Research on Sedimentation in Estuaries

FLUVIALLY DOMINATED SEDIMENTATION IN THE GREAT FISH ESTUARY

ROSIE REPORT No 4

By: JSV Reddering
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Department of Geology
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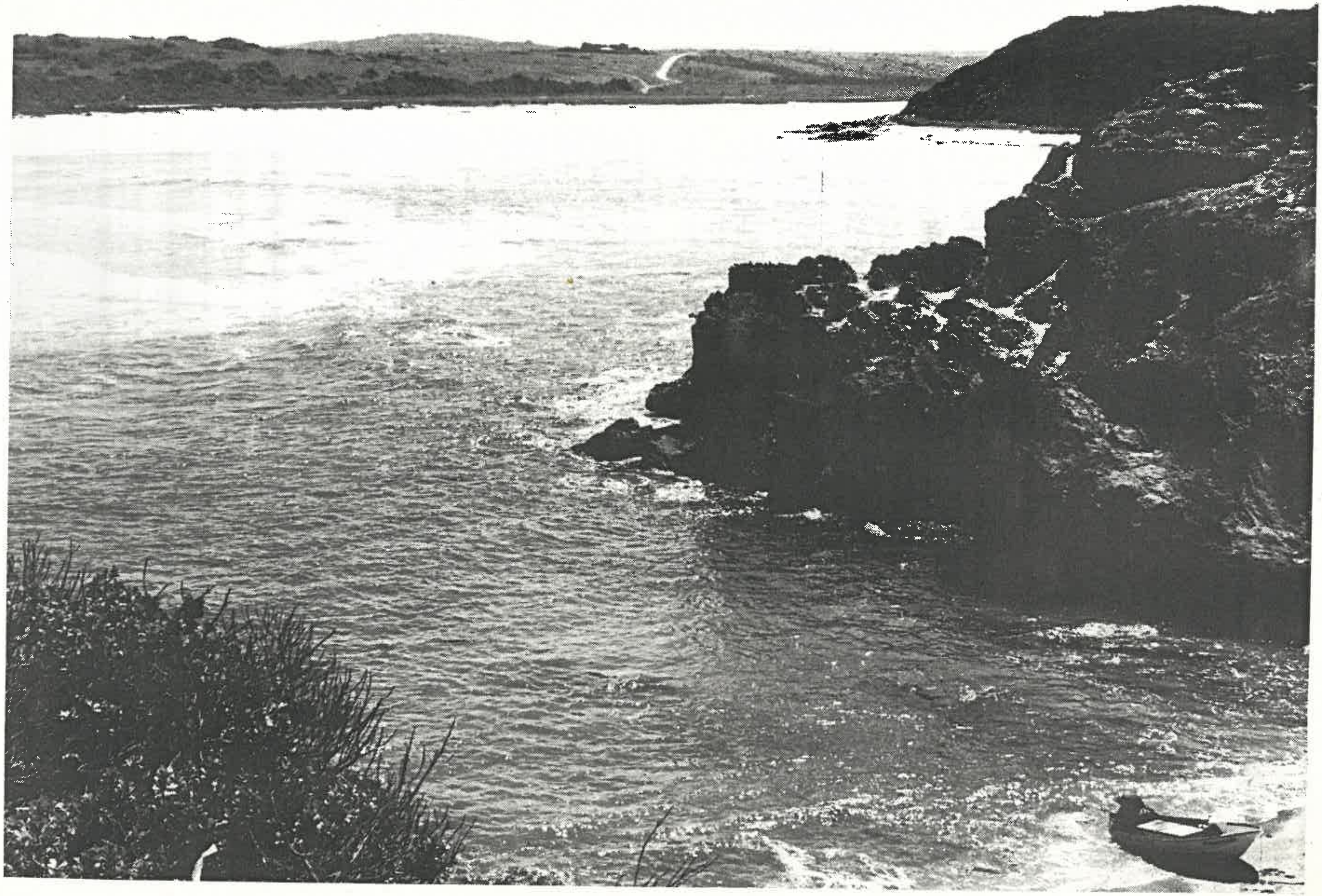


Lower Great Fish Estuary

CONTENTS

ABSTRACT

The catchment of the Great Fish River in the eastern Cape yields a large fluvial sediment load to the estuary. The river has a history of severe flash-type flooding. The estuary has a constricted inlet which is periodically blocked. Tidal currents are weak in the estuary and little marine sediment moves up into the estuary. Sediment in the estuary originates mainly from the catchment area. During periods of high discharge, sand is deposited in the upper reaches of the estuary whereas mud accumulates during times of low discharge. A considerable accumulation of clastic mud occurs in the zone where fresh water and sea water mix.

The bridge across the estuary has no adverse effect on tidal circulation but may be a flood hazard because it crosses the natural flood plain of the estuary.

Sediment accumulation in the Great Fish estuary is not of any permanent consequence. Freshwater floods pass through the estuary with sufficient frequency to remove any accumulated sediment.

FLUVIALLY DOMINATED SEDIMENTATION IN THE GREAT FISH ESTUARY

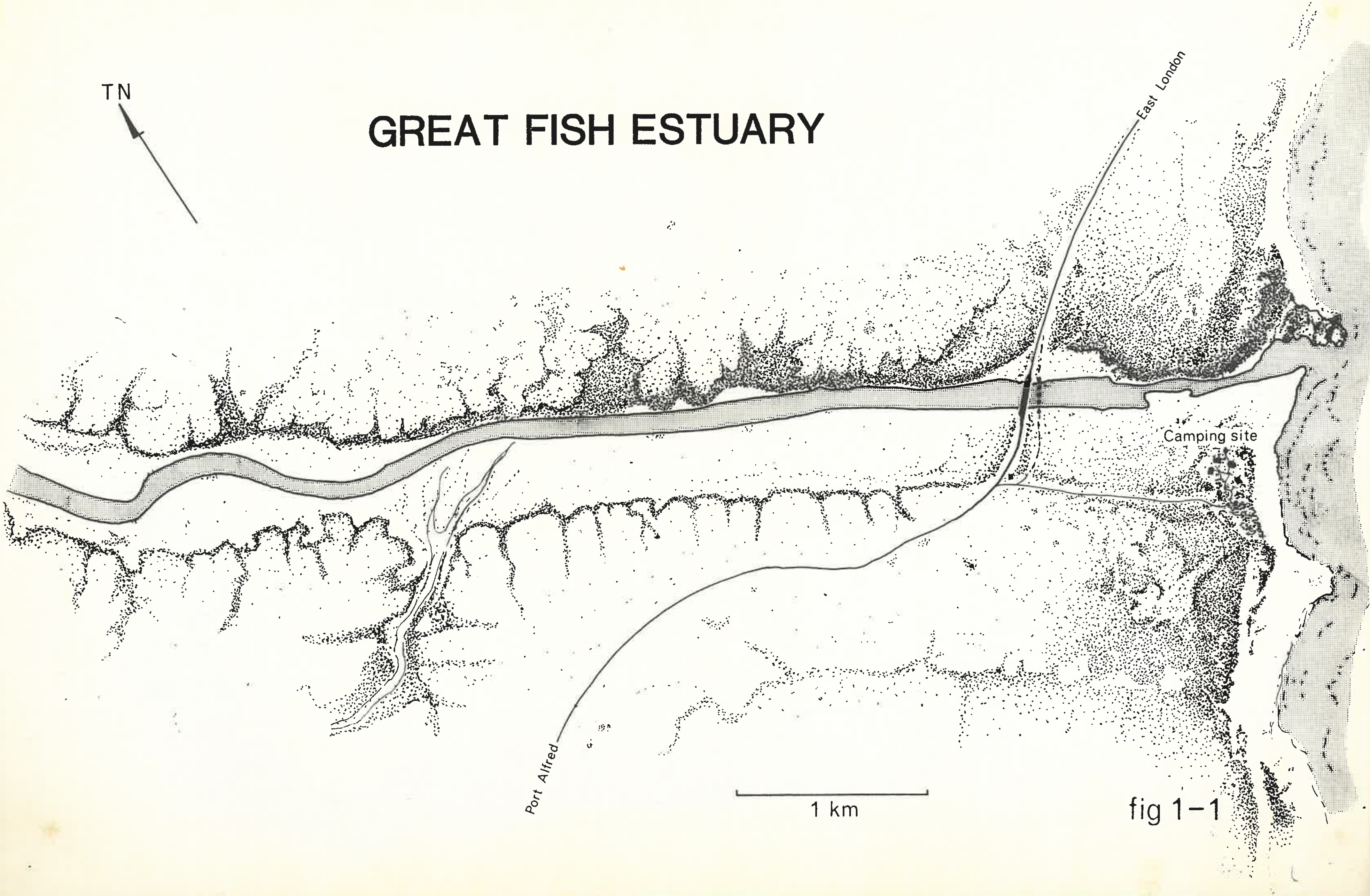
1. INTRODUCTION

The estuary of the Great Fish River is situated on the Cape east coast, about 30 km north-west of Port Alfred where it forms the border with Ciskei (figs. 1.1 and 1.2). Little development has taken place on the banks of the estuary so that it is almost untouched by man. Little is known about the estuary, but field observations and discussion with inhabitants indicate that the Great Fish River carries a large sediment load during floods. Such a high sediment load is a possible ecological threat to the estuary.

The aims of this study are:

1. To determine whether sediment build-up is taking place.
2. To establish the source of this sediment.

Many of the determinations done during the investigation of other estuaries (Reddering and Esterhuysen, 1981a, 1981b and 1981c) were not possible in the Great Fish estuary. Survey benchmarks were not transferred up-estuary so that cross-section surveying would have been meaningless. The conventional aerial photographic record often shows underwater topography. The Great Fish photographs show very little detail, probably owing to the high mud content in the water. Photo-interpretation maps could consequently not be prepared (section 3.2).



GREAT FISH ESTUARY
TN
East London
Camping site
Port Alfred
1 km

fig 1–1

Location of Great Fish River

33° 30'S ; 27° 07'E

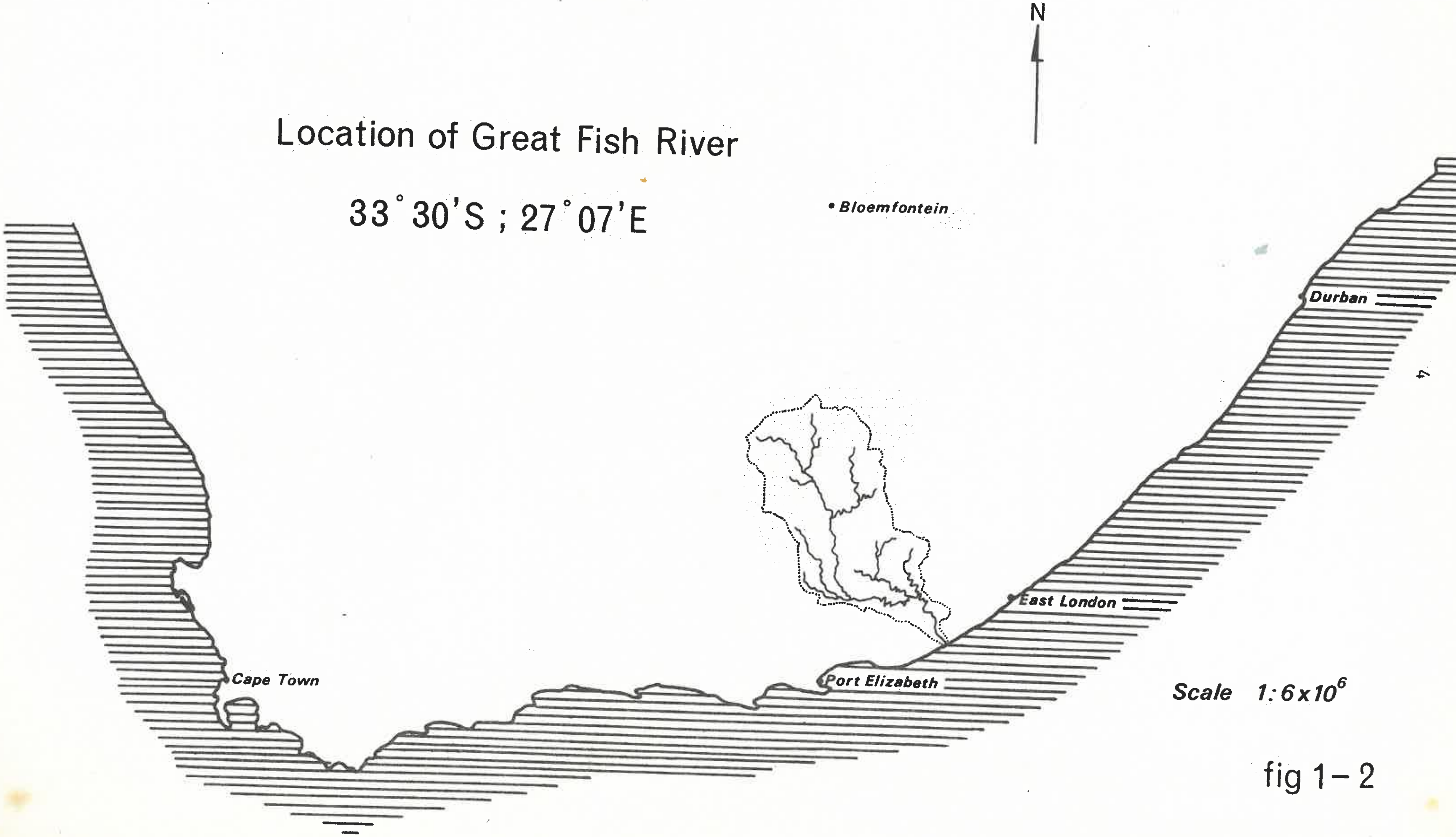


fig 1– 2

Field observations were hampered by low underwater visibility and a thick layer of unconsolidated mud on the bottom. Subtidal observations and sampling were carried out with the aid of SCUBA.

2. BACKGROUND INFORMATION

2.1 Catchment area (fig. 2.1)

The Great Fish River is about 460 km long and its drainage basin has an area of 29 300 km2. Livestock farming (sheep and cattle) is the main economic activity in the catchment area. Four dams are located on the river and its tributaries (fig. 2.1), (holding capacities in parenthesis): the Grassridge dam (58,4 X 10^6 m^3), Lake Arthur (29,7 X 10^6 m^3), the Kommandodrif dam (66,7 X 10^6 m^3) and the Katrivier dam (26,1 X 10^6 m^3).

2.1.1 Geology

The substrate of the catchment area consists mainly of mudstone. The Beaufort and Ecca Groups and the Dwyka Formation (fig. 2.2) consist of fine-grained sedimentary rocks with subordinate immature sandstones (e.g. the Katberg Sandstone Formation). Karoo dolerite dykes and sills outcrop over practically the entire catchment area.

Great Fish River Catchment Area

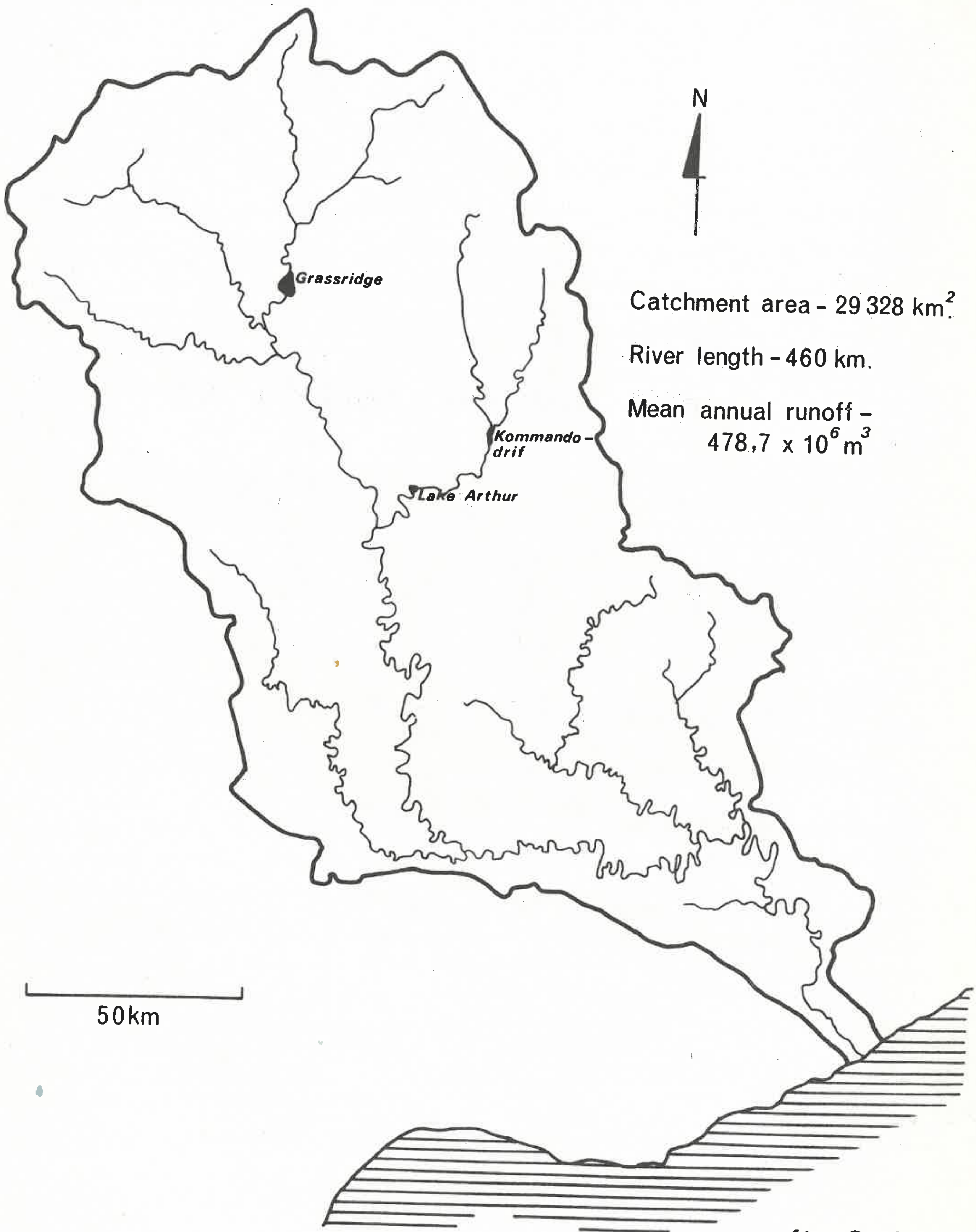
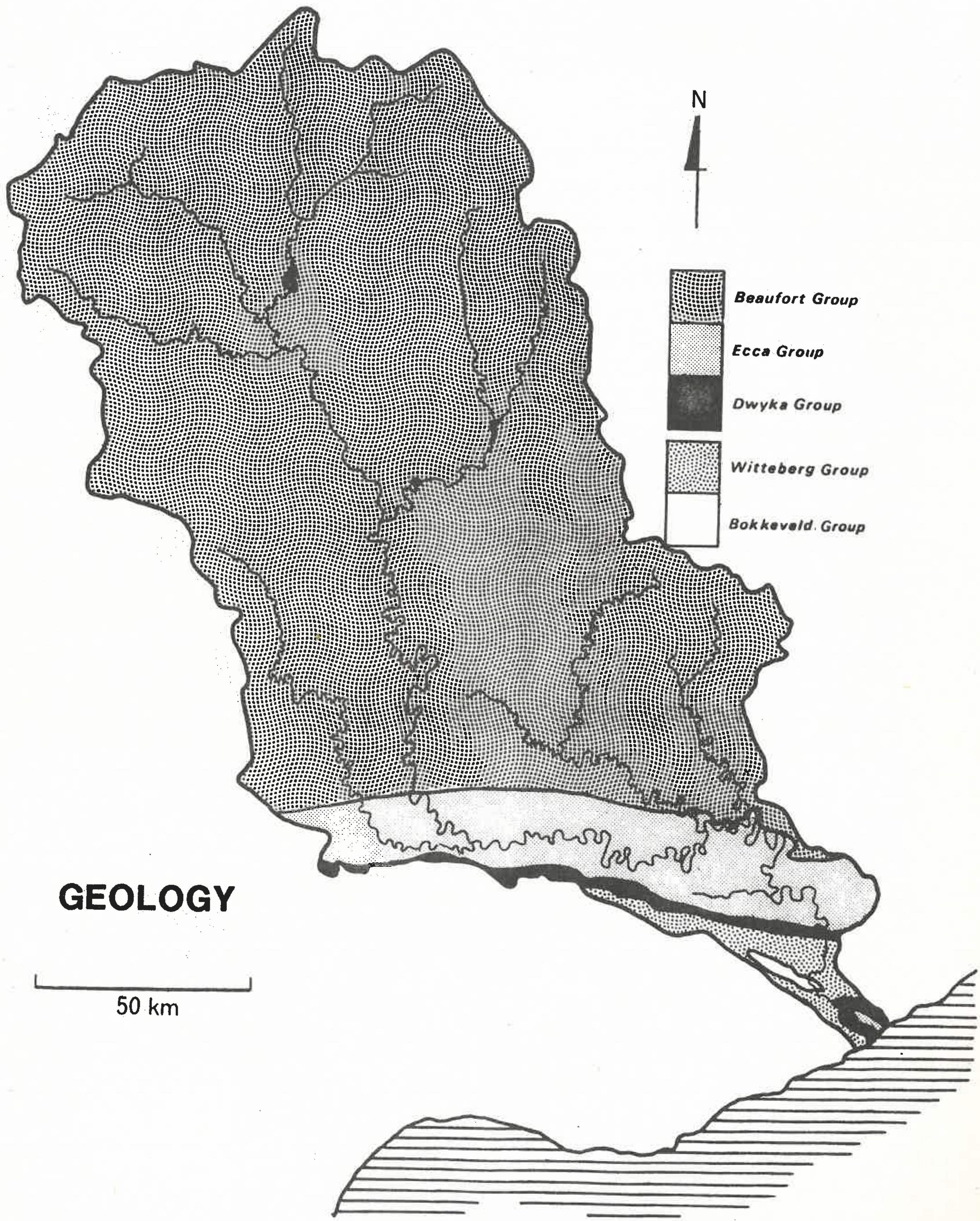


fig 2-1



N
Beaufort Group
Ecca Group
Dwyka Group
Witteberg Group
Bokkeveld Group
GEOLOGY
50 km

fig 2-2

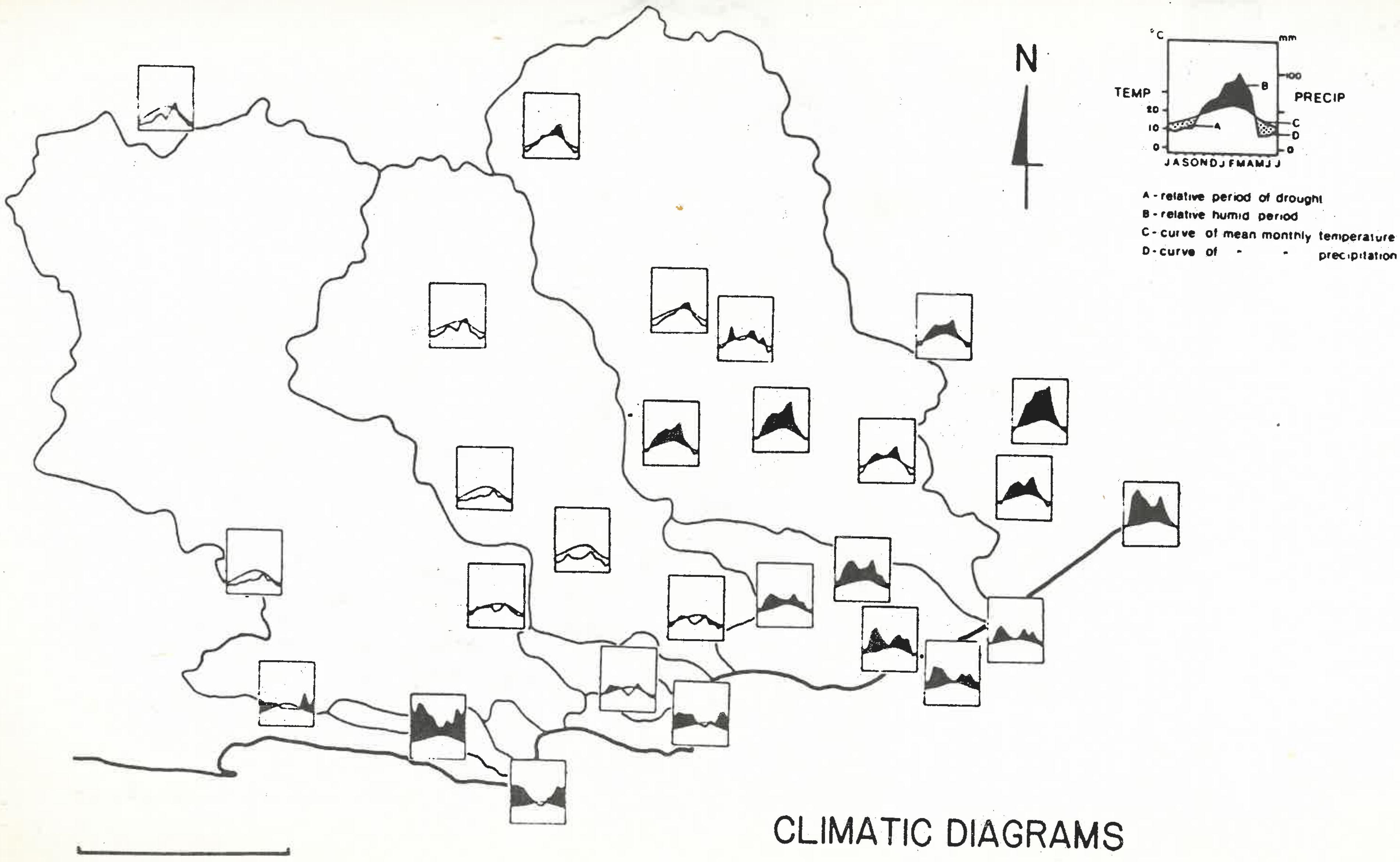
2.1.2 Climate

Owing to the size of the basin the climate varies over the Great Fish catchment area (figs. 2.3 and 2.4). The northern sector of the basin has a summer rainfall of between 250 mm and 500 mm a^{-1}. The central valleys receive a precipitation of 400 mm to 1000 mm a^{-1}, mainly during the summer season. The south-eastern coastal zone is a winter rainfall area and receives between 400 mm and 1500 mm of rain per year. Mean annual runoff is about 479×10^6 m^3 but a large portion of this is retained by dams. Freshwater discharge into the estuary is boosted by water from the Orange River irrigation scheme but the volume is negligible.

Wind patterns are non-uniform over the catchment area but south-westerlies prevail over the coastal area (and the estuary).

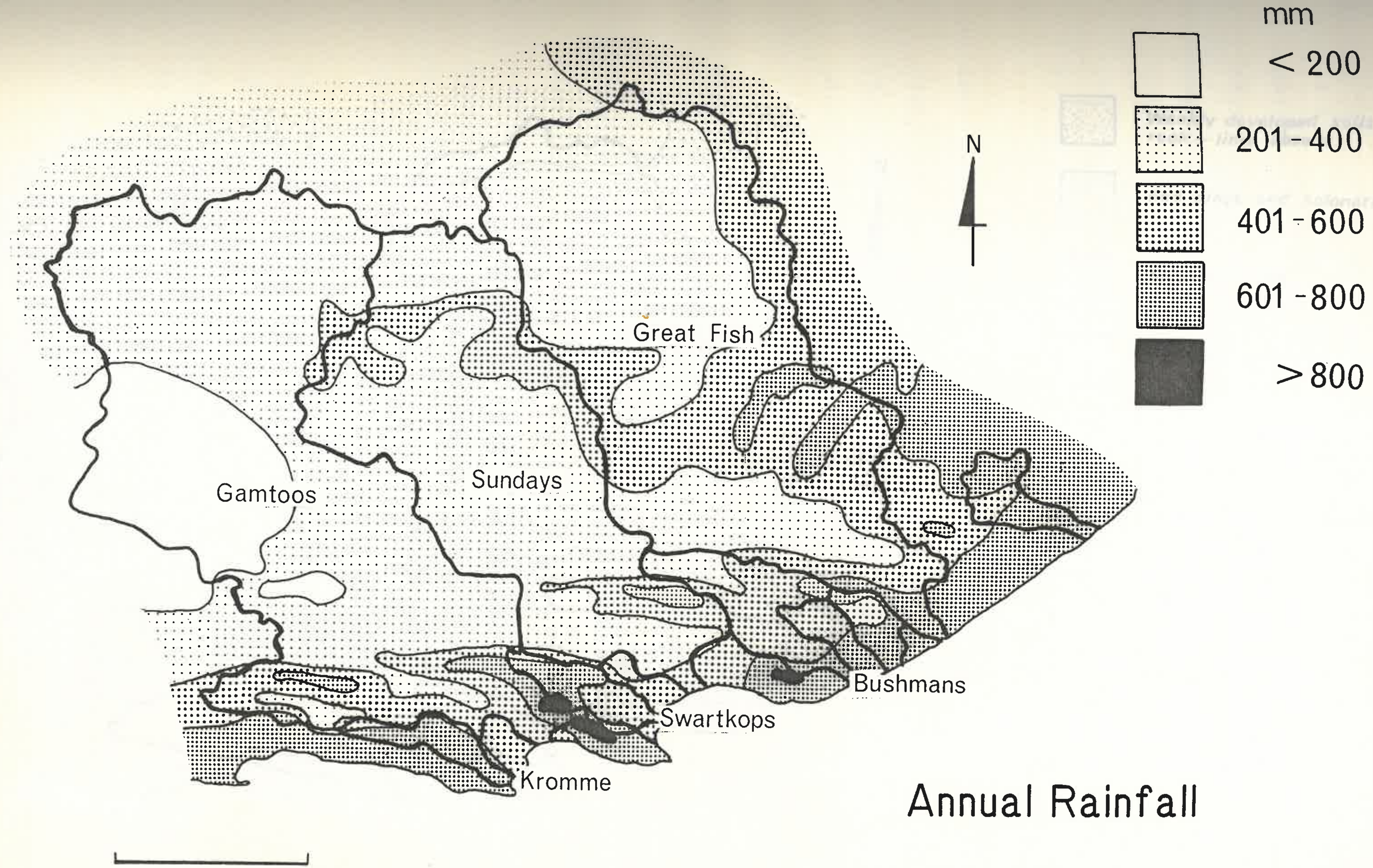
2.1.3 Soil and veld types

Heterogeneous soil development occurs in the catchment area. In the eastern part, solonetic soils and latosol catena are found whereas weakly developed lithosols predominate in the western area of the basin (MacVicar, 1971; fig. 2.5).



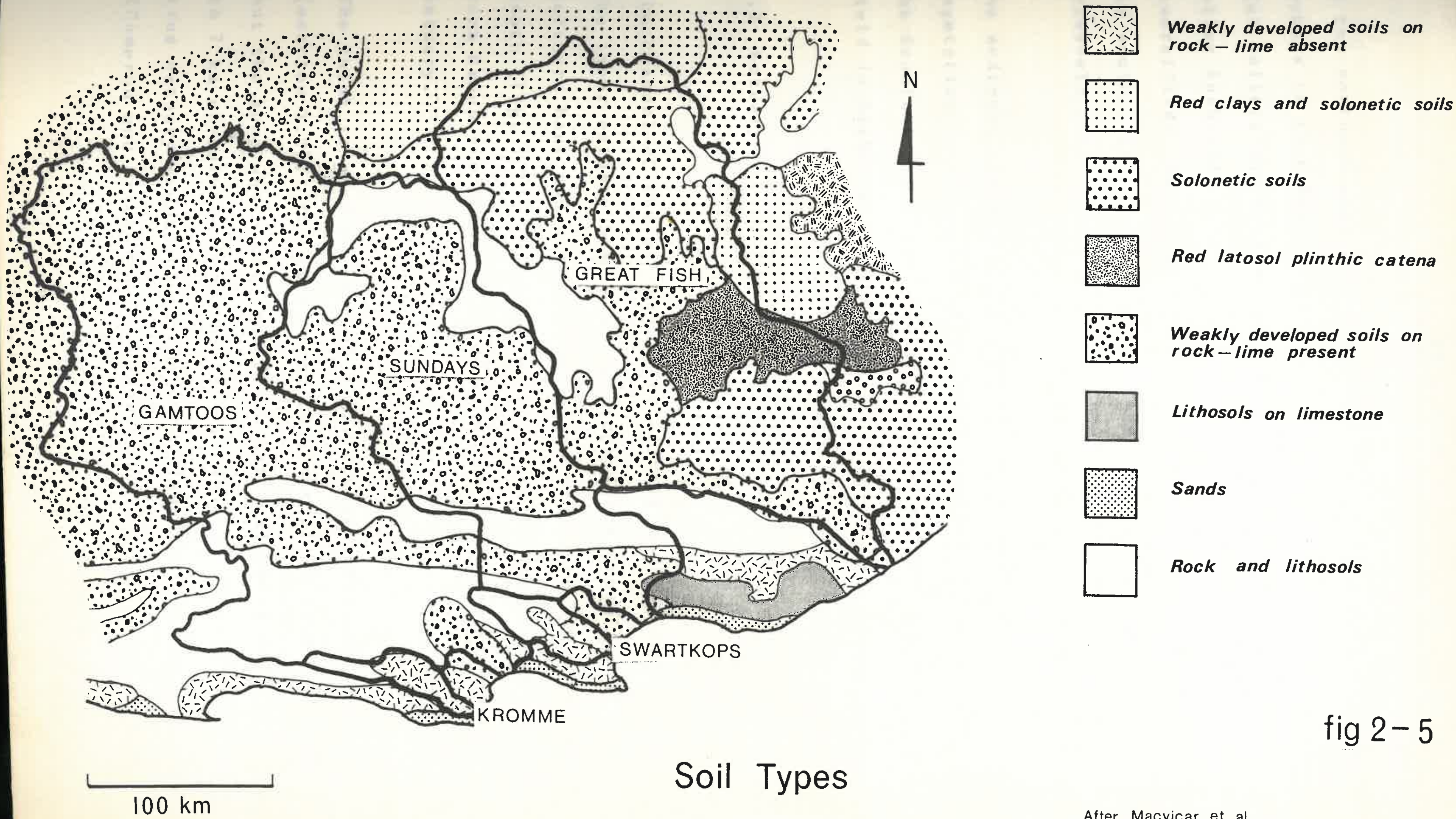
CLIMATIC DIAGRAMS

fig 2-3



Annual Rainfall

fig 2-4



Soil Types

fig 2-5

After Macvicar et al

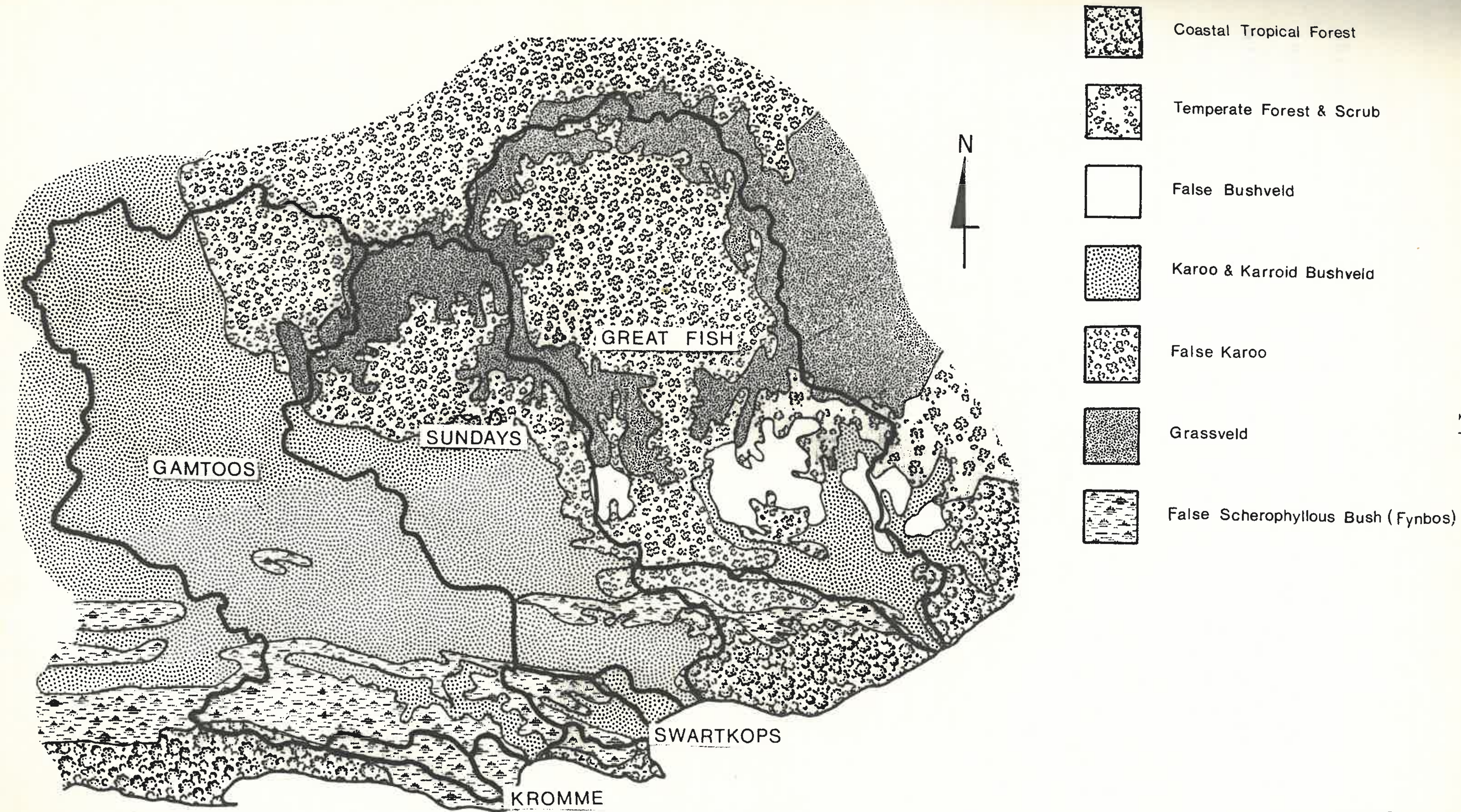
In the northern part of the basin False Karoo vegetation with pockets of true Karoo scrub are found. In the central Great Fish valleys the vegetation varies between False Karoo and Valley Bushveld. The eastern sector the vegetation is highly diversified. Valley Bushveld and Coastal Forest occurs in the south. The high-lying watershed is vegetated by Grassveld (fig. 2.6).

The sediment yield of this combination of soils and vegetation is clay-rich with subordinate sand. Soils derived the Beaufort Group are prone to erosion and the sediment yield is high (value unknown).

2.2 Estuary

The channel of the estuary is relatively narrow (50 to 100m). The lower estuary has rocky outcrops (Ecca Group) on its northern bank and a wide flood-plain (500 m to 700 m) to the south (fig. 1.1). Outcrops of shale and sandstone of the Ecca Group are commonly encountered on the banks of the upper estuary.

The inlet is shallow and has a history of temporary closure (section 3.2). The tidal head is about 11 km from the inlet but the zone where salt and fresh water mixes is only 5 to 7 km up-estuary from the inlet. This is therefore not a true estuary according to the established definition (Cameron and Pritchard 1963; section 5.2).



Veld Types

fig 2-6

After Acocks

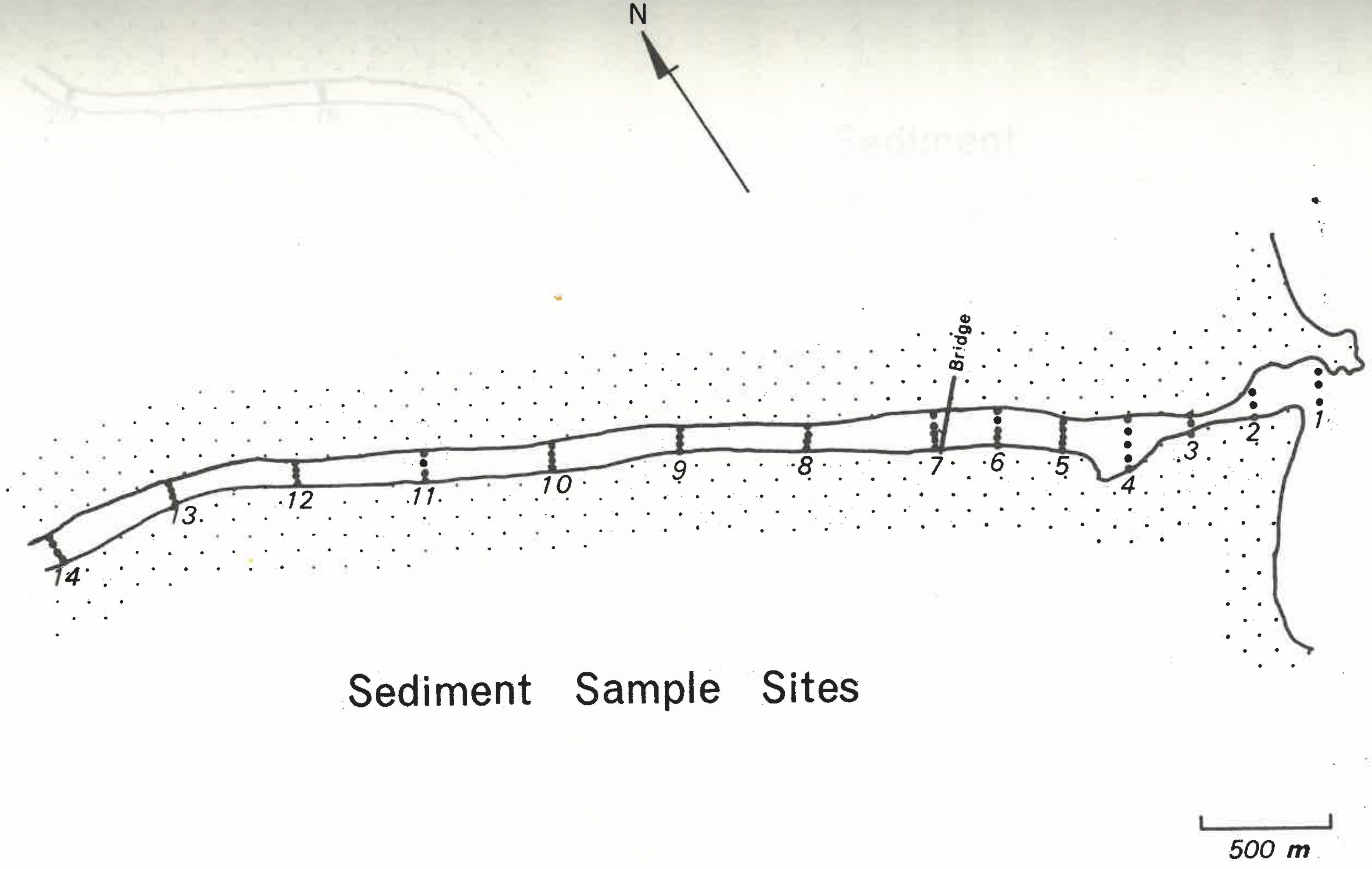
Channel patterns are determined mainly by the outcrops of rock on the banks. Where the substrate consists of older, incompletely consolidated fluvial-estuarine deposits the estuary has a meandering course.

A road bridge crosses the estuary 1,3 km from the inlet. An embankment makes up the south-western approach to the bridge. It crosses a supratidal saltmarsh (section 4.2). The remains of an older, flood-damaged bridge cross the estuary about 100 m seaward of the present bridge.

3. SEDIMENT DISTRIBUTION

3.1 Grain size distribution

Grain size was determined from samples taken on twenty lines across the estuary (fig. 3.1). These samples were collected at the bed and at a depth of 0,5 m into the sediment substrate and were obtained from the intertidal and subtidal zones. The arbitrary depth of 0,5 m into the substrate was chosen because one often encounters core pipe penetration problems beyond this depth. Sediment extrusion from the pipe in the field also limits the practical length of the core pipes. On these samples, sand grain analysis and mud content were determined. From the size distributions the statistical parameters were determined using formulae obtained from Buller and McManus (1979). The organic content in the samples was determined by H_2O_2 leaching using the method of McCave (1979). (This method does not give the total organic content but indicates that amount which is likely to influence the redox potential of the sediment.) $CaCO_3$-content was determined using a "carbonate bomb" (Schink et al., 1979). Detailed results of all the sediment analyses are presented in APPENDIX 1 and size distributions and mud content are contoured in figs. 3.2 and 3.3 respectively.



Sediment Sample Sites

fig 3 –

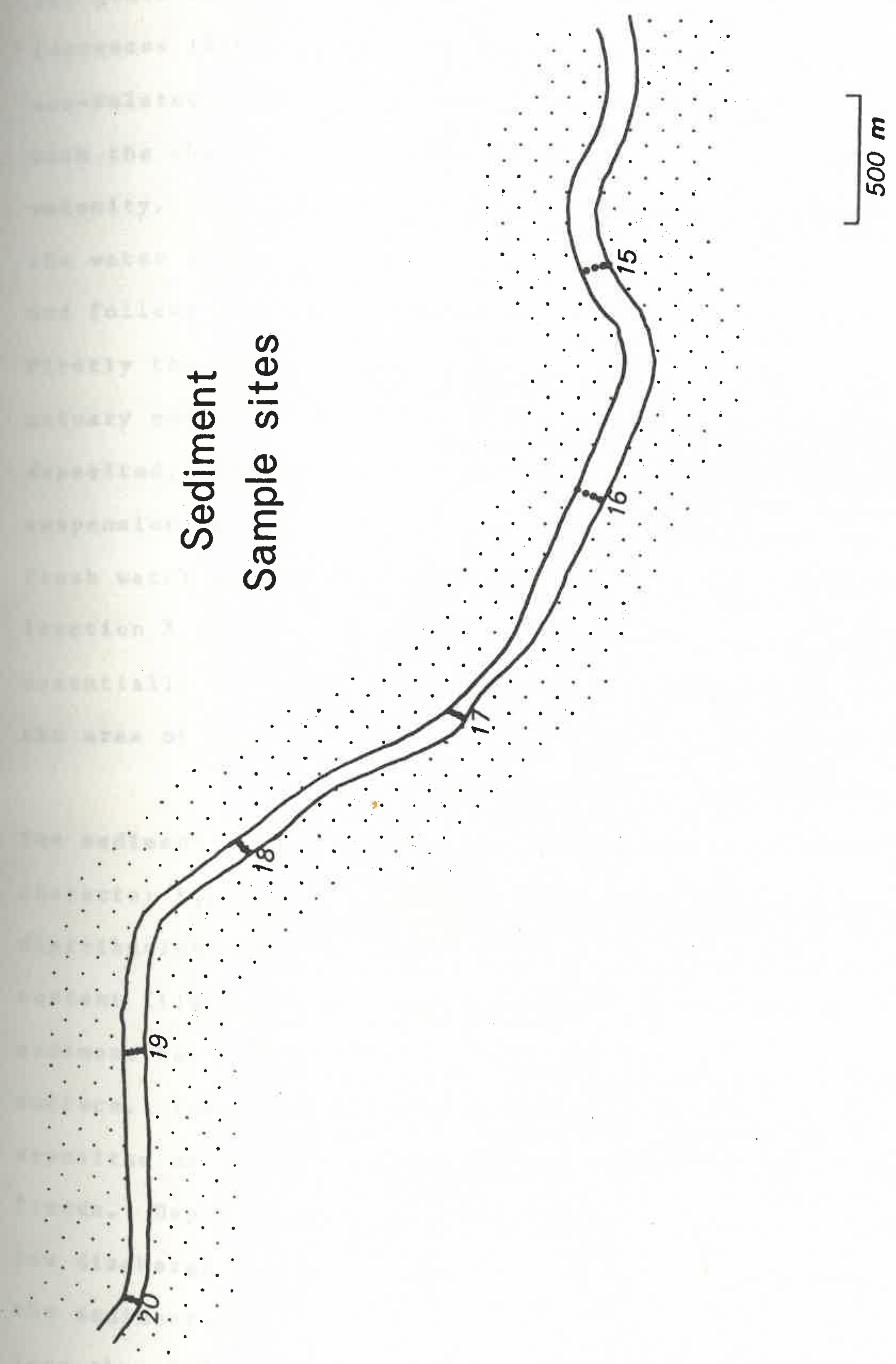
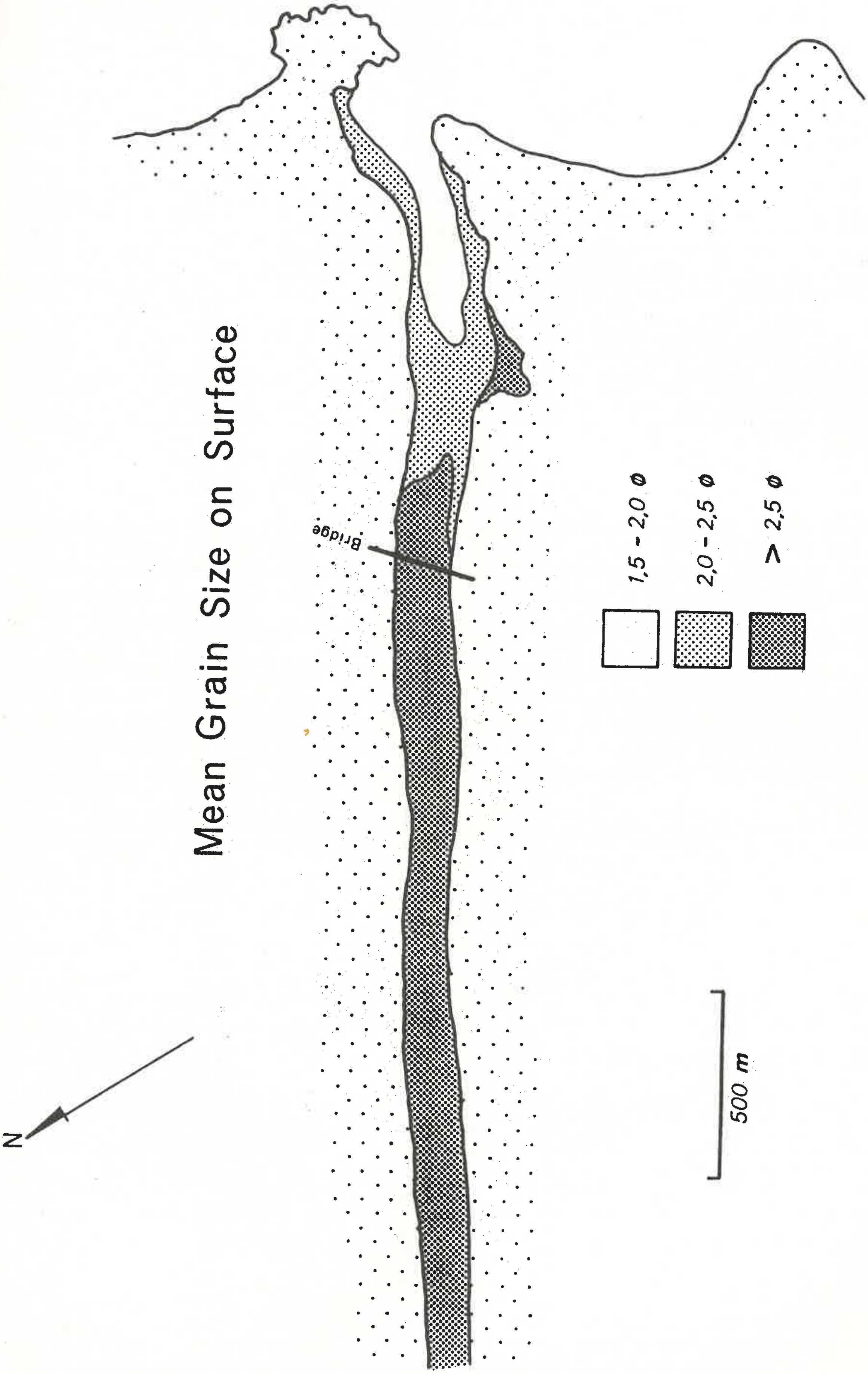


fig 3-1

The grain size decreases up-estuary whereas the mud content increases (figs. 3.2 & 3.3). This is the result of various non-related factors. The grain size of marine sand decreases with the characteristic up-estuary decrease in tidal current velocity. The reduced turbulence decreases the capacity of the water to entrain and transport sediment. The increase of mud follows from two independent estuarine properties. Firstly the tidal current velocity is low in the upper estuary and under such conditions suspended sediment is deposited. The second factor that influences deposition from suspension is flocculation. In the zone where sea water and fresh water mixes, clay floccules form and settle out (section 3.4). In the upper estuary where the water is essentially salt-free mud accumulation is much less than in the area of flocculation (fig. 3.3).

The sediment on the surface of the bed is similar in character to that 0,5 m deeper down. The grain size distributions (fig. 3.2) are similar, and so is the mud content (fig. 3.3). In the upper estuary the subsurface sediment has a lower mud content than that at the bed surface. The subsurface material consists primarily of sand deposited at fairly high velocity currents during freshwater floods. Deposition of suspended sediment during periods of low discharge causes the increase of mud in the sediments at the sediment-water interface. The thickness of this mud is less than 0,5 m. This is a thin mud accumulation compared to lower down in the estuary, where sea water and fresh water mixes. It indicates the effect of flocculation on the deposition of clastic mud.



Mean Grain Size on Surface

fig 3–2a

Mean Grain Size on Surface

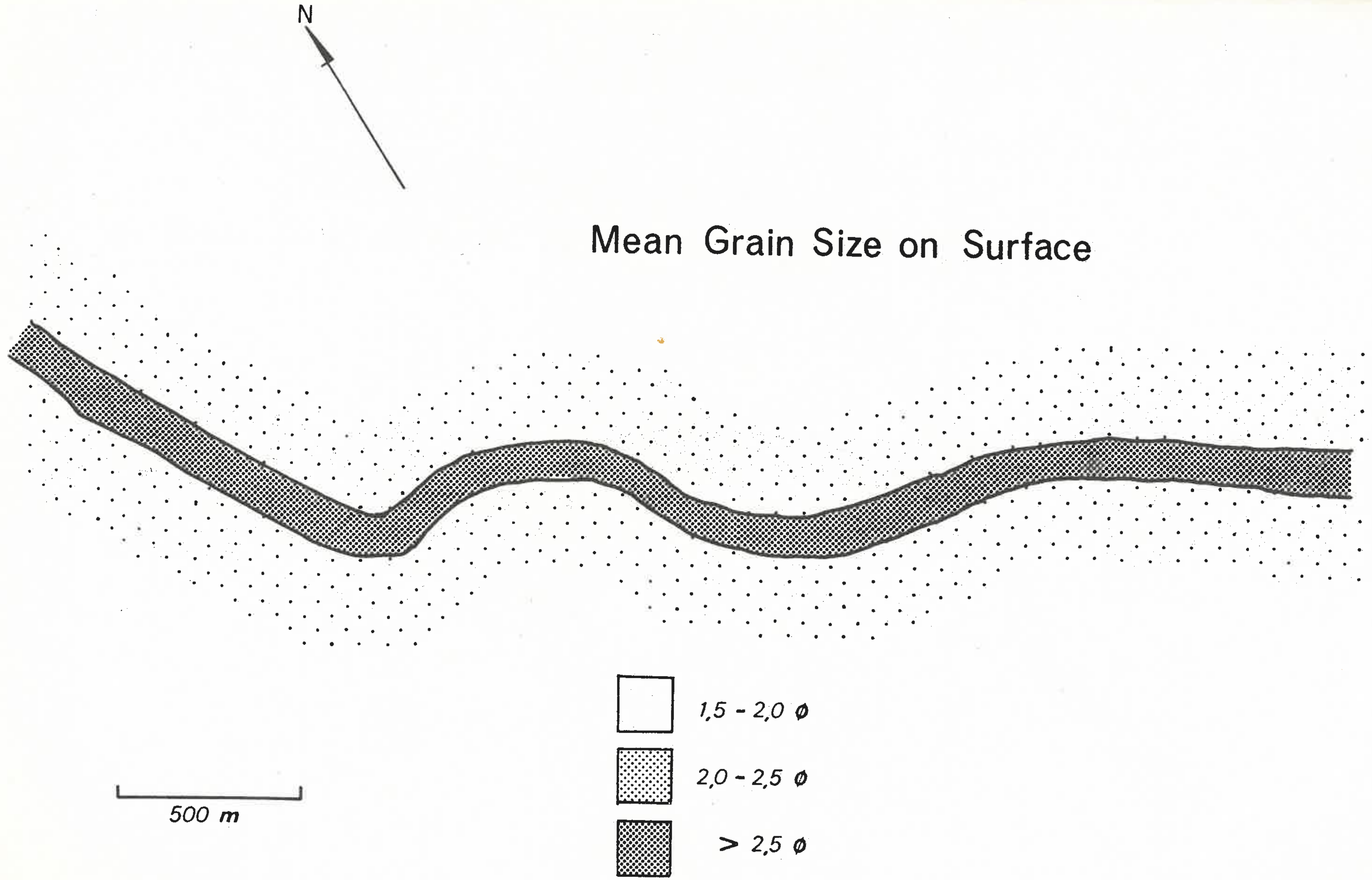


fig 3-2a

Mean Grain Size on Surface

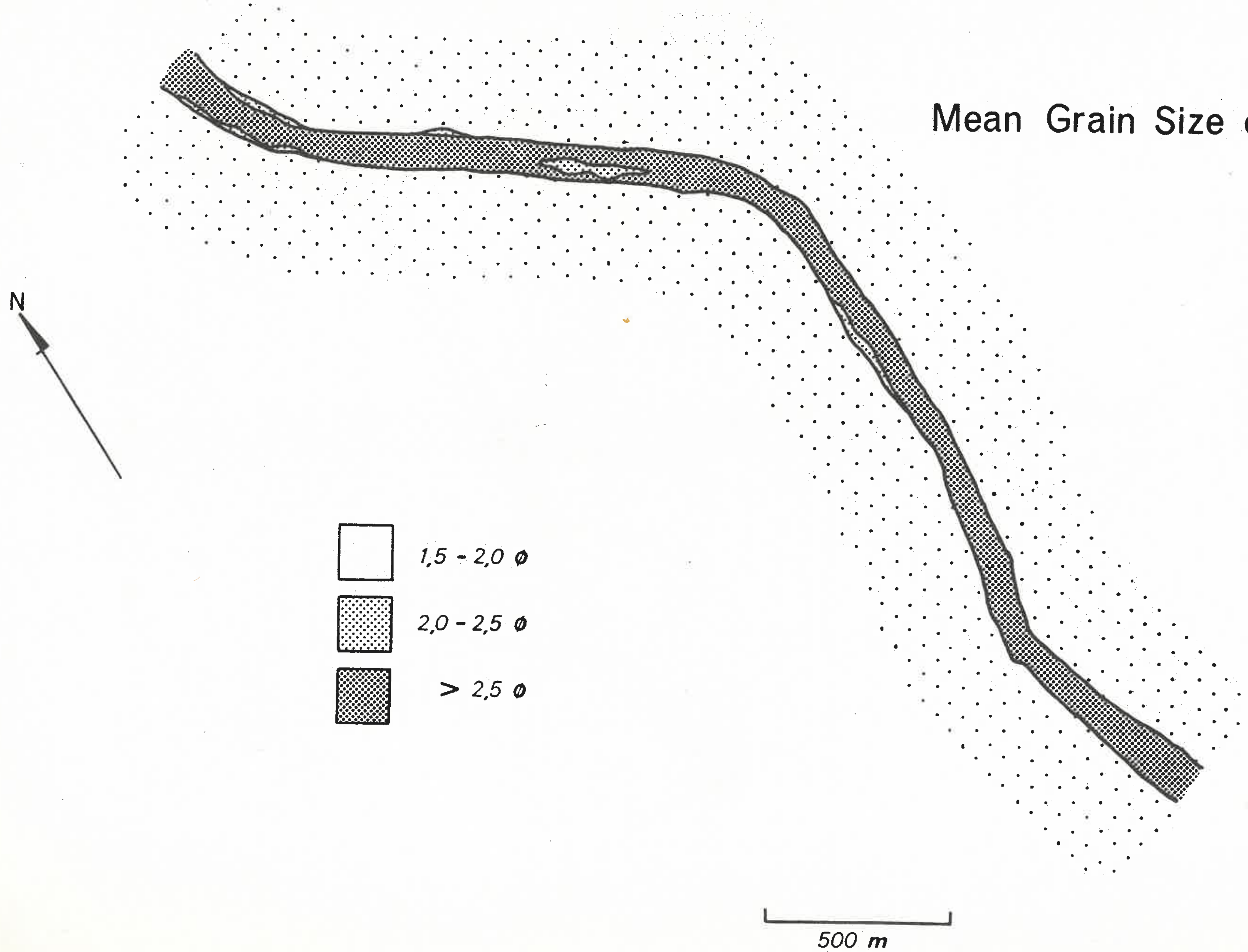


fig 3-2a

Mean Grain Size at -0,5m

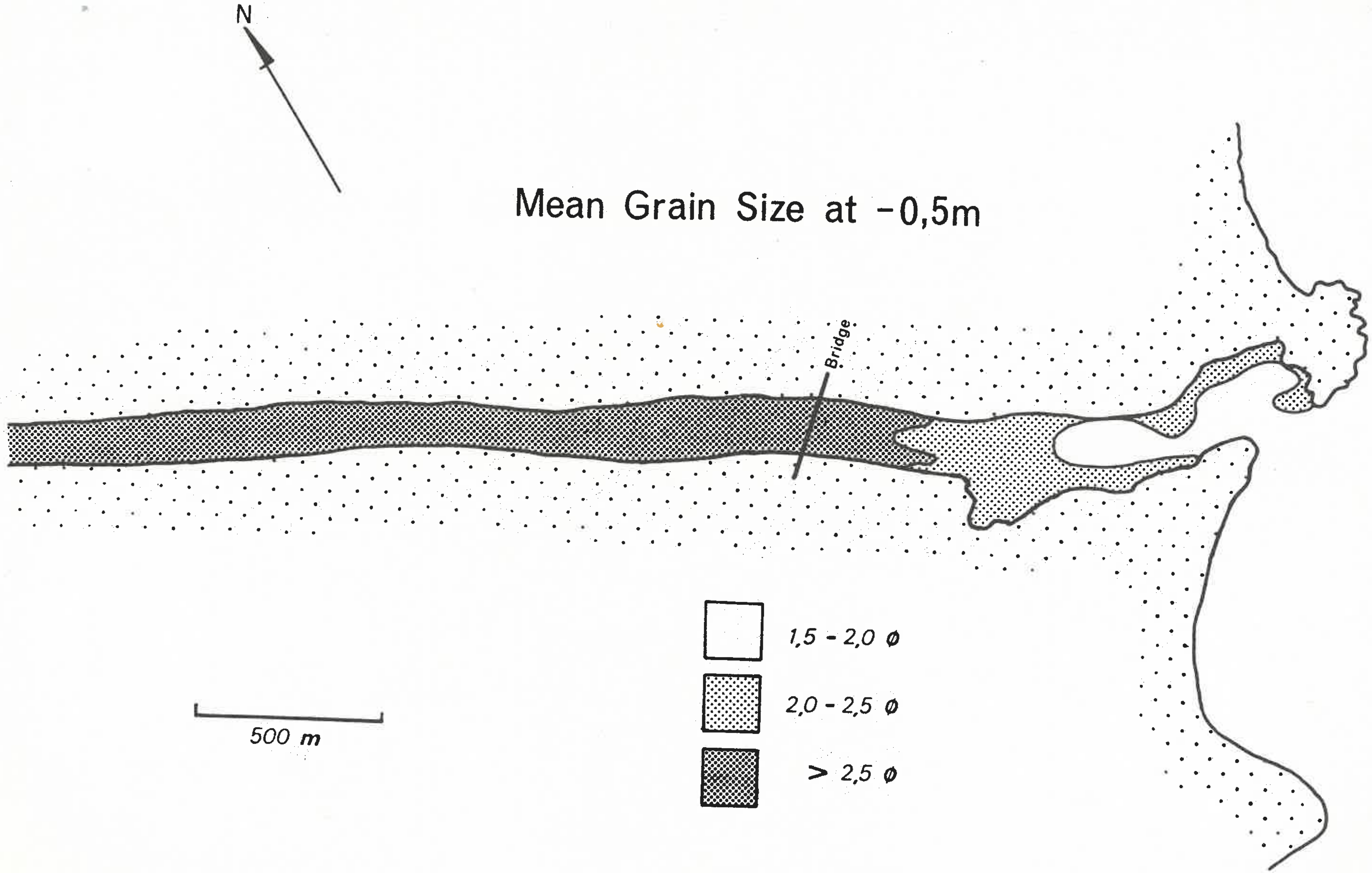


fig 3-2b

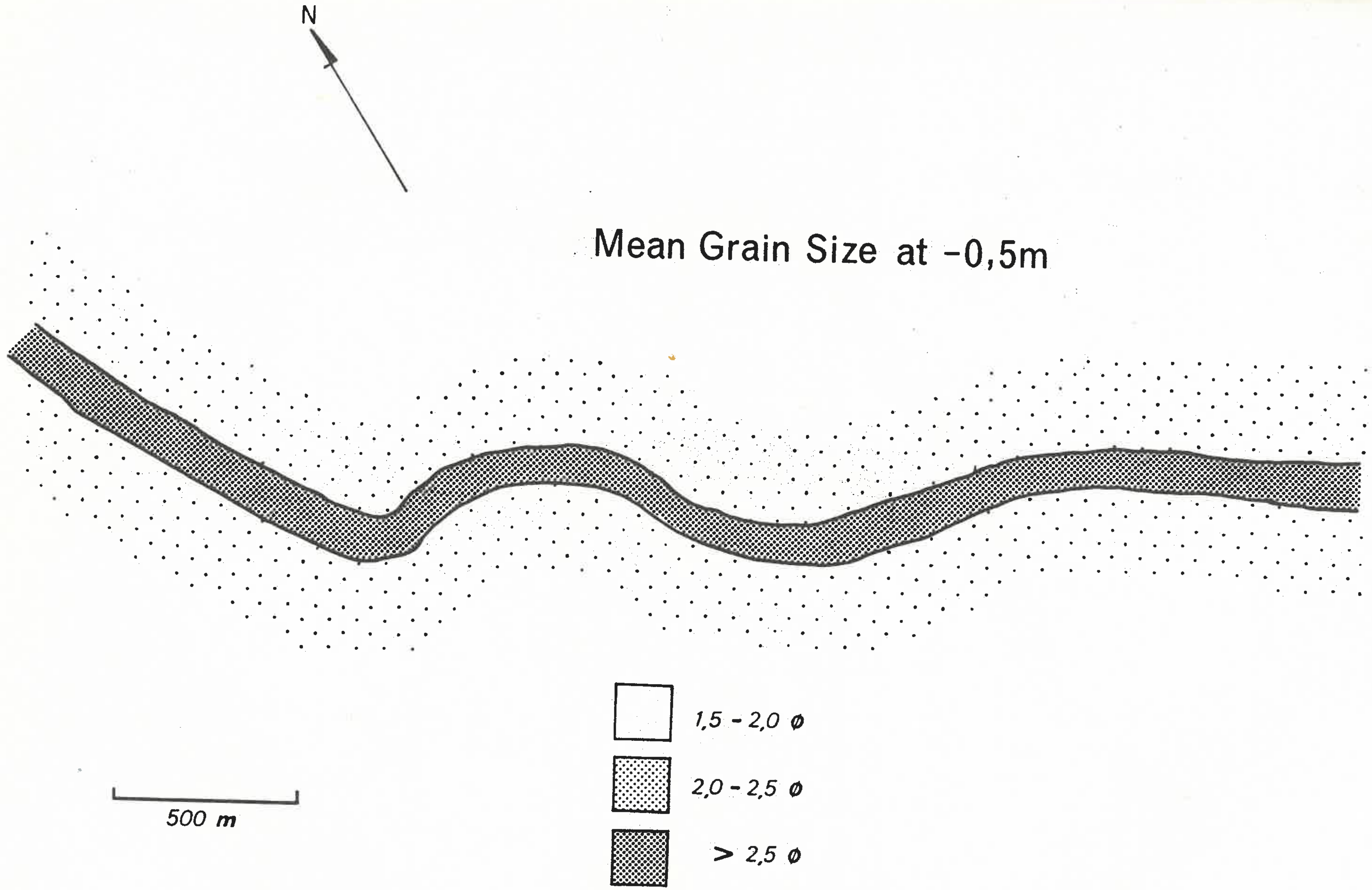


fig 3-2b

Mean Grain Size at -0,5m

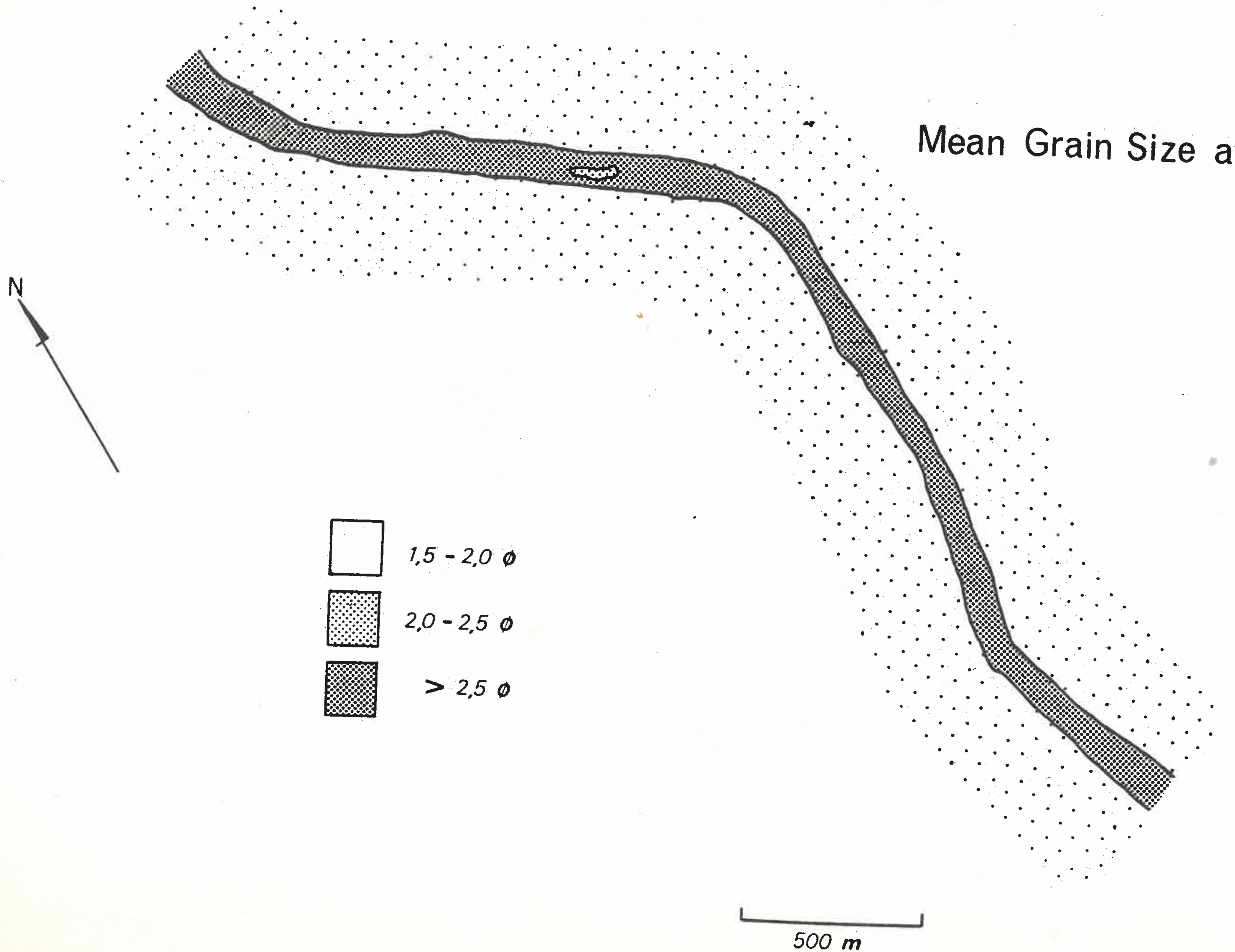


fig 3-2b

Surface Distribution of Mud

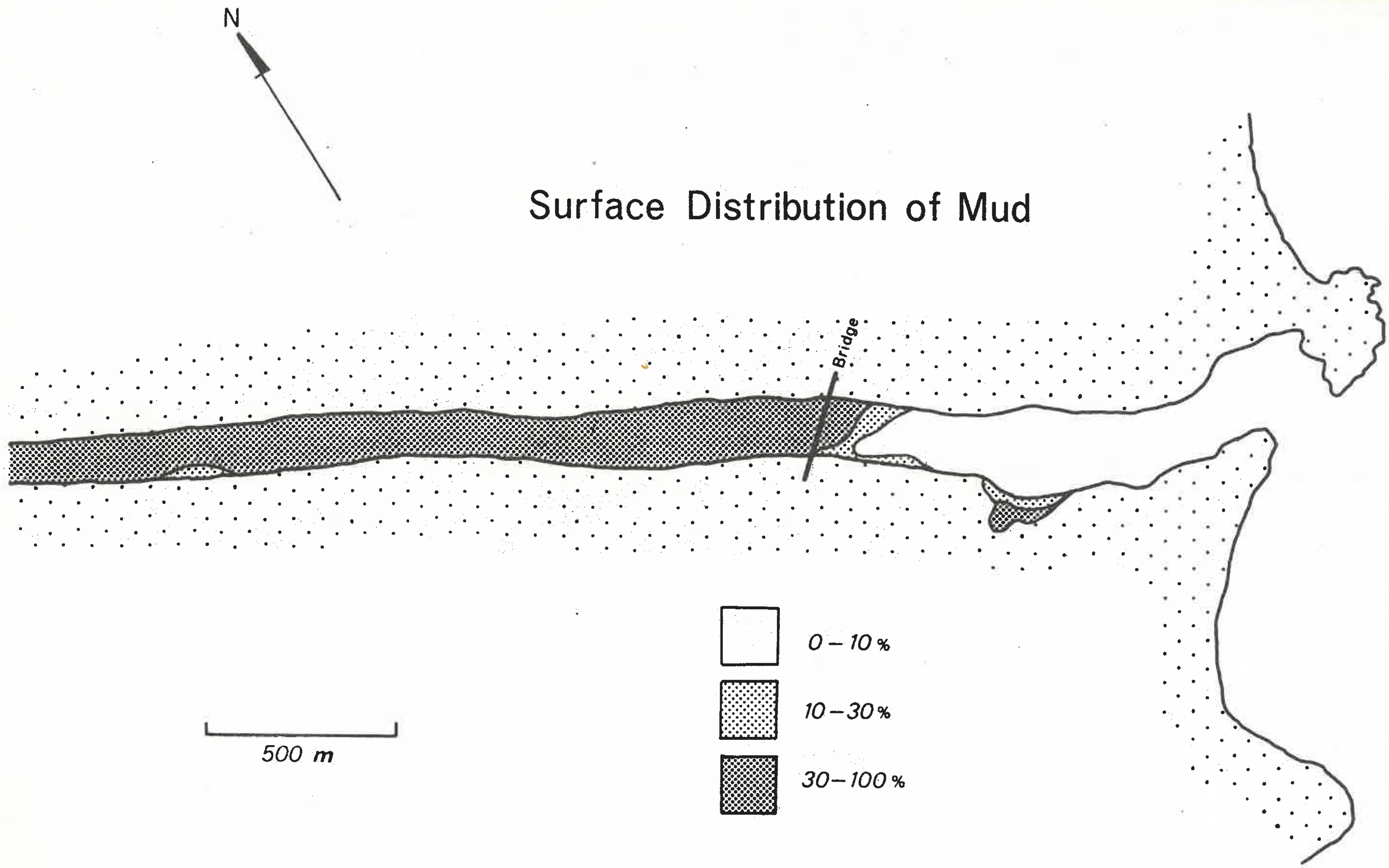


fig 3–3a

Surface Distribution of Mud

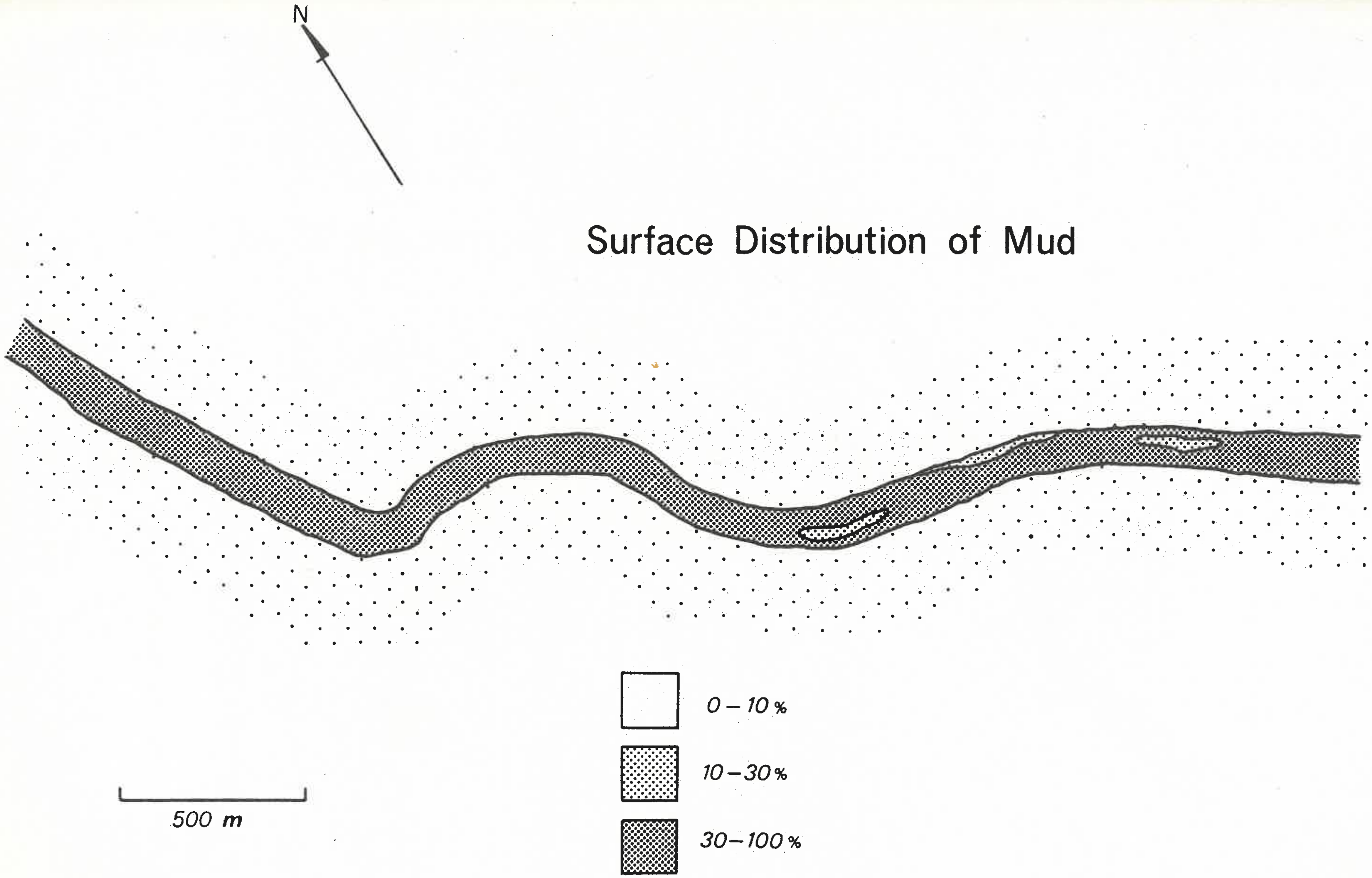


fig 3–3a

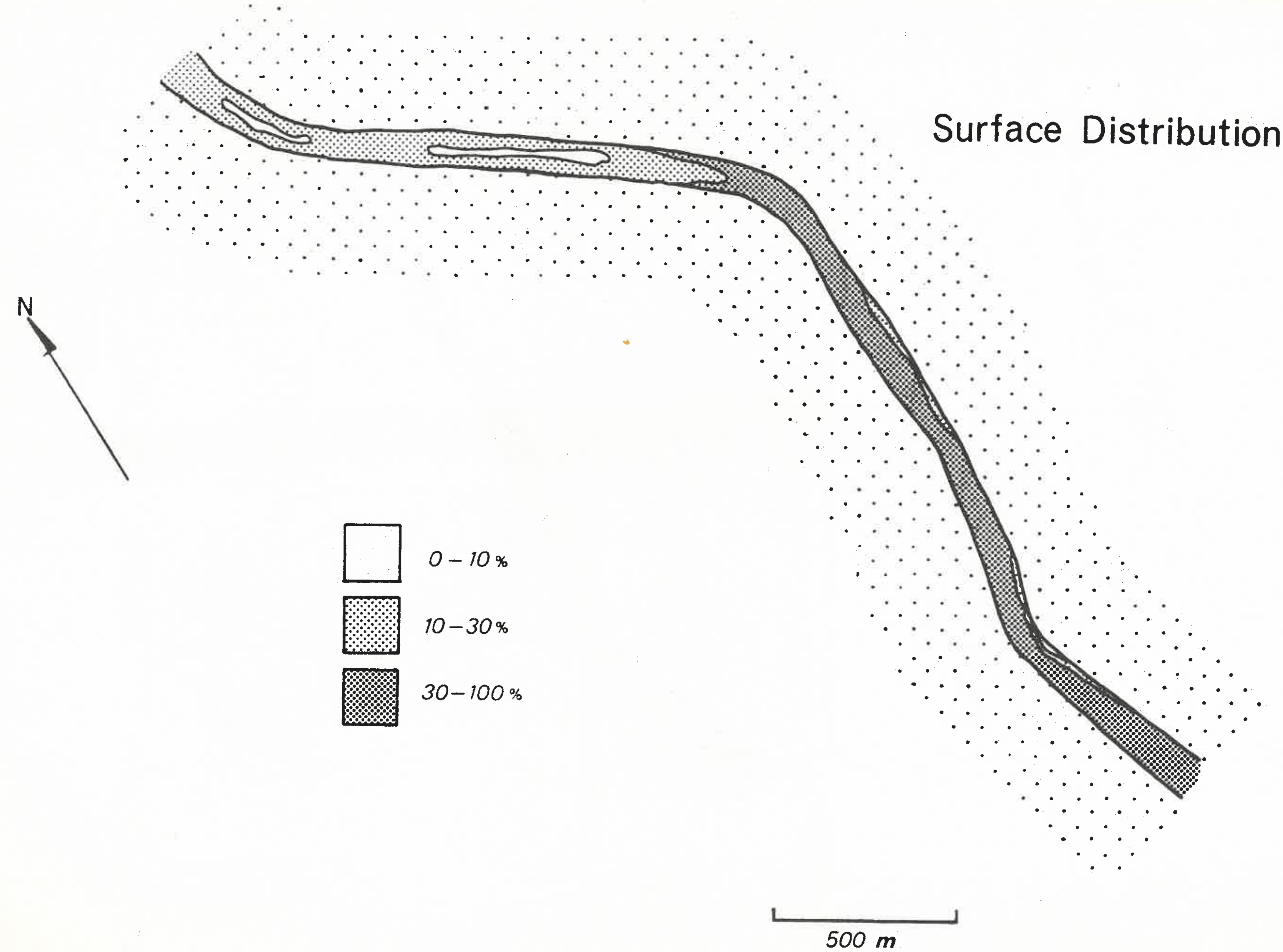


fig 3–3a

Mud Distribution at - 0,5m

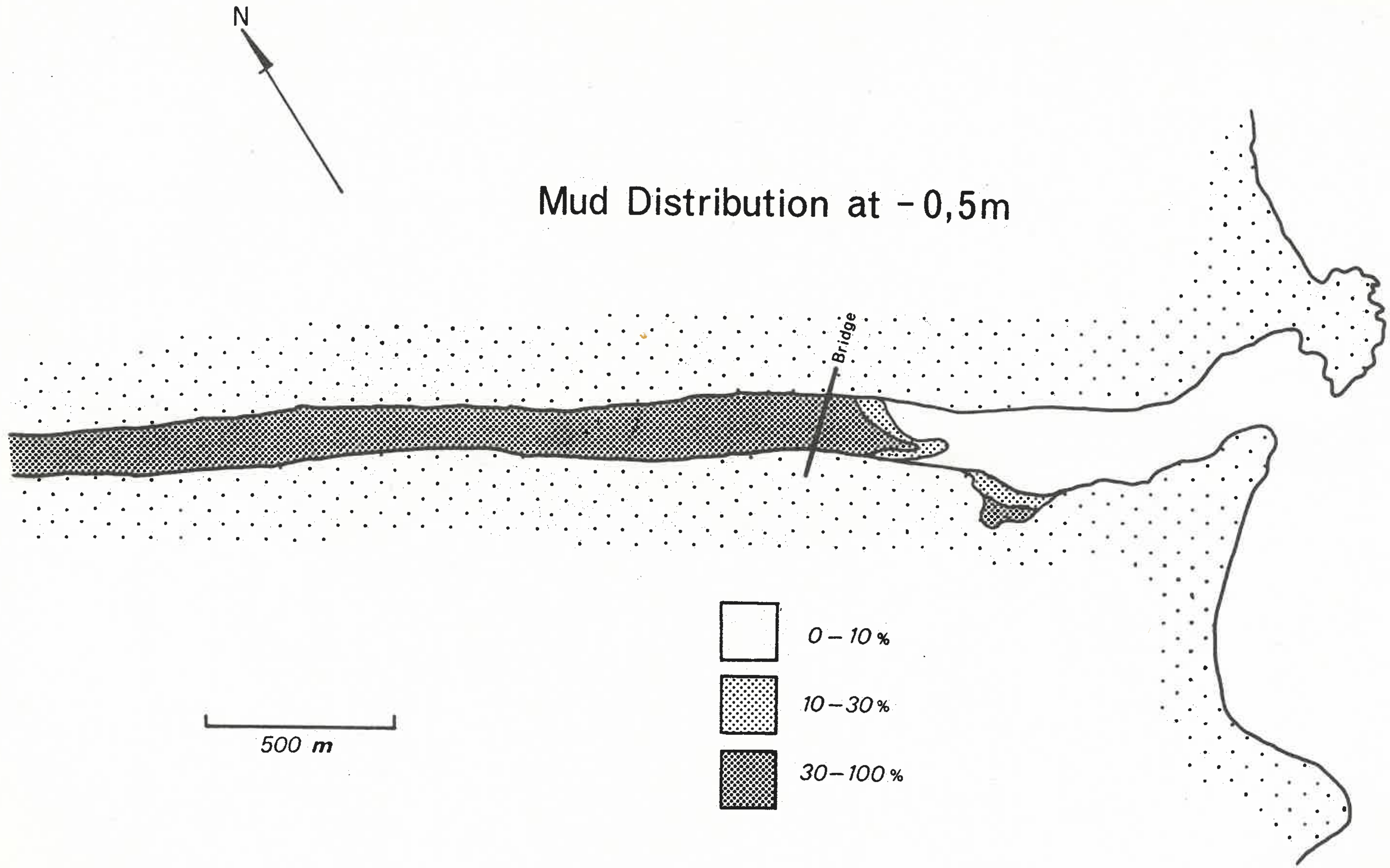


fig 3–3b

Mud Distribution at -0,5m

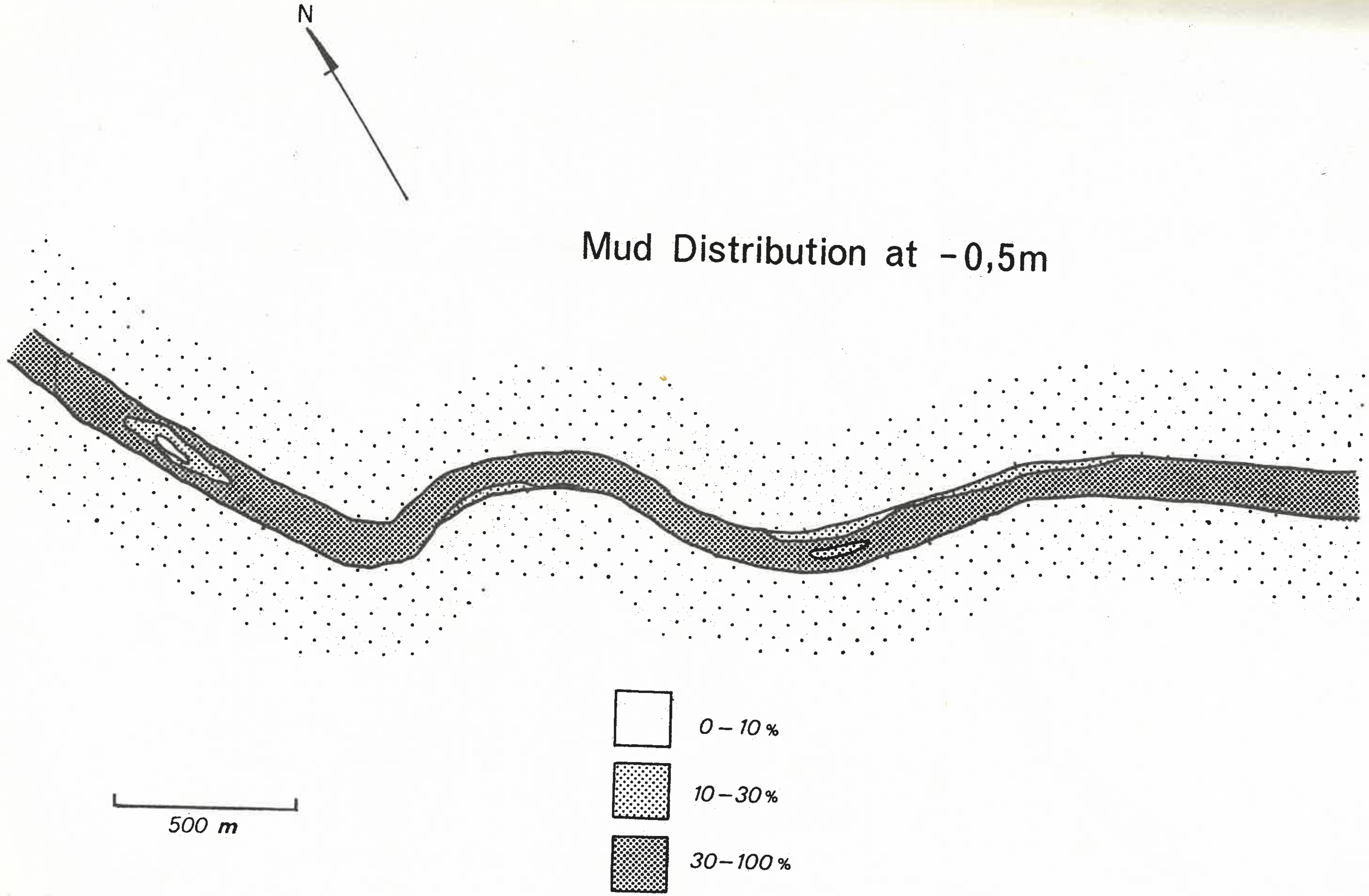


fig 3–3b

Mud Distribution at -0,5m

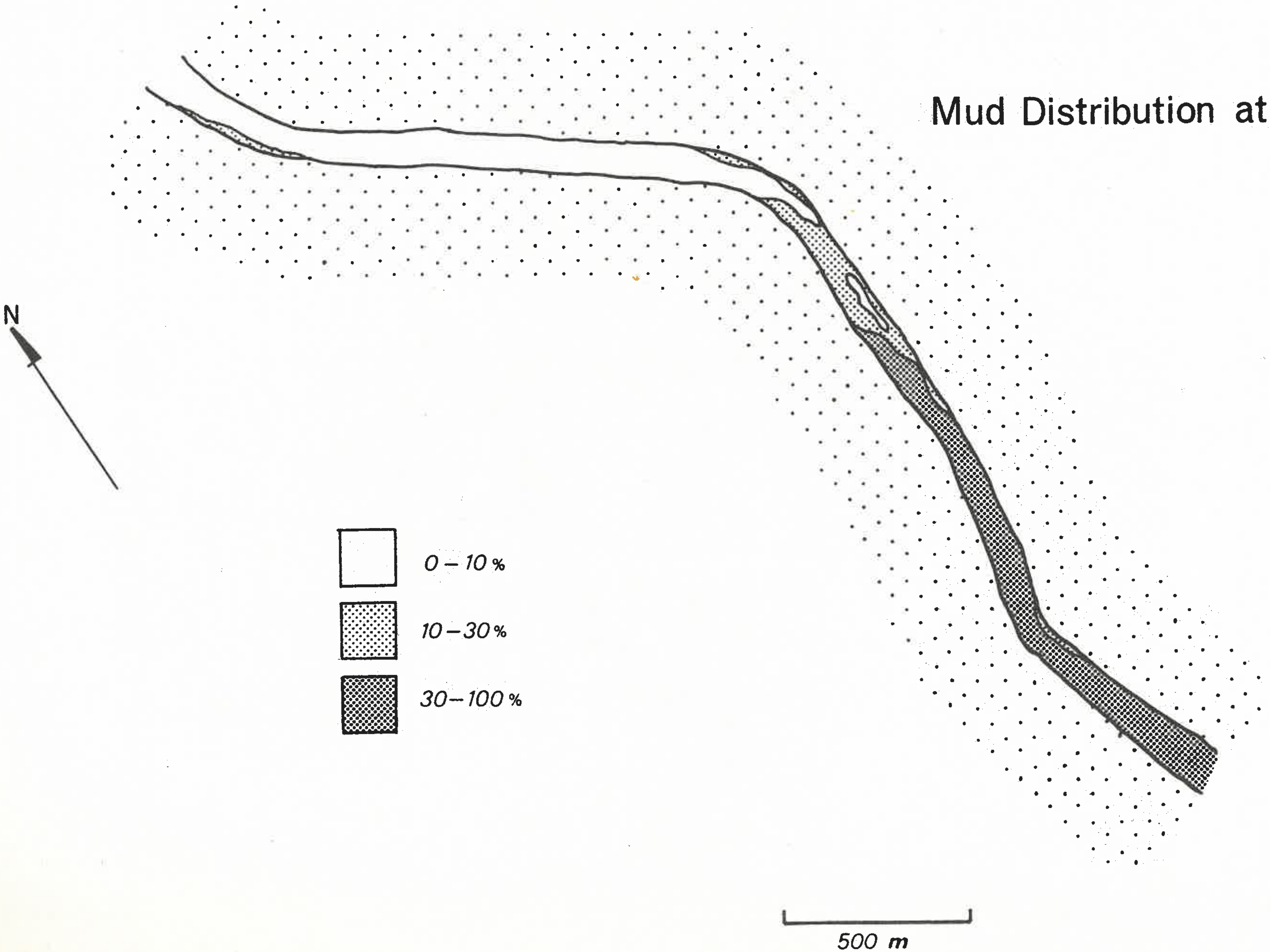


fig 3-3b

Biogenic carbonate sand essentially originates from the sea and its content decreases from about 35 % at the inlet to a trace amount about 1.2 km farther up-estuary. As marine sand extends no farther up-estuary and the carbonate is concentrated in the coarse fraction of the source sand on the adjacent beach, the up-estuary fining of marine sand will cause a decrease of the carbonate content.

Areas of high organic content coincide with areas of very low current velocity. In general the organic content increases from a low percentage at the inlet to higher but variable percentages farther up-estuary. The highest concentrations of organic material coincide with the area of flocculation deposition of clastic fine-grained material (section 3.4). From this it can be concluded that the fine-grained organic material is also deposited as floccules.

3.2 Aerial photograph interpretation

Owing to the high content of suspended material, the water of the estuary is turbid. As a result the aerial photographs show little detail of the underwater sediment bodies. A complete description is consequently impractical and photo-interpretation maps could also not be prepared. Near the inlet where the water is marginally clearer some photographs suggest a flood-tidal delta extending about 1,2 km up-estuary from the inlet. Its presence is confirmed by field observations while its marine source is further corroborated by laboratory studies (section 3.3).

The aerial photographs also show periodic blocking of the Great Fish inlet (e.g. during 1965-1966), presumably by wave-deposited sand bars.

3.3 Sediment source (fig. 3.4)

Sediments in the Great Fish estuary are predominantly of fluvial origin. The largest fraction of these sediments consists of mud which originates in the catchment area. Marine sand only migrates about 1,2 km up-estuary from the inlet.

Sand samples from all over the estuary were microscopically investigated. (These were first acid-leached to remove carbonate, oxidized to destroy organic material and sieved to obtain the medium sand size class.) Sand in the lower 1,2 km of the estuary consists of well rounded quartz grains with little other material. Sand in the upper estuary is a mixture of rock fragments, angular quartz grains and subordinate heavy minerals. The rounded sand in the lower estuary is of marine origin whereas the less mature sand in the upper estuary is fluvial. A comparison with other data (section 3.1) shows that fluvial mud makes up a considerable part of the sediment but is less abundant in the lower 900 m of the estuary.

Sediment Source

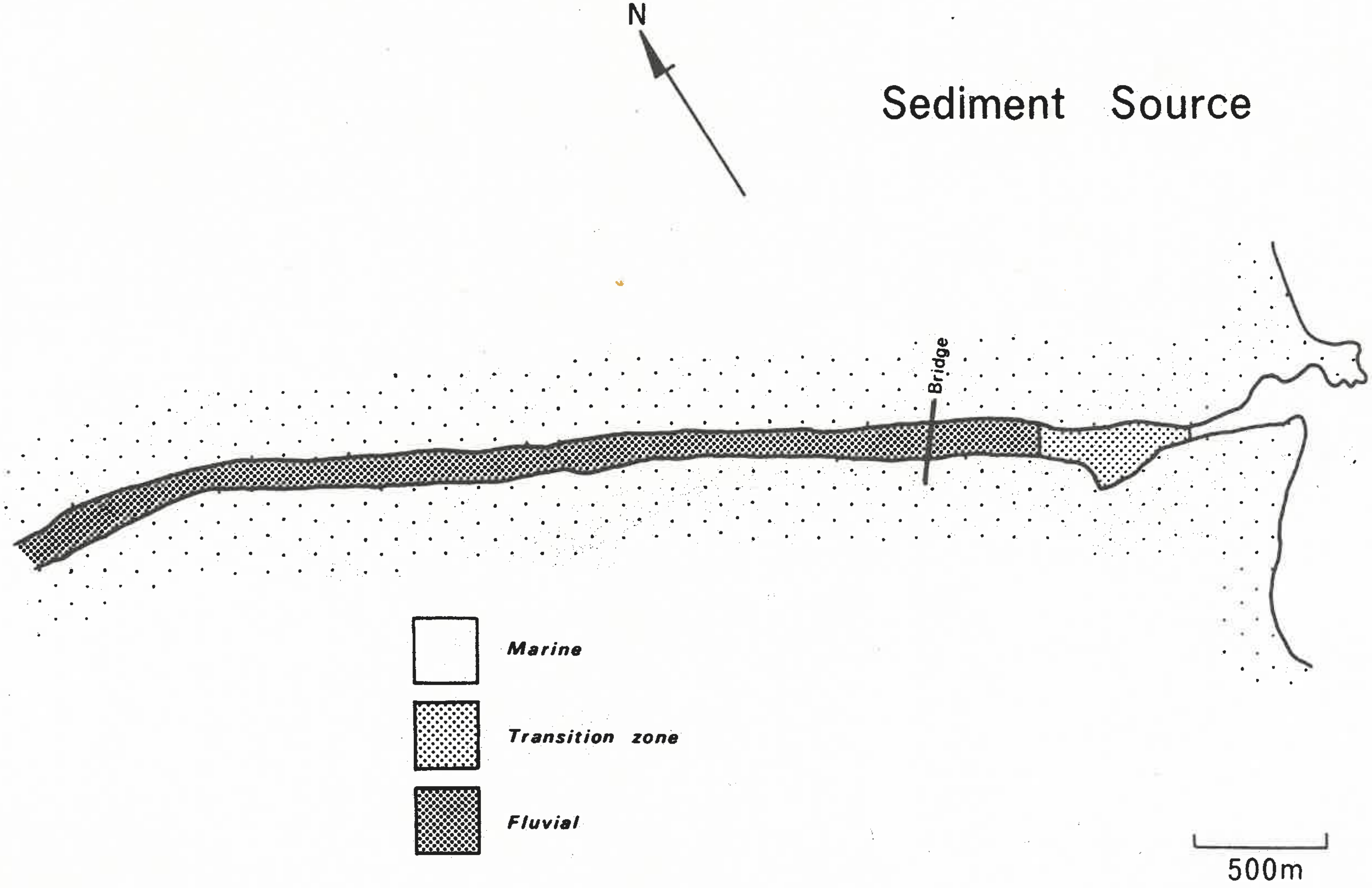


fig 3-4

Sand in the upper estuary is finer grained, and the grains are more angular than the marine sand near the inlet. Heavy minerals found in the upper estuary probably originate from the Karoo dolerites in the catchment area.

Sediments which form the shoals, particularly in the upper estuary, are of fluvial origin and were deposited during freshwater floods.

3.4 The effect of fresh water and salt water mixing.

Sea water and fresh water mixing takes place between about 1 km and 7 km up-estuary from the inlet. The fresh river water has a high suspended load of clay and silt. When this sediment comes into contact with salt water the clay particles flocculate as a result of electrostatic and surface tension attraction. The floccules have a much greater settling velocity than the individual clay particles and are deposited from suspension. This process, called "siltation", seems to be the main depositional process during times of low river discharge. The result is that a thick layer of unconsolidated mud covers the bottom in the zone of sea water and fresh water mixing. In many areas the apparent thickness of the clay accumulation exceeds 1 m. It is not a cause for undue concern because the unconsolidated mud contains a high percentage of interstitial water (probably about 60% to 80%) and is readily eroded. Because the mud contains so much water its effective thickness is less than it seems.

In the upper estuary the water turbulence resulting from the tide is low. Mud-loaded, fresh river water probably floats on a salt wedge prograding up-estuary from the sea. Mixing of fresh water and salt water takes place across the density interface. Such a salt wedge was however not observed in the field.

4. THE RATE OF SEDIMENT ACCUMULATION

4.1 General

Most estuaries on the south-eastern Cape coast are flood-dominant (Reddering and Esterhuysen, 1981a, 1981b, 1981c; Uncles et al., in prep.). Marine sediment entering such an estuary during the flood tide cannot completely be scoured from it during the ebbing tide. As a result marine sediment generally progrades from the inlet up into the estuary.

In the estuary of the Great Fish it is difficult to establish the extent of the movement of the marine and fluvial sediment bodies in the area of salt water and fresh water mixing because the entire sandy substrate is covered by a layer of mud (section 3.4).

The tidal influence on the Great Fish estuary seems to be weaker than in other south-east Cape estuaries. The up-estuary sediment movement is consequently not as marked as in the other estuaries, whereas, by contrast, the fluvial influence on the Great Fish estuary is more marked. The greater influx of fluvial sediment available (section 2.1.3) to the estuary plays a large role in the maintenance of the fluvial sediment dominance. This is further accentuated by the large fluvial discharge rate.

Shoaling in the estuary is mainly in the form of sand bars of the braided river type in the upper reaches of the estuary (section 3.3).

4.2 The effect of the bridges

The bridges across the estuary of the Great Fish River have little effect on the tidal circulation. The embankment of the present road-bridge crosses a part of the supratidal flats. This may have two consequences. Firstly the saltmarsh vegetation has been destroyed in the immediate vicinity of the bridge. This is not very serious as it involves only a limited area (about 1×10^5 m^3).

The supratidal flats of the lower estuary also act as a flood plain during fluvial floods. The bridge blocks this flood plain and dams the "emergency exit" of the river during floods. Apart from the possible effect on the backwater curve a serious flood is likely to damage the embankment. In August, 1970 the previous road bridge, called the Boy Retief bridge, was destroyed by a freshwater flood. Discharge records from Committees Drift (about 50 km from the coast) show that the discharge on that day was 1883×10^6 m^3 (Department of Water Affairs, 1978).

A further effect that may be environmentally detrimental is that during fluvial floods water may dam up behind the embankment and create a cell of flow separation in the zone of relatively quiet water over the supratidal flat adjacent to the embankment. Sediment will then be deposited in this cell of flow separation and increase the height of the supratidal flat. This is a gradual and probably a slow process but if the elevation of the supratidal flat is raised above the spring high tide level the saltmarsh will cease to be tidal. The supratidal vegetation will deteriorate and be replaced by terrestrial vegetation. As saltmarshes are of considerable environmental importance this effect of the embankment on the bio-ecology is undesirable.

4.3 The erosion base

The erosion base of a channel is the greatest depth to which the channel is eroded during an "average" flood. This surface is usually paved with pebbles, shell gravel or occasionally on a highly compacted clay substrate. If this erosion base is at the sediment surface or at a shallow depth below the sediment surface, little sediment has been deposited onto it. If however the erosion base is not intersected at a depth of 0,5 m into the sedimentary substrate (the routine depth of sampling for this investigation) it means that at least 0,5 m of sediment has accumulated since the last flood. In this way the position of the erosion base can be used as an aid to establish whether sediment accumulation is taking place.

During field observations the erosion base of the Great Fish estuary was only encountered near the inlet. It indicates that sediment accumulation is taking place. The depth of the erosion base below the sediment surface could not be determined as the thickness of the mud deposit in most places exceeded the penetration capacity of the 0,5 m long core tubes that were routinely used (section 3.1).

5. DISCUSSION AND CONCLUSIONS

5.1 The significance of the results

Results obtained in this investigation indicate that over the short term sediment accumulates in the Great Fish estuary. During freshwater floods the sediment load consists mainly of fluvial sand while suspended material predominates during periods of low discharge.

The results also show the importance of dissolved salt in deposition of suspended material. Marine sand influx into the estuary is volumetrically subordinate to that of fluvial material. Compared to the other estuaries on the South-east Cape coast this is unusual as marine sediment influx is usually the more important aspect of estuarine sedimentation (Reddering and Esterhuysen, 1981a, 1981b and 1981c).

The nature of the sediment accumulation and the flood behaviour of the Great Fish River indicate that the sediment accumulation in the estuary is normal. The mud accumulated in the estuary has a high water content and is as such readily eroded. Freshwater floods often have sufficient discharge to remove this sediment from the estuary. Discharge records (Department of Water Affairs, 1978) indicate that between 1960 and 1970, the largest daily average discharge ranged between 198 X 10^6 m^3 per day and 1883 X 10^6 m^3 per day.

5.2 Classification implications

The Great Fish inlet is periodically blocked (section 3.2). The area where salt water and fresh water mixes is limited to within 7 km from the inlet (section 3.4).

The internationally accepted definition of an estuary is: "An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water from land drainage" (Cameron and Pritchard, 1963).

From the above definition the Great Fish "estuary" is not a true estuary. It does not always have ".. a free connection .." with the open sea as the inlet is is periodically blocked by a sand bar. When the "estuary" is tidal, the zone of mixing extends 7 km up-estuary from the inlet. This means that the term estuary would apply only to the lower 7 km of the fluvio-marine transition. Day (1980) proposed a formal change of the definition of an estuary to include the "blind estuaries" that are found on the South African coast and on many other wave dominant coasts of the world. His definition reads: "An estuary is a partially enclosed coastal body of water which is either permanently or periodically open to the sea, and within which there is a measurable variation of salinity due to mixing of sea water with fresh water derived from land drainage". This amended definition thus proposes to change two of the fundamental properties of estuaries. This cannot be recommended.

Estuaries that conform to the established definition are significantly different to those with periodically blocked tidal inlets. The non-tidal "estuaries" do not conform to the established definition but are included in Day's (1980) variation. Differences between the types of coastal water include water exchange patterns, nutrient and pollutant exchange patterns, and the migration of various animal species. The hydraulic properties and sediment dispersal in the closed-inlet "estuaries" are also different from the permanently tidal estuaries.

The solution to the classification of estuaries cannot be solved by altering the existing definition. The term "blind estuary" is not really suitable, as it refers to a barred estuary. The problem can be overcome by calling the estuaries with periodically closed inlets "ephemeral estuaries" and refer loosely to these as "estuaries". In this way the "Great Fish estuary" as it is termed throughout this report is an ephemeral estuary. Of the 289 "estuaries" on the South African coast only 37 have permanently open tidal inlets (Moes, 1979). This means that there are only 37 estuaries on the South African coast. (This number is actually 36 because the inlet of the Great Fish is not permanent as quoted by Moes.) The remaining 253 estuaries are ephemeral.

5.3 Recommendations for further study

Although the aims of this study (section 1) have largely been achieved, all aspects of the sedimentation in the Great Fish estuary have not been explained fully. This is mainly the result of the extensive mud cover overlying the coarser substrate. Being below a reasonable level of investigation these sand accumulations could not be studied.

A further investigation should be carried out after a freshwater flood to determine its effect on the mud accumulation and to ascertain the true extent of sand deposition in the entire estuary.

An attempt should also be made to study the estuarine bottom topography with the aid of infrared aerial photographs.

ACKNOWLEDGEMENTS

Prof I C Rust and Anni Tonin carefully read the manuscript and suggested various improvements. This investigation was started as part of the East Cape Marine Pollution Programme and later transferred to the Estuaries Programme funded by SANCOR. Peter Wentworth explained the computer printing system to the authors.

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APPENDIX 1

This section lists the all the sediment data collected in the Great Fish estuary. The sample lines are marked on fig. 3.1. The positions of the sample stations can be found from the coded station numbers. For example sample F 3;2T originates from the Great Fish ("F" in the code) and was collected on line number 3 ("3", see fig. 3.1). It was taken at the bed surface ("T" denotes TOP) at position 2 on that line. This sampling spot (indicated as a dot, fig. 3.1) is the second from the LEFT, looking up-estuary. Samples were also collected 0,5 m below the surface of the bed by coring. These samples are indicated by a "B" (for BOTTOM) in the code.

All grain sizes listed below are in PHI-units and NOT in mm. ($PHI = -\log_2$ (grain size in mm / 1 mm))

This appendix has three sections: A, B and C. Section A lists the grain size class distributions of the samples. Section B gives the statistical parameters and section C lists the respective contents of bioclastic carbonate and of organic material.

APPENDIX 1 A

This section lists the grain size class distributions.

The parameters listed below are as follows:

VCS - Very coarse sand (grain diameters 1 mm to 2 mm)

CS - Coarse sand (grain diameters 0,5 mm to 1 mm)

MS - Medium sand (grain diameters 0,25 mm to 0,5 mm)

FS - Fine sand (grain diameters 0,125 mm to 0,25 mm)

VFS - Very fine sand (grain diameters 0,063 mm to 0,125 mm)

Mud - Silt + clay (grain diameters less than 0.063 mm)

Sample no	%VCS	%CS	%MS	%FS	%VFS	%Mud
F 1;1T	0.00	1.13	43.02	55.09	0.38	0.38
1B	0.00	0.45	37.27	60.45	0.91	0.91
2T	0.00	0.41	53.72	45.04	0.00	0.83
2B	0.00	0.39	28.96	69.11	0.77	0.77
3T	0.00	3.26	69.06	26.71	0.33	0.65
3B	0.00	0.82	50.00	48.09	0.55	0.55
F 2;1T	0.00	0.27	45.82	52.83	0.54	0.54
1B	0.00	2.89	54.07	41.47	0.79	0.79
2T	0.00	0.36	39.86	59.42	0.00	0.36
2B	0.00	0.96	48.80	49.28	0.48	0.48
3T	0.00	0.31	23.68	74.14	0.93	0.93
3B	0.98	0.98	27.78	67.97	1.63	0.65
F 3;1T	0.00	0.00	10.67	87.00	1.33	1.00
1B	0.00	0.00	13.01	85.13	1.12	0.74
2T	0.00	1.02	65.22	32.74	0.26	0.77
2B	0.00	1.15	66.74	31.19	0.00	0.92
3T	0.00	2.39	61.09	33.45	0.34	2.73
3B		Solid substrate				
F 4;1T	0.00	0.30	13.95	82.20	2.67	0.89
1B	0.00	0.37	9.59	85.61	2.95	1.48
2T	0.00	0.39	7.09	90.94	0.79	0.79
2B	0.00	0.00	19.49	75.74	1.10	3.68
3T	0.00	0.00	12.77	85.41	1.22	0.61
3B	0.00	0.33	22.11	75.58	0.99	0.99
4T	0.00	0.00	29.07	69.65	0.64	0.64
4B	0.28	1.14	42.17	55.56	0.28	0.57
5T	0.00	0.00	3.21	18.07	1.20	77.51
5B	0.00	0.00	2.81	17.42	2.25	77.53
F 5;1T	0.00	0.00	10.00	81.21	2.73	6.06
1B	0.00	0.00	18.36	70.90	2.26	8.47
2T	0.00	0.00	2.21	93.38	3.31	1.10
2B	0.00	0.00	0.00	0.36	5.40	94.24
3T	0.00	0.00	27.01	71.06	0.64	1.29
3B	0.00	0.00	18.95	79.30	0.87	0.87
4T	0.00	0.00	14.12	81.47	1.76	2.65
4B	0.00	0.00	13.97	82.96	2.23	0.84
5T	0.00	0.22	34.35	63.26	0.65	1.52
5B	0.00	0.00	0.00	0.00	0.00	100.00
F 6;1T	0.00	0.00	13.77	68.83	2.83	14.57
1B	0.00	0.00	0.00	1.10	6.25	92.65
2T	0.00	0.00	0.00	5.38	21.20	73.42
2B	0.00	0.00	0.35	1.39	22.30	75.96
3T	0.00	0.00	0.83	13.22	9.09	76.86
3B	0.00	0.00	0.00	0.00	0.42	99.58
4T	0.00	0.00	0.00	7.07	4.04	88.89
4B	0.00	0.00	0.00	62.98	27.34	9.69
5T	0.00	0.00	0.00	6.34	20.54	73.11
5B	0.00	0.00	0.41	20.58	18.93	60.08

Sample no	%VCS	%CS	%MS	%FS	%VFS	%Mud
F 7;1T	0.00	0.00	0.52	1.05	7.33	91.10
1B	0.00	0.34	0.68	4.39	38.18	56.42
2T	0.00	0.00	0.00	0.00	0.00	100.00
2B	0.00	0.00	0.00	0.00	1.46	98.54
3T	0.00	0.00	0.00	0.00	0.93	99.07
3B	0.00	0.00	0.00	0.00	0.54	99.46
4T	0.00	0.00	0.00	0.00	0.00	100.00
4B	0.35	0.70	3.14	34.15	18.82	42.86
5T	0.25	0.25	1.00	14.54	37.09	46.87
5B	0.60	0.30	0.60	11.34	27.46	59.70
F 8;1T	0.00	0.00	0.51	2.05	17.18	80.26
1B	0.34	0.34	0.68	4.76	12.24	81.63
2T	0.00	0.00	0.00	0.00	1.65	98.35
2B	0.00	0.00	0.00	0.00	0.00	100.00
3T	0.00	0.00	0.00	0.00	1.27	98.73
3B	0.00	0.00	0.00	0.42	0.84	98.73
4T	0.00	0.00	0.00	0.00	0.00	100.00
4B	0.00	0.00	0.00	0.00	0.00	100.00
5T	0.00	0.00	0.00	0.00	1.64	98.36
5B	0.00	0.00	0.55	0.55	3.83	95.08
F 9;1T	0.25	0.25	0.75	7.29	9.80	81.66
1B	0.00	0.00	0.00	0.53	1.60	97.87
2T	0.00	0.00	0.00	0.00	0.00	100.00
2B	0.00	0.00	0.00	0.00	0.00	100.00
3T	0.00	0.00	0.00	0.00	0.00	100.00
3B	0.00	0.00	0.00	0.00	0.56	99.44
4T	0.00	0.00	0.00	0.95	3.81	95.24
4B	0.30	0.30	0.61	13.41	35.67	49.70
F 10;1T	0.50	0.25	1.74	37.81	30.60	29.10
1B	0.00	0.24	0.98	20.05	25.67	53.06
2T	0.00	0.00	0.00	0.00	0.00	100.00
2B	0.00	0.00	0.00	0.00	0.00	100.00
3T	0.00	0.00	2.08	29.69	18.23	50.00
3B	0.00	0.00	0.57	9.09	6.25	84.09
4T	0.00	0.00	0.00	0.00	1.48	98.52
4B	0.00	0.40	0.40	5.95	8.33	84.92
F 11;1T	0.00	0.00	0.32	24.03	32.14	43.51
1B	0.00	0.00	0.35	20.56	16.03	63.07
2T	0.00	0.00	0.00	0.00	0.00	100.00
2B	0.00	0.00	0.00	0.42	16.95	82.63
3T	0.00	0.00	0.00	0.00	0.00	100.00
3B	0.00	0.00	0.00	0.00	0.00	100.00
4T	0.00	0.00	0.00	0.00	0.00	100.00
4B	0.00	0.00	0.00	0.00	0.00	100.00

Sample no	%VCS	%CS	%MS	%FS	%VFS	%Mud
F 12;1T	0.00	0.00	0.81	17.41	26.32	55.47
1B	0.00	0.00	1.65	36.63	13.99	47.74
2T	0.00	0.42	8.33	12.08	25.42	53.75
2B	0.00	0.00	0.71	2.14	7.86	89.29
3T	0.00	0.36	10.36	66.79	5.71	16.79
3B	0.00	0.00	8.19	66.55	6.05	19.22
4T	0.00	0.00	0.00	0.00	1.16	98.84
4B	0.00	0.00	0.00	0.87	0.87	98.26
F 13;1T	0.00	0.00	0.00	1.33	4.67	94.00
1B	0.00	0.43	2.15	30.90	30.90	35.62
2T	0.00	0.68	0.68	17.57	5.41	75.68
2B	0.00	0.00	0.00	7.95	4.64	87.42
3T	0.00	0.00	0.00	0.80	4.00	95.20
3B	0.00	0.00	0.00	0.00	1.31	98.69
4T	0.00	0.00	0.75	64.66	16.54	18.05
4B	0.00	0.00	0.27	64.13	21.47	14.13
F 14;1T	0.00	0.00	0.00	1.08	1.08	97.85
1B	0.00	0.36	0.00	18.64	46.24	34.77
2T	0.00	0.00	3.72	69.59	10.14	16.55
2B	0.00	0.00	5.09	67.02	6.43	21.45
3T	0.00	0.00	0.00	0.81	1.63	97.56
3B	0.00	0.00	0.78	14.84	14.84	69.53
4T	0.00	0.00	0.49	19.51	16.10	63.90
4B	0.00	0.00	0.30	40.06	50.15	9.50
F 15;1T	0.00	0.50	1.49	23.27	9.41	65.35
1B	0.00	0.00	6.36	61.84	22.61	9.19
2T	0.00	0.00	0.00	0.00	1.27	98.73
2B	0.00	0.00	0.00	0.00	0.74	99.26
3T	0.00	0.00	2.65	62.83	5.31	29.20
3B	0.00	0.67	1.33	22.00	3.33	72.67
4T	1.35	0.68	4.05	31.08	13.51	49.32
4B	0.00	0.46	1.38	12.44	5.53	80.18
F 16;1T	0.00	0.53	0.00	2.65	18.52	78.31
1B	0.00	0.00	0.00	0.00	0.67	99.33
2T	0.00	0.00	4.61	62.06	16.31	17.02
2B	0.00	0.00	0.39	59.30	35.66	4.65
3T	0.00	0.00	0.83	50.42	16.67	32.08
3B	0.00	0.00	0.75	55.47	40.00	3.77
4T	0.28	0.28	0.56	55.28	21.39	22.22
4B	0.00	0.00	0.37	4.44	23.33	71.85
F 17;1T	5.00	0.00	0.50	10.00	17.50	67.00
1B	0.00	0.00	0.00	0.00	0.00	100.00
2T	0.00	0.00	0.00	0.00	1.04	98.96
2B	0.00	0.00	0.00	0.81	1.61	97.58
3T	0.00	0.00	0.00	0.00	0.00	100.00
3B	0.00	0.00	0.00	0.70	0.70	98.60
4T	0.00	0.00	0.59	65.59	27.06	6.76
4B	0.00	0.00	1.07	72.95	19.93	6.05

Sample no	%VCS	%CS	%MS	%FS	%VFS	%Mud
F 18;1T	1.09	0.00	0.54	0.54	2.72	95.11
1B	0.68	0.00	0.00	0.00	0.00	99.32
2T	0.56	0.56	1.12	18.54	25.84	53.37
2B	0.00	0.00	0.40	49.00	39.36	11.24
3T	0.00	0.38	7.20	34.09	19.70	38.64
3B	0.00	0.00	6.95	77.04	14.20	1.81
4T	0.35	0.71	3.19	70.92	5.67	19.15
4B	0.00	0.00	0.32	66.67	19.74	13.27
F 19;1T	0.00	0.00	2.32	57.95	29.14	10.60
1B	0.00	0.00	22.65	66.99	8.41	1.94
2T	0.00	0.00	12.50	70.95	2.70	13.85
2B	0.00	0.00	1.64	73.36	21.38	3.62
3T	0.00	0.33	19.27	73.75	2.66	3.99
3B	0.00	0.00	0.32	61.04	35.39	3.25
4T	0.00	0.00	3.51	72.81	13.60	10.09
4B	0.00	0.00	2.08	84.82	11.61	1.49
F 20;1T	0.00	0.34	0.34	12.79	34.68	51.85
1B	0.79	0.40	1.19	48.62	29.25	19.76
2T	0.00	0.31	13.08	79.75	5.61	1.25
2B	0.00	0.00	0.38	61.36	32.58	5.68
3T	0.00	0.00	1.09	59.42	19.20	20.29
3B	0.00	0.00	0.74	58.09	34.93	6.25
4T	0.00	0.35	19.72	64.79	11.27	3.87
4B	0.00	0.00	4.84	82.58	10.32	2.26

APPENDIX 1 B

This section lists the statistical parameters of the Great Fish sediments. NOTE that the statistical parameters only apply to the sand size classes. Silt and clay are EXCLUDED from these parameters.

The parameters listed below are as follows:

Med. - The distribution median in PHI-units ($Md = P_{50}$) +

Mean - The mean grain size in PHI-units ($M = (P_{16}+P_{84})/2$)

Sort - Grain sorting in PHI-units ($So = (P_{84}-P_{16})/2$))

Ske. - Distribution skewness in PHI-units ($Sk = (M-Md)/S$)

Kurt - Distribution kurtosis in PHI-units

$$(Ku = (((P_{95}-P_5)/2)-S)/S)$$

\+ P_X is the Xth percentile of the relevant distribution.

Where data is lacking no sand is present in the sediment, that is the relevant sample consists of mud only (APPENDIX 1 A).

Sample no	Med.	Mean	Sort	Ske.	Kurt
F 1;1T	2.10	2.03	0.69	-0.10	0.33
1B	2.20	2.08	0.67	-0.17	0.35
2T	1.92	1.97	0.68	0.08	0.33
2B	2.29	2.16	0.62	-0.22	0.43
3T	1.67	1.80	0.62	0.21	0.46
3B	1.98	1.99	0.69	0.02	0.32
F 2;1T	2.07	2.03	0.68	-0.06	0.33
1B	1.86	1.94	0.70	0.11	0.33
2T	2.16	2.06	0.67	-0.15	0.34
2B	2.00	2.00	0.69	-0.00	0.32
3T	2.34	2.23	0.57	-0.20	0.53
3B	2.29	2.15	0.64	-0.23	0.43
F 3;1T	2.45	2.45	0.39	0.00	0.93
1B	2.43	2.43	0.40	0.00	0.98
2T	1.75	1.88	0.65	0.20	0.39
2B	1.73	1.86	0.64	0.21	0.40
3T	1.76	1.88	0.66	0.19	0.37
3B	Solid substrate				
F 4;1T	2.43	2.43	0.41	0.00	1.00
1B	2.46	2.46	0.39	0.00	0.92
2T	2.46	2.46	0.37	0.00	0.77
2B	2.38	2.30	0.51	-0.15	0.67
3T	2.43	2.43	0.40	0.00	0.98
3B	2.36	2.25	0.55	-0.19	0.58
4T	2.30	2.16	0.62	-0.21	0.43
4B	2.11	2.03	0.69	-0.12	0.33
5T	2.44	2.44	0.42	0.00	1.03
5B	2.48	2.48	0.44	0.00	1.39
F 5;1T	2.46	2.46	0.39	0.00	0.91
1B	2.39	2.31	0.51	-0.15	0.67
2T	2.51	2.51	0.36	0.00	0.32
2B	3.47	3.47	0.36	0.00	0.58
3T	2.31	2.19	0.60	-0.21	0.46
3B	2.39	2.32	0.49	-0.13	0.73
4T	2.42	2.42	0.41	0.00	0.99
4B	2.43	2.43	0.41	0.00	0.98
5T	2.23	2.11	0.65	-0.19	0.37
5B	-	-	-	-	-
F 6;1T	2.42	2.42	0.42	-0.01	0.96
1B	3.41	3.41	0.40	0.00	1.01
2T	3.37	3.29	0.50	-0.15	0.68
2B	3.46	3.46	0.37	0.00	0.82
3T	2.81	2.91	0.69	0.13	0.34
3B	3.50	3.50	0.34	0.00	0.32
4T	2.79	2.91	0.65	0.18	0.36
4B	2.72	2.85	0.62	0.21	0.42
5T	3.35	3.23	0.56	-0.20	0.55
5B	2.95	2.98	0.69	0.04	0.32

Sample no	Med.	Mean	Sort	Ske.	Kurt
F 7;1T	3.39	3.33	0.47	-0.13	1.21
1B	3.43	3.43	0.39	0.00	1.16
2T	-	-	-	-	-
2B	3.50	3.50	0.34	0.00	0.32
3T	3.50	3.50	0.34	0.00	0.32
3B	3.50	3.50	0.34	0.00	0.32
4T	-	-	-	-	-
4B	2.71	2.83	0.68	0.17	0.66
5T	3.28	3.13	0.64	-0.24	0.43
5B	3.27	3.10	0.66	-0.25	0.42
F 8;1T	3.43	3.43	0.39	-0.00	1.19
1B	3.25	3.05	0.71	-0.29	0.80
2T	3.50	3.50	0.34	0.00	0.32
2B	-	-	-	-	-
3T	3.50	3.50	0.34	0.00	0.32
3B	3.25	3.12	0.64	-0.20	0.39
4T	-	-	-	-	-
4B	-	-	-	-	-
5T	3.50	3.50	0.34	0.00	0.32
5B	3.36	3.12	0.68	-0.35	0.84
F 9;1T	3.06	2.97	0.74	-0.13	0.60
1B	3.33	3.21	0.57	-0.21	0.51
2T	-	-	-	-	-
2B	-	-	-	-	-
3T	-	-	-	-	-
3B	3.50	3.50	0.34	0.00	0.32
4T	3.38	3.30	0.50	-0.15	0.69
4B	3.29	3.14	0.63	-0.24	0.45
F 10;1T	2.87	2.93	0.70	0.09	0.33
1B	3.09	3.01	0.70	-0.11	0.33
2T	-	-	-	-	-
2B	-	-	-	-	-
3T	2.77	2.88	0.68	0.16	0.36
3B	2.81	2.91	0.69	0.13	0.34
4T	3.50	3.50	0.34	0.00	0.32
4B	3.10	2.99	0.72	-0.14	0.40
F 11;1T	3.12	3.04	0.68	-0.12	0.33
1B	2.88	2.95	0.68	0.10	0.33
2T	-	-	-	-	-
2B	3.49	3.49	0.35	-0.00	0.32
3T	-	-	-	-	-
3B	-	-	-	-	-
4T	-	-	-	-	-
4B	-	-	-	-	-

Sample no	Med.	Mean	Sort	Ske.	Kurt
F 12;1T	3.15	3.05	0.68	-0.16	0.34
1B	2.67	2.79	0.61	0.20	0.47
2T	3.09	2.77	0.94	-0.34	0.43
2B	3.32	3.12	0.66	-0.29	0.66
3T	2.46	2.46	0.42	0.00	1.25
3B	2.48	2.48	0.41	0.00	1.23
4T	3.50	3.50	0.34	0.00	0.32
4B	3.00	3.00	0.68	0.00	0.32
F 13;1T	3.36	3.26	0.54	-0.19	0.59
1B	2.96	2.96	0.71	-0.01	0.32
2T	2.62	2.71	0.57	0.17	0.74
2B	2.79	2.91	0.66	0.18	0.36
3T	3.40	3.38	0.42	-0.04	0.93
3B	3.50	3.50	0.34	0.00	0.32
4T	2.62	2.70	0.51	0.15	0.67
4B	2.67	2.79	0.57	0.21	0.51
F 14;1T	3.00	3.00	0.68	0.00	0.32
1B	3.29	3.16	0.62	-0.22	0.44
2T	2.55	2.55	0.41	0.00	0.94
2B	2.51	2.51	0.40	0.00	1.03
3T	3.25	3.12	0.64	-0.20	0.39
3B	2.97	2.97	0.70	0.00	0.32
4T	2.90	2.96	0.69	0.08	0.33
4B	3.10	3.03	0.68	-0.10	0.33
F 15;1T	2.66	2.78	0.63	0.19	0.58
1B	2.63	2.74	0.61	0.19	0.70
2T	3.50	3.50	0.34	0.00	0.32
2B	3.50	3.50	0.34	0.00	0.32
3T	2.52	2.52	0.38	0.00	0.72
3B	2.53	2.53	0.42	0.00	1.44
4T	2.62	2.73	0.67	0.17	1.01
4B	2.65	2.77	0.66	0.18	0.85
F 16;1T	3.41	3.41	0.40	0.00	1.17
1B	3.50	3.50	0.34	0.00	0.32
2T	2.59	2.66	0.52	0.13	0.76
2B	2.80	2.91	0.66	0.17	0.36
3T	2.66	2.77	0.57	0.20	0.52
3B	2.85	2.94	0.68	0.13	0.34
4T	2.68	2.81	0.61	0.21	0.46
4B	3.40	3.37	0.44	-0.06	0.95
F 17;1T	3.06	2.63	1.07	-0.40	1.14
1B	-	-	-	-	-
2T	3.50	3.50	0.34	0.00	0.32
2B	3.25	3.12	0.64	-0.20	0.39
3T	-	-	-	-	-
3B	3.00	3.00	0.68	0.00	0.32
4T	2.70	2.83	0.62	0.21	0.44
4B	2.63	2.72	0.53	0.17	0.63

Sample no	Med.	Mean	Sort	Ske.	Kurt
F 18; 1T	3.10	1.72	2.00	-0.69	0.17
1B	-	-	-	-	-
2T	3.10	3.00	0.72	-0.14	0.33
2B	2.90	2.96	0.68	0.09	0.33
3T	2.68	2.78	0.72	0.15	0.72
3B	2.55	2.55	0.43	0.00	1.25
4T	2.51	2.51	0.39	0.00	0.75
4B	2.65	2.75	0.55	0.19	0.57
F 19; 1T	2.73	2.86	0.65	0.19	0.39
1B	2.39	2.29	0.60	-0.17	0.84
2T	2.43	2.43	0.41	0.00	0.98
2B	2.63	2.73	0.55	0.18	0.59
3T	2.39	2.30	0.52	-0.16	0.66
3B	2.79	2.91	0.66	0.18	0.36
4T	2.57	2.57	0.42	0.00	0.97
4B	2.56	2.56	0.39	0.00	0.95
F 20; 1T	3.31	3.16	0.61	-0.23	0.46
1B	2.78	2.89	0.67	0.17	0.36
2T	2.45	2.45	0.42	0.00	1.10
2B	2.76	2.89	0.65	0.19	0.38
3T	2.65	2.77	0.57	0.20	0.53
3B	2.79	2.91	0.66	0.17	0.36
4T	2.43	2.35	0.59	-0.14	1.00
4B	2.53	2.53	0.40	0.00	0.90

APPENDIX 1 C

This section lists the respective contents of $CaCO_3$ and H_2O_2-leachable organic material.

The parameters listed below are as follows:

%Carb. - The percentage (m/m) of $CaCO_3$ in the sediment samples

%Org C - The percentage organic material in the samples

The "tr." occurring in the columns denotes trace amounts of carbonate. The sample effervesced when the acid was added but the carbonate content is too low to register a reading.

Sample no	%Carb.	%Org C
F 1;1T	34.00	0.40
1B	37.90	0.00
2T	35.10	0.00
2B	32.40	0.40
3T	34.50	0.00
3B	37.50	0.40
F 2;1T	34.70	0.40
1B	39.50	0.00
2T	31.00	0.00
2B	31.70	0.00
3T	29.70	0.00
3B	31.60	0.00
F 3;1T	28.90	0.40
1B	31.30	0.50
2T	47.20	0.40
2B	37.00	0.40
3T	33.60	0.50
3B	Solid substrate	
F 4;1T	27.60	0.70
1B	29.90	0.70
2T	29.00	0.50
2B	30.90	0.70
3T	29.80	0.80
3B	31.90	0.90
4T	28.10	0.50
4B	36.80	0.00
5T	0.00	6.10
5B	0.00	7.10
F 5;1T	30.90	0.90
1B	29.80	1.00
2T	32.30	0.70
2B	0.00	3.50
3T	31.70	0.40
3B	35.00	0.40
4T	33.30	1.10
4B	32.00	0.00
5T	32.00	0.40
5B	0.00	6.80
F 6;1T	16.20	1.60
1B	0.00	4.00
2T	tr.	2.80
2B	0.00	1.50
3T	0.00	8.10
3B	0.00	5.30
4T	tr.	6.50
4B	0.00	0.40
5T	0.00	2.40
5B	tr.	2.00

Sample no	%Carb.	%Org C
F 7;1T	0.00	4.00
1B	tr.	1.40
2T	0.00	8.70
2B	tr.	6.10
3T	tr.	11.30
3B	0.00	5.50
4T	tr.	10.30
4B	tr.	2.50
5T	tr.	1.30
5B	0.00	1.80
F 8;1T	0.00	2.90
1B	0.00	3.20
2T	tr.	9.30
2B	tr.	7.60
3T	0.00	10.50
3B	0.00	5.30
4T	tr.	10.50
4B	0.00	8.80
5T	tr.	7.60
5B	0.00	5.70
F 9;1T	0.00	2.70
1B	0.00	5.10
2T	tr.	7.90
2B	0.00	7.20
3T	tr.	7.70
3B	tr.	5.70
4T	0.00	1.50
4B	0.00	1.40
F 10 1T	0.00	1.20
1B	0.00	2.00
2T	0.00	4.80
2B	tr.	6.50
3T	tr.	5.30
3B	tr.	3.60
4T	0.00	6.10
4B	0.00	3.80
F 11 1T	0.00	1.60
1B	0.00	3.40
2T	tr.	6.50
2B	0.00	5.10
3T	0.00	10.10
3B	tr.	7.30
4T	0.00	8.70
4B	0.00	7.50

Sample no	%Carb	%Org C
F 12;1T	0.00	2.10
1B	0.00	3.30
2T	tr.	4.70
2B	tr.	3.60
3T	0.00	1.20
3B	0.00	1.60
4T	tr.	9.50
4B	0.00	8.10
F 13;1T	tr.	4.10
1B	0.00	1.80
2T	tr.	6.80
2B	tr.	5.90
3T	tr.	8.70
3B	tr.	5.40
4T	0.00	1.00
4B	0.00	1.40
F 14;1T	tr.	7.10
1B	0.00	1.50
2T	0.00	0.70
2B	0.00	1.70
3T	0.00	7.00
3B	tr.	2.60
4T	tr.	3.30
4B	0.00	0.90
F 15;1T	0.00	0.70
1B	0.00	0.50
2T	0.00	1.20
2B	0.00	1.00
3T	0.00	0.00
3B	tr.	0.70
4T	tr.	0.70
4B	0.00	1.50
F 16;1T	0.00	0.60
1B	0.00	4.40
2T	0.00	0.40
2B	0.00	0.40
3T	0.00	0.50
3B	0.00	0.00
4T	0.00	0.40
4B	0.00	0.60
F 17 1T	tr.	1.10
1B	Solid substrate	
2T	tr.	1.50
2B	0.00	1.10
3T	tr.	1.20
3B	tr.	0.00
4T	0.00	0.00
4B	0.00	0.00

Sample no	%Carb.	%Org C
F 18; 1T	tr.	4.20
1B	0.00	0.00
2T	tr.	0.80
2B	tr.	0.00
3T	tr.	1.10
3B	0.00	0.00
4T	0.00	0.40
4B	tr.	0.00
F 19; 1T	0.00	0.00
1B	0.00	0.50
2T	0.00	0.00
2B	tr.	0.80
3T	0.00	0.50
3B	tr.	0.40
4T	tr.	0.50
4B	0.00	0.00
F 20; 1T	tr.	0.50
1B	tr.	0.60
2T	0.00	0.00
2B	tr.	0.00
3T	tr.	0.80
3B	tr.	0.00
4T	0.00	0.40
4B	0.00	0.00