 m, with 2 m to 3 m swells occurring 35 per cent of the time.

Direction of swell approach along the Natal coast has two dominant modes (Figure 6). Swells have a south-easterly orientation about 40 per cent of the time, (CSIR, 1973; Begg, 1978). Onshore swells (north-easterly to easterly) in the St Lucia area have a similar frequency. The onshore swells do not produce a unidirectional longshore current. However, during southerly swells a northerly longshore current is set up, which is responsible for moving large quantities of sediment in a northward direction annually. Although a northward-directed longshore current does dominate under southerly swells, local reversals in the longshore drift do occur around such features as ebb-tidal deltas seaward of inlet mouths.

Van Heerden (1976a) found that there was a strong correlation between angle of wave approach and wind direction. Southerly winds tend to enforce south-easterly swells, while northerly winds geneally create conditions of onshore swells.

3.6 Ocean Currents

The Agulhas Current, a major western boundary current, flows southward down the Natal coast. Off St Lucia, where the continental shelf is very narrow, high velocities (up to 2 m/s and more) in the Agulhas are generally found within 15 km of the coast. Under such conditions a distinct nearshore current regime cannot be established and the most important current affecting the coast is the swell-induced longshore drift.

4. COASTAL FLOOD PLAIN AND ESTUARINE PROCESSES PRIOR TO 1930

In order to quantify the responses of the various systems to cyclone Domoina correctly an in-depth assessment of long-term processes is necessary.

The river discharge regime depends on the climate factors active within the drainage basin. In general rivers characterized by temporal discharge tendencies and variation in discharge throughout a hydrolic year exert a strong influence on alluvial valley and coastal sedimentary body geometrics (Coleman, 1976).

4.1 Mechanism of Sediment Transport

Before proceeding further and noting that most of the problems associated with the estuaries are sediment related, it is important to review the dominant mechanisms of sediment transport. Sediments derived from the catchment vary from gravel to fine clay and as such can be divided into two groups based on the manner in which they are transported and subsequently deposited. Material coarser than medium sand moves as "bedload" during floods. That is, the particles skip, roll or slide along the bottom of the channel where the water is deepest and currents are strongest. The rest of the sediment load, medium sand and finer, moves as "suspended load". Such material is kept in suspension by the turbulence (internal eddies) within the flowing water. Suspended load is still carried downstream at a velocity below that where bedload is deposited. Suspended sediments are usually deposited on the banks of "levees" of rivers where the water is shallower and "bed friction" becomes important but most deposition occurs where flood waters leave the deeper confines of river valleys and spread out over large, flat areas.

4.2 Long-term Fluvial Processes

Rivers are the main agents that transport the sediments from land to the coastal regions of seas and lakes, where these sediments are deposited in thick sequences or transported further to continental shelves and deep-sea basins and produce deep-water sediments.

On the other hand, not all the sediment made available by the weathering processes on land is ultimately carried to seas and lakes. A portion is deposited on land under the influence of fluvial processes. With suitable sedimentary tectonics, sequences of fluvial deposits several thousand metres thick can be formed. This is especially true for the lower reaches of rivers, where vast flood plains are built up and a large amount of fluvial sedimentation takes place. In some cases, extensive and thick deposits of alluvial fans are built along the valley sides and mountain fronts. In other words, rivers are not only erosional and transporting agents but also depositing agents.

4.3 A Generalized View of Natural Development Processes in Coastal Receiving Basins

The geology, morphology and dominant physical processes of the receiving basin or coastal plain dictate how the fluvial sediment is deposited and the form that the deposits take. Narrow steep-sided coastal plains ensure that most of the river-borne sediment is advected to the coast, with resultant changes in coastal configuration. Wide, flat coastal plains generally act as sinks for river-borne sediment and the coastline configuration is very stable. Extreme floods, however, can create both short-term and long-term changes in the coastline.

In wide, flat coastal flood plains river gradients are generally low and suspended sediment loads are high in comparison with bedloads and the stream produces a distributary network of meandering channels. In addition, wide coastal flood plains have an in-built ability to accept most of the sediment supplied to them by rivers. Build-up occurs as a consequence of differential sedimentation associated with the periodic switching of loci of deposition, as channels switch from one part of the plain to another.

Meander channels on coastal flood plains occupy only a small part of the plain at any one time and show an organized distribution of channel processes and a clear separation of channel and overbank environments (Figure 7). The meander channel lies within a meander belt, which is a complex of active channels, abandoned channels and near-channel sub-environments. Shifts in the meander belt reflect natural subsidence and concentration of sedimentation.

Sedimentation is concentrated close to the meander belt and an "alluvial ridge" is built above the level of the flood plain (Fisk, 1952) (Figure 8). This increasingly unstable situation is periodically relieved by the breaching of a channel bank during floods and the sudden shifting of the meander belt to a new position on the alluvial plain, a process known as "avulsion". The new course captures an increasing proportion of the flow and the old meander belt is abandoned.

Subsidence is the second important mechanism that forces channel switching in coastal fluvial plains. The term subsidence is applied to the relative rise in sea level and/or the relative lowering of base level in coastal environments. A number of mechanisms are responsible for these apparent changes, including eustatic sea-level fluctuations, continental downwarping, dewatering and compaction of sediments and human activities (Van Heerden, 1985).

Swamps and marshes more distant from the channel cannot maintain base level due to a sedimentation rate that does not balance subsidence. Thus topographic lows are created in inactive parts of fluvial plains. During a flood the river may break into such areas and occupy a new course to the sea. Associated with the new channel would be a new episode of levee building and meandering. As natural levee height decreases in a downstream direction on coastal plains, the frequency of switching increases in the same direction.

The channel switching process results in the flood plain being built up of interfingering sediment lobes (Figure 9).

4.4 Human Influences in Coastal Plains

Human activities can greatly enhance the subsidence rate. Firstly, draining (dewatering) wetlands increases compaction and hence subsidence. Secondly, the channelization of rivers and creation of artificial levees impede the spread of sediment to areas adjacent to the channel. Thus sedimentation does not balance local subsidence and the lowering of the base level increases. Lastly, channelization and artificial levee construction, especially if levee material is dredged from the river floor, create a situation where the local water table is lowered. Such dewatering increases the local subsidence rate.

Therefore, although channel switching is a natural process in subsiding coastal fluvial plains, it can be restricted by man's activities. Consequently, situations can be created for major, flood-induced channel switching.

4.5 Morphology and Natural Depositional Processes of Mfolozi Flats

Figure 10, compiled from aerial photomosaics and oblique air photos, shows the location of numerous old channel traces, indicating that channel switching commonly occurred on the Mfolozi Flats (Van Heerden, 1984). The Mfolozi Flats are apparently underlain by more than 30 metres of relatively fine-grained sediments (Orme, 1973) typically deposited from suspension consisting of silts and clays and originally having a high water content. Considering this thick sequence of fine-grained sediments it can be confirmed that subsidence due to dewatering and compaction is an active process on the Mfolozi Flats and is aided after each flood by the sediment "loaded" during the flood. The subsidence rate of the surface of the Mfolozi Flats is not known at present but subsidence rates of 1,3 cm per year have been recorded (Van Heerden, 1983) in a similar type of environment in the Atchafalaya River Basin, Louisiana, USA.

The aerial photograph set reveals that the Mfolozi River had occupied its course between points A and B in the upper section of the Flats (Figure 10) for quite a long period. The pre-Domoina river course was relatively deep and wide with well-established confining natural levees. Traces of old crevasse splays or channels displayed in earlier photography (1960) indicate that sedimentation in the upper section during this period occurred through the overtopping of the natural levee system (Figure 10) rather than through channel switching. River channel elevation would have progressively increased with each successive flood.

Channel switching in the mid section of the flats appears to have occurred chiefly at two locations (Van Heerden, 1984). Major, fairly long-term upstream diversions occurred in the upper reach of the mid-section (Area C, Figure 10), while switching was more common further downstream (Area D, Figure 10). The well-developed meander pattern of the channel between Areas C and D indicates that this channel was in use for a long period. Using historical maps and photographs and features such as the abundance or lack of tree cover on old levees enables one to infer the chronological order of channel switching. Interestingly, the order of switching reveals that the southern half of the mid-section had not been occupied by a major course of the Mfolozi for some time (Figure 10).

The earliest known maps of the St Lucia area (1884, Figure 11) reveal that at the time the Mfolozi flowed from point E to point D and then flowed in a northerly direction to reach the St Lucia Estuary at Honeymoon Bend. Shortly thereafter, however, it switched to course 3 and then to course 4 (Figure 10) below point D. As a result the Mfolozi entered the St Lucia Estuary at a point downstream (seaward) of Honeymoon Bend (Figure 12) in 1905. Interpretation of the 1937 aerial photographs revealed that after the large flood in 1925 the Mfolozi River flowed from point A to point B in the upper section of the flats. From point B it meandered along the southerly route shown in Figure 10 to point C, the shorter route being a man-made cut after 1937. From point C to point E, it flowed along the northerly route shown and then flowed to point D. From here it took the course marked 5 to the Msunduze River and then flowed into the St Lucia Estuary close to the coast behind a spit complex. At this time, the river width decreased downstream as did the height of the levees. During the 1925 flood the lower reaches of the Mfolozi, the Msunduze and the St Lucia Estuary were scoured out as is evident from aerial photographs taken in 1937 (Figure 13). Although in 1937 the various channels were fairly narrow, relatively wide mud flats existed on either side of the channels. The mud flats represented channel flank accretion subsequent to major flood (1925) induced channel scour.

After farming began, the Mfolozi River was shortened and a canal dug between point E in the mid-section of the flats and a large meander in the Msunduze River near the coast. This new course, marked number 6 in Figure 10, thus linked the river directly to a tidal creek offshoot of the Msunduze and considerably shortened the river course to the sea.

4.6 St Lucia and Mfolozi Estuaries' Conditions Prior to 1930

The St Lucia Estuary and lower Mfolozi River each occupy drowned river valleys that are deeper than 50 m at the coast (inferred from Orme,1975, and Van Heerden, 1976b). Apparently both paleo-river systems had a common mouth at St Lucia, reflecting the lack of Pleistocene "beach rock" between Mapelane and a point a few kilometres north of the St Lucia mouth. Historical reports and modern surveys (Begg, 1978) indicate that both systems had a common mouth until man's intervention in the early 1950s.

During the last 100 years the point of junction of the two estuaries appears to have slowly migrated seawards. Although one can question the accuracy of early maps, charts published in

1879 and 1884 (Kriel et al., 1965) reveal that the confluence of the Mfolozi River and St Lucia Estuary was near Honeymoon Bend and that the mouth was further north than it is at present (Figure 11). Interpretation of aerial photographs and ground truth surveys (Van Heerden, 1984) confirm this feature shown in early charts. Judging by the size of the dune field that built up from windblown estuarine sediments north of the mouth, this condition must have been stable for some time.

The first detailed survey of St Lucia was undertaken by Croft in 1905 (Figure 12, Kriel et al., 1965). His map reveals that the Mfolozi had two entrances (forks) into the St Lucia Estuary and that both were located seaward of the earlier course. As a result the general trend of the combined mouths was similar to the present one. This move initiated a new phase of coastal dune growth as sediments were blown northwards from the estuary bank. The size of the dunes as revealed in the 1937 aerial photographs (Figure 13) and lack of any mention of these in Croft's 1905 survey led Van Heerden (1984) to conclude that the new orientation of the estuary occurred in about 1900. During the following 30 years the western fork of the Mfolozi River was progressively abandoned in favour of the eastern fork.

Table 3 is a summary of historical records (compiled from Kriel et al., 1965) concerning the condition of the combined St Lucia and Mfolozi Estuaries. From 1576 to 1927, when farming activities were initiated on the flats, the estuary was open for the greater part of the year. The norm appears to have been for the estuary to close for about three to four months of the year (August to November).

All early surveys and maps reveal the combined system to have had an opening in the general area of the present mouth, with a shallow arm extending northwards from the estuary behind the beach (Figure 12). Although very little historical coastal process data are available, this central location was most likely representative of periods of low river flow. During and immediately after floods, when large amounts of sediment were deposited in the nearshore, the mouth could well have migrated further north along the arm north of the mouth. At such times the oblique southerly swell approach combined with a large littoral sediment pool would have forced the southern bank or spit of the estuary to extend rapidly northwards, while the estuary waters eroded the northern bank. Similar processes have been documented elsewhere on the Natal coast following major floods (Van Heerden, 1976a) and are schematically shown in Figure 14. Once the nearshore sediment supply had diminished the mouth would have been re-established in a more normal position (Figure 14) due to wave overwash erosion processes. Mouth migration forced by discharge fluctuations would explain why the northern spit was a "low barren" feature until stabilized by man (Figures 12 and 14).

In general, during low-flow months, the mouth would have had a central location and could have closed annually for a few months. At such times low flows would have dominated in the Mfolozi and fresh waters would have been forced up the St Lucia Estuary to the lake. Fine-grained sediments were most likely deposited in the mouth area as well as in the lower reaches of the St Lucia Estuary. The high Mfolozi flows during the wet season would have intersected the low barrier somewhere north of the mid-point and the mouth may even have migrated further north. However, the important feature of the floods would have been that the mouth and lower reaches of the Mfolozi River would have been scoured open. At the same time rising waters in the lake system would have increased flows down the lower reaches of the St Lucia Estuary, thus scouring the system. A few months following the flood the mouth may have switched to a more central location in the fronting barrier due to overwash and tidal scour processes.

It would appear that on a more or less annual basis the estuary was scoured open, then sealed, followed by some deposition and then opened again. Superimposed on this cycle would have been periods of either longer closure or opening.

An important aspect, prior to 1930, of the two estuaries having a common mouth was that direct discharge of the Mfolozi into the St Lucia Estuary maintained the ebb-dominated character of the estuary for months following a major flood. However, with low discharges the overriding influence of the high swell regime would eventually force mouth closure.

4.7 Beach Processes

The large-scale crescentric beach configuration between Mapelane and First Rocks (Figure 6) tends to approximate an equilibrium in which the wave climate provides precisely the energy and mean wave approach angles required to transport and redistribute the sediments supplied to the beach. The beach configuration, then, is controlled mainly by the curvature and orientation of the refracted wave crests and by the locations and relative importance of the beach sediment sources and losses (sinks).

At present there are three main sediment sources. The oblique south-easterly wave approach sets up a northward-directed surf zone current (Figure 6) that transports sediment (some originally from the Tugela) around Mapelane. Similar surf zone currents are also responsible for transporting sediment out of the area past First Rocks. Additional inputs of at times large quantities of sediment are the Mfolozi River and the St Lucia Estuary.

Rip currents between bars orientated obliquely to the coast and parallel to wave approach may extend 2 km seaward and are responsible at times for transporting sediment out of the littoral zone, that is, they may act as sinks.

The wide surf zone, the presence of one or more bars, three dimensional inshore topography and different scales of rip cells are characteristic of a dissipative beach. Here wave energy is mostly dissipated in the surf zone where turbulent viscosity is high. Spatial variation in bar types reflects segregation into subregions of contrasting turbulent viscosity. Dissipative beaches, close to major deposition areas such as the Mfolozi River mouth are usually progradational features.

However, progradation is most marked in areas dominated by onshore winds. In the study area winds are either offshore or alongshore. Such conditions do not encourage hummocky dune growth and beach progradation in the study area. They lead rather to subaerial wind erosion that annually appears to balance deposition on the beach.

5. MODERN (POST-1930) MFOLOZI FLAT PROCESSES AND THE ST LUCIA PROBLEM

Land-use practices of the farmers on the Mfolozi flood plain severely restricted channel switching because the farmers lowered the base level of the river as they excavated and used channel bottom sediments to raise the artificial confining levees. In addition, the draining of wetlands for cane increased the rate of compaction and hence subsidence. The artificial system thus created consisted of a river with high banks surrounded by much lower, depressed cane fields.

Changes in the sedimentation patterns as a result of river channel manipulation were the underlying cause for the ecological stress experienced by the St Lucia Estuary following the initiation of farming on the Mfolozi Flats after 1930. Prior to farming, the flats accepted most of the river-borne sediment and the relatively sediment-free waters reaching the coast kept the then combined systems open and free of silt. After farming was initiated, sediments were transported down the Mfolozi River and right through the flats to the coast due to the confined, artificially-stabilized channel. As a result of this increased sediment supply, both estuaries became heavily silted and estuary mouth closures became common and were of long duration.

Response to channelization appears to have been fairly rapid since in 1932 the mouth was artificially opened for the first time and in 1935 oyster collection for the Durban markets was suspended because of "too much silt" (Kriel *et al.*, 1965). In 1936 the first public complaints were made about the deterioration of fishing (Kriel *et al.*, 1965). Mouth closure became more common and the estuary reached a sediment-filled state in 1951. It was only in 1955 that the estuary was finally opened. In the mean time the Mfolozi River was artificially given a separate mouth in 1952. This move plus the siltation problem prompted the artificial stabilization of the mouth of the St Lucia Estuary. Because the Mfolozi River flood and tidal basin scour effect was missing, dredging became a perennial activity.

As mentioned earlier, beach configuration reflects an equilibrium between a number of factors. The creation of a separate mouth for the Mfolozi and the stabilization of the St Lucia Estuary mouth disrupted the equilibrium and subsequent nearshore sediment distribution. Firstly, the creation of the groynes and associated sediment trapping caused shoreline progradation to the south of the St Lucia mouth. Comparison between the 1966 and 1972 shorelines (Figure 15) reveals seaward extension in excess of 300 m. Such a situation leads to the starving of sediment in areas further north. Secondly, the siting of the heaviest groyne on the north bank of the estuary led to sediment trapping in the St Lucia Estuary mouth. That is, sediments supplied by the Mfolozi migrated along the coast to the estuary mouth where they "sat", necessitating near-continuous and expensive dredging operations. Material from these operations was dumped on the shore south of the estuary mouth, thus acting as a permanent sediment sink. The result of groyne emplacement and associated sediment starvation through trapping and dredger losses meant that beach areas north of the mouth were no longer in equilibrium. The most dramatic effect of disturbance appears to have been the collapse of a large section of the Holocene dune barrier south of First Rocks as the fronting beach retreated.

6. RESPONSES TO CYCLONE DOMOINA

Van Heerden (1984), who conducted site visits immediately after the flood waters had subsided, stated that the storm had enhanced many natural processes. In addition, he felt that flood responses on the Mfolozi Flats were similar to those documented on other coastal fluvial plains such as the Atchafalaya River Basin and Mississippi Delta Plain of Louisiana, USA.

6.1 Mfolozi Flats

Depositional responses were dramatic on the Mfolozi Flats, mostly due to the Mfolozi River creating a new course to the sea via the older Msunduze River (Figure 16). Prior to Domoina the Mfolozi Flats consisted of an artificially leveed river channel surrounded by much lower cane fields. The extreme flood generated by cyclone Domoina was all that was needed to force channel avulsion.

A major new channel was initiated as a switch occurred in the upper reaches of the flats (Figure 16), an area where switching seldom occurs. Judging by the amounts and localities of sediment deposition, avulsion must have occurred early in the flood. As will be shown shortly, this early switch of river channel location was indeed fortunate for the St Lucia and Mfolozi estuaries. Barring man's intervention, the new channel has the potential to be a long-lived feature. The former Mfolozi River, seaward of the new confluence with the Msunduze, was not carrying much water after the flood as its upstream end had been sealed by a subaqueous levee, typical of what occurs when older channels are abandoned.

The sedimentary wedge seaward of the railway bridge, deposited during Domoina (Figure 16), is a typical shallow water fluvial delta displaying the characteristic branching and rejoining of channels around sand-rich lobes (Van Heerden, 1984). The thickness of the "sand" deposited varied between 1 and 2 m (Roberts and Pyke, 1984). Fluvial delta sediments sampled near the railway bridge in the upper reaches of the flats consist of fine to medium-grained, well-sorted sand (Van Heerden, 1984). Such sediments are usually deposited from suspension as flood waters pass from a confined to an unconfined state. In this case, as the flood waters moved out of the confines of the river valley and specifically out of the confines of the artificially leveed Mfolozi River, they spread out rapidly over the flats with a resultant drop in velocity. At the diversion point the coarsest fraction of the suspended load was deposited, this being the medium to fine-grained sands sampled by Van Heerden (1984).

Flood waters would have continued their lateral spreading as they moved down the progressively broadening flats. As a result, a longitudinal reduction in velocity occurred so that even finer portions of the sediment load were deposited. The spreading of fluvial waters when moving from the confined to the unconfined state and the resultant sedimentation usually creates a sediment wedge that thins seaward and exhibits a progressive decrease in grain size. This is the reason why the seaward one-third of the flats was only covered by a few centimetres of silt and clay, although high discharges were experienced.

Flood waters that reached the seaward section of the flats were therefore carrying minimal amounts of sediment. As a result these waters had the ability to entrain material, with dramatic consequences for both the St Lucia and the Mfolozi Estuaries.

6.2 St Lucia and Mfolozi Estuaries

The major changes induced by Domoina are clearly revealed by comparing Figure 17a with 17b (1979 vs February 1984). Both estuaries increased in width, the impression being that their mouths had been "blown open". The beach fronting Mapelane retreated some 100 m landwards (compare the beachlines against the relatively-fixed seaward edge of the vegetation).

All man-made structures were washed away at the St Lucia mouth and the estuary assumed a more northerly orientation. Flood waters from the Mfolozi spilled into the St Lucia Estuary approximately 2 km upstream of the estuary mouth. Flow over the flood plain occurred as sheet flow but portions of these waters concentrated in a topographic low (former course of the Mfolozi River, Van Heerden, 1984) before entering the estuary. Fortunately these waters were relatively sediment-free, most of the load having been deposited on the upper Mfolozi Flats. As a consequence, the fast-flowing, turbulent waters had the ability to entrain sediment previously deposited in the lower reaches of the estuaries. Under the impetus of the Mfolozi waters plus waters from a rapidly-rising lake system, the St Lucia Estuary was scoured out to depths at least equal to those created during dredging and greater than those that existed circa 1900 (Figure 12) (Kriel et al., 1965). In some places, these depths were dramatically exceeded, for example, there was a depth of 14 m where Mfolozi flood waters piled into the estuary. The average depth of the St Lucia estuary was 6 m after the flood as against 1,5 m previously (Figure 18).

The Mfolozi Estuary increased in cross-section as the southern bank retreated some 300 m because the greatest flood discharge occurred in the Mzunduze River. The relatively sediment-free character of these flood waters ensured that sufficient energy was available to erode the southern bank, including sand dunes some 50 m high. In addition to bank erosion, the bed of the estuary was scoured to a mean depth of 6 m (Figure 19), considerably deeper than the 1,5 m mean prior to the flood.

As revealed by bathymetric and side-scan sonar surveys (Figures 20 and 21), a massive ebb-tidal delta or sand body was formed seaward of the Mfolozi Estuary (Figure 20) during Domoina and debris was spread over many square kilometres on the continental shelf seaward of the two estuaries.

6.3 Sediment and Water Budgets

The establishment of a sediment budget is an important feature of any quantification of process responses. Unfortunately such budgets are difficult to determine, given the data available at present in literature.

The best estimate of the run-off of the Mfolozi River appears to be 820 × $10^6 m^3$ per year (Chew and Bowen, 1965; Hutchinson, 1976) and that of the Msunduze 89 × $10^6 m^3$ per year (Chew and Bowen, 1965). The figure for the simulated mean run-off quoted by Perry (in prep.), that is, 887 × 10^6 m^3 per year, includes both the Mfolozi and the Msunduze. Orme (1974) estimated the sediment load of the Mfolozi River as being 1,5 × $10^6 m^3$ per year. More recently Flemming and Hay (1983) have estimated the sediment load produced in the catchments of all the rivers north of the Tugela and south of Sordwana Bay, an area dominated by the Mfolozi and Mhlatuze Rivers, as being 4,243 × $10^6 m^3$ per year. The run-off of the Mhlatuze River is estimated as being 435 × $10^6 m^3$ per year (Chew and Bowen, 1965). If one assumes that each river carries the same sediment load per cubic metre of water discharged, it can be calculated that the sediment load of the Mfolozi amounts to some 2,75 × $10^6 m^3$ per year. This estimate is somewhat higher than that made by Orme (1974). According to Rooseboom's sediment yield map (Rooseboom, 1975), for Natal, the sediment yield rates for the Mhlatuze and Mfolozi are,

Mhlatuze	288 tons/km^2/yr
Mfolozi	235 tons/km^2/yr.

Utilizing Rooseboom's map (Rooseboom, 1975), an estimate of the Mfolozi sediment load would be 1,27 × $10^6 m^3$ per year. It would therefore apear that the best estimate of the mean annual sediment yield of the whole Mfolozi system is of the order of 1,5 × $10^6 m^3$ per year.

CSIR (1985) showed that a good approximation of sediment yield with relation to run-off is

$$S \alpha R^b$$

where S = sediment yield
R = run-off, and
b varies between 1 and 2.

Using this relationship together with the run-off data in Table II shows that the minimum annual sediment yield of the Mfolozi system could vary between 0,05 and 0,2 × $10^6 m^3$ and the maximum annual sediment yield between 14 and 125 × $10^6 m^3$. This latter figure brackets the estimates of sediment discharge during cyclone Domoina.

Alluvial valleys can be considered as conduits for sediment transport from the catchment to the receiving basin (Coleman, 1976; Van Heerden, 1985). Assuming that this is the case for the Mfolozi River, for correct management it is important to know how much sediment can be deposited in the receiving basin (under natural conditions) and the volume entering the sea.

Simple calculations indicate the ability of the coastal flood plain to accept vast volumes of sediment. Firstly, if subsidence were 0,5 cm per year for the whole plain, 1,2 × $10^6 m^3$ of sediment could be deposited annually to keep pace with subsidence. Secondly, sea level has risen 23 cm in the last 100 years (Barnett, 1984). Thus 52,2 × $10^6 m^3$ of sediment could have been deposited during this period to maintain base level. Combining subsidence and rise in sea level gives a potential annual sedimentation of 1,75 × $10^6 m^3$, with no change in base level. This is a substantial amount of potential sedimentation (sink) annually and more than equals the estimates of sediment supplied from the catchment. Therefore, it would appear that under natural conditions very little sediment would be transported to the coast. However, the system broke down once channelization was initiated in 1927 as overbank spillage and flooding with associated sedimentation was prevented. Instead most of the sediment load was carried to the coast via the deep artifically-confined channel on the flood plain.

The floods associated with cyclone Domoina forced a fairly natural channel switch. Resultant processes strikingly demonstrated the capability of the Mfolozi Flats to absorb vast amounts of river-borne sediment and the ability of the sediment-free waters to erode and restore the Mfolozi and St Lucia estuaries. It is estimated that, during cyclone Domoina, approximately $80 \times 10^6 m^3$ of sediment was deposited on the Mfolozi Flats - equal to what could normally have been deposited in about 50 years prior to the commencement of sugar cane farming!

Van Heerden and Swart (1984) determined that the ebb-tidal delta created seaward of the Mfolozi Estuary mouth during the floods had a volume of $5 \times 10^6 m^3$. They also calculated that at least $16 \times 10^6 m^3$ of sediment was eroded during the excavation and enlargement of the Mfolozi Estuary. The dissimilarity of these figures suggests that most of the sediment tied up in the ebb-tidal delta was only carried a few kilometres and represents the coarse fractions (sand) of the material that was eroded. The finer fractions, which commonly would have occurred in old channels and marshes, would have been swept out to sea. This phenomenon adds credence to the view that flood waters were relatively sediment-free when they reached the seaward edge of the flats and thus had the ability to entrain estuarine sediments. In this way the two estuaries were at least restored to their pre-1920 depths, although they still have separate mouths.

7. RECOVERY AFTER CYCLONE DOMOINA

7.1 Synoptic Shoreline Changes

The erosion associated with cyclone Domoina created an imbalance in the trend of the shoreline and was responsible for the formation of a large ebb-tidal delta seaward of the Mfolozi mouth. In addition, both estuaries were deeply scoured. The natural trend thereafter would be for the shoreline to prograde to its original location and for spits to develop at each of the estuaries' mouths. Such transformations did characterize the shoreline up to May 1985 (Figures 17 and 22) but a detailed review of the air photographs revealed a number of interesting facets to the natural restoration.

The two dominant sources of sediment are those supplied from the south by longshore drift and the sands tied up in the ebb-tidal delta. In both cases movement of sand either alongshore or onshore is dependent on the swell characteristics. With a view to easier presentation the discussion of synoptic alterations will be dealt with on a definable area basis.

7.1.1 Shoreline south of Mapelane (2 km)

This area is typically characterized by a rocky low-tide platform (aeolianites), small, rocky headlands and small, sandy high-tide beaches. Large swells and storm surge during cyclones Domoina (01.02.1984) and Imboa (19.02.1984) severely eroded the existing beaches, creating low-slope dissipative beaches. In addition, rock pools in the fronting rock platform and between the beach and rocks were all scoured out. Directly after Domoina large rips existed at breaks through the rock platform, a characteristic of strongly-embayed and headland-bounded dissipative beaches following storms. During the cyclones there was accentuated run-up and berm overtopping and the formation of erosional cusps. The cause of these features would appear to have been strong subharmonic resonance (Chappell and Wright, 1978), which is the lowest energy needed to induce beach cut. As a result, low, flat dissipative profiles characterized the beaches south of Mapelane Rocks after the storm. Such profiles require the highest amount of energy to be eroded, so the resulting situation was ideal for deposition to start occurring on the beaches.

After the cyclones sediment, introduced mainly from the south under the influence of northerly longshore drift, was initially deposited on the northern sides of rocky headlands and in the deeper rock pools. Thereafter sediment started to accumulate on the beaches. By 1 June 1984 (Figure 17c) an estimated 18 000 m^3 sediment had been deposited. Deposition continued in such a manner that by 2 August 1984 the shorelines appeared to have attained an equilibrium position. After August 1984 alterations in the shoreline were short-lived and very localized, generally reflecting periods with strong north-westerly winds.

7.1.2 Mapelane Bay

During cyclones Domoina and Imboa the high wave energy was responsible for the offshore transport of sediment accumulations in the bay landward of the aeolianite reef, an extension of Mapelane Rocks (Figures 17a and 21). As a result of the deeper water in the bay and scoured-out estuary entrance, rapid shoreline erosion was initiated to the detriment of the Natal Parks Board resort at Mapelane. At the resort the beach and hummocky dunes that generally characterize this area had been artificially stabilized and buildings had been erected.

Due primarily to the diminished supply of longshore current-derived sand from the south, infilling of the bay proceeded slowly after Domoina. Beach retreat continued, with maximum retreat rates of 3 m per day during spring tides. Sand eroded off the beach was either transported northwards into the mouth of the Mfolozi Estuary or made its way into Mapelane Bay. After

2 August 1984, when the shoreline south of the bay appeared to have reached an equilibrium state, Mapelane Bay started to shallow rapidly and with attendant reduction in wave energy shoreline retreat terminated in November 1984 (Figure 22a).

It is important to note that the beach in Mapelane Bay retreated until it reached the foot of the older, extremely well-vegetated dunes that exist landward of the former hummocky dunes. This fact indicates that the beach is a fairly dynamic area and has undergone periods of retreat in the past. Future developments at Mapelane should take cognizance of this fact and keep human influences on hummocky foredunes to a minimum.

7.1.3 Mfolozi Estuary

7.1.3.1 Inlet concepts

Before proceeding further it is important to review some of the concepts related to tidal inlet stability. A basic concept governing inlet configuration states that inlet size is controlled by a dynamic equilibrium between the scouring action of the tidal currents and the tendency of the infilling of sediment delivered by the longshore currents (Inman and Frautschy, 1965). A related investigation by Walton and Adams (1976) demonstrated that there is also a good correlation between tidal prism and ebb-tidal delta size. In addition, these workers showed that the volume of sand stored in the ebb-tidal deltas of inlets shows a strong correlation with cross-sectional inlet throat area. A further conclusion reached was that in areas of high wave activity there appears to be a well defined limiting relationship in the amount of sand stored in the offshore bar as a function of tidal prism and that the volume is less on high-energy coasts than similar inlet sizes on low-energy coasts.

These statistical studies of long-term equilibrium, however, yield no information on the magnitude and time-scale of response in inlet geometry to fluctuations in tidal prism due to astronomical factors and storms. Furthermore, progressive alterations in ebb-tidal delta geometry can drastically affect the paths and rates of longshore sediment transport into the main inlet channel, thus greatly affecting channel size. This last point has a direct bearing on both the Mfolozi and the St Lucia estuaries specifically, as many thousands of cubic metres of sediment are moved into and out of each estuary with each tidal cycle.

The volume of the Mfolozi ebb-tidal delta was calculated to be $4{,}62 \times 10^6 m^3$ after the June 1984 bathymetric survey (Figure 20). According to Walton and Adams (1976) the inlet cross-sectional area/ebb-tidal delta volume relationship is given by

$$V = aA^b$$

where

V = volume of sand stored in the ebb-tidal delta
A = inlet channel cross-section area (in square feet)
a,b = correlation coefficients.

For highly exposed coasts the relationship becomes

$$V = 33{,}1\ A^{1{,}28}$$

Using this equation for the Mfolozi cross-section following Domoina yielded a volume for the ebb-tidal delta of $2{,}3 \times 10^6 m^3$. Therefore, more sand was present in the ebb-tidal delta following Domoina than could theoretically be stored due to the tidal prism. This fact was to have a strong influence on the subsequent changes in the Mfolozi Estuary.

A further important aspect of the Mfolozi ebb-tidal delta was that because of its size and seaward protuberance wave refraction became a permanent feature and a local reversal in the longshore current from north to south occurred in the vicinity of the St Lucia Estuary mouth. This phenomenon will be expanded on fully in the chapter dealing with the theoretical wave refraction studies.

7.1.3.2 Synoptic changes

Growth of the south spit in the Mfolozi mouth was initiated shortly after the erosion associated with cyclone Domoina. On 4 April 1984 the spit was 120 m long and extended to 240 m in length by 1 June 1984 (Figure 17c). Spit growth reflected sediments supplied mostly from the eroding beach/dunes facing Mapelane Bay and that moved landwards from the ebb-tidal delta. The spit accreted as a recurved feature reflecting wave refraction around and into the estuary (Figure 23a). The estuary was still 6 m deep. which would have aided the wave refraction mechanism. By June 1984 the original spit had retreated so far up the estuary that the growth of a second spit was initiated and the ebb-tidal delta fronting the Mfolozi Estuary had evolved into a number of bars shallow enough to cause even moderately-sized swells to break. As a result wave penetration into the estuary was diminished and the spit started to elongate alongshore instead of being a recurved feature. In addition, northward displacement of the mouth was aided by the growth, due to longshore sediment supply, of the flood tide ramp that existed south of the mouth (Figure 17c).

By 29 June 1984 (Figure 17e) the spit had grown some 275 m and the deep section of the Mfolozi mouth cut during Domoina was now completely covered and consequently the tidal inlet throat had been severely restricted in depth (Figure 23b). Up to this point in time the spit maintained its width as it retreated into the estuary, in pace with the beach retreat in Mapelane Bay. Due to the large cross-section of the throat, ebb-outflows had continuously eroded the landward edge of the spit. However, although the estuary was deep the shallowing of the throat section due to spit migration forced a decrease in the tidal prism and hereafter hampered the ability of the tidal inlet to maintain itself.

In the middle of August 1984 the spit, the face of which had retreated up the estuary some 25 m since mid-July, had become a thinner, more elongated feature (Figure 17g), revealing that ebb-tide flows were still energetic enough to erode the back of the spit. By 2 August 1984 the bars on the surface of the ebb-tidal delta had been moulded into substantial features due to the shoaling ocean waves. Their size and associated deposition in Mapelane Bay ensured that wave energy reaching the spit had decreased, although longshore sediment supply continued.

Shortly after the 2 August photographs the recurve nature of the spit terminated as a new phase of spit growth was initiated with a more easterly orientation. This, the third phase of spit growth, continued in such a manner that by November 1984 the new spit was some 170 m long. The remnants of earlier spit growth had diminished somewhat in size due to the erosion associated with ebb-tide outflows.

By November 1984 the front of the ebb-tidal delta revealed by surface bar forms, had migrated landward and the distinct seaward bulge of the ebb-tidal delta was much reduced (Figure 22a). Refraction of ocean swells around the ebb-tidal delta was not as marked as previously and all bar forms had a more normal, shore-parallel orientation.

From November 1984 to May 1985 sedimentation on the spit within the bay and fronting the estuary mouth continued in such a manner that most bar forms existed landward of the line joining the Mapelane reef and St Lucia Estuary mouth (Figure 22c). Wave refraction with resultant local reversals in longshore current was no longer a feature of the study area. The abundance of sediment in the ebb-tidal delta meant that the inlet could not maintain itself due to a reduced tidal interchange (prism) and the estuary mouth progressively shallowed as it narrowed. The confinement of the estuary mouth throat meant that the estuary formed a very efficient sediment trap, as is evidenced by the changes in the cross-section measured in June 1985. By June 1985 the channel from the Mfolozi River to the Msunduze River, excavated during Domoina in the upper flats, had been sealed and all river flow was directed once more down the Mfolozi River. The floods of February 1985, therefore, could not spread out over the flats and most of the sediment was deposited in the Mfolozi Estuary. It can be calculated that $2{,}0 \times 10^6 m^3$ of silts and clays was deposited in the estuary from December 1984 to June 1985, the greatest volume of which was deposited in the February 1985 flood.

7.1.4 Beaches between estuaries

Following cyclone Domoina, the shoreline in this area consisted of exposed marsh deposits. Shallow linear bars parallel to the outflow direction of the Mfolozi were present in the surf zone (Figure 17b).

As the Mfolozi spit elongated following Domoina, the beach area on the opposite side of the estuary mouth eroded due to the confinement of tidal currents. This situation continued until March 1985. During the February 1985 floods the depth of the Mfolozi Estuary halved (Figure 19), which would have reduced the tidal prism and hence the currents because of an increase in bottom friction effects. As a result tidal current scour in the throat area would have been reduced. In addition, the development of bars close inshore on the ebb-tidal delta would have reduced the erosional effects of large swells, especially at high tide. The future growth/erosion of the area immediately north of the Mfolozi mouth will depend on trends in the development of the spit.

For the most part the beach between the mouths prograded throughout the study, although by May 1985 the beach had not attained the orientation possessed prior to cyclone Domoina

(Figures 17 and 22). As an estimate between 1,0 and 1,5 × $10^6 m^3$ of sediment appears to have been deposited on the prograding beach. As revealed in Figures 17 and 22 most of the progradation and straightening of the shoreline occurred after August 1984 when, as mentioned earlier, longshore currents started to introduce sediments from the south into Mapelane Bay and the Mfolozi mouth area. The coincidence of these two features suggests that at least some of the sand tied up in the beaches originated from areas south of Mapelane. Another major source of sand was the ebb-tidal delta off the Mfolozi mouth through direct onshore swell-driven sediment movement. Wave refraction around the delta would have forced a local reversal in longshore drift opposite the St Lucia mouth, which would have fed in sand from the north. The beach between the estuaries should continue to prograde due to the mechanisms discussed above until the shoreline attains an orientation equal to that before Domoina.

7.1.5 St Lucia Estuary mouth

The floods generated by cyclone Domoina were responsible for scouring the St Lucia Estuary to a mean depth of 6 m, although locally depths exceeded 14 m. Deepening reduced bottom friction effects and increased the tidal prism. This increase plus the fact that an ebb-tidal delta was virtually non-existent off the St Lucia Estuary (Figure 20) enhanced the estuary's ability to maintain its throat cross-sectional area through tidal scour.

In the last section it was stated that a local reversal in the longshore current towards the south occurred in the vicinity of the St Lucia mouth. Such a reversal would have tended to force spit growth from the northern bank of the estuary in a southerly direction. However, the opposite situation occurred in St Lucia (Figures 17 and 22).

Immediately following Domoina, spit growth was initiated from the southern bank of the estuary. Such growth reflects an unnatural source of sediments due to man's past activities in the area and the effects of wave action, specifically at high tides.

Since the early 1950s the practise had been to pump sediment, dredged out of the estuary, onto the southern bank. In this way more than 2,0 × $10^6 m^3$ of sediment was placed as a spoil pile on the southern bank of the estuary. During cyclone Domoina the estuary cut through the northern edge of the spoil pile, leaving a scarp some 6 m to 7 m high, which fronted both onto the estuary and onto the surf zone (Figure 17b). Thereafter the seaward edge of the spoil pile was eroded by southerly swells and the sand transported into the estuary to form a spit. By this process the spit continued to grow and migrate into the estuary until mid-June 1984, when the growth of a second spit was initiated seaward of the first. The second spit accreted and aggregated quickly and by early August 1984 had coalesced with the first spit as a large composite feature with two horns (Figure 17g). Hereafter, as will be discussed shortly, the southern spit growth was influenced by tidal processes and longshore sediment supply.

Although no definitive spit growth occurred at the northern edge of the St Lucia Estuary mouth, sedimentation in this area produced a protrusion or bulge into the inlet (Figure 17c). The protrusion continued to expand until early August 1984. At this time the tidal inlet had attained its equilibrium cross-section. Side-scan sonar data collected in the channel during June, July and September revealed that scour of the lower reaches of the estuary was active at least until September 1984, reflecting its ebb-dominated character.

Unlike the Mfolozi system, the St Lucia ebb-tidal delta was smaller than the theoretical maximum. In addition, longshore reversals "kept" sediment out of the mouth.

Upstream migration of the southern spit terminated in October primarily because wave run-up to the edge of the spoil pile had been reduced due to the progradation of the shoreline. In the period following Domoina 500 000 m^3 of sediment was removed from the spoil pile. During the same period 420 000 m^3 of sediment was deposited in the spit.

Between August and November 1984 the two smaller components of the spit aggregated into one large spit, without a noticeable volume change. During these low-rainfall months, flood-tide processes started to become more important and the sediment protrusion on the northern bank slowly migrated upstream, partly as a consequence of the estuary mouth assuming a more southerly orientation.

During the rainy months between November 1984 and March 1985 the system once again became strongly ebb-dominated due to stronger outflows forced by high lake levels. As a result the upstream edge of the southern spit was eroded, as was the northern bank protrusion. The March 1985 aerial photographs (Figure 22b), although taken when the water level was close to MSL, reveal that the mouth appeared to have scoured out as a result of the ebb-dominated situation during the summer.

The May 1985 photographs indicate that the southern spit had marginally decreased in size but had recurved further back into the estuary. Lateral migration of the tidal inlet and subsequent changes in the southern spit and northern protrusion reflect driving forces such as the size and angle of approaching ocean swells and reversals or lack thereof in longshore drift. It must be remembered that by May the ebb-tidal delta off the Mfolozi no longer protruded as far seaward as the previous year.

The St Lucia Estuary inlet appears to be maintaining its dimensions. The bathymetric survey performed in June 1985 revealed that minimal sedimentation had occurred since the Domoina flood. Maintenance of this ebb-dominated system is supported by the following:

(a) Lake levels above MSL;
(b) an ebb-tidal delta smaller than the theoretical maximum, and
(c) local reversal in longshore drift, which moves the sand off the mouth in a southerly direction.

Until wave refraction around the Mfolozi ebb-tidal delta and associated longshore current reversal terminate, the St Lucia Estuary should continue to have a free connection with the sea. However, the introduction of sediment into the estuary from a source such as the Mfolozi Link Canal could dramatically alter this picture as any sediment introduced would decrease flow efficiencies through shallowing.

7.1.6 Beaches north of St Lucia

The beaches north of the St Lucia Estuary were not severely eroded during cyclone Domoina. Since then they have steadily increased in width and, as revealed in Figure 21, swell-driven onshore movement of sediment as low-amplitude sand dunes would have aided the restoration of these beaches.

7.2 Wave Refraction Studies

7.2.1 General

Wave data for the Zululand coast are mostly available as deep-sea data or as data collected at a specified depth some distance offshore. However, littoral processes are driven nearly predominantly by the incident wave climate. Fortunately, deep-sea wave data can be converted into wave characteristics at the edge of the breaker zone (or at another neashore location) by means of a numerical technique used in the prediction of wave refraction, that is, the extent to which the wave height and the approach direction are modified by the changing depth and topography.

This section will describe how the data referred to in Section 2.6 are utilized to obtain nearshore wave data that in turn serve as input for the prediction of littoral processes.

7.2.2 Deep-sea input wave data

VOS wave data (Section 2.6) are the most useful to obtain height, period and direction frequencies simultaneously, since this is the only source of readily-available wave direction data. The VOS data, which are listed in Table 1, can be summarized as follows:

Table A: Summary of VOS wave data

Deep-sea direction sector	Percentage occurrence	Wave height (m)		Mean wave period T_p (s)
		$(H_{mo})_{50}$*	$(H_{mo})_{90}$*	
15°-45°	10,3	2,2	3,6	12,1
45°-75°	6,5	1,9	3,5	12,3
75°-205°	6,6	2,2	3,6	12,8
105°-135°	5,5	2,1	3,7	12,8
135°-165°	11,0	2,3	4,0	13,0
165°-195°	21,1	2,7	4,6	13,3
195°-225°	12,2	2,7	5,1	13,0

* H_{mo} = Subscript 50 (or 90) means that 50 per cent (or 90 per cent) of the observed waves had an equivalent H_{mo} value lower than that quoted.

The table reveals that the wave climate is characterized by two distinct populations, one with a mean direction around 30° and the other with a mean direction of 180°. Furthermore the southerly population is characterized by higher wave heights and longer wave periods. Bearing in mind that the general coastal orientation between the St Lucia mouth and First Rocks is 28° and the perpendicular to the coast is 118°, it is apparent that the waves in the St Lucia area arrive predominantly from south of the normal (47 per cent of the time as opposed to 26,2 per cent of waves from north of the normal). North-bound longshore wave-driven currents within the breaker zone will therefore dominate. The net north-bound longshore sediment transport in the area is estimated below.

The grid dimensions are as follows:

Grid no.	Grid square size (m)	Number of points in		Co-ordinates of right-hand corner of grid[2]	
		X-direction	Y-direction[1]	X_O (m)	Y_O (m)
1	239,2	31	92	4 784,0	0
2	239,2	31	95	4 784,0	21 324,4
3	119,6	44	89	0	0
4	119,6	32	84	1 375,4	10 285,6
5	59,8	62	75	1 375,4	20 033,0
6	59,8	62	75	1 375,4	24 338,6
7	59,8	62	75	1 375,4	28 644,2
8	119,6	32	92	1 375,4	32 890,0

Comments:

1 X-direction is perpendicular to shore and Y-direction parallel to shore.

2 As seen when looking toward shore from sea.

3 See Figure 24a-24e.

The information in Table A in Section 7.2.2 along with Equation (2) in Section 2.6 reveals that wave data are available for the following peak wave periods:

11,0 s; 12,7 s; 14,1 s; 15,4 s; 16,5 s; and 17,5 s.

In addition, as discussed in Section 7.2.2, the mean value of the peak period for each of the five directions is also known. Since the refraction depends on the wave direction and wave period, it is necessary to do refraction computations for all possible combinations of wave period and direction.

The runs were numbered as follows:

Period (s)	Deep-sea direction[2] (degrees)				
	60°	90°	120°	150°	180°
Mean post-Domoina[1,3]	1	2	3	4	5
Mean pre-Domoina[4]	6	7	8	9	10
11,0	11	12	13	14	15
12,7	16	17	18	19	20
14,1	21	22	23	24	25
15,4	26	27	28	29	30
16,5	31	32	33	34	35
17,5	36	37	38	39	40

1 "Mean" indicates the mean peak period per direction as shown in Section 7.2.2.

2 Each direction represents the central direction in a 30°-wide sector.

3 The contours in grid 6, that is, in the coastal area fronting the Mfolozi and St Lucia estuaries, are given as surveyed by SOS in 1984 (post-Domoina) (Figure 24d).

4 The contours in grid 6 (smoothed) are believed to represent the pre-Domoina condition (Figure 24d).

The results are given for each period/direction combination in four figures, containing -

- the refraction diagram, with rays stopping in a water depth of 3 m;

- the longshore variation in the longshore component of the wave energy flux along the 3 m contour, expressed in m^3/s;

- the longshore variation in the breaking wave height; and

- the longshore variation in the breaker angle.

These figures are reproduced in Appendix A as Figures A1 to A40, with subscripts 1 to 4 referring to the above four end products. Thus Figure A27.3, for example, will refer to waves with a period of 15,4 s and a deep-sea angle of approach of 90° and will depict the longshore variation in the breaking wave height.

The averaged deep-water wave variables (f_I, T_p, H_{mo}) are given in Table 4. The wave data along the 3 m contour, as given in Appendix A, were transformed to the breaker line associated with its combination of peak period, deep-sea direction and accompanying mean wave height by assuming plane bed conditions and by using shoaling and Snell's law. The results are given in Appendix B. The same run numbers as used in Appendix A apply. The results are given for each period/direction combination at the breaker line in four figures which contain -

- the variation of angle of wave approach relative to the local contours, given along the coastline;
- the variation of breaking wave height along the coastline;
- the variation in initial breaker depth along the coastline; and
- the longshore variation in the longshore component of the breaker line wave energy flux expressed in m^3/s.

Each of these figures contains two lines, namely a full line that represents the actual breaker line values at 100 m intervals and a dotted line that represents the smoothed breaker line values at 500 m intervals. The latter line was in each case used for the computations in the next section.

7.2.3 Longshore transport potential

The longshore sediment transport rates S_x are computed by means of the SPM formula (SPM, 1984), as modified by Swart and Fleming (1976). This formula was applied to each wave condition in turn and the results were then summed to give the total transport rate. Details of the formula are as follows:

$$S_x = K(D)\ f_I\ T_p\ H_{mo}^2\ K_{rb}^2\ \sin 2\theta_b \qquad \ldots(3)$$

where

$K(D)$ = grain size parameter
= $91 \times 10^4 \log(0,00146/D_{50})$ (m/yr.s)

D_{50} = median grain size (m)

f_I = fractional occurrence of a given wave condition

K_{rb} = refraction coefficient at breaker line

θ = angle between the wave crest and the local bed contour at the breaker line (degrees).

The median grain size D_{50} of the beach sediment, as determined from the results in Table 5, is 296 µm, with a standard deviation of 74 µm. The 95 per cent confidence band of median diameters is therefore between 147 µm and 444 µm. The corresponding possible variation in K(D) is as follows:

lower envelope	D_{50} = 147 µm	$K(D) = 90,7 \times 10^4$ m/yr.s
mean	D_{50} = 295 µm	$K(D) = 63,1 \times 10^4$ m/yr.s
upper envelope	D_{50} = 444 µm	$K(D) = 47,0 \times 10^4$ m/yr.s

It is assumed that sediment is freely available when south-bound transport takes place and that the actual transport would be 50 per cent of the maximum transport potential when north-bound transport takes place (this on account of the extensive occurrence of rocky outcrops to the south of Mapelane). By using this availability of sediment, the frequency of occurrence of waves as given in Table 4 and the breaker zone wave data, Equation (3) gives the longshore variation of the total longshore transport rate. The results are given in Figures 25.1 to 25.3 and represent the results for -

- the sum total resulting from the mean wave periods per direction for the pre-Domoina topography;

- the sum total resulting from the mean wave periods per direction for the post-Domoina topography; and

- the sum total resulting from all the wave period/direction combinations for the post-Domoina topography.

This figure indicates that the net north-bound longshore transport rate in the area to the south of Mapelane is ~ 1 × 10^6 m^3 per year. The dredged volume inside the St Lucia mouth during 1983 amounted to 606 000 m^3 per year (Sutton, pers. comm.), which corresponds fairly closely with the net longshore transport rate just south of Mapelane. Usually the influx of sediment into an estuary mouth is much less than the 60 per cent of the net drift rate indicated here but this high influx rate is most probably related to the fact that the Mapelane to St Lucia coastline area is shown in Figures 25.1 to 25.3 to be accretive.

Comparison of Figures 25.1 and 25.2 indicates that the net transport direction is reversed in the post-Domoina situation in the area between the Mfolozi and St Lucia mouths. This reversal is one of the reasons for the beach recovery discussed earlier.

To the north of St Lucia the trend in the net north-bound transport rate gradually increases, albeit in an erratic manner. The area immediately to the north of St Lucia would, according to these figures, be generally accretive, which agrees with the observations reported earlier in the report.

7.2.4 Aeolian transport rates

When the shear stress exerted by the wind on the sandy surface on a beach or dune field exceeds a certain critical value, sand particles are brought into motion. Numerous researchers have studied this phenomenon either theoretically or experimentally in both the laboratory and the field and have come up with expressions for the rate of wind-blown or aeolian sand movement under given wind conditions. A study of the literature revealed the following 16 formulae for the prediction of aeolian transport rates:

Formula	Reference	Comments
BAGNOLD	Bagnold (1954)	
KAWAMURA	Kawamura (1950)	
OBRIEN	O'Brien & Rindlaub (1936)	Valid for $U* \geq 0,2$ m/s
HSU	Hsu (1974)	
MOSSA	Mossa (1981)	
CHIU1	Chiu (1970)	Neglects particle distribution
CHIU2	Chiu (1970)	Incorporates particle distribution
KADIB	Kadib (1966)	Expressions fitted to graphical curves by Swart (in prep.)
NAKASJIMA	Nakasjima (1979)	
TSUCHIYA1	Tsuchiya & Kawata (1975)	As interpreted from the Japanese by Swart (in prep.)
TSUCHIYA2	Tsuchiya & Kawata (1975)	
TSUCHIYA3	Tsuchiya & Kawata (1975)	
ZINGG	Zingg (1952)	
ZANKE1	Zanke (1980)	
SANKE2	Zanke (1980)	
MBKS	Hotta _et al_. (1984) Horikawa _et al_. (1983, 1984) Kubota _et al_. (1982)	Modified Bagnold-Kawamura formula, further adapted by Swart (in prep.)

The above-mentioned aeolian transport predictors were all rewritten by Swart (in prep.) to give volumetric transport rates. The independent variables used in these formulae in some or other way are -

- The shear velocity at the bed $U*$;
- the median grain size D_{50} or in some cases the particle size distribution D_i;
- the mass density of the air ρ_a and the particles ρ_s;
- gravitational acceleration g; and
- kinematic viscosity of air ν_a.

Horikawa et al. (1984) showed that air temperature and humidity and the moisture content of the sandy surface are also important variables but at present no reliable theory exists to incorporate them into predictive equations. The type and extent of vegetation cover on the sandy surface also affects the aeolian transport rates. McLachlan et al. (1982) provided some quantitative data to show the extent of the reduction in the unhindered transport rate due to vegetation.

A computer program was written that computes for each direction/velocity combination in a wind statistics table the aeolian transport rate according to each of the above-mentioned 16 formulae. These transport rates are then ranked in order of descending magnitude and the highest three as well as the lowest three transport rates rejected. The average of the remaining 10 predictions is then taken as the best estimate of the transport rate of the specific direction/velocity combination. By repeating this procedure for every velocity interval for a given direction and by taking due cognizance of the frequency of occurrence of each direction/velocity combination, the total aeolian drift for the given direction is found. The results are given in m^3/km/yr. Swart (in prep.) defined an aeolian creep diagram, which is a visualization of the aeolian drift rates for all wind directions (see Figure 27). The hatched area represents the amount of drift, which is plotted from the edge of the circle inwards, that is, in the direction in which the sand will be blown, on the basis of prediction in 22,5° direction sectors.

Utilizing the VOS wind data, such as shown in Figure 26, aeolian creep diagrams were produced. The results are given here as Figure 27 and can be summarized as follows:

Direction of wind-blown sand transport (S)	Magnitude of Vector-averaged component of S × 10^3 (m^3/km/yr)
South-bound	20,3
West-bound	13,0
North-bound	40,3
East-bound	12,4

These figures indicate that the potential east and west-bound aeolian drift components are approximately equal but that the north-bound transport rate exceeds the south-bound transport rate by 20 × 10^3 m^3/km/yr. If it is assumed that sand can blow from the edge of the St Lucia estuary over a 400 m distance these figures point to a net north-bound removal of sand from the estuary of 8 × 10^3 m^3/yr.

Swart (in prep.) showed that the annual potential aeolian drift rate can vary by up to a factor 3 between the highest and lowest predicted annual drift rates, depending on the nature of the wind data. Dampness in the St Lucia area could tend to reduce the actual drift rate.

8. SUMMARY OF RESULTS AS RELATED TO A MANAGEMENT STRATEGY

The management strategy outlined below is based on the concept of "least interference". In other words, the authors feel that there should be a minimal amount of management and management should attempt to simulate natural processes.

1. **The key to the successful management of the Mfolozi and St Lucia Estuaries is the correct management of the Mfolozi Flats.** Prior to farming the flats accepted most of the river borne sediment. Build-up occurred as a consequence of differential sedimentation associated with periodic change in loci of deposition as channels switched from one part of the flats to another. The relatively sediment-free waters that reached the coast had the ability to keep the then combined systems open and unsilted. Pre-Domoina farming practices saw sediments advected down the Mfolozi River to the coast due to a confined, artificially-stabilized channel, which also inhibited channel switching. The St Lucia Estuary then acted as a sink for these sediments, to such an extent that the St Lucia mouth became permanently sealed, initiating the present ongoing dredging programme. During Domoina a major switch in the course of the river occurred and vast amounts of sediment were deposited on the upper flats, resulting in relatively sediment-free waters reaching the coast. These waters eroded and scoured out both estuaries and some coastal areas, including the Mapelane dune, some 40 m high.

2. **It is recommended that no diversion works or canalization be allowed in the lower reaches of the Mfolozi or the Mzinduze, downstream of the sugar cane fields, as such works would decrease the possibility of channel switching during future floods,** causing the advection of unwanted sediments to the coast. In addition natural swamp and marshland in the lower reaches of the flats should be given conservation status. These areas would act as sediment traps during

major floods due to the relatively unconfined nature of the channels and the presence of natural topographic lows. Lastly, due to the openness of the area and its productive marsh systems, detrital input into the Mfolozi and Mzinduze ensures that these estuaries remain highly productive. It must be remembered that the St Lucia Resort is dependent on sport-fishing and that the Mfolozi Estuary is important to attract and serve as a nursery for the common sport-fish species.

3. Both the St Lucia and the Mfolozi estuaries are maintaining themselves. However, the estuary mouths are changing in configuration. The spit at Mfolozi is being built up from Mapelane beach erosion and sediment moved alongshore. The Mfolozi estuary mouth is decreasing in size and may be trying to find a second outlet. As the Mfolozi is a large estuary, any attempts at preserving St Lucia should ensure that the Mfolozi is not adversely affected. The spit at the mouth of the Mfolozi Estuary is forcing mouth migration northwards. The same feature, however, ensures that marine sands do not enter the Mfolozi system during periods of low river flows. Conversely, the Mfolozi estuary acts as a large reservoir for river-borne sediments advecting through the flats as was demonstrated during the February 1985 floods. **In fact, due to the size and proximity of the Mfolozi mouth, management of the Mfolozi is preferred to management of the influx of sand into St Lucia.**

4. At St Lucia the sediments making up the spit are derived mostly from the spoil pile. A minor amount is supplied by alongshore drift as wave energy is reduced, specifically during south-easterly swells, by the presence of bars associated with the Mfolozi ebb-tidal delta. **The St Lucia estuary may maintain itself for a long time, especially if no sediments are introduced at upstream locations.** At present the large tidal basin behind the spit ensures strong

flushing. Unfortunately, the continual erosion of the spoil pile and deposition in the estuary may lead to a situation requiring dredging.

5. **It is recommended that no hard structures be placed for the stabilization of the St Lucia mouth.** If it is felt necessary, the northern embankment could be graded to an even slope, especially where the northern bank was scoured out by Domoina. The marsh area known as Shark Pool off the North Bank should be encouraged to function as a tidal creek. A wooden walkway should be constructed at the estuary end to allow free movement of tidal flows.

6. **It is recommended that no southern groyne be built at St Lucia.** Dredging of marine sand inside the mouth should continue landwards of the southern sand spit as before; the dredged material should be pumped onto the beaches north of the St Lucia mouth. As long as dredged sand cannot be pumped to the north, dredging should not be done. It is anticipated that the dredging rate would on average be 600 000 m^3/yr. **It is recommended that the St Lucia mouth should not be dredged to the extent that it widens as this would enhance the influx of marine sand.**

7. The levees on the seaward section of the Mfolozi Flats for the prevention of the short-circuiting of the Mfolozi to St Lucia did more harm than good, since they caused the formation of extensive drainage channels towards the sea (see Figure 17b). **No such levees should be constructed in the future.**

8. **Natural southern spit/bar configurations should be allowed to develop at both Mfolozi and St Lucia.** In both cases the cross-sectional area at the mouth would be regulated by river discharge since the northern bank is stable.

9. **Wind-blown sediment movement from the northern bank of the St Lucia Estuary** in a northerly direction could be responsible for transporting up to 8 000 m^3 of sand annually from the estuary. This process breaks down when dune fields are stabilized. It is recommended that the exotic casuarine trees at present growing on the coastal dunes be removed.

10. It is recommended that the natural redevelopment of the Mfolozi/St Lucia system should be monitored closely. Therefore the three-monthly aerial photography should be continued. The Marine Geoscience Division of the NRIO will assess these photographs and interpret them free of charge as they become available. In addition the system should be monitored for the next two to three years, not only physically but also biologically.

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TABLE 1: Summary of VOS wave data
(after Swart and Serdyn, 1981)

YEAR	(1960-1979)
LATITUDE : 28-29	LONGITUDE : 32-33
TOTAL NUMBER OF OBSERVATIONS =6,056	

YEAR (1960-1979)
LATITUDE : 28-29 LONGITUDE : 32-33
TOTAL NUMBER OF OBSERVATIONS =6056

* $T_{vos}^{(s)}$ →

↓ H_{vos}

* value of H_{vos} in ½ m intervals

20- 30- 40

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0	3	7						10
1	3	37	6		1	1		48
2	8	75	19	4	1			107
3	13	84	33	14	4	1		149
4	14	58	31	8	3	2		116
5	3	21	27	9	3	1	2	66
6	6	16	12	11	4	2	3	54
7		3	3	1	1			8
8	1	7	3	3	3			17
9		1		4				5
10	1			1				2
14						1		1
16				1				1
UND.	24	11	3	1				39
TOTAL :	76	320	137	57	20	8	5	623

50- 60- 70

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0		4						4
1	2	22	4	5	3			36
2	8	57	24	14	6			109
3	8	36	21	10	6	1		82
4	9	25	20	4	3			61
5	2	6	9	3	4	1		25
6	1	7	11	9	2			30
7		1	4	2				7
8		2	1	1				4
9			1	2				3
10			1					1
12			1					1
UND.	15	11	3	1				30
TOTAL :	45	171	100	51	24	2	0	393

TABLE 1 CONTINUED

YEAR (1960-1979)

LATITUDE : 28-29 LONGITUDE : 32-33

TOTAL NUMBER OF OBSERVATIONS =6056

80- 90-100

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0		2						2
1	3	21	6	2				32
2	9	35	21	11	2			78
3	12	30	36	19	5	2		104
4	7	18	25	18	7	3		78
5	3	3	13	9	7	3		38
6	4	4	10	11	3	2	1	35
7			1	1	1			3
8			5	1	1	1		8
9				2				2
10				1	2			3
UND.	12	3						15
TOTAL :	50	116	117	75	28	11	1	398

110-120-130

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0		5						5
1	2	19	3	3				27
2	9	24	22	9	2		1	67
3	3	21	25	17	7			73
4	3	11	17	17	3	1		52
5	5	11	15	8	8			47
6		4	12	7	2	1		26
7	1	1	2	5	3		1	13
8		1	2	1	1	2		7
9			1	1				2
10				2				2
12				1			1	2
UND.	12	1						13
TOTAL :	35	98	99	71	26	4	3	336

TABLE 1 CONTINUED

YEAR (1960-1979)
LATITUDE : 28-29 LONGITUDE : 32-33
TOTAL NUMBER OF OBSERVATIONS =6056

140-150-160

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0		4						4
1	2	21	5	2	2			32
2	9	40	26	13	3	1		92
3	17	36	55	24	11	3		146
4	15	32	50	39	13	9		158
5	7	9	34	16	5	4	1	76
6	3	5	18	17	10	6	2	61
7	1	1	5	12	2	1		22
8	4	5	7	13	4		1	34
9	1		1	2	1			5
10			2	5	1			8
11						1		1
12	1		1	2		1		5
13				1				1
18		1						1
UND.	15	1	3	1				20
TOTAL :	75	155	207	147	52	26	4	666

170-180-190

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0	1	2						3
1	4	13	9	4	1			31
2	7	67	30	16	5			125
3	13	55	56	33	11	6	1	175
4	20	50	60	53	22	10		215
5	19	29	74	37	22	5	1	187
6	14	23	53	56	31	12	2	191
7	5	13	20	23	12	5		78
8	11	9	24	30	10	8	5	97
9	3	4	3	13	7	2		32
10	1	2	8	11	12	6	1	41
11			1	5	4	1		11
12	2	1	3	10	7	3	1	27
13			4	2				6
14	1				2		1	4
15			1					1
16		1	1			1		3
17							1	1
18			1					1
UND.	31	7	5	2	2	1		48
TOTAL :	132	276	353	295	148	60	13	1277

YEAR (1960-1979)
LATITUDE : 28-29 LONGITUDE : 32-33
TOTAL NUMBER OF OBSERVATIONS =6056

200-210-220

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0		9						9
1	3	18	4	4	2			31
2	7	44	13	7	3			74
3	5	42	28	12	1	5	1	94
4	17	40	41	27	9	2		136
5	7	27	30	21	9	2	2	98
6	3	17	28	19	15	5	2	89
7		3	11	11	8	3		36
8		5	21	14	8	2	2	52
9	2	1	5	7	2		2	19
10	1	1	4	10	6	2		24
11		2	2	1	1			6
12	1	2	6	4	3	2		18
13	1	1	1		2			5
14			1	3	4	2	1	11
15			1					1
16	1			1			1	3
17		1						1
18				1	1	1	1	4
19						1		1
20				1	1			2
UND.	14	6	5	1				26
TOTAL :	62	219	201	144	75	27	12	740

230-240-250

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0		4						4
1	1	14	1	3	1			20
2	1	16	7	4				28
3	2	16	10	7				35
4	1	8	8	3	3			23
5	1	7	3	1	1			13
6		1	1	1		1		4
7	1	2		1	2			6
8			1		1		1	3
9		1						1
10				2				2
14							1	1
UND.	7	3	1					11
TOTAL :	14	72	32	22	8	1	2	151

YEAR (1960-1979)
LATITUDE : 28-29 LONGITUDE : 32-33
TOTAL NUMBER OF OBSERVATIONS =6056

260-270-280

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
1		3		1				4
2	1	7	2	1				11
3		3	3					6
4		3		1		1		5
6		1						1
UND.	2	5						7
TOTAL	3	22	5	3	0	1	0	34

290-300-310

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0	1							1
1		7						7
2	2	3						5
3		1						1
4	1	2		1				4
5		2		2				4
6			1					1
UND.	1							1
TOTAL	5	15	1	3	0	0	0	24

YEAR (1960-1979)

LATITUDE : 28-29 LONGITUDE : 32-33

TOTAL NUMBER OF OBSERVATIONS =6056

320-330-340

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0		1						1
1	1	10	1					12
2		18	3					21
3		9	3	1	1			14
4		7	6		1			14
5	1	3	1	1	1			7
6	1	1						2
9				1				1
UND.	1	2		1				4
TOTAL :	4	51	14	4	3	0	0	76

350-360- 10

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0		2						2
1	2	26		1				29
2	6	44	6	2				58
3	3	42	18	9	1			73
4	4	29	15	6	4	2	1	61
5	6	21	17	2	1	1		48
6	2	8	10	4	5	1	1	31
7		5	5	1				11
8		2	1					3
9			1	1			1	3
10		1						1
14					1			1
UND.	14	4	3					21
TOTAL :	37	184	76	26	12	4	3	342

TABLE 1 CONTINUED

YEAR (1960-1979)
LATITUDE : 28-29 LONGITUDE : 32-33
TOTAL NUMBER OF OBSERVATIONS =6056

DIRECTIONS UNDEFINED OR CALM

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0	39	26						65
1	3	4						7
2	14	2						16
3	39			1				40
4	31	1						32
5	23		1					24
6	21							21
7	4							4
8	3							3
9	2							2
10	1							1
UND.	781							781
TOTAL	961	33	1	1	0	0	0	996

ALL DIRECTIONS

	UND.	<=5	6-7	8-9	10-11	12-13	>=14	TOTAL
0	44	66						110
1	26	215	39	25	10	1		316
2	81	432	173	81	22	1	1	791
3	115	375	288	147	47	18	2	992
4	122	284	273	177	68	30	1	955
5	77	139	224	109	61	17	6	633
6	55	87	156	135	72	30	11	546
7	12	29	51	57	29	9	1	188
8	19	31	65	63	28	13	9	228
9	8	7	12	33	10	2	3	75
10	4	4	15	32	21	8	1	85
11		2	3	6	5	2		18
12	4	3	11	17	10	6	2	53
13	1	1	5	3	2			12
14	1		1	3	7	3	3	18
15			2					2
16	1	1	1	2		1	1	7
17		1					1	2
18		1	1	1	1	1	1	6
19						1		1
20				1	1			2
UND.	929	54	23	7	2	1		1016
TOTAL	1499	1732	1343	899	396	144	43	6056

TABLE 2: Simulated run-off for Mfolozi River
(supplied by J.E. Perry)

SIMULATED RUN-OFF FOR MFOLOZI NN 1A   CATCHMENT AREA= 10075.0SQ.KM.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL	%M.A.R.
1921	32.80	768.55	351.67	62.03	39.33	39.34	18.67	10.65	10.68	8.85	16.44	16.05	1314.46	148.14
1922	35.52	266.35	205.86	416.21	153.38	20.66	18.72	7.58	4.96	5.25	5.24	4.09	1077.02	121.38
1923	4.55	11.63	56.44	34.95	30.78	54.46	94.39	19.12	12.05	7.13	6.02	17.83	294.55	33.20
1924	24.32	407.15	313.11	134.98	191.39	5127.75	1744.75	59.37	30.22	22.84	17.97	20.58	8096.33	912.49
1925	39.92	36.78	76.89	19.27	13.94	27.48	17.66	9.72	11.17	10.41	6.55	14.30	233.99	26.37
1926	73.84	23.49	16.25	15.03	24.32	50.81	33.18	13.76	6.82	11.78	12.88	9.80	243.25	27.42
1927	32.44	46.44	47.34	81.18	48.39	23.99	18.21	12.49	6.66	4.89	5.84	11.02	358.89	40.45
1928	14.32	17.79	15.39	17.57	12.96	274.28	121.98	22.48	16.59	20.28	15.19	24.20	584.46	65.93
1929	76.57	91.47	48.51	543.58	225.31	49.88	95.49	20.75	16.10	6.34	7.38	11.62	1124.28	126.70
1930	12.37	17.42	22.34	19.80	15.36	12.78	8.47	5.81	4.35	4.93	4.70	3.85	131.48	14.82
1931	6.31	15.49	13.45	6.49	572.37	287.10	196.15	157.24	65.11	23.84	11.80	7.47	1364.87	153.82
1932	7.56	12.59	64.23	49.45	35.44	21.84	10.60	6.12	4.19	6.73	7.94	5.24	236.75	26.68
1933	6.86	190.60	144.35	470.48	163.89	35.20	24.57	21.61	17.65	16.01	24.68	20.36	1146.31	129.19
1934	14.80	30.59	284.42	125.68	31.94	21.70	15.25	12.03	10.37	7.66	6.46	4.89	565.79	63.77
1935	4.67	4.38	6.37	95.63	179.72	105.91	43.42	62.70	46.10	20.76	9.73	7.46	586.85	66.14
1936	20.50	294.15	117.34	160.81	249.59	96.49	73.86	11.80	7.92	8.23	7.91	12.12	1010.73	113.91
1937	14.92	13.87	191.44	94.31	42.50	31.88	29.90	27.62	23.33	30.61	24.00	13.75	533.13	60.09
1938	31.72	33.55	153.03	83.46	511.86	270.30	59.88	30.86	22.06	19.74	17.44	24.73	1267.83	142.89
1939	38.57	425.39	188.48	73.88	33.99	38.71	25.95	75.47	144.35	75.43	22.58	19.67	1182.54	133.28
1940	19.87	56.70	286.78	123.93	27.72	14.84	21.18	20.70	12.43	8.19	6.32	8.14	604.80	68.16
1941	9.86	19.21	16.91	91.43	93.66	147.17	65.67	16.97	10.90	17.80	13.55	19.19	522.34	58.87
1942	31.99	65.00	399.54	166.08	45.52	189.72	430.93	170.47	36.70	49.55	117.21	66.10	1770.70	199.56
1943	173.77	144.79	115.35	46.60	253.19	104.11	16.57	8.64	31.34	30.87	15.51	55.23	1016.87	114.63
1944	52.04	36.11	34.19	34.29	48.26	401.71	141.64	24.68	11.91	7.19	5.10	3.75	822.87	92.74
1945	5.77	4.89	11.18	257.61	117.20	38.07	25.55	13.58	7.03	5.84	3.99	4.60	494.51	55.73
1946	18.97	37.35	36.82	34.72	125.12	74.30	30.63	17.08	14.41	13.47	9.03	8.21	422.11	47.57
1947	14.81	111.56	77.84	34.39	27.64	65.55	44.88	19.35	6.44	5.11	3.88	6.48	419.93	47.33
1948	25.21	43.39	34.76	61.16	57.05	42.10	71.76	46.24	22.11	13.38	6.13	7.56	432.95	48.78
1949	25.80	80.26	243.28	115.19	31.81	35.08	74.76	14.81	10.75	6.42	7.42	5.35	622.93	70.21
1950	6.47	8.47	46.46	39.03	17.73	24.47	26.68	19.65	11.68	7.78	33.08	36.86	272.48	30.71
1951	52.16	29.75	59.60	39.98	25.84	18.21	11.16	9.23	7.96	12.38	10.91	5.89	283.07	31.90
1952	6.09	26.69	185.22	85.12	37.75	28.16	18.51	13.03	8.78	6.84	6.15	6.25	430.59	48.53
1953	10.73	32.19	29.25	17.78	36.28	35.41	29.43	39.26	32.23	16.81	9.77	18.60	307.74	34.68
1954	226.09	190.87	59.75	130.65	93.24	113.58	61.39	24.10	12.60	7.66	5.00	3.69	928.62	104.66
1955	22.03	50.22	56.83	26.35	559.16	223.00	25.25	14.47	12.59	9.32	7.22	12.98	1019.42	114.89
1956	37.47	99.64	346.62	149.42	67.04	46.62	76.12	48.04	16.91	29.99	32.72	635.24	1587.83	178.95
1957	1096.99	329.33	29.92	114.92	182.66	70.30	33.28	26.39	14.68	9.01	5.99	7.71	1921.09	216.51
1958	23.86	201.14	105.38	181.46	94.50	26.98	11.06	16.39	15.57	9.20	8.38	14.06	707.98	79.79
1959	32.38	34.46	84.38	44.81	48.30	50.35	59.18	41.54	16.16	8.16	7.09	11.33	447.14	50.39
1960	27.12	246.76	617.05	223.24	51.19	28.65	27.26	27.03	54.25	29.11	12.28	19.97	1413.91	159.35
1961	31.97	35.23	25.45	18.64	13.97	37.53	31.55	18.00	9.03	5.60	8.37	6.17	243.51	27.44
1962	18.56	128.68	349.36	145.84	39.97	40.01	38.17	23.39	32.92	846.04	316.98	22.90	2002.57	225.70
1963	14.75	26.01	23.67	39.56	30.50	13.82	22.15	20.73	13.90	10.78	7.75	5.60	228.72	25.78
1964	156.35	112.32	63.74	28.72	15.87	9.14	6.03	6.44	10.25	12.88	19.39	16.01	459.34	51.77
1965	26.43	34.65	23.75	62.23	77.76	36.49	13.05	10.79	10.52	8.34	8.30	9.73	322.04	36.30
1966	10.74	16.15	87.76	110.62	335.48	136.87	52.47	34.79	15.52	10.42	7.73	5.86	824.41	92.91
1967	21.85	177.83	84.00	25.02	20.31	27.36	21.66	10.26	5.38	4.25	10.41	12.45	420.78	47.42
1968	11.99	21.52	83.08	46.94	17.73	170.38	90.81	31.63	17.72	10.41	6.68	6.61	517.50	58.32
1969	83.62	64.09	31.71	18.26	16.35	12.99	8.33	11.30	10.93	7.99	8.21	15.44	291.22	32.82
1970	38.51	62.15	37.97	63.39	36.71	20.98	74.62	198.96	92.21	27.02	17.60	13.70	635.82	71.66
1971	33.51	37.23	84.24	279.70	756.98	256.73	24.04	25.01	23.05	15.74	10.55	6.34	1558.12	175.61
1972	8.37	23.76	22.98	23.20	221.86	94.55	36.08	24.60	11.13	6.54	21.07	70.65	564.79	63.65
1973	52.62	76.04	73.67	117.30	55.53	23.69	23.04	20.34	15.40	12.65	9.18	5.22	484.68	54.63
1974	5.92	57.43	165.78	410.65	367.80	118.55	61.03	29.47	15.51	8.81	6.07	50.85	1296.07	146.30
1975	46.77	56.14	169.53	221.09	245.51	139.37	108.77	74.87	41.40	20.45	11.61	7.73	1143.24	128.85
MEAN	53.24	99.89	119.95	110.56	124.94	172.84	78.23	31.91	21.51	29.54	18.70	26.78	887.28	
S	149.09	131.18	125.52	115.81	161.52	685.86	237.96	36.50	25.34	112.79	43.90	84.85	1099.12	
V%	280.04	132.35	104.94	104.77	129.28	396.82	304.16	170.44	117.81	381.78	234.75	316.84	123.88	
MEDIAN	23.54	36.11	67.34	63.39	48.26	39.34	24.68	20.23	12.60	9.32	8.37	11.82	565.79	

MEAN ANNUAL RUN-OFF= 857.28 MILLION CUBIC METRES. COMPILED FROM HRU REPORT NO.9/81 DATA

TABLE 3: SUMMARY OF HISTORIC OBSERVATIONS OF ST LUCIA/MFOLOZI

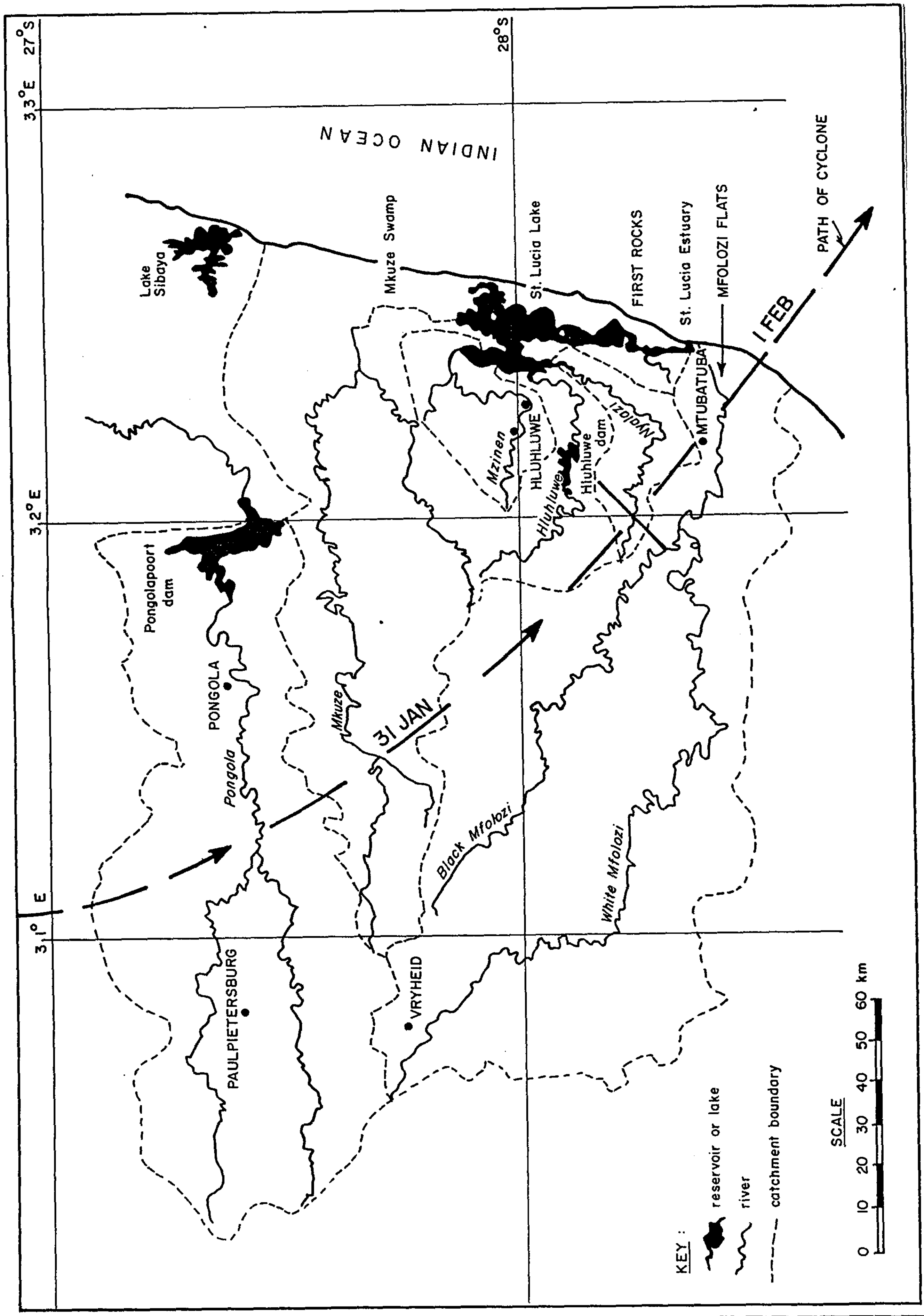
Date		Modern history of St Lucia	Estuary mouth	
Year	Month	Remarks	Open	Closed
1576	?	Mouth shallow, shoal extends long way out to sea	x	
1590	?	River in flood	x	
1823	?			x
1833	?			x
1849	?	Navigable entrance	x	
1851	Sep.	Mouth almost closed	x	x
1852	March	Mouth 12 feet deep	x	
1852	Aug.	Mouth about to close	x	x
1853	?	Mouth 500 feet wide and 12 feet deep	x	
1856	Apr.	River in flood	x	
1879	?	British map of Zululand, mouth open, Mfolozi enters estuary at Honeymoon Bend	x	
1833		Boer map of St Lucia, mouth open, Mfolozi enters Honeymoon Bend	x	
1885	?	British admiralty state mouth closed Sep.-Nov.	x	x
1895	?	British admiralty state mouth closed Sep.-Nov.	x	x
1902	?	Mouth deep	x	
1903	?			x
1905	Jan.	Mouth 4 feet deep and 300 feet wide	x	
1911	?	River in flood	x	
1918	?	Large flood	x	
1922	Nov.			x
1923	Feb.		x	
1925	?	Large flood	x	
1927	?	Start draining Mfolozi swamps, total area 67 ml^2		
1932	?	Estuary, which was closed, opened artificially	x	x
1935	?	Oyster collection ceased due to silt		
1936	?	Complaints started, fishing deteriorating		
1937	?	First air photo, mouth 100 feet wide	x	
1939	?	Further reports of estuary silting up		
1948	July			x
1951	?	Mouth closed till 1955, reclamation started		x
1952		Mfolozi new mouth		
1955	?	Mouth opened artificially	x	
1957	?	Air photos, narrow mouth	x	
1955		1955-1961 mouth mostly closed		x
1960	?	Air photo		x
1963	?	Large flood		x
1964	July	Air photo, narrow mouth, open art.	x	
1965	Apr.			x

TABLE 4: Deep-sea wave data

θ	T_p	H_{mo}	f_I
60°	11,0	2,17	2,9
	12,7	2,66	1,8
	14,1	2,65	0,9
	15,4	2,36	0,4
	16,5	2,63	0,04
	17,5	0,0	0,0
90°	11,0	2,09	2,1
	12,7	2,55	2,2
	14,1	2,73	1,4
	15,4	3,03	0,5
	16,5	2,98	0,2
	17,5	3,40	0,02
120°	11,0	2,20	1,8
	12,7	2,61	1,8
	14,1	2,86	1,3
	15,4	2,89	0,5
	16,5	3,66	0,07
	17,5	4,14	0,06
150°	11,0	2,38	2,8
	12,7	2,72	3,8
	14,1	3,28	2,7
	15,4	2,98	1,0
	16,5	3,17	0,5
	17,5	3,53	0,07
180°	11,0	2,70	4,9
	12,7	3,17	6,4
	14,1	3,47	5,4
	15,4	3,71	2,7
	16,5	3,84	1,1
	17,5	4,17	0,2

TABLE 5: St Lucia sand sample analyses

Sample No.	D_{50} (µ)	Sample No.	D_{50} (µ)	Sample No.	D_{50} (µ)
1	280	29	230	57	400
2	260	30	250	58	240
3	380	31	420	59	-
4	370	32	270	60	280
5	350	33	260	61	260
6	250	34	280	62	380
7	220	35	280	63	310
8	340	36	280	64	310
9	340	37	300	65	220
10	300	38	270	66	220
11	340	39	360	67	280
12	410	40	-	68	230
13	270	41	190	69	330
14	290	42	280	70	-
15	370	43	-	71	480
16	460	44	190	72	320
17	320	45	200	73	340
18	-	46	220	74	270
19	230	47	-	75	390
20	220	48	220	76	280
21	320	49	210		
22	550	50	320		
23	-	51	210	$\bar{x}$ = 29 µm	
24	-	52	250		
25	210	53	210	$\bar{s}$ = 74 µm	
26	270	54	350		
27	370	55	-		
28	210	56	-		



TRACED :	ST. LUCIA RESEARCH	FIGURE
CHECKED :	Figure 1: Study area.	1
DATE :		
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Figure 2. Trisponder remote set-up on beach at Mapelane

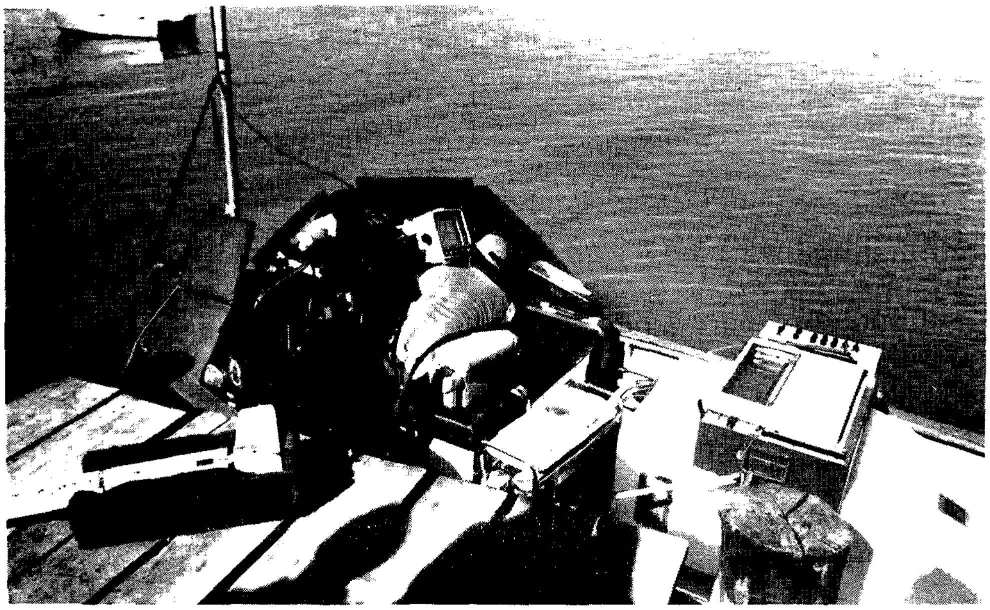

Figure 3. Survey boat fitted out with side-scan sonar. Note recorder on stern and fish on jetty.

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH Figure 2. Trisponder remote set-up on beach at Mapelane Figure 3. Survey boat fitted out with side-scan sonar	FIGURE 2 & 3

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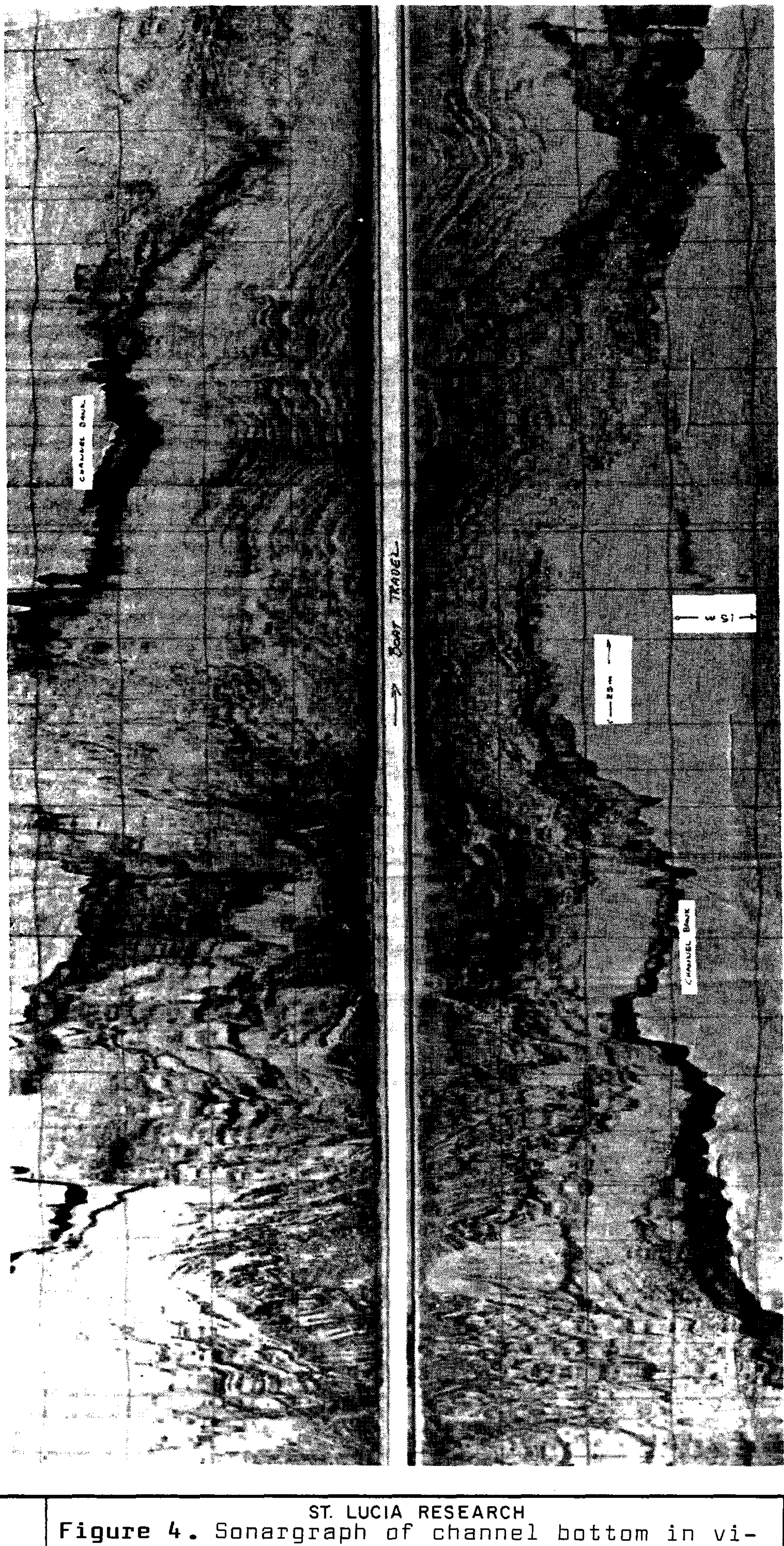

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH **Figure 4.** Sonargraph of channel bottom in vicinity of Honeymoon Bend. Exposed on channel floor are old sedimentary sequences indicative of the amount of scour during Domoina	FIGURE 4

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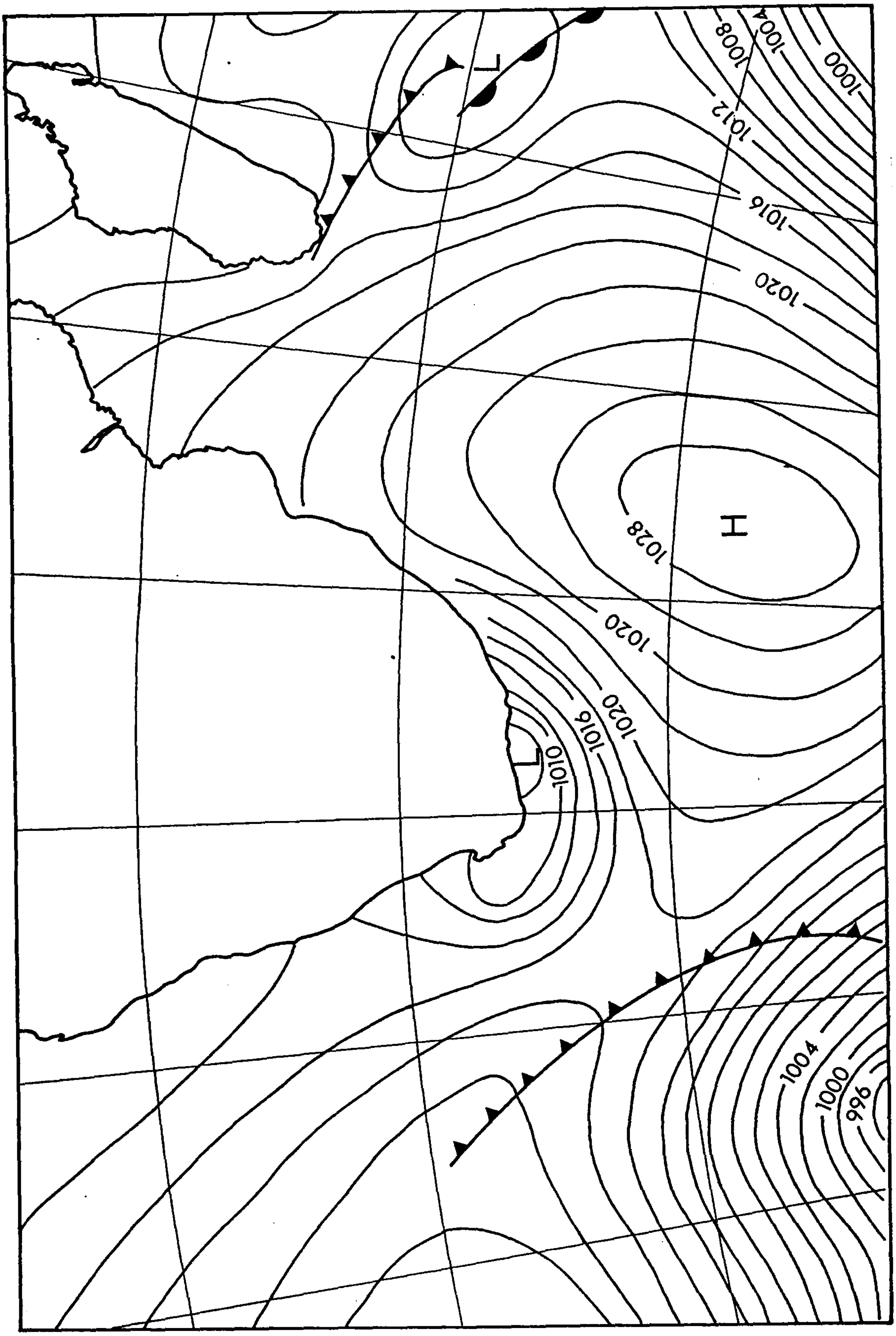

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH **Figure 5.** Synoptic weather chart showing an approaching cold front and coastal low hugging the south coast of South Africa.	FIGURE 5

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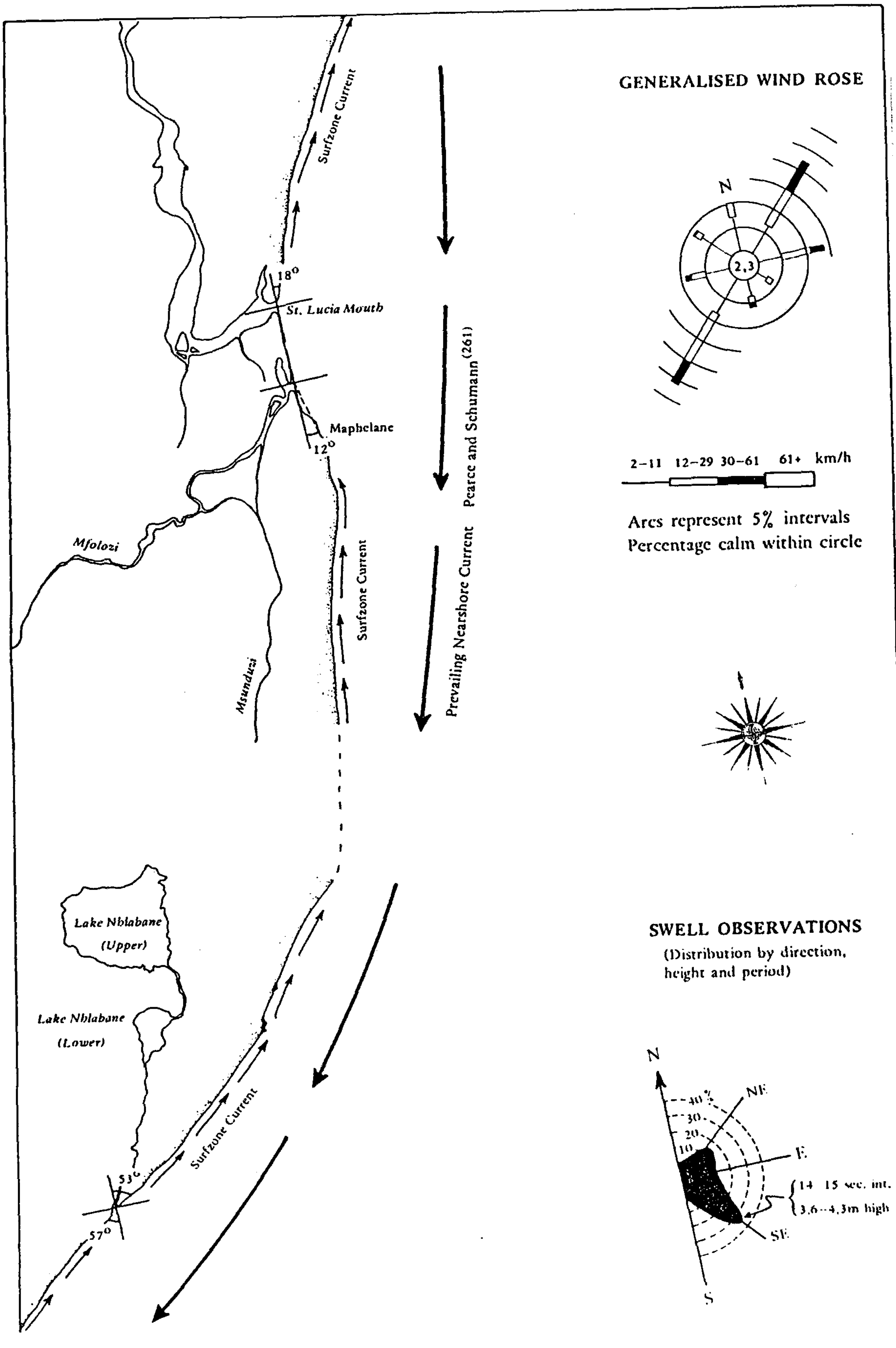

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Figure 6. Oceanographic features. (From Begg 1978)

FIGURE 6

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DATE :
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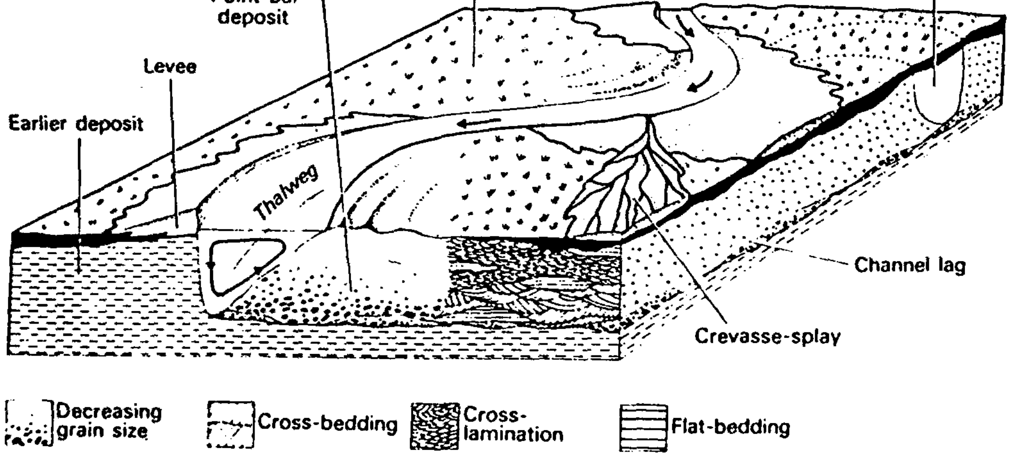

Figure 7. Cross-section of river meander on a flood plain

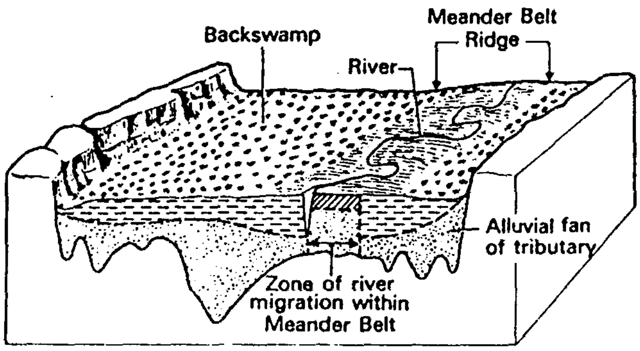

Figure 8. Morphology of coastal fluvial plain

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH Figure 7. Cross-section of river meander on a flood plain. Figure 8. Morphology of coastal fluvial plain	FIGURE 7 & 8

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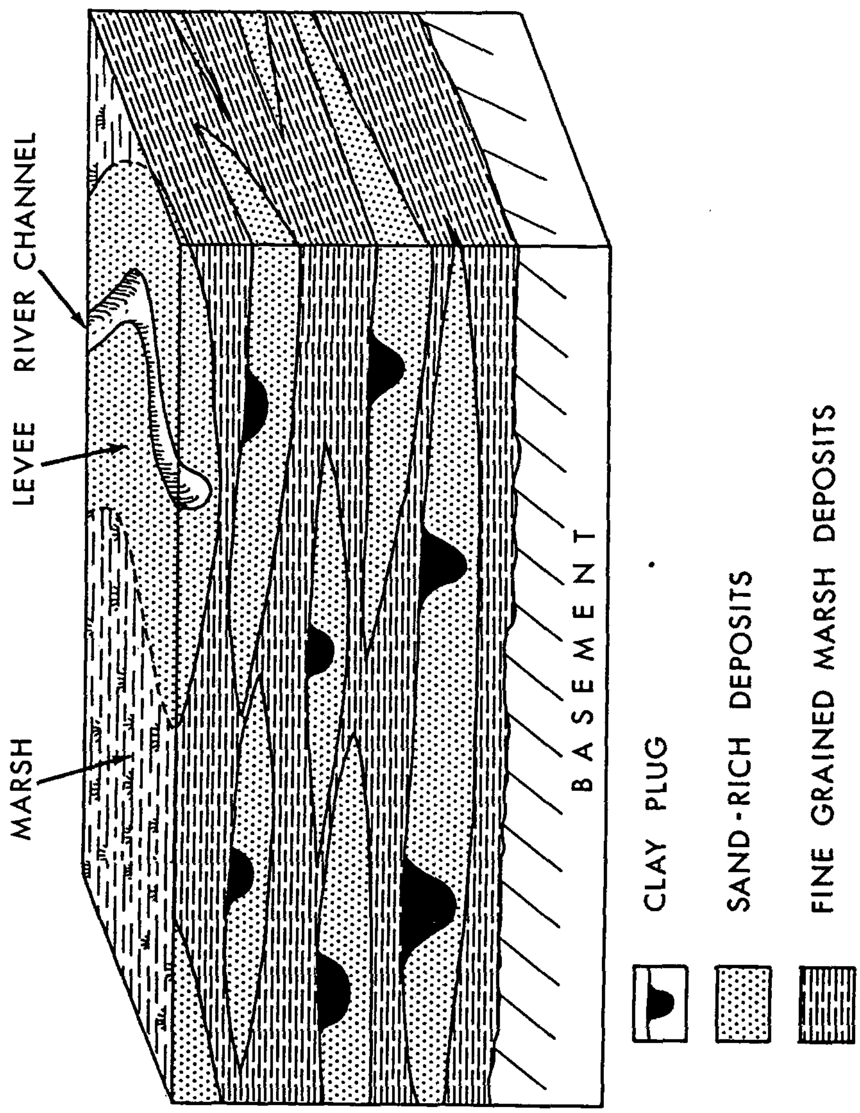

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH Figure 9. Generalized geological section of river flood plain	FIGURE 9

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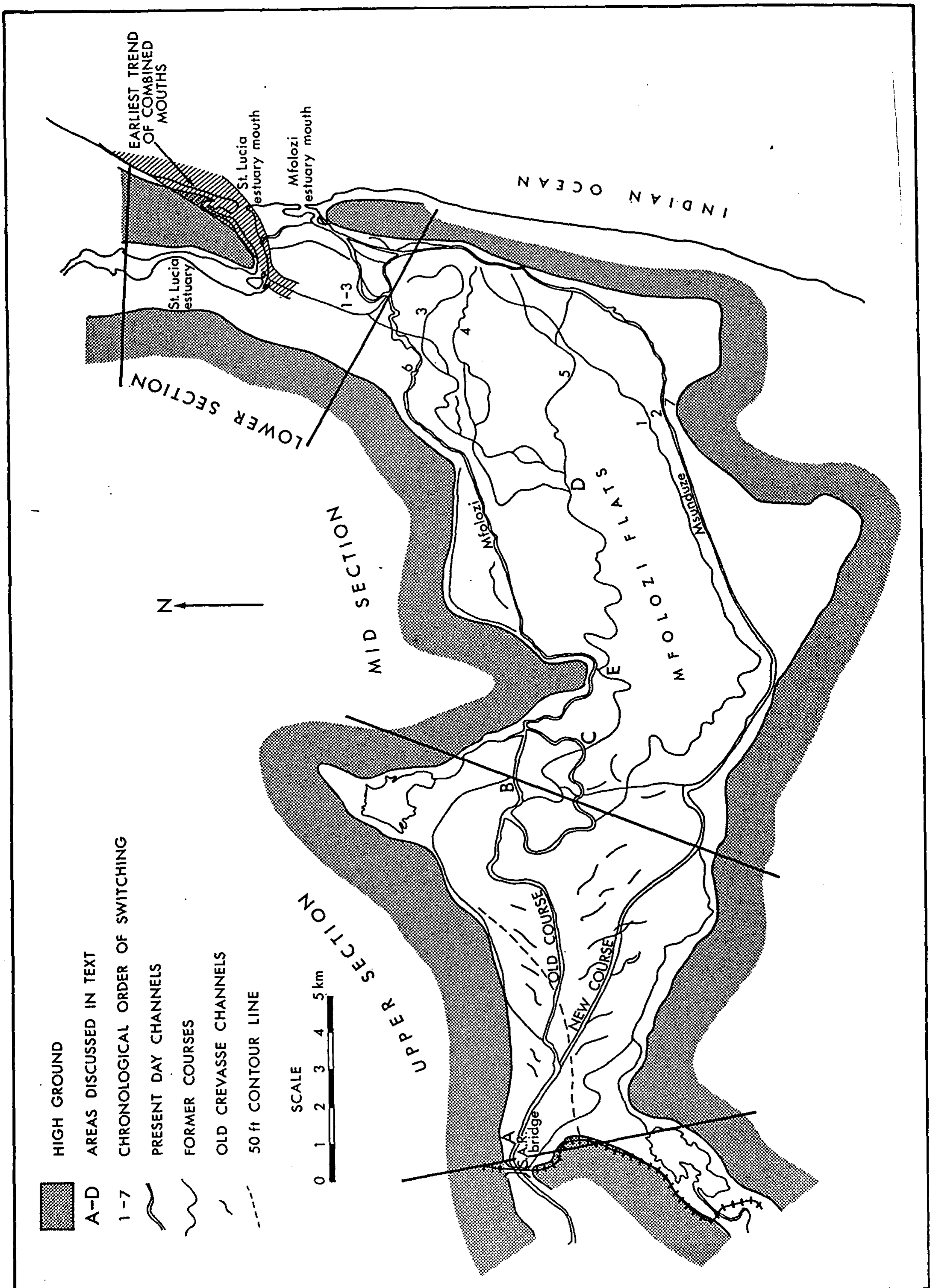

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH Figure 10. Channel traces on the Mfolozi Flats	FIGURE 10

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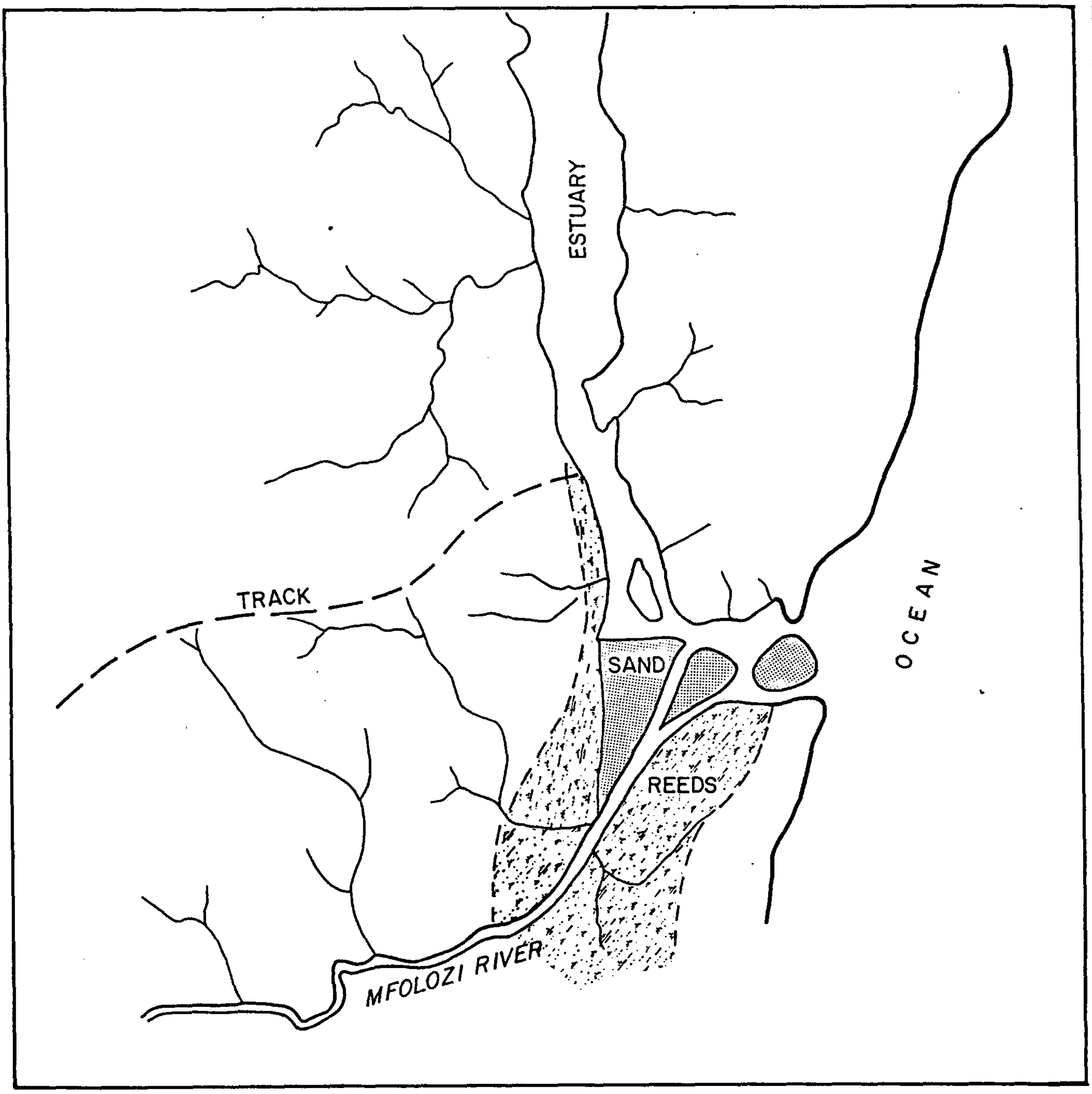

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH Figure 11. St Lucia estuary circa 1884	FIGURE 11

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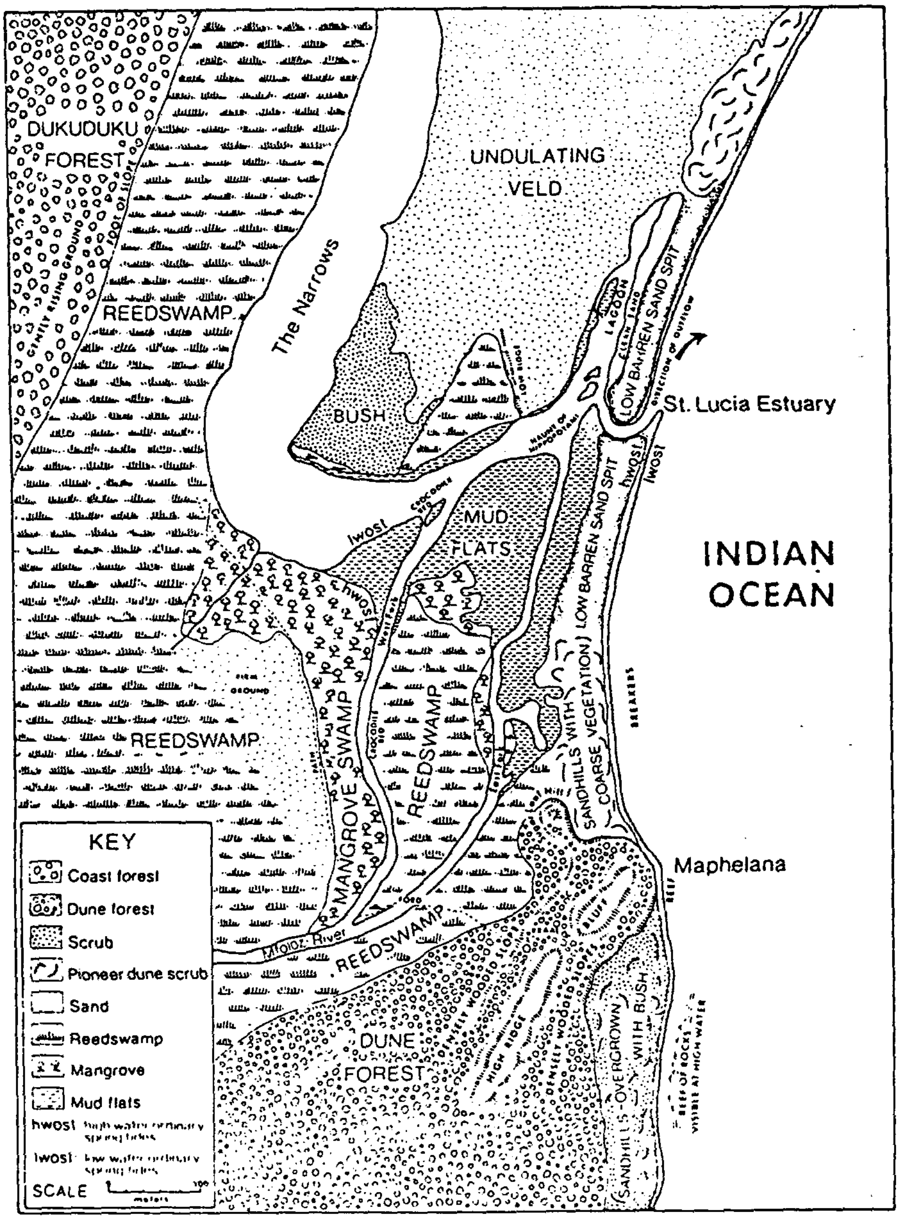

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH Figure 12. Crofts survey, 1905 (From Begg Begg 1978)	FIGURE 12

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ST LUCIA ESTUARY

5 - 5 - 1937

11 H I5

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH **Figure 13.** Photograph mosaic of St Lucia Estuary 1937	FIGURE 13

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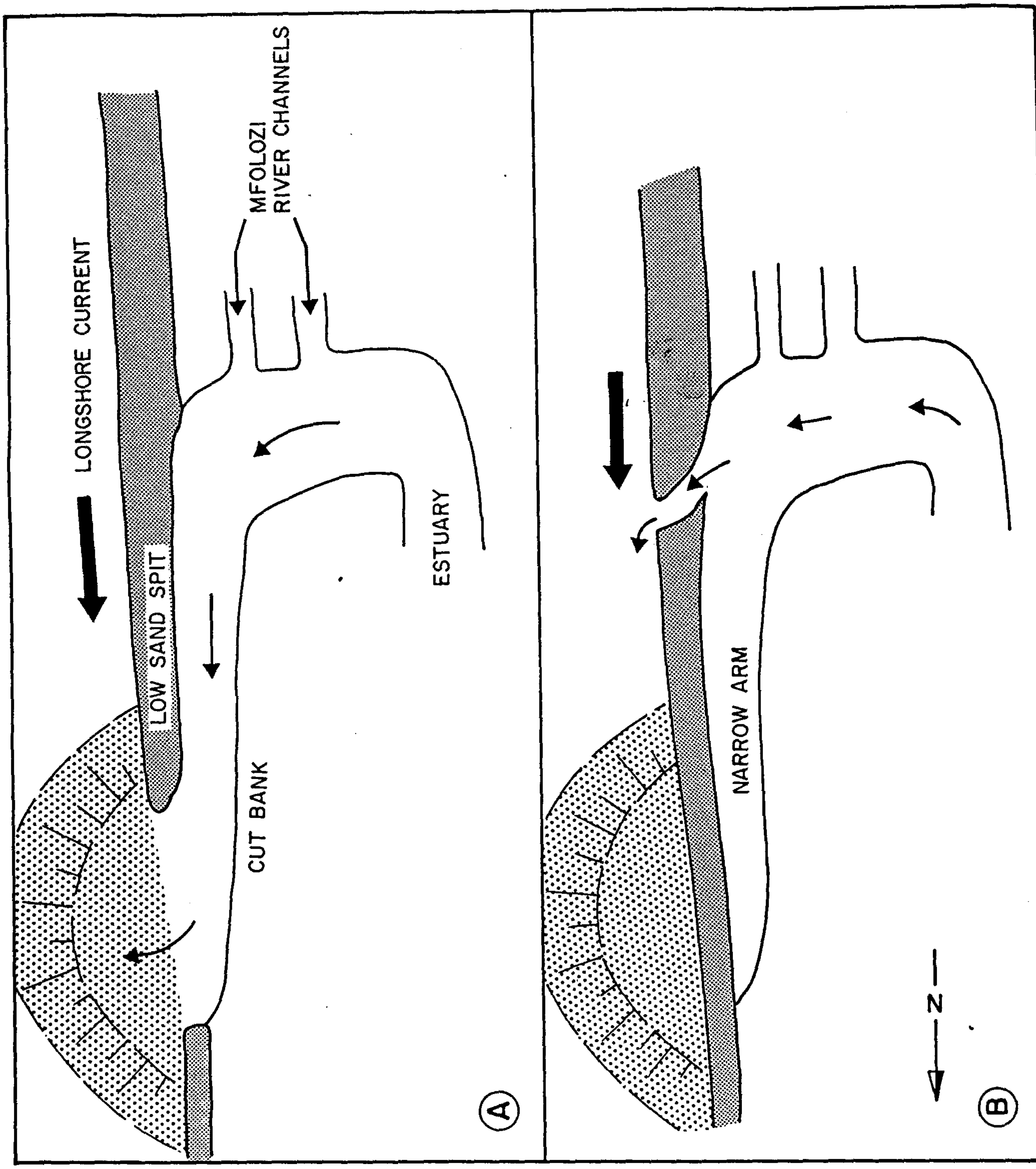

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH Figure 14. Schematic of mouth position during and after major river floods	FIGURE 14

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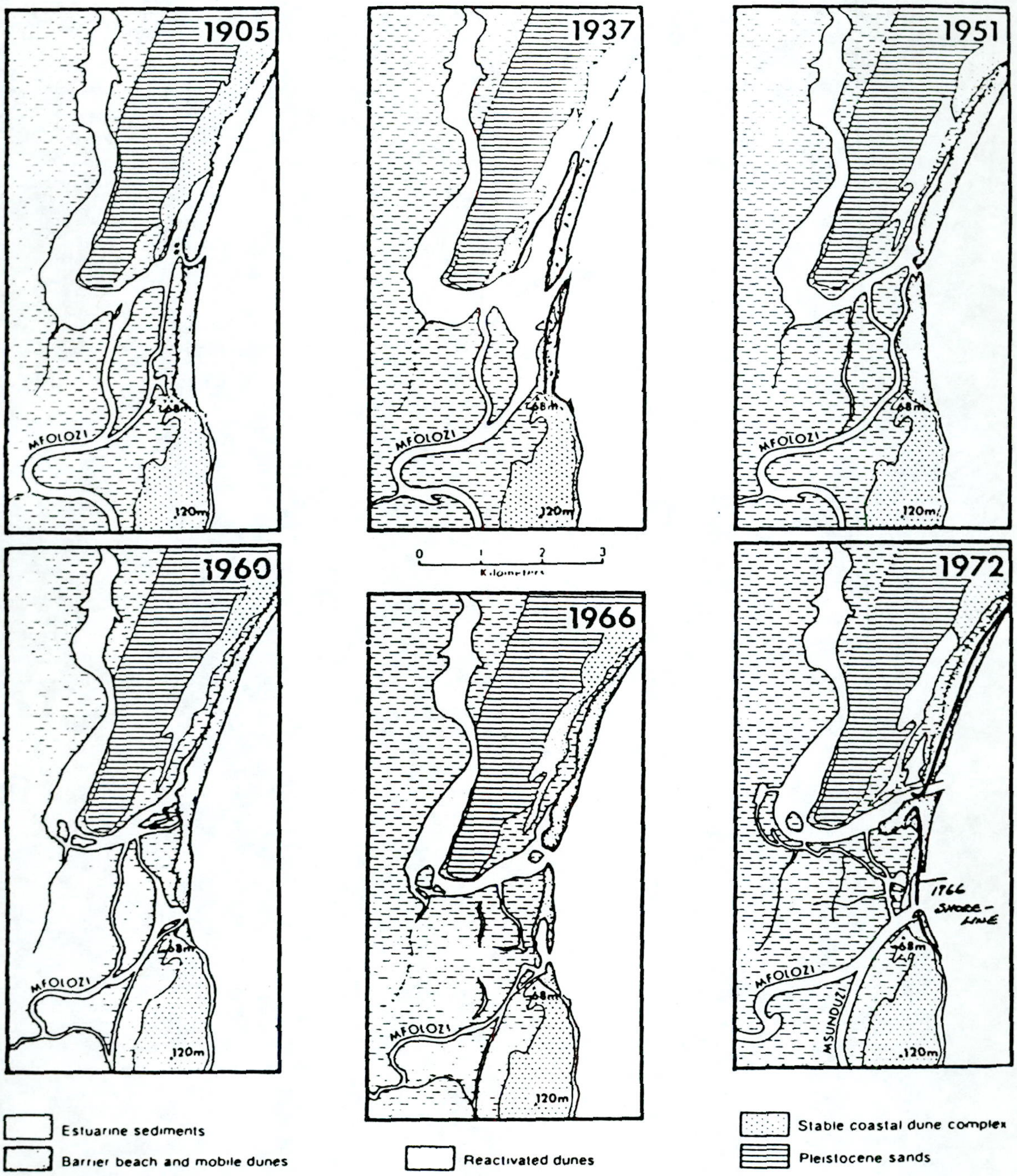

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH **Figure 15.** Natural and man-made changes in the St Lucia and Mfolozi Estuaries; 1905 to 1972 (Modified from Begg 1978).	FIGURE 15

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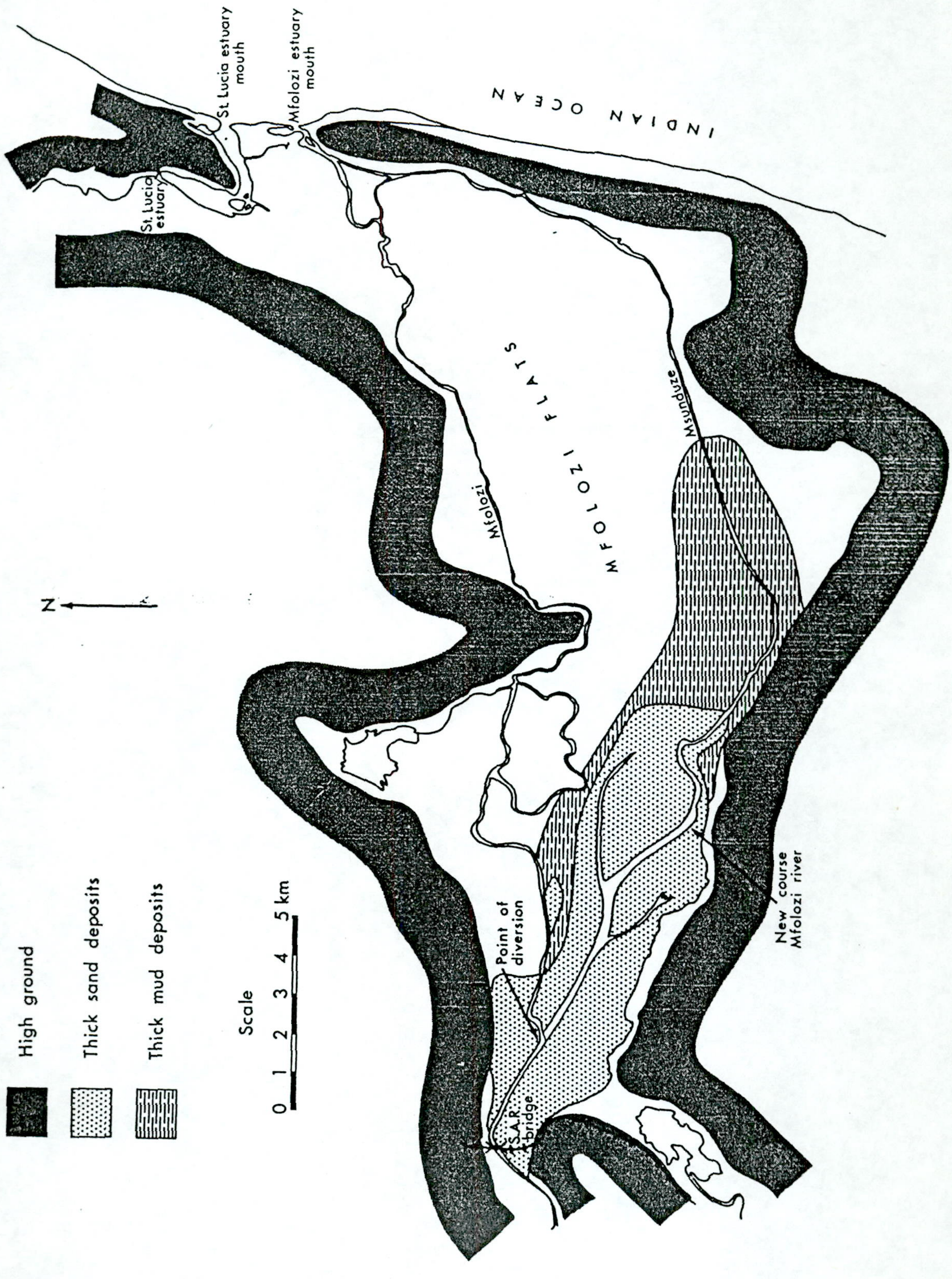

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH Figure 16. Domoina flood deposits on Mfolozi Flats	FIGURE 16

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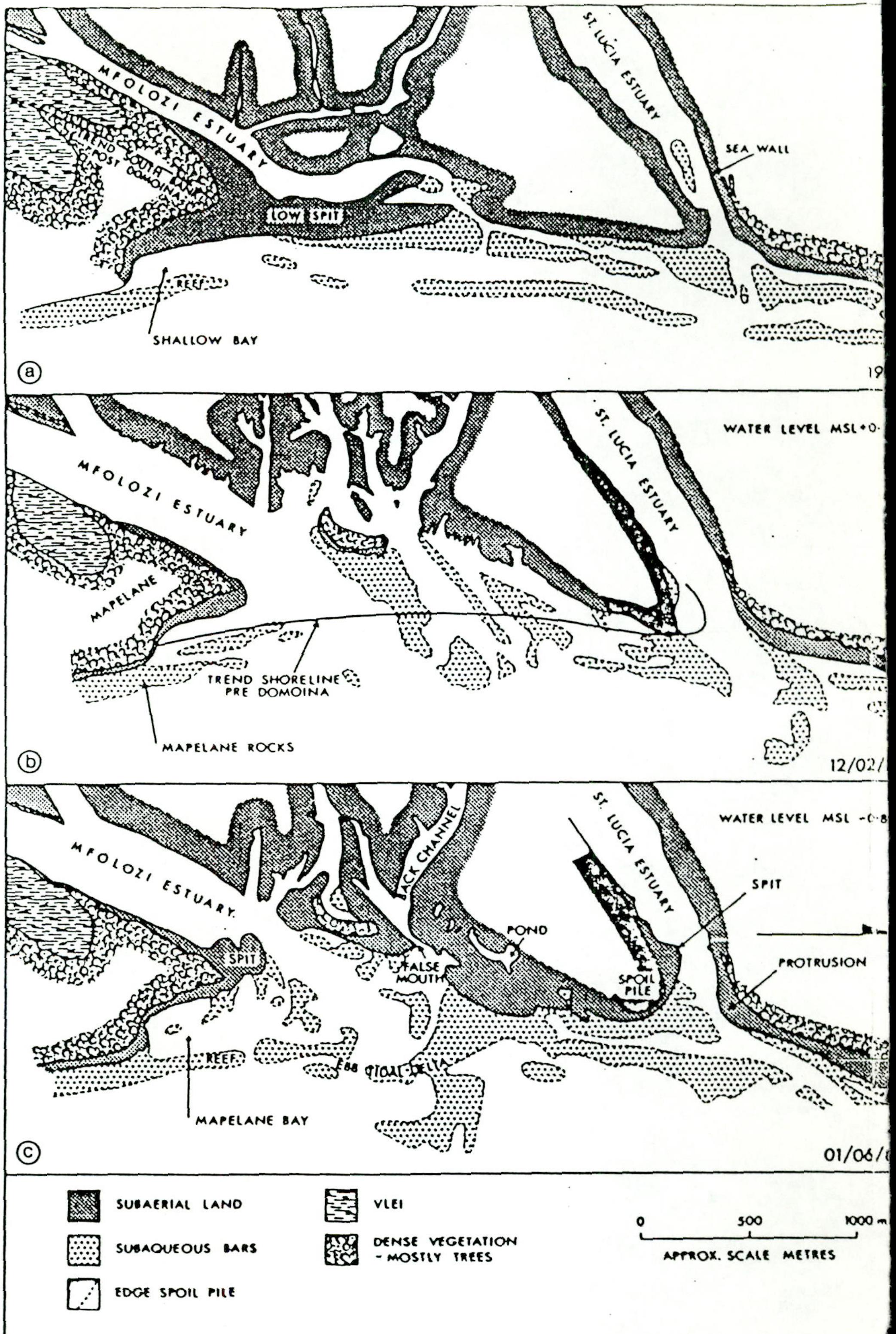

AIR PHOTO INTERPRETATION - ST LUCIA & MFOLOZI ESTUARIES

1979 : 12/02-02/08/1984

COMPILED BY DR I.L. VAN HEERDEN
ENVIRONMENTAL SERVICES GROUP
P.O. BOX 50 NEWLANDS 7725

FIGURE 17

TRACED: CHECKED DATE REF	ST. LUCIA RESEARCH AIR PHOTO INTERPRETATION - ST LUCIA & MFOLOZI ESTUARIES 1979 : 12/02-02/08/1984	FIGURE 17

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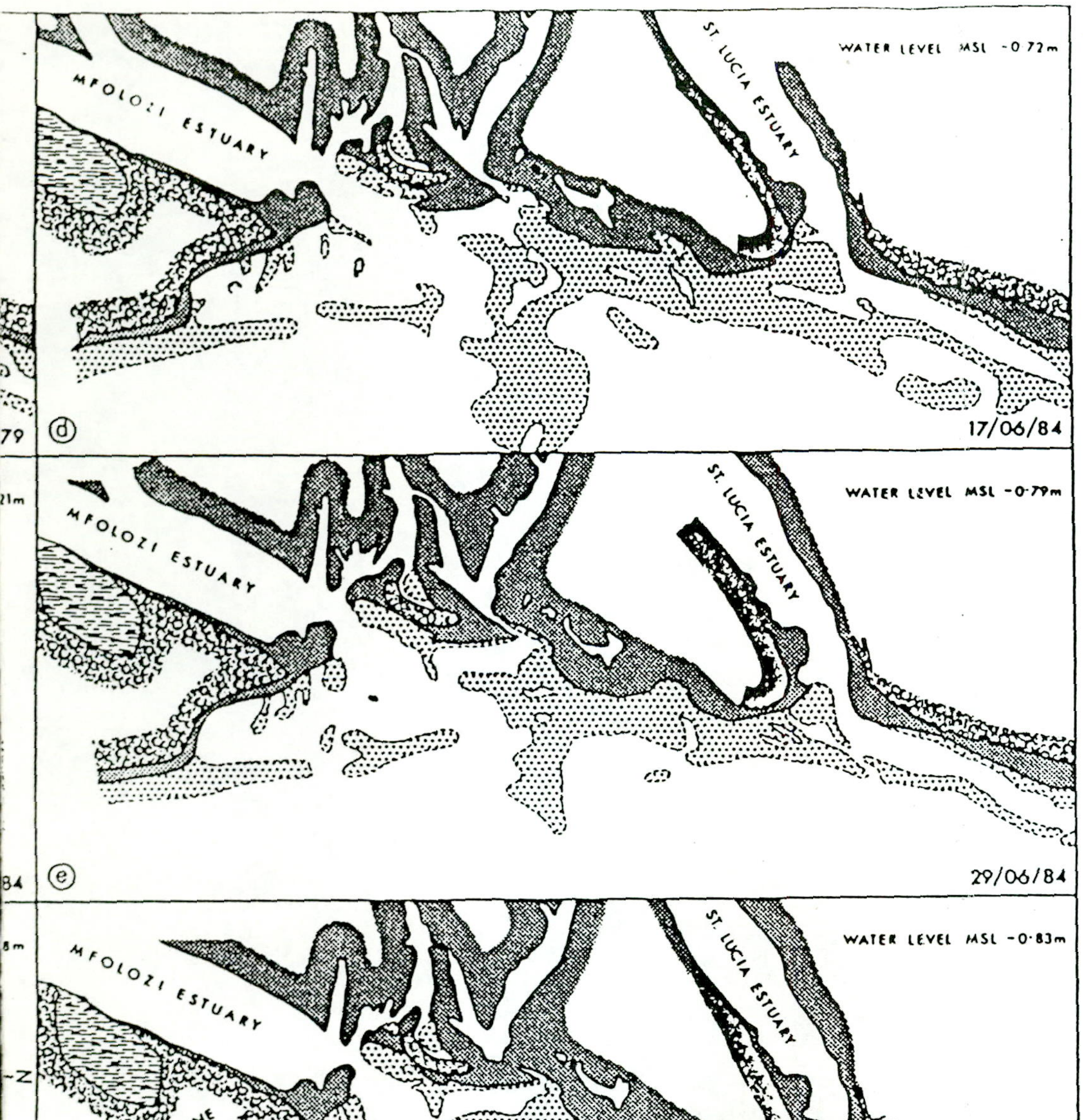
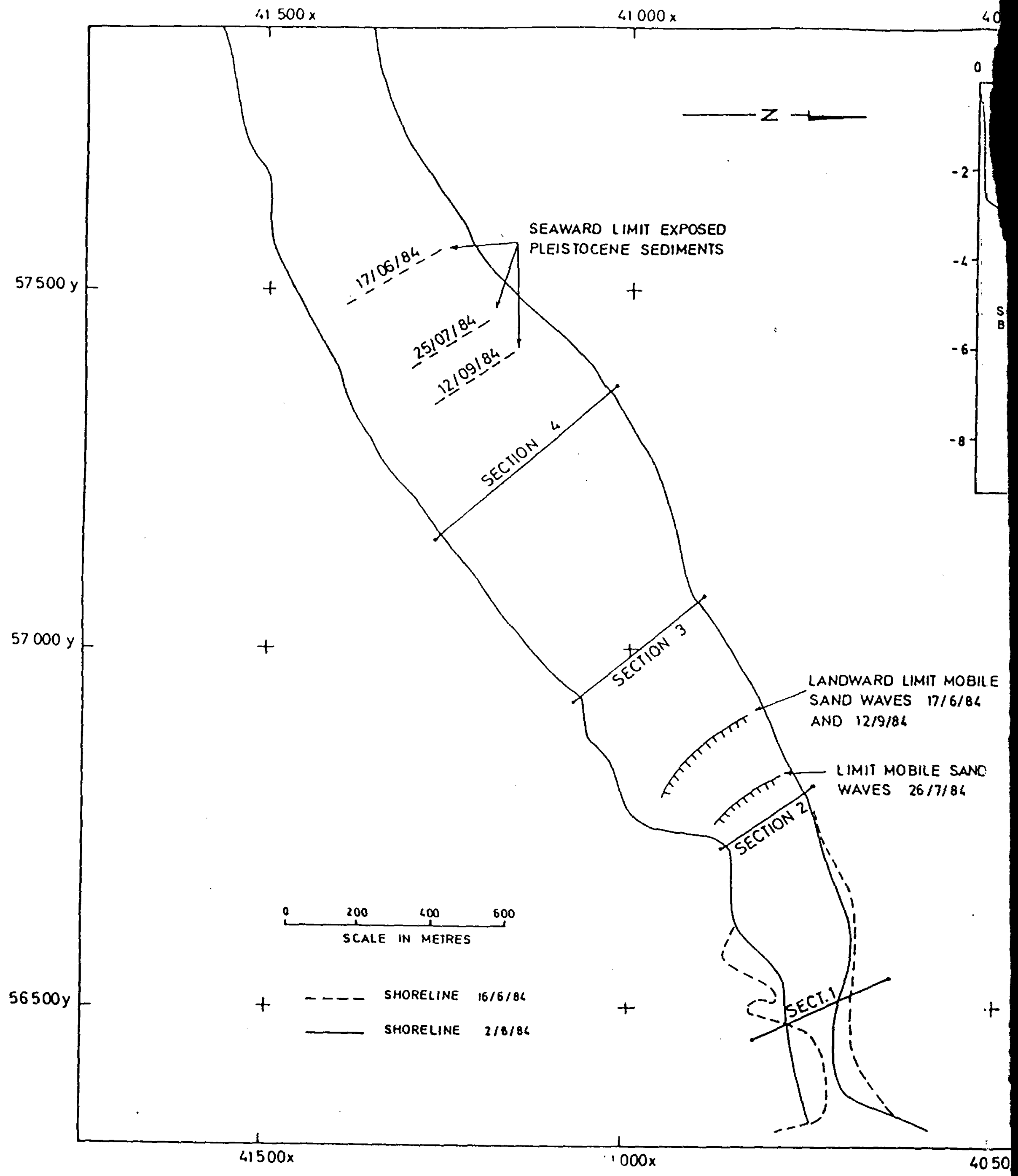
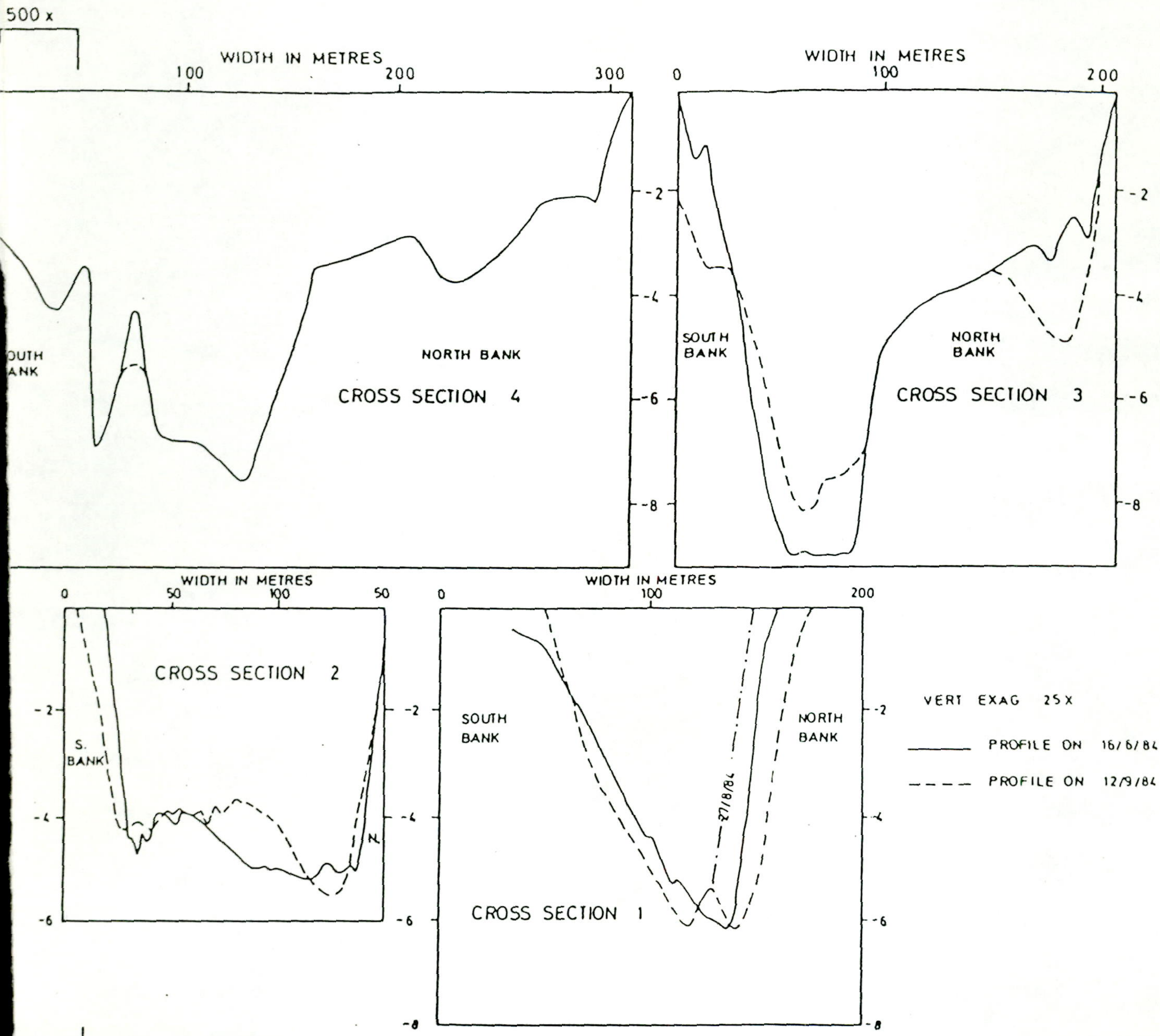


MFOLOZI ESTUARY
ST. LUCIA ESTUARY
WATER LEVEL MSL -0.72m
(d)
17/06/84
MFOLOZI ESTUARY
ST. LUCIA ESTUARY
WATER LEVEL MSL -0·79m
(e)
29/06/84
MFOLOZI ESTUARY
ST. LUCIA ESTUARY
WATER LEVEL MSL -0·83m
MAPELANE
SUBAQUEOUS LEVEE
(f)
14/07/84
MFOLOZI ESTUARY
ST. LUCIA ESTUARY
WATER LEVEL MSL -0·80m
TREND SHORELINE POST DOMOINA
POND
REEF
TIDAL DELTA
TREND SHORELINE PRE DOMOINA
(g)
02/08/84



TRACED: CHECKED DATE REF	ST. LUCIA RESEARCH CHANNEL CROSS SECTIONS - ST LUCIA ESTUARY 16/06/84 - 12/09/84	FIGURE 18

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



CHANNEL CROSS SECTIONS - ST LUCIA ESTUARY

16/06/84 — 12/09/84 . COMPILED BY

DR. I.L. VAN HEERDEN
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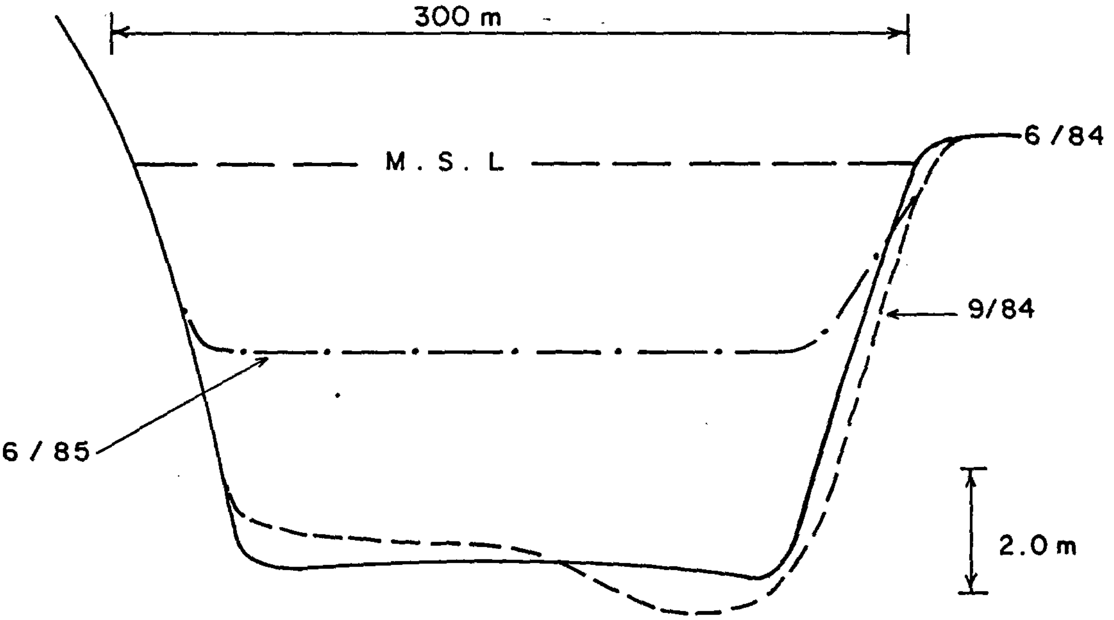
FIGURE 18

0 x



TRACED :
CHECKED :
DATE :
REF :

ST. LUCIA RESEARCH

Figure 19. Typical Mfolozi x-sections

FIGURE 19

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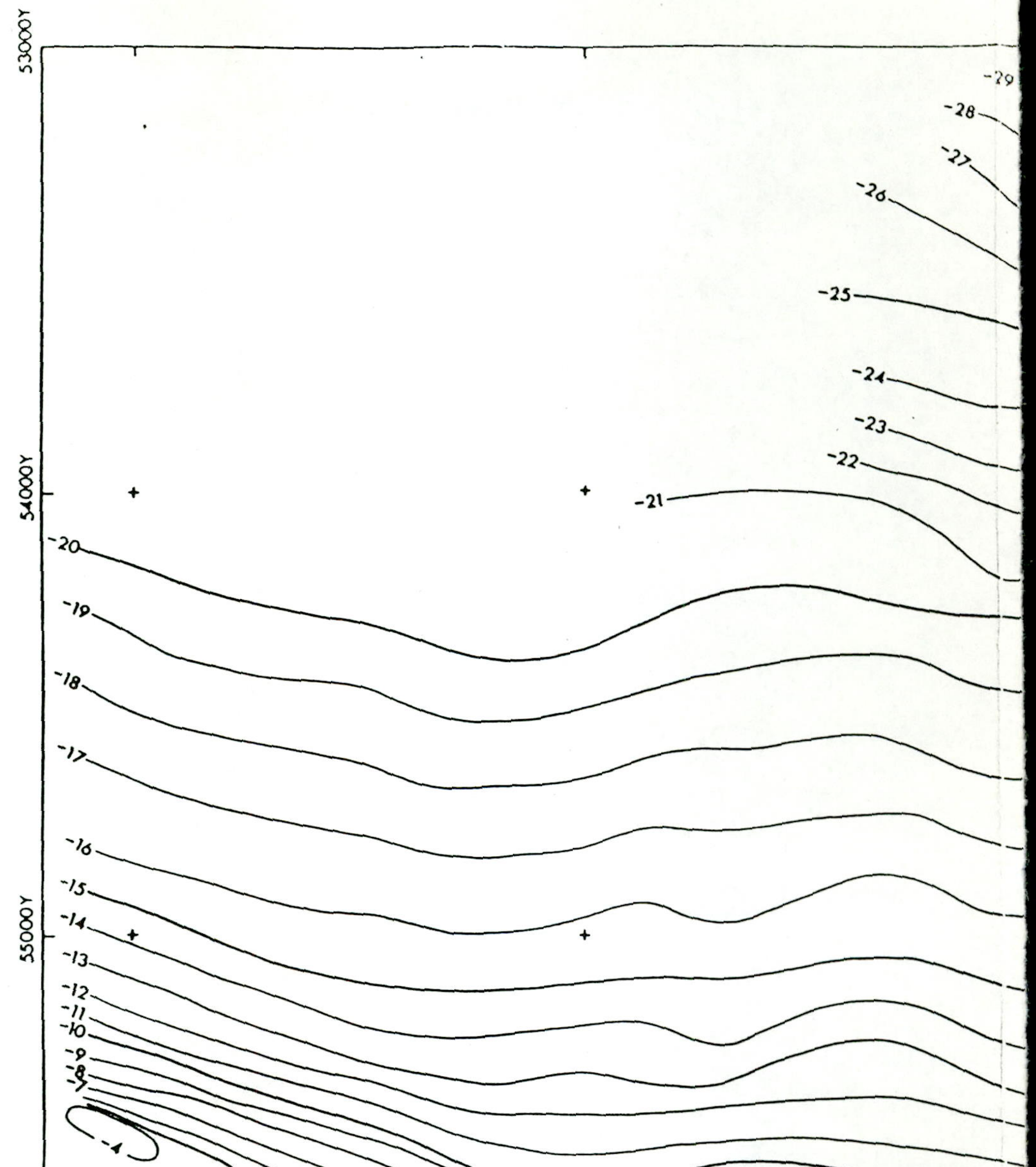

TRACED: CHECKED DATE REF:	ST. LUCIA RESEARCH ST. LUCIA OFFSHORE BATHYMETRY	FIGURE 20
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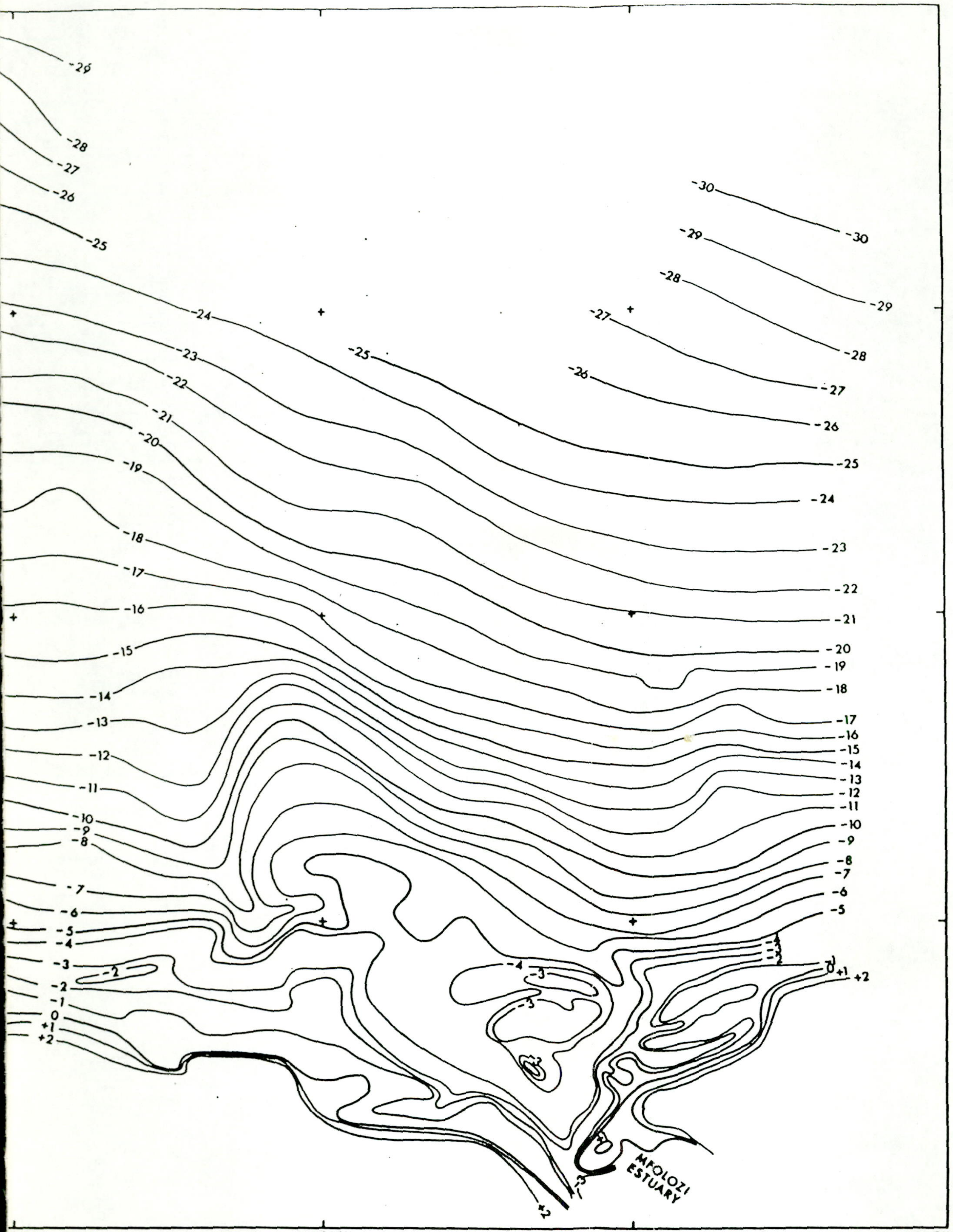
ST

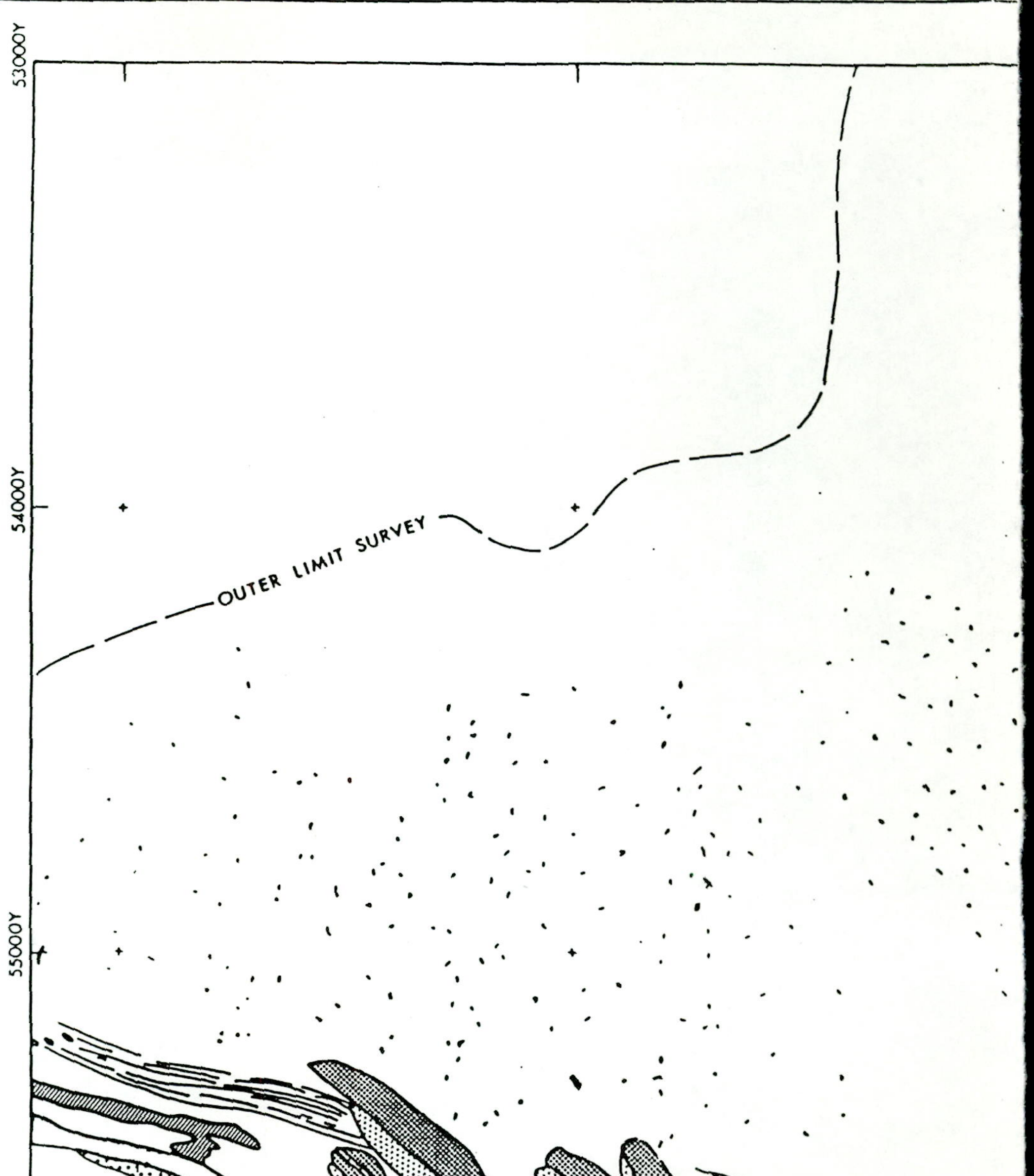


LUCIA OFFSHORE BATHYMETRY

COMPILED BY DR. I.L. VAN HEERDEN
ENVIRONMENTAL SERVICES GROUP
P.O. BOX 50, NEWLANDS 7725

SURVEY DATES 26/7, 27/7 & 2/8/84

DATUM LOCAL M.S.L. FOR PERIOD 25/7/84 - 16/8/84



TRACED CHECKED DATE REF	ST. LUCIA RESEARCH ST. LUCIA OFFSHORE GEOLOGY	FIGURE 21

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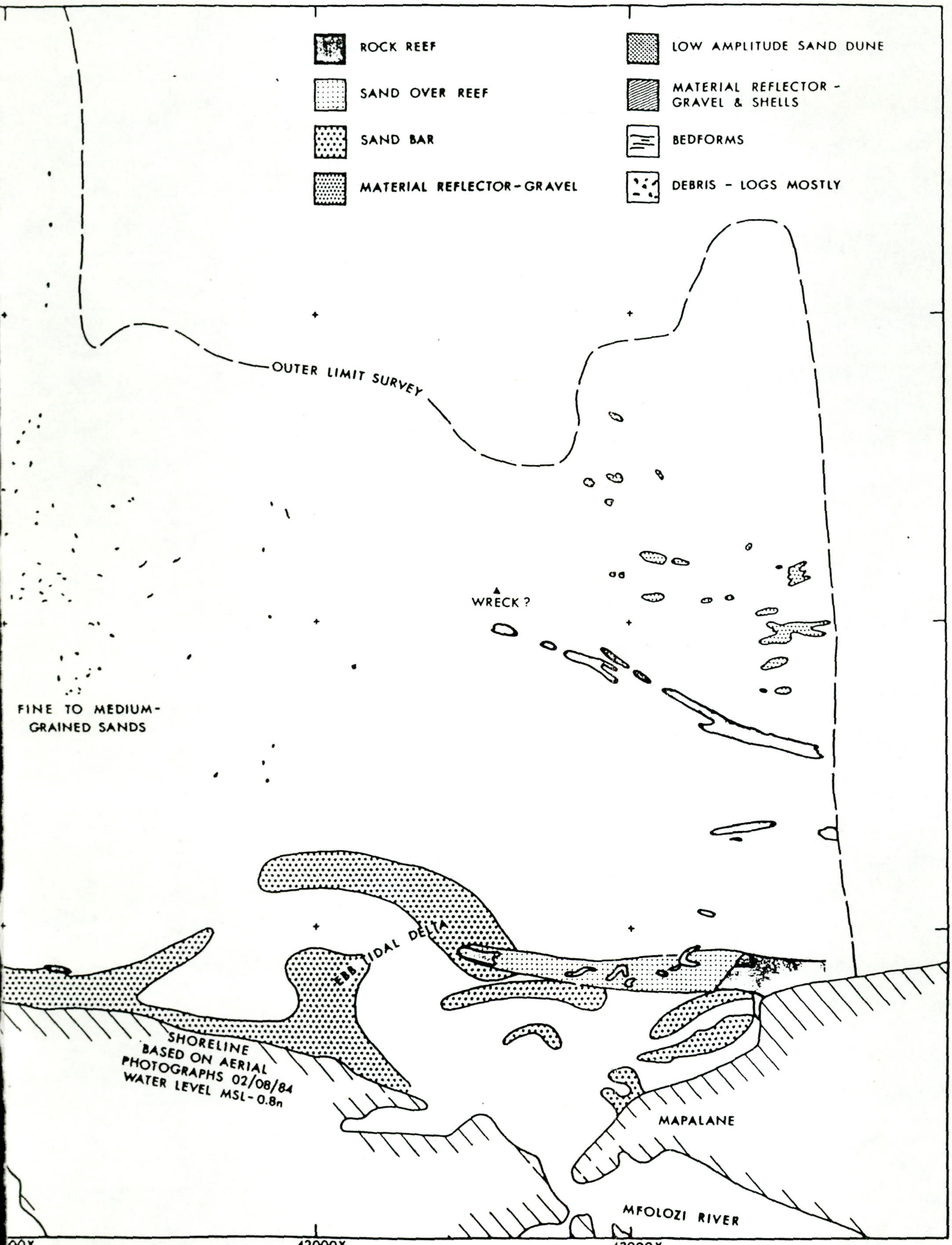

LUCIA OFFSHORE GEOLOGY

SURVEY DATES 26/7, 27/7 & 2/8/84

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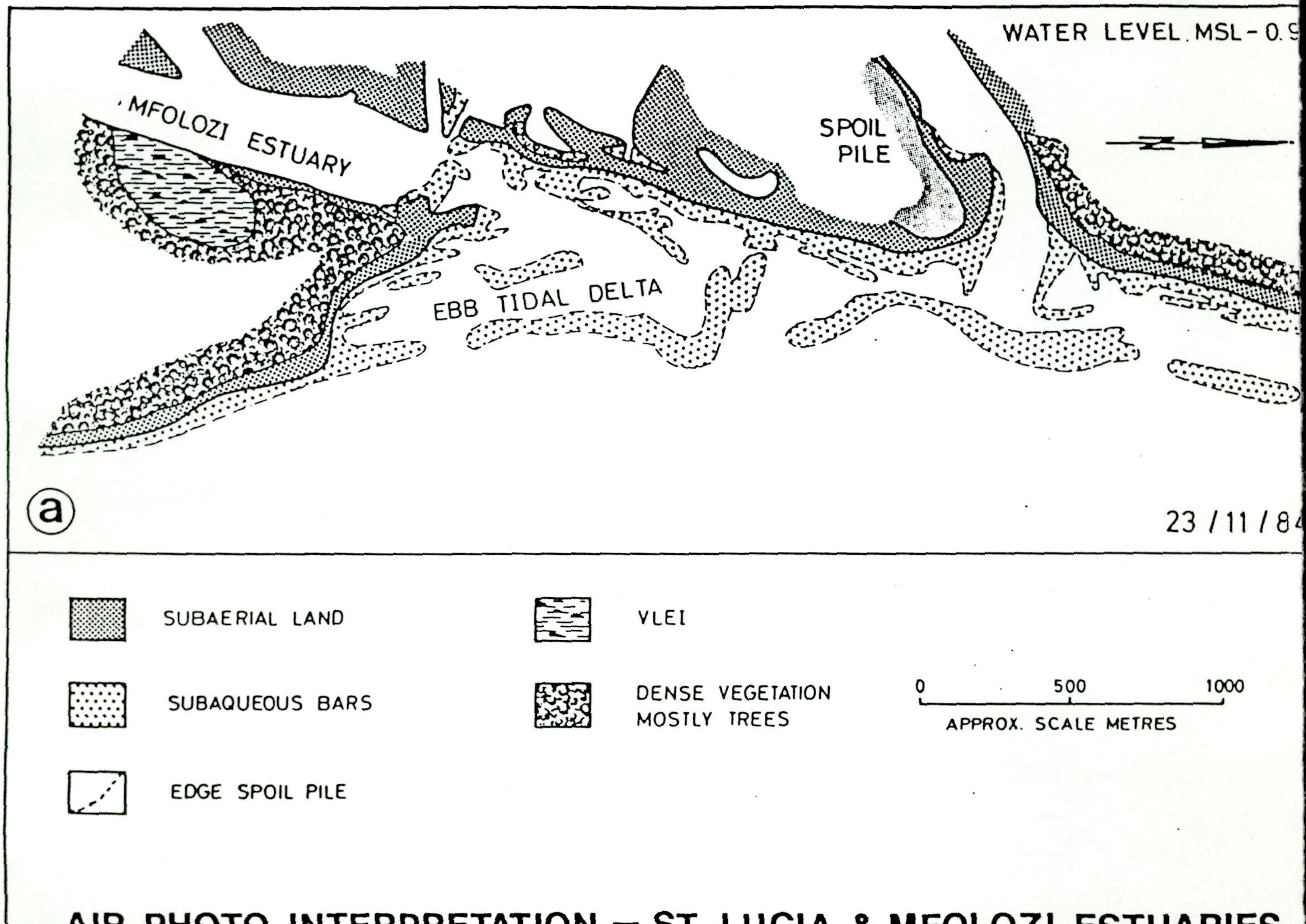
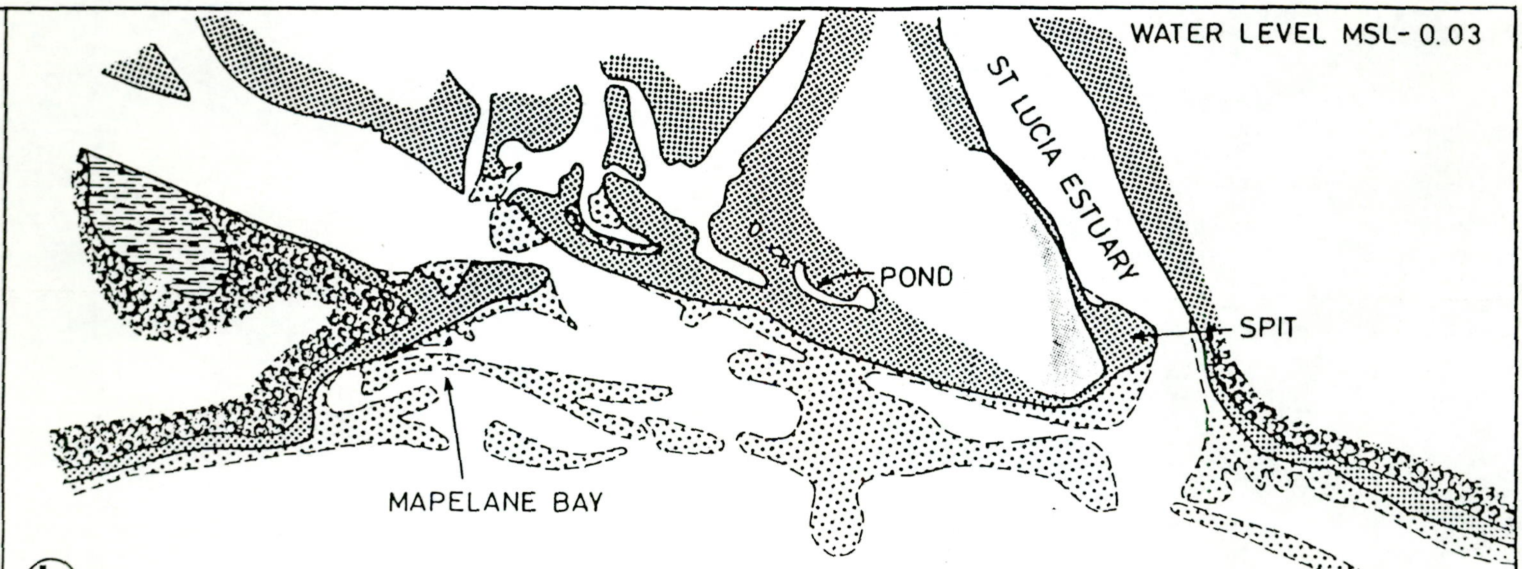
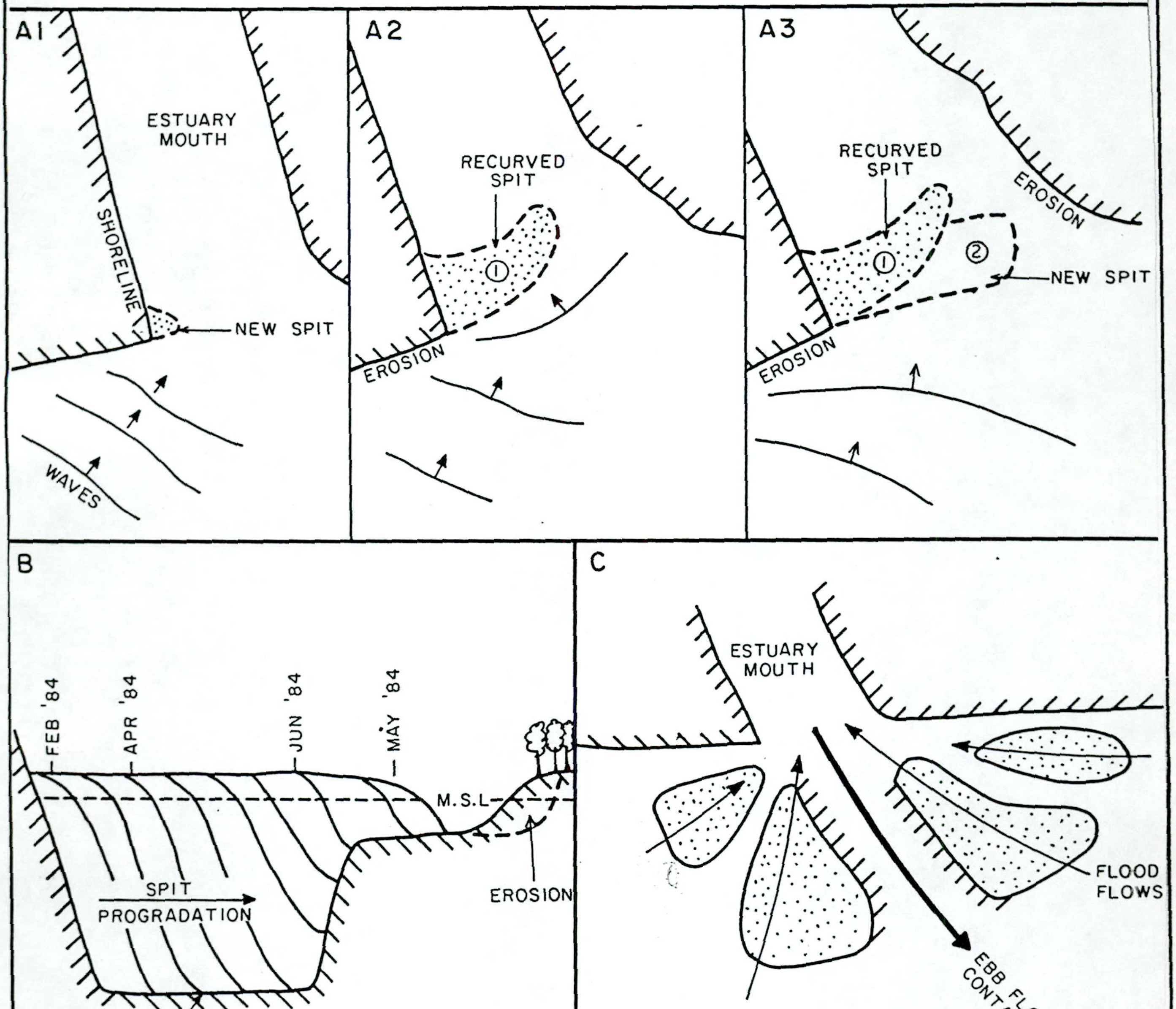


AIR PHOTO INTERPRETATION – ST LUCIA & MFOLOZI ESTUARIES

11/84 – 5/85

TRACED: CHECKED DATE REF	ST. LUCIA RESEARCH AIR PHOTO INTERPRETATION - ST. LUCIA AND MFOLOZI ESTUARIES 11/84 - 5/85	FIGURE 22
NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY		


WATER LEVEL MSL- 0.03
ST LUCIA ESTUARY
POND
SPIT
MAPELANE BAY
b
08 / 03 / 85
WATER LEVEL MSL- 0.86
SHORELINE
AFTER DOMOINA
SPIT
MAPELANE
SHORELINE
PRE-DOMOINA
FLOOD TIDE
RAMP
c
20 / 05 / 85



TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH Figure 23 A. Schematic of spit growth B. Changes in channel x-section with time C. Ebb tidal delta and tidal flows	FIGURE 23

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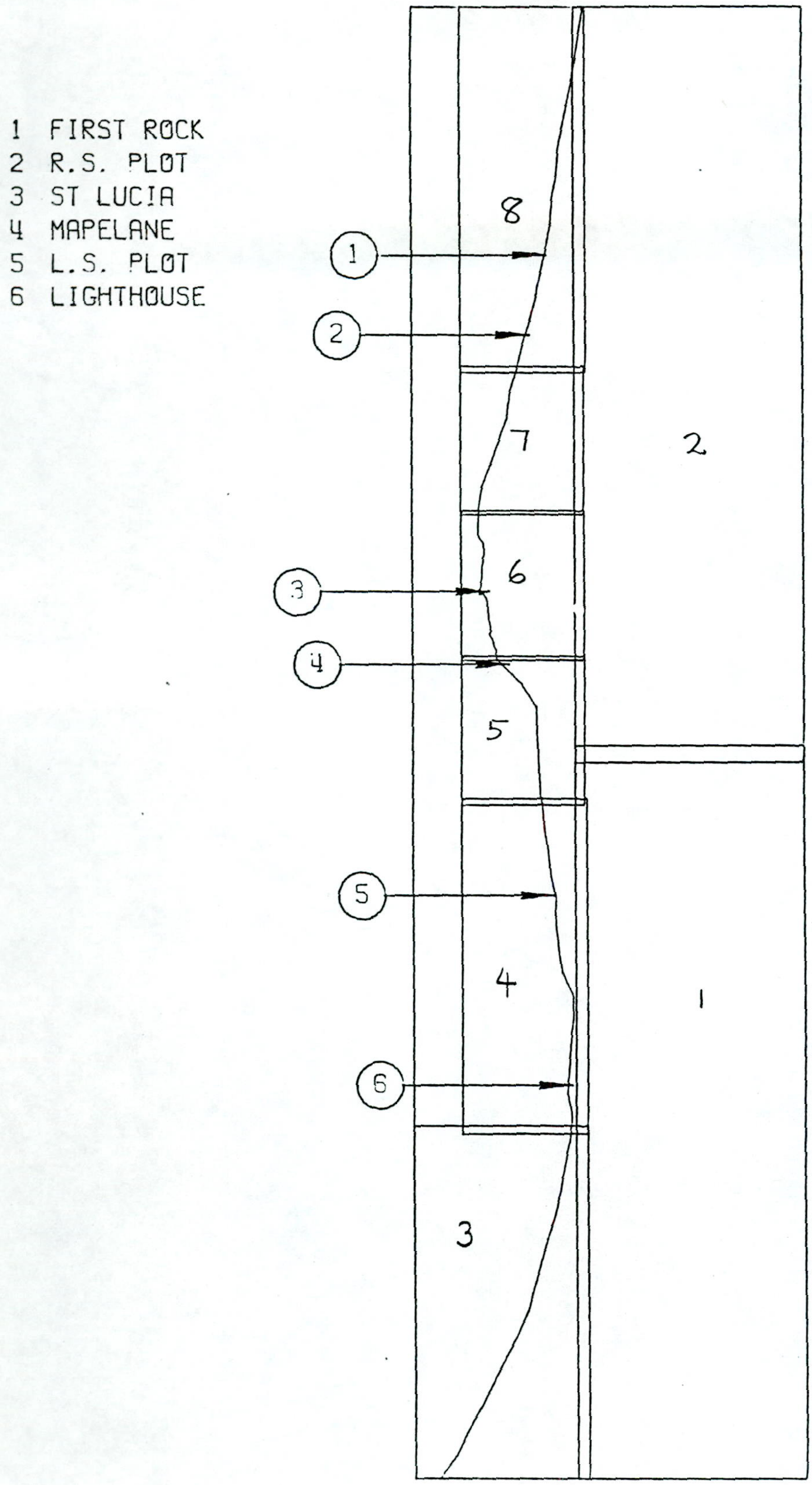

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH ST LUCIA - (LINREF) TIDE LEVEL: M.S.L. WAVE PERIOD: 12.3 S DIRECTION: 60.0 DEGREES SCALE' 1/200000	FIGURE 24a

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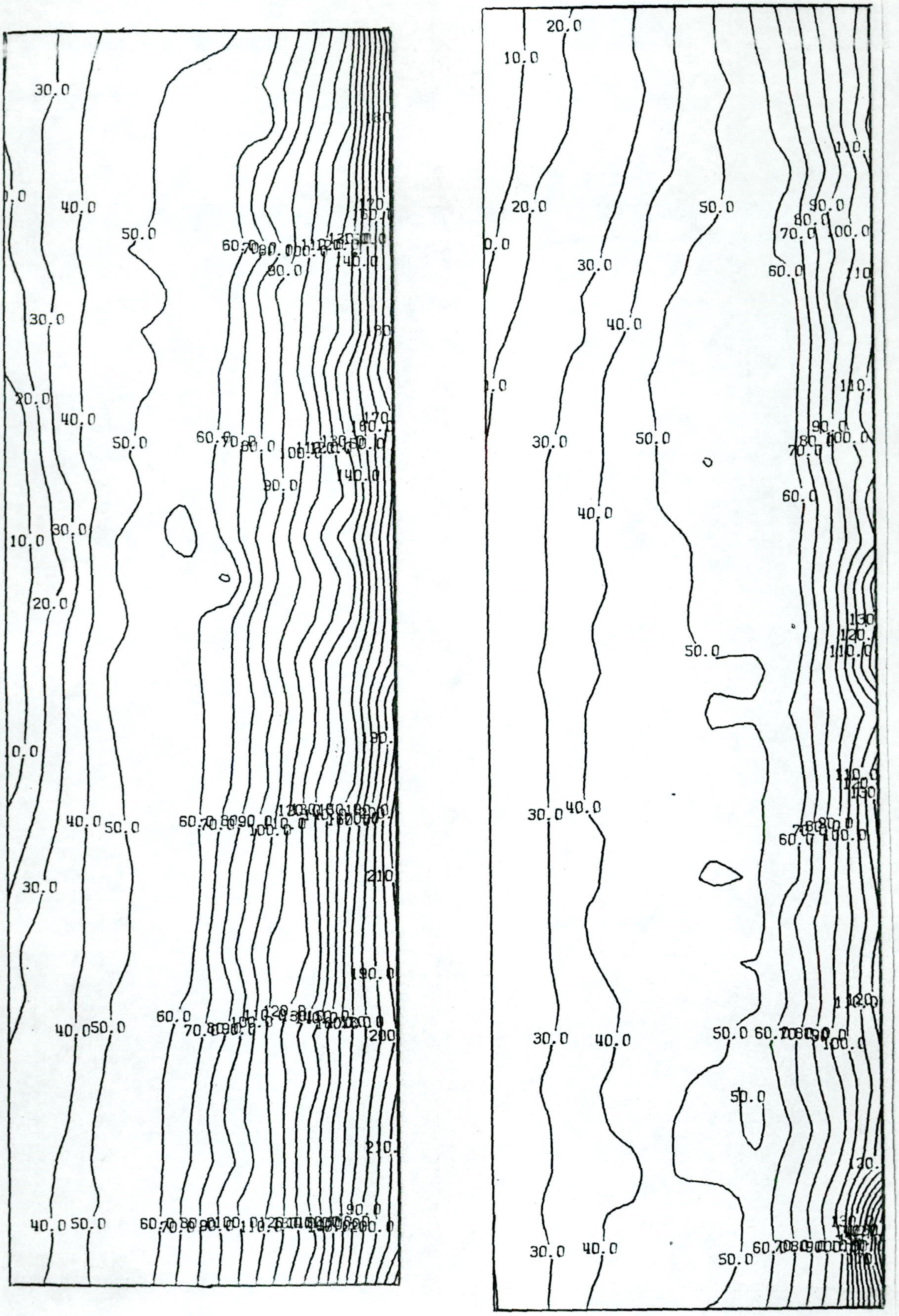

GRID 1

GRID 2

TRACED : CHECKED : DATE : REF :	ST. LUCIA RESEARCH Figure 24b. CONTOURS FOR REFRACTION GRID 1 AND 2.	FIGURE 24b.

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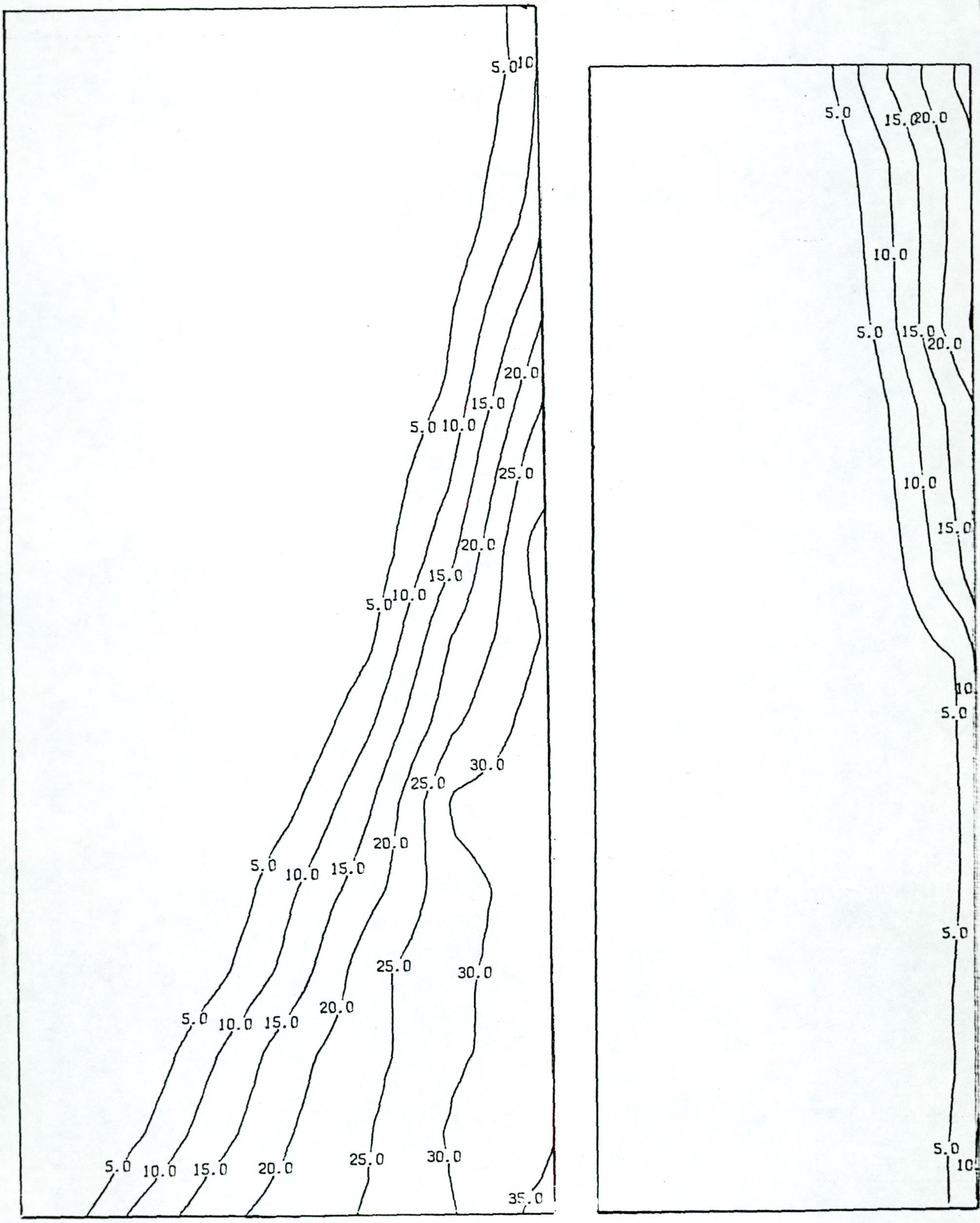

GRID 3 GRID 4

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DATE :
REF :

ST. LUCIA RESEARCH

Figure 24c. Contours for refraction grid 3 and 4

FIGURE 24c

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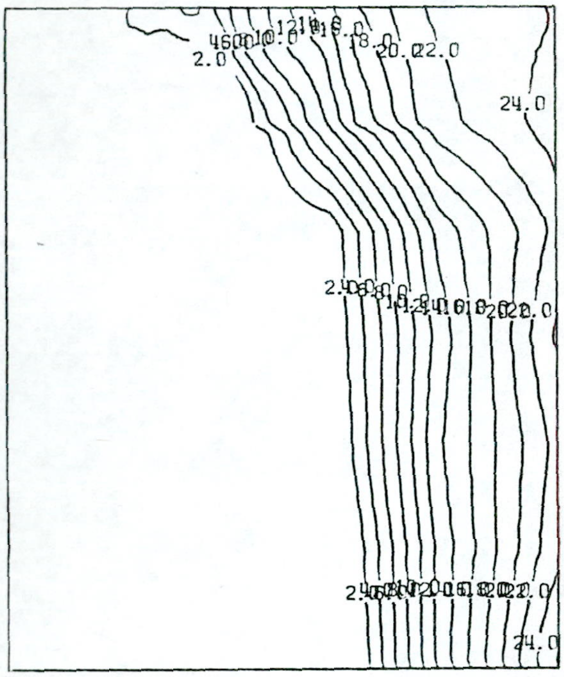
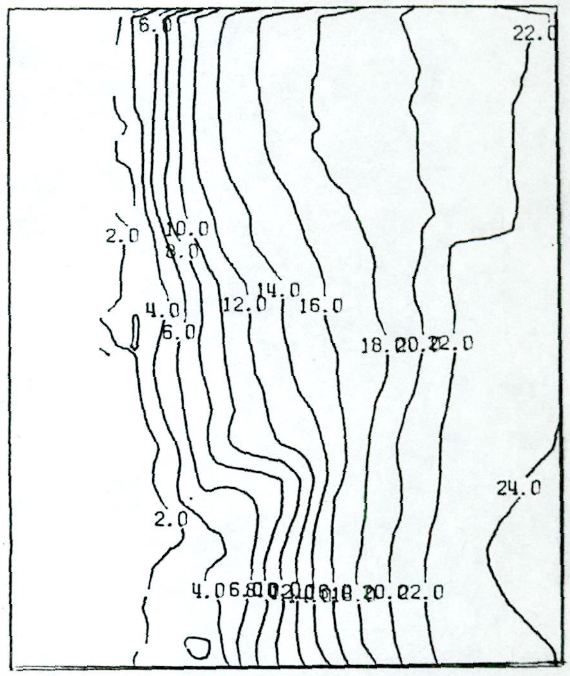
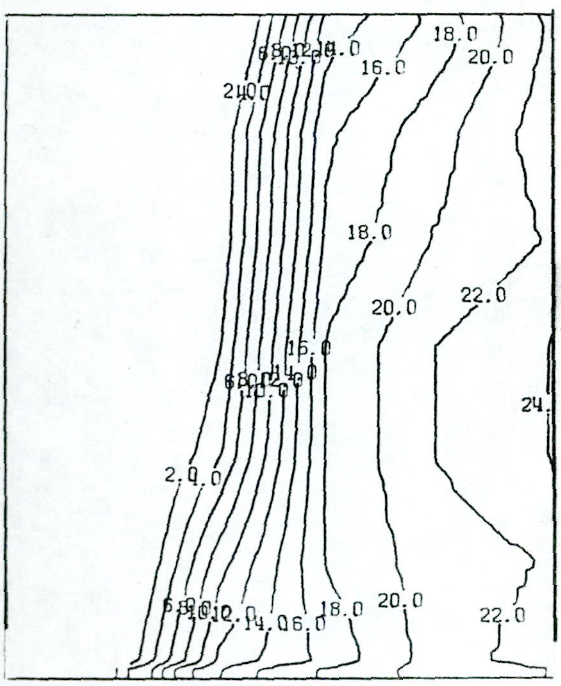


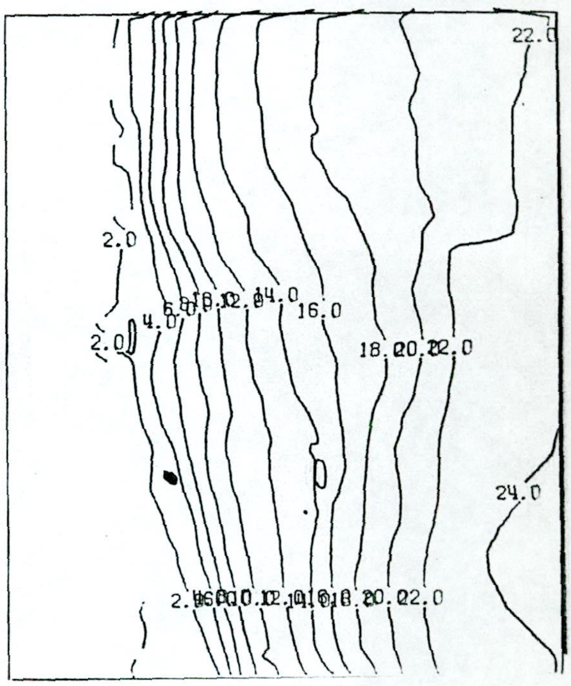
GRID 5



GRID 6



GRID 7



GRID 6 (SMOOTHED)

TRACED: - CHECKED: DATE: REF.:	Figure 24d. CONTOURS FOR REFRACTION GRID 5,6,7 AND 6 (SMOOTHED)	FIGURE 24d

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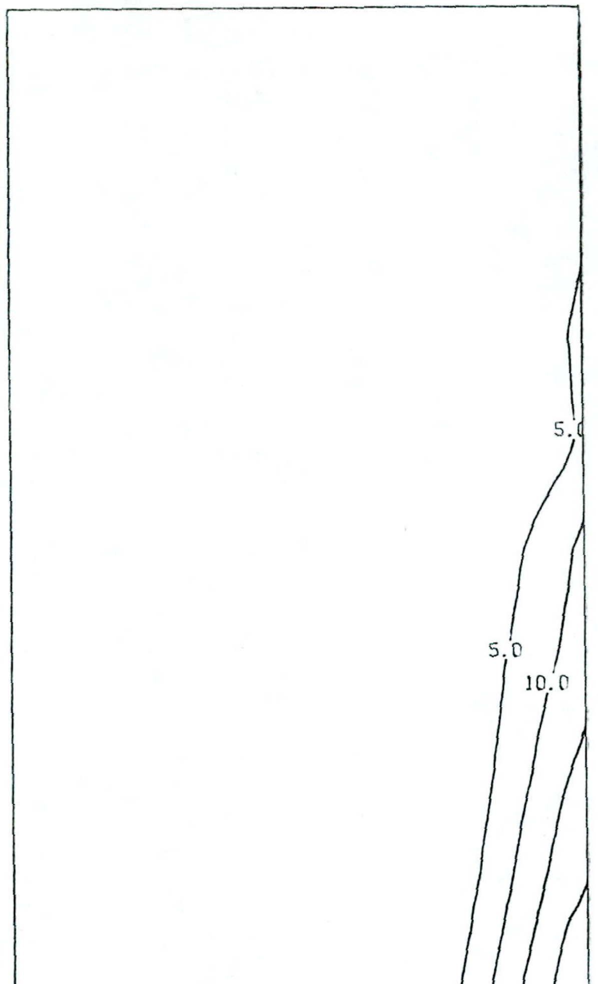

GRID 8

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DATE:
REF.:

Figure 24e. CONTOURS FOR REFRACTION GRID 8

FIGURE 24e

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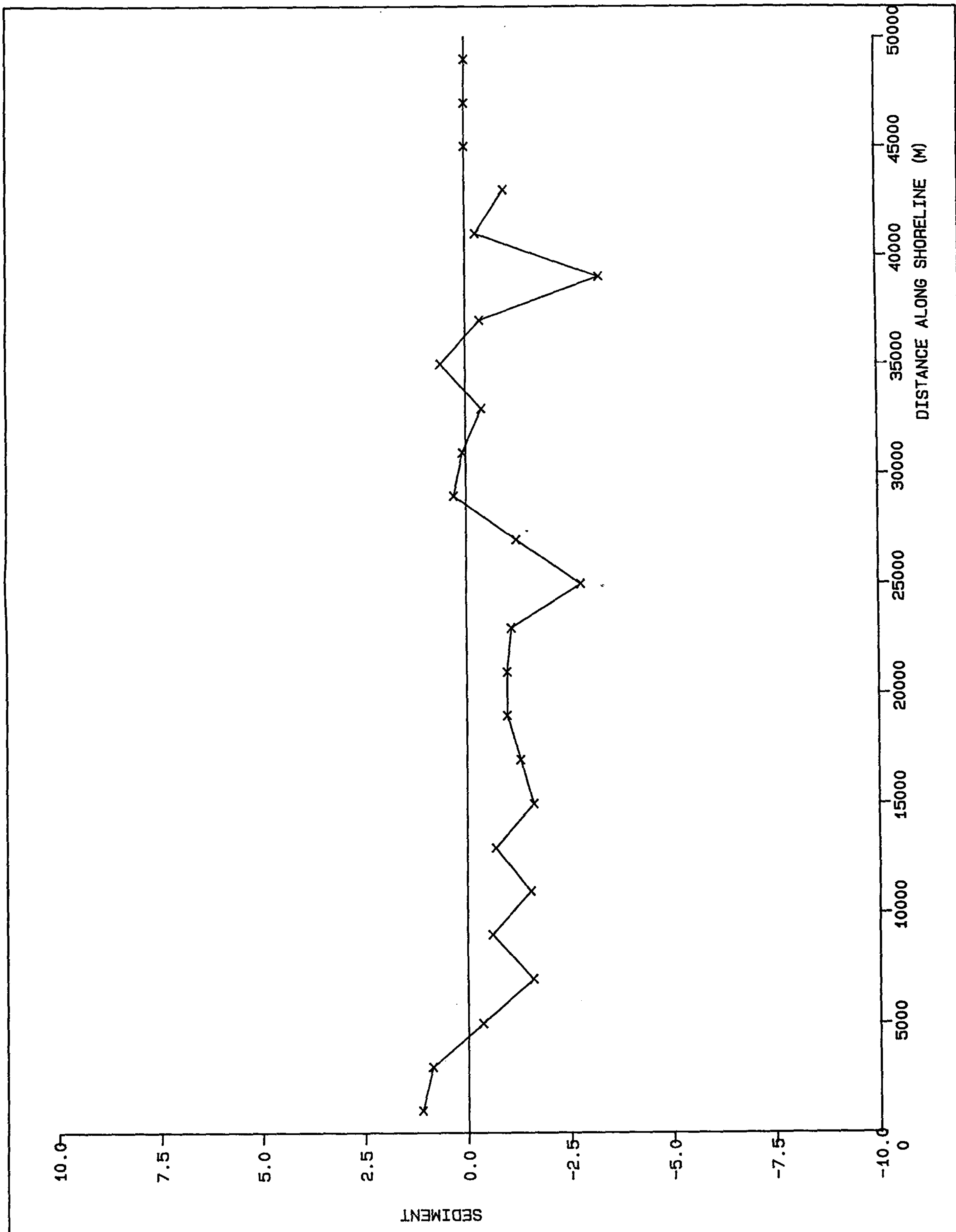

TRACED : COMPLOT CHECKED: DATE : REF. :	ST LUCIA **Figure 25.1.** Pre-Domoina Potential Longshore Sediment Transport Rates. $(\times 10^6)$: Average Periods.	FIGURE 25.1

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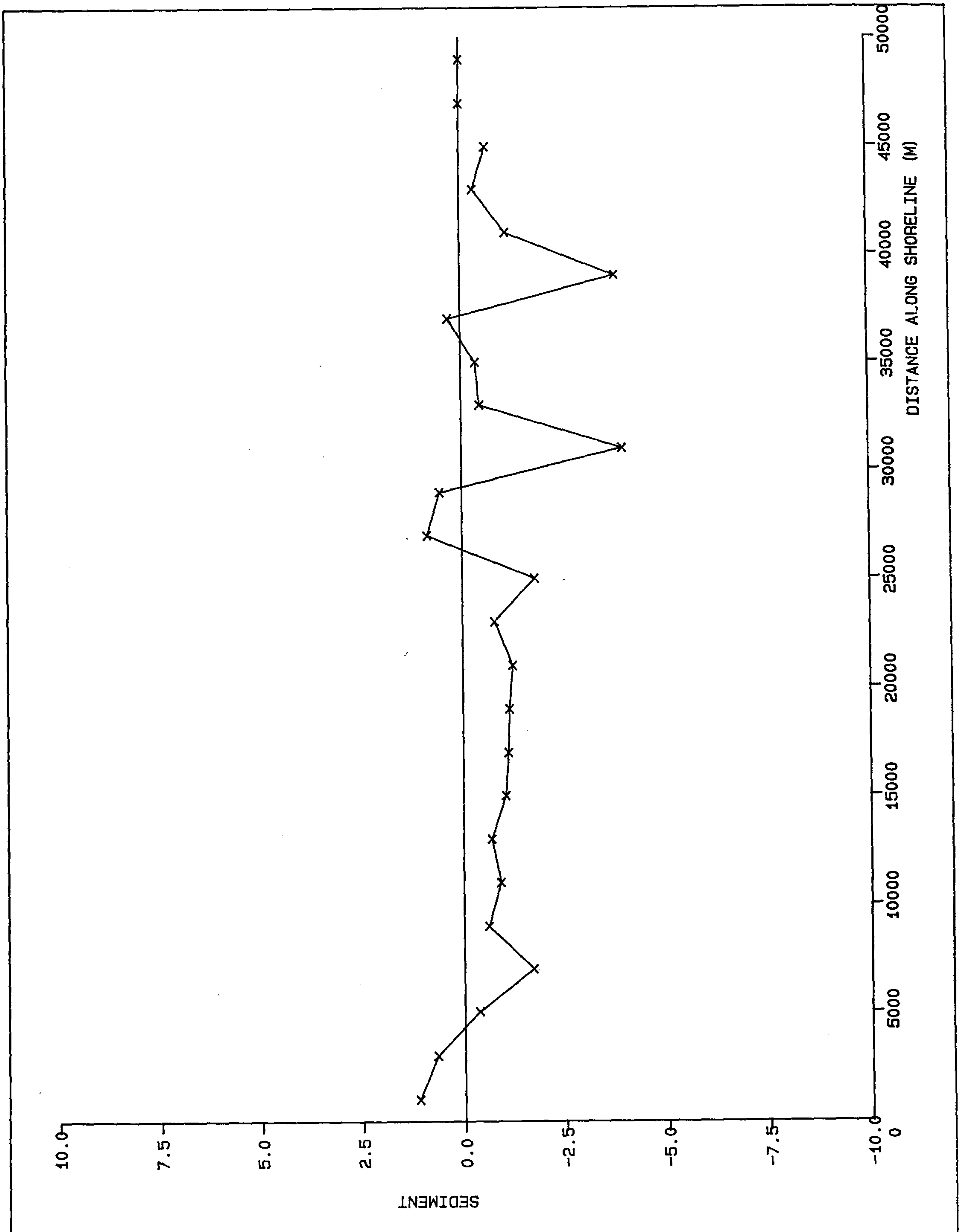

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DATE :
REF. :

ST LUCIA

Figure 25.2. Post-Domoina Potential Longshore Sediment Transport Rates ($\times 10^6$): Average Periods

FIGURE 25.2

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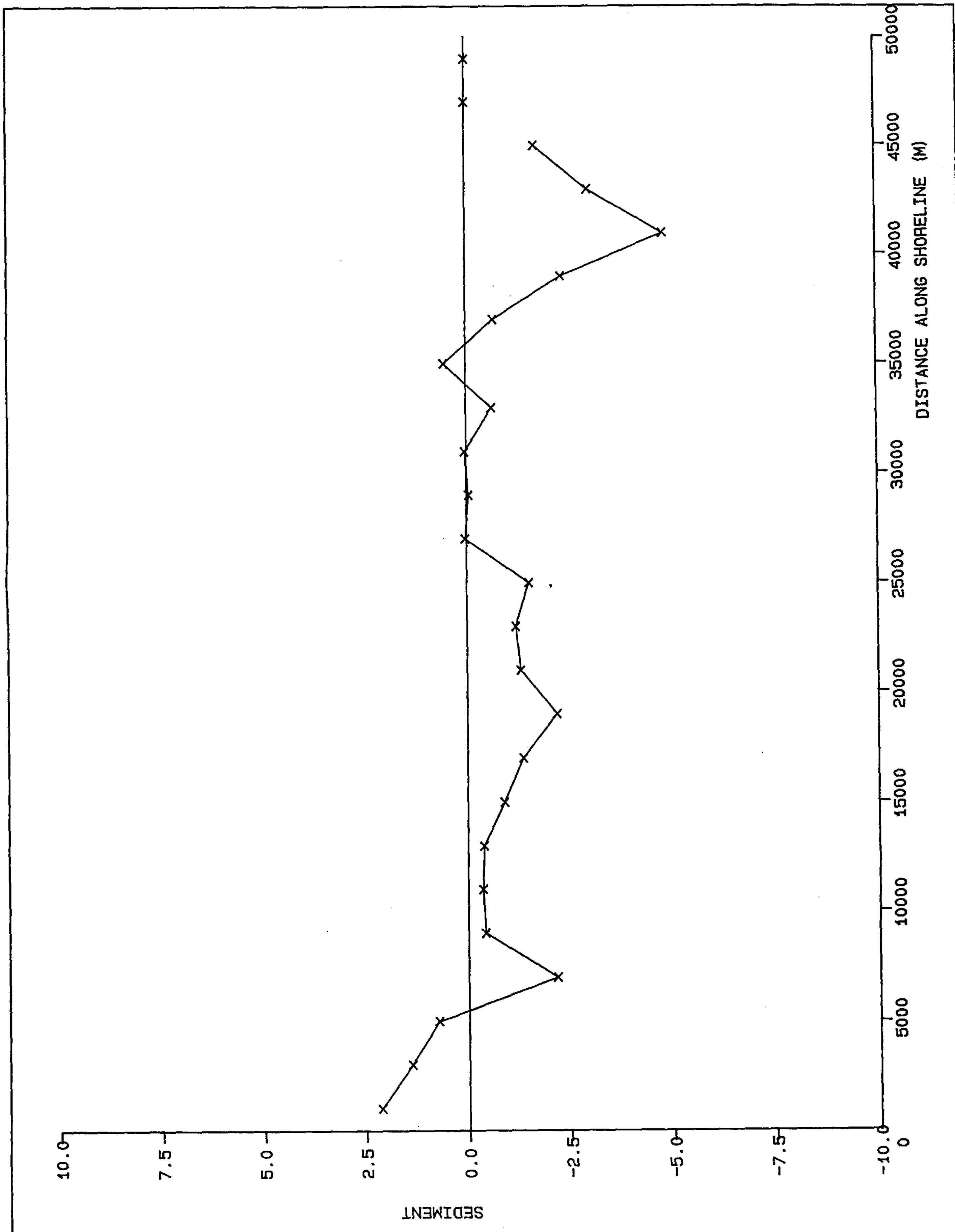

TRACED : COMPLOT CHECKED: DATE : REF. :	ST LUCIA Figure 25.3. Post-Domoina Potential Longshore Sediment Transport Rates ($\times 10^6$). All periods	FIGURE 25.3

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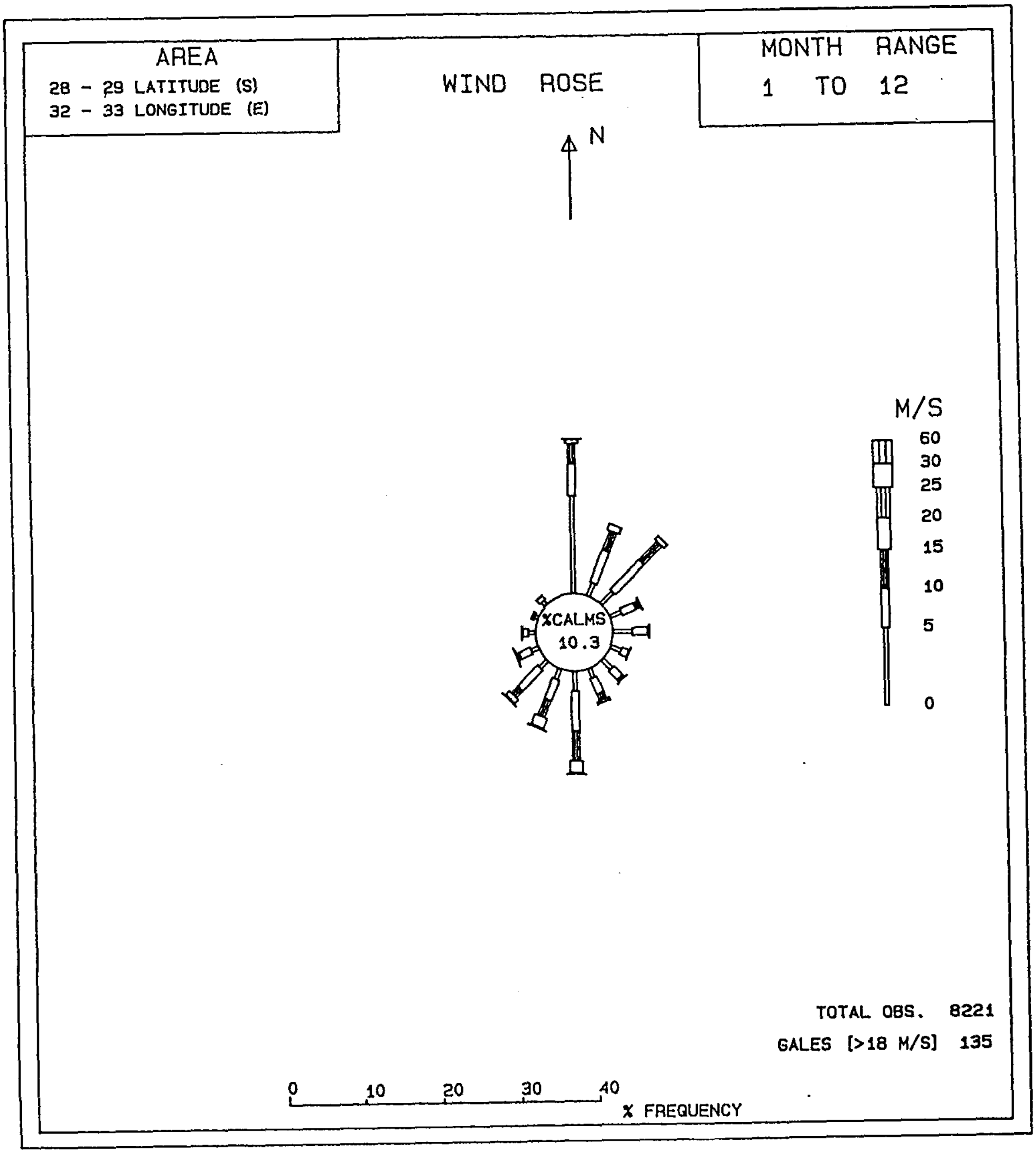

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DATE :
REF :

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Figure 26. VOS Wind Rose

FIGURE
26

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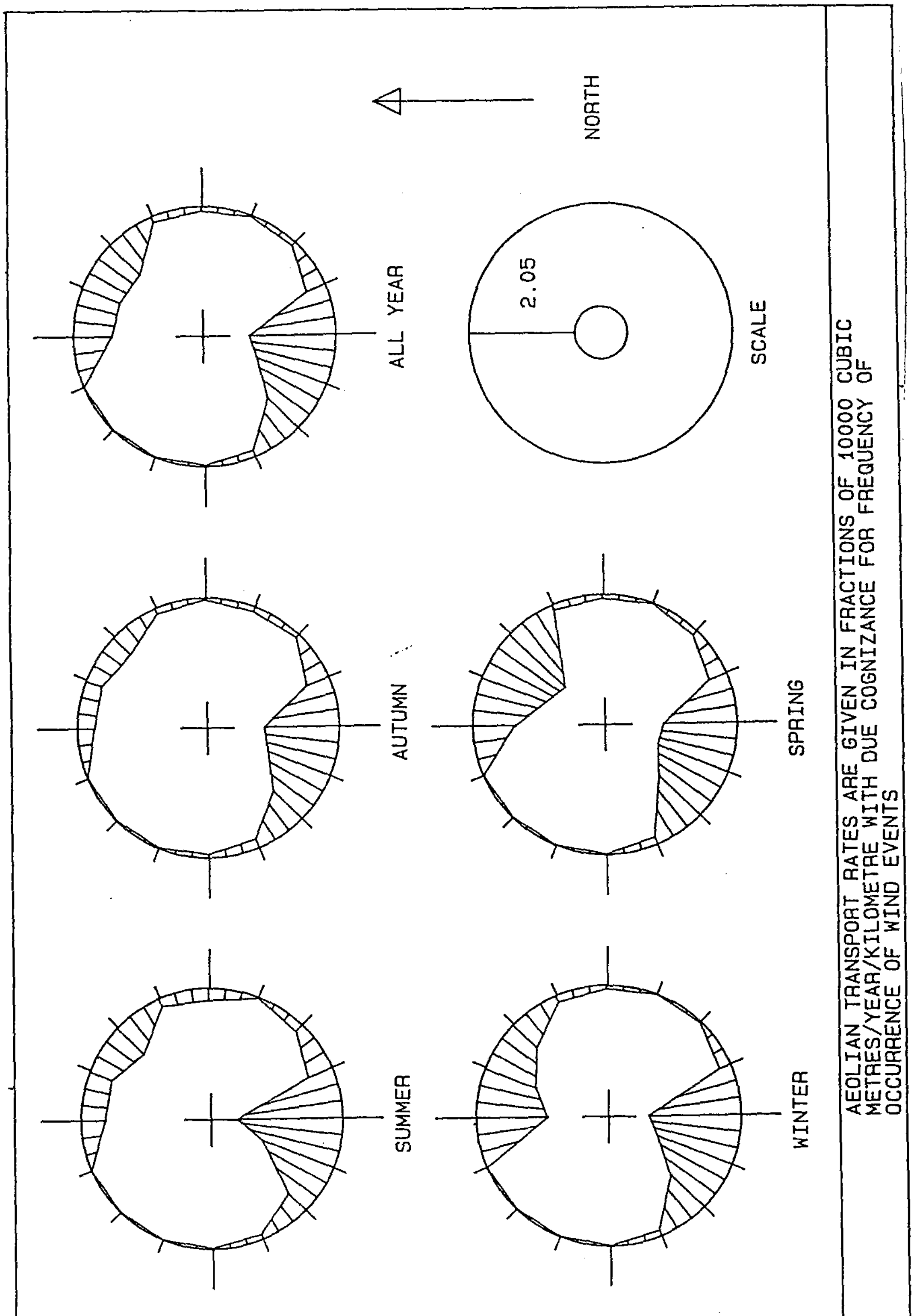

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Figure 27. Aeolian creep diagram

FIGURE
27

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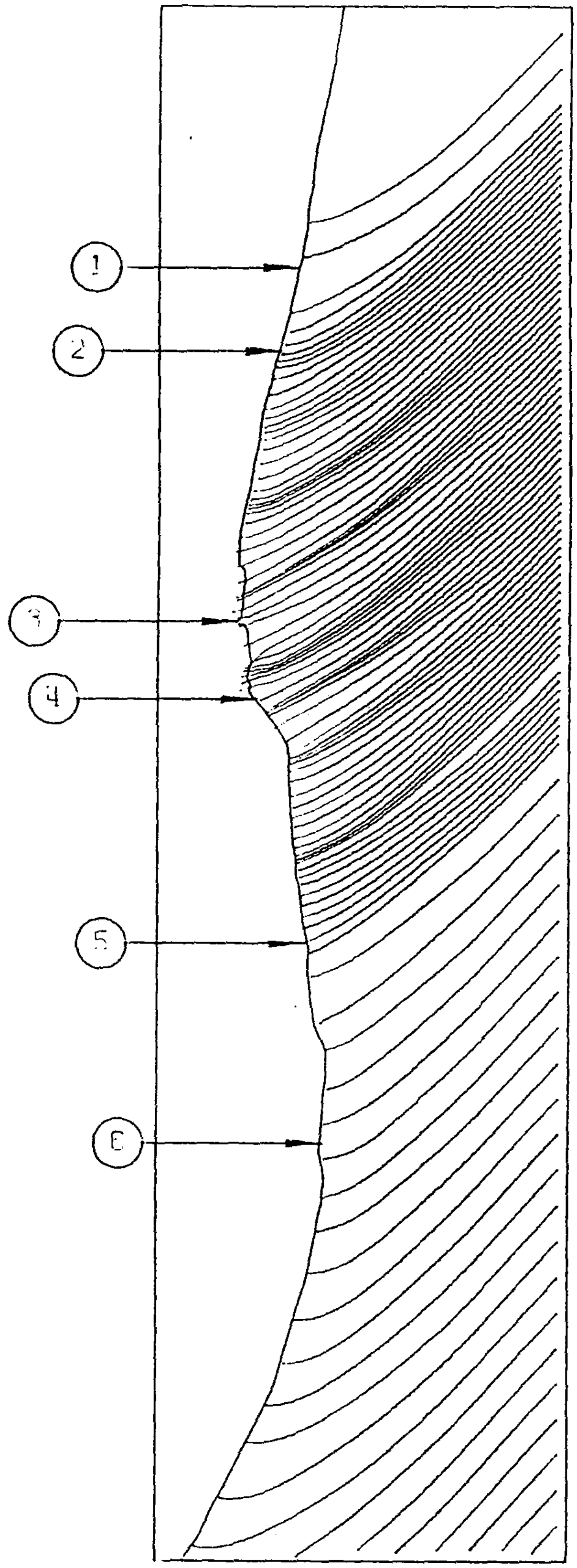
APPENDIX A: RESULTS OF REFRACTION ANALYSIS

(sample results only; Volume II contains the complete set of results)



1 FIRST ROCK
2 R.S. PLOT
3 ST LUCIA
4 MAPELANE
5 L.S. PLOT
6 LIGHTHOUSE

TRACED : LINREF CHECKED : DATE : REF.	ST LUCIA - (LINREF) TIDE LEVEL: M.S.L. WAVE PERIOD: 12.3 S DIRECTION : 60.0 DEGREES SCALE :1/200000	FIGURE A1.1

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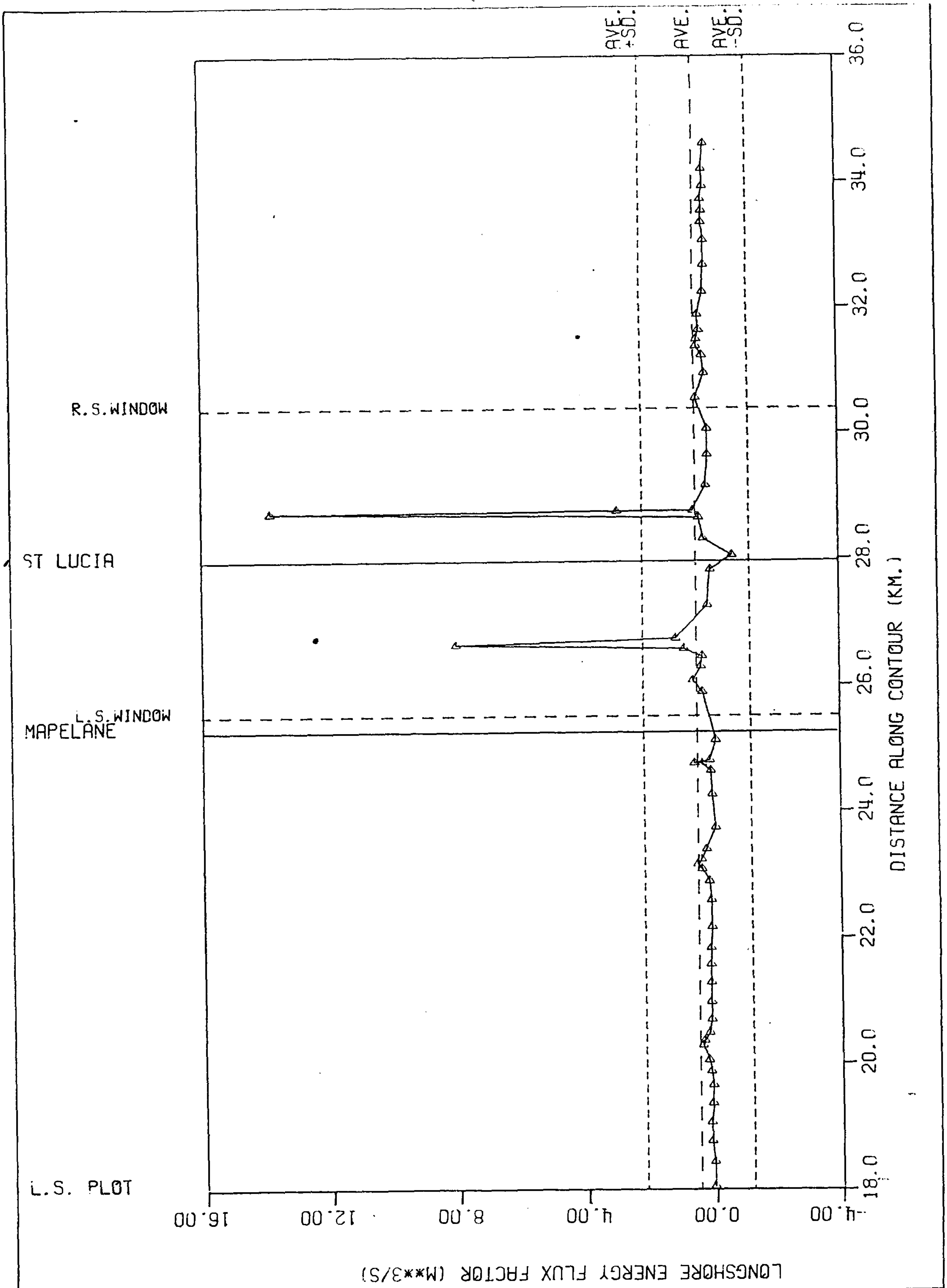

TRACED : LINREF CHECKED: DATE : REF.	ST LUCIA - LINEAR REFRACTION LONGSHORE ENERGY FLUX FACTOR (M**3/S) 60.0 DEGREES : T=12.3 (S.)	FIGURE A 1.2

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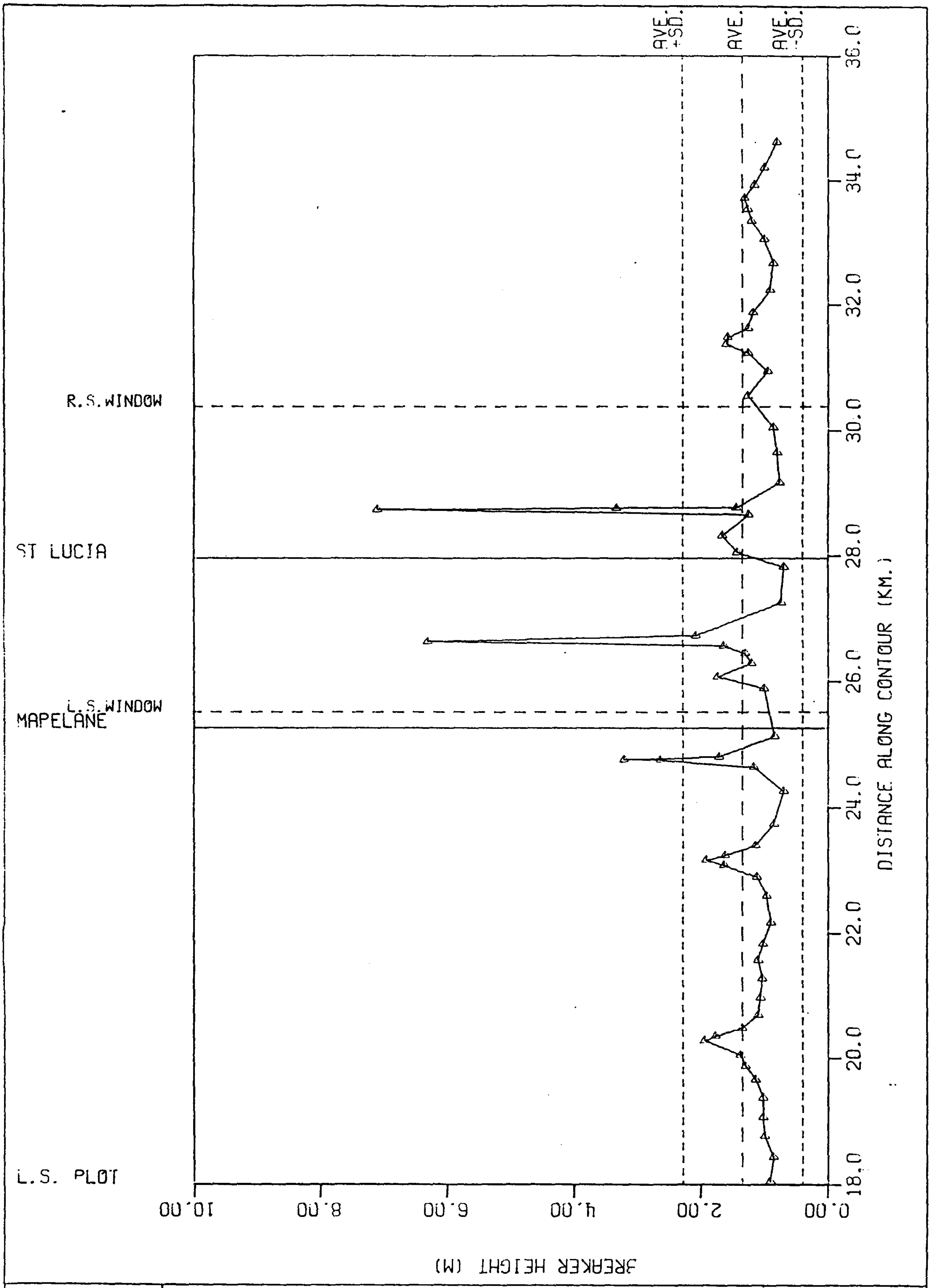

TRACED : LINREF CHECKED: DATE : REF.	ST LUCIA - LINEAR REFRACTION BREAKER HEIGHT (M) 60.0 DEGREES : T=12.3 (S.)	FIGURE A 1.3

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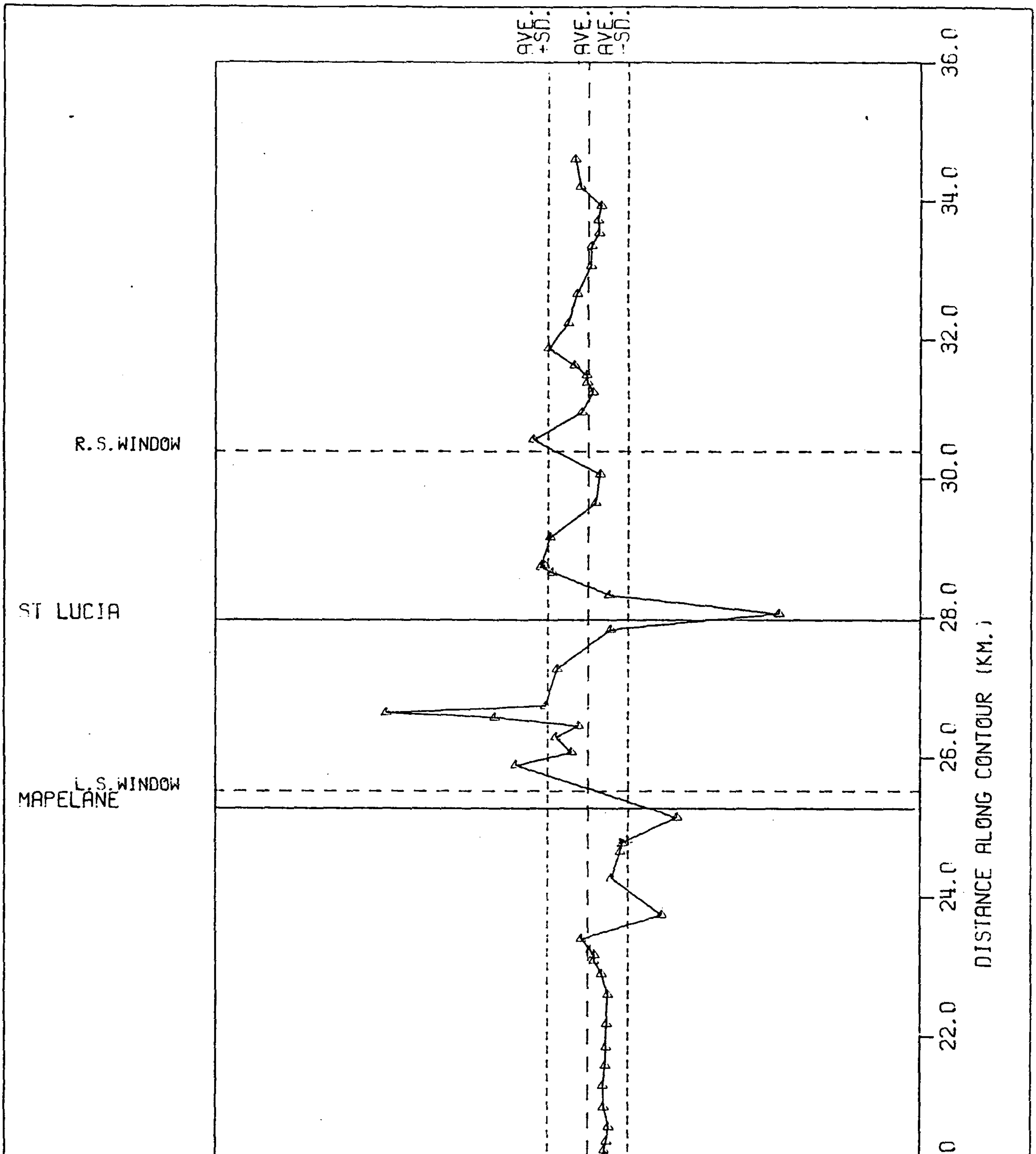

TRACED : LINREF CHECKED: DATE : REF. :	ST LUCIA - LINEAR REFRACTION BREAKER ANGLE (DEG) 60.0 DEGREES : T=12.3 (S.)	FIGURE A I.4

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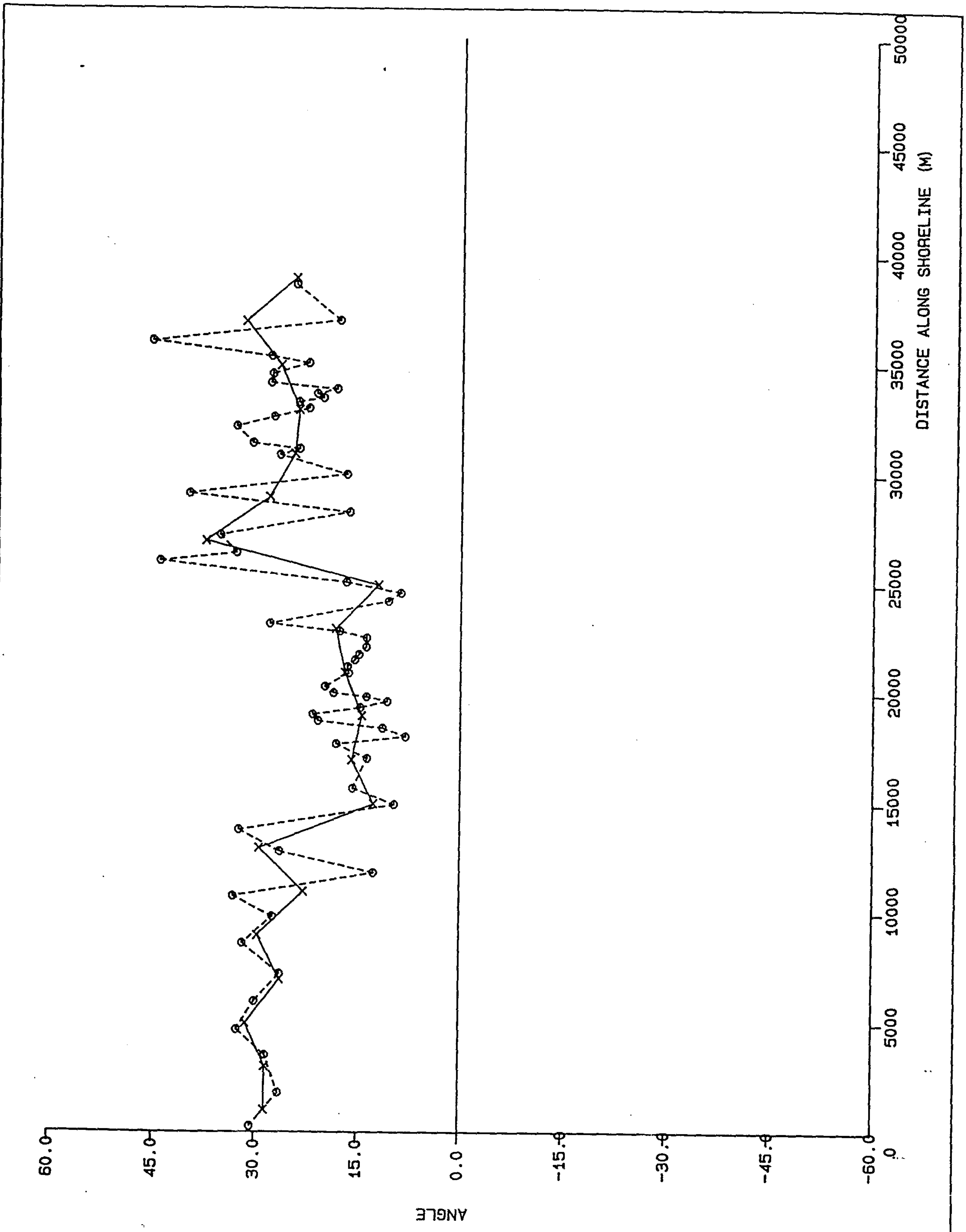
APPENDIX B: SMOOTHED BREAKER LINE DATA ON BASIS OF REFRACTION ANALYSES IN APPENDIX A

(sample results only; Volume II contains the complete set of results)



TRACED : COMPLOT CHECKED: DATE : REF. :	ST LUCIA ANGLE DIRECTION = 60 DEG. T=12.3 S	FIGURE B I.I.

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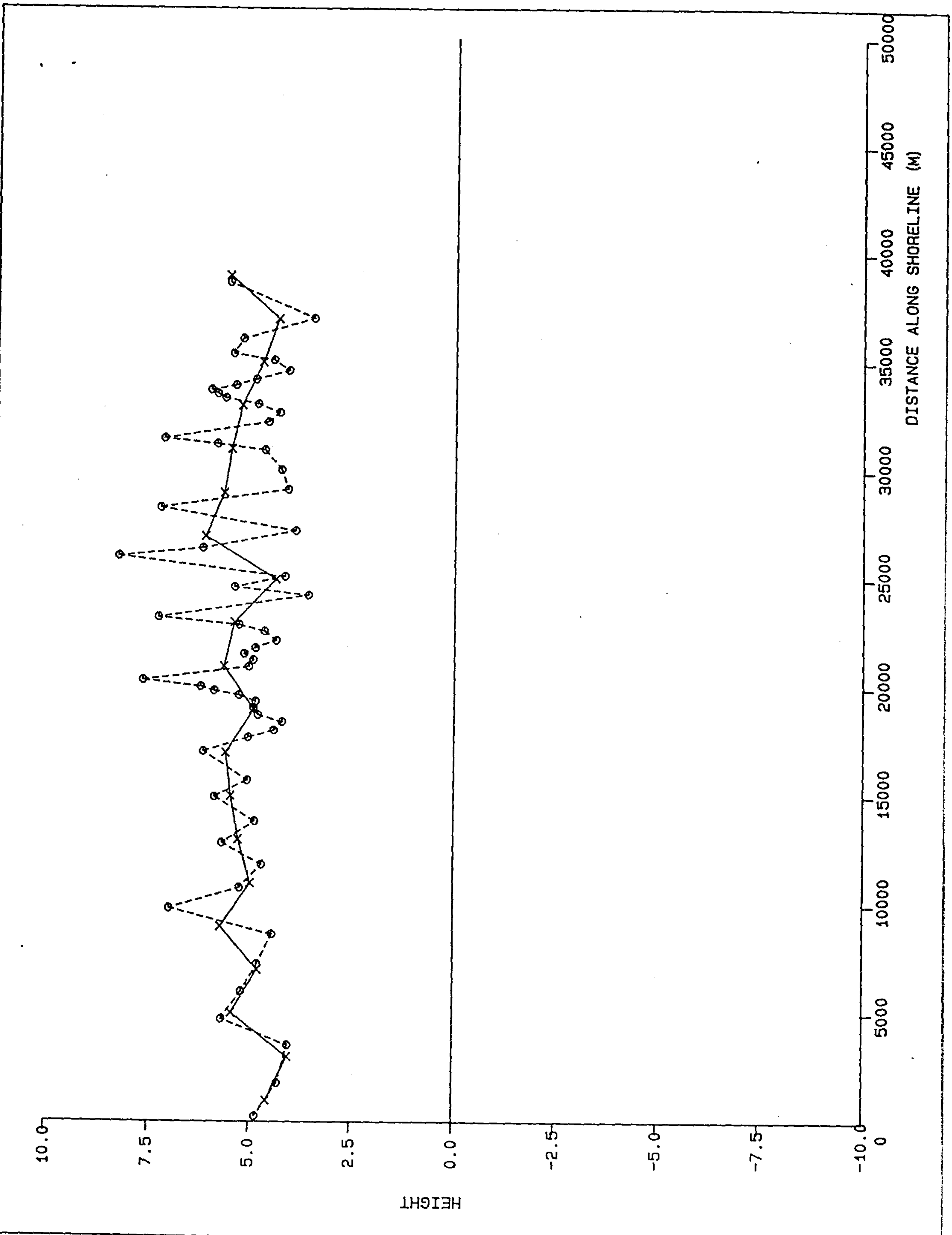

TRACED : COMPLOT CHECKED: DATE : REF. :	ST LUCIA HEIGHT DIRECTION = 60 DEG. T=12.3 S	FIGURE B1.2.

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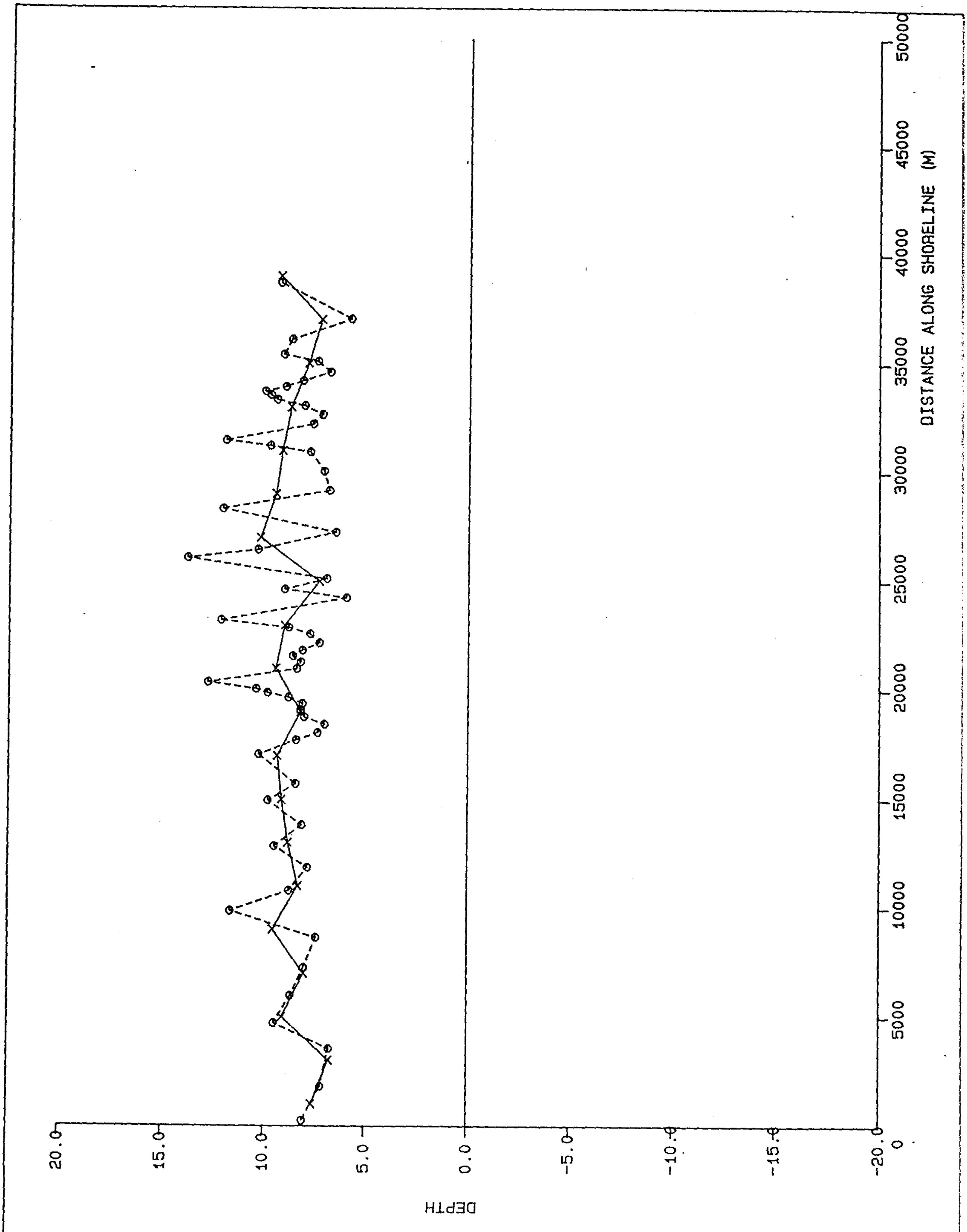

TRACED : COMPLOT CHECKED: DATE : REF. :	ST LUCIA DEPTH DIRECTION = 60 DEG. T=12.3 S	FIGURE B1.3

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