Research on Sedimentation in Estuaries

THE SEEKOEI ESTUARY: EXAMPLE OF DISRUPTED SEDIMENTARY ECOLOGY

ROSIE REPORT No 5

By: K Esterhuysen

Project leader: IC Rust

Department of Geology
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SEEKOEI ESTUARY

CONTENTS

1. INTRODUCTION

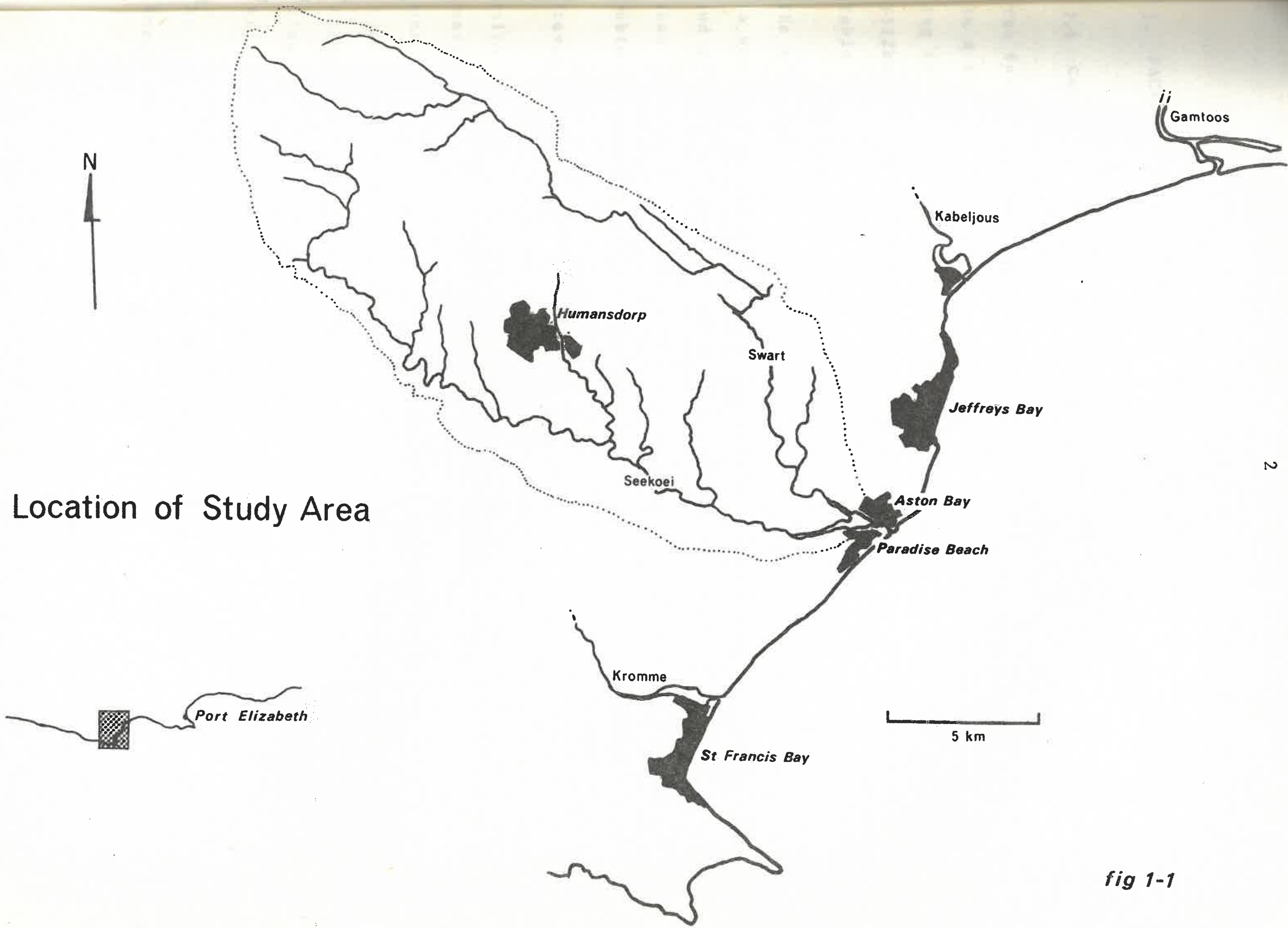
The Seekoei Estuary is a recreational attraction flanked by the resort towns of Aston Bay and Paradise Beach in the Eastern Cape (Fig 1-1). The two communities are now linked by a riprap causeway constructed across the estuary. Although the causeway was originally built as a weir to improve the estuary, it has attracted criticism for allegedly causing the deterioration of the estuary. Since its construction in 1971 sediment build-up and salinity changes have been reported. The causeway was not designed to cope with either normal tidal exchange or river flood discharge, nor is it functional as a safe roadway.

Sedimentation studies were undertaken to evaluate the influence of the causeway on the estuarine system.

In the winter of 1979, the causeway was breached by floods, improving tidal flow throughout the system. In December 1980 the gap was closed by the local authority. Culverts, installed above the normal high tide level, allowed only for slow out-flow of fluvial water. The upper estuary was deprived of seawater replenishment and tidal action.

A first survey was conducted in early November 1980, when it was learnt that the causeway was about to be repaired. The survey was repeated twelve months later. The results of the two surveys are reported here.

Brief field observations were also made in November 1982.



Location of Study Area

fig 1-1

2. BACKGROUND INFORMATION

2.1 Catchment area of the Seekoei and Swart Rivers

The Seekoei and Swart Rivers originate northwest of Humansdorp and flow in a trellis drainage pattern for about 30 kilometres before discharging into the estuary (Fig 1-1). The drainage basin is relatively small ($312km^2$) and has a geological substrate consisting of Palaeozoic Table Mountain Group quartzite and Bokkeveld Group slate.

'he study area lies in a southern Cape climatic zone which is temperate o warm. Precipitation is spread evenly over all seasons though autumn nd spring show peaks. The mean annual precipitation is 570mm and the ean annual run-off of the Seekoei-Swart drainage system is 27 x 10^6 ıbic metres.

revailing winds are southwesterly with an 18% frequency.

oils are shallow and poorly developed. The Table Mountain Group ıartzite weathers to a sandy, loose-textured soil. This soil lacks ıcro-plant nutrients as it is readily leached by meteoric water. :lerophyllous plants (fynbos) favour such conditions and occur in the ıtchment area. Lime is common in the lowlands, but absent in upland tes. The fluvial sediment yield is low, and consists mostly of mud rived from the Bokkeveld slate.

e main economic activity is animal husbandry, with the emphasis on eep farming. Some wheat cultivation also occurs.

2.2 Estuary

2.2.1 Original state of estuary

The estuary was originally 4,2km long and covered an area of 0,89km^2. Its tidal inlet is ephemeral and opens into St Francis Bay. The maximum width of the estuary is 580m and the original inlet was normally about 10m wide. The junction of the Seekoei and Swart Rivers is 1365 metres from the inlet. Tidal reach was 4,2km and the original tidal prism was about 0,82 x 10^6 cubic metres of water per cycle.

The estuary is surrounded by the unconsolidated coastal sediments and underlain by near vertical dipping slate beds of the Bokkeveld Group. Slate outcrops occur along the eastern banks of the estuary.

The estuary had a stable shallow ephemeral inlet. This was situated approximately 350 metres to the east of the present inlet where its depth was controlled by the underlying slate substrate. This ensured that the estuary never drained completely.

The longshore drift is in an easterly direction and the sea's tidal range is 1,6m.

2.2.2 Present state of estuary

A swimming pool complex has been constructed in the position of the original inlet (1969). To safeguard this complex an embankment was erected across the channel (Fig 3-2). A 320m long causeway crosses the estuary 510m upstream.

The Seekoei River Nature Reserve (0,22km^2) is situated on the eastern bank of the upper estuary.

The estuary is excluded from the regulations of the Sea Shore Act of 1935 as it was in private possession at the time of proclamation. It is now administered jointly by the Jeffreys Bay Municipality and the Humansdorp Divisional Council.

3. HISTORICAL DEVELOPMENTS

The Seekoei Estuary once retained a relatively large volume of water at low tide. This stable environment provided an excellent habitat for flourishing aquatic life, with waterfowl in particular being attracted to the estuary.

Episodic floods breached the sandbarrier to the west of the rock sill making a new temporary inlet, and flushing accumulated sediment into the sea. After a flood the inlet would migrate eastwards under the combined action of the longshore drift and waves. The inlet would continue along this path until it reached the bedrock outcrop. There the underlying substrate would halt the migratory pattern and stabilize the inlet. Within a few months the stable tidal lagoon would be re-established (Fig 3-1, copied from aerial photographs).

During the development of Aston Bay in the late 1960's and early 1970's, a swimming pool complex was constructed on the beach in the normal position of the inlet (Fig 3-2). The inlet was artificially shifted westward as its original path was now effectively blocked by an embankment. The inlet channel was artificially straightened and this effectively increased the water surface gradient. Faster flowing ebb currents which resulted excavated a channel with its base well below the low water mark. The estuary was therefore almost totally drained at low tide, exposing an intertidal zone of sand and mud banks. Without a constant level of water, waterfowl did not frequent the area any more and fish-life diminished rapidly.

This was unacceptable to the property developers. The aesthetic value of the estuary was of great importance to their marketing and selling campaign. They attempted to re-established the original state of the estuary by erecting a make-shift barrier across the new inlet. This ill-conceived construction was inadequate and was soon destroyed by wave action and tidal currents. A low weir was then constructed some 500m upstream of the inlet in order to retain water at low tide in the upstream part of the estuary (Fig 3-3). In time the weir was widened and raised and eventually became a causeway, enabling light traffic to cross the estuary.

The Seekoei River Nature Reserve was established principally as a sanctuary for waterfowl in 1969. Fluctuations in the estuary's water level caused the waterfowl to move away. Construction of the swimming pool complex and the subsequent environmental changes not only had an adverse effect on this area, but negated the primary purpose of the reserve.

Although the causeway was breached and severely damaged by floods in 1976 and 1979, the local authorities under pressure from local inhabitants chose to repair the causeway in order to maintain a direct crossing over the estuary.

During the construction of and repairs to the causeway little consideration seems to have been given to provision of suitable drainage of the tidal flow. Culverts and pipes were installed, but proved to be insufficient and allowed only for slow out-flow of fluvial water.

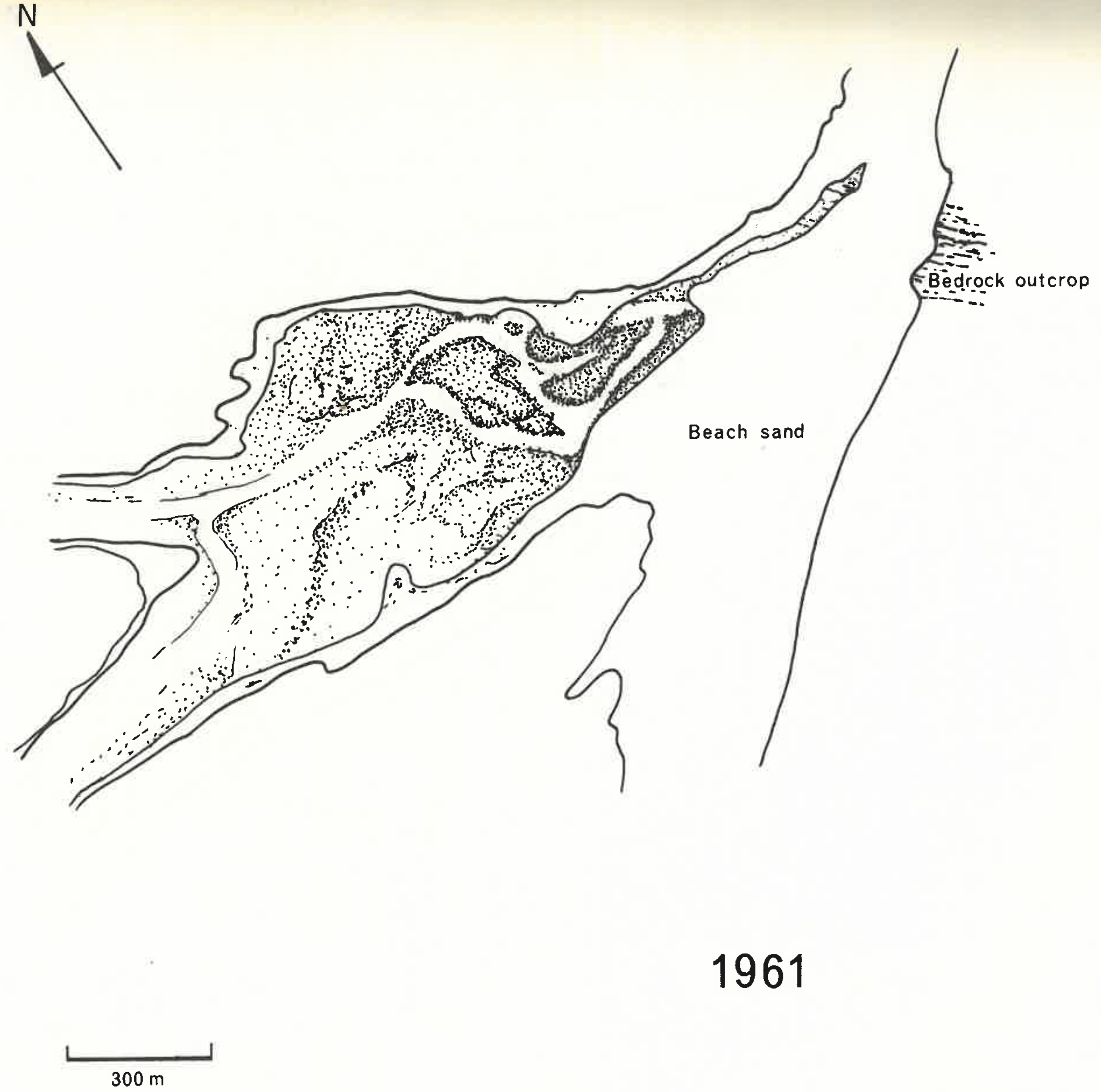


fig 3-1

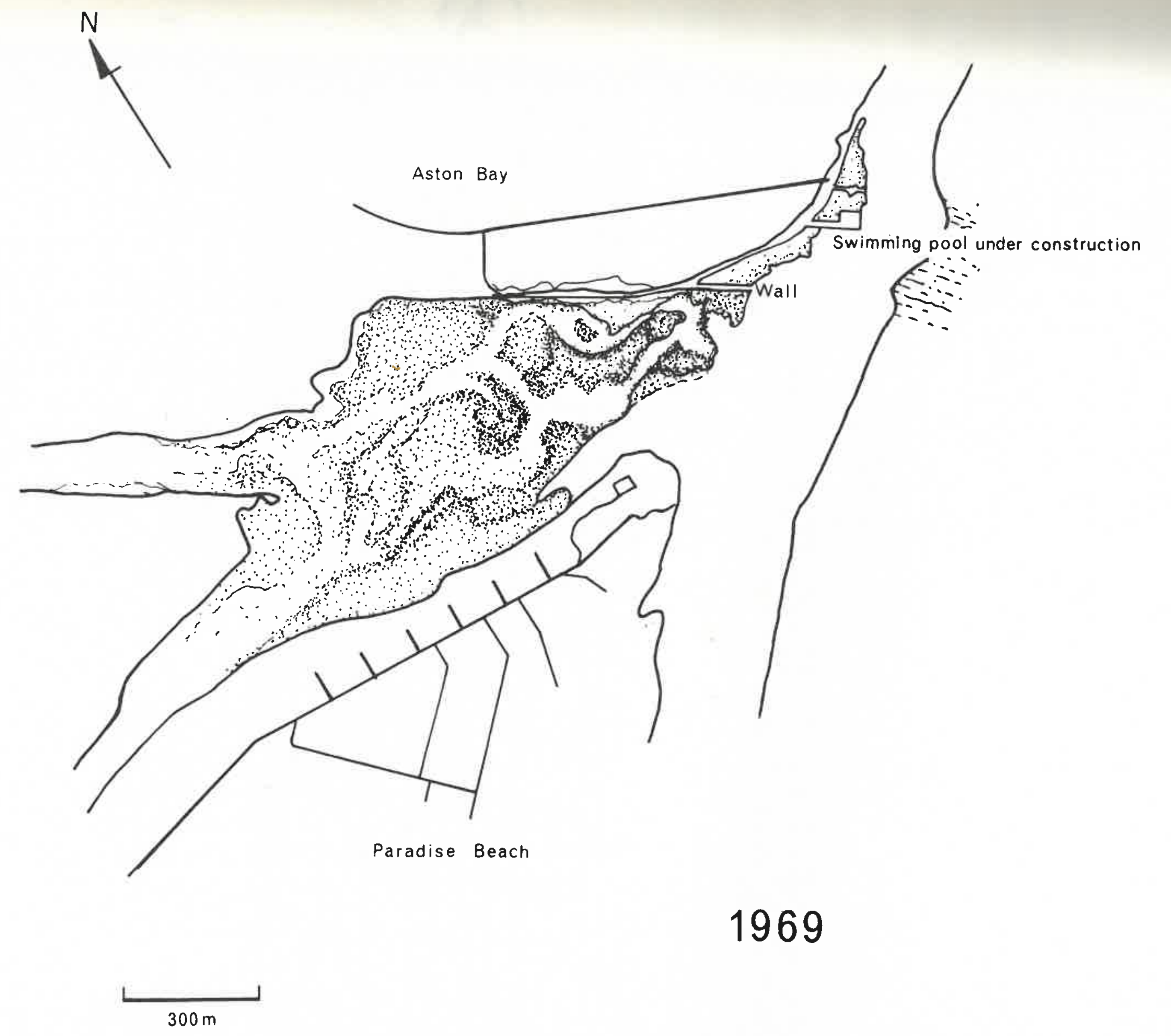

N
Aston Bay
Swimming pool under construction
Wall
Paradise Beach
1969
300 m

fig 3-2

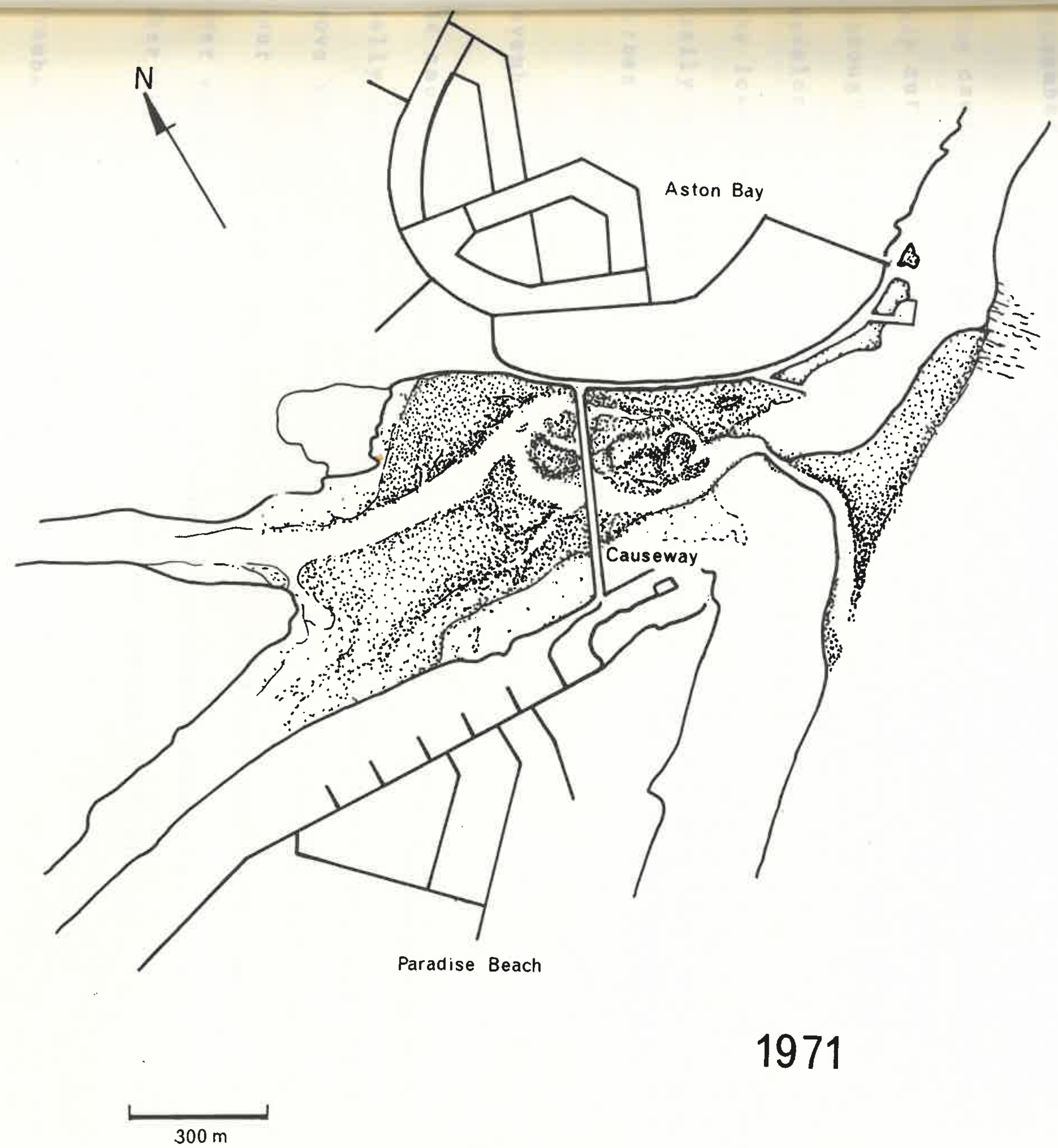


fig 3-3

4. FIELD OBSERVATIONS

November 1980

The causeway had been breached since July 1979 and a 15 metre wide gap cut through the rock and rubble infill. The depth of the channel through the causeway was approximately 5 metres at low tide. A well developed estuarine system with normal tidal channels was present in the lower section while the channels in the upper section were not easily recognisable as tidal channels. Tidal inlet was 8 metres across at high tide.

ovember 1981

he causeway had been repaired and raised. Tidal influence was vir-ually excluded from the upper estuary. Drainpipes were installed bove the high water level, allowing only for fluvial runoff. The pper estuary was once again flooded as before the 1979 flood. The ower estuary showed clear signs of sediment accumulation since Nov-mber 1980. Tidal inlet was 4 metres across at high tide.

vember 1982

e tidal inlet was completely blocked by beach sand, deposited under e action of the longshore current. Further signs of sediment accu-lation were present in the lower estuary. The water level in the tuary was very high and only marginally below some of the low-lying operties adjoining the estuary. All signs of the original inlet annel were obliterated by extensive infill. Limited volumes of sea-ter washed into the lower estuary over a sandbar at high tide.

5. SURVEYS AND SAMPLING

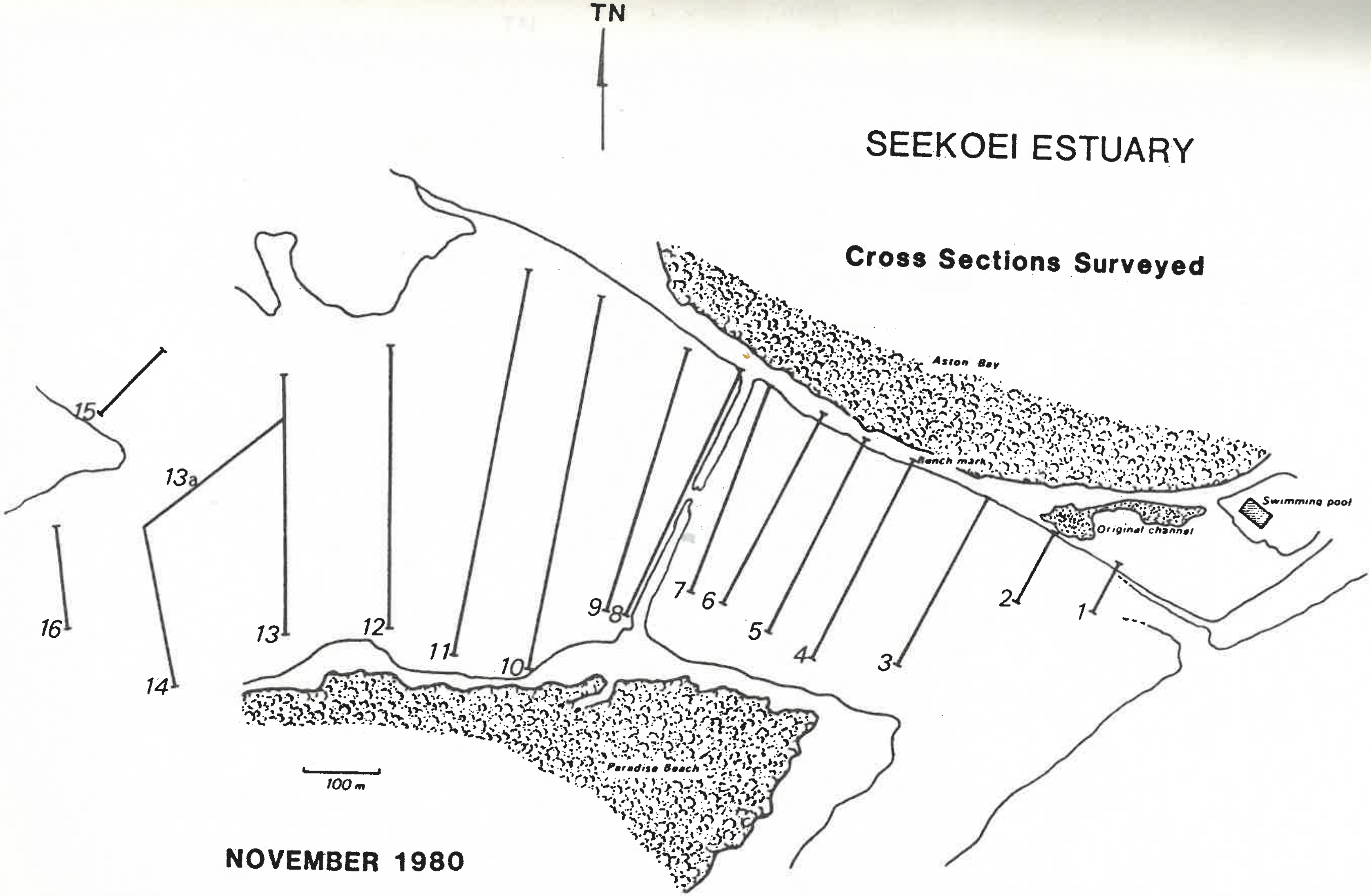
To monitor the sedimentation patterns, two bathymetric maps were prepared. The estuary was surveyed in early November 1980 and, using the same datum, the survey was repeated in November 1981. Cross-sections were located at convenient intervals, from the inlet to the junction of the Seekoei and Swart Rivers (Figs 5-1a,b). The datum was 1,419m above mean sea level. The cross-sections were measured by means of a theodolite. Results of the surveys are presented in SECTION 6.1.

Sediment samples from the intertidal and subtidal zones (Figs 5-2a,b) were obtained at both the bed surface and, by coring, at a depth of 0,5 metres into the substrate. The grain size proportions were determined by wet sieving through a 0,063 millimetre sieve and dry sieving of the coarser material. The samples were also analysed for their $CaCO_3$ and organic carbon content. Calculations and statistical analysis were handled with the aid of a micro-processor.

Water samples collected in 1981 and during the observation trip in November 1982 were analized for salinity.

SEEKOEI ESTUARY

Cross Sections Surveyed

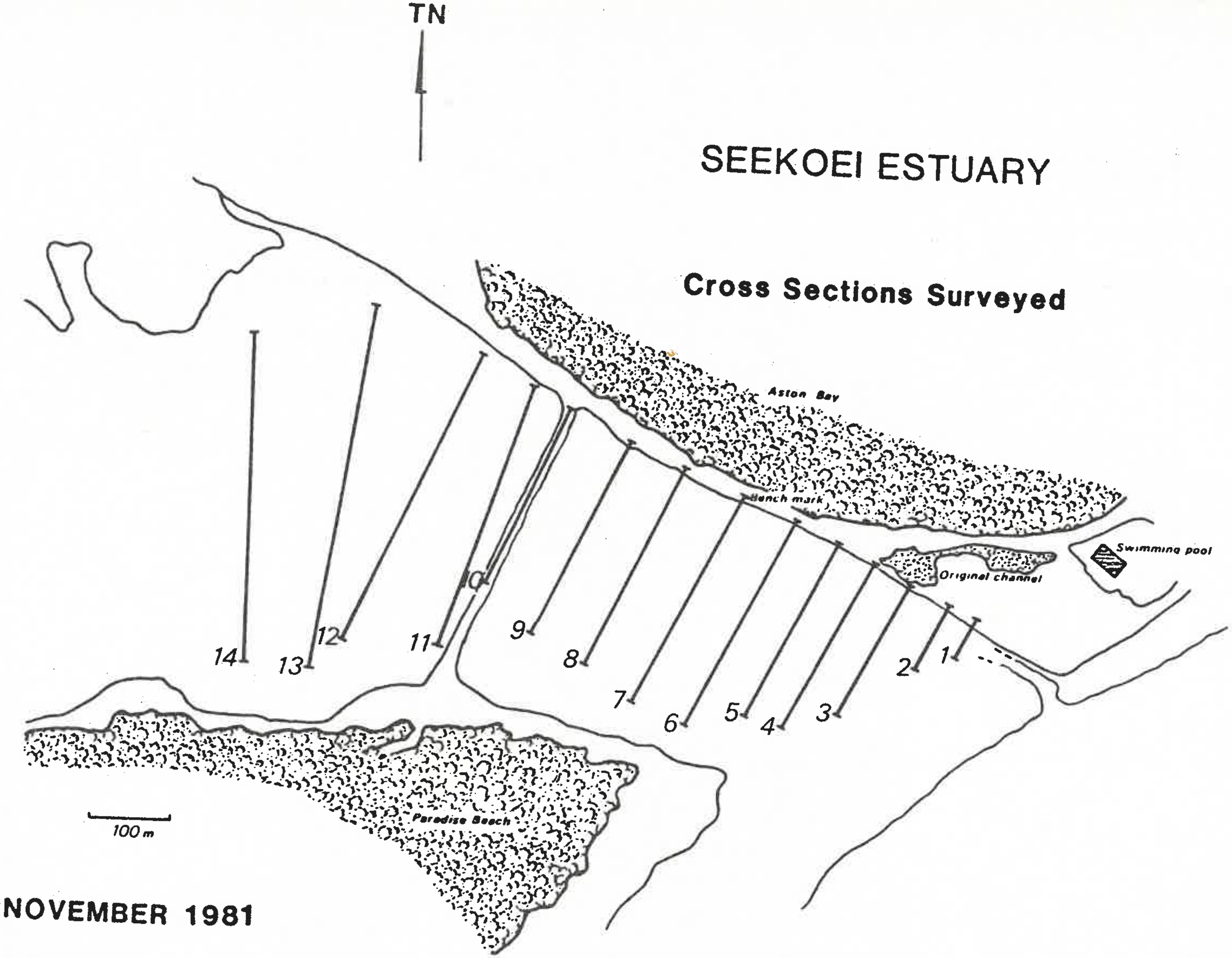


NOVEMBER 1980

fig 5-1a

SEEKOEI ESTUARY

Cross Sections Surveyed



NOVEMBER 1981

fig 5-1b

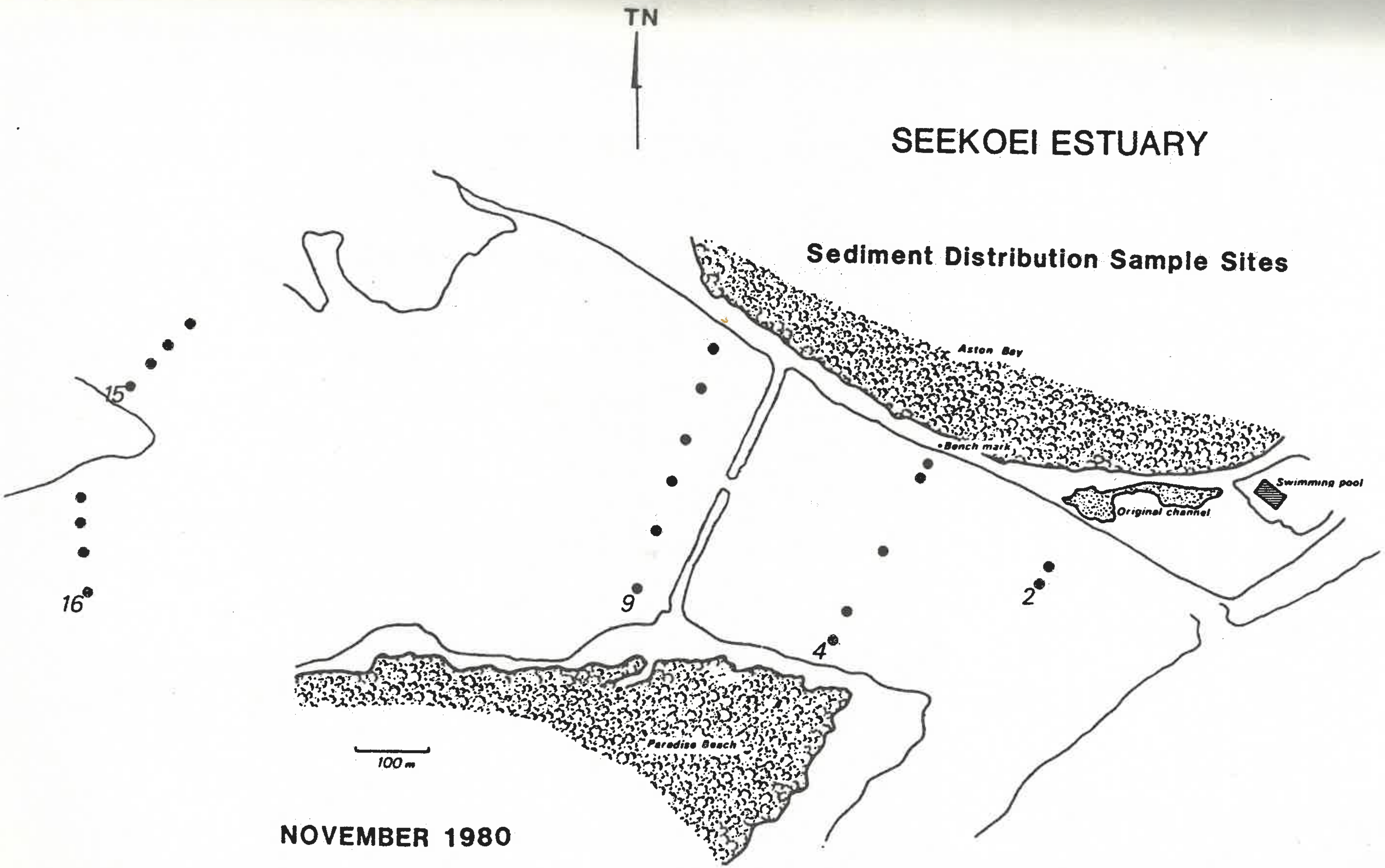

SEEKOEI ESTUARY
Sediment Distribution Sample Sites
TN
Aston Bay
Bench mark
Swimming pool
Original channel
Paradise Beach
2
4
9
15
16
100 m
NOVEMBER 1980

fig 5-2a

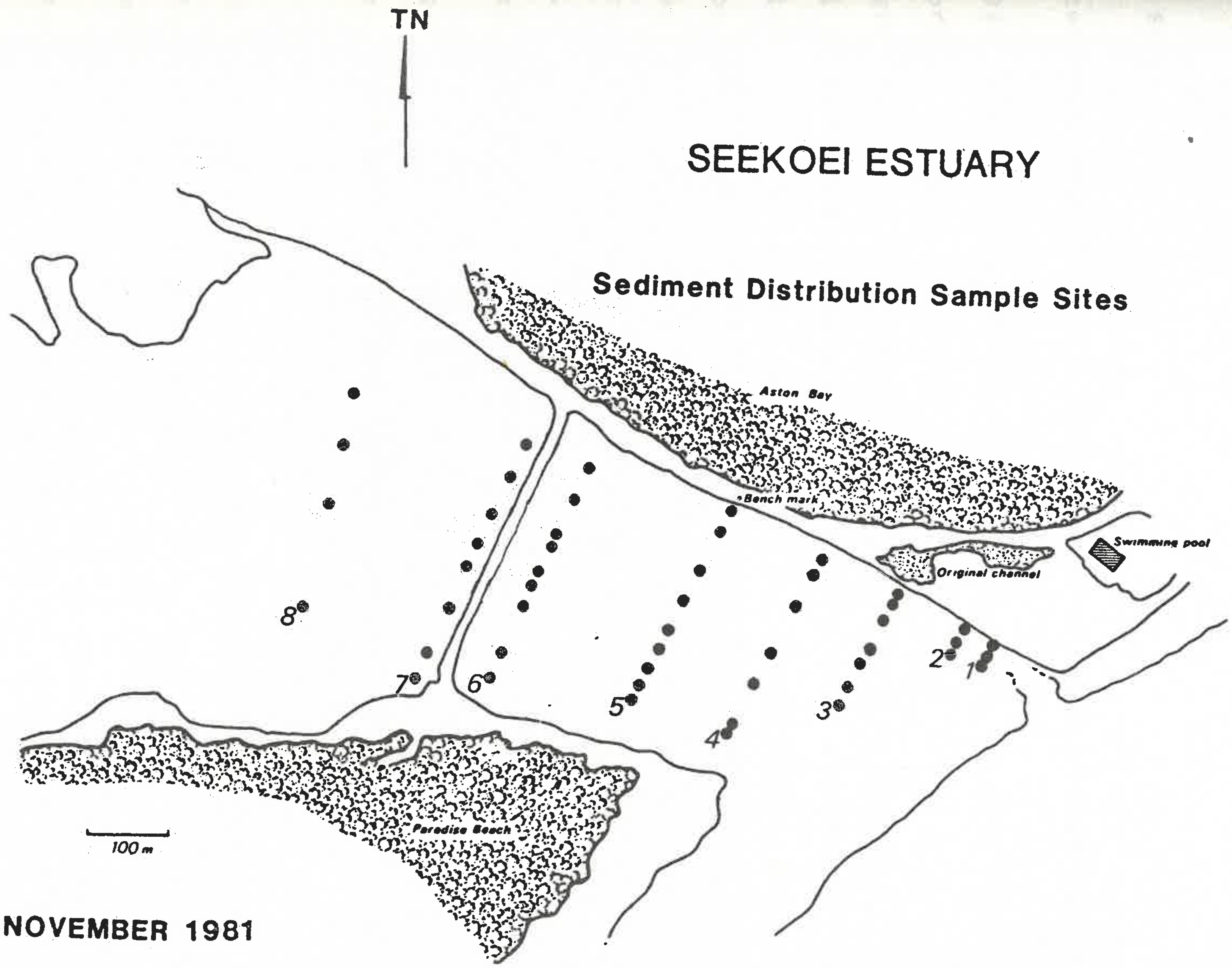

TN
SEEKOEI ESTUARY
Sediment Distribution Sample Sites
Aston Bay
Bench mark
Swimming pool
Original channel
1
2
3
4
5
6
7
8
Paradise Beach
100 m
NOVEMBER 1981

fig 5-2b

6. RESULTS

6.1 Surveys

The two bathymetric maps highlight certain differences (Figs 6-1a,b).

In 1980 the entire system was subjected to tidal influence. Well developed tidal channels existed in both the lower and upper estuary. The greatest depth was located at the gap in the causeway. As the tidal water exchanged between the upper and lower estuaries, it had to flow through a restricted opening. The strong current through the gap produced a scouring "jet" effect which eroded the channel to 5,5 metres below the low tide level. The upper estuary drained down to low tide level, exposing the intertidal sand and mud banks in that area. The depth of the inlet channel was approximately 0,5 metres at low tide.

By 1981 the causeway had been repaired, the sediment distribution had undergone noticeable changes, and the estuary had changed significantly.

The upper estuary was practically isolated from tidal influences. The causeway had been raised, thus preventing even spring tides from washing over the embankment into the upper estuary.

Within a year the well developed channels of the lower estuary had been replaced by a poorly drained system. With the causeway as the new effective tidal head, the volume entering and leaving during a tidal cycle was greatly reduced. More sediment was transported into the channels from the adjacent beach and surf zone, than was removed by the ebb currents. This sand accumulation made it continually more difficult for the flood tide to enter the lower estuary, resulting in imbalanced sedimentation. Sediment accumulation also occured in the upper estuary. It consisted mostly of fine-grained material of fluvial origin. Small quantities of organic detritus were also present. The rate of influx was much slower compared to that of the lower region.

The cross-sections are presented in APPENDIX 2.

6.2 Sediment volume changes

In the area between the inlet and the confluence of the Seekoei and Swart rivers the sediment volume increased by 3,54 x 10^4 cubic metres between November 1980 and November 1981. This can be compared to dumping 32 lorry loads (at $3m^3$ per load) of sand into the estuary each day during that period.

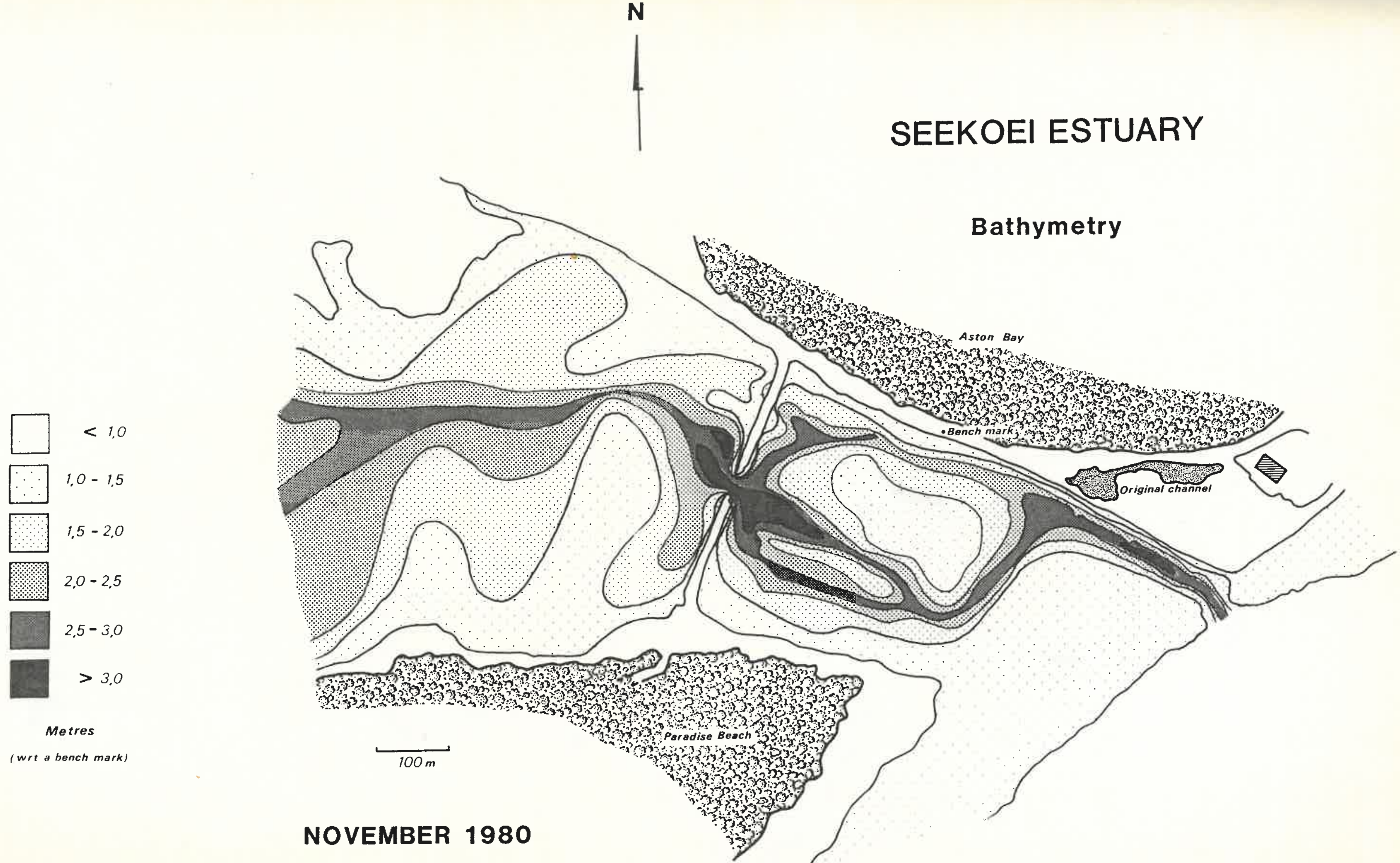
6.3 Sediment analysis

No significant difference is observed between the sediment grain size distribution of 1980 and 1981. Most of the sediment samples analysed have a mean grain size between 0,15mm and 0,25mm. Sediment distribution at the surface and at a depth of 0,5m below the sediment surface is also very uniform.

Mud distribution decreases from the tidal head of the estuary to its inlet. In places mud also increases from the subtidal zone to the supratidal regions. A decrease in current velocities, both towards the tidal head and the banks, explains these phenomenona. Fine-grained particles settle more rapidly from suspension in quiet water than in turbulent water.

SEEKOEI ESTUARY

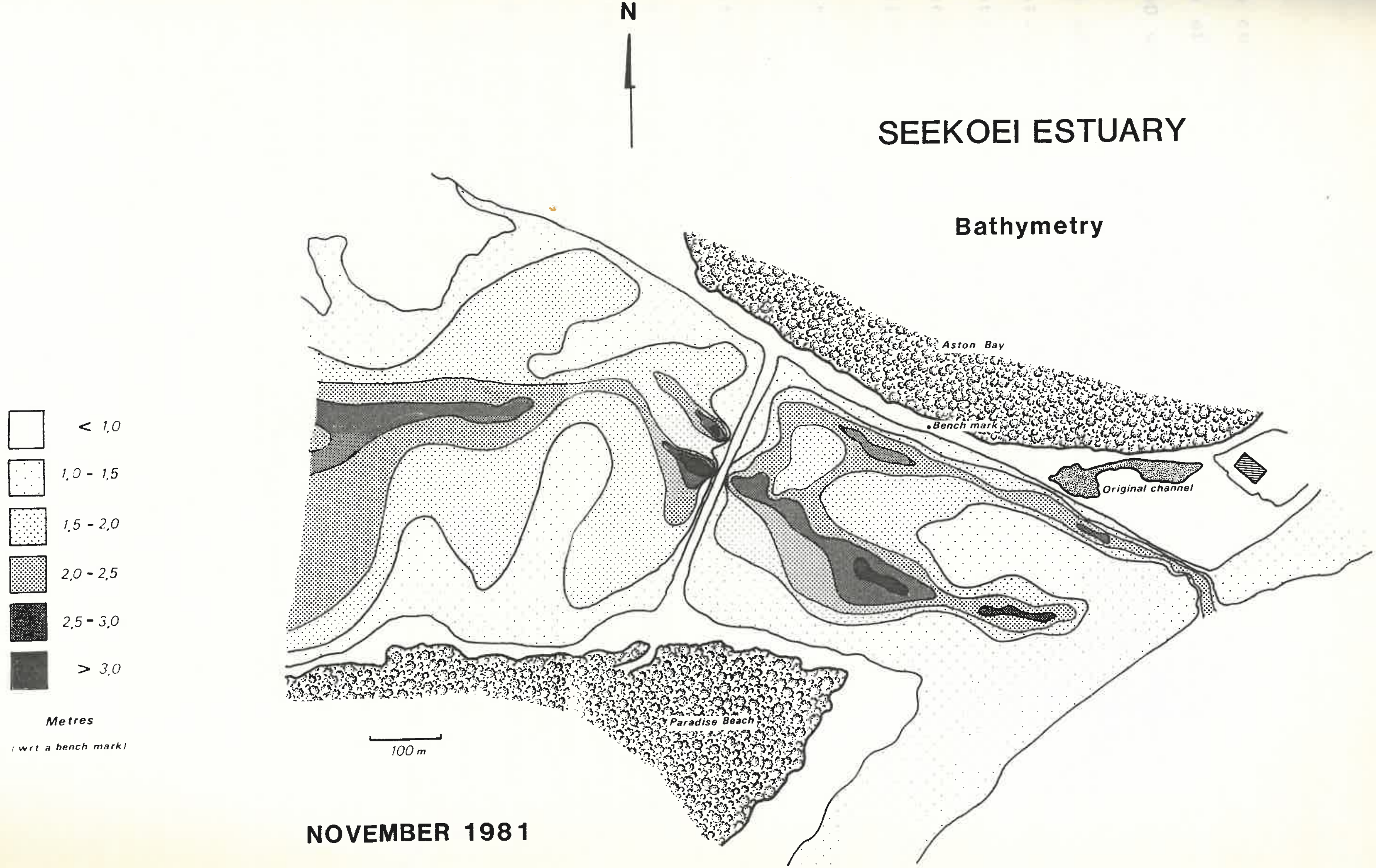
Bathymetry



NOVEMBER 1980

SEEKOEI ESTUARY

Bathymetry



NOVEMBER 1981

The samples collected in 1981 had a slightly higher mud content than the samples of 1980. These differences may be attributed to the flood of July 1980 when the estuary was flushed.

The amounts of organic carbon and $CaCO_3$ present in 1980 and 1981 are very similar. The average of all the different organic carbon percentages obtained in 1980 is 2,03% and for 1981 it is 2,20%. The average percentages of $CaCO_3$ are also very alike, i.e. 35,84% (1980) and 37,22% (1981).

Detailed results appear in APPENDIX 1.

6.4 Salinity

The salinity of estuarine water gradually decreases from the inlet to the tidal head. The causeway is clearly interfering with this natural phenomenon. Grindley (1976) found the salinity on the seaward side of the causeway to be 27 ppt (seawater is 35 ppt) and on the landward side only 7 ppt. Water samples collected just up-estuary from the causeway in 1981 had a markedly lower salinity (14 ppt) compared to the water in the lower estuary (26 ppt). In 1982 the sampling was repeated at the same localities and the water in the upper estuary had a salinity of 10 ppt whereas the salinity of the lower estuary water was 19 ppt.

7. DISCUSSION

In an estuary the different environmental factors combine and interact as a highly dynamic equilibrium. Should any of these factors be changed, an overall environmental change will occur. This has been amply demonstrated in the case of the Seekoei Estuary.

Siting of the swimming pool complex in the original inlet was most ill-considered. This complex was built without proper and thorough investigation into all the possible implications it may have on the estuary. By shifting the inlet artificially to the west, the desirable and once stable tidal lagoon was lost.

Constructions subsequently built to re-establish the original water volume may appear at first to be successful, but they can have a negative influence. If the causeway remains in its present form continued and non-reversable deterioration of the estuary can be expected as a result of disrupted tidal influence. The maintenance of a natural and normal tidal exchange throughout the whole system is essential for the survival of the estuary.

The causeway introduced a severe disturbance into the estuarine system. It not only separates the estuary into two unlike areas, but effectively blocks the tidal flow from reaching up-estuary. The lower area operates as a "normal" estuary, but with a very limited tidal prism. The original water volume available for sediment transport and redistribution was limited due to the short tidal head (4,2km) and relative small mean annual runoff (27 x 10^6 cubic metres). Now it has been reduced drastically.

A comparison of the bathymetric maps (Figs 6-1a,b) shows that excessive sediment build-up is taking place in the lower estuary and to a lesser degree in the upper "estuary". Wind deposited sand and longshore current deposited sand are gradually transported into the lower estuarine channels, whereas fluvial sediment is deposited in the upper regions. The fluvial sediment consists mostly of very fine-grained clay particles that settle out as mud. This accumulation of mud is not only undesirable, but the mud may also prove difficult to be removed by tidal processes in the future. Clay particles form a very firm bond once they have settled. Higher than normal current velocities are therefore required for their erosion. Without a properly maintained tidal flow, imbalanced sediment accumulation can be expected to continue.

With the causeway acting as a retaining barrier, and with a steady inflow from the fluvial system, the upper estuary will eventually be dominated by freshwater. The raised water level will propably cause the destruction of the normal intertidal and supratidal environments. In time the entire upper region can be expected to become a freshwater reservoir. Abrupt salinity changes, i.e. a 26:14 ratio in 1981 and a 19:10 ratio in 1982 between the lower and upper estuary, seem to confirm such a trend.

The flooded upper estuary will act as a natural sediment trap for all fluvial sediment and organic debris. In the stagnant bottom water the O_2 level can be expected to drop owing to the decay of organic matter. In the putrefaction process O_2 is drawn from the immediate surrounding as an active participant. With a lower O_2 content in the water, the chances of organisms to survive and propagate will be greatly reduced.

This will have a negative influence on the bio-ecology of the upper region. The estuary's aesthetic value will diminish if the aquatic life cycle is disrupted and the estuarine population allowed to decline. Grindley (1976) specified a number of unwanted biological changes that occurred when the upper region was flooded in 1976.

Estuarine systems depend on the occasional flood to flush accumulated sediment from the estuary. With the causeway acting as barrier to down-river flow, the scouring effect of floods will be reduced.

Should the causeway remain in place it can be expected that during fluvial floods water levels upstream of the obstruction could rise sufficiently to flood lands, roads and property. In addition most fluvial sediment will be deposited in the upper estuary.

5. CONCLUSION

In its present form the causeaway has a limited lifespan. Any sizeable fluvial flood will severely damage the causeway as happened in 1976 and 1979. The expense of repair and maintenance of the causeway will increase, and will also accumulate into a considerable overall amount.

The primary reason for deterioration of the Seekoei Estuary can be attributed to the artificial shifting of the tidal inlet. Subsequent constructions, e.g. the causeway, have compounded the environmental problems of the estuary. The ultimate solution to this problem would be to remove these constructions and to re-establish the original tidal lagoon. Such drastic changes are however not feasible as the swimming pool complex is an expensive and desirable construction. A more reasonable solution would be to breach the causeway and build an artificial sill across the present position of the inlet. The sill should not only be of durable construction, but the same height as mean sea level to retain water in the estuary at low tide. If the need for a direct link between the two towns is valid, a properly constructed bridge should be built, allowing for both unrestricted tidal flow and floods, as well as safe vehicular and pedestrian traffic.

9. ACKNOWLEDGEMENTS

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11. APPENDIX 1

A complete list of all the sediment parameters which were obtained in November 1980 and November 1981 are listed in this section. The sample positions are marked on figs 5-2a,b. The positions of the sample stations can be found from the coded station numbers listed below. For example sample number SE 7:2T originates from the Seekoei ("SE") and was collected on line 7. It was taken from the sediment surface ("T" indicates TOP) at position 2 on line 7. This sampling spot is indicated as a dot (Figs 5-2a,b) and is the second from the LEFT looking up-estuary. Samples collected 0,5m below the sediment surface are indicated by a "B" (BOTTOM).

All grain sizes listed below are in PHI-units and not in mm.

(PHI = $-\log_2$ [grain size in mm/1mm])

The parameters listed below are as follows:

VCS - Very coarse sand (grain diameters between 1mm and 2mm)
CS - Coarse sand (grain diameters between 0,5mm and 1mm)
MS - Medium sand (grain diameters between 0,25mm and 0,5mm)
FS - Fine sand (grain diameters between 0,125mm and 0,25mm)
VFS - Very fine sand (grain diameters between 0,063mm and 0,125mm)
Mud - Silt and clay (grain diameters less than 0,063mm)

Median - The distribution median in PHI-units (Md = P50) +
Mean - The mean grain size in PHI-units (M = [P16 + P84]/2)
Sorting - The grain sorting in PHI-units (S = [P84 - P16]/2)
Skewness - The distribution skewness in PHI-units (Sk = [M-Md]/S)
Kurtosis - The distribution kurtosis in PHI-units (K = [{(P95 - P5)/2} - S]/S)

% $CaCO_3$ - The percentage (by mass) calcium carbonate in the sediment
% Org C - The percentage (by mass) of peroxide digested organic material

+ Px = The xth percentile of the cumulative distribution.

All parameter formulas were obtained from Buller and McManus (1979).

1980

Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE 2:1T	0,00	0,98	20,00	77,65	0,59	0,78	2,37	2,27	0,35	-0,18	0,65	36,4	1,7
SE 2:1B	0,57	1.34	27.15	69,98	0,19	0,76	2,29	2,15	0,63	-0,63	0,44	37,6	2,1
SE 2:2T	0,00	0,92	6,59	89,74	2,38	0,37	2,47	2,47	0,38	0,00	0,79	50,9	1,5
SE 2:2B	0,00	0,92	17,76	80,09	0,46	0,77	2,39	2,32	0,48	-0,13	0,78	39,8	1,3
SE 4:1T	0,15	0,46	18,59	77,88	1,08	1,84	2,38	2,31	0,50	-0,14	0,72	38,7	1,6
SE 4:1B	0,00	0,51	13,55	78,77	2,30	4,86	2,43	2,43	0,41	0,00	1,02	36,4	1,2
SE 4:2T	0,47	1,58	40,38	55,21	0,32	2,05	2,12	2,03	0,69	-0,13	0,33	34,9	1,9
SE 4:2B	0,00	0,58	27,43	69,07	1,17	1,75	2,31	2,17	0,62	-0,22	0,44	42,1	5,1
SE 4:3T	0,00	0,20	10,87	86,76	1,38	0,79	2,44	2,44	0,39	0,00	0,96	45,5	1,6
SE 4:3B	0,20	0,40	21,67	75,15	0,80	1,79	2,36	2,25	0,55	-0,19	0,58	37,9	1,2
SE 4:4T	0,32	1,12	36,38	59,62	0,64	1,92	2,19	2,07	0,68	-0,17	0,35	35,6	2,0
SE 4:4B	0,17	0,52	26,31	67,60	1,05	4,36	2,31	2,17	0,62	-0,22	0,45	37,4	1,5
SE 4:5T	0,17	0,34	16,52	75,56	1,89	5,51	2,40	2,35	0,47	-0,10	0,81	39,5	0,7
SE 4:5B	0,00	0,33	18,42	76,64	1,48	3,12	2,39	2,32	0,50	-0,13	0,72	37,2	1,3

Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE9:1T	0,14	0,58	14,99	67,72	2,74	13,83	2,40	2,35	0,48	-0,10	0,80	35,4	2,3
SE9:1B	0,36	0,72	17,59	70,20	2,87	8,26	2,39	2,30	0,53	-0,16	0,68	31,5	1,8
SE9:2T	0,58	1,35	32,95	58,77	5,59	0,77	2,25	2,12	0,70	-0,18	0,44	39,1	1,4
SE9:2B	1,31	1,31	17,18	68,09	5,07	7,04	2,39	2,28	0,57	-0,19	0,72	41,4	1,5
SE9:3T	6,39	3,53	36,13	49,75	1,18	3,03	2,05	1,93	0,78	-0,15	1,03	33,5	1,1
SE9:3B	0,40	1,19	11,86	50,59	5,93	30,04	2,43	2,35	0,54	-0,13	1,07	34,5	7,7
SE9:4T	0,17	0,68	20,95	72,13	2,03	4,05	2,36	2,25	0,56	-0,19	0,58	3[illegible],7	2,5
SE9:4B	0,19	0,75	15,82	68,17	3,95	11,11	2,41	2,34	0,50	-0,12	0,75	34,6	1,6
SE9:5T	0,42	1,53	20,80	69,76	3,19	4,30	2,36	2,23	0,59	-0,21	0,56	26,0	2,3
SE9:5B	0,23	0,93	19,44	62,50	5,09	11,81	2,38	2,26	0,59	-0,19	0,65	28,8	2,6
SE9:6T	0,48	1,12	23,44	65,07	2,39	7,50	2,33	2,19	0,62	-0,22	0,47	24,7	1,5
SE9:6B	0,00	0,30	16,05	77,41	2,38	3,86	2,41	2,39	0,45	-0,10	0,39	17,7	1,7
SE4:1T	0,89	0,89	6,70	16,52	12,05	62,95	2,61	2,56	0,94	0,00	0,50	0	5,4
SE4:1B	SOLID SUBSTRATE	------	------	------	------	------	------	------	------	------	------		

Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE14:2T	2,29	3,15	18,91	45,85	8,88	20,92	2,33	2,15	0,77	-0,24	0,97	-	-
SE14:2B	28,15	3,89	17,85	30,89	5,49	13,73	1,62	1,11	1,62	-0,32	0,25	6,6	1,3
SE14:3T	13,83	5,83	23,30	29,37	4,61	23,06	1,81	1,31	1,42	-0,35	0,37	7,3	3,1
SE14:3B	SOLID SUBSTRATE		-----	-----	-----	-----	-----	-----	-----	-----	-----		
SE14:4T	0,53	2,50	24,95	55,47	2,69	13,82	2,27	2,11	0,69	-0,23	0,40	tr	1,2
SE14:4B	2,38	3,09	21,62	60,81	2,38	9,74	2,30	2,11	0,69	-0,27	0,64	tr	1,1
SE16:1T	1,61	2,26	14,52	42,26	6,77	32,58	2,36	2,19	0,71	-0,24	0,91	tr	0,8
SE16:1B	SOLID SUBSTRATE		-----	-----	-----	-----	-----	-----	-----	-----	-----		
SE16:2T	2,66	2,66	14,62	46,51	7,31	26,25	2,36	2,17	0,73	-0,26	1,13	10,6	2,1
SE16:2B	0,64	1,28	12,14	55,59	6,71	23,64	2,43	2,37	0,53	-0,11	1,16	19,1	1,9
SE16:3T	0,56	1,13	9,30	40,00	5,92	43,10	2,44	2,36	0,56	-0,14	1,13	9,2	1,7
SE16:3B	1,00	1,50	13,47	56,61	5,99	21,45	2,41	2,32	0,57	-0,17	0,97	9,5	1,5
SE16:4T	8,86	1,66	10,80	32,13	7,76	38,78	2,29	1,75	1,19	-0,45	0,79	tr	3,1
SE16:4B	71,79	2,79	5,73	8,94	1,68	9,08	-0,37	0,26	1,09	0,59	0,71	7,6	1,2

1981

Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE 1:1T	0	0	38,53	60,17	0,43	0,87	2,18	2,08	0,67	-0,16	0,35	34,1	2,1
SE 1:1B	0	0	40,33	58,85	0	0,82	2,16	2,06	0,67	-0,14	0,34	45,2	0,4
SE 1:2T	0,4	1,99	46,22	50,60	0	0,8	2,02	1,99	0,70	0	0,32	35,4	1,3
SE 1:2B	SOLID SUBSTRATE												
SE 1:3T	0	0,87	37,55	60,26	0	1,31	2,18	2,07	0,57	-0,17	0,35	47,8	2,0
SE 1:3B	SOLID SUBSTRATE												
SE 2:1T	0	0	15,44	82,35	0,74	1,47	2,41	2,41	0,41	0	1,0	42,6	2,0
SE 2:1B	0	0,44	25,44	71,49	0,44	2,19	2,32	2,19	0,59	-0,22	0,48	55,3	0,0
SE 2:2T	0	0,45	15,38	82,35	1,36	0,45	2,41	2,41	0,41	0	1,02	47,6	1,9
SE 2:2B	0	1,99	20,60	75,75	0,33	1,33	2,35	2,23	0,56	-0,21	0,6	50,0	2,2
SE 2:3T	2,6	11,98	47,40	35,95	0,52	1,56	1,73	1,80	0,78	0,1	0,73	69,8	2,9
SE 2:3B	SOLID SUBSTRATE												
SE 3:1T	0	0	10,67	87,56	0,44	1,33	2,44	2,44	0,38	0	0,94	39,1	1,4
SE 3:1B	0	0	14,41	83,84	0,87	0,87	2,42	2,42	0,40	0	1,0	47,2	1,5

Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE 3:2T	0	0,35	8,74	77,97	3,15	9,79	2,46	2,46	0,39	0	0,91	42,4	1,9
SE 3:2B	0,32	1,58	50,79	46,06	0,32	0,95	1,94	1,97	0,69	0	0,33	34,3	1,4
SE 3:3T	0	0	8,39	89,35	1,29	0,97	2,46	2,46	0,38	0	0,92	28,2	1,9
SE 3:3B	0	0	5,31	91,15	2,36	1,18	2,46	2,46	0,37	0	0,41	39,8	1,7
SE 3:4T	0	0	2,66	94,68	0,38	2,28	2,49	2,49	0,35	0	0,32	48,0	2,7
SE 3:4B	0	0,43	13,68	83,33	2,14	0,43	2,43	2,43	0,41	0	1,01	40,4	1,9
SE 3:5T	0	0,38	17,31	78,85	1,15	2,31	2,4	2,35	0,47	-0,1	0,81	61,4	1,3
SE 3:5B	0,33	0,67	14,33	82,00	1,0	1,67	2,41	2,41	0,41	0	1,06	40,0	1,8
SE 3:6T	0	0,6	19,28	69,88	4,82	5,42	2,39	2,3	0,55	-0,16	0,64	43,5	4,6
SE 3:6B	0	0	14,23	83,90	0,37	1,5	2,42	2,42	0,40	0	1,0	82,1	2,3
SE 3:7T	59,12	0,19	6,53	29,17	1,92	3,07	-0,18	0,90	1,64	0,66	0,17	62,8	2,8
SE 3:7B	SOLID	SUBSTRATE											
SE 4:1T	0	0	6,9	90,80	1,53	0,77	2,47	2,47	0,37	0	0,67	49,2	1,5
SE 4:1B	0	0	19,34	79,20	0,36	1,09	2,38	2,31	0,49	-0,14	0,71	49,8	2,0

Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE 4:2T	0,34	1,01	23,91	59,26	0,34	15,15	2,29	2,14	0,63	-0,23	0,43	33,7	2,2
SE 4:2B	0,66	0,33	33,11	64,57	0,33	0,99	2,24	2,1	0,66	-0,2	0,38	37,8	1,5
SE 4:3T	0,33	1,95	28,66	56,68	0,98	11,4	2,24	2,09	0,68	-0,21	0,38	37,1	2,4
SE 4:3B	0	0	26,98	71,75	0,32	0,95	2,31	2,19	0,6	-0,22	0,46	29,8	2,2
SE 4:4T	0	0,34	26,9	70,0	1,38	1,39	2,32	2,18	0,61	-0,22	0,46	37,6	2,4
SE 4:4B	0	0	10,55	88,0	0,36	1,09	2,44	2,44	0,38	0	0,94	37,8	1,3
SE 4:5T	0	0,35	15,19	80,92	3,18	0,35	2,42	2,42	0,42	0	1,0	35,5	2,3
SE 4:5B	0	0	12,12	86,2	0,34	1,35	2,43	2,43	0,39	0	0,98	39,8	1,4
SE 4:6T	0,56	1,67	34,44	55,56	3,89	3,89	2,21	2,09	0,71	-0,17	0,35	39,5	2,1
SE 4:6B	0,26	0,52	33,94	63,73	0,26	1,3	2,23	2,1	0,66	-0,2	0,37	37,5	1,2
SE 4:7T	4,05	0,37	6,64	67,16	8,49	13,28	2,48	2,48	0,44	0	2,12	49,2	1,6
SE 4:7B	SOLID SUBSTRATE												
SE 5:1T	0	0,65	17,32	78,43	0,65	2,94	2,39	2,33	0,48	-0,12	0,79	36,5	1,6
SE 5:1B	0	0,28	17,61	76,7	0,85	4,55	2,39	2,33	0,48	-0,12	0,76	33,7	1,3

Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE 5:2T	0,82	0,54	21,53	62,4	1,36	13,35	2,33	2,19	0,61	-0,23	0,49	32,7	0,6
SE 5:2B	0,67	0,33	19,06	68,56	2,01	9,36	2,37	2,26	0,55	-0,19	0,6	30,5	0,9
SE 5:3T	0	0,31	28,44	65,14	0,31	5,81	2,28	2,15	0,63	-0,22	0,42	29,5	0,5
SE 5:3B	0	0,26	20,31	71,72	0,77	6,94	2,36	2,26	0,54	-0,19	0,6	32,6	12,5
SE 5:4T	0	0,33	21,5	69,38	0,98	7,83	2,35	2,24	0,57	-0,2	0,55	35,9	1,2
SE 5:4B	0	0,28	18,77	72,83	1,96	6,16	2,38	2,30	0,52	-0,15	0,67	38,3	1,0
SE 5:5T	0	0,3	18,21	71,64	2,09	7,76	2,39	2,31	0,51	-0,15	0,68	36,8	1,0
SE 5:5B	0,29	0,58	22,38	71,51	0,87	4,36	2,34	2,22	0,58	-0,21	0,53	35,6	0,9
SE 5:6T	0	0	16,94	80,17	0,41	2,48	2,4	2,37	0,44	-0,1	0,86	38,8	1,5
SE 5:6B	0,29	0,58	21,35	75,15	0,88	1,75	2,36	2,25	0,55	-0,2	0,59	37,2	0,4
SE 5:7T	0	0,3	22,62	72,32	1,49	3,27	2,35	2,24	0,57	-0,2	0,54	38,9	0,9
SE 5:7B	0,3	0,3	23,56	70,69	1,21	3,93	2,34	2,21	0,59	-0,21	0,51	38,0	0,9
SE 5:8T	0,58	2,34	44,15	48,83	0	4,09	2,02	1,98	0,7	0	0,32	28,2	0,5
SE 5:8B	SOLID	SUBSTRATE											

Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE 5:9T	0,57	0,57	14,49	81,53	1,42	1,42	2,41	2,41	0,41	0	1,06	33,2	1,2
SE 5:9B	SOLID	SUBSTRATE											
SE 6:1T	0,32	0,63	17,78	61,27	2,22	17,78	2,37	2,25	0,57	-0,2	0,58	19,1	1,7
SE 6:1B	0,26	0,51	16,07	59,44	1,53	22,19	2,37	2,27	0,54	-0,18	0,62	21,2	1,0
SE 6:2T	0,51	0,51	4,06	23,35	8,12	63,45	2,57	2,66	0,62	-0,15	1,07	tr	4,8
SE 6:2B	0,35	0,7	20,21	49,48	1,74	27,53	2,3	2,16	0,64	-0,22	0,43	23,7	1,1
SE 6:3T	0,38	1,15	22,14	66,41	1,53	9,4	2,33	2,20	0,6	-0,22	0,5	27,4	1,1
SE 6:3B	0	0	13,8	71,72	2,36	12,12	2,42	2,42	0,42	0	0,98	37,5	1,2
SE 6:4T	4,91	4,91	29,47	48,42	1,75	10,53	2,11	1,95	0,79	-0,21	0,91	20,5	0,7
SE 6:4B	0	0,53	18,16	79,74	0,79	0,79	2,39	2,33	0,48	-0,12	0,76	38,0	1,0
SE 6:5T	0	0	1,28	2,56	1,28	94,87	2,5	2,5	0,86	0	0,51	tr	8,3
SE 6:5B	45,32	2,46	3,94	26,6	1,48	20,20	-0,12	0,93	1,65	0,64	0,16	10,0	1,0
SE 6:6T	0	0,31	16,72	76,78	1,86	4,33	2,4	2,36	0,46	-0,1	0,83	33,3	0,4
SE 6:6B	0,53	2,93	29,79	58,24	1,6	6,91	2,23	2,08	0,69	-0,22	0,37	38,9	1,2

Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE 6:7T	2,99	1,2	10,18	31,74	4,79	49,1	2,35	2,14	0,75	-0,28	1,4	tr	3,6
SE 6:7B	SOLID	SUBSTRATE											
SE 6:8T	1,05	1,39	20,21	53,31	4,53	19,51	2,33	2,18	0,66	-0,23	0,53	28,6	2,4
SE 6:8B	0	0,58	15,41	73,55	3,20	7,27	2,41	2,38	0,46	-0,1	0,87	38,2	1,2
SE 6:9T	0,6	1,19	21,79	66,87	1,79	7,76	2,34	2,2	0,61	-0,23	0,51	31,6	1,1
SE 6:9B	0,28	1,39	18,08	69,17	2,50	8,61	2,38	2,27	0,55	-0,19	0,63	40,8	1,0
SE 7:1T	0	0,6	18,32	69,67	2,4	9,01	2,38	2,29	0,53	-0,16	0,69	21,80	1,2
SE 7:1B	0	2,04	16,62	62,68	2,92	15,74	2,37	2,26	0,57	-0,20	0,62	20,0	0,9
SE 7:2T	0,36	0,73	16,06	63,87	2,55	16,42	2,39	2,30	0,53	-0,17	0,67	28,5	1,6
SE 7:2B	3,24	1,18	16,47	69,71	2,65	6,76	2,37	2,23	0,59	-0,23	0,65	30,8	1,2
SE 7:3T	0	0,75	20,7	73,32	0,75	4,49	2,36	2,25	0,55	-0,19	0,56	31,5	1,0
SE 7:3B	0,27	0,81	15,63	70,08	2,96	10,24	2,4	2,34	0,49	-0,12	0,78	32,6	1,0
SE 7:4T	0,31	0,62	20,19	55,59	2,48	20,81	2,33	2,2	0,62	-0,22	0,48	30,1	2,5
SE 7:4B	0	0,48	5,8	46,86	7,25	39,61	2,51	2,51	0,44	0	1,45	34,8	1,1

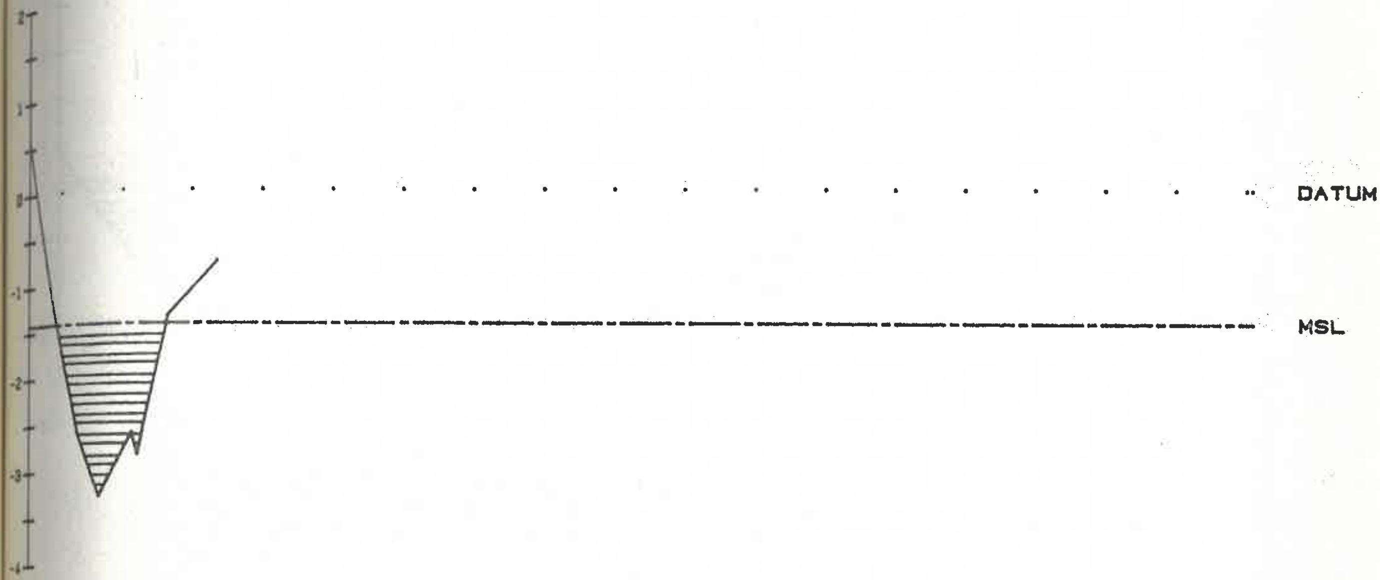
Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE 7:5T	0,32	2,54	34,6	40,95	1,59	20,0	2,06	2,01	0,72	-0,1	0,33	29,0	1,6
SE 7:5B	0,22	0,67	38,12	59,19	0,9	0,9	2,18	2,07	0,68	-0,16	0,35	31,2	2,2
SE 7:6T	0,27	0,53	29,44	63,4	1,59	4,77	2,27	2,14	0,65	-0,21	0,40	34,0	2,2
SE 7:6B	0	1,08	15,72	70,46	3,79	8,94	2,41	2,35	0,49	-0,11	0,79	42,0	1,8
SE 7:7T	0	0,52	14,99	79,33	1,03	4,13	2,41	2,4	0,42	0	1,01	34,7	1,9
SE 7:7B	0,43	0,43	20,73	69,98	2,59	5,83	2,36	2,25	0,57	-0,2	0,57	36,6	1,7
SE 7:8T	0	0,37	11,48	59,63	3,7	24,61	2,43	2,43	0,43	0	0,99	37,3	1,6
SE 7:8B	0	0,28	12,43	67,13	3,04	17,13	2,43	2,43	0,42	0	0,99	39,4	2,0
SE 8:1T	0	1,14	20,53	62,74	2,66	12,93	2,35	2,22	0,6	-0,21	0,52	16,3	1,2
SE 8:1B	0	1,08	19,06	68,35	3,24	8,27	2,38	2,27	0,56	-0,18	0,6	18,0	2,2
SE 8:2T	0	0,6	19,34	70,69	3,02	6,34	2,38	2,29	0,54	-0,17	0,62	27,1	1,9
SE 8:2B	0,36	1,09	13,45	74,55	3,65	6,91	2,42	2,42	0,43	0	1,06	28,5	1,9
SE 8:3T	0	1,08	20,79	65,23	2,15	10,75	2,35	2,22	0,59	-0,21	0,53	35,5	2,6
SE 8:3B	0,25	0,5	10,53	83,21	2,01	3,51	2,44	2,44	0,39	0	1,0	39,3	1,8

Station number	% VCS	% CS	% MS	% FS	% VFS	% Mud	Median Ø	Mean grain size Ø	Sorting Ø	Skewness Ø	Kurtosis Ø	% $CaCO_3$	% Org C
SE 8:4T	0	0,72	12,23	38,85	5,04	43,17	2,4	2,29	0,61	-0,18	0,87	26,6	4,4
SE 8:4B	2,01	2,29	21,78	58,17	3,44	12,32	2,31	2,13	0,69	-0,25	0,44	33,8	5,1

12. APPENDIX 2

Cross-sections were surveyed at convenient intervals, from the inlet to the junction of the Seekoei and Swart Rivers (Figs 5-1a,b). The survey datum was 1,419m above MSL. Some sections were extended to MSL by interpolation (broken line). All sections are viewed downstream.

SECTION 1   SEEKOEI ESTUARY   NOVEMBER 1980



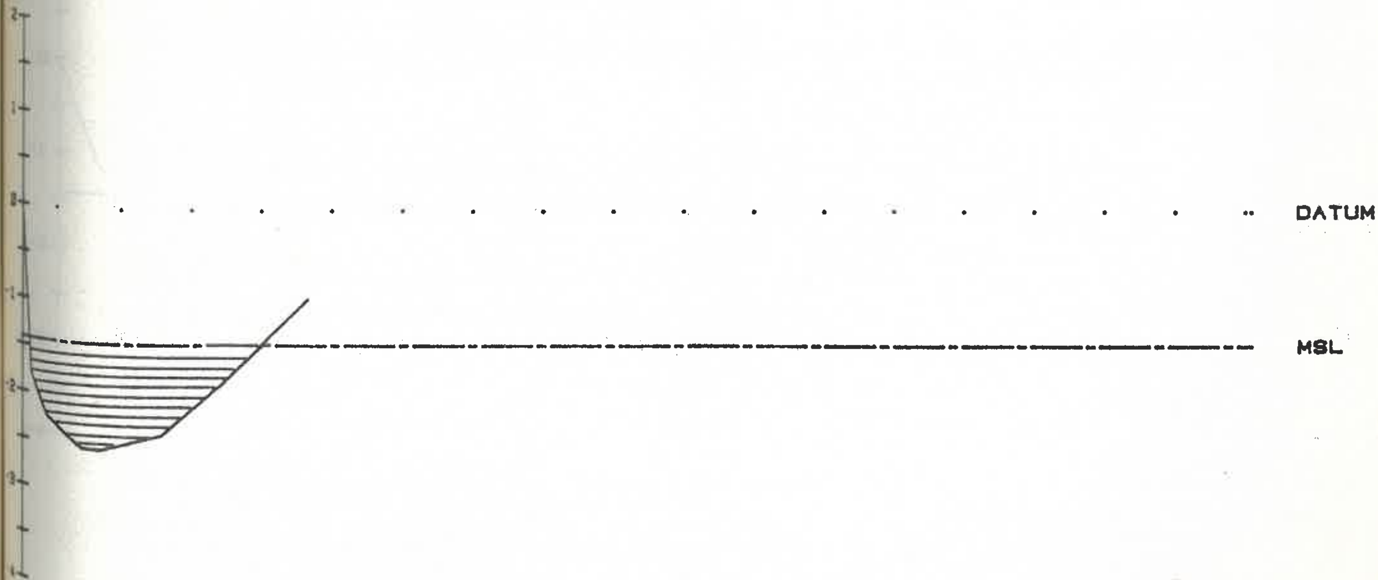
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X   SECTION VIEWED DOWNSTREAM

100M

ROSIE – UPE GEOLOGY

SECTION 2   SEEKOEI ESTUARY   NOVEMBER 1980



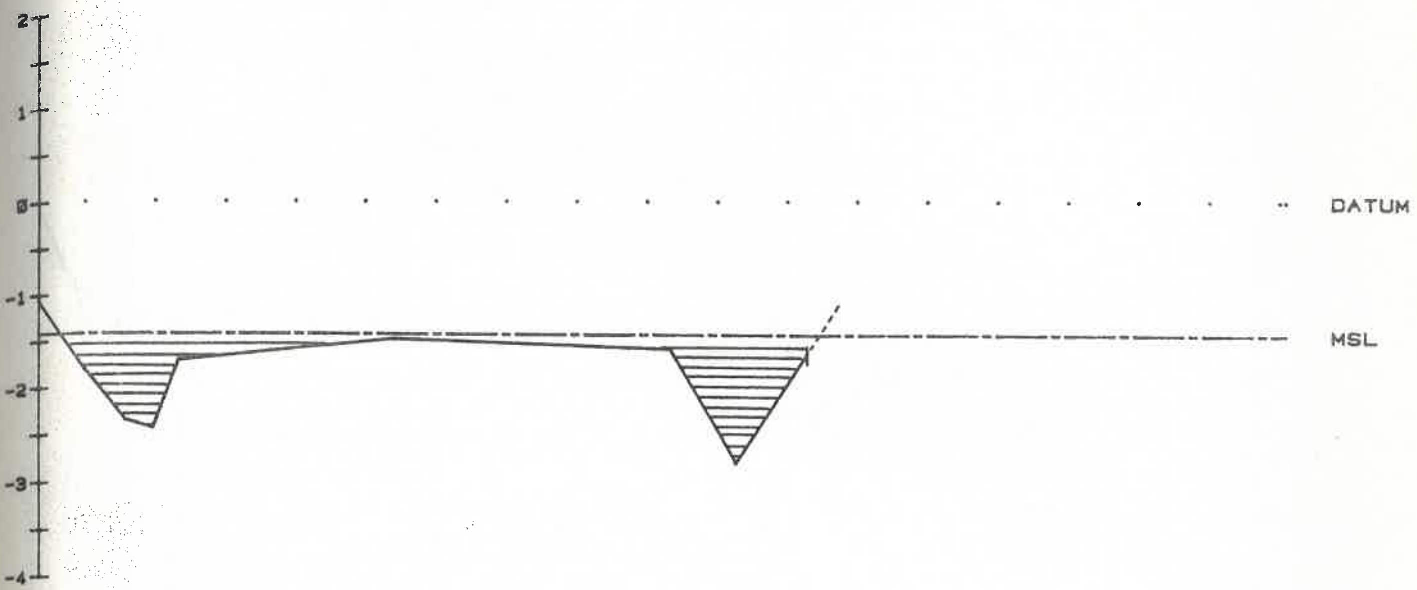
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X   SECTION VIEWED DOWNSTREAM

100M

ROSIE – UPE GEOLOGY

SECTION 3 SEEKOEI ESTUARY NOVEMBER 1980



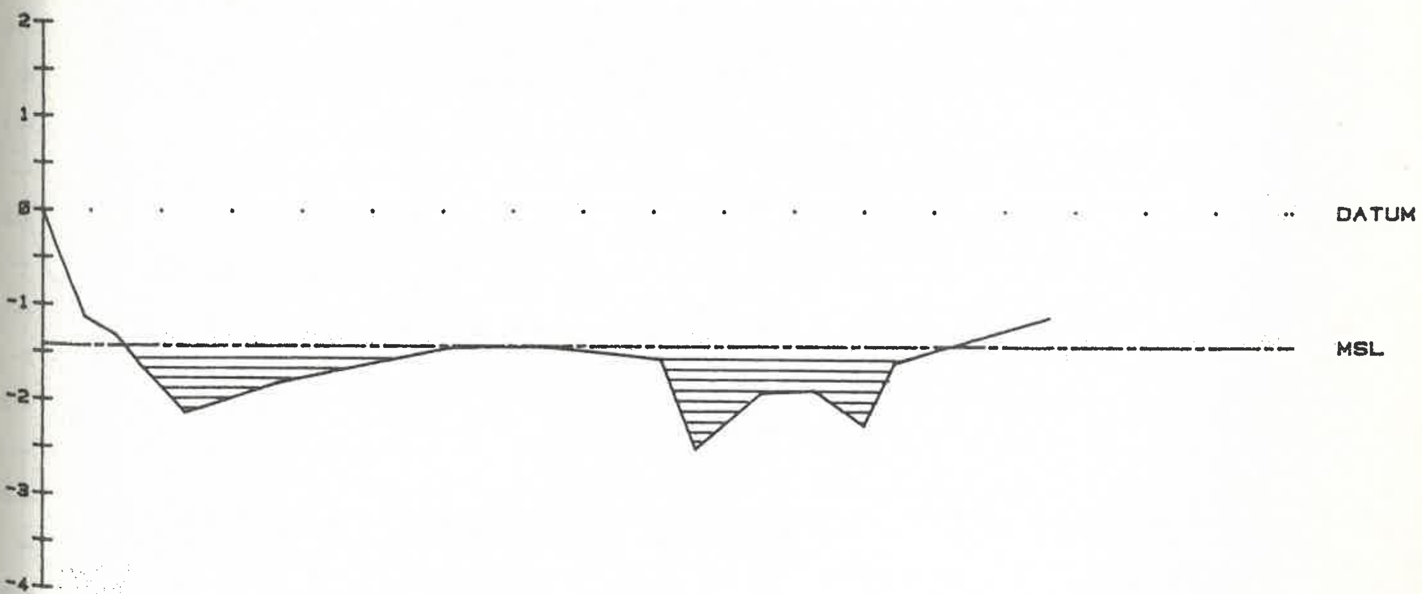
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

100M

ROSIE - UPE GEOLOGY

SECTION 4 SEEKOEI ESTUARY NOVEMBER 1980



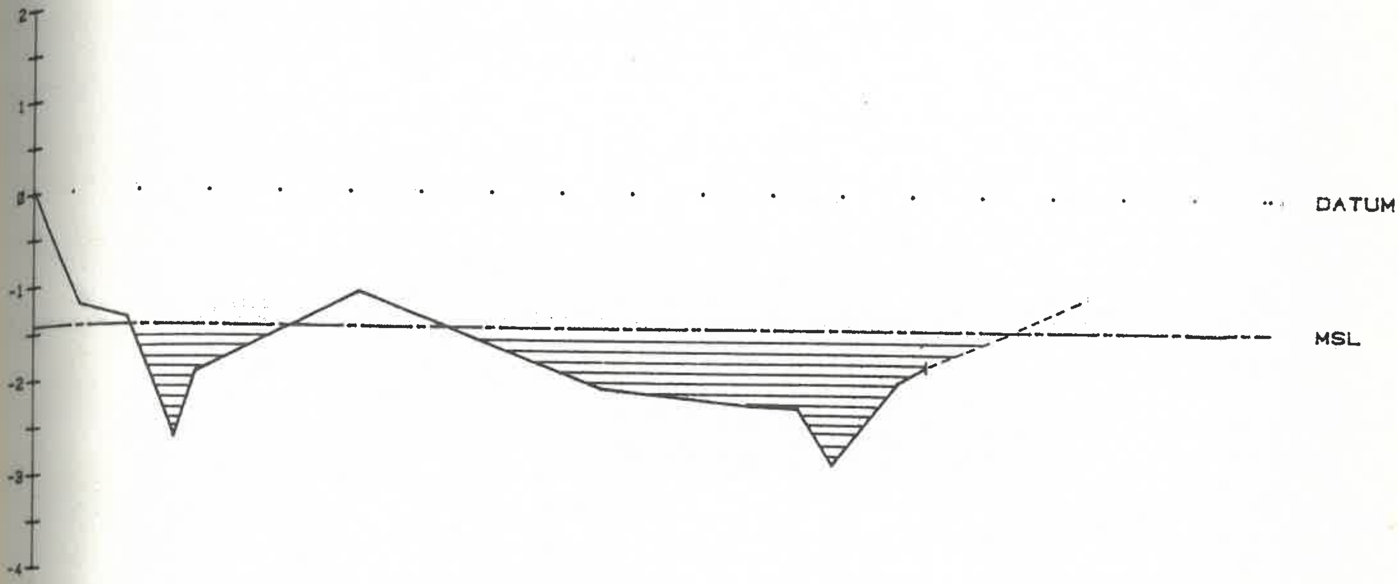
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

100M

ROSIE - UPE GEOLOGY

SECTION 5 SEEKOEI ESTUARY NOVEMBER 1980



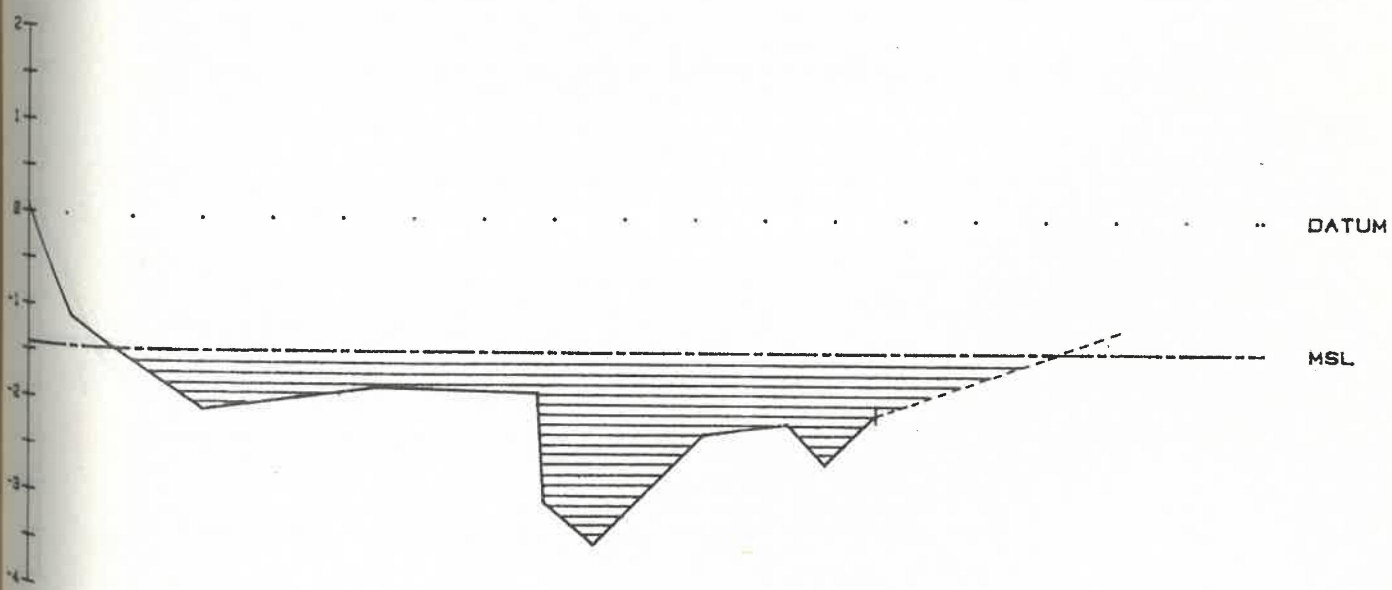
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

100M

ROSIE - UPE GEOLOGY

SECTION 6 SEEKOEI ESTUARY NOVEMBER 1980



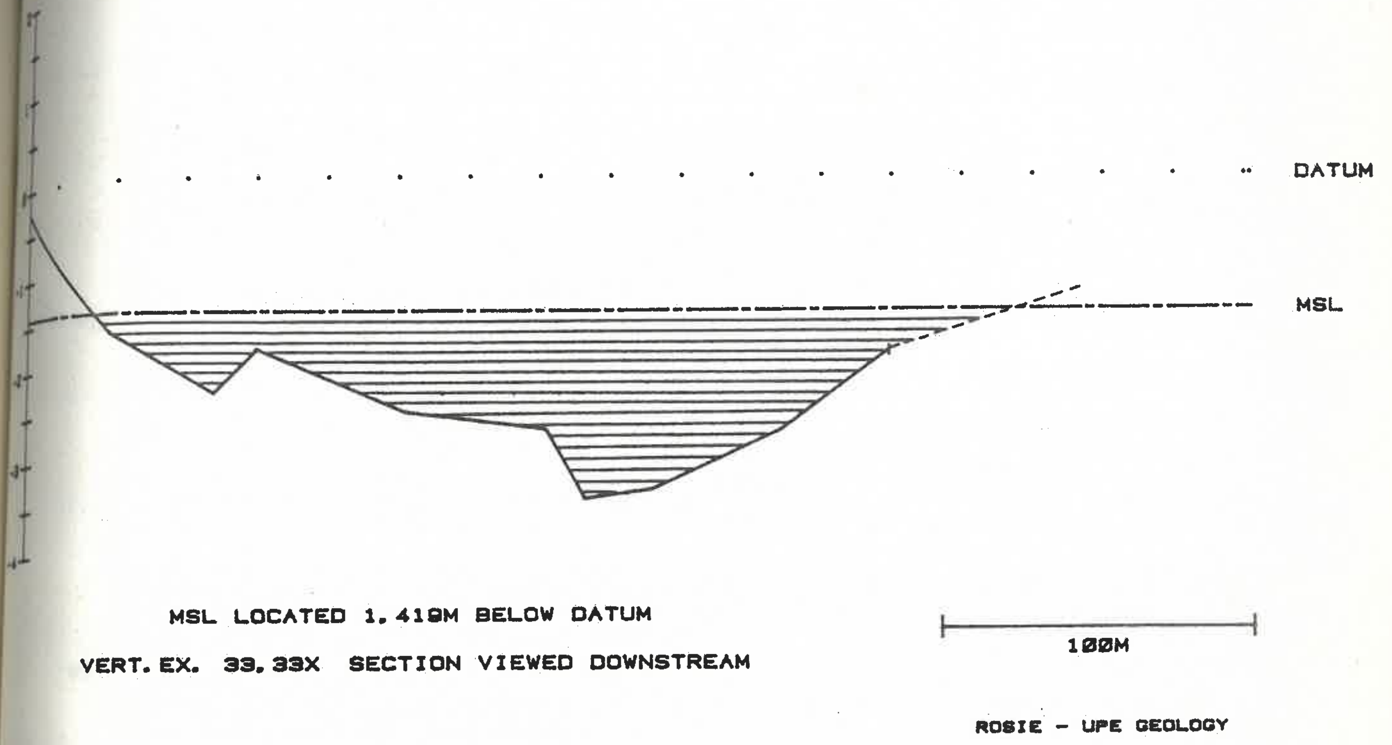
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

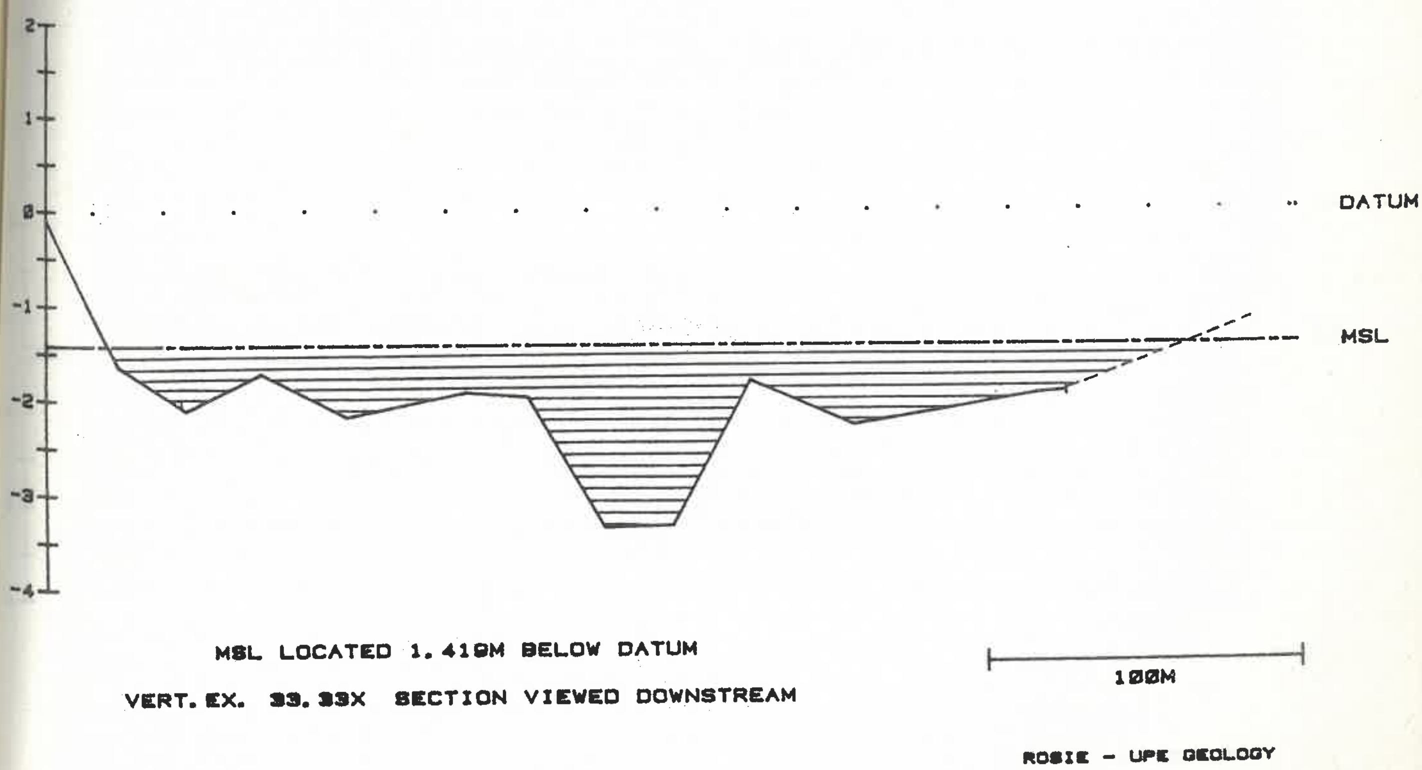
100M

ROSIE - UPE GEOLOGY

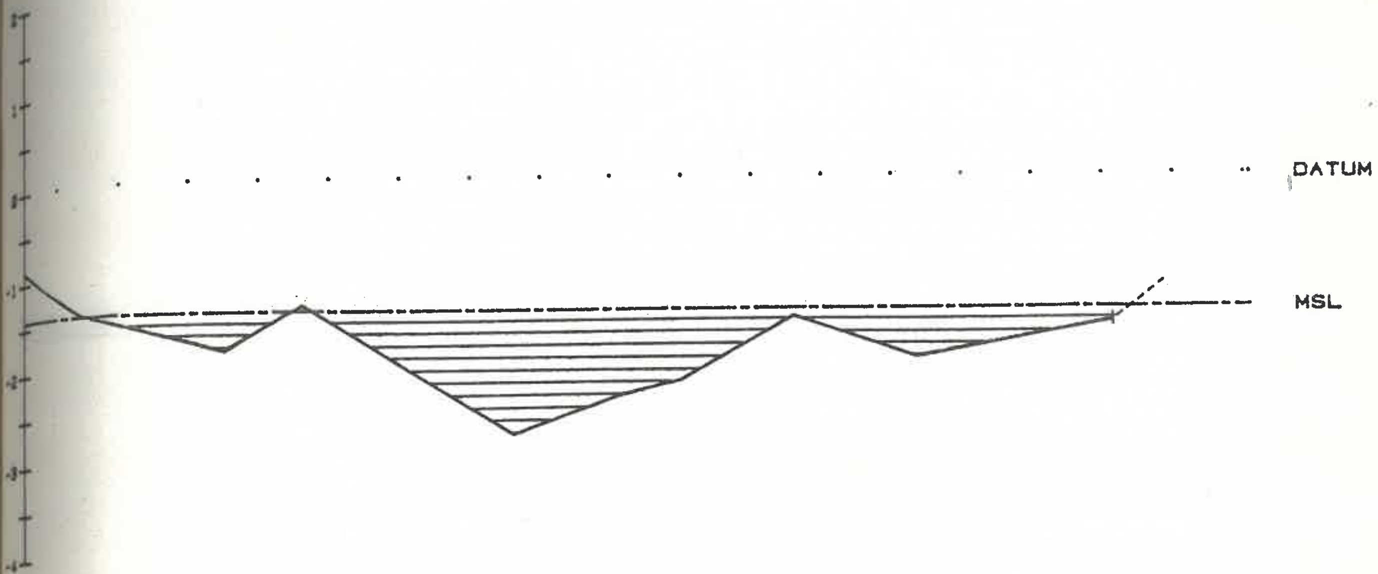
SECTION 7 SEEKOEI ESTUARY NOVEMBER 1980



SECTION 8 SEEKOEI ESTUARY NOVEMBER 1980



SECTION 9 SEEKOEI ESTUARY NOVEMBER 198Ø



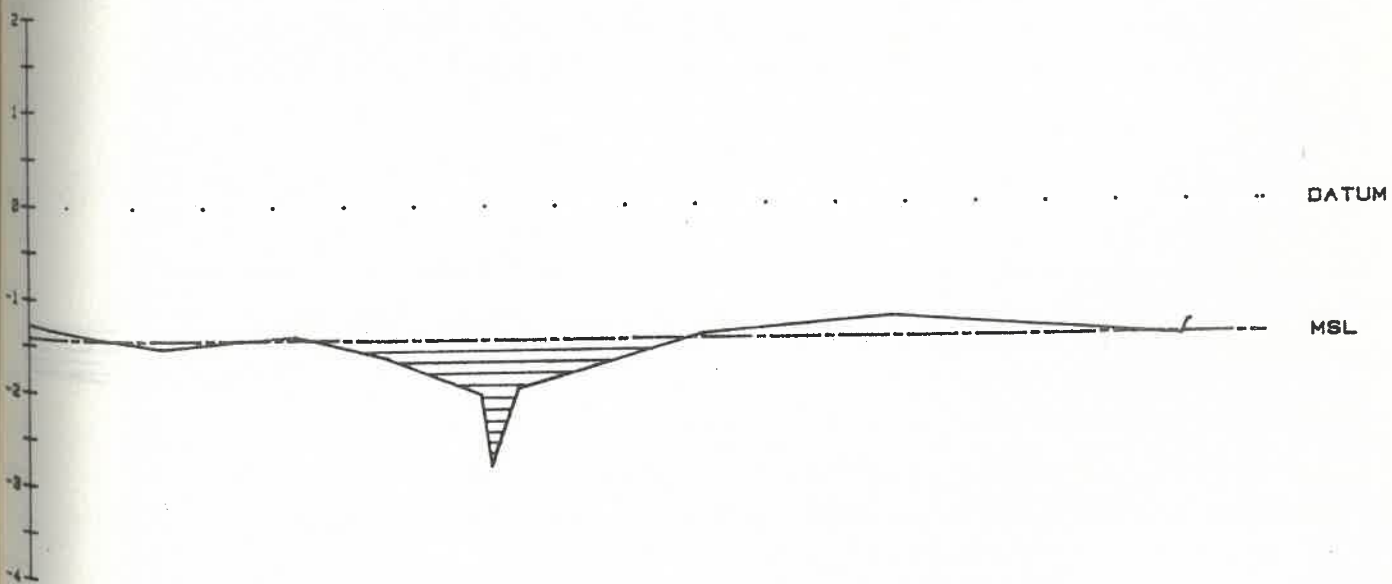
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

1ØØM

ROSIE - UPE GEOLOGY

SECTION 1Ø SEEKOEI ESTUARY NOVEMBER 198Ø



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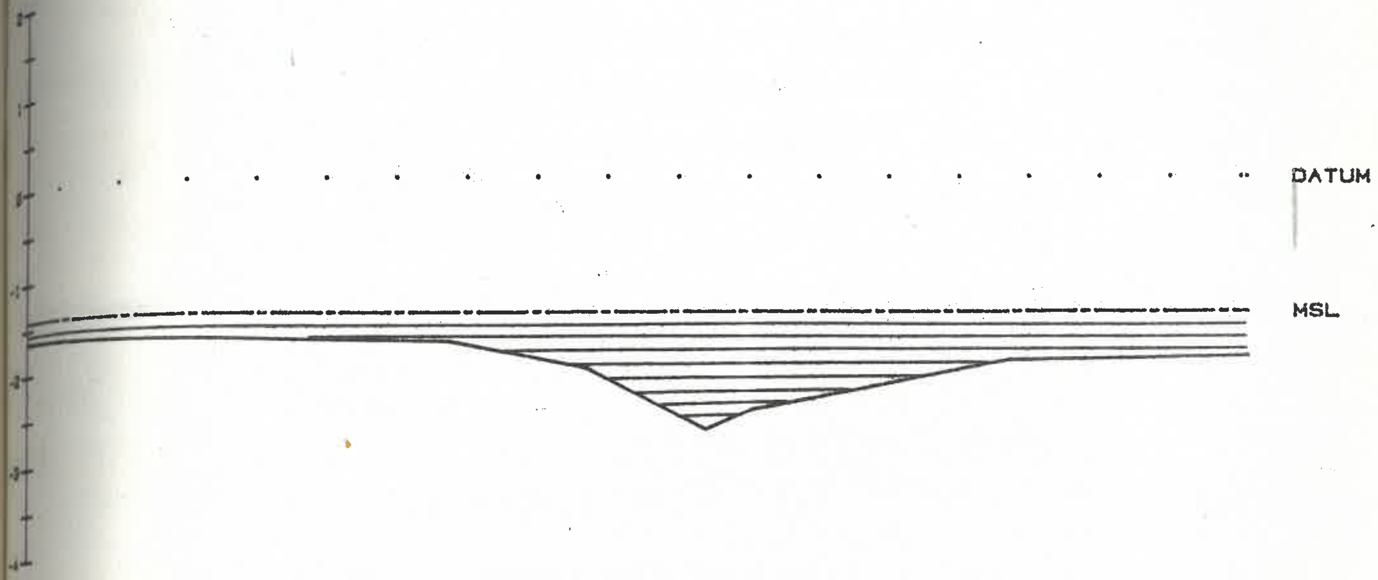
1ØØM

ROSIE - UPE GEOLOGY

SECTION 11 SEEKOEI ESTUARY NOVEMBER 1980



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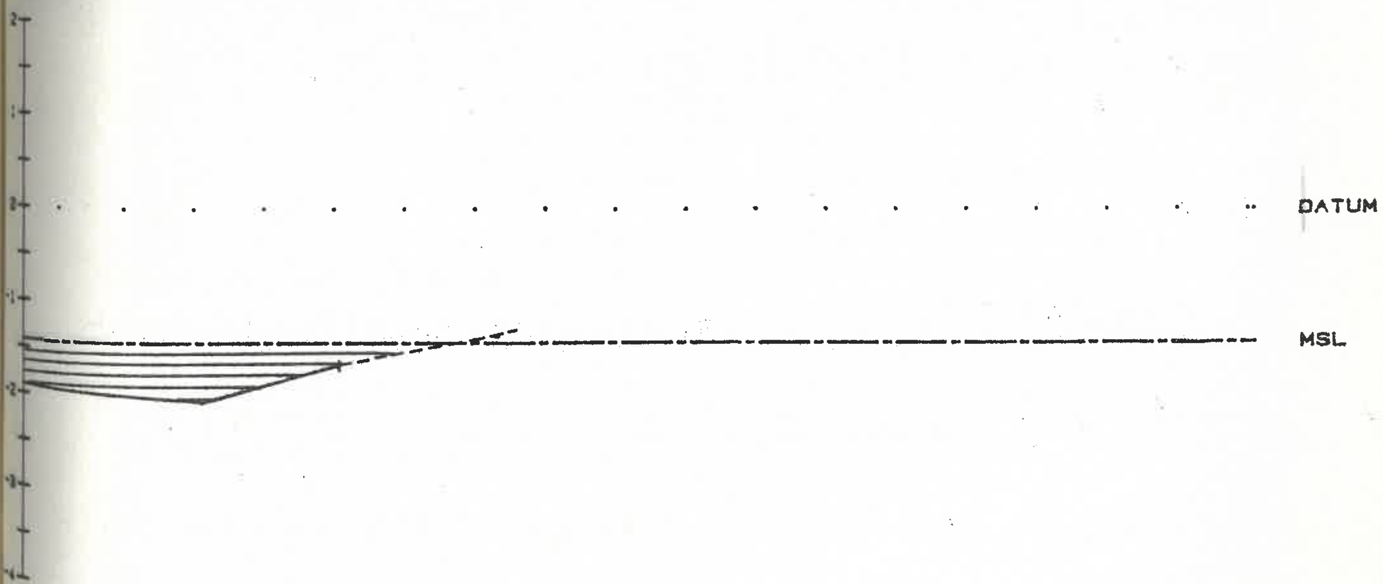
ROSIE - UPE GEOLOGY

SECTION 11 CONT'



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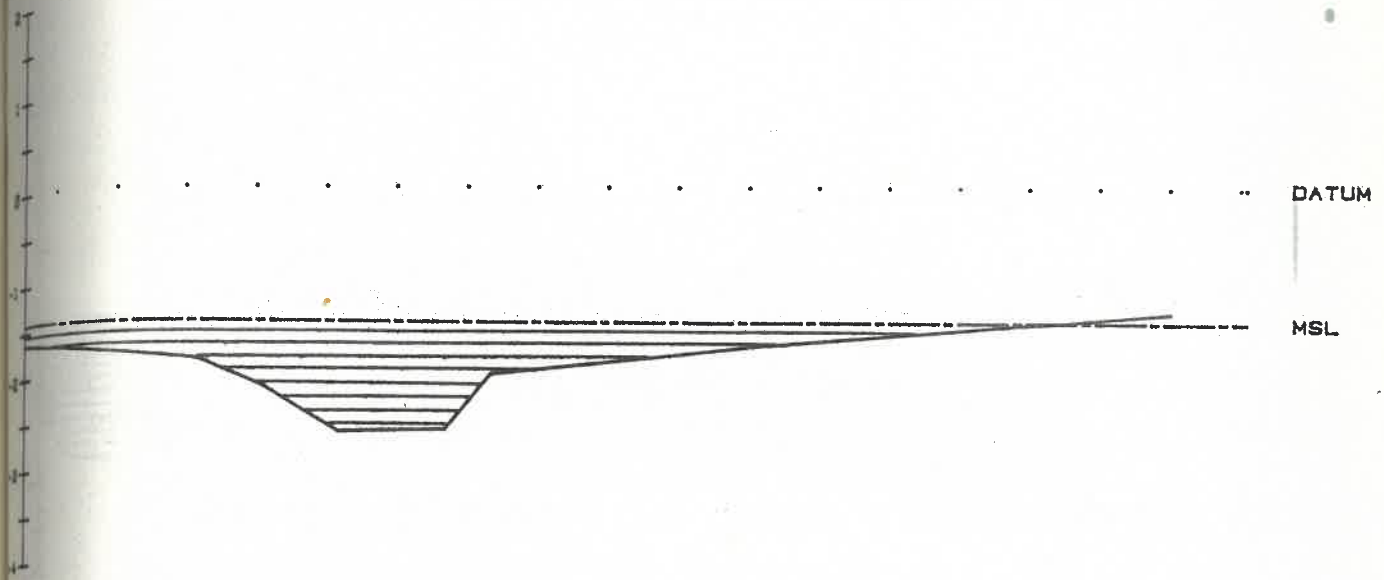
100M

ROSIE - UPE GEOLOGY

SECTION 12 SEEKOEI ESTUARY NOVEMBER 1980



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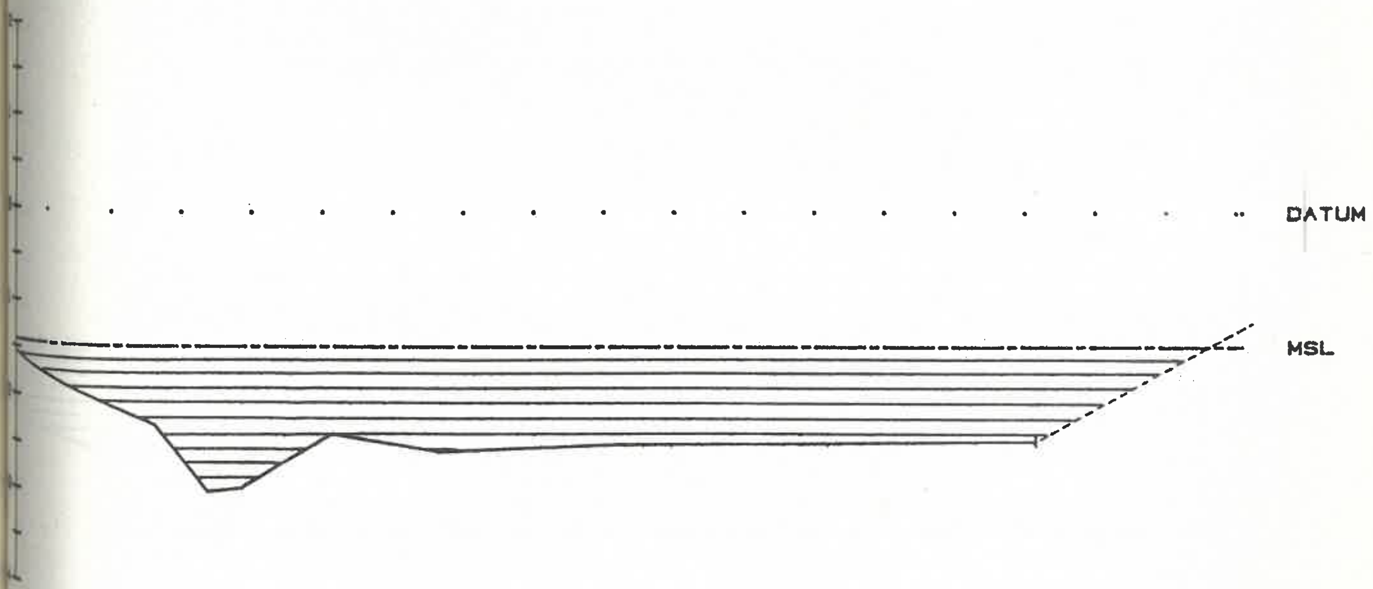
100M

ROSIE - UPE GEOLOGY

SECTION 13 SEEKOEI ESTUARY NOVEMBER 1980



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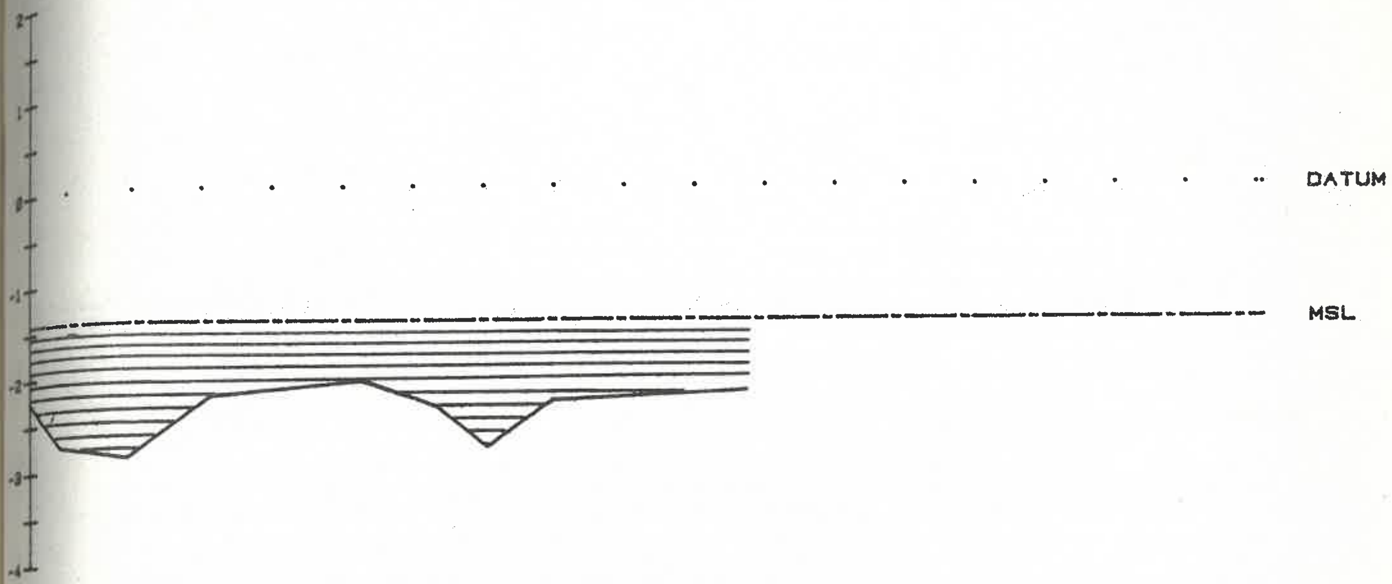
100M

ROSIE - UPE GEOLOGY

SECTION 13A SEEKOEI ESTUARY NOVEMBER 1980



MSL LOCATED 1.419M BELOW DATUM

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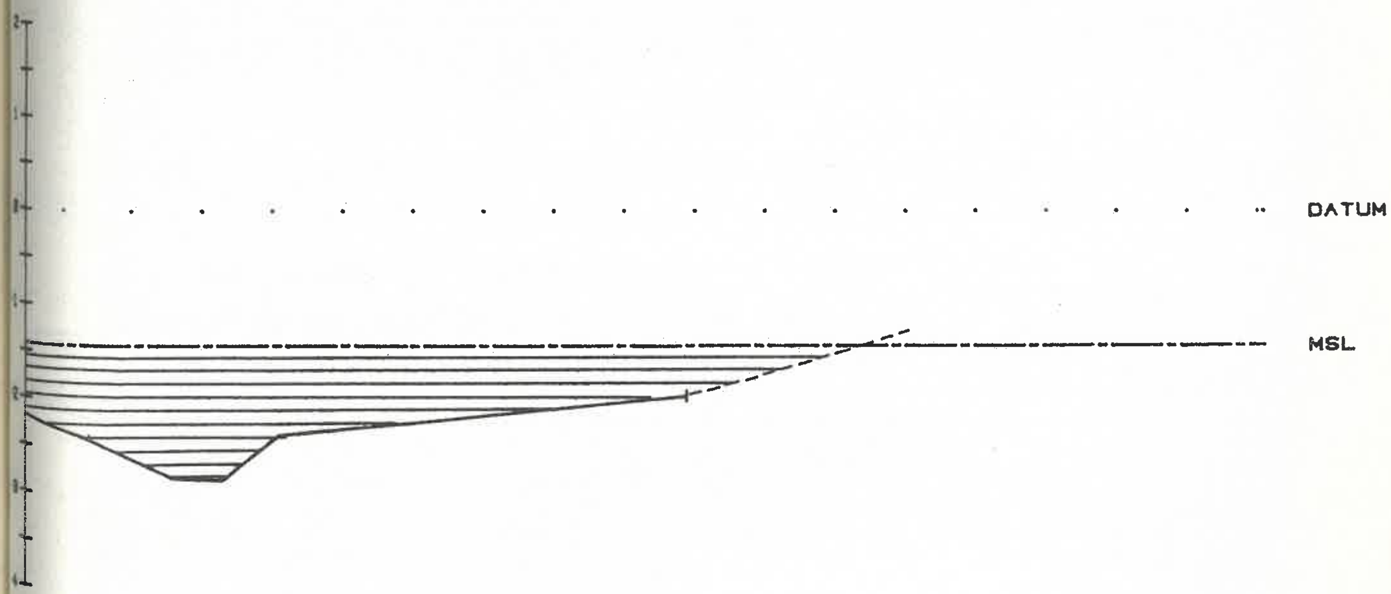
100M

ROSIE - UPE GEOLOGY

SECTION 14 SEEKOEI ESTUARY NOVEMBER 1980



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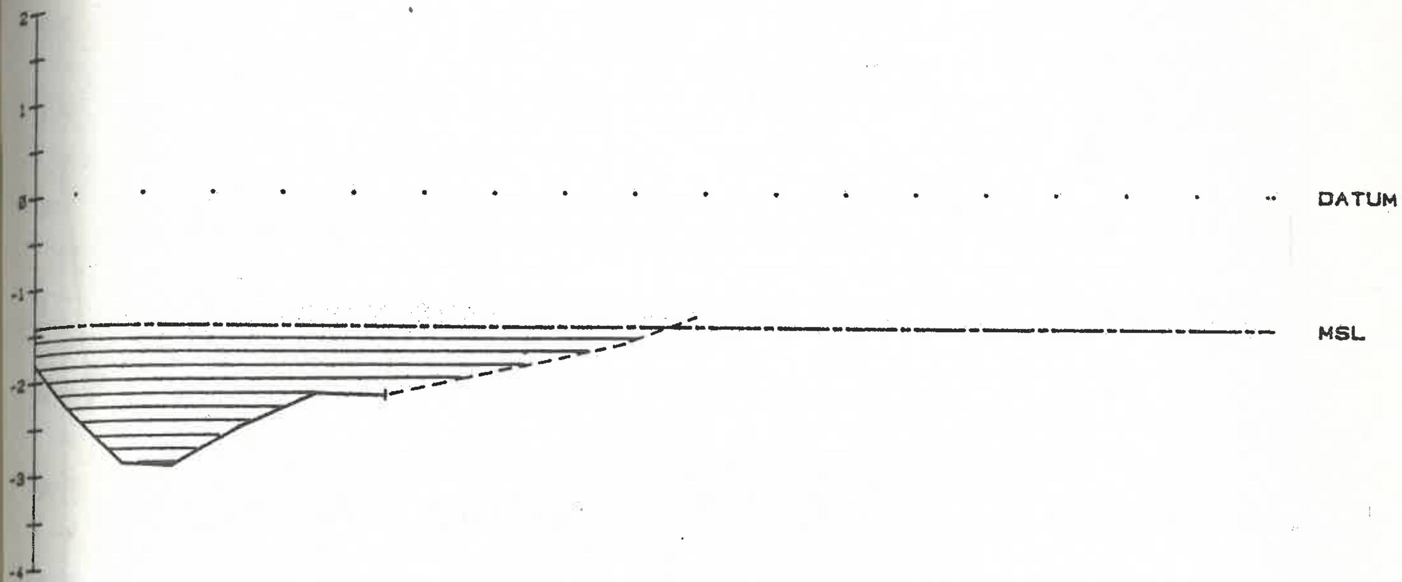
VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

100M

ROSIE - UPE GEOLOGY

SECTION 15 SEEKOEI ESTUARY NOVEMBER 1980



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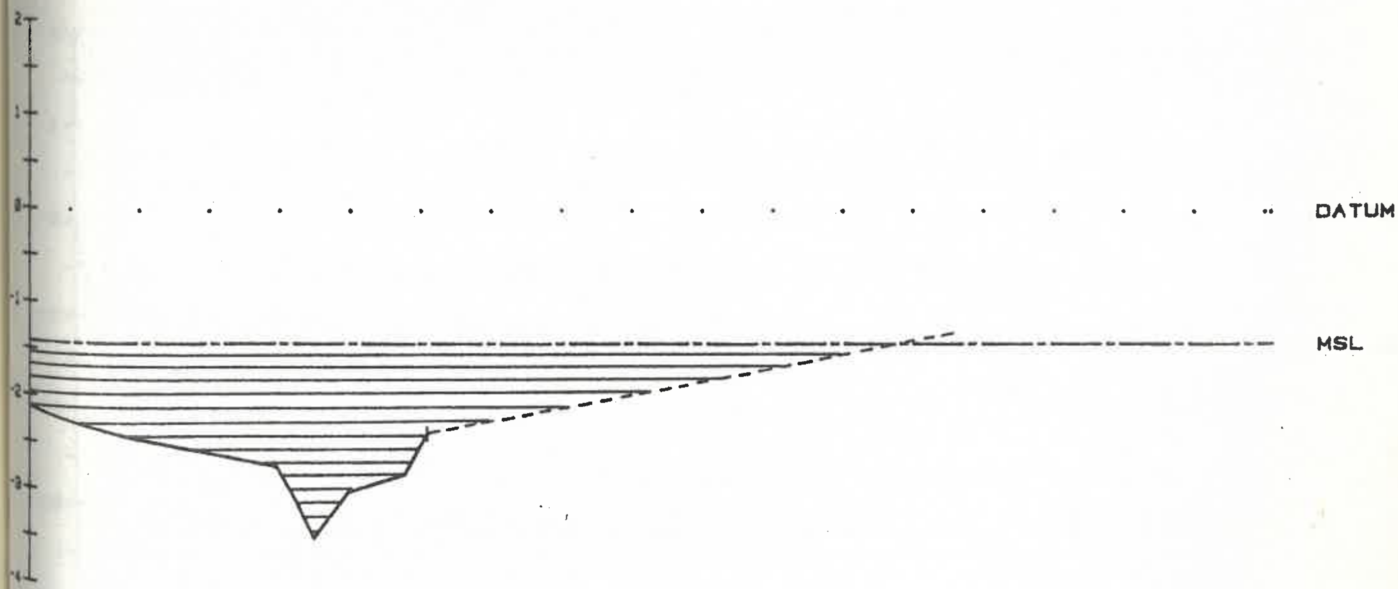
100M

ROSIE - UPE GEOLOGY

SECTION 16 SEEKOEI ESTUARY NOVEMBER 1980



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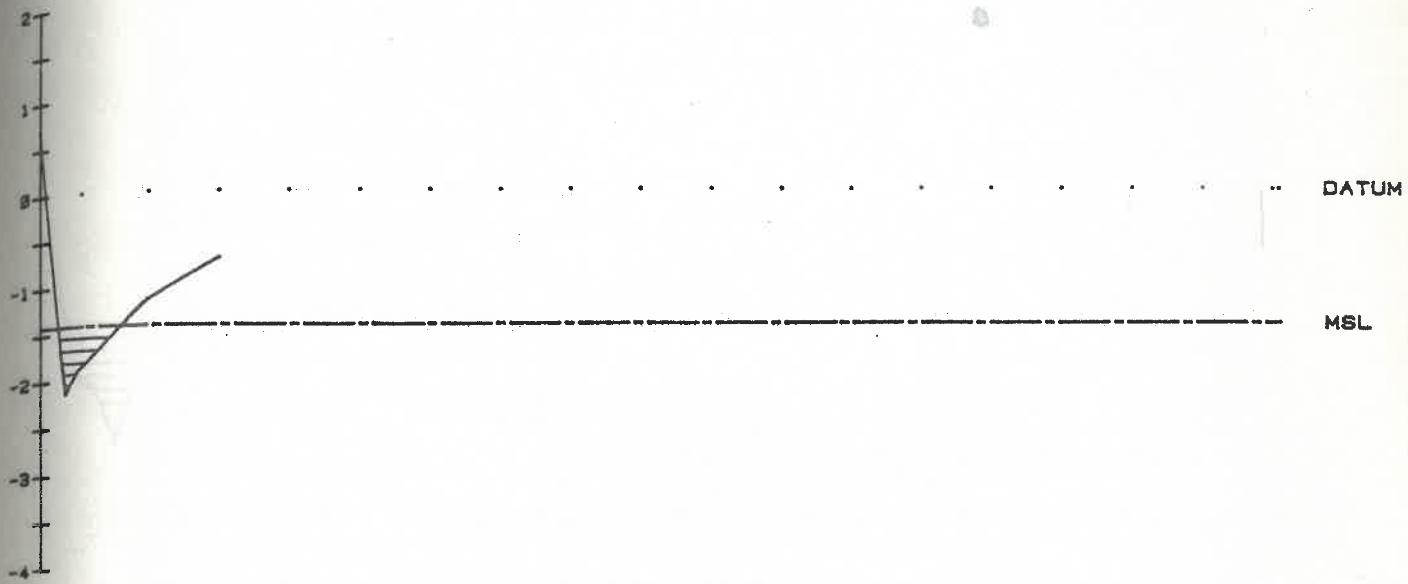
100M

ROSIE - UPE GEOLOGY

SECTION 1 SEEKOEI ESTUARY NOVEMBER 1981



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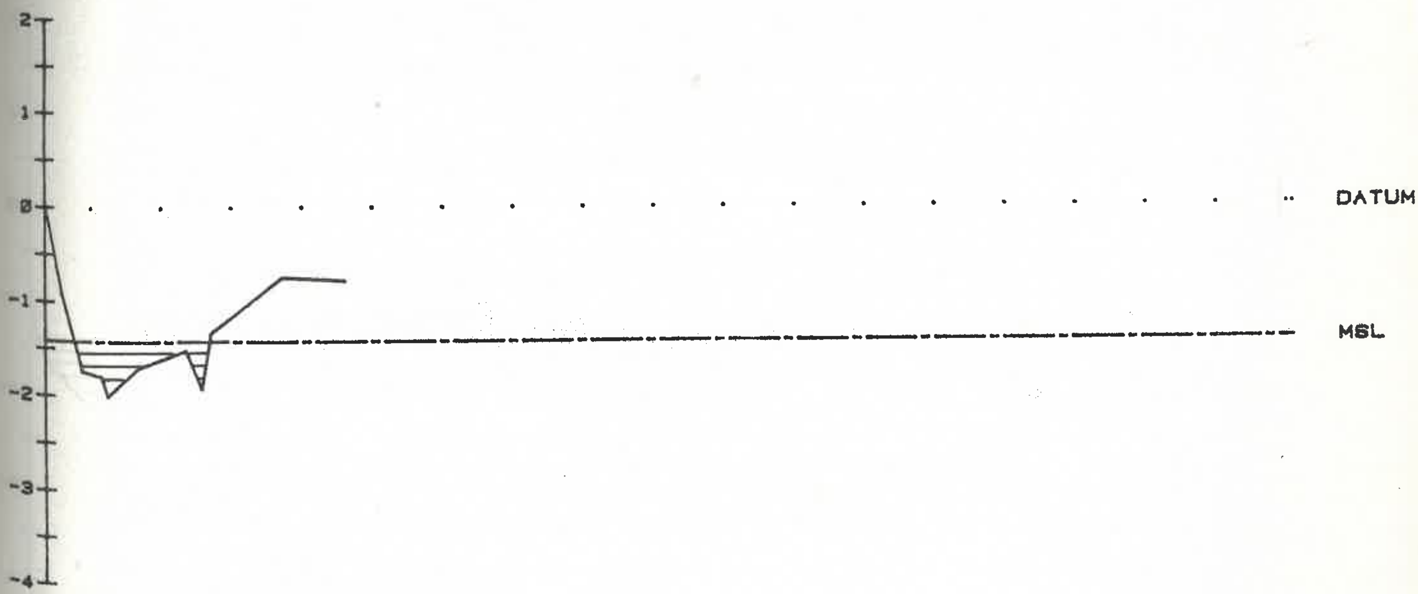
100M

ROSIE - UPE GEOLOGY

SECTION 2 SEEKOEI ESTUARY NOVEMBER 1981



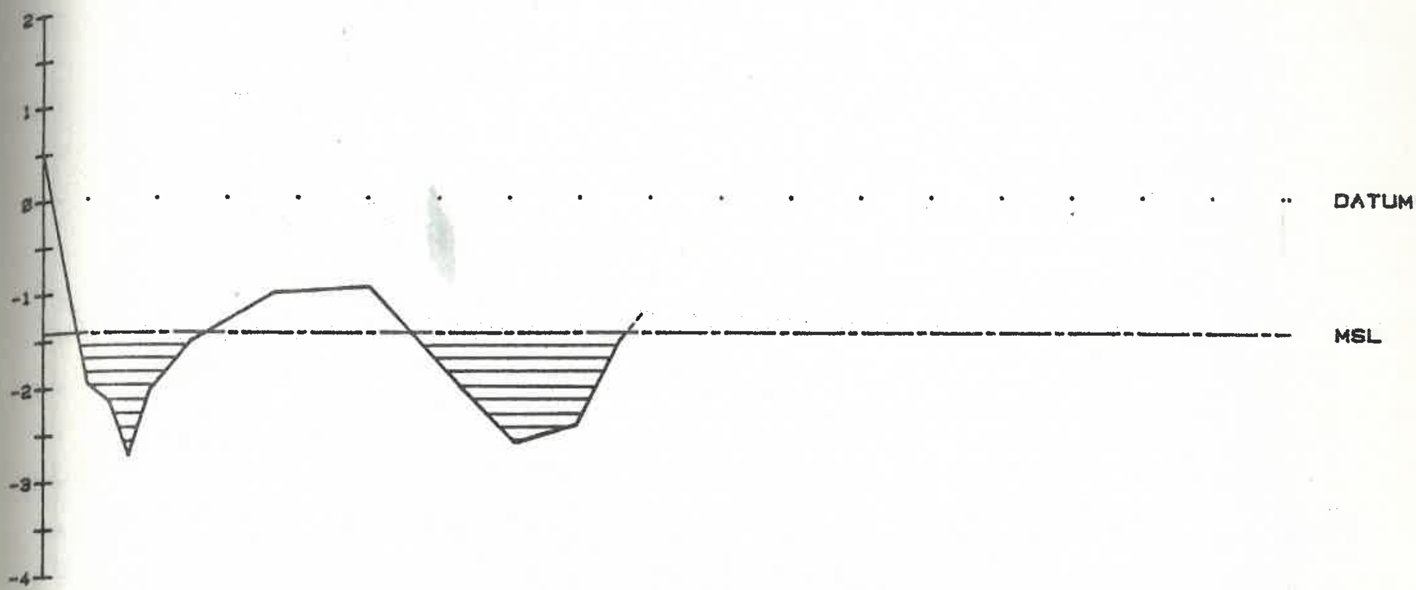
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

100M

ROSIE - UPE GEOLOGY

SECTION 3 SEEKOEI ESTUARY NOVEMBER 1981



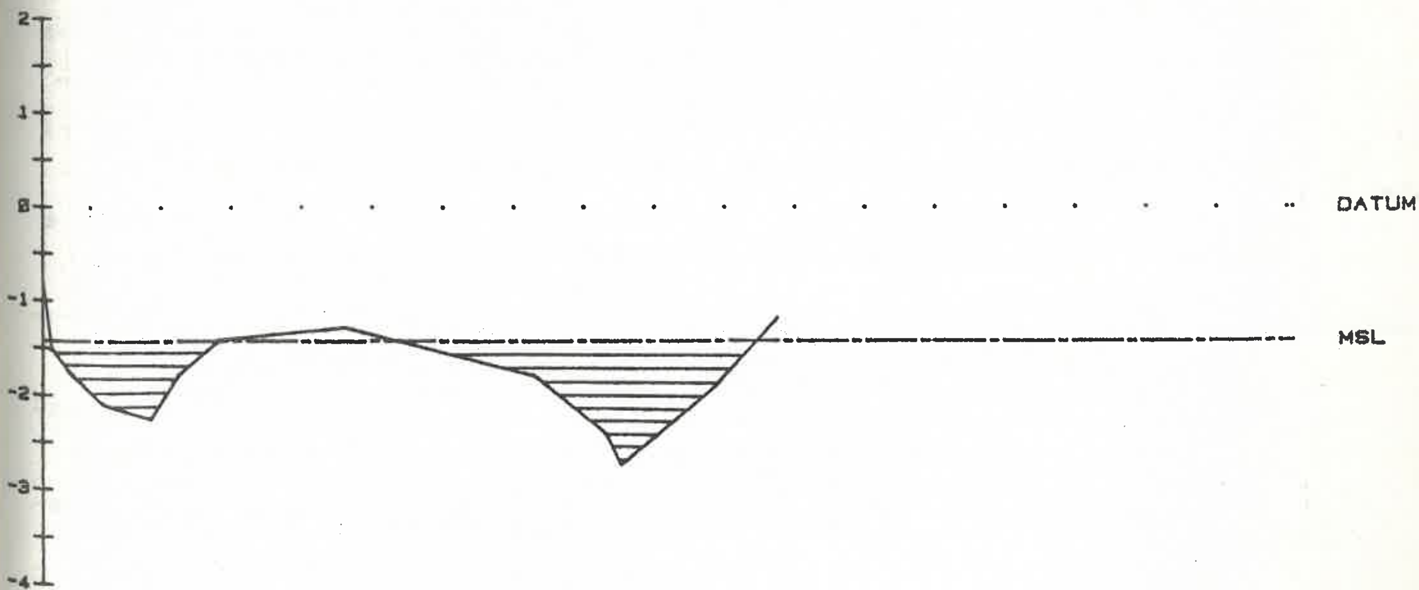
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

100M

ROSIE - UPE GEOLOGY

SECTION 4 SEEKOEI ESTUARY NOVEMBER 1981



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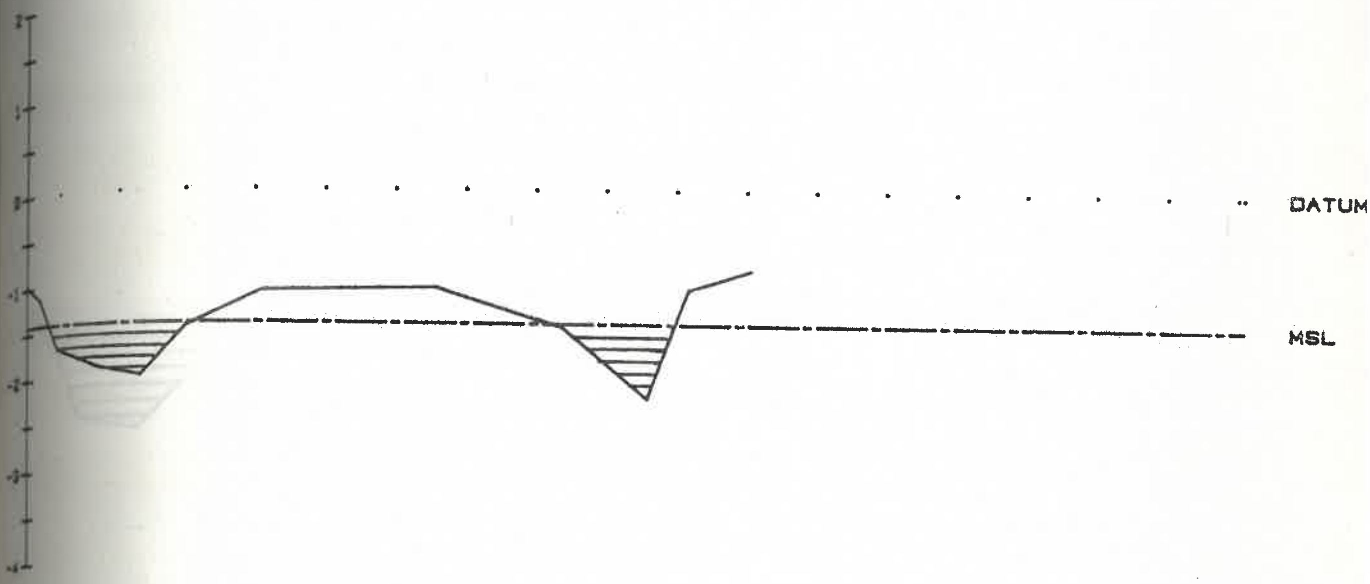
VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

100M

ROSIE - UPE GEOLOGY

SECTION 5 SEEKOEI ESTUARY NOVEMBER 1981



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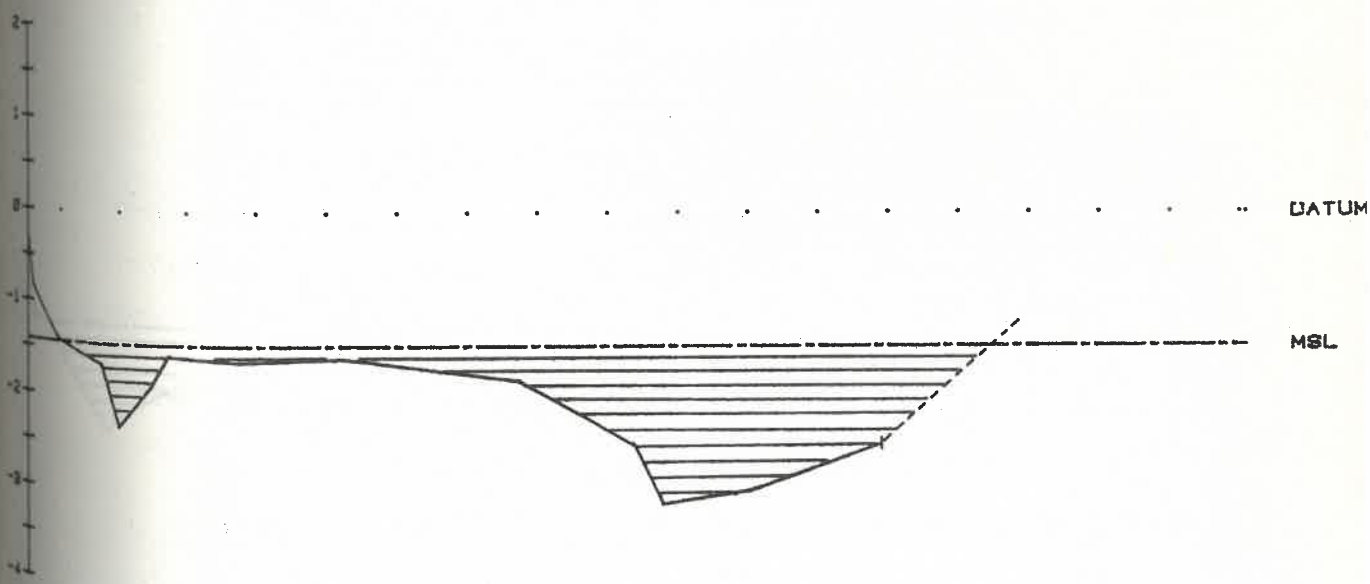
100M

ROSIE - UPE GEOLOGY

SECTION 6 SEEKOEI ESTUARY NOVEMBER 1981



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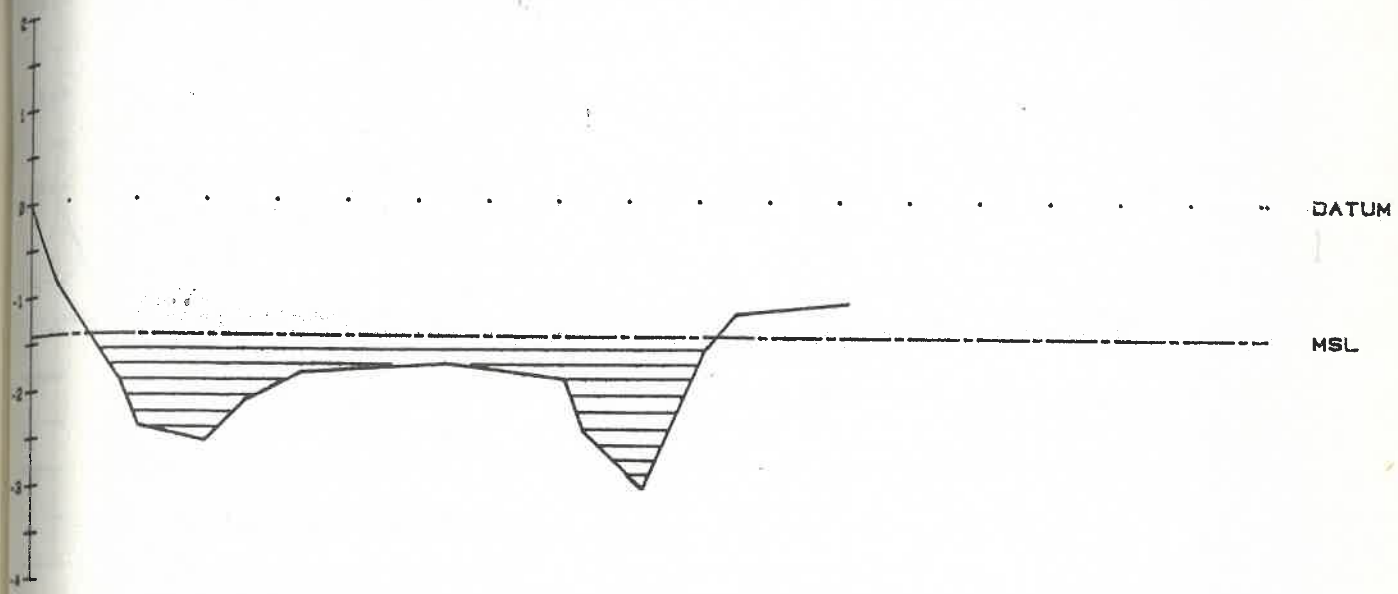
ROSIE - UPE GEOLOGY

SECTION 7 SEEKOEI ESTUARY NOVEMBER 1981



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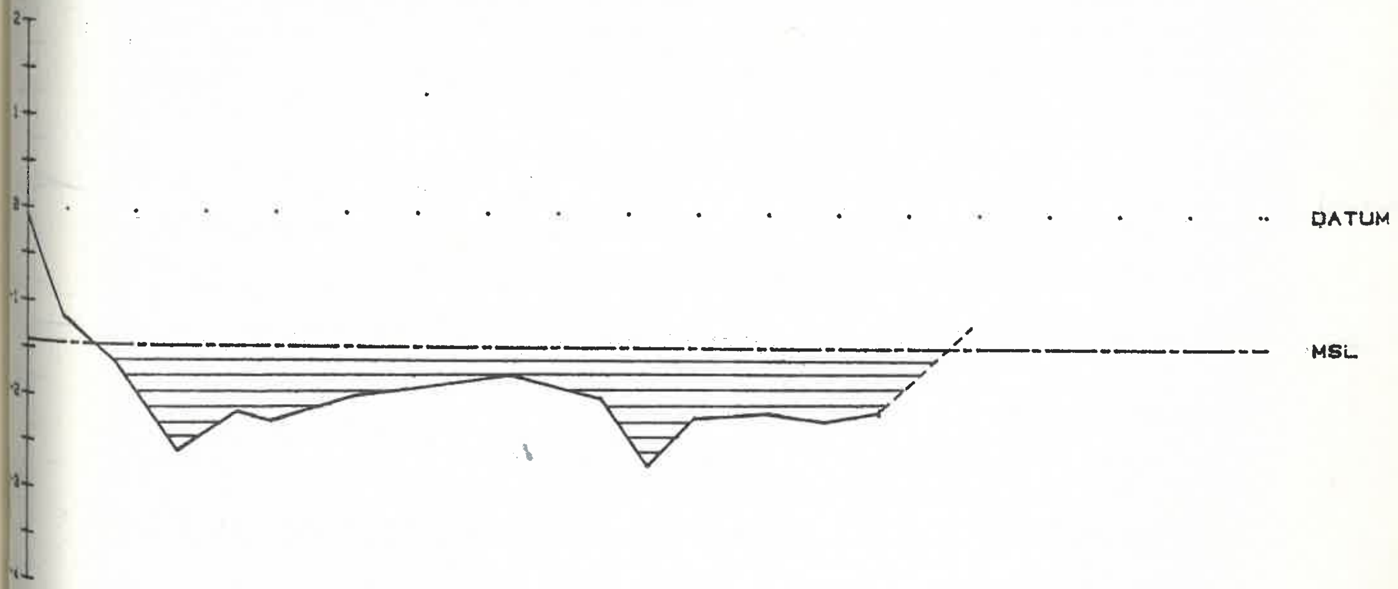
100M

ROSIE - UPE GEOLOGY

SECTION 8 SEEKOEI ESTUARY NOVEMBER 1981



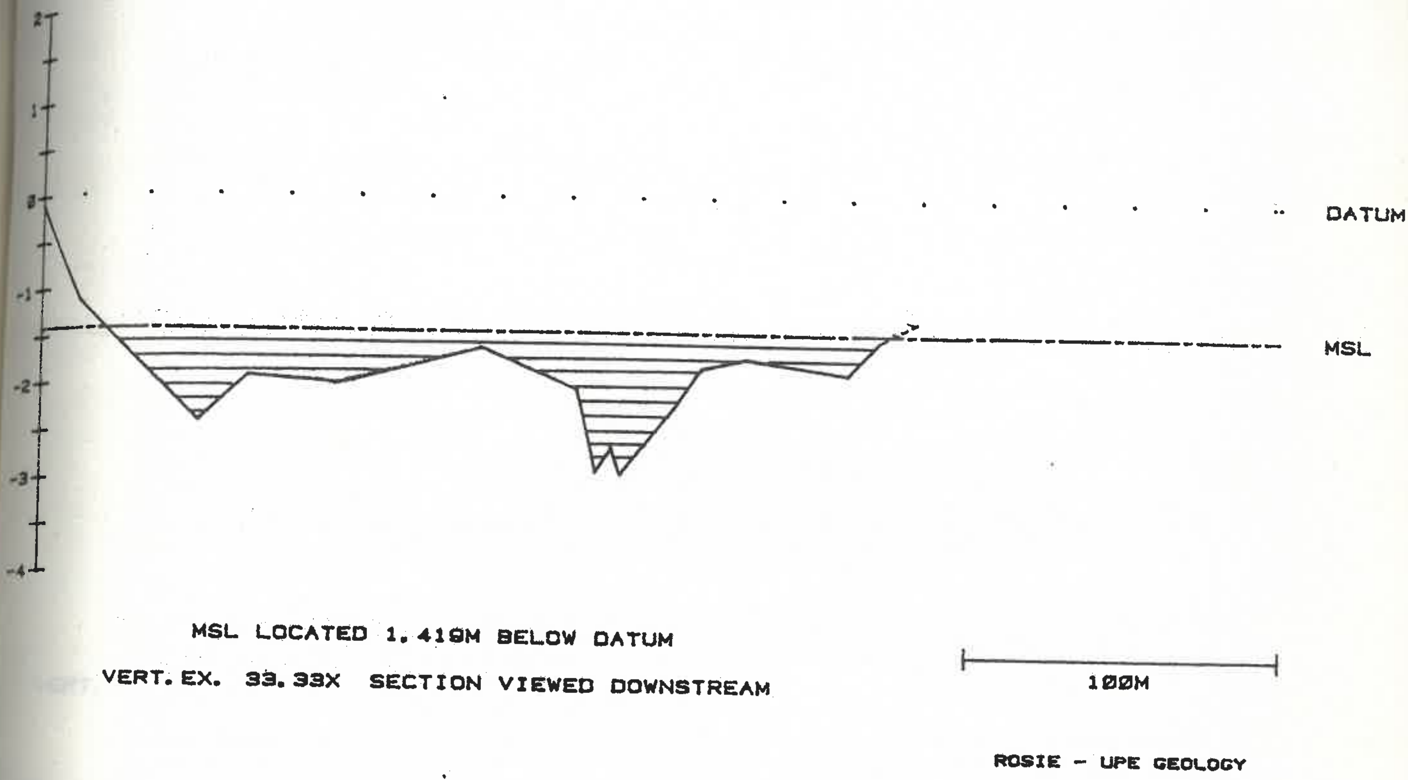
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

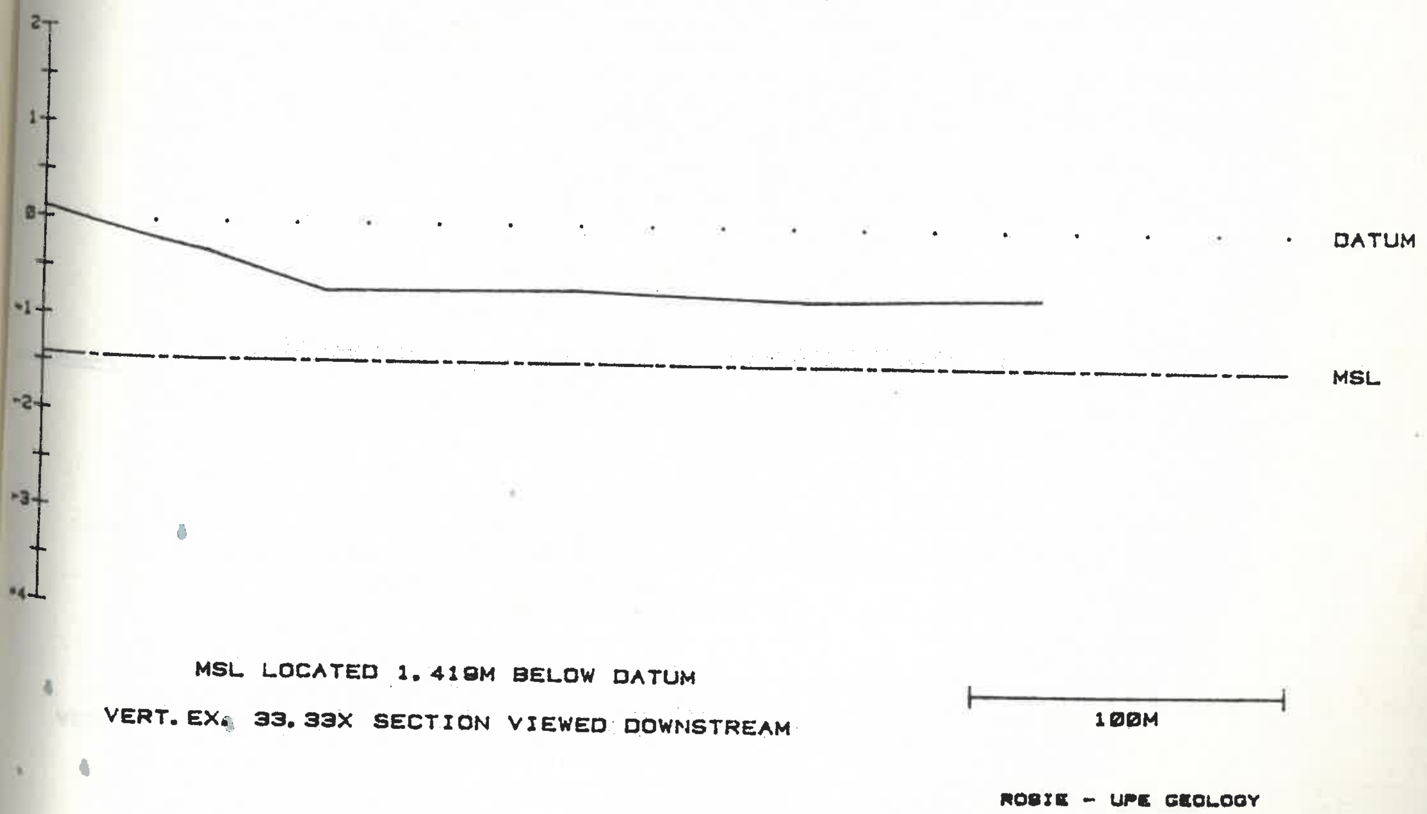
100M

ROSIE - UPE GEOLOGY

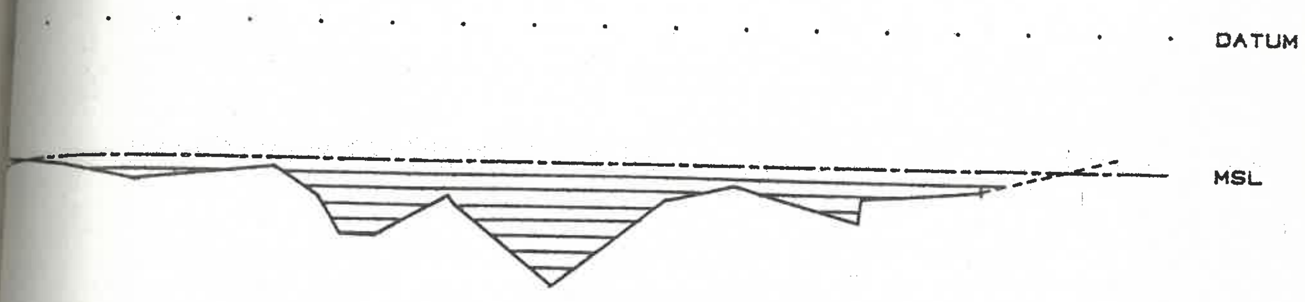
SECTION 9 SEEKOEI ESTUARY NOVEMBER 1981



SECTION 10 SEEKOEI ESTUARY NOVEMBER 1981



SECTION 11 SEEKOEI ESTUARY NOVEMBER 1981



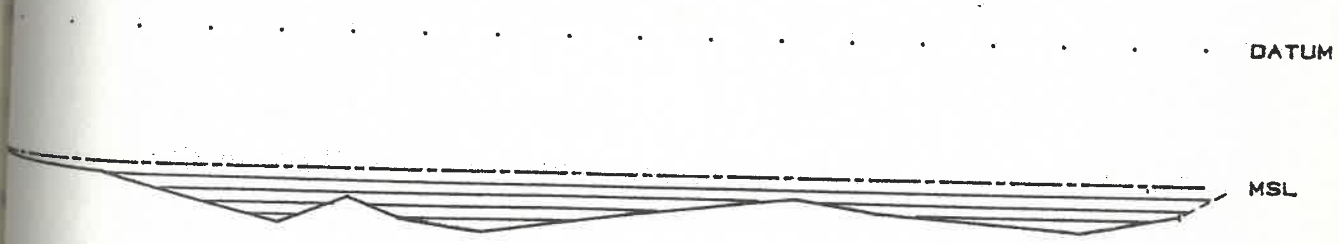
MSL LOCATED 1.419M BELOW DATUM

VERT. EX. 33.33X SECTION VIEWED DOWNSTREAM

100M

ROSIE - UPE GEOLOGY

SECTION 12 SEEKOEI ESTUARY NOVEMBER 1981



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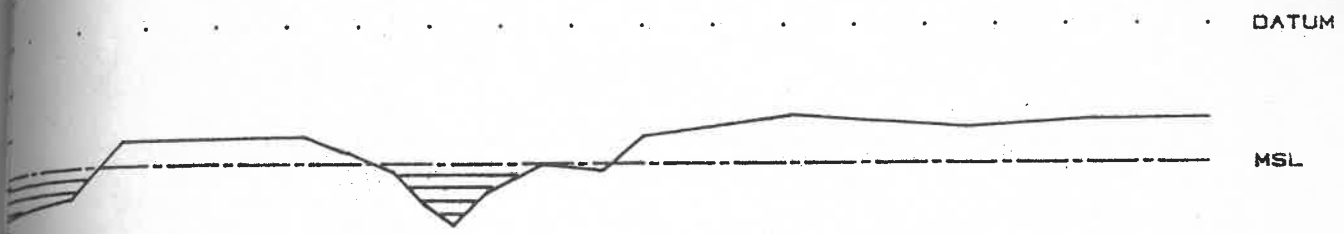
ROSIE - UPE GEOLOGY

SECTION 13 SEEKOEI ESTUARY NOVEMBER 1981



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ROSIE - UPE GEOLOGY