

Preliminary results on phosphorus status of suspended sediment from cyclone Sadie

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Abstract

The sediment plume generated by cyclone Sadie was sampled five days after the peak of the flood, along two transects from the mainland to the nearest reef. Although rapid mixing of flood water with marine waters had already occurred, sufficient amounts of suspended sediment for chemical analysis were collected in the Johnstone Rivers estuary and the adjacent nearshore area. Total phosphorus (P) concentrations of the plume sediments were high and of the same magnitude and range as those of bottom fluvial sediments of the catchment. Phosphorus sorption parameters of the suspended sediments indicated that they were not in equilibrium with the P status of their surrounding water and, although they could desorb large quantities of P into P-free water, there was no supportive evidence for such a desorption process occurring in-stream. Increasing salinity did not promote further P desorption.

Surficial sediments from the marine nearshore zone are undoubtedly of terrestrial origin but their total P content is much lower than that of plume sediment. Assuming that the suspended sediments discharged by the rivers are eventually deposited in the nearshore area, it can be inferred that during the deposition/diagenesis process, suspended sediments lose approximately 80% of their total P.

Introduction

Following the increasing concern on the fate and behaviour of suspended sediments and nutrients discharged by the major rivers along the Queensland coast, the long-awaited cyclone Sadie provided the ideal conditions to study sediment plumes. Since a comprehensive data set on the phosphorus (P) status of sediments from the Johnstone Rivers catchment and the adjacent offshore area has been generated over the past five years (Pailles and Moody 1992; Pailles et al. 1993), the main objectives of this study were (a) to determine the P status of suspended sediments discharged into the Great Barrier Reef lagoon during cyclonic events, and (b) to link the P status of suspended sediments to the P status of sediments in the catchment and in the marine offshore area. This linkage will contribute to a better understanding of P dispersion and dynamics in the transition from fluvial through estuarine to marine conditions.

Materials and methods

Water samples were collected on 5 February 1994, five days after the peak of the flood due to cyclone Sadie in the Johnstone Rivers. Samples were taken in two transects from the river mouth to the nearest offshore reefs (Fig. 1). Due to the low total suspended solids (TSS) load in the inner and mid-shelf waters (3 to 5 mg L^{-1}), sufficient suspended sediment samples for analysis could only be obtained by sampling the estuarine and nearshore waters where TSS concentrations ranged between 7 and 24 mg L^{-1} . Accordingly, suspended sediment samples were taken at five locations in the estuary and nearshore area (Fig. 1). Since the rivers had been flooding for five days, it is likely that, although the sediments were collected in an upstream direction, they were of similar origin. Water plus suspended sediment samples were collected 0.5 m below the surface in acid-rinsed and sample-rinsed polyethylene 20 L drums. Electrical conductivity (EC), temperature, pH, and redox potential (Eh) of the samples were measured in situ. A few drops of HgCl_2 were added to inhibit plankton growth and the samples were stored at 4°C in the dark. Analysis of the suspended sediments occurred in the following weeks.

In the laboratory, the samples were filtered through acid-washed and sample-washed $0.45 \text{ }\mu\text{m}$ membrane filters. The filtrates were analysed for dissolved orthophosphate-P content using the methods described later. Equilibrium phosphorus concentration (EPC), total P and resin-P were determined on the suspended sediments separated by filtration. EPC of the suspended sediment was determined on separate samples at the in situ EC, and at an EC similar to that of sea water by using 3.5% NaCl as the suspending solution. EPC was determined by the method described in Pailles and Moody (1992), except that 25 mg of sediment were shaken with 25 mL of the appropriate NaCl solution. Resin-P was determined by shaking (end-over-end at 30 rpm) for 18 h , 25 mg of sediment in 25 mL of deionised water with 15.6 cm^2 of each of a cation exchange and anion exchange resin strip. After shaking, the strips were removed from the suspension, rinsed with deionised water and P displaced from the anion exchange membrane by eluting with 40 mL of 0.15 M HCl . Orthophosphate-P (DIP) was determined on the eluate using an auto-analyser procedure (Warrell and Moody 1984) based on the Murphy and Riley (1962) colorimetric method. Desorbable P was calculated by measuring the solution orthophosphate-P concentration after shaking 25 mg of sediment in 25 mL of a P-free solution of the same EC and pH as the respective surrounding water (by adjusting the EC and pH with additions of NaCl and NaOH). Total-P was extracted by the sodium carbonate fusion method of Olsen and Sommers (1982) adjusted to a smaller quantity of sediment and analysed colorimetrically by the Murphy and Riley (1962) method. Orthophosphate-P in the water was also determined using an auto-analyser procedure (Warrell and Moody 1984) based on the Murphy and Riley (1962) colorimetric method. Total suspended solids (TSS) concentrations in the water were determined by filtering two aliquots of 100 mL through pre-weighed $0.45 \text{ }\mu\text{m}$ membrane filters, then re-weighing the filters after drying at 40°C for 24 h .

Results and Discussion

Plume sediment characteristics

Five days after the peak of the flood, turbid waters were only encountered in the estuary and within 1 km offshore (station KK). A line separating brown freshwater from blue-green sea water was visible close to the coastline. Further offshore and up to the nearest reefs, the waters were clear. Field observations were confirmed by TSS concentrations obtained in the laboratory (Table 1). TSS decreased with increasing salinity (Fig. 2), indicating rapid mixing and dilution with sea water. Similarly, the EC of the water indicates that the influence of the freshwater discharged from the Johnstone Rivers was only detected within 1 km offshore (station KK). The EC of offshore waters were similar to those measured under fair-weather conditions (Pailles unpublished data). Furthermore, pH, EC, temperature and TSS data recorded at different depths suggest that, five days after the flood peak, there was no clear stratification of the sediment plume, and rapid mixing with sea water had occurred.

Experiments with plume sediments in situ

Orthophosphate-P concentrations in the suspension waters were much lower than the EPCs of the suspended sediments (cf. figures 2 and 3) suggesting that the sediments were not in equilibrium with their surrounding waters. This may be due to the suspended sediments being in equilibrium with the solution in the diffusion zone surrounding them (Froelich 1988), but this zone is 'insulated' from the bulk solution because of the low diffusion coefficient of P in solution.

Table 1. Physical and chemical characteristics of offshore waters following cyclone Sadie, n.d.: not determined

Station	Latitude <i>dec degrees</i>	Longitude	Bottom depth <i>m</i>	Sample depth <i>m</i>	Temp <i>°C</i>	Cond. <i>mS/cm</i>	pH	Eh <i>mV</i>	TSS <i>mg/L</i>	D.I.P <i>µg/L</i>
GG	17 21 12	146 17 04	40	14	29.0	50.3	8.12	130	3	11.0
				1	28.5	52.3	8.10	120	4	6.0
FF	17 22 42	146 15 37	34	1	28.0	53.9	8.12	130	4	4.5
DD	17 25 16	146 11 84	23	15	29.0	54.6	8.14	120	4	5.5
				1	29.0	53.1	8.16	140	1	2.5
BB	17 28 62	146 07 74	20	18	29.0	53.3	8.17	158	4	4.5
				1	29.0	50.9	8.19	181	5	3.5
KK	17 30 03	146 05 18	4.5	2	30.0	52.5	8.03	158	4	13.0
	17 30 31	146 04 96	2	0.5	28.5	43.4	8.13	184	4	6.5
F	17 26 10	146 18 46	39	15	28.0	n.d.	8.04	195	5	4.0
				1	29.0	52.1	8.16	208	5	<1.0
D	17 25 15	146 14 44	30	15	29.0	53.0	8.08	212	11	<1.0
				1	30.0	51.6	8.02	195	5	1.0
A	17 28 60	146 09 90	21	19	29.0	52.2	8.08	203	4	2.0
				1	30.0	52.1	8.13	190	5	2.5
K	17 29 54	146 07 17	15	12	29.5	52.9	8.13	200	5	2.0
				1	30.0	52.0	8.14	193	3	2.0
2	17 30 81	146 04 86	2.5	0.5	28.0	31.5	8.03	188	1	5.0
1	17 30 43	146 04 69	2	0.5	28.0	23.1	7.76	180	7	9.0
3	17 30 51	146 04 22	2	0.5	26.0	16.4	7.49	188	24	2.0
4			4	0.5	27.0	8.9	7.19	177	21	7.5
5			5	0.5	27.0	3.2	7.10	160	15	7.0

The quantity of P that could be desorbed from the suspended sediments into P-free water of similar EC averaged 19 mg kg^{-1} ($17\text{--}21 \text{ mg kg}^{-1}$) (Table 1), suggesting that P is easily desorbed. This amount of desorbable P is two orders of magnitude higher than that desorbing from fluvial and estuarine bottom sediments in similar experiments (Pailles and Moody 1992) (Table 2). However, there was no trend indicating the orthophosphate-P concentration in the water changed with salinity (Fig. 2). The concentration remained at a level which is indicative of offshore reef waters. Therefore, there is no clear evidence that suspended sediment is contributing P to the water column through desorption processes. This conclusion is further supported by the lack of any trends in either EPC (Fig. 3) or resin-P (Table 1) of the suspended sediments with increasing salinity.

Total P figures for the suspended sediments averaged $1886 \pm 570 \text{ mg kg}^{-1}$ ($1069\text{--}2679 \text{ mg kg}^{-1}$) (Fig. 3). Similar total P figures were obtained by Pailles et al. (1993) for fluvial bottom sediments in the tributaries of the North and South Johnstone Rivers during the dry season. This suggests that the suspended sediments in the flood plume were derived from the same parent materials as the tributary sediments found during base flow conditions. The wide range in total P observed in suspended

sediments is a reflection of the wide range in total P content of the parent material in the catchment. These range from P- rich basalt (ca. 400 mg kg⁻¹) to low-P granite (ca. 600 mg kg⁻¹).

Experiments with plume sediments in sea water (3.5 % NaCl)

Desorbable P and EPC decreased when suspended sediments were shaken in 3.5 % NaCl (Table 2) suggesting that P is more tightly bound to the particles in the marine environment. This result confirms our previous observations on the behaviour of bottom fluvial and estuarine sediments in sea water (Pailles and Moody 1992).

Table 2. EPC and desorbable-P of plume sediments, fluvial and estuarine bottom sediments in situ and in artificial seawater, I.S. = Insufficient Sample

3.5% NaCl		In Situ					Event
EPC µg/L	P des. mg/kg	EPC µg/L	P des. mg/kg	Resin-P mg/kg	EC mS/cm	Sediment #	
							CYCLONE SADIE PLUME SEDIMENT
11	9	34	21	107	3.2	5	
19	15	I.S.	I.S.	152	8.9	4	
15	12	32	20	144	16.4	3	
53	30	I.S.	I.S.	160	23.1		
33	17	33	17	128	31.5	2	
							CYCLONE SADIE BOTTOM SEDIMENTS
3.1	I.S.	4.00	0.04				<i>Fluvial</i>
3.7	I.S.	3.70	0.04				
3.1	I.S.	5.60	0.11				
2.5	I.S.	8.10	0.10				
I.S.	I.S.	11	0.09				<i>Estuarine</i>
I.S.	I.S.	33	0.20				
55	I.S.	30	0.09				
							MARINE TERRIGENOUS ZONE
			65-105	I.S.	76-120		<i>Sludge Sediments</i>
			127-166	I.S.	82-84		<i>Surficial Sediments</i>

P sorption parameters of suspended sediments, offshore sludges, and surficial sediments of the terrigenous zone

EPCs of the suspended sediments were lower than those of the sludges and surficial sediments of the offshore terrigenous zone (Fig. 3). This result suggests that bottom sediments and sludges are more likely to desorb P than suspended sediments. Yet, their total P contents were much lower than those of suspended sediments (Fig. 3). The physical, mineralogical and geochemical characteristics of offshore sludges and sediments clearly indicate that they are of terrestrial origin (Pailles and Moody submitted).

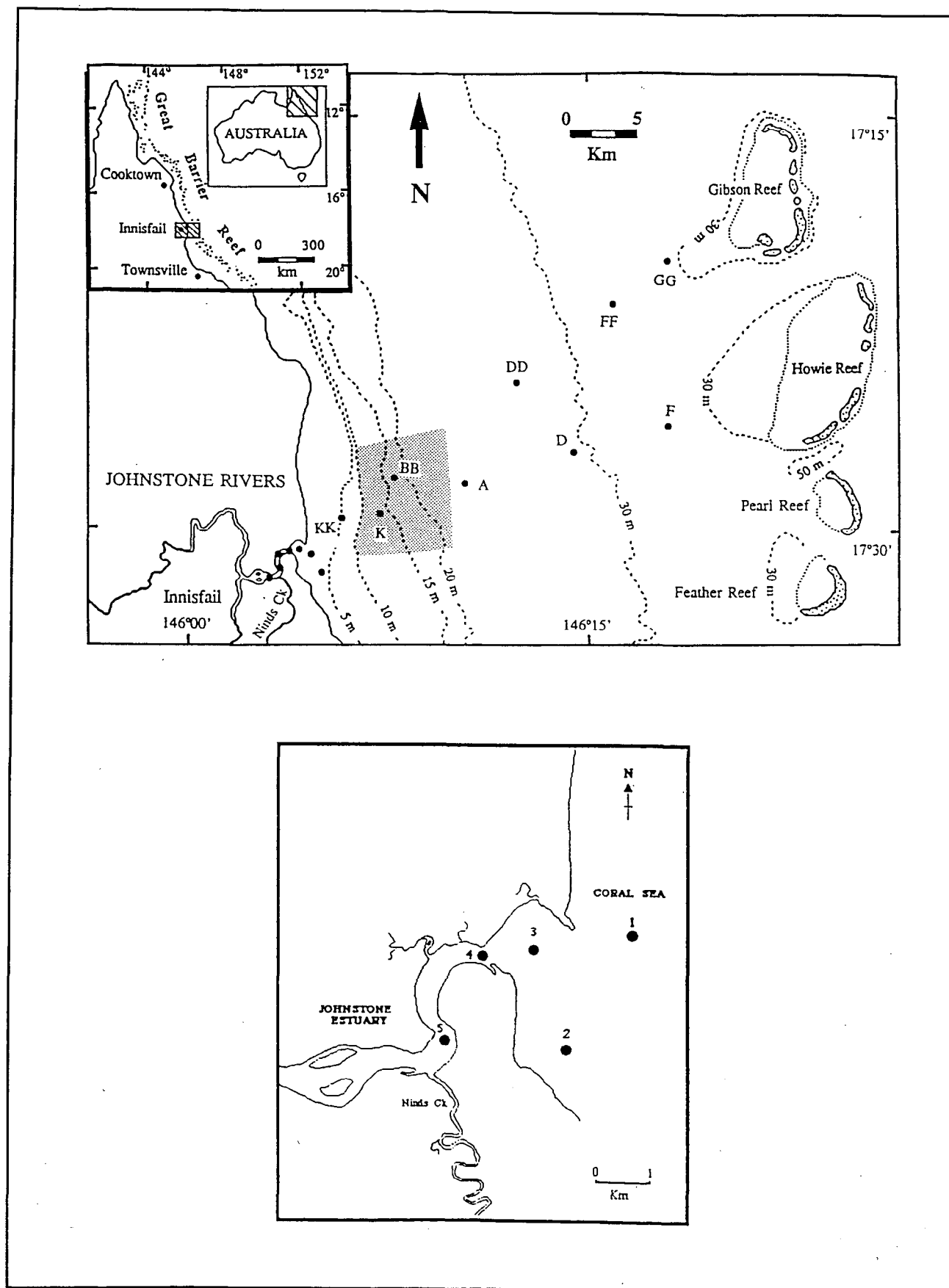


Fig. 1. Sample locations along the transects and in the estuary. The area shaded in grey represents anoxic terrigenous sediments

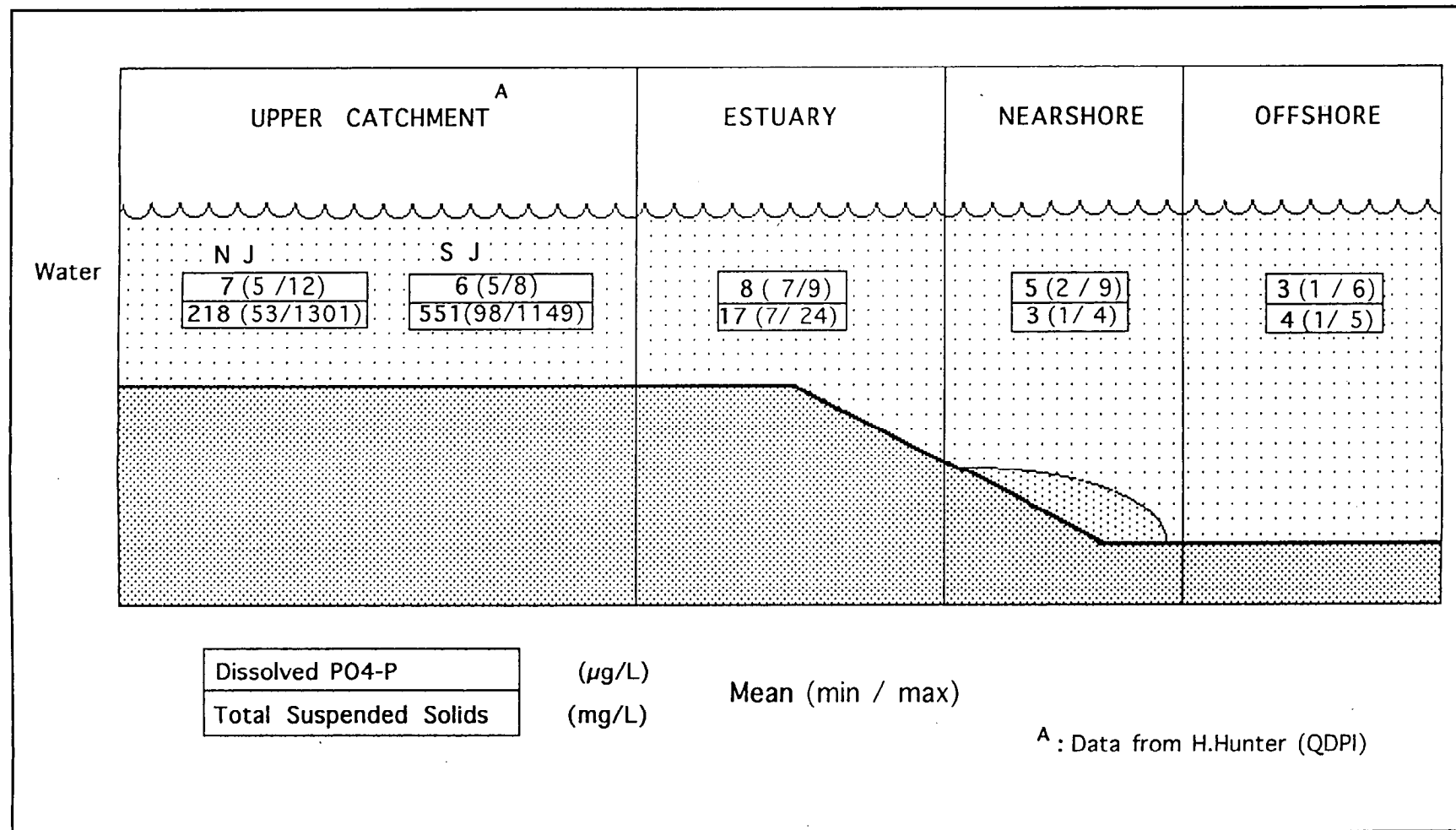


Fig. 2. Dissolved PO₄-P and total suspended solids in the waters of the Johnstone Rivers and the adjacent offshore area following cyclone Sadie

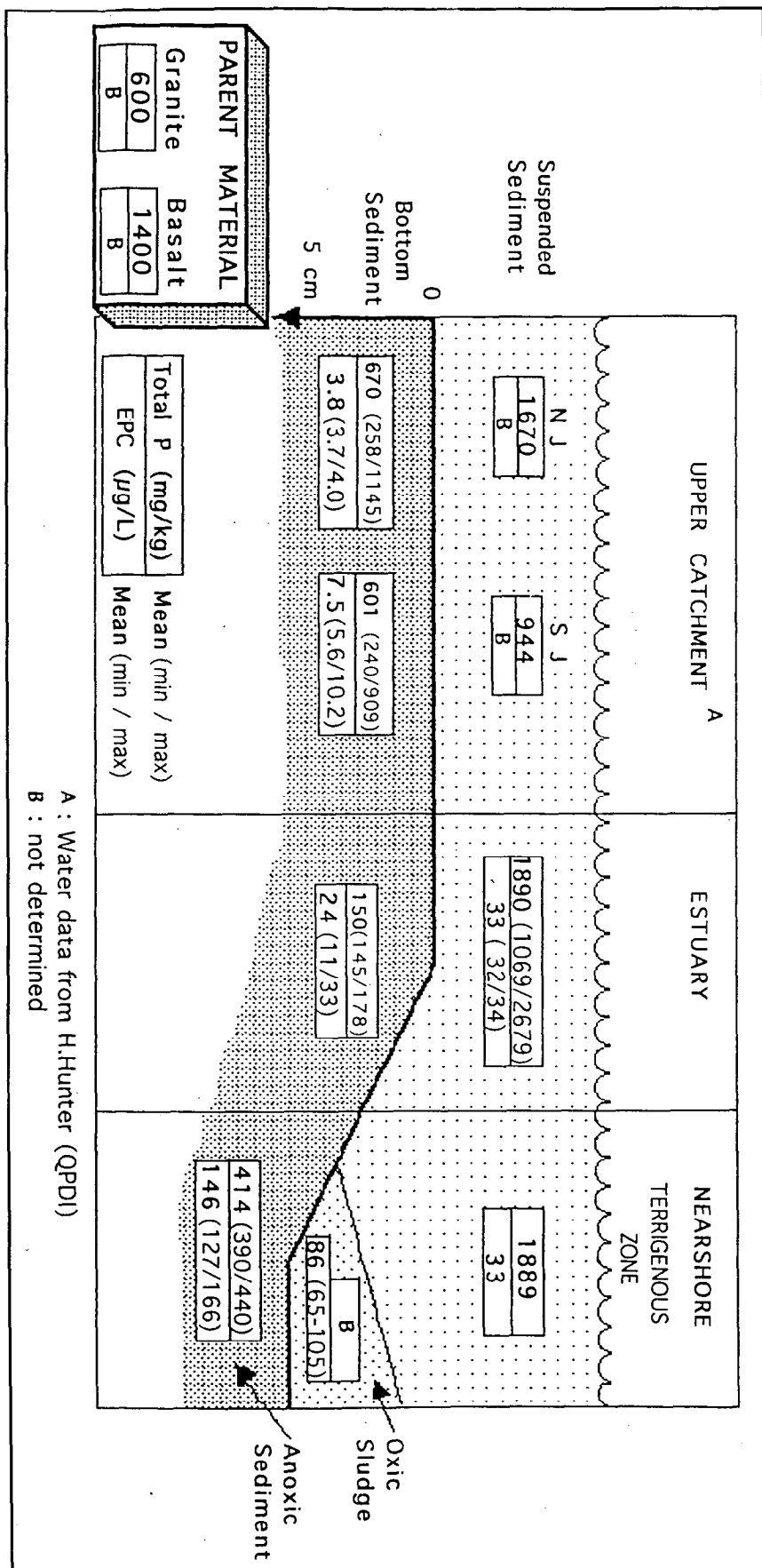


Fig. 3. Total P and EPC of suspended and bottom sediments in the Johnstone Rivers and adjacent nearshore area. Suspended sediment values correspond to cyclone Sadie whereas bottom sediment values correspond to base flow conditions

Thus assuming that the suspended sediments discharged by the rivers are eventually deposited in the nearshore area, it can be inferred that during the deposition/diagenesis process, suspended sediments lose 65 to 90% of their total P (Fig. 3). In contrast, resin-P concentrations in suspended sediments and in offshore sludges/surficial sediments are similar (Table 2), suggesting that the same amount of desorbable P is always available regardless of total P.

Data from Hunter (1996) indicate that, as a consequence of cyclone Sadie, 192 552 tonnes of sediment were discharged to the sea. Using an average total P concentration of 1890 mg kg^{-1} for suspended sediments, this sediment yield equates to 364 t of P discharged to the sea. This value is very close to the value given by Hunter (314 tonnes of P discharged during cyclone Sadie) which was arrived at using total P figures measured by Kjeldahl digestion. Nevertheless, on the assumption that suspended sediments will lose approximately 80% of their total P content, 251 to 291 tonnes of P (based on Hunter's and our data respectively) could therefore be released to the water column.

Conclusions

The results obtained from this study demonstrate that suspended sediments have a high total P content and that they are of the same origin as fluvial bottom sediments. Desorption experiment results confirm that increasing salinity does not promote the desorption of P from the suspended sediments. It is rather likely that the development of anoxic conditions (caused by the presence of significant amounts of organic C and a high clay content) in offshore surficial bottom sediments, and/or the presence of sulphates, would favour the release of P into solution (Caraco et al. 1989). This scenario would tend to support the findings of Bell (1991) that the release of P occurs after sediment re-suspension during major storms.

The results of this work highlight the need to investigate (a) if P is released from settled suspended sediments undergoing early diagenesis/reduction, (b) the factors governing desorption (eg. pH, Eh, salinity and sulphate content) and (c) the amounts of P released and the rate of release from sediments undergoing reduction.

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