# EFFECT OF WATER-BASED DRILLING MUD ON BENTHIC ORGANISMS

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ABSTRACT

The effect of water-based drilling mud (WBM) was studied with respect to its acute toxicity on the prawn tiger, *Penaeus monodon*, and recolonisation by benthos on sediment incorporated with several concentrations of drilling mud. Acute toxicity to *Penaeus monodon*, after 4 days exposure was estimated to be 8320 mg/L. After one month, cores containing concentrations of drilling mud from $25 \times 10^4$ to $75 \times 10^4$ mg/L placed at the mean tide level showed an increasing built-up of organic matter from 0.27 to 0.71%, a decreasing sediment median diameter from 0.50$\phi$ to 0.80$\phi$, and an increasing numerical dominance of the polychaete *Capitella capitata*. The conditions did not improve after two months. However cores placed at the low tide level where flushing and water exchange was constantly taking place, conditions in all of them, except those containing WBM only, has recovered and were colonised by benthos species with density and diversity nearly similar to those in the control cores.

Keywords: Waterbased mud, effect, benthos

## INTRODUCTION

Drilling fluid or mud is used in oil and gas drilling operations to lubricate and sometimes to provide hydraulic power to the bit and to control the well pressure. In the South China Sea offshore oil and gas fields the most commonly used drilling muds are water-based (WBM) and low toxicity oil-based (OBM). Mud and cuttings brought up from the well are treated to separate the cuttings from the mud and to reduce the hydrocarbon concentration to the generally acceptable level of <100 ppm before disposal into the sea. A cluster of six associated offshore platforms in the South China Sea is estimated to discharge almost 60,000 metric tonnes of drilling muds during an operational period of 17-18 months.

Drilling discharge that will eventually settle on the seabed and likely to cause two major biological effects (Dicks, 1982) The first is toxicity from the components, principally barite, a little hydrocarbon, traces of metals such as chromium, copper, lead and cadmium. These components could directly affect benthic organisms by killing those which come into contact or ingest the contaminated sediments. Secondly large amount of fine sediments may physically bury and smother the animals, besides changing the sediment texture, resulting in an alteration of the faunal community of the seabed. The extent of these damages will depend upon the number of wells drilled and the water current regime of the area.

The objectives of this preliminary study on the effects of whole water-based drilling mud (WBM) on benthic organisms were to examine the direct toxicity in terms of the median lethal concentration ($LC_{50}$) at Day 4 and secondly to observe recolonization patterns by benthos on sediment incorporated with various concentrations of WBM.

## MATERIALS AND METHODS

### Water-Based Drilling Mud

The drilling mud used for all the experiments was provided by a petroleum company from Malaysia. The main components of the mud were seawater (18,000 ppm), modified potato starch (3 lb/barrel), polyanionic cellulose or Pascaseal (1.5 lb/barrel), sodium hydroxide (1 lb/barrel), sodium carbonate (0.25 lb/barrel). Drill solids and barite made up the balance which represented the bulk of the 10-15 different materials present in a typical drilling fluid (Gettleson, 1980).

### Acute Toxicity

Acute toxicity testing was done under laboratory conditions using post larvae at Day 10 (PL 10) of the tiger prawn, *Penaeus monodon*. Post larvae were obtained from a commercial hatchery in Penang, Malaysia, and acclimatised in the laboratory for one week before commencement of experiment.

Testing was conducted, under ambient temperature (30 ± 2C) and static conditions, in perspex containers, each filled with 2 L of filtered seawater. Stocking density was 10 PL per container or 5 PL/L. Aeration and feeding with *Artemia salina* (GSL San Franscico Bran) was supplied throughout the experiment.

Drilling mud was thoroughly stirred to obtain a homogeneous mixture of solids and fluid, before dilution was made to obtain concentration ranges from 0-50,000 ppm. Mortality of the prawns was monitored over one week and dead prawns were removed from the containers to prevent fouling of the water. No water renewal was made throughout the experiment. Median lethal concentration ($LC_{50}$) at Day 4 was estimated by the <Quant> software.

Recolonisation Experiment

This experiment was initially conducted at the mud banks of the mangrove swamp at Sementa, Selangor and later at the reclaimed foreshore at Bayan Baru, Penang due to logistic reasons. Recolonisation was determined after 3 months at the former and after 1 and 2 months at the latter.

Sediment was collected from each site and defaunated by autoclaving at 121 C for 15 minutes. Autoclaved sediment was dried at 80 C, then mixed (weight/weight) with various proportions of the whole mud to give a final weight of 1 kg and final concentration of WBM ranging from 0-$10^6$ ppm. Controls contained 1 kg of sediment but no WBM. Each concentration was done in triplicate.

The mixture of sediment incorporated with WBM were put into polyethylene cores (23 cm height x 13 cm internal diameter), resulting in sediment depth of about 10 cm. The bottom of each core was sealed with a polyethylene plate of similar diameter, but the top was unsealed. Eight small holes (diameter 2 mm) were perforated around the core above the sediment surface to slow down the inflow of seawater. Each core was welded to a long polyethylene pole at mid-length which was embedded to a depth of 0.5 meter, forming an anchor for the core, such that the bottom of the core just rested on the seabed. Cores were placed at the low tide level at the Sementa mangrove swamp, and at the mean tide level at Bayan Baru. The number of cores were calculated to supply sufficient samples for monthly collection, without replacement, to determine the benthos community in each core. Background population was sampled using similar cores at the time of collection of the treatment cores.

After the designated time, sediment from each core was poured into separate plastic containers and taken to the laboratory. A small amount was removed and dried at 80 C to determine particle size by dry sieving and organic matter by the Walkey Black method (Holme and McIntyre, 1987). The remainder was stained with Rose Bengal and preserved in 5% formalin for subsequent taxonomic and enumeration work. Barium in the cores after 3 months at Sementa, was determined by Dr. S.L. Tong, Institute of Advance Studies, University of Malaya.

## RESULTS

### Acute toxicity

Post larvae in all the treatment concentrations, including the control began to die after 24 hour exposure to WBM (Table 1). The $LC_{50}$ after 4 days was estimated to be 8,320 ppm. The results was however quite heterogeneous ($X^2$=1.23) since the control and lower concentration of WBM also caused high mortalities of the prawn.

### Recolonization

#### (A). Sementa mangrove swamp

After 3 months, the benthos community in the lowest concentration of WBM ($3x10^3$ ppm) was similar to the control and background population, both in density and diversity of benthos species (Table 2). Species composition in these three cores was also similar showing a large proportion of polychaetes, but very few number of the opportunist polychaete *Capitella capitata*. The common species encountered in these cores included *Armandia* sp, *Goniada* sp, *Glycera* sp, *Leonates* sp, *Prionospio cirrifera*, *P. polybranchia* and *Syllidia* sp, which are subsurface deposit-feeders and motile carnivorous species. A few crustacea such as the Cumacea *Diastyllis* sp and Harpacticoida were also found.

Cores containing concentrations of WBM above $3x10^3$ ppm however, showed significantly lower mean no individual/species ($p<0.05$, Table 3), very much less number of species but diversity in terms of the Shannon Wiener index, H' was not different from the background. Nevertheless those species that were present were similar to the common species encountered in the control core and background population.

In several of the cores, young and reproductive stages were also encountered, such as gravid and epitokous polychaetes, and developing cumacean youngs within the marsupium (Table 4). There was also a large number of fish eggs in all the cores, with developing embryos within all the cores. However, these eggs probably settle down randomly, without selection, after spawning and fertilization in the water column, but their development into normal frys cannot be ascertained from this study.

After 3 months submergence the amount of barium remained in the cores varied slightly from about 106 to 177 ug/g of sediment as compared to the 303 ug/g of sediment in the cores containing the highest concentration of drill mud (Table 5). These results suggested that barium may not be limiting the recolonisation of benthos in the drilling mud contaminated substrates.

At the end of three months the fine particles such as clay and silt was present in different proportions in all the cores (Table 6). There was no accumulation of more clay in the cores with high concentrations of WBM. This was probably due to the dynamic exchange of the sediment inside the core with the surrounding environment since the site experienced more tidal flusshing. Sorting coefficient was not different for all the cores.

(B). Bayan Baru Shore

After one month of submergence cores containing WBM showed much higher density of *Capitella capitata*, compared to the control and the background community (Table 7), up to a maximum of 173 no. of individual per core of 0.07 $cm^2$ for $7.5x10^5$ ppm of WBM. However, cores containing all concentrations of WBM had a depauperate composition of other species and diversity of only <0.5 (Shannon Wiener index, H'). The untreated control cores supported benthic population density very much less then the background, probably due to the small surface area of the core for recruitment.

After 2 months, conditions even in the control cores showed deterioriating environmental conditions, with the recruitment of *Capitella capitata* and a reduction in the total number of other species from 12 to 6. Population of *C. capitata* however reduced drastically in the cores containing higher conentrations of WBM. The background population remained relatively similar to the previous month indicating that changes in the experimental cores were not due to natural seasonal population dynamics.

There was also an increased accumulation of organic matter in all the cores after 2 months (Table 8). In the control core, organic matter content almost doubled from 0.29% in the first month to 0.48% in the second month. In all the cores, the inner side above the sediment was colonised by barnacles, gastropod such as *Thais* sp which lay their eggs and attached them there.

Incorporation of drilling mud resulted in a slight increase in the fine deposit fraction of clay, by 1-2% when $5x10^5$ ppm (50%) and $7.5x10^5$ ppm (75%) WBM was mixed with the sediment respectively (Table 6). This was observed even after one month at the study site suggesting the increase may be higher earlier. This resulted in a reduction of the median diameter from about 0.5 $\phi$ to 0.80 $\phi$, but little change in the sorting coefficient. Two months later this difference was no longer detected due to the dynamic exchange with the surrounding environment.

DISCUSSION

Under laboratory conditions the estimated $LC_{50}$ of whole WBM to *Penaeus monodon* PL 10 at 8,320 ppm was lower than that observed for the benthic fish *Branchiostoma carbaeum* which showed $LC_{50}$ values at Day 4 for whole mud from the Gulf of Mexico to be $2.6x10^5$ ppm (Clark and Patrick 1987). However they suggested that sediments contaminated with drilling mud may pose an acute lethal threat to infaunal species when concentrations approached 8% (or $8x10^4$ ppm). In contrast the mysis, *Mysidopsis bahnia* was more sensitive requiring from 0.026%-0.0026% (26 to 260 ppm) to kill half the tested population. Sensitivity to drilling fluid is variable with each species but generally its toxicity is much lower compared to soluble fraction of hydrocarbons.

The heterogeneity of the acute toxicity test was actually due to unsynchronised moulting caused by differential growth rates of the same batch of postlarvae. It was found that while most of the postlarvae were at intermolt stage when the carapace have hardened, some slower growing individuals may have just begun to molt, exposing their soft tissue to the pollutants (Lai, unpublished data, 1993).

The recolonisation patterns in cores containing WBM somewhat mimicked the seabed conditions beneath offshore petroleum production platforms. In the North Sea and Gulf of Mexico oil and gas fields, the seabed up to a circumference of 100-250 m from the well-head received the maximum deposition of drill mud and cuttings. As a result, there was high organic enrichment in the sediment and a marked reduction in the species diversity (H'<1.5), but maximum density of *Capitella capitata* up to >5000 no. of individuals per $m^2$ (Addy *et al.*, 1984, Miur, 1987). Such conditions were encountered in the cores containing $2.5-7.5x10^5$ ppm of WBM during the first month of experiment.

*Capitella capitata* is an opportunistic or r-selected species (Pianka, 1970) which could reproduce quickly and rapidly build up a large population in a habitat normally regarded as non-habitable by most species. It has been associated with sediments of high organic content and poorly oxygenated conditions to as low as 2 mm Hg oxgyen tension for one month (Warren, 1977). However as organic decomposition continued to deplete more oxygen, conditions will become disastrous even for *Capitella capitata*. This was evident from cores with higher concentration of WBM after the second month.

The increase in the clay proportion by 1-2% when high concentration of WBM was added was also encountered in the North Sea platforms. Maurer *et al.* (1981) showed a significant increased proportion of clay in the sediment out to 800 m from the well site from 7-10% clay pre-drilling to 10-12% post drilling. The increased clay content was suggested to have affected the abundance of annelids by diminishing recruitment of larvae and burying shallow dwelling infauna (Menzie *et al.*, 1980).

However these conditions did not appear to have affected those organisms that live on the surface of the seabed or colonised the sides of the cores above the sediment, i.e., the epifauna and fouling organisms. This was indicated by the presence of molluscs eggs, developing crustacea and gravid polychaetes in all the cores after two months or more.

The implication from this study was that long term discharges of drilling mud onto the seabed, especially localised beneath the platform where tidal flushing may be obstructed by the structures, may eventually kill all the benthic fauna. The extent of this impact zone will vary with the length of production period and the current regime of the area.

Addy *et al.* (1984) proposed three zones of impact caused by oil and gas extraction, as a zone of damage beneath the platform within a radius of 100-250 m, a transition zone where some amount of recovery of the benthic community both in density and diversity between 200-800 m and a zone of no detectable impact beyond 500 m. This study showed that a transition zone probably exist if concentration of the mud was between $10^4$-$10^5$ ppm, comprising of a reduced diversity and density, but relatively similar species composition to uncontaminated habitats. A zone of no impact probably exists if concentrations of WBM was $\leq 10^3$ ppm with no detectable differences in the benthic environment from control sites. However the epibenthic and fouling organisms which colonised structures above the water surface are unlikely to be affected. If drilling activities and discharges were halted, the potential recovery of benthic community to the pre-opertional state may take from 3 months to more than three years (Miur *et al.*, 1987) depending on the type of mud used and the degree of deposition.

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Table 1: Survival of tiger prawn postlarvae after exposure to various concentration of water-based drill mud under laboratory condition, 17/11/93

| Drill mud Concentration [ppm] | Drill mud Dilution [%] | 0hr PL10 | 24hr PL11 | 48hr PL12 | 72hr PL13 | 96hr PL14 | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 10 | 9 | 6 | 4 | 1 | |
| 500 | 0.5 | 10 | 6 | 4 | 4 | 1 | |
| 3,333 | 3.3 | 10 | 8 | 5 | 5 | 1 | |
| 5,000 | 5 | 10 | 5 | 4 | 3 | 2 | <- [8320 ppm]# |
| 33,333 | 33.3 | 10 | 6 | 6 | 5 | 5 | |
| 50,000 | 50 | 10 | 6 | 6 | 3 | 3 | |

# Heterogeneity significant, G = 1.23

Table 2: Abundance of benthos after 3 months submergence at Sementa mangrove estuary. Each value is the amalgamated total from 3 cores of 0.04 $m^2$

| Species | Concentration of WBM (ppm) 0 | 0 | $3x10^3$ | $10^4$ | $3x10^4$ | $3x10^5$ | $10^6$ | $>10^6$ |
|---|---|---|---|---|---|---|---|---|
| Core No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | (Background) | Ctr | | | | | | |
| POLYCHAETA | | | | | | | | |
| 1 Armandia sp | - | 12 | 12 | 5 | - | 6 | 8 | - |
| 2 Ancistrosyllis sp | 1 | - | 1 | - | - | 2 | - | - |
| 3 Capitella capitata | - | 1 | 4 | 4 | - | - | - | - |
| 4 Dendroneris sp | 1 | - | - | - | - | - | - | - |
| 5 Goriada sp | 3 | 1 | 2 | - | 1 | - | - | - |
| 6 Glycera sp | - | 2 | 1 | - | - | - | - | - |
| 7 Laonome sp | - | 1 | - | - | - | - | - | - |
| 8 Leonates sp | - | 7 | 3 | - | 1 | - | - | - |
| 9 Lumbrinereis sp | - | 1 | - | - | - | 1 | - | - |
| 10 Malmgrenia sp | - | 4 | 3 | - | - | 1 | 5 | 2 |
| 11 Marphysa mossambica | - | 1 | - | - | - | - | - | - |
| 12 Mediomastus sp | 1 | - | - | - | - | - | - | - |
| 13 Nereis sp | 1 | 3 | 8 | - | - | 1 | - | - |
| 14 Polydora sp | - | 5 | 3 | 1 | - | - | - | - |
| 15 Pontoceros sp | - | 1 | 1 | - | - | 1 | - | - |
| 16 Prionospio cirrifera | 18 | 15 | 13 | 3 | 4 | 11 | 4 | - |
| 17 P. malmgreni | 18 | - | 1 | - | - | - | - | - |
| 18 P. polybranchia | 14 | 4 | 7 | 1 | 1 | 4 | - | - |
| 19 P. sexoculata | 2 | - | - | - | - | - | - | - |
| 20 Sternaspis costata | 1 | - | - | - | - | - | - | - |
| 21 Syllidia sp | - | 26 | 11 | 1 | - | 4 | 3 | 4 |
| CRUSTACEA | | | | | | | | |
| Amphipoda | | | | | | | | |
| 22 Melita sp | - | - | - | 5 | - | - | - | - |
| Cumacea | | | | | | | | |
| 23 Diastyllis sp | - | 7 | 1 | - | - | - | 7 | - |
| Harpacticoida | | | | | | | | |
| 24 Microsetella sp | - | 4 | 1 | - | - | 3 | 1 | 1 |
| 25 Harpacticoid II | - | 3 | 2 | - | - | - | - | - |
| Decapoda | | | | | | | | |
| 26 Caridean prawn | - | 1 | 1 | 1 | - | - | - | - |
| 27 Dotilla mictyroides | - | - | 1 | - | - | - | - | - |
| 28 Grapsidae | - | - | - | - | - | - | - | 2 |
| MOLLUSCA | | | | | | | | |
| 29 Nudibranch | - | 1 | - | - | - | - | - | - |
| 30 Thais sp | - | - | - | - | - | - | - | 3 |
| OTHERS | | | | | | | | |
| 31 Turbellaria | - | - | 2 | - | - | 1 | - | - |
| 32 Nemertea | 4 | - | - | - | - | - | - | - |
| Total no. of benthos | 64 | 100 | 78 | 21 | 7 | 35 | 28 | 12 |
| Total no. of benthos/$m^2$ | 1600 | 2500 | 1950 | 525 | 175 | 875 | 700 | 300 |
| Total no. of species | 11 | 20 | 20 | 8 | 4 | 11 | 6 | 5 |
| Shannon index H' | 1.796 | 2.455 | 2.570 | 1.857 | 1.154 | 2.044 | 1.648 | 1.517 |
| Evenness index J | 0.749 | 0.819 | 0.858 | 0.893 | 0.832 | 0.852 | 0.920 | 0.943 |

Table 3: Oneway ANOVA between benthos count and concentration of drill mud based on field experiment at Sementa estuary

| Source | D.F. | Sum of squares | Mean squares | F ratio | Probability p |
|---|---|---|---|---|---|
| Between groups | 7 | 248.2773 | 35.4682 | 3.4853 | <0.05 |
| Within groups | 248 | 2523.7813 | 10.1765 | | |
| Total | 255 | 2772.0586 | | | |

Duncan Range Test

| Mean no. of indiv./species | Conc (ppm) | $3x10^4$ | $>10^6$ | $10^4$ | $10^6$ | $3x10^5$ | 0 | $3x10^3$ | 0 |
|---|---|---|---|---|---|---|---|---|---|
| | Core No. | 5 | 8 | 4 | 7 | 6 | 1 | 3 | 2 |
| 0.2188 | 5 | | | | | | | | |
| 0.3750 | 8 | | | | | | | | |
| 0.6563 | 4 | | | | | | | | |
| 0.8750 | 7 | | | | | | | | |
| 1.0938 | 6 | | | | | | | | |
| 2.0000 | 1 | * | | | | | | | |
| 2.4375 | 3 | * | * | * | | | | | |
| 3.1250 | 2 | * | * | * | * | * | | | |

Table 4: Number of sexually mature individual (♂/♀) per core

| | | Concentration of WBM (ppm) in the cores | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 Background | 0 Ctr | $3x10^3$ | $1x10^4$ | $3x10^4$ | $3x10^5$ | $10^6$ | $>10^6$ |
| POLYCHAETA | | | | | | | | | |
| 1 Capitella capitata | ♂ | - | - | - | - | - | - | - | - |
| | ♀ | - | 1 | - | - | - | - | - | - |
| 2 Leonates sp | ♂ | - | 1 | 1 | - | - | - | - | - |
| | ♀ | - | 2 | - | - | - | - | - | - |
| 3 Nereis sp | ♂ | - | - | 2 | - | - | - | - | - |
| | ♀ | - | 1 | 6 | - | - | - | - | - |
| 4 P. polybranchia | ♂ | - | - | - | - | - | - | - | - |
| | ♀ | 2 | - | - | - | - | - | - | - |
| 5 Syllidia sp | ♂ | - | - | - | - | - | - | - | - |
| | ♀ | - | 1 | - | - | - | - | - | - |
| CRUSTACEA | | | | | | | | | |
| Amphipoda | | | | | | | | | |
| 6 Melita sp | ♂ | - | - | - | 1 | - | - | - | - |
| | ♀ | - | - | - | 2 | - | - | - | - |
| Cumacea | | | | | | | | | |
| 7 Diastyllis sp | ♂ | - | - | - | - | - | - | 1 | - |
| | ♀ | - | 2 | - | - | - | - | 4 | - |
| Harpacticoida | | | | | | | | | |
| 8 Microsetella sp | ♂ | - | 2 | - | - | - | - | - | - |
| | ♀ | - | 2 | 1 | - | - | - | 1 | - |
| 9 Harpacticoid II | ♂ | - | - | - | - | - | - | - | - |
| | ♀ | - | - | 1 | - | - | - | - | - |
| Decapoda | | | | | | | | | |
| 10 Caridean prawn | ♂ | - | - | - | - | - | - | - | - |
| | ♀ | - | - | 1 | - | - | - | - | - |
| Others | | | | | | | | | |
| 11 Tubificidae | ♂ | - | - | - | - | - | - | - | - |
| | ♀ | 3 | - | - | - | - | - | - | - |
| Subtotal (♂ & ♀) | | 5 | 12 | 12 | 3 | 0 | 0 | 6 | 0 |
| Total benthos/core | | 64 | 100 | 78 | 21 | 7 | 35 | 28 | 12 |
| % gravid | | 7.8 | 12 | 15.4 | 25 | 0 | 0 | 21.4 | 0 |

Note: (♂/♀) = Male/Female

Table 5: Concentration of barium in the cores after 3 months submergence at Sementa estuary

| No. | Soil [g] | Drilling mud [g] | Conc. [ppm] | Ba [ug/g] A | B | C | Av. |
|---|---|---|---|---|---|---|---|
| 0 | 1000 # | 0 | 0 | - | - | 167.2 | 167.2 |
| 1 | 1000 | 0 | 0 | 148.7 | - | 157.2 | 153.0 |
| 2 | 1000 | 3 | 3000 | 106.5 | 122.9 | 137.8 | 122.4 |
| 3 | 1000 | 10 | 10000 | 157.1 | 147.9 | 152.7 | 152.3 |
| 4 | 1000 | 30 | 30000 | - | 134.2 | 149.6 | 141.9 |
| 5 | 1000 | 100 | 100000 | - | - | - | - |
| 6 | 1000 | 300 | 300000 | 153.8 | 158.1 | - | 156.0 |
| 7 | 1000 | 1000 | 1000000 | - | - | 176.6 | 176.6 |
| 8 | 0 | 1500 | >1000000 | - | - | 302.8 | 302.8 |

Note: # Control soil samples from location in which the experiment was conducted and they were not autoclaved as polyethylene bottles 1 - 8.

- Bottles either missing or containing too little sample for analysis.

Table 6: Particle size of drill mud substrates from Sementa after 3 months submergence

| Core No. | Concentration of WBM | % by weight Clay | Silt | Sand | Md (ϕ) | Qd (ϕ) | Skq (ϕ) |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 2.40 | 4.28 | 93.31 | 0.40 | 1.25 | 0.25 |
| 2 | 0 | 2.88 | 7.95 | 89.16 | 0.42 | 1.45 | 0.43 |
| 3 | 3,000 | 12.44 | 10.54 | 76.6 | 1.80 | 1.90 | 0.20 |
| 4 | 10,000 | 12.50 | 7.99 | 79.50 | 1.50 | 1.85 | 0.25 |
| 5 | 30,000 | 9.40 | 6.92 | 83.26 | 0.75 | 1.73 | 0.53 |
| 6 | 300,000 | 6.80 | 8.95 | 84.20 | 1.65 | 1.75 | -0.10 |

Note: $(\phi) = -\log_2 mm$

Table 7: Abundance of benthos in PVC cores at Bayan Baru
Each value is the amalgamated total from 3 cores,
each of area 0.0235 $m^2$

| | First Month | | | | | Second Month | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | WBM (ppm) | | | | | WBM (ppm) | | | | |
| | 0 Background | 0 Ctr | $2.5x10^5$ | $5x10^5$ | $7.5x10^5$ | 0 Background | 0 Ctr | $2.5x10^5$ | $5x10^5$ | $7.5x10^5$ |
| Species | | | | | | | | | | |
| POLYCHAETA | | | | | | | | | | |
| 1 Ancistrosyllis | 8 | - | - | - | - | 3 | - | - | - | - |
| 2 Armandia | - | - | - | - | - | 2 | - | - | - | - |
| 3 Axiothella | 5 | 1 | - | - | - | 2 | - | - | - | - |
| 4 Bhawania | 4 | - | - | - | - | 2 | - | - | - | - |
| 5 Capitella capitata | 1 | - | 88 | 27 | 173 | - | 18 | 15 | 2 | 5 |
| 6 Ceratonereis costae | 125 | 3 | 1 | 1 | - | 68 | 5 | - | - | 2 |
| | | | | | | (14) | (3) | | | |
| 7 Eusyllis | 10 | 1 | - | - | - | 14 | - | - | - | - |
| 8 Exogone | 8 | - | - | - | - | - | 1 | - | - | - |
| 9 Glycera | 5 | - | - | - | - | 8 | - | - | - | - |
| 10 Heteromastus | - | - | - | - | - | 14 | - | - | - | - |
| 11 Mediomastus | 1 | 2 | - | - | - | 8 | - | - | - | - |
| 12 Poecilochaetus serpens | - | - | - | - | 1 | 1 | - | - | - | - |
| 13 Phyllodoce | - | - | 1 | - | - | - | - | - | - | - |
| 14 Pisione oerstedi | 1 | - | - | - | - | - | - | - | - | - |
| 15 Prionospio cirrifera | 1 | - | - | - | 1 | - | - | - | - | - |
| 16 P. malmgreni | 2 | 3 | - | - | - | 4 | - | - | - | - |
| 17 P. polybranchiata | 5 | - | - | - | - | - | - | - | - | - |
| 18 P. sexoculata | 17 | 15 | 4 | - | - | 17 | - | - | - | - |
| 19 Nerine cirratulus | 1 | - | - | - | - | - | - | - | - | - |
| 20 Protodorvillea egena | - | - | - | - | 1 | - | - | - | - | - |
| 21 Saccrocirrus | - | - | - | - | - | 1 | - | - | - | - |
| 22 Langerhansia cornuta | 1 | - | - | - | - | 1 | - | - | - | - |
| CRUSTACEA | | | | | | | | | | |
| 23 Alphaeid prawn | - | 6 | - | - | 1 | - | 2 | - | 2 | - |
| 24 Dotilla mictyroides | - | 1 | - | - | - | - | - | - | - | 1 |
| 25 Harpacticoida | 1 | - | - | - | - | - | - | - | - | - |
| AMPHIPODA | | | | | | | | | | |
| 26 Gammarus | - | - | - | 1 | - | - | - | - | - | - |
| MOLLUSCA | | | | | | | | | | |
| 27 Corbula | - | 1 | - | - | - | - | - | - | - | - |
| 28 Macoma | - | 1 | - | - | - | - | - | - | - | - |
| OTHERS | | | | | | | | | | |
| 29 Aspidosiphon | - | 1 | - | - | - | - | - | - | - | - |
| 30 Nemertea | - | - | - | 1 | 2 | - | - | - | - | - |
| 31 Tubificidae | 1 | - | - | - | - | - | 2 | - | - | - |
| Total no. of benthos | 197 | 35 | 94 | 30 | 179 | 145 | 28 | 15 | 4 | 8 |
| Total no. of benthos/$m^2$ | 8383 | 1489 | 4000 | 1277 | 7617 | 6170 | 1192 | 638 | 170 | 340 |
| Total no. of species | 18 | 11 | 4 | 4 | 6 | 14 | 5 | 1 | 2 | 3 |
| Shannon index H' | 1.532 | 1.860 | 0.293 | 0.435 | 0.199 | 1.837 | 1.088 | - | 0.693 | 0.900 |
| Evenness index J | 0.530 | 0.776 | 0.211 | 0.314 | 0.111 | 0.696 | 0.676 | - | 1.004 | 0.819 |

Note: Figure in bracket refers to no. of gravid females

* These are excluded from the calculation of diversity indices.

Table 8: Particle size of drill mud substrates at Bayan Baru

| Core No. | Concentration (ppm) | % by weight Clay | Silt | Sand | Organic matter | Md (ϕ) | Qd (ϕ) | Skq (ϕ) |
|---|---|---|---|---|---|---|---|---|
| [First Month] | | | | | | | | |
| 1 | 0 [Background] | 2.67 | 0.17 | 96.96 | 0.31 | +0.40 | 1.05 | -0.40 |
| 2 | 0 | 1.43 | 2.16 | 96.20 | 0.29 | +0.15 | 1.175 | 0.025 |
| 3 | 250,000 | 1.61 | 2.63 | 95.57 | 0.27 | +0.50 | 1.150 | 0 |
| 4 | 500,000 | 3.47 | 2.60 | 93.46 | 0.65 | +0.60 | 1.175 | 0.025 |
| 5 | 750,000 | 3.76 | 3.28 | 92.30 | 0.71 | +0.80 | 1.150 | -0.050 |
| [Second Month] | | | | | | | | |
| 2 | 0 | 1.02 | 2.19 | 96.64 | 0.48 | +0.05 | 1.375 | -0.026 |
| 3 | 250,000 | 3.89 | 4.08 | 90.84 | 1.17 | +0.15 | 1.475 | -0.025 |
| 4 | 500,000 | 2.17 | 1.34 | 96.46 | 0.87 | +0.30 | 1.350 | -0.050 |
| 5 | 750,000 | 3.22 | 1.72 | 94.06 | 0.93 | 0 | 1.375 | +0.025 |

Note: $(\phi) = -\log_2 mm$