1. TRACE METALS[2] IN TORRES STRAIT SEDIMENTS

BACKGROUND

The Pilot Study of the Torres Strait Baseline Study (TSBS) concluded that the Fly River is the major source for the northern Torres Strait of fine-grained terrigenous sediments with an associated suite of trace metals (including aluminium, cobalt, chromium, copper, iron, manganese, nickel, lead, silicon and zinc), some of which increased in concentration after the monsoon season (Dight and Gladstone 1993). Concentrations of metals within this suite are low in the central and eastern Torres Strait. Other trace metals in Torres Strait marine sediments occurred at higher concentrations in either sediments with coarse-grained carbonate sediments of marine origin (cadmium, magnesium), or were not associated with any particular sediment type (arsenic, mercury and selenium).

There were, however, two inconsistencies in this data: (1) few of the trace metals originating from the Fly River (except cobalt, nickel and silicon) increased in concentration in the post-monsoon sampling. This is despite several recent oceanographic studies which have indicated that brackish water and sediments from the Fly River intrude further into the Torres Strait during the monsoon period (December-March) when winds are predominantly from the north-west (references by Wolanski et al 1992a,1992b, 1992c, 1992d); (2) some Fly River associated metals were in higher concentrations in the western Torres Strait, and their concentrations increased in the monsoon season, suggesting an additional source of trace metals for the Torres Strait (possibly Irian Jaya or western Cape York). These inconsistencies were addressed in the design of the Main Study.

The Pilot Study also concluded that the concentrations of cadmium, copper and zinc in Torres Strait sediments (including those in one sampling location inside the Fly River delta) were similar to those recorded by earlier studies in the Torres Strait, and they all fell within the levels which had been recorded from unpolluted tropical coastal areas elsewhere (Dight and Gladstone 1993).

A more comprehensive sampling program was designed for the Main Study, the objectives of which were to:

(1) sample from additional locations in the north-western Torres Strait near the Papua New Guinea coastline to identify other possible sources of trace metals into the Torres Strait;
(2) assess the extent of Fly River influence on the Torres Strait by sampling from a greater number of stations as early as possible in the monsoon season; and
(3) provide a baseline of information on concentrations of trace metals in sediments from a wide area of the Torres Strait against which future trends can be assessed.

METHODS AND MATERIALS

Sample Collection and Storage

Sediment samples were collected, using a Smith-McIntyre stainless steel grab, from the stations shown in figure 1.1[3] (as recommended by Dight and Gladstone 1993) between 8 October and 1

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[2] Following Rainbow (1988) the term 'trace metal' will be used synonymously throughout this report with the term 'heavy metal' to include both the essential metals (As, Cr, Co, Cu, Fe, Mn, Ni, Se, Sn, Zn) and the non-essential metals (Ag, Cd, Hg, Pb).

[3] Figures and tables referred to in the text are included at the end of the chapter, in the order to which they are referred in the text.

November 1992 (pre-monsoon season) and between 7 and 19 March 1993 (monsoon season). Each station was a circle of radius 500 m within which three sites were chosen by a process of randomly selecting a distance and bearing from the centre of the site; three replicate grab samples were collected in each site (i.e. a total of nine replicate grab samples per station). The latitude and longitude of each site was recorded with GPS and the depth was recorded from the ship's depth sounder. All sampling and sample storage was done aboard the Ok Tedi Mining Ltd research vessel 'Western Venturer'.

After the grab was retrieved to the ship's deck the excess water was allowed to drain then the sample was deposited on a plastic dish. This was transferred to the ship's laboratory where sub-sampling was done in a laminar flow hood. Sub-samples were collected from the surface of the sample to a depth of 5 cm using plastic corers of diameter 2.5 cm. Five replicate sub-samples were taken and combined in a plastic container to form a single replicate sample. Surgical gloves were worn while sub-sampling and transferring sub-samples to plastic containers. Each sample was immediately frozen and remained frozen until transfer to the laboratories of the Queensland Department of Primary Industries (Agricultural Chemistry) in Brisbane. All plastic containers (the dish used to collect sediment from the grab; the corer; the sample containers) were washed in 10% nitric acid prior to use and stored in clean plastic bags. The collecting dish and the corer were washed in Reverse Osmosis Polished water (prepared by the procedure described in appendix 7) between samples and at the end of each site's sampling.

Surface salinity was recorded (using a YSI Model 33 S-C-T Meter; YSI Incorporated, Yellow Springs Ohio) at the same time as sediment samples were being collected. During the recording of surface salinity the probe was held just below the water surface at a depth of 15-30 cm.

Trace Metal Analysis

All samples were analysed by Queensland Department of Primary Industries' (Agricultural Chemistry) laboratory in Brisbane. This laboratory successfully participated in the National Oceanic and Atmospheric Administration (NOAA) Eighth Round Inter-comparison for Trace Metals in Marine Sediments and Biological Tissues.

Procedures followed are outlined in detail in appendix 1.

NB: Results reported and discussed here for arsenic were analysed by different methods in each season: pre-monsoon samples were analysed by hydride generation atomic absorption spectrometry (AAS) and monsoon samples were analysed by X-ray fluorescence (XRF). In a second round of analyses the monsoon samples were re-analysed by AAS, however it was not possible to include the revised results in the statistical analysis which had already been done for this chapter. They are included in this report as appendix 2. Although the AAS absolute results were higher for the same samples than those results obtained using XRF, the inter-station patterns appear to be similar. Accordingly, the results for seasonal comparisons of arsenic reported later in this chapter are not a valid comparison and should be treated cautiously. Additional statistical analysis is required on the revised arsenic results.

Statistical Analysis

A combination of descriptive exploration, univariate analysis of variance (ANOVA) and canonical discriminant analysis (CDA) were used. ANOVA and CDA were undertaken after metal concentrations had been transformed to their natural logs. Visual inspection of the normality and homogeneity of variances (Underwood 1981) indicated that these were improved after natural log transformation.

CDA was done for all metals from all stations (i.e. the results for each metal were pooled for each station) in each season and inspected visually on a reduced plot of the first two canonical variates. The influence of each metal on the trends depicted in the reduced plot was derived from plots of both their canonical coefficients and structural coefficients. Metals having a strong influence on trends depicted in the reduced plots have canonical and structural coefficients which are high, and situated at similar locations on both plots. Metals which displayed contradictory results for the canonical and structural coefficients are regarded as being less influential on trends depicted in the reduced plots.

ANOVA was done on individual metals to test the null hypothesis that the metal level did not vary between seasons, stations and sites within stations. F ratios and variance components were constructed using the formulae shown in appendix 6. Variance components were calculated after preliminary examination of the ANOVAs revealed that for many metals there was a significant effect of site. Although F ratios can be statistically significant for such nested factors, they can be chemically meaningless. Calculations of the total variance explained by each factor (Underwood 1981) is a useful way of checking the magnitude of these effects.

Calculations of a large number of ANOVAs on the same data set increases the likelihood of a Type I error (Underwood 1981). This can be compensated for by calculating an adjusted alpha significance level (Day and Quinn 1989). In this case an adjusted alpha signifciance level was calculated by the Dunn-Sidak method (Day and Quinn 1989) where $\alpha_{adj} = 1\text{-}0.95^{1/r}$, and r = 15 (the number of metals tested), i.e. $\alpha_{adj} = 0.003$. F ratios are significant when their p value is less than 0.003 (not the usual 0.05).

RESULTS

Seasonal and Spatial Patterns in Surface Salinity

Patterns in surface salinities during the pre-monsoon and monsoon seasons were complex (figure 1.2). During the pre-monsoon season (October-November 1992) surface water of lower salinity (from 27.0 to 30.2 ‰) extended from the mouth of the Fly River (at S1) southward from S6 through the Great North-East Channel to S17 (relative to waters to the east where salinity varied from 31.0 to 33.0 ‰, and to waters to the west of the Warrior Reefs at S18 where salinity varied from 32.2 to 33.9 ‰). Lower salinity surface water also extended westward from the mouth of the Fly River along the Papua New Guinea coastline to S11 (over which salinity varied from 27.0 to 30.0 ‰).

During the monsoon season (March 1993) there was a narrow band of lower salinity surface water (from 29.5 to 30.8 ‰) between the mouth of the Fly River and along the Papua New Guinea coastline (figure 1.2). Surface salinities in the Great North-East Channel (32.0-32.1 ‰) and to the west of the Warrior Reefs (31.8-32.0 ‰) were slightly greater than the coastal salinities, but less than salinities in the eastern reefs (32.9-33.3 ‰).

Surface salinities recorded during the pre-monsoon season were usually less than those recorded during the monsoon season (figure 1.2). The only exceptions to this trend were stations to the west of the Warrior Reefs where surface salinities during the pre-monsoon season were greater than during the monsoon season.

Physico-Chemical Properties of Sediments

Torres Strait sediments varied widely in their physico-chemical properties (appendix 3). Sediments from station S1 at the mouth of the Fly River had the highest proportion (38.3%) of fines (i.e. < 63 µm), and showed a significant increase during the monsoon season. This station

also had the smallest amounts of coarse material. Station S12 along the Papua New Guinea coastline had a similar proportion of fines (37.1%) in the pre-monsoon season, but this was not associated with a similarly large amount of less fine material (10.9% of the < 63 µm-200 µm class); the proportion of fines did not increase in the monsoon season at this station, suggesting that there may be considerable spatial variation in sediment characteristics there. The amount of fines in other stations close to the mouth of Fly River (S6, S15) and along the Papua New Guinea coastline (S8, S10, S11, S13) was similar to stations in the central (S5, S18) and eastern Torres Strait (S7, S14). There were higher amounts of fines in stations in the Great North-East Channel (S16, S17), but they displayed minor changes between seasons.

Sediment organic carbon content (appendix 3) was highest at S1 at the mouth of the Fly River, and decreased in the following progression: stations along the Papua New Guinea coastline (S8, S10, S11, S12, S13), stations in the northern Torres Strait (S6, S15), stations in the central Torres Strait (S5, S16, S17, S18), stations in the eastern reefs (S7, S14). The greatest increase in sediment organic carbon content from the pre-monsoon to monsoon seasons (from 0.79 to 1.08%) occurred at station S1 at the mouth of the Fly River; levels increased only slightly at most other stations over the same period.

Amounts of calcium carbonate were low (around 1.0%) at the mouth of the Fly River, medium (up to 40%) at one station near the mouth of the Fly River (S15) and at stations along the Papua New Guinea coastline (S8, S10-13), and high (> 50.0%) at all other stations.

Trace Metals and Other Elements in Sediments

Trace metal levels in pre-monsoon and monsoon sediments are summarised in appendices 4 and 5.

Spatial Patterns

CDA on all trace metals in both seasons revealed two canonical variates which explained 64.54% and 20.11% of the variation respectively (figure 1.3). Four groups of stations are apparent in the reduced plot in figure 1.3:

- Group 1: a group to the far left of the reduced plot consisting of station S1 (the station closest to the mouth of the Fly River) in both pre-monsoon and monsoon seasons
- Group 2: a large group around the centre of the reduced plot consisting of the stations S6, S8, S10, S11, S12, S13, S15 in both pre-monsoon and monsoon seasons, and station S18 in the pre-monsoon only
- Group 3: a group to the right of the focus of the reduced plot comprising stations S5, S7, S14, S16 and S17 in the pre-monsoon season, and S18 in the monsoon season
- Group 4: a group consisting of the same stations (except for S18) in the monsoon season, located at the bottom of the reduced plot

Each group is comprised of stations from similar locations in the Torres Strait (see figure 1.1). Group 1 (station S1) is the closest of all stations to the mouth of the Fly River. Group 2 consists of stations in the northern Torres Strait just south of S1 (S6 and S15), the north-central Torres Strait (S18), and stations along the coastline of Papua New Guinea (S8, S10, S11, S12, S13). Groups 3 and 4 consists of stations in the central Torres Strait (S5), Great North-East Channel (S16 and S17), and the reefs to the east of the Torres Strait (S7 and S14).

Graphs of the structural and canonical coefficients (figure 1.4) show little consistency in metals possibly influencing the arrangement of groups in the reduced plot. Consequently, the patterns

in the reduced plot will be explained by reference to plots of each metal at each station (appendix 5) and results of ANOVA (appendix 6).

Stations in Groups 3 and 4 (i.e. stations in the central Torres Strait and eastern reefs: S5, S7, S14, S16, S17 in appendix 5) have low levels of the following metals and other elements, compared with other stations in the Torres Strait: aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, silicon and zinc. These stations also have higher levels of the following metals and other elements, compared with other stations: cadmium, magnesium and also calcium. There is little difference between these stations and all other stations in their levels of selenium.

Stations in Groups 1 and 2, which includes stations at the mouth of the Fly River, the northern Torres Strait and coastal Papua New Guinea (i.e. S1, S6, S8, S10, S11, S12, S13, S15 in appendix 5) have higher levels of the following metals and other elements: aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, silicon and zinc.

In particular, Station S1 at the mouth of the Fly River has higher levels of the following metals and other elements, compared with Group 2 (coastal and northern Torres Strait) stations: aluminium, copper, nickel, silicon and zinc.

ANOVA of individual metals and other elements in both seasons (appendix 6) revealed that levels of all metals differed significantly amongst stations. Differences amongst stations explained the greatest amount of variation in the levels of all metals and other elements (see % of total variance in appendix 6), except for selenium. The amount of variation explained by differences amongst stations varied from 41.84% for mercury, to 95.56% for calcium. Differences amongst stations accounted for only 18.82% of the variation in selenium levels.

Comparison of the mean levels of metals and other elements among stations revealed the following trends (appendices 5 and 6):

- *aluminium*: in both pre-monsoon and monsoon seasons mouth of the Fly River>PNG coastal stations and northern Torres Strait stations>stations in the central Torres Strait and eastern reefs;
- *arsenic*: in both pre-monsoon and monsoon seasons PNG coastal stations and northern Torres Strait stations>mouth of the Fly River, central Torres Strait and eastern reefs;
- *calcium*: in both pre-monsoon and monsoon seasons stations in the eastern reefs and central Torres Strait> northern Torres Strait stations> PNG coastal stations>mouth of the Fly River;
- *cadmium*: in both the pre-monsoon and monsoon seasons stations in the eastern reefs> PNG coastal stations> northern and central Torres Strait stations>mouth of the Fly River;
- *cobalt*: in both the pre-monsoon and monsoon seasons mouth of the Fly River, PNG coastal stations, and northern Torres Strait stations>central Torres Strait and eastern reefs;
- *chromium*: in both pre-monsoon and monsoon seasons PNG coastal stations, mouth of the Fly River, northern Torres Strait stations>central Torres Strait stations> eastern reefs;
- *copper*: in the pre-monsoon season mouth of the Fly River>PNG coast, northern Torres Strait>central Torres Strait and eastern reefs; in the monsoon season mouth of the Fly River>all other stations;
- *iron*: in both the pre-monsoon and monsoon seasons PNG coastal stations, mouth of the Fly River, northern Torres Strait stations>central Torres Strait stations> eastern reefs;
- *mercury*: in the pre-monsoon season mouth of the Fly River>PNG coastal stations, northern Torres Strait, central Torres Strait and eastern reefs; in the monsoon season mouth of the Fly River, PNG coastal stations, and northern Torres Strait>central Torres Strait>eastern reefs;
- *magnesium*: in both the pre-monsoon and monsoon seasons central Torres Strait, eastern reefs, and northern Torres Strait>PNG coastal stations>mouth of the Fly River;

- *manganese*: in both the pre-monsoon and monsoon seasons PNG coastal stations, northern Torres Strait, mouth of the Fly River>central Torres Strait and eastern reefs;
- *nickel*: in the pre-monsoon season mouth of the Fly River>PNG coastal stations and northern Torres Strait>central Torres Strait and eastern reefs; in the monsoon season mouth of the Fly River, PNG coastal stations and northern Torres Strait>central Torres Strait and eastern reefs;
- *lead*: in both the pre-monsoon and monsoon seasons PNG coastal stations, northern Torres Strait, mouth of the Fly River>central Torres Strait and eastern reefs;
- *selenium*: little variation amongst all stations in both seasons;
- *silicon*: in both the pre-monsoon and monsoon seasons mouth of the Fly River>PNG coastal stations and northern Torres Strait>central Torres Strait and eastern reefs;
- *zinc*: in both the pre-monsoon and monsoon seasons mouth of the Fly River>PNG coastal stations and northern Torres Strait>central Torres Strait and eastern reefs.

ANOVA also revealed that the levels of some metals and other elements varied amongst sites within stations (appendix 6). These metals included: aluminium, arsenic, calcium, cadmium, cobalt, chromium, iron, mercury, magnesium, manganese, selenium, silicon and zinc. However, even though these F ratios were significant in the ANOVA, site-related variation accounted for a very small amount of the total variation (from 0 to 5.61%, with 15.04% for manganese), and was also considerably less than variation related to station differences. There were no site-related significant differences in levels of copper, nickel and lead.

In summary, this examination of spatial patterns in the levels of trace metals and other elements in the Torres Strait revealed a suite of metals and one element which are probably derived from terrigenous sources in Papua New Guinea (because their concentrations are highest at the mouth of the Fly River, the northern Torres Strait and coastal Papua New Guinea stations). These were aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, silicon and zinc. Concentrations of a number of these (aluminium, copper, mercury, nickel, silicon and zinc) were consistently higher at the mouth of the Fly River. Metals and other elements which are probably derived from marine sources (because their concentrations were consistently higher at stations in the eastern reefs and central Torres Strait) include calcium, cadmium and magnesium. Levels of selenium were similar throughout the Torres Strait.

Seasonal Patterns

The group of stations consisting of those from the eastern reefs and central Torres Strait shifted their location on the CDA reduced plot between the pre-monsoon and monsoon seasons (figure 1.3). Plots of canonical and structural coefficients do not reveal any obvious basis for this (figure 1.3). However, examination of the plots for each metal at each station (appendix 5) revealed the following seasonal differences between the groups of stations: cobalt and magnesium levels decreased at eastern reefs and central Torres Strait stations from the pre-monsoon to monsoon seasons, whereas they increased at other stations over the same time; nickel levels at eastern reefs and central Torres Strait stations increased from the pre-monsoon to monsoon season, whereas they changed little at other stations.

There were complex patterns in the variations of trace metals and other elements between seasons (appendices 5 and 6). In summary:

Metals and other elements which changed significantly between seasons at all stations

- aluminium and zinc increased in the monsoon season;
- arsenic, selenium and silicon were higher in the pre-monsoon season

Metals which changed significantly between seasons but not at all stations

- cobalt levels increased from the pre-monsoon to monsoon season at stations at the mouth of the Fly River, coastal Papua New Guinea and northern Torres Strait; levels decreased over the same period at stations in the central Torres Strait and eastern reefs;
- chromium levels increased between the pre-monsoon and monsoon seasons at all stations except S12 (coastal Papua New Guinea);
- mercury levels decreased between the pre-monsoon and monsoon seasons at all stations except S8 (coastal Papua New Guinea);
- nickel levels decreased between the pre-monsoon and monsoon seasons at all central Torres Strait and eastern reefs stations, but varied little at all other stations;
- lead levels increased from the pre-monsoon to monsoon season at all stations except S12 (coastal Papua New Guinea).

Metals which did not change between seasons

- iron levels did not change between pre-monsoon and monsoon seasons.

Metals and other elements which did not change between seasons, but not at all stations

- calcium levels were similar between pre-monsoon and monsoon seasons except at stations S12 and S8 (coastal Papua New Guinea) and S6 (northern Torres Strait);
- cadmium levels were similar between pre-monsoon and monsoon seasons except at stations in the eastern reefs (S7 and S14) where they decreased from pre-monsoon to monsoon;
- copper levels were similar between pre-monsoon and monsoon seasons except at the mouth of the Fly River (S1) where they were higher in the monsoon season;
- manganese levels were similar between pre-monsoon and monsoon seasons except at a coastal Papua New Guinea station (S8) where they were significantly less in the monsoon season.

Seasonal changes in metals and other elements were independent of their source (i.e. whether terrigenous or marine). Levels of terrigenous metals and elements either increased from the pre-monsoon to monsoon season (aluminium, zinc, cobalt, chromium, lead); or decreased over the same period (arsenic, silicon, mercury, nickel); or remained the same (iron, copper, manganese). Marine metals and other elements were similarly variable: cadmium levels increased between pre-monsoon and monsoon seasons at eastern reef stations but were unchanged at other stations; magnesium levels decreased between pre-monsoon and monsoon seasons in the central Torres Strait and eastern reefs, but increased at all other stations; calcium levels remained the same at all stations except northern Torres Strait and coastal Papua New Guinea. Selenium, not associated with any particular sediment type, decreased throughout the Torres Strait between the pre-monsoon and monsoon.

In summary, levels of most metals and other elements in sediments changed between seasons. The patterns of change across seasons and among stations was independent of both the location of stations and the source of the metals and elements.

DISCUSSION

The Extent of Influence of the Fly River into Torres Strait

A wedge of lower salinity surface water originating from the Fly River was found to extend into the Great North-East Channel during the pre-monsoon and monsoon seasons as far southward as sediment station S17, approximately half way into the Torres Strait (confirming the patterns reported by Wolanski et al 1984). During the monsoon season, when the prevailing winds are from the north-west (Dight and Gladstone 1993) the surface salinities were similar on both sides of the Warrior Reefs. This suggests either that surface water penetrate the Warrior

Reefs during the monsoon season, or alternatively, it points to the existence of a secondary source for lower salinity water into the central Torres Strait along the Papua New Guinea coastline. The latter has been hypothesised by other authors (see review by Wolanski 1991 and sediment results in Dight and Gladstone 1993).

Wolanski et al (1984) suggested that this wedge of lower salinity surface water entering the Torres Strait from the Fly River '... is probably a nearly permanent feature...' (p. 296), but representing only a small percentage of the total outflow of the Fly River. Recent work by Wolanski and others (Wolanski et al 1992a, 1992b, 1992c, 1992d) has suggested that the extent of penetration of Fly River water into the Torres Strait varies seasonally, under the influence of prevailing wind directions. Lower salinity surface water was found to penetrate further during the monsoon season, than during the trade wind season. The results of the present study differ from this pattern: surface water salinity at comparable locations at the mouth of the Fly River and in the Great North-East Channel during the pre-monsoon season was less than during the monsoon season.

Results from this study suggested that lower salinity surface water from the Fly River enters the Great North-East Channel and does not penetrate the reefs in the eastern Torres Strait. However, anecdotal observations suggest the latter is not always true. In February 1992 a plume of brown water reached Darnley Island (approximately 67 kms from the mouth of the Fly River) and deposited large amounts of logs, nets and some canoes on the beaches (D Lui pers. comm.). These events are not common, however, and are on unknown signigicance for long-term trace metal concentrations in local sediment and biota.

The results of these salinity patterns are important for the interpretation of trace metal data in the Torres Strait for two reasons: (1) dissolved and suspended particulate metals originating from the Fly River could penetrate to the middle of the Torres Strait through the Great North-East Channel; (2) trace metal levels in areas west of the Torres Strait could be influenced by sources unrelated to the Fly River. With regards to (1) Baker et al (1990) measured suspended particulate copper levels in seawater samples collected from a range of locations in the northern and central Torres Strait. Their data showed high levels of particulate copper near the mouth of the Fly River (4.2-13.3 ppb), decreasing significantly in the Great North-East Channel (0.9-5.8 ppb). Suspended particulate copper levels were lowest west of the Warrior Reefs.

Results of the physico-chemical analysis of sediments suggest a limited penetration of the Torres Strait by Fly River sediments. Amounts of fine sediment decreased markedly away from the Fly River into the Great North-East Channel and seasonal changes in amounts of fines were only observed at one station at the mouth of the Fly River. Carbonate content was high at all stations except at the mouth of the Fly River and along the Papua New Guinea coastline. The number and spacing of samples collected in the present study is insufficient to delineate with any finer resolution the limits of the Fly River's influence. However, the results of this limited sampling (especially for the distributions of carbonate content and fine sediments) correspond with the much more extensive sampling done in the Fly River delta and throughout the central and northern Torres Strait by Harris et al (1989). Harris (1991) has suggested that only about 2% of the annual sediment discharge of the Fly River enters the Torres Strait and that, based on the distributions of terrigenous mud, carbonates and copper and zinc levels (Harris et al 1989), little of this is deposited south of Bramble Cay (S15 in figure 1.1). The suggestion of other sources of terrigenous trace metals into the north-central Torres Strait from rivers along the Papua New Guinea coastline is supported by the distribution of fine sediments and organic carbon in these areas.

Distributions, Concentrations and Sources of Trace Metals and Other Elements in Torres Strait Sediments

Multivariate analysis of trace metal data revealed four clusters of stations. Each cluster was composed of sediment stations from similar locations in the Torres Strait. Station S1 at the mouth of the Fly River was a distinct group. Stations in the northern Torres Strait and along coastal Papua New Guinea formed a distinct group. Stations in central Torres Strait, Great North-East Channel and eastern reefs formed a third distinct group.

The station at the mouth of the Fly River had high levels of the same suite of metals and elements but in addition the levels there of aluminium, copper, mercury, nickel, silicon and zinc were much higher. Sediments there also have the highest proportion of fine material and organic carbon, and the lowest proportions of calcium carbonate. The group of stations in the northern Torres Strait and coastal Papua New Guinea had higher levels of aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, silicon and zinc. Sediments from these stations had a significant proportion of fine material and organic carbon, and lower content of calcium carbonate. By comparison, sediments from stations in the central Torres Strait, Great North-East Channel and eastern reefs had higher levels of calcium, cadmium and magnesium, and low proportions of fine material and organic carbon, and a high calcium carbonate content. Only one metal, selenium, occurred in similar concentrations throughout the Torres Strait.

The distribution and concentration of these metals in the Torres Strait suggests that the Fly River and smaller coastal rivers along the Papua New Guinea coastline are sources of a distinct suite of trace metals and other elements for the northern Torres Strait. These metals are: aluminium, arsenic, cobalt, chromium, copper, iron, mercury, manganese, nickel, lead, silicon and zinc. Differences in concentrations of some of these metals between the station at the mouth of the Fly River and others along the coastline suggests that some metals are in higher concentrations in sediment coming from the Fly River compared with smaller coastal rivers. These metals are: aluminium, copper, mercury, nickel, silicon and zinc.

The conclusions drawn here, about the sources of trace metals in Torres Strait sediments, were based on analysis of whole sediment samples. Trace metals in sediments are mostly bound within the smaller particle size fractions. There was considerable variation in the grain size composition of sediments collected from the different stations throughout the Torres Strait. Accordingly, a more thorough understanding of the sources and spatial variations of trace metals in the Torres Strait will require additional statistical analysis which accounts for variation in grain size among stations.

In general, these trends agree with those reported in the Pilot Study (Dight and Gladstone 1993). Unlike the results reported here, the Pilot Study found that mercury and arsenic (in addition to selenium) were not associated with any particular sediment type. Mercury levels in the Pilot Study did not differ significantly amongst sampling stations; in the present study, however, mercury levels were consistently higher at Fly River and coastal stations. In retrospect, the conclusion of the Pilot Study that arsenic is not associated with any particular sediment type is surprising, given that levels were highest close to the Papua New Guinea coastline.

The geographic extent of Papua New Guinea coastal influences on Torres Strait trace metals can be estimated by examination of the levels of particular metals and their seasonal changes. Cobalt, magnesium and nickel levels in the northern Torres Strait stations S6 (at the northern end of the Great North-East Channel) and S15 (near Bramble Cay) were all less than station S1 at the mouth of Fly River, and higher than levels at stations further south in the Great North-

East Channel (S16 and S17) and the eastern reefs (S14). Seasonal changes in these metals at stations S6 and S15 followed the same pattern as Stations S1; this seasonal change was different from that which occurred at stations further south (S14, S16, S17). Similarly, levels of the same metals at station S18 in the north-central Torres Strait were slightly less than levels at coastal stations, and higher than levels at a central Torres Strait station further south (S5). Seasonal changes in these metals at S8 were the same as those occurring at coastal stations, and different from those occurring further south at S5.

This suggests that Fly River sediments and their characteristic suite of trace metals extend southward into the Torres Strait to a line between stations S6 (latitude 9°12'S) and S15 (latitude 9°08'S). Further southward sediments become more marine in their physical characteristics and their trace metal and element content. The influence of other Papua New Guinea coastal rivers on the trace metal content of sediments in the central Torres Strait, west of the Warrior Reefs, possibly extends southward as far as station S18 (9°35'S, 142°47'E).

Comparisons with Other Studies of Torres Strait Sediments

There are no consistent differences between the Main and Pilot Studies in metal concentrations at the same stations. Copper levels at S1 at the mouth of the Fly River in the Main Study during the pre-monsoon (mean = 17.89 mg/kg, SD = 2.472) were less than levels recorded at the same station and season during the Pilot Study (mean = 21.6 mg/kg, SD = 8.2); however Main Study monsoon levels (mean = 23.11 mg/kg, SD = 3.100) were greater than Pilot Study post-monsoon levels (mean = 16.7 mg/kg, SD = 1.4). Copper levels at S6 during the Main Study pre-monsoon (mean = 6.44 mg/kg, SD = 0.882) and monsoon seasons (mean = 6.78 mg/kg, SD = 1.202) were less than those reported for the Pilot Study in both the pre-monsoon (mean = 7.8 mg/kg, SD = 1.2) and post-monsoon seasons (mean = 7.2 mg/kg, SD = 0.8).

As proposed in the previous section of this Discussion, the trace metal characteristics of station S6 appear to be influenced by Fly River outflow. Estimates of copper levels at S6 were less variable than those for S1. The greater variability of estimates for S1 will affect the ability of future monitoring programs to unambiguously detect any trends in trace metal levels at this station in the short term. Decisions about changes should therefore consider changes in levels at all stations likely to be influenced by the Fly River.

Sediment copper concentrations in the Torres Strait and at the mouth of the Fly River determined in this study are similar to concentrations reported in previous studies. Copper concentrations at S1 (17.89-23.11 mg/kg) are within the range of values reported for nearshore Gulf of Papua stations (7-24 ppm) by Robertson and Alongi (1991). Copper concentrations in the < 2 mm sediment fraction reported in the present study are less than those determined by Ok Tedi Mining Ltd (reported by Waite and Szymzcak 1991) at similar locations for the < 100 µm fraction. S1 copper concentrations (17.89-23.11 mg/kg) were less than those found by Ok Tedi Mining Ltd at nearby Parama Island (35 µg/g); they were also less at S10 (7.67-8.78 mg/kg) compared with two nearby locations at Gimini Reef (10-16 µg/g; 16 µg/g).

Copper concentrations determined by Schneider (1990) for complete sediment samples are similar to results from the present study for stations in the northern Torres Strait and central Great North-East Channel. Copper concentrations found in the present study for the stations closest to the mouth of the Fly River and the most southern sites, are slightly higher than those reported by Schneider (1990). Baker and Harris (1991) reported concentrations of copper (28 µg/g), lead (13 µg/g) and zinc (91 µg/g) for sediments from the Fly River delta which were similar to values reported for the same metals at a similar location (S1) in the present study (17.89-23.11 mg/kg, 14.78-19.78 mg/kg, and 94.56-94.78 mg/kg respectively). Concentrations of copper (8.2 µg/g), lead (2.8 µg/g) and zinc (23 µg/g) in the Torres Strait reported by Baker

and Harris (1991) are similar to the range of concentrations for the same metals found in the present study (2.67-12.50 mg/kg, 4.44-21.0 mg/kg, and 7.56-59.70 mg/kg respectively).

Comparisons with Studies from Other Regions

Robertson and Alongi (1991) reported that copper concentrations in the nearshore Gulf of Papua were similar to concentrations in other tropical coastal habitats and concluded that these levels were 'not abnormally high' (p 248); results from the present study are within the range of values reported by Robertson and Alongi (1991). Levels of cadmium, copper, lead and zinc in Torres Strait sediments are similar to levels found in clean offshore areas in the tropics (Peerzada and Rohoza 1989; Brady et al 1994; Reichelt and Jones 1994) and less than areas regarded as contaminated (Peerzada and Rohoza 1989; Subrananian et al 1989; Gonzalez and Torres 1990; Brady et al 1994; Reichelt and Jones 1994). Levels of copper at station S1 near the mouth of the Fly River (17.89-23.11 mg/kg) overlap with copper levels from a contaminated site in Darwin Harbour (15.7-32.2 µg/g; Peerzada and Rohoza 1989); however the latter site does not have a significant riverine influence. Levels of copper at S1 are less than levels recorded at contaminated sites in Townsville harbour (Reichelt and Jones 1994), Cuba (Gonzalez and Torres 1990) and various locations in Indian estuaries and the Bay of Bengal (Subrananian et al 1989). The highest concentrations of cadmium recorded in the present study (0.08 mg/kg at S7 and 0.05 mg/kg at S11) are less than the range of values considered to be 'normal' for 'cleaner inshore areas' (GESAMP 1985, p 12).

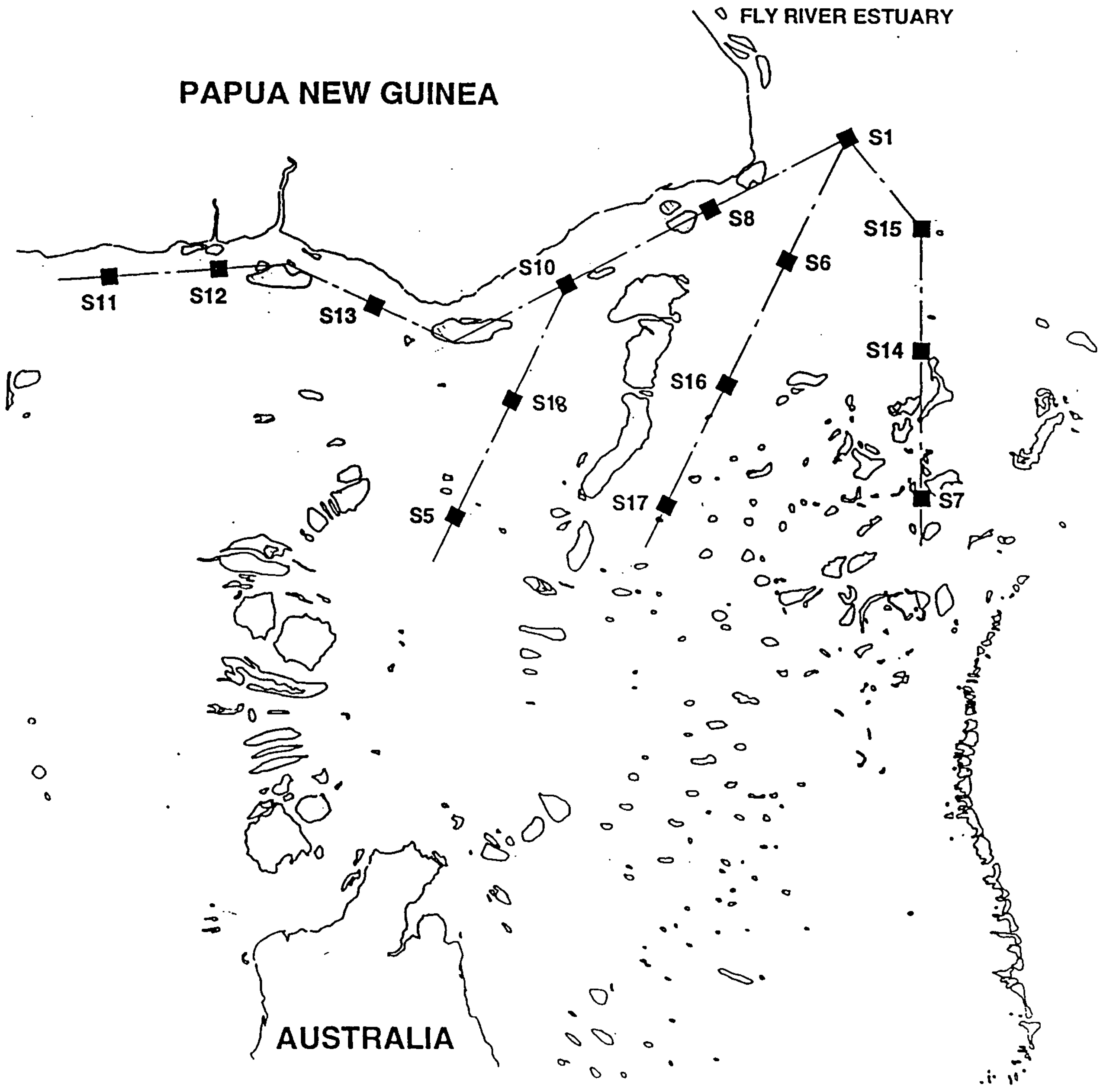

Figure 1.1. Locations of sediment collecting stations in the Torres Strait

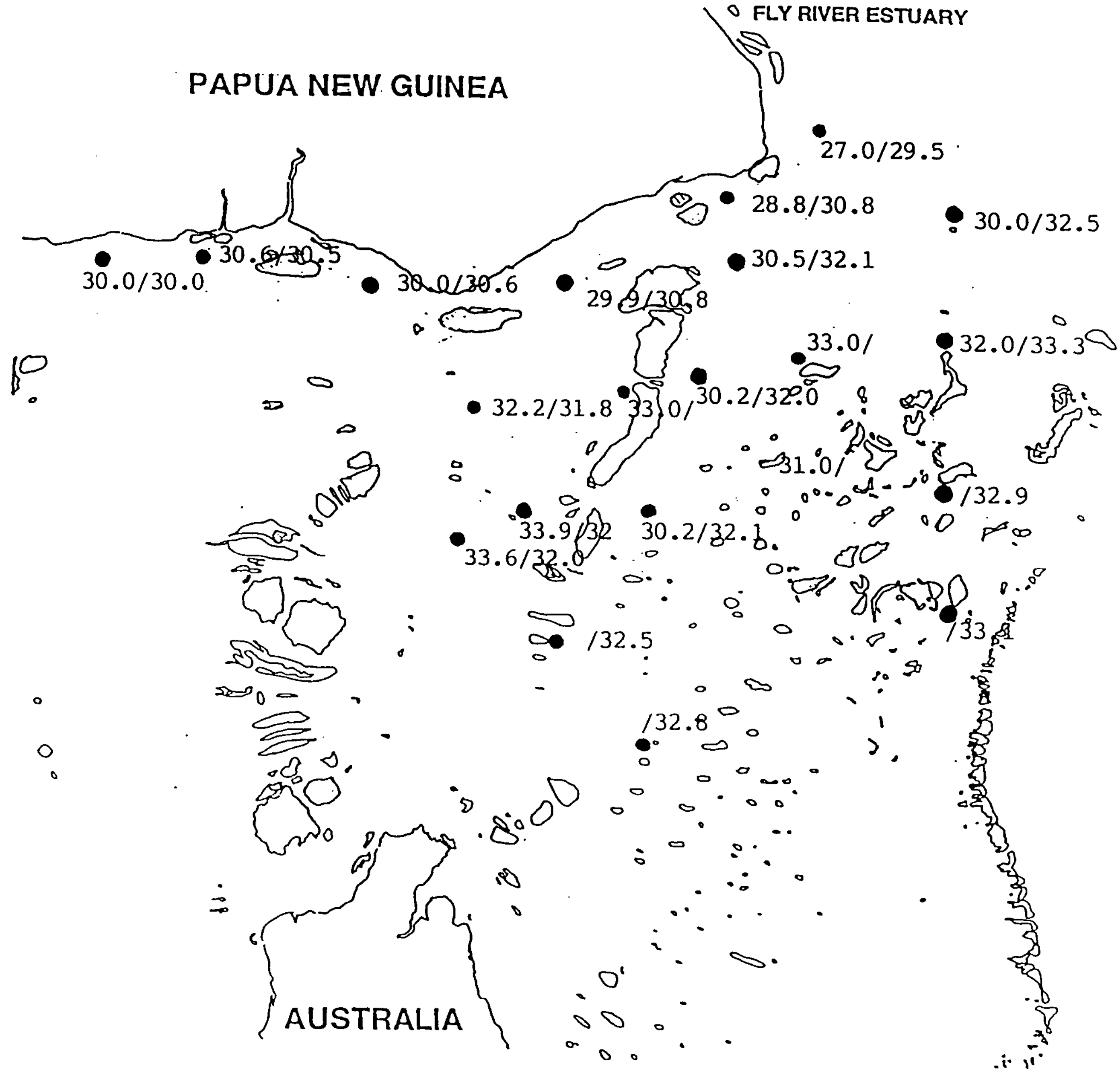

Figure 1.2. Surface salinities (in parts per thousand) in the Torres Strait during the pre-monsoon (October-November 1992) and monsoon (March 1993) seasons. The first value is the pre-monsoon salinity, the second is the monsoon salinity.

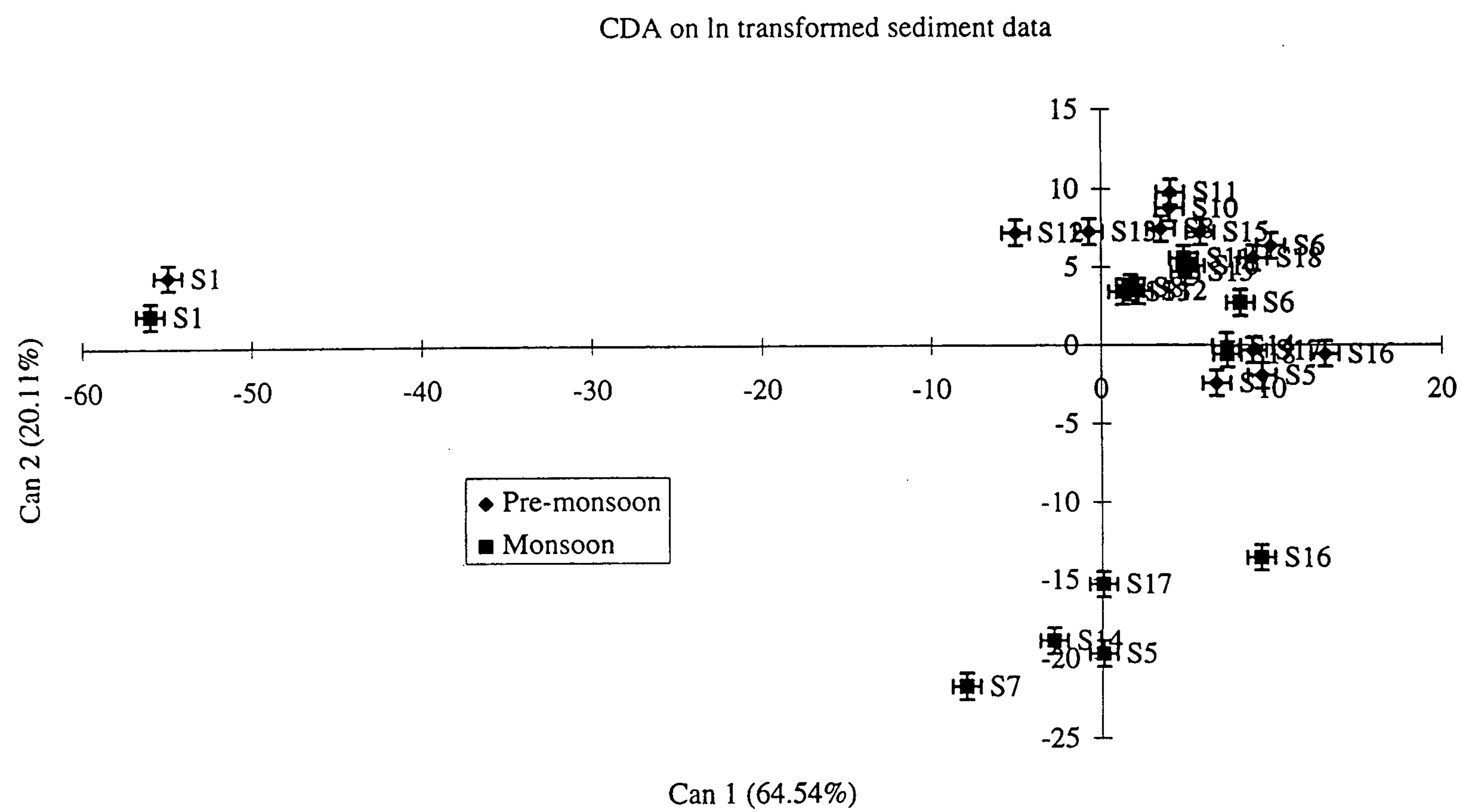

Figure 1.3. Canonical discriminant analysis (CDA) reduced plot, based on trace metal concentrations in Torres Strait sediments in pre-monsoon and monsoon seasons. The cluster of stations above the focus of the two axes contains the following stations: S6, S8, S10, S11, S12, S13, S15 in both pre-monsoon and monsoon seasons, and S18 in the pre-monsoon only. Bars around each station are 95% confidence intervals.

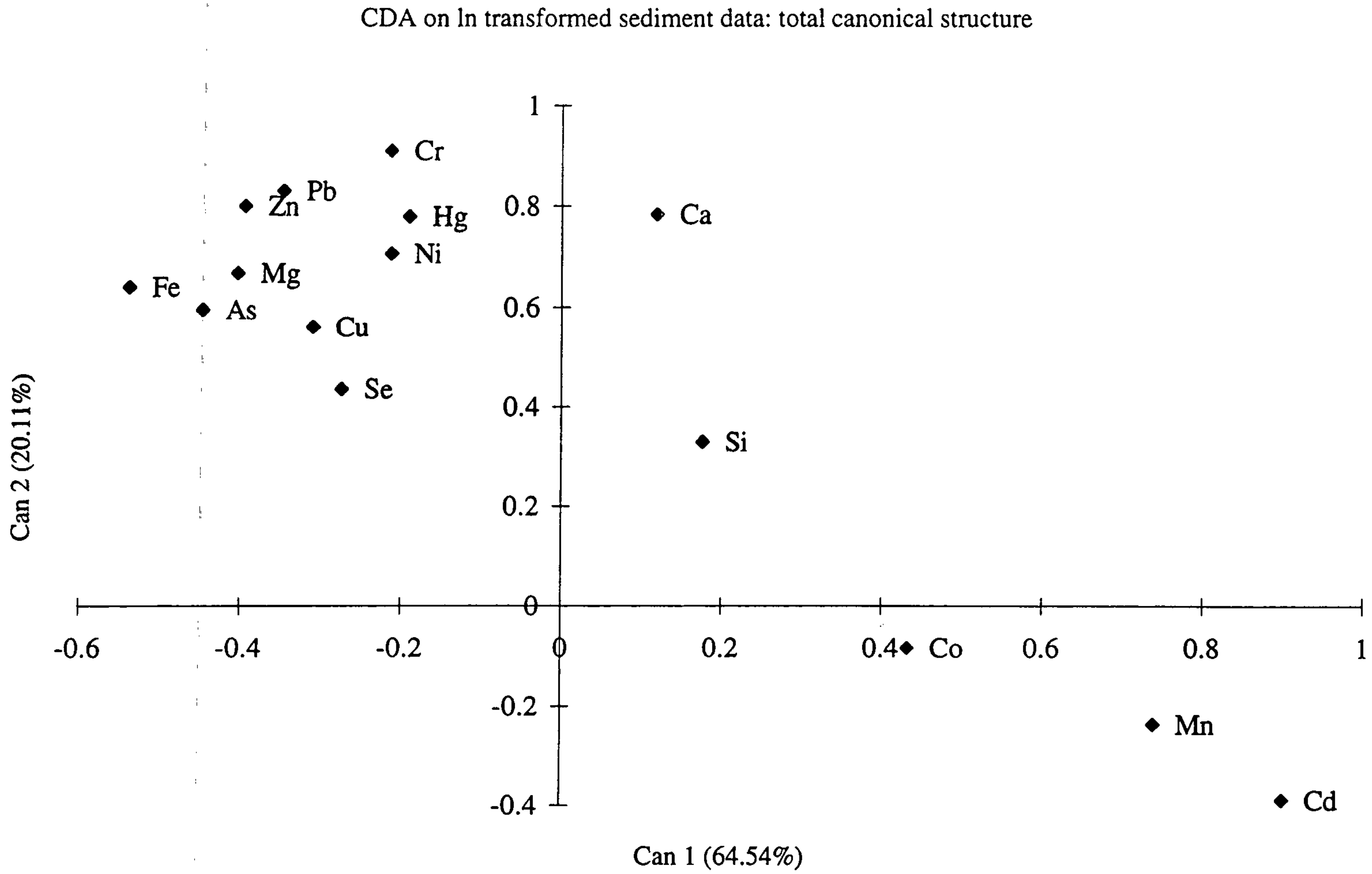

Figure 1.4. Plots of structural coefficients (this page) and canonical coefficients (following page) as a basis for explaining the patterns shown in the reduced plot (figure 1.3).

CDA on ln transformed sediment data: raw canonical coefficients