Technical Memorandum 3

Transport of Trace Metals in the Magela Creek System, Northern Territory

III. Billabong sediments

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SUMMARY

Preliminary analysis of sediments collected from billabongs of the Magela Creek system has indicated widespread variations in sediment types and trace metal concentrations. The poor reproducibility found for trace metal levels in total sediment samples was largely overcome by analysis of the <20 µm fraction obtained by sieving to remove sand particles and organic detritus. Trace metal analysis of the <20 µm sediment fraction showed acceptable reproducibility of results and enabled the trace metal levels in sediments from different billabongs to be compared.

The results indicate that this sediment fraction will be most useful for monitoring potential accumulation of trace metals in the Magela Creek system.

1 INTRODUCTION

Elevated levels of trace metals are generally found in the sediments taken from polluted rivers, lakes and estuaries (Förstner and Wittmann 1979). This has led a number of workers to suggest the analysis of sediments as a means of monitoring the build-up in trace metals in a given aquatic system.

Since it has been reported (Fox et al. 1977) that a number of the billabongs downstream of the Ranger uranium deposits appear to accumulate suspended material transported by Magela Creek, monitoring of the trace metal levels in such billabongs should provide a convenient means for determining whether changes have occurred as a result of the mining operations.

The method, however, is not without its limitations. For example, significant variations have been found to occur in the trace metal levels in sediments taken from a single billabong or a series of billabongs. Variations can arise as a result of different physical environments, such as depositional or erosional areas, deep central sections or outer littoral zones that may be covered with macrophytes during the wet season. The particle size distribution of the sediment has a very marked influence on the trace metal levels, since metals are often preferentially associated with the finer grain sizes (Förstner and Wittmann 1979). Differing chemical environments can also affect the levels of trace metals held by sediments. Areas that become anaerobic for extended periods may result in metals being released back into the water column (Förstner and Wittmann 1979). However, it must be recognised that monitoring trace metal levels in sediments can only provide an historical record of events.

In common with a number of other potential methods for monitoring heavy metal levels, there is still considerable uncertainty in assessing the biological implications of elevated trace metal levels found in sediments.

We report here the results of preliminary work within the Magela Creek system aimed at better defining the sediments in a number of billabongs that could potentially be used as monitoring sites. In particular, the variations in particle size distribution, and in trace metal concentrations associated with certain ranges of particle sizes, were investigated.

2 SAMPLING

Samples were taken from eight billabongs on two occasions; at the end of the dry season in November 1978, and at the end of the following wet season in May 1979. Additional samples were collected in November 1979, and the results of analyses currently under way will be reported separately.

The sediment samples taken in November 1978 and May 1979 were obtained using an Ekman grab; sample positions are shown in Figure 1. The areas sampled included two backflow billabongs (Gulungul and Georgetown), two channel billabongs (Mudginberri and Island), three flood plain billabongs (Leichhardt, Jabiluka and Nankeen) and a flood plain swamp (Barote). Mudginberri Billabong and Barote Swamp were sampled only in November 1978 and Leichhardt Billabong only in May 1979. Multiple samples were taken from Gulungul, Georgetown, Island and Jabiluka.

Two Ekman grab samples were combined in a clean plastic bag, mixed well and a subsample was transferred to an acid-washed clear plastic jar, taken to the laboratory and frozen. It was kept frozen until analysis.

3 METHODS

3.1 Size Fractionation of Sediments

Wet sieving of 50 g of wet sediment (approx. 10 g of dry sediment) through a 63 μm nylon sieve (300 mL ultrapure water) was used to separate the sediment into two initial fractions. The >63 μm fraction retained by the sieve was dried in a vacuum oven at 45°C, while the <63 μm fraction was further sieved through a 20 μm sieve; the retained fraction was oven-dried. The <20 μm fraction was subjected to a pipette analysis (Guy 1969) to obtain the <2 μm fraction. Representative results are shown in Figure 2.

The reproducibility of this size separation procedure was tested by analysing in triplicate a sediment sample taken from Gulungul Billabong in May 1979 (GL2 M79). The results given in Table 1 show very good reproducibility for the three size fractions. The total trace metal concentrations in the three size fractions were also determined (see Section 3.3). The analytical reproducibility was best for the <20 μm fraction, with the relative standard deviation varying between 6 and 9% for the four metals tested.

3.2 Percent Weight Loss on Ignition

The method used was as follows: 5-10 g of dry sediment was weighed to constant weight after drying at 100°C. After ignition at 400°C for 7 h the sample was desiccated overnight, weighed and the percent weight loss calculated. Under these conditions, the dominant contribution to the weight loss would be oxidation of organic matter (Jaffe and Walters 1977). Results are given in Table 2.

3.3 Trace Metal Determination

Trace metals were determined after the sediment samples had been digested firstly with H_2O_2 and then HNO_3 to oxidise all organic material, and then with HF to decompose the mineral matrix. The detailed procedure was as follows.

> Approximately 1 g (determined to constant weight) of dry, ground sediment was placed in acid-washed Teflon beakers and 3 mL of Milli-Q water added to wet the sediment. Ten mL of 30% H_2O_2 was then added and the solution capped and allowed to stand overnight. The H_2O_2 was removed by heating on a water bath until effervescence ceased. This was followed by the addition of 5 mL of Suprapur HNO_3 that was heated to fuming on a hot plate and reduced to a small volume. Five mL of HF was added and the solution heated to fuming. Ten mL of 5% H_3BO_3 was then added to the digested sediment which, after cooling to room temperature, was made up to volume (50 mL) in a volumetric flask with immediate transfer to a clean plastic bottle.
>
> The trace metals Fe, Mn, Cu, Zn, Pb, Ni and Cr were subsequently determined in the final digest using flame AAS (Varian AA6 with background corrector). Conditions used for the AA are recorded in the Appendix.
>
> The possible matrix effect was tested by comparing the slopes of graphs obtained by adding standards to a 1M HNO_3 matrix with those obtained by adding standards to digests from two quite different sediment types - a fine, richly organic sediment from Gulungul Billabong (GL2 M79), and a coarse, sandy

sediment from Island Billabong (IS7 M79). The results, given in Table 3, show there was no significant matrix effect for Fe, Mn, Cu, Zn, Ni or Cr, the metals tested.

The reproducibility of the total digestion procedure was tested by analysing 1 g (dry weight) replicates of the two sediments. The results are given in Table 4. In all cases, the relative standard deviation was better than 10%.

4 RESULTS AND DISCUSSION

Data on sediment fractionation and loss of weight on ashing are given in Table 2. The trace metal concentrations for the unfractionated sediment samples collected in November 1978 and May 1979 are given in Table 5, while those for the individual fractions separated from the November 1978 samples only are contained in Table 6.

It was generally found that each billabong studied had a number of features unique to itself. Where this was so, that billabong is discussed separately from the rest.

4.1 Georgetown Billabong

Georgetown Billabong consists of two shallow basins separated by a sill. The sediments within each basin are predominantly fine silt and clay and the sediment on the sill is higher in sand.

A visual inspection of a large number of sediments taken from this billabong in November 1979 showed marked differences in the proportions of sand and clay throughout the billabong, and confirmed the high silt/clay nature of the basin sediments noted above. The sediments appear to be particularly influenced by water depth and by the inflow of Magela Creek during the wet season. We have some evidence to suggest that, at least in one basin (GT2), the clayey surface sediment may cover a sandy layer. This will be further investigated by coring at a number of sites.

This variability in sediment type is also shown by the trace metal and organic matter concentrations in eight samples taken longitudinally along the billabong in November 1978 (Table 2). The organic matter varied between 0.1% and 10.7%; the highest values (GT2, GT3 and GT7) corresponded to positions close to the central points of the two basins. Positions GT4, GT5 and GT6 were close to or on the sill.

The total trace metal concentrations in sediments collected in November 1978 were consistently highest in those sediments taken from the basin areas (GT2, GT3 and GT7, Table 5). These contain higher levels of fine silt and clay fractions which have been generally found to contain the highest trace metal concentrations. The above trend was confirmed by the results of total trace metal levels (see Table 5) found in sediments taken in May 1979 from GT2 (basin) and GT4 (sill). The large variation in the trace metal concentrations would make it extremely difficult to use the total sediments from this billabong as a monitoring medium.

Fractionation of a sample collected at site 2 in November 1978 (GT2 N78) showed that for all metals (Fe, Mn, Cu, Zn, Pb, Ni and Cr), the largest concentrations in the silt and clay fractions (<63 µm) were present in the <20 µm fraction (Table 6). There was little difference in the levels associated with the <20 µm fraction and those in the clay fraction (<2 µm). Trace metal concentrations in the <20 µm fraction from a sample collected at GT3 in November 1978 were very similar to those found in the above sample.

4.2 Gulungul Billabong

Gulungul Billabong is a backflow billabong 6 km downstream of the Ranger deposits. Sediments from this billabong were relatively consistent in nature, being predominantly fine silt and clay (68-76% <20 μm size) and extremely unconsolidated. They also contained a very high amount of organic matter (16-20% weight loss). The aquatic vegetation known to grow prolifically in this billabong during the wet season no doubt contributes to the high levels of organic matter.

The trace metal concentrations in the unfractionated sediments, taken at different times (November 1978 and May 1979) and at various sites (see Fig. 1), were found to be rather similar (Table 5). This is shown by the means and standard errors for four samples listed below.

(μg/g)	
Fe	13 000 ± 2000
Mn	117 ± 8
Cu	24 ± 1
Zn	16 ± 3
Pb	7 ± 2
Ni	15 ± 2
Cr	22 ± 2

There was a remarkable similarity in the trace metal levels associated with each of the size fractions. This was in contrast to the results for the other billabongs, where there was evidence of enrichment in the smaller size fractions (Table 6).

4.3 Channel Billabongs

The sediment samples collected in November 1978 from the two main channel billabongs, Island and Mudginberri, were of a highly sandy nature with very little organic matter. Recent work using a core sampler has shown that the sediment profile in Island Billabong consists of a surface sandy layer, approximately 10 cm thick, over a clayey subsurface layer.

As expected, quite low levels of metals were found in these total sediments (Table 5). The Zn concentrations in the >63 μm fraction were surprisingly high. It is unlikely that the Zn is present in the crystal lattice of the sand, since a sample of creek bed sand collected near Georgetown Billabong contained less than 2 μg/g of Zn in comparison with the 96-130 μg/g concentrations of the Island and Mudginberri samples. The total Zn concentrations in sediments taken from both sampling sites in Island Billabong in May 1979 were an order of magnitude *less* than those in the November 1978 sediment samples (Table 5). We are presently investigating the possibility that heavy minerals such as ZnS were the cause of the high levels found in the November 1978 samples.

Rather high metal concentrations were found in the <20 μm and 20-63 μm fractions obtained from samples IS1, IS7 and MG3 in November 1979. A possible reason for this is that these fractions consist predominantly of deposited phytoplankton relatively rich in trace metals. In a previous study (Davies and Hart 1981), high trace metal levels were reported in the particulate matter collected from these two billabongs.

Grab samples obtained during November 1979 indicated that, since the 1978-79 wet season, at least 10 cm of a fine sediment had been deposited in Island Billabong on top of the sandy bed. As a consequence, we are placing increased effort on characterising sediments from the entire Mudginberri Corridor area. In November 1979 a number of billabongs in this area were cored; these included Mudginberri, Island, Anseranus (backflow just downstream of Mudginberri), Boomerang (large billabong to the northeast of Mudginberri), Mayamarleprard and Three Croc. (to the north of Mayamarleprard).

4.4 Flood Plain Billabongs

Three billabongs on the Magela flood plain were sampled. These were Jabiluka and Nankeen in both November 1978 and May 1979 and Leichhardt in May 1979.

The sediments from Jabiluka and Nankeen appeared to be rather similar and somewhat different from those taken from Leichhardt. For example, a visual examination showed the sediments from Jabiluka and Nankeen to be fine textured (more than 70% was <20 µm in size) and dark in colour, while those from Leichhardt were light grey in colour, clayey and of an extremely sticky texture. Particle size analysis for the Leichhardt sediment is not yet available. The organic content was also different, being somewhat lower in Leichhardt (5.6%) than in the other two billabongs (Jabiluka 10.7% and 7.1% at two sites; Nankeen 7.1%).

Trace metal concentrations of the sediments from these billabongs also distinguished Leichhardt from the others. For analyses of the unfractionated sediment (total) from the samples NK5, JB1 and JB6, the trace metal concentrations were similar (Table 5) (ranges (µg/g): Fe 27 800-22 800; Mn 92-143; Cu 10-14; Zn 22-28; Ni 8-12). By comparison, Leichhardt showed elevated values for Fe, Mn and Zn ((µg/g): Fe 34 100; Mn 447; Cu 13; Zn 36; Ni 14), Mn in particular showing a threefold increase.

The trace metal levels in total sediments collected at the various sites in Jabiluka and Nankeen in November 1978 were little different from values obtained in samples collected at the same sites in May 1979. The samples collected in November 1978 were also separated into a number of size fractions, and the trace metal levels determined in each fraction (Table 6). The results showed similar trends to those already discussed for Gulungul in that there was generally an enrichment in the smaller size fractions (<2 µm, <20 µm).

It is interesting to compare the characteristics of the two sediments taken from Jabiluka Billabong in November 1978. Sample JB1 was taken from the southern end of this billabong, and it appears from dye tracer work (Smith et al. 1979) that the velocity of water entering the billabong at this end is somewhat higher than that entering further along the billabong. Water appears to 'funnel' into the billabong from the flood plain.

Additional evidence for the southern end being a more energetic environment is provided by the sediment textural analysis data (Fig. 2). In the sample collected at JB1, 69% was <20 µm in size, while at JB2 <20 µm size particles made up 86% of the sediment.

It is generally considered that the flood plain billabongs are depositional environments and, as such, may be at risk from material transported during the wet season from the Ranger operations. The following rather simplistic calculation shows that this may not be as clear-cut as originally thought.

Amount of Suspended Sediment (SS)

(a) flushed from billabong at start of wet season approx. 100 tonnes

assume (i) average SS concentration at end of dry = 250 mg/L (Davies and Hart 1981)

(ii) volume of billabong = 0.2 km^2 x 2 m depth
= 4 x 10^8 L

(b) deposited in billabong during wet season approx. 6 tonnes

assume (i) all SS transported by Magela Creek (5300 tonnes, Hart et al. 1981) is deposited evenly on flood plain

(ii) flood plain area = 185 km^2
Jabiluka area = 0.2 km^2.

Note: The 100 tonnes of suspended material flushed per year from Jabiluka corresponds to the erosion of approx. 0.2 mm from the bottom.

It is apparent from the above calculation that considerably more material is flushed from the billabong at the start of the wet than could be deposited in it during the wet season. Some of the material flushed out will no doubt have been eroded from the billabong banks during the dry season, and some will be material continually resuspended from the sediments. The relative proportions of each are unknown.

4.5 Barote Swamp

Sediment from Barote Swamp consisted mainly of fine silt and clay with almost 80% <20 µm in size. The sediment was also rich in organic matter (14.5% weight loss). In physical appearance, sediment from Barote Swamp resembled that from Gulungul Billabong.

5 TRACE METAL CONCENTRATIONS IN <20 µm SIZE FRACTION FOR ALL BILLABONGS

Because of the major differences found in the trace metal levels in the unfractionated sediments taken from various locations both within a single billabong and in different billabongs, it is apparent that if sediments are to be used as a monitoring medium for trace metals, comparisons must be made on the basis of levels in a consistent size fraction. This is because the different size fractions can contain vastly different trace metal levels.

In this report we have adopted the <20 µm size fraction as the best to use for the following reasons:

(i) enrichment of sediments is most likely to occur in the smaller size fractions since there is a greater surface area available, at least for sorption type reactions to occur;

(ii) the <20 μm fraction is easily obtained;

(iii) the reproducibility of both the size separation and the trace metal analysis steps is adequate. This contrasts with the situation when total sediments are used, since there can be major problems with the homogeneity of the sample;

(iv) the smaller size fractions are likely to be the most easily transported by the system and, as such, are the fractions in which any contamination will show up first.

Table 7 contains the trace metal concentrations in the <20 μm fraction separated from all sediments collected in November 1978. Care must be exercised in any attempt to discern trends in these data, because at present there is a lack of data relating to the *in situ* variability in trace metal levels in the <20 μm fraction of sediments taken from each billabong. Preliminary work in our laboratories suggests the *in situ* variability for each metal in the <20 μm fraction may be around 10%. This tentative figure will be used in the following discussion.

5.1 Iron

Iron levels were highest in the two channel billabongs, Mudginberri and Island. The depletion of Fe in the other billabongs, compared with the channel billabongs, is possibly due to their sediments being more anaerobic and releasing Fe to the water column. Interestingly, the two areas with the lowest levels of Fe, Gulungul Billabong and Barote Swamp, also contained the highest levels of organic matter in their sediments.

5.2 Manganese

The trend in Mn levels follows closely that for Fe. Levels were highest in the two channel billabong sediments, and considerably less in Gulungul, Jabiluka and Barote Swamp. Again, this trend possibly arises because of a lower redox potential in the last two sites, which leads to release of sediment-bound Mn to the water column.

5.3 Copper, Zinc, Lead, Nickel and Chromium

Copper levels in flood plain billabongs were less than half those in Gulungul and Georgetown. This may result from an increasing ability for flood plain waters to mobilise Cu. The marked difference in Cu levels in Mudginberri and Island cannot be explained.

The trend in Zn levels was generally the reverse of that for Cu. Levels were lowest in the backflow billabongs and increased down the system.

Lead levels were low and showed little change through the system. Chromium levels appeared rather high, but also showed little variation. Nickel levels showed considerable variability.

Cadmium was determined for a number of sediments, but was always below the detection limit of 0.2 μg/g.

We believe it would be premature at this stage to compare billabong sediment results with the levels in the particulate matter transported by Magela Creek. The levels, however, have been quoted in Table 7 so that comparisons can be made as data become available.

6 CONCLUSION

Sediment samples were taken from eight billabongs in the Magela Creek system and analysed for Fe, Mn, Cu, Zn, Pb, Ni and Cr. Relative to calculated world average metal concentrations in Recent lacustrine sediments (Förstner and Wittmann 1979), the concentrations of metals in these billabong sediments were very low. Due mainly to the variations in sediment types in these billabongs, quite large differences were found in trace metal levels when the total sediment was analysed. Also within the one billabong, e.g. Georgetown, Island, very marked differences in the sediment type can be found. This variability makes it difficult to use trace metal levels in total sediment to monitor trace metal pollution.

A number of workers have preferred to use a smaller size fraction (<2 or <20 µm), since it is argued that this will more closely represent the fraction that is most easily transported through the system. Preliminary work reported here suggests that analysis of the <20 µm fraction of billabong sediments, while requiring a little more effort since sediments must be fractionated, nevertheless provides more reproducible results and shows considerably less variability in trace metal levels throughout the billabong. So far nylon sieves have been used to obtain the <20 µm fraction; however, we are concerned about the possible adverse effects due to incomplete fractionation and attrition of sediment particles. A simple sedimentation process is presently being tested, with a view to replacing the sieve method.

All sediment samples collected as part of the first two surveys (November 1978 and May 1979) were obtained using an Ekman grab. Recent work suggests that these grab samples may be less informative than core samples, where depth profiles are obtained. All further work will be on core samples.

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APPENDIX ATOMIC ABSORPTION CONDITIONS (VARIAN AA6)

	Fe	Mn	Cu	Zn	Pb	Ni	Cr
λ (nm)	385.9	279.4	324.7	213.8	283.2	231.9	357.8
Gain	8.2	6.3	3.5	6.6	2.2	6.4	2.7
Slit (μm)	50	100	50	100	200	100	100
Lamp (mA)	5	4	5	5	5	5	5
Burner height	12.5	12.5	12.5	12.5	12.5	12.5	15.0
Background	X	✓	X	✓	✓	✓	X
H_2 Lamp intensity	X	9	X	1.75	6.3	1.7	X
Flame acetylene (75 kPa)	2	3.2	2	2	3.5	2	3.0
Air (100 kPa)	7.5	7.5	7.5	7.5	7.5	7.5	7.5

TABLE 1 REPRODUCIBILITY OF SIZE FRACTIONATION AND TRACE METAL ANALYSES

Parameter	Size Fraction (μm) >63	63-20	<20	<2
Size Composition (%)	6.7 ± 1.5	7.3 ± 2.3	86 ± 3	54 ± 8
Fe (μg/g)	7000 ± 1000	8400 ± 1300	11 800 ± 700	14 100 ± 300
Mn (μg/g)	83 ± 19	118 ± 11	121 ± 10	104 ± 4
Cu (μg/g)	32 ± 16	29 ± 1	33 ± 2	33 ± 2
Zn (μg/g)	60 ± 40	22 ± 3	15 ± 1	15 ± 1

Values are means ± standard error.

TABLE 2 SEDIMENT FRACTIONATION AND LOSS OF WEIGHT ON ASHING

Sample	November 1978					May 1979
	Size Fractionation (%)				Weight Loss (%)	Weight Loss (%)
	>63	63-20	<20	<2		
GT1	nd	nd	nd	nd	4.9	nd
GT2	11	7	81	51	6.9	5.2
GT3	12	2	85	nd	6.4	nd
GT4	nd	nd	nd	nd	3.6	2.4
GT5	nd	nd	nd	nd	4.2	nd
GT6	nd	nd	nd	nd	2.3	nd
GT7	nd	nd	nd	nd	10.7	nd
GT8	nd	nd	nd	nd	0.1	nd
GL1	14	17	68	54	20.4	nd
GL2	9	15	76	57	18.6	16.5
GL4	nd	nd	nd	nd	nd	20.4
MG3	99	<1	1	nd	0.4	nd
IS1	69	2	28	nd	5.2	5.0
IS7	100	<1	nd	nd	0.3	3.9, 4.3
LC	nd	nd	nd	nd	nd	5.6
JB1	12	18	69	44	12.9	10.9
JB6	7	7	86	57	11.2	7.2, 7.0
NK5	10	13	76	55	8.3	7.1
BR	14	17	68	53	14.5	nd

GT = Georgetown GL = Gulungul MG = Mudginberri IS = Island
LC = Leichhardt JB = Jabiluka NK = Nankeen BR = Barote Swamp
nd = not determined

TABLE 3 EFFECT OF SAMPLE MATRIX ON TRACE METAL ANALYSES

			Matrix Effect[a]			
Sample	Fe	Mn	Cu	Zn	Ni	Cr
GL2 M79	0.5	1.7	4.7	0.6	0.8	4.1
IS7 M79	3.2	0.6	5.0	-1.9	1.3	2.3

[a] Matrix effect $= \dfrac{\text{Slope of standard additions to sample}}{\text{Slope of standard additions to } HNO_3} \times \dfrac{100}{1}$

TABLE 4 ANALYTICAL REPRODUCIBILITY OF TOTAL DIGESTION PROCEDURE

		Trace Metal Concentrations (µg/g)		
Sample	Fe	Mn	Cu	Zn
GL2 M79 (n=5)	12 800 ± 300	118 ± 1.5	25 ± 0.5	15 ± 1
IS7 M79 (n=4)	8 600 ± 400	43 ± 1.5	5.6 ± 0.5	19 ± 1

TABLE 5 TRACE METAL CONCENTRATIONS IN UNFRACTIONATED (TOTAL) SEDIMENTS

(Values in µg/g dry sediment)

Sample	Fe		Mn		Cu		Zn		Pb		Ni		Cr	
	N78[a]	M79[b]	N78	M79	N78	M79	N78	M79	N78	M79	N78	M79	N78	M79
GT1	26 400	nd	203	nd	39	nd	11	nd	nd	nd	nd	nd	nd	nd
GT2	20 600	17 200	126	114	44	33	15	17	8	15	33	26	43	74
GT3	17 500	nd	111	nd	34	nd	16	nd	15	nd	25	nd	80	nd
GT4	nd	5700	nd	34	nd	11	nd	6	nd	<1	nd	<1	nd	39
GT5	8000	nd	65	nd	31	nd	10	nd	nd	nd	nd	nd	nd	nd
GT6	4000	nd	24	nd	12	nd	9	nd	nd	nd	nd	nd	nd	nd
GT7	20 600	nd	130	nd	43	nd	16	nd	nd	nd	nd	nd	nd	nd
GT8	400	nd	<1	nd	4	nd	2	nd	nd	nd	nd	nd	nd	nd
GL1	14 600	nd	124	nd	23	nd	15	nd	9	nd	13	nd	21	nd
GL2	14 600	12 300	121	116	24	25	14	15	7	7	15	16	23	23
GL4	nd	10 300	nd	105	nd	25	nd	20	nd	5	nd	17	nd	20
MG3	1100	nd	7	nd	<1	nd	96	nd	<1	nd	<1	nd	<1	nd
IS1	12 400	3800	57	20	5	8	120	9	<1	<1	<1	<1	9	10
IS7	650	8900	4	41	1	5	130	11	<1	<1	<1	<1	<1	7
LC	nd	34 100	nd	447	nd	13	nd	36	nd	7	nd	14	nd	40
JB1	27 000	25 600	104	100	11	14	25	28	5	6	8	12	25	35
JB6	32 100	22 800	89	92	11	11	31	22	7	6	12	8	40	32
NK5	33 300	27 800	125	143	11	10	30	26	6	6	9	11	34	31
BR	18 600	nd	71	nd	22	nd	25	nd	8	nd	16	nd	39	nd

See Table 2 for explanation of sample site abbreviations.
For sample locations see Figure 1.

[a] N78 - November 1978 collection; [b] M79 - May 1979 collection; nd = not determined.

TABLE 6 TRACE METAL CONCENTRATIONS IN VARIOUS SIZE FRACTIONS SEPARATED FROM SEDIMENTS COLLECTED IN NOVEMBER 1978.

Sample	Size Fraction (µm)	Fe	Mn	Cu	Zn (µg/g)	Pb	Ni	Cr
GT2	<2	34 100	125	54	19	10	54	58
	<20	33 600	122	52	19	10	55	56
	20-63	11 600	113	25	8	4	5	17
	>63	6700	58	8	36	3	<5	6
Total - Calculated		28 800	113	45	20	9	51	48
Total - Experimental		20 600	126	44	15	8	33	41
Total-Calc. less >63 µm		31 800	121	51	18	10	51	53
GT3	<20	29 400	126	49	15	9	<5	49
	20-63	12 600	115	21	12	5	<5	19
	>63	4000	83	1	71	<1	<5	<1
Total - Calculated		26 000	121	43	22	9	<5	48
Total - Experimental		17 600	111	34	16	15	<5	80
Total-Calc. less >63 µm		29 000	126	48	15	9	<5	48
GL1	<2	18 600	101	16	15	9	16	28
	<20	15 300	114	22	16	15	na	42
	20-63	13 800	101	26	13	8	17	24
	>63	13 900	134	24	21	9	11	18
Total - Calculated		14 800	115	23	15	14	na	36
Total - Experimental		14 600	124	23	15	9	na	21
Total-Calc. less >63 µm		15 000	111	23	16	13	13	38
GL2	<2	19 100	103	30	25	10	28	33
	<20	17 300	107	29	17	10	22	30
	20-63	13 600	133	22	17	9	14	28
	>63	14 300	17	28	37	10	10	18
Total - Calculated		16 500	103	29	19	10	20	29
Total - Experimental		14 600	121	24	14	7	15	23
Total-Calc. less >63 µm		16 700	111	28	17	10	21	30
JB1	<2	36 500	116	15	38	8	18	51
	<20	32 600	105	15	30	8	12	44
	20-63	6600	44	8	9	3	<5	5
	>63	29 100	106	9	31	7	15	16
Total - Calculated		27 800	96	13	23	7	10	34
Total - Experimental		27 000	104	11	25	5	8	25
Total-Calc. less >63 µm		25 900	92	14	26	7	12	36
JB6	<2	45 300	94	15	34	6	16	53
	<20	35 900	87	15	28	6	9	47
	20-63	25 200	77	10	21	5	5	23
	>63	3600	76	9	28	5	5	29
Total - Calculated		35 200	81	14	29	6	8	44
Total - Experimental		32 100	89	11	31	7	12	40
Total-Calc. less >63 µm		35 000	86	15	27	6	9	45

TABLE 6 (ctd)

Sample	Size Fraction (µm)	Fe	Mn	Cu	Zn (µg/g)	Pb	Ni	Cr
NK5	<2	50 100	147	21	38	7	16	49
	<20	40 400	136	19	32	7	11	44
	20-63	7600	72	7	22	4	<5	5
	>63	18 000	71	18	36	5	<5	13
Total - Calculated		33 500	120	17	30	6	11	36
Total - Experimental		33 300	125	11	30	6	11	34
Total-Calc. less >63 µm		35 600	127	17	33	7	9	38
BR	<2	30 200	74	27	23	12	23	58
	<20	25 700	78	26	22	12	19	54
	20-63	11 900	78	20	12	5	5	24
	>63	11 400	52	16	56	5	5	24
Total - Calculated		21 100	74	23	25	10	15	44
Total - Experimental		18 600	71	22	25	8	16	39
Total-Calc. less >63 µm		22 900	78	25	20	11	16	48

na = not available

GT = Georgetown; GL = Gulungul; JB = Jabiluka; NK = Nankeen; BR = Barote Swamp. For sample locations see Figure 1.

TABLE 7 TRACE METAL CONCENTRATIONS IN <20 µm FRACTION SAMPLED IN NOVEMBER 1978

Billabong	Sample	Fe	Mn	Cu (µg/g)	Zn	Pb	Ni	Cr
Georgetown	GT2	33 600	122	52	19	10	55	56
	GT3	29 400	126	48	15	9	<5	49
Gulungul	GL1	15 300	114	22	16	15	nd	42
	GL2	17 300	107	29	17	10	22	30
Mudginberri	MG3	45 700	182	62	39	nd	nd	nd
Island	IS1	43 300	186	16	28	nd	nd	nd
	IS7							
Jabiluka	JB1	32 600	105	15	30	8	12	44
	JB6	35 900	87	15	28	6	9	47
Nankeen	NK5	40 400	136	19	32	7	11	44
Barote swamp	BR	25 700	78	26	22	12	19	54
Particulate matter transported by Magela Creek (Hart et al. 1981, Table 3)		13 600-72 400 (25 500)	32-1061 (294)	1-61 (16)	30-213 (90)	<10-115	nd	nd

Values in brackets are mean trace metal concentrations. nd = not determined.

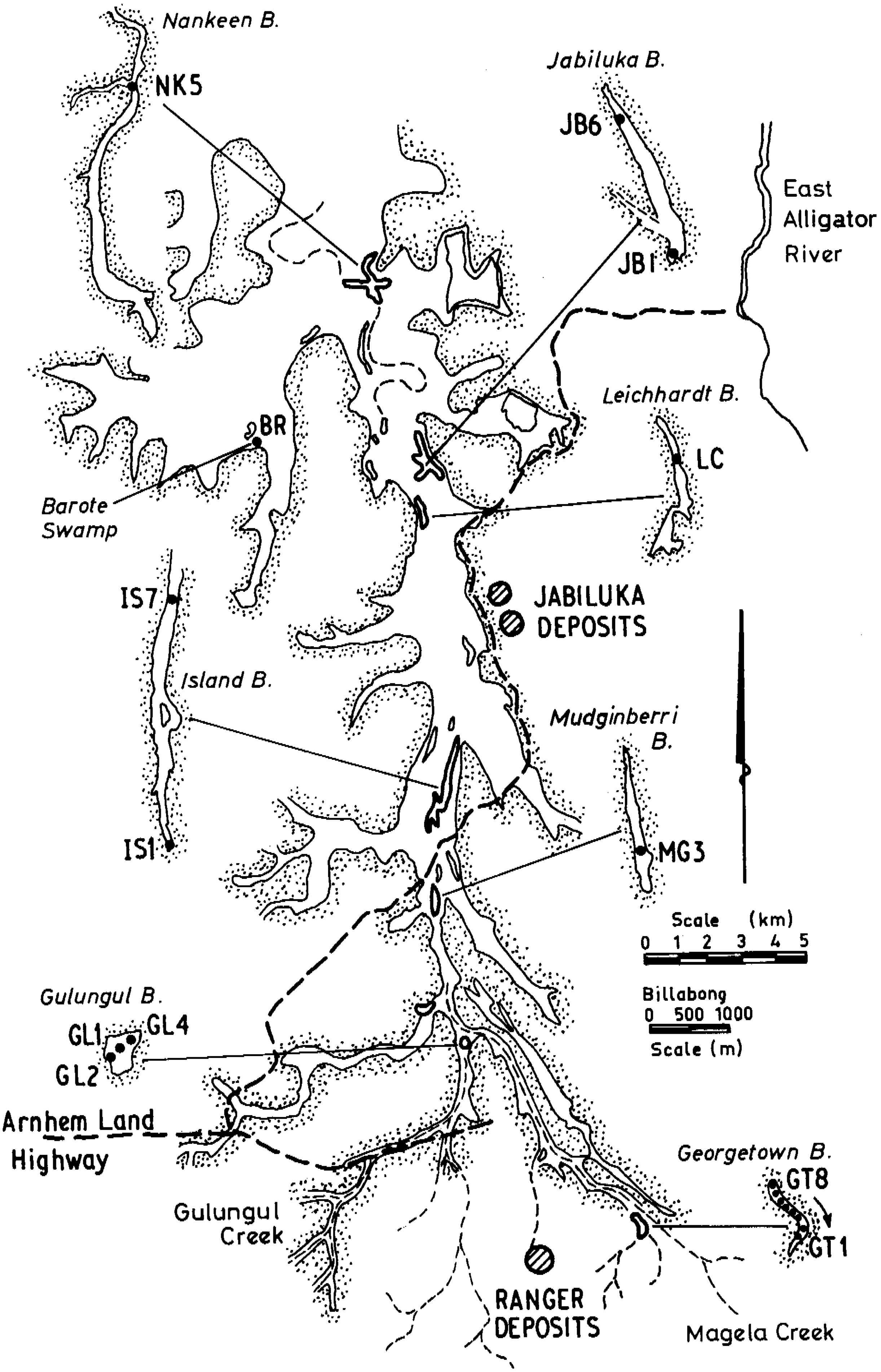

FIG. 1 MAP SHOWING LOCATIONS OF BILLABONGS SAMPLED AND SAMPLING SITES WITHIN EACH BILLABONG

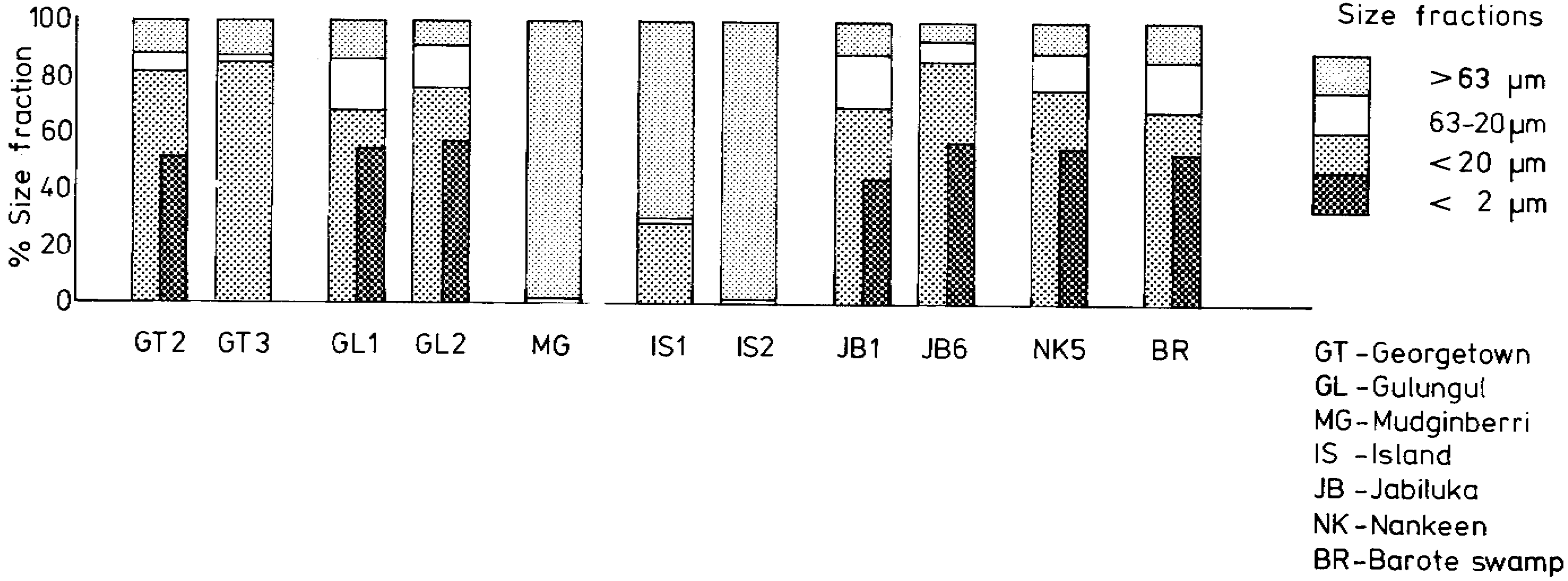

FIG. 2 TEXTURAL ANALYSIS OF BILLABONG SEDIMENTS