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TIDAL SCOUR IN THE GIPPSLAND LAKES

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ABSTRACT: The present Gippsland Lakes system formed as sea level rose during the Holocene, and since then has been a depositional basin of very fine grained organic rich sediments. Opening of the artificial entrance in 1889 has subjected the Lakes to greater tidal influence, and as a result many physiographical changes have occurred. One feature of major significance is the extent of tidal scour deepening due to erosion averages 3 m in Reeves Channel, reaching a maximum of 9 m in the narrowest section at Metung. Detectable scour has occurred as far west as Point Turner in Lake Victoria. The extent of scour has been determined by comparison of a survey compiled in 1895 and soundings done in September 1979.

Current and salinity measurements within the scour channels show significant stratification, and results indicate that the erosion is occurring during flood tide by the action of high salinity bottom currents. The less dense lake water transports eroded sediment seaward in a surface current during ebb tide. In Reeves Channel flood tide currents of *50-100* cm/sec are transporting coarse sediment into the Lakes in the form of sand waves. Currents capable of erosion — *(10-15* cm/sec) were recorded in the tidal channel developing south of Raymond Island. The salinity of the Lakes is believed to be increasing due to the continued deepening of Reeves — Channel. Therefore the sedimentary regime of the Lakes has changed from a depositional basin, a concept accepted at present, to a dynamic estuarine environment.

INTRODUCTION

The complex of islands, peninsulas and submerged banks which comprise the Gippsland Lakes system result from the partial drowning of an original coastal plain topography. Successive transgressions into the Gippsland Basin since the late Tertiary produced the sequence of sand barriers; Bird (1965) has identified these land forms as remnants of two prior phases of barrier formation lying behind an outer barrier formed during the recent transgression of the sea. Evolution of the outer barrier formed this vast sheltered expanse of water.

The fine sediment of the lake bottom reflects the low energy environment in which they have been deposited, An average of 10 m of sediment has accumulated since their formation and cores taken within Lake King and Lake Victoria show the sediment to be 5-30% organic, 10-30% carbonate and the complement to be clay and silt deposited from the rivers. Marine fauna within the sub-surface samples testify to the fact that the Lakes have always been connected to the sea, at least by an intermittent entrance as described by Rawlinson and others (Fryer 1973).

The opening of the artificial entrance in June 1889 made a permanent connection with the sea and subjected the Lakes to greater tidal influence. The most immediate effect must have been an increase in salinity followed by major ecological changes. Documentary evidence of the ecology before 1889 is not detailed and only major biological changes have been noted since. The bathymetry of the Lakes however, was surveyed in detail between 1892 and 1895, no doubt in anticipation of increased shipping trade passing through the Lakes.

The purpose of the present study has been to determine the nature of any changes in the bathymetry since 1889 and to assess the implications of these changes. The area studied included both Lake King and eastern Lake Victoria as both of the Lakes are subject to tidal effects to some extent. Thus any remarks referring to the ‘Lakes’ in this paper exclude Lake Wellington.

METHOD

Initial work involved a series of sounding traverses spaced between 200 and 500 m apart, to establish the extent and form of any depth changes since the 1895 survey. Positioning of starting and finishing points of each traverse were established using colour aerial photographs, giving an estimated error of up to 20 m. The depths were recorded on a strip chart by a Furuno depth sounder. The profile obtained was then digitized and a printout produced of the computed depths and corresponding Australian Military Grid coordinates across each traverse. The depths were then plotted on an overlay at the same scale as the original Gippsland Lakes Survey.

The original survey by J. B Mason was compiled between 1892 and 1895, several years after the entrance had been opened. Mason's charts were mapped on a 1:4800 scale from Lakes Entrance to Metung with an average line spacing of 50 m, and a 1:7200 scale for the rest of Lakes King and Victoria with an average line spacing of 100 m. The results of the original survey are believed to be of a high standard. However, the exact datum could not be established (pers. comm. Chief Hydrographic Surveyor, Public Works Department). All depths were measured relative to the level of Low Water Ordinary Spring Tide as were the present results, so the datums would be essentially the same. This fact is reinforced by the results of long traverses across uneroded areas of Lake King which agreed consistently with the original survey. In view of the limited accuracy of the present study and the possibility of slight differences in the datums, depth differences of less than 30 cm were not recorded. It should be noted that during normal river flow and calm weather, changes in water level west of Metung are less than 10cm.

Current readings were taken to determine the area showing a current pattern dominantly attributable to tidal fluctuations. An ebb-flood current cycle was still distinguishable as far west as Point Turner in Lake Victoria, and on this basis two stations were established to study the pattern of current flow in the areas of greatest deepening. The two stations established were in the deepest sections off Metung Peninsula and Harrington Point.

An Endeco current meter was used to monitor current speed, direction and depth over a 12 hour period at each station. To supplement the current

Fig. 1— Isoallobath map of southwestern part of Lake King.

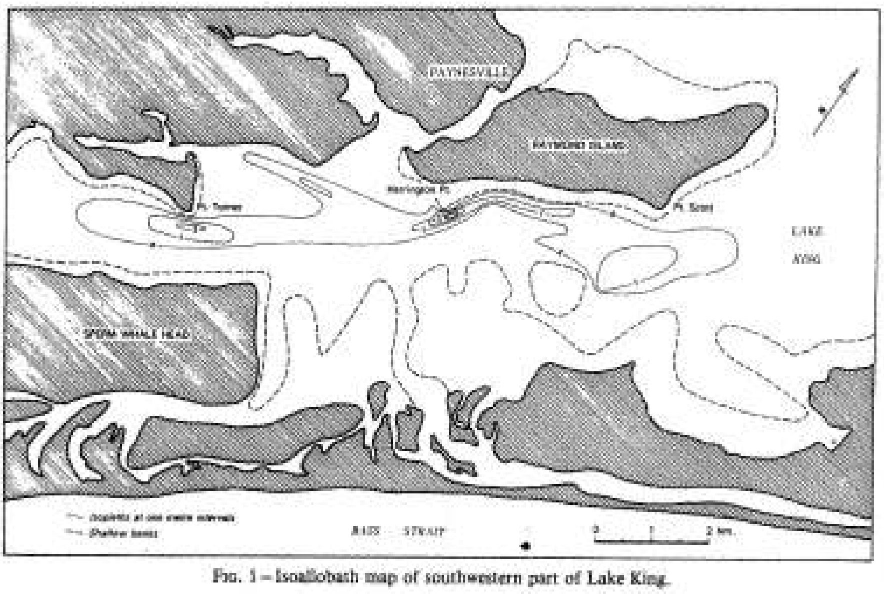

FIG. 1 – Isoallobath map of southwestern part of Lake King.

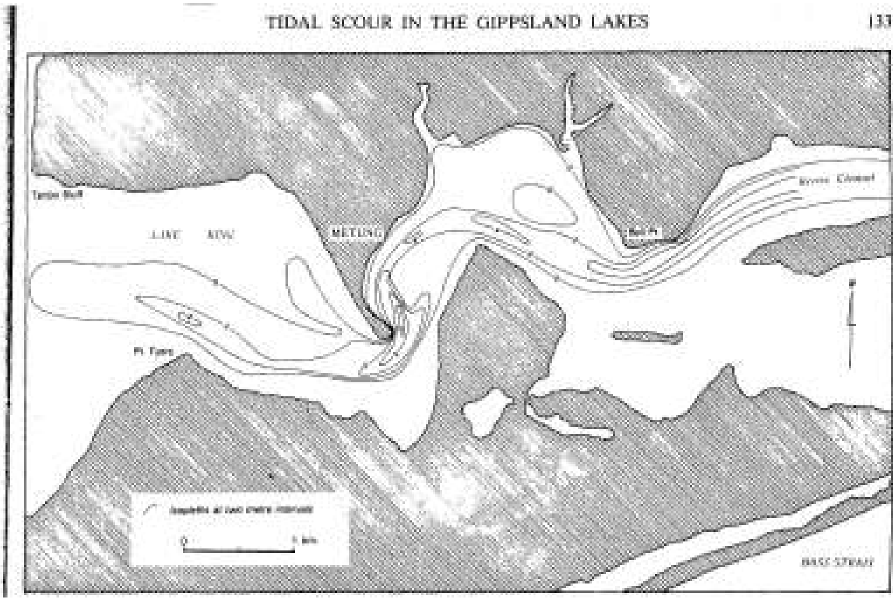

FIG. 2— Isoallobath map of eastern part of Lake King to Reeves Channel

data, readings of salinity, temperature and turbidity, were taken at regular intervals during the tidal cycle.

RESULTS

In order to assess the significance of the changes in bottom form between the present survey and that of Mason, two isoallobath maps (Figures 1 and 2) were drawn for the period *1895* to 1979. These were prepared by super-imposing the results of the two surveys and plotting the points of negative or positive depth change. Isopleths were then drawn in relation to these points to establish the configuration of the depth change. The pattern that emerges is a channel system scoured deep into the Lake's sediment. The depth of scour averages 3 m in Reeves Channel but reaches a maximum of 9 m in the narrowest section at Metung. This amounts to the erosion of an estimated *5* x **106** m3 of sediment over an area of 11 km2.

The scour channel is not detectable west of Tambo Bluff in Lake King until it begins again south of Raymond Island, continuing west past Point Turner. In this section an estimated *2.5* x **106** m3 of sediment has been eroded from an area of 8 km2.

Current measurements within the scour channels showed two distinct patterns of flow, attributable to ebb and flood tide. The ebb flow was dominantly a flow of the upper lake water of lower salinity. The flood flow however entered the system as a dense saline wedge creating bottom currents well into the Lakes system. The bottom currents conform with the shape of the scour channel, while the currents shallower in the profile may vary in direction. Currents measured in uppermost water layers were quite often directly attributable to movement by the wind.

DISCUSSION

The intrusion of the sea into the Lakes began with the unexpected breakthrough by storm waves in June 1889. This completed the artificial cut in the barrier that had begun nearly 20 years prior. Tidal currents quickly scoured the entrance to a navigable depth and Reeves Channel became a tidal channel through which ebb and flood currents moved in response to the tidal level at the entrance. The 12 km meandering passage into the main body of the Lakes was a significant constriction to the tidal flow and tidal levels in Lake King were greatly diminished relative to the entrance.

Due to the extensive area of the Lakes tidally affected, the volume flowing through the entrance created currents strong enough to maintain a navigable entrance as hoped. The subsequent formation of an offshore bar has been a major restriction to shipping and was the subject of an investigation by the Public Works Department (Fryer 1973).

EROSION

Bottom sediment of the Lakes for the major part has a mean size of less than 7 microns and a biogenic content up to *50°7* (Davies *et a!.* 1977). Sub-surface samples throughout Lake King show the sediment to be predominantly clayey-silt with a water content of 60 to 70% (King I980b). In the uneroded areas water content in the upper 0.5 m exceeds 70% (Table 1). Due to the fine grain size and lack of consolidation, the sediment is vulnerable to erosion by current velocities as low as 10-15 cm/sec (Young & Southard 1978). Currents produced by the intruding saline wedge range in velocity from 10 cm/sec to 100 cm/sec, and are therefore capable of causing erosion. The rate of erosion is proportional to the shear velocity and the type of material exposed on the bed. Systematic bottom sampling of the scour channels was not carried out, but two bottom samples taken in the deepest sections at Bell Point and Metung indicate that the sediment being eroded at present is clayey-silt (Table 2) consistent with the composition of the sub-surface samples taken in Lake King.

TABLE-1

RESULTS OF ANALYSES DONE ON A CORE TAKEN IN LAKE KING, APPROXIMATELY I *KM* EAST OF POINT FULLARTON

T Depth (cm)	*SILT content (Wt ¾)*	*Clay content (Wt %)*	*Mean size Microns)*	*Car bonate Content (wt%)*	*Organic content (Wt%)*	*Water content (Wt%)*
0- 10	66	34	***6.5***	17	20	73
30- 35	73	27	10.5	20	23	70
60- 65	84	16	13.6	21	15	69
90- 95	84	16	10.3	21	29	68
120-125	98	2	16.6	17	5	68
150-155	78	22	10.5	12	2	67
180-185	64	36	10.6	13	31	67
200-205	78	22	12.0	13	17	67

TABLE 2

RESULTS OF ANALYSES ON TWO BOTTOM SAMPLESTAKEN IN THESCOUR CHANNEL OFF BELL Pt AND SHAVEN Pt, METUNG

Sample Position	Sand content (WI %)	Silt content (WT %)	Clay content (WT %)	Car-bonate content (WT%)	Or-ganic content (Wt%)
Bell Point	12	44	44	25	38
Shaving Point	21	27	51	30	28

Scour is continuing despite the recorded increase in sediment consolidation with depth. This is believed to be due to the activity of both benthic micro fauna and macro fauna (Saila 1976). Inspection of the bottom while diving in the scour chan nels indicates that the upper 5-10 cm is kept in a relatively homogeneous and unconsolidated state due to bioturbation.

In terms of the salinity pattern, the Lakes can be classified as a mixed estuary (Drake 1976) i.e. a nett landward flow of saline water and a seaward flow of less saline lake water. The degree of saline intrusion is determined by the fresh water head relative to the tidal strength. In periods of exceptionally high river discharge there is no intrusion of saline water. Conversely, during periods of low river flow when evaporation exceeds fresh water inflow, there is a large nett inflow of saline water. During flood tide the saline wedge moves along the bottom at a velocity ranging from an average of 50 cm/sec in Reeves Channel to 10-15 cm/sec in Lake King. The ebb current of lake water attains its greatest speed in the upper part of the water column. At Metung where scour is greatest the ebb current was only detectable for the upper 9 m of the 18 m water column, while during flood tide the whole water column moves in response to the incoming flood tide (Table 3). Therefore it is clear that the scour is caused by the movement of saline bottom water into the Lakes.

SEDIMENT TRANSPORT

The current velocity results collected over a 12 hour period at Metung were used to estimate the tidal volumes for the ebb and flood flow through the channel at Metung (P.W.D. 1980). These results were further analysed (King 1980a) so that flow volumes for the upper (0-7 m) and lower water layer were considered separately. The results are given in Table 4, and show that despite a large Nett out flow over the complete ebb-flood cycle, there was a nett inflow through the lower section, this results in a nett landward transport of

TABLE 3

RESULTS SHOWING THE VARIATION OF THE NORMALIZED CURRENT VELOCITY, SALINITY AND TEMPERATURE WITH DEPTH AT PEAK EBB DISCHARGE ON THE 30.10.79 AND PEAK FLOOD INPUT ON THE 31.10.79 AT METUNG.

Tide	*Depth (M)*	*Current Velocity (m/sec)*	*Salinity (ppt)*	*Temperature (C)*
Flood	1.8	0.36	19.3	15.5
	3.7	0.31	19.7	15.5
	5.5	0.31	19.7	15.5
	7.3	0.19	28.0	14.6
	9.1	0.13	30.3	14.5
	11.0	0.15	31.1	14.4
	12.8	0.10	32.3	14.3
	15.0	0.13	33.2	14.3
Ebb	1.8	0.41	19.6	15.5
	3.7	0.32	19.6	15.5
	5.5	0.26	23.0	15.3
	7.3	0.07	29.6	14.7
	9.1	0.09	30.8	14.7
	11.0	0.00	31.1	14.7
	12.8	0.00	31.1	14.7
	15.0	0.00	31.2	14.6

suspended sediment and saline water through the bottom section with every flood tide cycle.

The sediment scoured during flood tide is believed to make up a major part of the suspended sediment load of the saline bottom water. It follows that a large proportion of the eroded sediment has been transported back into Lake King, representing a significant input of suspended sediment. The Nett outflow during the tidal cycle recorded, resulted in the export of suspended sediment, but without long term current data no firm statement can be made about the overall sediment budget of the Lakes. A Nett retention of river sediment within the Lakes is expected however, based on knowledge of the processes which act to retain sediment in an estuarine cell (Meade 1969).

Bed load transport is occurring as a result of the nett landward movement of the saline bottom water. This is most evident in Reeves Channel where sand is being transported landward in the form of sand waves. A thin veneer of sand is encroaching into the Lakes, along Reeves Channel and at present it has reached just east of Nungurner. Observations while diving, showed that deposition of this veneer of sand has halted the scour. An interesting phenomenon observed while on the bottom in the 18 m channel at Metung, was a bed of what proved to be rounded "pebbles" of mud rolled along the bottom during flood tide. No explanation can be given as to how they formed and it tends to complicate any attempt to understand the exact mechanism by which the fine grained sediment is being eroded.

SALINITY

Salinity in the Lakes was the subject of a Parliamentary Public Works Committee inquiry in *1952;* it concluded that there had not been an appreciable increase in salinity of the Lakes as a result of the artificial opening. Bird (1978) however provides evidence based primarily on *Phragrnites* die back, to support a hypothesis of salinity increase since 1889, and the results of this investigation add substantially more weight to the conclusion of a salinity increase.

The scour channel that has developed in Reeves Channel now provides a significantly deeper passage for the exchange of water between the main body of the Lakes and Bass Strait. This has increased saltwater intrusion into the Lakes system by reducing the mean velocity of the lake water outflow but also a smaller proportion of the water column is affected by the outflow during ebb tide (Hinwood 1964). The results at Metung (Tables 3 & 4) show that 95% of the ebb flow volume passes through the upper 7 m of the 18 m water column, and there is a nett input of saline water through the lower section with each tidal cycle. Thus saline water is pumped into the Lakes and only exported after vertical mixing with lake water.

It seems incontestable that salinity increase within the lake system has occurred as a direct result of the artificial opening of the Lakes. The results of this study highlight the fact that a con-

TABLE 4

RESULTS OF FLOW VOLUME CALCULATIONS CARRIED OUT ON THE CURRENT VELOCITY DATA ACQUIRED AT METUNG ON THE 30-31.10.79. THE CROSS-SECTION OF THE CHANNEL WAS DIVIDED INTO AN UPPER AND LOWER SECTION BASED ON THE SALINITY AND TEMPERATURE STRATIFICATION.

Date	*Tide*	*Tidal volume (m3) Upper section (O-7m)*	*Lower section (7m-18rn)*
30.10.79	*Flood*	*7.2X10 6*	*1.9X10 6*
31.10.79	*Ebb*	*-11.8X10 6*	*-6.8X10 5*
Nett Discharge		*-4.6X10 6*	*+1.3X10 6*

tinued deepening of the lake bottom due to scour is causing a steady increase in the salinity of the Lakes. It is contested that this is occurring due to the inability of the ebb current to flush out the saine bottom water which intrudes during flood tide. The ultimate result of the continual scouring of the channels will be the exposure of the barrier sands believed to underlie the lake deposits.

CONCLUSION

Opening of the artificial entrance in 1889 has had a pronounced physiographical effect on the Gippsland Lakes, the flood tide currents have caused considerable scouring of the lake bottom sediment particularly east of Metung. The pattern of sediment transport has been altered, with the result that a tidal delta has formed near the entrance and suspended sediment is being distributed by tide induced currents within the Lakes. The salinity of the Lakes is believed to be steadily increasing by intrusion of saline water along the scour channels during flood tide, and little or no flushing of this lower layer of saline water during ebb tide.

An aspect of importance for bottom sampling within the Lakes is that bottom samples taken within the scour channels are samples of older exposed sediments and unlikely to be representative of present conditions.

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