APPENDIX

NEARSHORE HYDRODYNAMICS AND SEDIMENT DYNAMICS OF THE FRINGING REEF COAST IN THE CAPE TRIBULATION AREA

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Abstract

The hydrodynamics of fringing reefs and associated nearshore waters in the Cape Tribulation area are described within the context of an examination of the effect of disturbed rainforest catchments on adjacent fringing reefs. The theory of water and sediment dynamics is reviewed. Field data were collected during periods in January 1988 and July 1988, with moderate southeasterly wind conditions prevailing during both periods. Water velocity and direction data, suspended sediment concentration data, and surficial sediment data are used in conjunction with nearshore coastal process theory to examine local water circulation, and the relative importance of resuspended and river derived suspended sediments. The available evidence suggests that wind and wave generated circulation dominates in the nearshore, but is modified by local morphology. Offshore surficial sediments contain a high proportion of muds, and resuspension of these sediments occurs under modal wind and wave conditions. River derived sediments may add to offshore suspended sediment concentrations during extreme weather events, but are only significant in the near vicinity of the stream mouths, with sedimentation likely only in zones of very low velocity. Cape Tribulation fringing reefs are likely to have developed in conditions of high turbidity and high suspended sediment concentrations.

1. Introduction

Following the construction of a road linking Cape Tribulation and Bloomfield, the Great Barrier Reef Marine Park Authority initiated a research and monitoring programme to provide a sound basis for the management of the mainland fringing reefs in the area (Craik and Dutton, 1987). A component of this research is to examine the 'effects of disturbed rainforest catchments on adjacent fringing reefs in the Cape Tribulation area' (Craik and Dutton, 1987). This report details a study which contributes to this research.

Although the Cape Tribulation fringing reefs have developed and been maintained with high suspended sediment concentrations and turbidity (Johnson and Carter, 1987), it is clear that increased sedimentation and suspended sediment levels, resulting from catchment land use change, could cause the siltation tolerance of corals in the area to be exceeded. The literature relating to siltation effects on coral reefs is well summarised by Johnson (1987). Ayling and Ayling (1987) report early results of studies examining the effect of silt runoff on the Cape Tribulation reefs.

The research utilises nearshore coastal process theory tested by Lagrangian and Eulerian hydrodynamic techniques to examine the movement and redistribution of sediments which reach the reef flat and offshore areas from the numerous small streams which flow from the mainland, and which are resuspended from the offshore seabed. Fieldwork was undertaken during January 1988 and July 1988.

The research objectives were:

1. To describe nearshore water circulation under winter and summer wind conditions
2. To describe water circulation within bays under winter and summer wind conditions
3. To determine the conditions under which resuspension of offshore sediments will occur, and to examine the redistribution of these sediments
4. To examine the dispersion of sediments derived from streams flowing onto the reef flat.

2. The study area

The study area (Figure 1) extends approximately 19 km from Cape Tribulation in the south to approximately 3 km south of the Bloomfield River (Figure 2). The coastline consists of a series of headlands separating bays, containing sandy beaches and reef flats of various widths. The outer living coral zone is generally narrow, and variable in its occurrence. The offshore area can be divided into an inner shelf (to 20 m water depth), a flatter middle shelf (20 - 40 m water depth) and a mid-shelf reef tract some 15 km offshore (Johnson and Carter, 1987). The coastal ranges lie in close proximity to the coast with dense tropical rainforests growing to the coastline. The coastline falls within the Cairns Section of the Great Barrier Reef Marine Park, and is zoned Marine National Park 'B'.

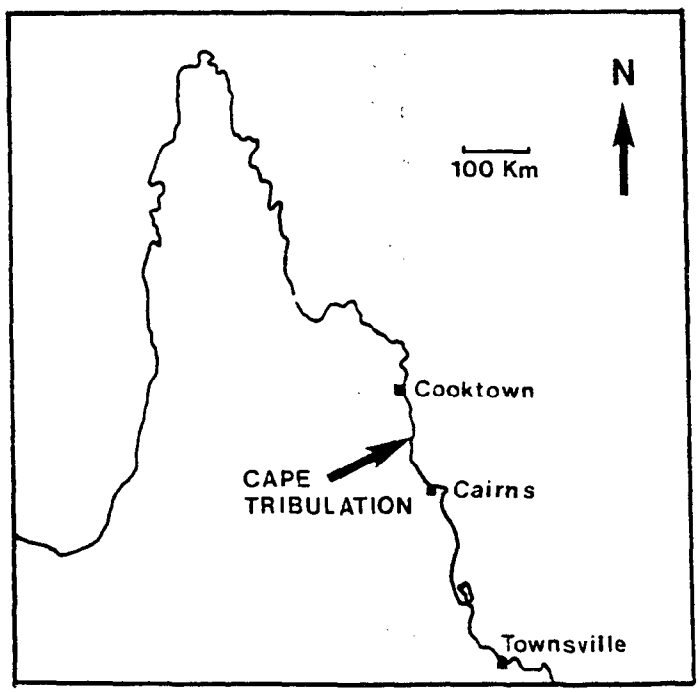

Figure 1: Location map of the Cape Tribulation area. Source: Johnson and Carter (1987)

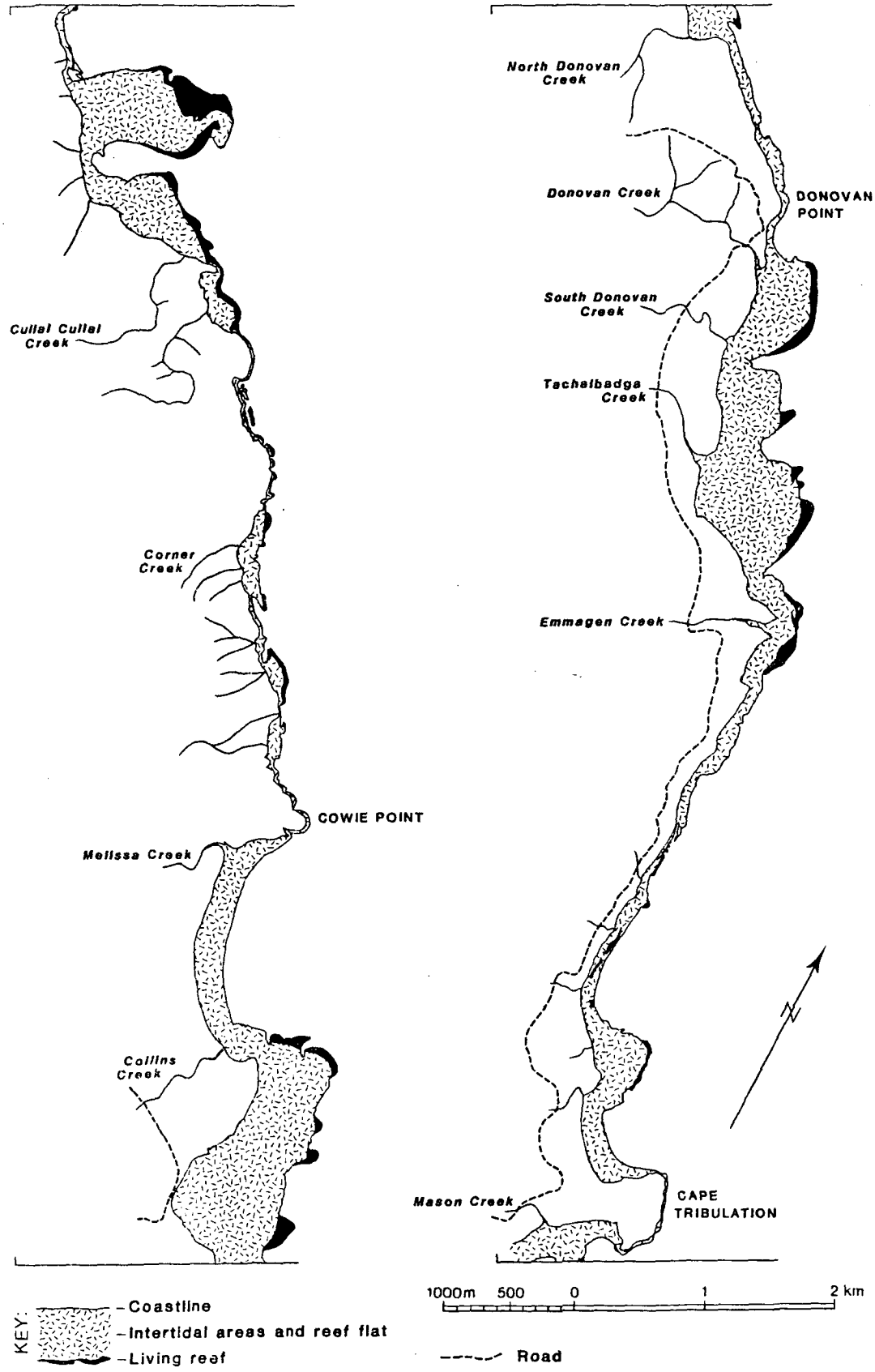

Figure 2: The study area, Cape Tribulation area.

The most noticeable climatic influences of the area are the persistent southeasterly trade winds and the marked seasonality of climate. The winter dry season is associated with anticyclones crossing the continent at about 30°S causing ridges of high pressure along the coast adjacent to the Great Barrier Reef. In summer, low pressure systems dominate although weaker ridges may persist. From December to March moist air masses move over northern Australia, with winds typically from the north or northwest. Tropical cyclones may occur during the months November to May. Pickard (1977) and Downey (1983) provide comprehensive accounts of the regional climatic features. Annual average rainfall is approximately 4000 mm at Cape Tribulation (Ayling and Ayling, 1987), with annual totals of 6000 mm being not unusual. Annual average evaporation is in the order of 1250 mm (Bureau of Meteorology, 1971).

Wind and wave data relevant to the study area are limited. Data from Cairns indicate modal wave heights in the order of 0.2-0.6 m (Beach Protection Authority, 1978), with cyclonic wave heights, limited by the short fetch, recording a maximum of 3.21 m (Hopley, 1982). Because the prevailing southeast winds blow obliquely up the inner mid shelf between the mainland and the inner reef tract, Johnson and Carter (1987) report the common formation of waves 1-2 m high reaching the coast in the Cape Tribulation area.

Tidal data for Cape Tribulation is based on the 'Secondary Place' table for Low Isles (Department of Harbours and Marine, 1988) (Table 1). Tides are semi diurnal with significant diurnal inequality.

Table 1: Tidal data, Low Isles (with respect to Standard Port, Cairns)

	HW	LW	MHWS	MHWN	MLWN	MLWS	ML	Rat	Con
Cairns	Standard Port		2.4	1.7	1.3	0.6	1.50		
Low Isles	0 00	0 00	2.3	1.6	1.3	0.6	1.46	0.92	+0.10

Circulation is a function of mean flows and oscillatory motions. It is expected that in the vicinity of Cape Tribulation flows will be a combination of currents set up by the wind, and tidal currents. In the vicinity of nearshore high islands, many studies have reported consistency in reversing tidal stream directions indicating minimal wind driven flow (Hamner and Hauri, 1977, 1981; Falconer et al., 1986; Parnell, 1987, 1988). In other areas wind driven flow dominates. Perhaps most significant for the Cape Tribulation area is a two and a half year data set for currents near Green Island (Wolanski, 1983;

only 15 km offshore, where coral growth extends down to 30-40 m. Sediments of the lower slope becomes increasingly muddy seawards where they merge with those of the inner shelf."

Cape Tribulation fringing reefs are developed on coastal sediment bodies, with carbonate rich reefal deposits prograding seawards over finer grained, terrigenous sediments which are accumulating on the inner shelf seaward of the reef flat (Johnson and Carter, 1987).

A number of rivers of various sizes flow from the mainland catchments adjacent to the study area. Most of the rivers are ephemeral, with high discharge and rapid response during periods of heavy rainfall, due to the steep compact catchments they drain. Discharge measurement is almost impossible and movement between streams difficult during heavy rainfall events. In the lower reaches the stream beds consist of coarse gravels to small boulders and it is likely that there is significant subsurface baseflow. In all but the large rivers, water discharges into the backreef zone, often into entrapped pools and occasionally breached estuarine systems, and flows as a wide shallow wash across the intertidal zone. Within the study area, only Emmagen Creek retains a distinct estuarine channel mouth, approximately 50 m wide.

The nearshore waters of the Cape Tribulation area are characteristically turbid, even under light wind conditions (Johnson and Carter, 1987; Hoyal, 1986). Ayling and Ayling (1987) report that under prevailing southeasterly wind conditions sediments are resuspended causing a wide band of turbid water against the coast. Under these conditions water visibility ranges from 0.5 to 2 m. Following extended calm periods water visibility is usually only 2 to 6 m. With all sediments associated with the reef having a high (>50%) terrigenous component it is likely that the Cape Tribulation reefs have always grown under conditions of high terrigenous sediment inputs (Johnson and Carter, 1987).

A description of the geology of the mainland and an analysis of the sediments of the Cape Tribulation area can be found in Johnson and Carter (1987). They find that the inputs of modern terrigenous sediments likely to be transported in suspension are dominated by kaolinite/illite assemblages, while the modern marine assemblages are dominated by smectite and illite-smectite mixed layer clays, with the different assemblages probably being due to the rapid diagenesis of clays when they

are immersed in the marine environment. Immediately north of Donovan Point, the inner shelf surficial sediments contain 25 to 71% muds. These are available for resuspension into the water column. Johnson and Carter (1987) conclude that it is not possible to use the clays as tracers of discharge from mainland catchment, or in the determination of the importance of resuspended sediment on suspended sediment concentrations.

Hoyal (1986), in a study of the effect of disturbed rainforest catchments on sedimentation in the Cape Tribulation area, used suspended sediment measurements and sediment traps to examine the nature of sedimentation across the reef flat and living reef zone. A number of his observations are relevant although it must be noted that standard deviations for groups of his samples are high and he concludes that "this large natural variability in sedimentation rates may mean that sedimentation rates are not significantly different over the whole study area:" (Hoyal, 1986, 78).

Hoyal (1986) concludes:

1. Low sedimentation rates accompanied periods of low rainfall and low wind velocities.
2. Highest sedimentation rates accompanied a period with a large number of days with winds greater than 15 knots.
3. Sedimentation rates for fine sediment on the living reef were found to be highest in the northern sector of the study area, and suggests that this may be the result of the northward current moving sediments from the south, or the generally shallower nature of the bathymetry to the north, ensuring more sediment above the fairweather wavebase allowing greater resuspension of sediments.
4. Intertidal fine sedimentation decreases from north to south.
5. Sedimentation rates for fine sediment are high inshore, low across the sand and reef flat and high on the living reef. This is explained in terms of the wave energy regime.
6. Sand deposition is related to proximity of source.
7. Sedimentation rates are related to rainfall and wind strength and direction, with temporal trends due to these factors being more important than spatial trends related to land use. A differentiation of the importance of rainfall and wave influence was not possible.

3. Methods

The examination of the physical processes on mainland fringing reefs requires the intermingling of the theory of sediment dynamics, with our knowledge of reef processes. The literature on the dynamics of the nearshore coastal zone is extremely large (Dyer, 1986), although there is still much not understood.

This study considers the Cape Tribulation coastal system in the context of an open coastal sediment transport system (with regional circulation and wave generated longshore currents dominating), but recognising particular features of the reef environment. The factors of most significance in this regard are the dramatic change in water depth at the reef front and the importance of grooves in directing flow. Basic hydrodynamic forces operating are determined from the literature and field observation, and field measurements are undertaken to confirm appropriate application of the theory. Time and budget did not allow long term measurements to be undertaken to enable a detailed description of regional hydrodynamics.

Water velocities and water movement directions were determined using either an Ott tethered current meter and hand held compass (with 2, 50 second sampling periods being averaged), or using dye as a visual tracer from a fixed marker (buoy), with distance traveled over three minutes being estimated and direction of travel being determined by hand held compass. It is realised that the method of velocity data collection has errors associated with it (see note in Tables 7 and 8) and the temporal coverage is short. Velocity and direction data are used only to confirm flow direction under the conditions sampled, and gain an approximate estimate of velocity. Wind velocity and direction was measured using a hand held cup anemometer and a hand held compass.

Larger quantities of dye were injected near the mouths of Emmagen Creek (2 occasions) and South Donovan Creek (1 occasion), and tracked over longer periods of time. The dye used was Rhodamine WT, a fluorescent tracer which has been used widely in marine environments. Parnell (1987) gives a detailed description of the properties and uses of Rhodamine WT.

Suspended sediment samples (1 litre) were collected using a hand operated pump, and analysed by filtration. Seabed sediments were collected using

$$U_{100} = 122.6D^{0.29} \text{ for } D < 0.2 \text{ cm}$$

$$U_{100} = 122.6D^{0.45} \text{ for } D > 0.2 \text{ cm}$$

where U_{100} =velocity measured in cm/s,100 cm above the sediment bed and D is the diameter of the sediment grain in cm. This relationship, for a unidirectional flow, is particularly important in the determination of the ability of currents to resuspend material. For the generally recognised upper size boundary for silts and clays (D = 0.0064 cm), U_{100}=28.3 cm/s. For D<0.001 cm, the theory is not well developed, but U_{100} is likely to be not less than 15 cm/s. If there is any consolidation or binding (which is likely in most marine circumstances), U_{100} is likely to be much greater.

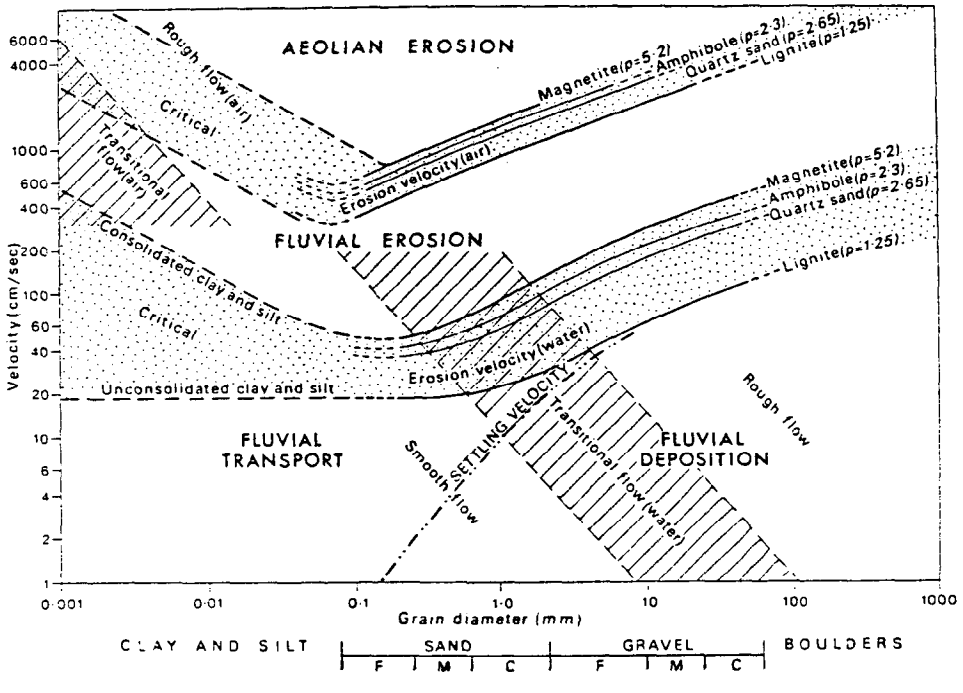

Figure 3: Curves showing relations of grain size to critical fluvial and aeolian erosion velocity for uniform materials of different density. The critical fluvial erosion velocity refers to a height of 1 m above the bed. Source: Chorley *et al.* (1984).

Table 2: Output from Komar and Miller's (1975) computer programme (Appendix A) examining depth of disturbance from oscillatory currents under waves, for sediment size G=0.001 cm

GRAIN DIAMETER= 0.001 cm
WAVE PERIOD = 4 sec
THRESHOLD ORBITAL VELOCITY, UM= 5.27 cm/s

Wave height (cm)	Depth (cm)	H/L	H/Depth
20	682	0.00844	0.0293
30	854	0.01230	0.0351
40	973	0.01623	0.0410
50	1065	0.02019	0.0469
60	1140	0.02416	0.0526
70	1202	0.02815	0.0582
80	1256	0.03213	0.0636
90	1304	0.036128	0.0690
100	1346	0.040121	0.0742
110	1384	0.044115	0.0794
120	1419	0.048112	0.0845
130	1451	0.052109	0.0895
140	1481	0.056107	0.0945
150	1508	0.060105	0.0994

Table 3: Output from Komar and Miller's (1975) computer programme (Appendix A) examining depth of disturbance from oscillatory currents under waves, for sediment size G=0.01 cm

GRAIN DIAMETER= 0.01 cm
WAVE PERIOD = 4 sec
THRESHOLD ORBITAL VELOCITY, UM= 11.37 cm/s

Wave height (cm)	Depth (cm)	H/L	H/Depth
20	363	0.0099	0.0550
30	528	0.0133	0.0567
40	650	0.0170	0.0614
50	745	0.0208	0.0670
60	822	0.0247	0.0729
70	887	0.0286	0.0788
80	943	0.0325	0.0848
90	991	0.0364	0.0907
100	1035	0.0404	0.0966
110	1074	0.0444	0.1024
120	1109	0.0483	0.1081
130	1142	0.0523	0.1138
140	1172	0.0563	0.1194
150	1200	0.0603	0.1249

In summary, therefore, unidirectional currents >15 cm/s, or modal wave conditions in water depths to about 15 m have the ability to resuspend sediments of silt and clay sizes. However, as research into sediment movement on the seabed continues, it is becoming more obvious that poorly understood modes of current generation such as infragravity waves can cause sediment movement and bedform development in water depths far below that previously established in the literature (Boczar-Karakiewicz and Bona, 1986). It is likely that the estimates above are conservative.

Once in suspension, however, velocities need to fall dramatically before sedimentation occurs. For sediment with D<0.0064 cm, velocities need to fall to below 1 cm/s before it falls to the bottom. This is not likely to occur in any areas generally subjected to a regional, wind driven current. In the context of Cape Tribulation situation, areas of sedimentation are likely to be zones sheltered by reef (at either large or small scales), and very sheltered locations such as may be found in the shallow water of the intertidal areas on calm days. Sediment with D>0.0064 cm requires higher velocities to be maintained to keep it in suspension. This generally means that sand and gravel sediment is deposited close to source, and movement across the bed occurs as bedload or by saltation.

A number of studies in reef environments have shown that despite velocities being too small to initiate major sediment movement, sediment does move (Frith, 1983), this being attributed to bioturbation. Tudhope and Scoffin (1984), Suchanek (1985), Vaugelas (1985) and Parnell (1987) all illustrated the very important role of Callianassa shrimps in the process of sediment movement in reef areas. Other organisms, including Gastropod snails, Holothurians and basking fish perform the same task. The principal role of these organisms is to entrain sediment into the water column by ejecting it upwards. The sediment is then able to be carried in suspension or carried in the water current for a short distance before being redeposited (Figure 5).

The behaviour of sediment in suspension in freshwater streams which then flow into the sea needs to be examined. Freshwater is less dense than saltwater, and will flow in a layer on the surface when it meets the sea. Suspended sediment contained in this layer will remain in it and flow with the freshwater as a surface lens. Mixing will occur, however, and the freshwater lens will reduce in size as mixing progresses away from

the stream inflow. In streams which reach the sea by flowing in a wide sheet across the intertidal zone, mixing will occur rapidly.

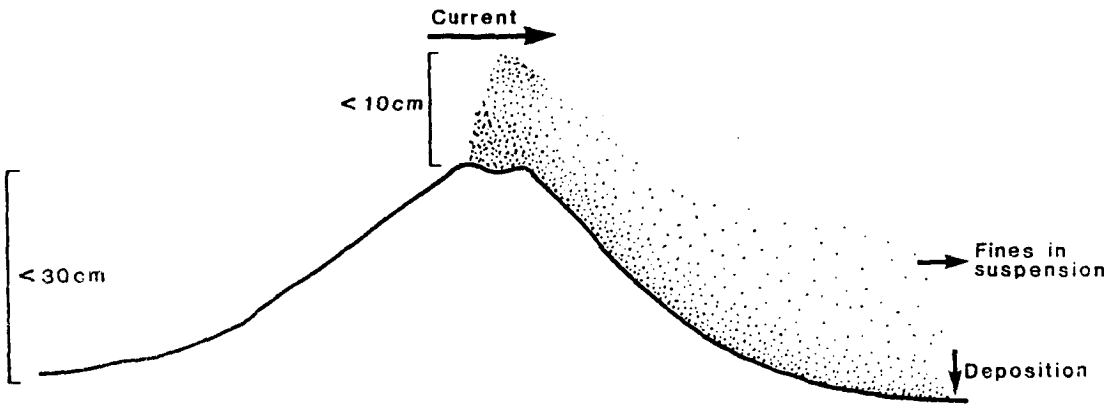

Figure 5: The process of sediment movement in low velocity currents caused by Callianassa burrowing.

When reaching salt water particles in suspension in the silt size range and coarser remain hydraulically independent. However, clays will flocculate (or clump) on contact with salt water, hydraulically behaving as particles of greater size. The degree of flocculation rises in proportion to the clay content of the sediment. The cause of flocculation in salt water is well described by Dyer (1986). The implication of this is that when clay particles in suspension in freshwater first come into contact with saline water (even at salt concentrations as small as 0.6 ppt (Krone, 1978)), they clump together and behave as would a larger particle. In very low velocities this may cause sediment to fall to the bottom.

Flocculation is demonstrated in an experiment by Swales (1988). A sediment sample was dispersed and made up to 15 g/l. Grainsize analysis (using pipette analysis) was undertaken on two subsamples of the dispersed sample (A and B). Further subsamples were then treated with