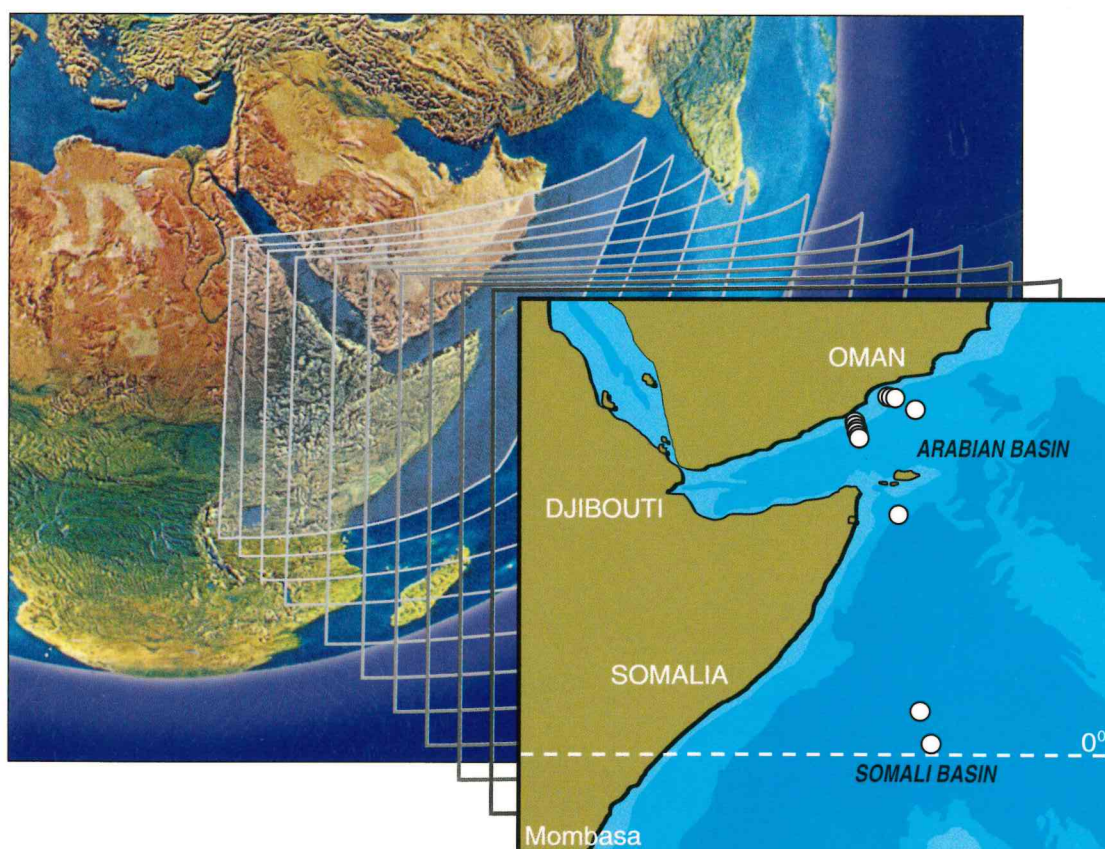


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T.J.W. Happee, R.F. Nolting



Nederlands Instituut voor Onderzoek der Zee

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Netherlands Institute for Sea Research (NIOZ)
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T.J.W. HAPPEE, R.F. NOLTING

NETHERLANDS INSTITUTE FOR SEA RESEARCH

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ABSTRACT

This research is part of the Netherlands Indian Ocean Programme 1990-1995. The overall objective of this research project is: "to study the effect, on a spatial and temporal scale, of the monsoon on the climate system in the northern Indian Ocean". The goal of this research is to describe the horizontal and vertical distribution of trace metals and major elements in the sediments of the northern Indian Ocean and the processes to which these elements are subjected. At greater water depth a higher bottom water oxygen concentration was found compared to those at shallow stations in the upwelling zone. The highest concentrations of organic carbon and nitrogen are found at stations near the margin between upwelling water and the open ocean. The contribution of pelagic formed material increases with increasing water depth. The distribution of the major elements is rather uniform with depth. Except for CaCO_3 which showed a decrease at the two stations where the water depth was > 5000 m and are situated beneath the compensation depth for CaCO_3 . The mean concentration of Mn, Cu, Zn, Ni and Pb in the upper 2 centimeter of the sediment increased with increasing water depth. For Mn this increase is one order of magnitude. This can be explained by several possibilities: difference in grain size, atmospheric transport and lateral sediment transport. Cd and Cr showed an opposite behaviour, a decrease with increasing water depth. For the vertical concentration-depth distributions of trace metals the overall trend is: rather smooth profiles with low concentrations in the upwelling area and rather patchy profiles with high concentrations at the deepest stations (near the equator). K_d values were calculated for each trace element and appeared to be patchy, except for Mn which showed increasing K_d values with increasing water depth. It implies a higher mobility of Mn in the upwelling area compared to those at greater water depth. Summarising it can be said that sediments in the upwelling area differs greatly from those at greater water depth and near the equator.

SAMENVATTING

Dit onderzoek is een onderdeel van het Netherlands Indian Ocean Programme 1990-1995. Het doel van dit project is om het effect te bestuderen, in ruimte en tijd, van de moeson op het klimaat in de noordelijke Indische Oceaan. Een onderdeel van dit onderzoek is het beschrijven van de horizontale en verticale verdeling van spoor metalen en hoofd elementen in de sedimenten van de noordelijke Indische Oceaan en de processen die zich in deze sedimenten afspelen. De zuurstof concentratie in het bodem water is hoger in de gebieden met een grotere water diepte dan in de ondiepe gebieden in de upwelling zone. De hoogste concentraties organisch koolstof en stikstof zijn gevonden op de grens tussen upwelling en de open oceaan. Hoe groter de water diepte hoe groter het aandeel van pelagisch gevormd materiaal is in de totale aanvoer van materiaal naar het sediment. De verdeling van de hoofd elementen in het sediment is tamelijk homogeen. Voor CaCO_3 is een afname gevonden in de sedimenten waar de water diepte groter dan 5000 meter is, deze bevinden zich beneden de compensatie diepte van CaCO_3 . De gemiddelde concentratie van Mn, Cu, Zn, Ni en Pb in de bovenste 2 centimeter van het sediment neemt toe met de water diepte. De Mn concentratie nam toe met meer dan een factor tien. Dit zou op verschillende manieren verklaard kunnen worden: deeltjes groote, atmosferisch transport en lateraal sediment transport. In tegenstelling tot deze elementen neemt de concentratie van Cd en Cr juist af met de water diepte. Over het algemeen zijn de verticale verdelingen van spoor metalen in het sediment in het upwellings gebied tamelijk constant met lage concentraties maar is deze verdeling in de verder weggelegen en diepere gebieden variabel met hogere concentraties. Voor elk spoor metaal zijn de Kd waarden berekend die behalve voor Mn geen trend vertoonden. De Mn Kd waarden worden hoger met toenemende water diepte. Dit houdt in dat Mn mobieler is in het upwellings gebied vergeleken met de sedimenten op grotere water diepte. Concluderend kan worden gezegd dat er groote verschillen bestaan tussen het upwellings gebied en de gebieden nabij de equator.

1. INTRODUCTION

This research is part of the Netherlands Indian Ocean Programme (NIOP), which is organised and sponsored by The Netherlands Marine Research Foundation (SOZ) of The Netherlands Organisation of Scientific Research (NWO). This project runs between 1990 and 1995. The overall objective of this research project is "to study the effect, on a spatial and temporal scale, of the monsoon on the climate system in the northern Indian Ocean".

One of the subjects of this project and the goal of this research is to describe the horizontal and vertical distribution of trace metals and major elements in the sediments of the northern Indian Ocean and the processes in which these elements are involved. Because ocean sediments are important sinks and in some occasions sources for trace metals, the biogeochemical processes which cause precipitation or dissolution of trace metals from these sediments, need to be understood. Sediments can also respond to processes which take place in the water column (e.g. change in primary production), and act as a historical record in trace metal supply (pollution record). Trace metals are also important elements in the nutrition of phytoplankton. For example iron deficiency is supposed to limit the growth of phytoplankton. A part of the biogeochemical processes which take place in sediments can be explained by the vertical concentration profiles of these elements in sediments and porewaters.

To achieve the goal of this research, samples were collected along several tracks in the northern Indian Ocean and analysed for various elements in different fractions. The solid phase of the sediment samples was divided into two fractions; the easy leachable fraction and the residual fraction. In these fractions the concentrations of Mn, Fe, Cu, Zn, Ni, Pb, Cr and Cd were determined. The porewaters (interstitial water) of the sediment samples were analysed for Mn, Fe, Cu, Zn, Ni, Pb and Cd. To determine the major element composition of the sediments, the samples were analysed for Ca, Si, and Al. Also the porosity, the oxygen concentration, the percentage carbon, the percentage nitrogen and the C/N-ratio were determined. Additional research involved sediment-trap results and sedimentation rate determination.

With the results horizontal and vertical trace metal-concentration profiles are constructed. Together with other results such as C/N-ratio, oxygen profiles and with the known biogeochemical processes these profiles and the distribution of major elements are explained.

In chapter one the necessary theory is explained for better understanding of the processes in the sediment. In chapter two the sampling and analysis methods are described. In chapter three the results are discussed. Finalising with conclusions about the preceding results and discussion.

2. THEORY

2.1 Sedimentation

Sediments in the oceans contain compounds of different origins. These compounds can be divided into those with an anthropogenic origin or natural origin and are organic or inorganic. There are three major ways by which these materials are transported to the oceans: via rivers, via the atmosphere (terrigenous origin) and by hydrothermal vents (e.g. underwater volcanism). Another important source is that of organic matter formed by biogenic production in the water column (pelagic production). Via these sources the oceans receive a variety of materials, which will dissolve in the water column, mineralise or sink to the sediment. [Chester, 1990]

Not all of the supplied material will reach the bottom of the ocean. Of the organic material 75 % is remineralised in the first 500 meters of the water column. Within 1500 meters of the water column almost 90 % of the pelagic formed organic material is remineralised [Martin et al., 1987].

2.2 Upwelling

In the early summer, monsoon winds in the northern Indian Ocean cause an upwelling zone in front off the Somalia, Oman and Yemen coasts. The monsoon winds drive the surface water off shore and this will be replaced by water from greater depth. This water is much colder and is rich in nutrients causing extensive blooms of phytoplankton growth while it warms up [SOZ, 1991].

2.3 Diagenesis

All biological-, physical- and chemical processes together, which can cause changes to the sediment, are called diagenesis.

When organic material reaches the bottom of the ocean it is remineralised due to oxidation processes. For oxidation of organic material an electron acceptor is necessary. First oxygen is used as an electron acceptor. After depletion of oxygen, denitrification takes place and further $Mn(IV) \rightarrow Mn(II)$, $Fe(III) \rightarrow Fe(II)$ and

$\text{SO}_4^{2-} \rightarrow \text{S}^{2-}$ will act as electron acceptors. When Fe(III) and Mn(IV) are used as electron acceptors, the reaction products (Fe(II) and Mn(II)), dissolve in the interstitial water [Froelich et al., 1979; Stumm & Morgan, 1981].

When organic material is buried by other material or by bioturbation, the oxidation of the organic material will continue. Depending on the supply of organic matter the sediment has an oxygen layer of 1 mm to a few meters [Chester, 1990]. In the oxygen rich part trace metals, which were initially bound to the organic matter, will dissolve due to the oxidation of this organic matter. Cu for instance has mostly a porewater-concentration maximum in the top sediment layer. Downwards, when Cu adsorbs onto sediment particles, the Cu concentration in the porewater decreases strongly with depth [Klinkhammer et al., 1982; Sawlan and Murray, 1983]. Beneath the oxygen layer, when Mn and Fe are used for oxidation of organic matter, the dissolved Mn- and Fe concentration will increase strongly with depth due to the release of Fe(II) and Mn(II) from the solid phase [Froelich et al., 1979]. Ni shows usually the same concentration-depth profile as Mn, probably because Ni is bound to MnO_2 and dissolves when MnO_2 is used for oxidation of organic matter [Klinkhammer et al., 1982; Shaw et al., 1990].

The Pb and Zn concentrations in the sediments can act as a historical record for anthropogenic influences. Since the industrial revolution the anthropogenic input of Pb and Zn in some civilised areas is bigger than the natural input of Pb and Zn. Especially in deep waters, where bioturbation and sedimentation rates are low and due to the restricted mobility of Pb and Zn, the concentration profiles of solid phase Pb and Zn can show a remarkable increase in the upper layer of the sediment compared to background values. The sediment layer, which is enriched, corresponds with the years of enhanced industrialisation [Nolting and Helder, 1991].

In porewater dissolved trace metals can adsorb on sediment particles or can be oxidised and precipitate as oxides. Due to downward diffusion they can also precipitate as sulphides or carbonates. Sulphides are coming from reduction of sulphates by organic matter [Froelich et al., 1979; Canfield et al., 1992].

2.4 Distribution of major elements

The major elements; Ca, Al and Si are all abundant in the sediments of the oceans. Usually expressed as CaCO_3 (calcite, aragonite), Al_2O_3 (aluminium silicate) and SiO_2 (opal, quartz). One of the most important sources for CaCO_3 and SiO_2 are biogeneuous shells. Due to a change from terrigeneuous inputs (by wind and rivers) to pelagic formed sediments (compounds from oceanic origin), the percentage CaCO_3 is usually smaller near the coast compared to deeper waters. Of course this depends on the place and does not include sediments in the neighbourhood of limestone cliffs for instance [Chester, 1990; Sirocko et al., 1989].

CaCO_3 appears in nature mainly in two forms, namely calcite and aragonite. The first one is stabile and the second one is metastabile. This means that aragonite will dissolve earlier compared to calcite. In the northern Indian Ocean sediments the proportion between aragonite and calcite is respectively 15 % and 85 %. At a certain depth the CaCO_3 dissolves. The lysocline is the depth at which a significant decrease in CaCO_3 occurs and the compensation depth is the depth below which less than 10 % CaCO_3 is present [Kolla et al., 1976; Sirocko, 1989]. Table 1 shows the lysocline and compensation depth for aragonite and calcite in the studied area.

Table 1: Lysocline and compensation depth for aragonite and calcite.

	Aragonite	Calcite
Lysocline (m)	1200 - 1550	2800 - 3575
Compensation depth (m)	1550 - 2000	> 4035

Since the trace metal concentration of CaCO_3 is very low, it causes dilution of the actual amount of trace metals in these sediments. For comparing the different trace metal concentrations in sediments at the different stations they are calculated on a CaCO_3 free basis. Si-rich sediments have generally a restricted distribution and are usually confined to the edges of the oceans [Chester, 1990].

2.5 Oxygen concentration in sediments and bottom waters

The oxygen concentration in bottom waters of the oceans depend on the oxygen consumption of organic matter, the supply of oxygen by diffusion and advection. When upwelling causes enhanced primary production, more organic matter reaches the bottom of the ocean, which will lead to higher oxygen demands and so lower oxygen concentrations. This situation is shown in figure 1. Oxidation of organic matter causes an oxygen minimum zone which in some cases extends to the ocean floor. So the secondary oxidators will be used earlier [Chester, 1990; Froelich et al., 1979].

Further offshore, primary production decreases, resulting in a lower supply of organic matter with increasing water depth. This results in a lower oxygen demand and the oxygen will penetrate deeper in the sediment. In deeper water the supplied organic matter will be further oxidised [Chester, 1990; Froelich et al., 1979].

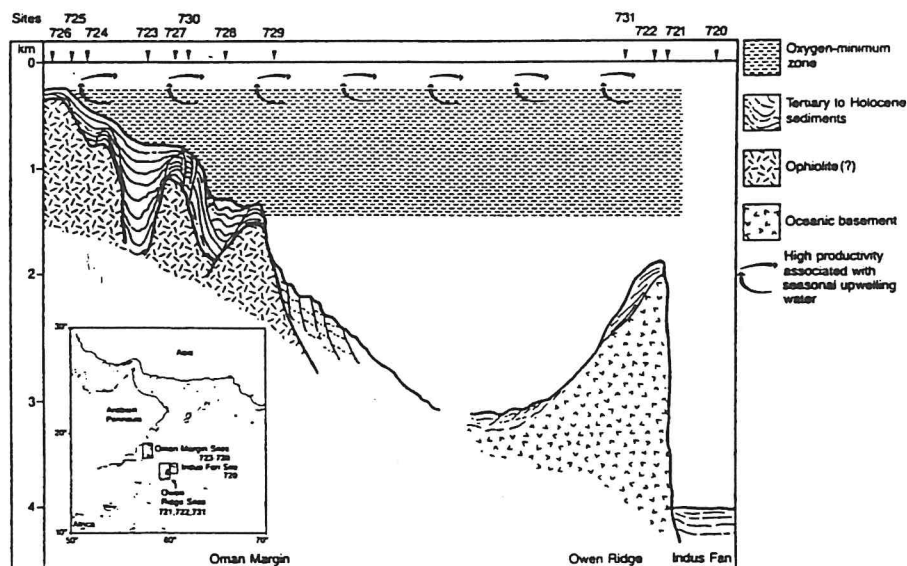


Figure 1: Oxygen minimum zone in the northern Indian Ocean.

2.6 C/N-ratio

The proportion of carbon and nitrogen in sediments can be explained by differences in the supply of pelagic and terrigenous material. Organic matter of pelagic origin has a C/N-ratio of approximately 6.2 ± 0.4 , terrigenous organic matter on the other hand has a ratio of approximately 90 ± 10 . So the C/N-ratio depends on the proportions of these two sources. Usually sediments close to the coast or near rivers have a relatively high C/N-ratio due to the important share of terrigenous material in the total amount of organic matter. On the contrary the supply of organic material to sediments in open oceans are mainly of pelagic origin, which cause a low C/N-ratio. With formula 1 it is possible to calculate the contribution of pelagic and terrigenous sources to the total amount of organic matter [Macdonald et al., 1991].

Formula 1:

$$F_t / (C/N)_t + F_m / (C/N)_m = 1 / (C/N)$$

$$F_t + F_m = 1$$

F_t = Terrigenous fraction organic matter

F_m = Marine fraction organic matter

3. SAMPLING AND ANALYSIS

3.1 Sampling

The sediment samples were collected with help of a boxcore from August 10 to September 4, 1992 on board the research vessel "R.V. Tyro". The stations were situated in the northern Indian Ocean, which is shown in Figure 2. The exact locations and water depth of the stations are listed in Table 2. All boxcores of this project were acquired with a large cylindrical coring device with a diameter of 0.5 meter, which left the boxcore undisturbed. The boxcore simultaneously sampled bottom water and the upper 60 centimeters of the sediment. Bottom water samples were taken after retrieval of the boxcore on deck. After most of the overlying water was removed, samples were taken with a small plastic tube for the determination of oxygen profiles, porosity and resistivity. Next three sub-cores were collected with plastic liners (6 centimeters in diameter). The sub-cores were brought into a container which was kept at the same temperature as that of the bottom water. The sub-cores were sliced in 10 parts from top to bottom of; 0.0-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.0, 2.0-3.0, 3.0-4.0, 4.0-6.0, 6.0-8.0, 8.0-10.0 and 10.0-14.0 centimeters, respectively. For two very deep stations (station 325 and 351) the first centimeter was sliced in 4 subslices with a thickness of 0.25 cm each. This was done to obtain a better resolution of the sediment core in that part of the ocean floor where sedimentation rates were low. Three slices of the same depth were combined (otherwise the amount of porewater would not be enough) in a teflon squeezer and the porewater was removed by means of nitrogen pressure (1-3.5 bar) over a 0.2 μ m cellulose-nitrate filter. After the porewater was removed from the sediment it was collected in acid-cleaned polyethylene bottles and acidified to pH 2. The pressed sediment slices were packed in labelled plastic bags and stored in the deep freeze until analysis at NIOZ. Nutrients (phosphate, nitrate and silicate) and Mn^{2+} and Fe^{2+} in the porewater were analysed on board by an auto analyser.

3.2 Sediment analysis

All chemicals were of Suprapure® quality and the water was of nanopure quality. Reagents like HNO_3 or freon were three times quartz distilled to obtain even cleaner products. The used lab ware was cleaned in 6 N HCl for at least 24

hours. Teflon materials were cleaned in 7 N HNO_3 at 60 °C for at least 24 hours. After cleaning the lab ware was thoroughly rinsed with nanopure water (5 times), dried in a cleanroom and stored in plastic bags.

Back at NIOZ the sediment samples were analysed. First approximately 3 grams of sample was dried in a petri dish at 60 °C for at least 24 hours. Then the samples were ground in a teflon mortar with pestle to make it homogeneous and easy to weigh. Next an exact amount of approximately 100 milligrams of sediment was transferred into a 50 ml polypropylene volumetric flask and filled with 0.1 N HCl to make a final volume of 50 ml. After leaching for 18 hours the solution was filtered over a 0.45 μm cellulose nitrate filter (Sartorius) to separate the residual fraction and the dissolved fraction.

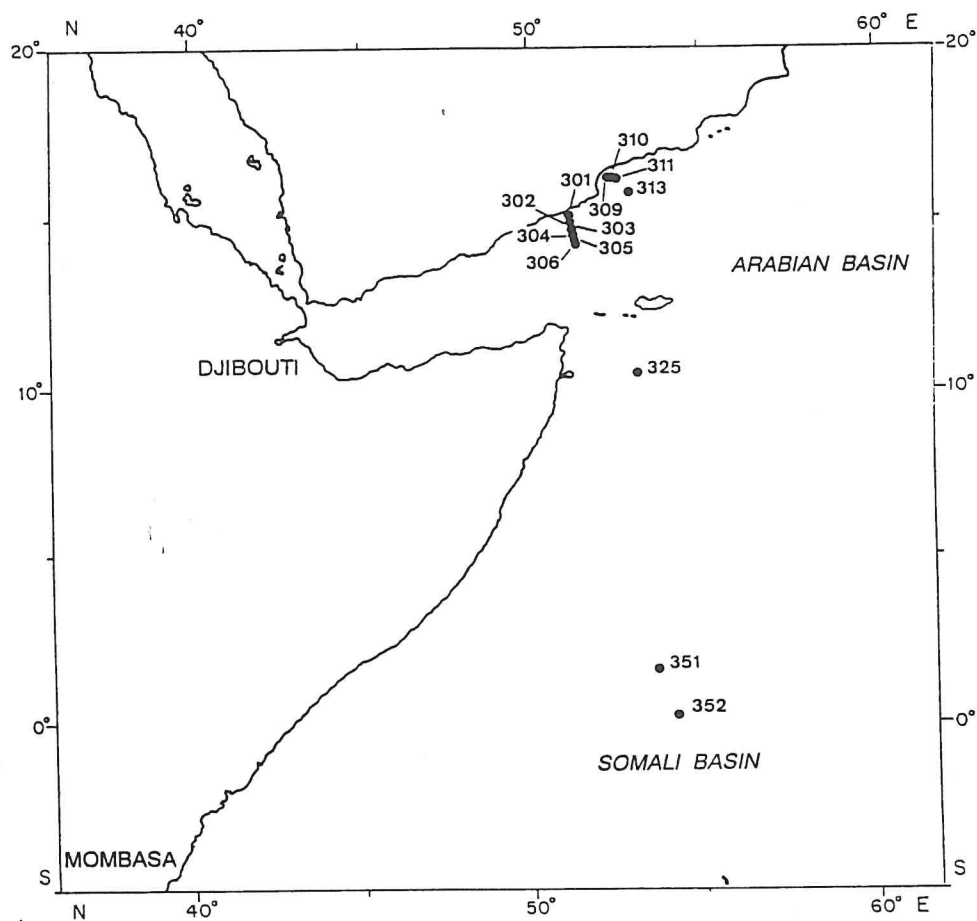


Figure 2: Locations of the stations in the northern Indian Ocean.

Station nr.	Latitude	Longitude	Depth (m)
301	15:07.99 N	51:25.13 E	75
302	15:01.15 N	51:27.48 E	208
303	14:52.60 N	51:29.60 E	477
304	14:47.40 N	51:31.59 E	784
305	14:43.51 N	51:34.69 E	1124
306	14:30.90 N	51:37.60 E	1504
309	16:05.53 N	52:37.63 E	485
310	16:04.00 N	52:41.70 E	880
311	16:02.00 N	52:46.07 E	1088
313	15:52.70 N	53:00.60 E	2230
325	10:41.00 N	53:33.00 E	4069
351	01:48.20 N	53:42.30 E	5170
352	00:23.10 N	54:30.30 E	4815

Table 2: Exact position and water depth of stations in the northern Indian Ocean.

To dissolve the residual fraction, the filters were destroyed in a teflon bomb using 1 ml of aqua regia ($\text{HCl}:\text{HNO}_3 \rightarrow 3:1$), 5 ml of HF and heating at 120 °C for 2 hours. After cooling of the bombs the solutions were quantitatively transferred into 50 ml polypropylene volumetric flasks, which contained 30 ml saturated boric acid to complex the fluorides, and replenished with nanopure water to exactly 50 ml.

The major elements were analysed with the Flame Atomic Absorption Spectrophotometry technique (FAAS) because their concentration was rather high. A Perkin Elmer 2380 was used. Used apparatus are listed in appendix 1, experimental conditions are listed in appendix 2. Ca was only determined in the leachable fraction because almost all Ca dissolves in the leachable fraction (less than 1 % in the residual fraction). Si was only determined in the residual fraction because the fraction of Si that dissolves in 0.1 N HCl is negligible. The remaining major elements Fe, Mn, Zn and Al were analysed both in the leachable and the residual fraction. For Al and Si a N_2O -acetylene flame was used. The other major elements were analysed with an air-acetylene flame. Due to matrix effects internal calibration curves were used for determining Ca, Al and Si. Fe, Mn and

Zn showed no matrix effects when comparing external calibration curves with internal calibration curves, so external calibration curves were used.

Due to the low trace metal concentrations in the leachable as well as in the residual fraction, they were analysed by Graphite Furnace technique using a Perkin Elmer 5100 with Zeeman correction or a Perkin Elmer 5000 with deuterium correction, both with an auto sampler. Used apparatus and experimental conditions are listed in appendix 1 and 3. For Cd, Cu and Pb the Stabilised Temperature Platform Furnace (STPF) technique was used. Cr and Ni were analysed using pyrolytically coated graphite tubes instead of STPF. All trace metal concentrations were determined with external calibration curves except for Pb. The Pb-concentration was determined with an internal calibration curve and addition of 10 µl of 0.1 N HNO₃ to increase the sensitivity.

3.3 Porewater analysis

Zn, Fe and Mn, which had rather high concentrations, were directly analysed with the flame-AAS technique (Perkin Elmer 2380). Fe and Mn were determined with external calibration curves. Due to matrix effects Zn was determined with internal calibration curves.

Cu, Pb, Ni and Cd were first pre concentrated and further analysed with the furnace-AAS technique (Perkin Elmer 5100 with Zeeman correction). To concentrate the porewater samples the modified method according to Danielsson et al. (1978) was used. First, exactly 5 ml of the sample was buffered with 100 µl of an ammonium-acetate buffer to a pH of 4-5 in a clean 10 ml polypropylene test-tube. A too low pH destroys the APDC/DDDC complex. Secondly, 50 µl of 1 % APDC/DDDC-solution (ammoniumpyrolydine dithiocarbamate / diethylammonium diethyldithiocarbamate) was added to the solution to complex the trace metals. Subsequently 4 ml of 3 times quartz distilled freon-TF was added, and the solution was vigorously shaken for 3 minutes. After phase separation the water was removed and stored in a teflon bottle for later use (recovery determination). Then 50 µl of 3 times quartz distilled HNO₃ was added to the freon to destroy the APDC/DDDC complex, the solution was vigorously shaken for 2 minutes. The solution had to stand for 30 minutes. Finally 0.95 ml of nanopure water was added to the mixture for back extraction and to obtain a

total volume of exactly 1.00 ml. Totally the sample was 5 times concentrated. With the stripped water from the freon extraction a standard addition calibration curve was prepared for each element and extracted in the same way as the samples. When the expected concentration of the standard addition (x-axis) and the found concentration of the standard addition (y-axis) were placed against each other in a diagram, the angle of the diagram showed the recovery of the extraction. The recoveries of the pre concentration were approximately: 103 % for Cd, 100 % for Pb, 107 % for Ni and 69 % for Cu. Cu concentrations are corrected for the found recovery. The recovery of the other trace metals is supposed to be 100 %.

Mn and Fe in porewater were also analysed directly on board with an auto analyser, but for both Mn as Fe these concentrations were lower compared to the Mn and Fe concentrations analysed at NIOZ. The higher concentrations in the last ones were probably caused by dissolution of Fe and Mn particles smaller than 0.2 μm . These particles (colloids) in the porewater were able to pass the filter. After acidifying the porewater samples and the longer period before analysing (+/- 1.5 years) the particles dissolved and can explain the higher concentrations

3.4 Porosity

To determine the porosity, samples of 5.0 cm^3 from different depths in the sediment were collected. After the samples were weighed they were dried at 100 $^{\circ}\text{C}$ for more than 24 hours. To obtain the porosity, the amount of evaporated water was calculated, divided by 5.0 cm^3 and multiplied by 100 %.

3.5 Carbon, nitrogen and C/N-ratio

The amount of carbon and nitrogen was determined with a nitrogen, carbon, sulphur analyser (Carlo Erba instruments; NA 1500 Series 2). After 10 mg of sediment was weighed in tin cups, the inorganic carbon (predominantly CaCO_3) was removed by adding several times 50 μl of sulphurous acid (drying at 60 $^{\circ}\text{C}$ after every amount of sulphurous acid). After all inorganic carbon was removed (no more effervesce of the sample when adding sulphurous acid) the samples were analysed.

3.6 Accuracy and precision

To guarantee a good accuracy and precision some precautions were taken. The internal and external calibration curves were prepared with Titrisol® (Merck) or DILUT-IT® (Baker) 1000 +/- 2 ppm stock standards. Only calibration curves with good correlation coefficients were used to calculate the concentrations in the samples. A duplo measurement was always done. A few times, samples were analysed a second time to verify the reproducibility of the analysis, which proved to be good. Both for the leachable as well as the residual fractions blanks were determined during the whole procedure. The concentration of the blanks for all elements appeared to be negligible compared to the concentration in the samples, except for Cd which had a very small blank concentration of 0.07 ppb. Nevertheless, all samples were corrected for the mean blank concentration.

To assure a good accuracy of the obtained results, several reference samples were analysed in the same way as the sediment samples. The reference samples had known trace metal and major element concentrations and uncertainties and were from the Community Bureau of Reference (BCR) in Brussels. The used reference samples were: BCR 141 (calcareous loam) and BCR 142 (a light sandy soil). To control the accuracy of the found concentrations Sheward charts were used. For both BCR 141 as well as BCR 142 three samples were taken and dissolved in the same way as the residual fractions. For each element two or more of the BCR solutions were analysed to determine the precision of the analysis. The precision of the analysis appeared to be good as is shown in table 3.

Every analytical run, a sample with a known concentration was analysed and the found concentration was filled in on this chart. When the found concentration was above or below 2 times the uncertainty of the used BCR sample, something was supposed to be wrong. In table 3 the found and certified values of the used BCR samples are listed. Most of the found and certified values corresponded well with each other, so a good accuracy was obtained during the analytical procedure.

Element	BCR 141 (calcareous loam)		BCR 142 (light sandy soil)	
	Determined	Certified	Determined	Certified
Cu	32.20 +/- 0.33	32.6 +/- 1.4	27.6 +/- 0.47	27.5 +/- 0.6
Cd	0.39 +/- 0.08	0.36 +/- 0.10	0.30 +/- 0.06	0.25 +/- 0.09
Ni	30.17 +/- 1.89	(31 +/- 3)	27.4 +/- 0.4	29.2 +/- 2.5
Pb	29.83 +/- 0.72	29.4 +/- 2.6	40.7 +/- 0.80	37.8 +/- 1.9
Zn	80.05 +/- 1.20	81.3 +/- 3.7	88.8 +/- 2.0	92.4 +/- 4.4
Cr	70.50 +/- 1.64	(75 +/- 10)	73.2 +/- 4.5	(75 +/- 9)
Mn	506 +/- 17	(547 +/- 32)	536 +/- 25	(569 +/- 26)
Fe ₂ O ₃	3.5 +/- 0.4	(3.74)	2.80 +/- 0.01	(2.80)
Al ₂ O ₃	10.52 +/- 0.0	(10.56)	N.D.	(9.48)
CaO	15.35 +/- 0.11	(17.98)	3.91 +/- 0.28	(4.94)
SiO ₂	N.D.	(42.58)	66.9 +/- 0.4	(68.22)

Table 3: Found and certified values and uncertainties of trace metals and major elements in the BCR samples 141 and 142. Values between brackets are not certified. N.D. means not determined. Concentrations of trace metals are given in µg/g dry weight. Concentrations of the major elements are given in % (w/w) in dry weight of the most abundant mineral.

Both the BCR's were also separated in a leachable and residual fraction. When cast up the leachable and residual fraction, a loss of approximately 6 % was found in comparison with the concentration found in not separated BCR samples.

4. RESULTS AND DISCUSSION

4.1 Characteristics of the sediment

4.1.1 Porosity

The porosity in the upper part of the sediments was approximately 65 % at the stations close to the coast, further offshore values of approximately 75-90 % were found (appendix 4).

4.1.2 Bottom water oxygen concentration

Due to upwelling in the northern Indian Ocean large quantities of organic matter are formed, which mineralised in the ocean. This will lead to an oxygen minimum zone in approximately the upper km of the water column (figure 3, appendix 5). In deeper waters less organic matter reaches the ocean floor and more oxygen is present in the bottom waters.

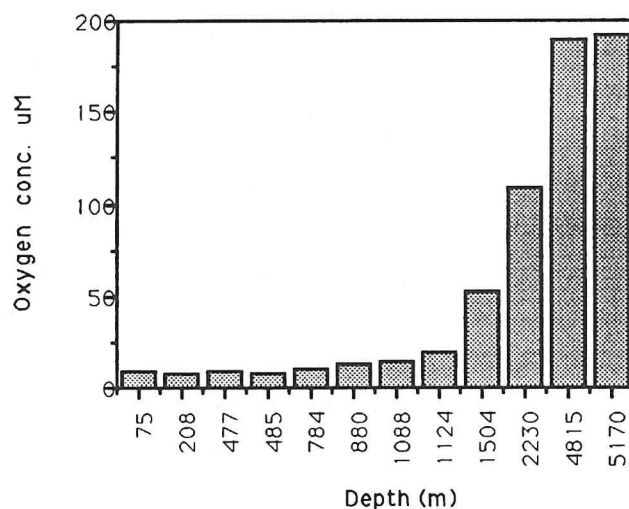


Figure 3: Oxygen concentration (μM) in the bottom waters of the northern Indian Ocean plotted against water depth (m).

4.1.3 Amounts of organic carbon and nitrogen and the C/N ratio

Going into seaward direction the percentage carbon and nitrogen show a sharp increase with a maximum at approximately 1500 meters (figure 4, appendix 6). Found values are high compared to other deep sea sediments [Chester, 1990]. The carbon content changed from approximately 1 to 3.5 % and the nitrogen from 0.1 to 0.3 %. This increase is most probably caused by processes forced by upwelling. Organic matter, which is formed due to the sudden abundant supply of nutrients by the upwelling current, is carried off shore and discharged on the deep ocean floor. This causes a lower supply of organic matter at the shallow (near coast) sediments and a higher supply to the deeper located sediments. Also the fact that most of the growth of phytoplankton takes place at the margin between upwelling waters and open ocean water contributes to this increase.

At greater water depth a large decrease in the amount of nitrogen and carbon is observable with values which are approximately in the same order of magnitude as those found at the shallow stations. This decrease is probably caused by increasing water depth. At deeper waters less organic matter is supplied to the sediment, because most of it will be mineralised before it reaches the ocean floor and primary production is less compared to that in the upwelling area.

The C/N-ratio decreased predominantly when moving from shallow to deeper water (figure 5). It decreased from values of approximately 12.5 to 7. Terrigenous formed compounds have a high C/N-ratio (50-100) compared to pelagic formed compounds (5.4-8.3) [Macdonald et al., 1991]. A change in the supply from terrigenous to pelagic compounds will lead to a lower C/N-ratio. Macdonald et al. (1991) calculated the C/N-ratio for terrestrial and pelagic compounds, to be 90 and 6.2 respectively. With these values the contribution of both terrigenous and pelagic compounds to the total amount of organic matter were calculated. Because the uncertainty in the life time of the organic matter the calculated values have to be taken with some restrictions. Because it is not certain that the material deposited in the surface layer in this coastal area is real newly formed organic matter, it is possible that a part of this organic matter is older material coming from other parts of the Indian Ocean. Further research will be done to get better insight in the contributions of different sources. Close to the coast in shallow waters, 50 to 60 % of the organic compounds were of pelagic

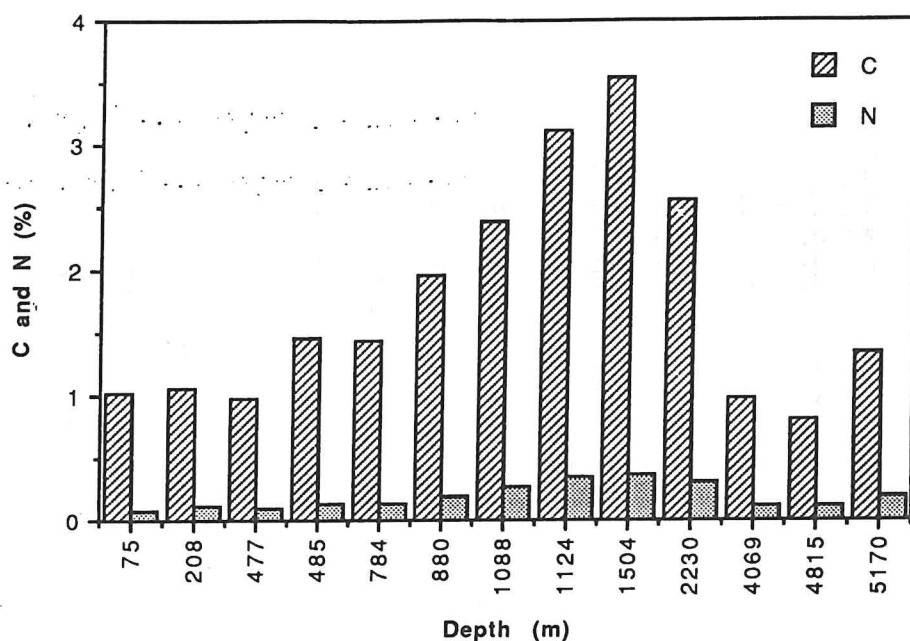


Figure 4: Mean carbon and nitrogen content (%) in the first two centimeter of the sediment in the northern Indian Ocean plotted against water depth

origin, in deeper waters further offshore this was 70 to 90 %. The remaining part is of terrigenous origin. Contribution of pelagic and terrigenous sources to the total amount of supplied organic matter is shown in table 4.

Carbon and nitrogen content-depth profiles in the sediments at the different stations were almost identical (figure 6 and 7). Values of carbon and nitrogen contents and C/N-ratio are listed in appendix 7. In the first 1.5 centimeters a sharp decrease was visible which changed to a slight decrease deeper in the sediment. This is probably due to the fact that fresh organic compounds at the surface layer of the sediment were not yet mineralised, deeper in the sediment the mineralisation is further advanced and less organic matter is present.

The C/N-ratio at the shallow water stations (301 to 309) were almost constant with depth, there was no visible trend. On the contrary, at the deeper stations the C/N-ratio showed a sharp increase with depth in the first 2 centimeters of the

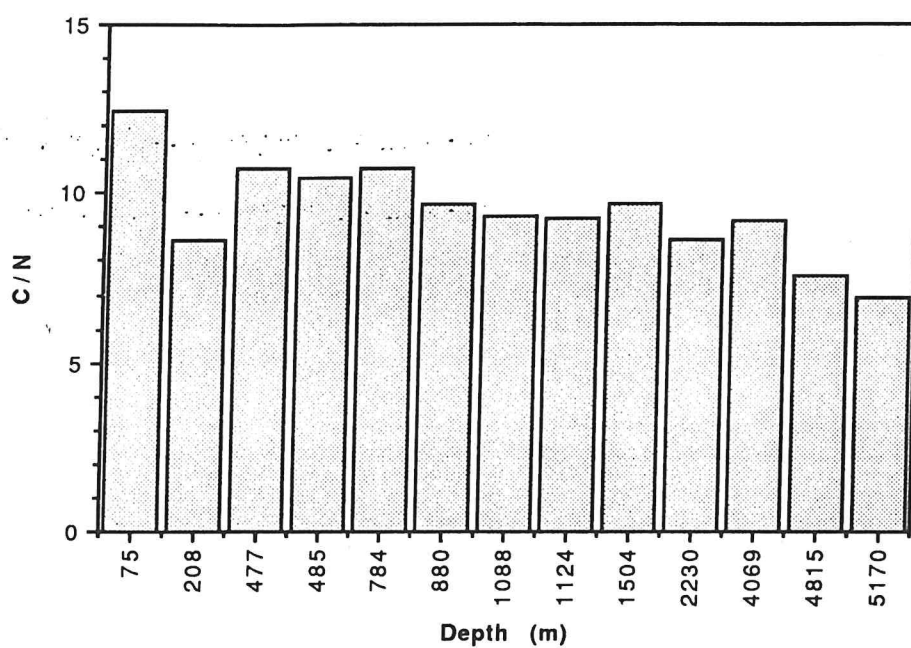


Figure 5: Mean C/N-ratio in the first two centimeter of the sediments in the northern Indian Ocean plotted against water depth

Station	Depth (m)	Pelagic (%)	Terrigenous (%)
301	75	46	54
302	208	70	30
303	477	55	45
304	784	55	45
305	1124	65	35
306	1504	61	39
309	485	56	44
310	880	61	39
311	1088	64	36
313	2230	70	30
325	4069	65	35
351	5170	89	11
352	4815	81	19

Table 4: Contributions of pelagic and terrigenous compounds to the total amount of organic matter in the first two centimeters of the sediments.

sediment, followed by a more slight increase deeper into the sediment (figure 8). This difference was probably caused by lower bioturbation- and sedimentation

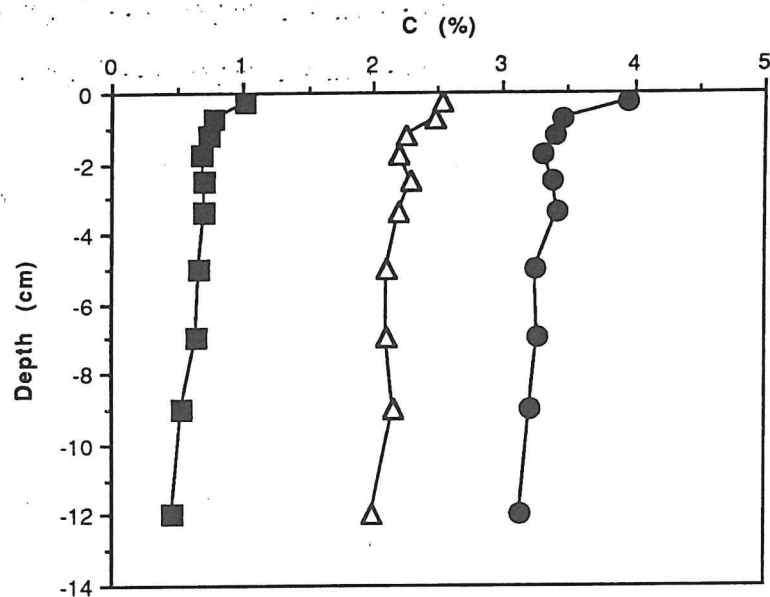


Figure 6: Concentration of C (%) against depth (cm) in sediment at stations 306 ● , 311 Δ and 352 ■ .

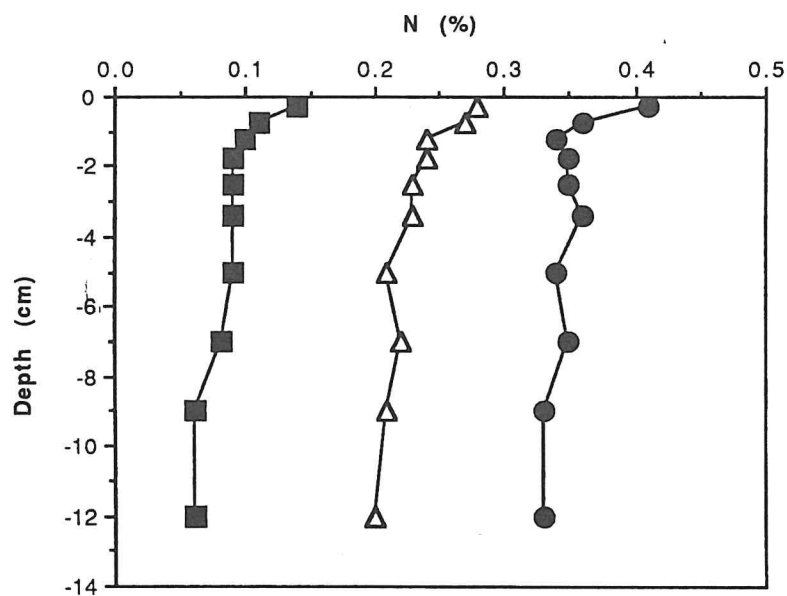


Figure 7: Concentration of N (%) against depth (cm) in sediment at stations 306 ● , 311 Δ and 352 ■ .

rates in the deeper stations. Nitrogen containing compounds are less stable during diagenesis, resulting in an increasing C/N-ratio with age and thus with depth of the sediment [Degens and Mopper, 1976; Macdonald et al., 1991].

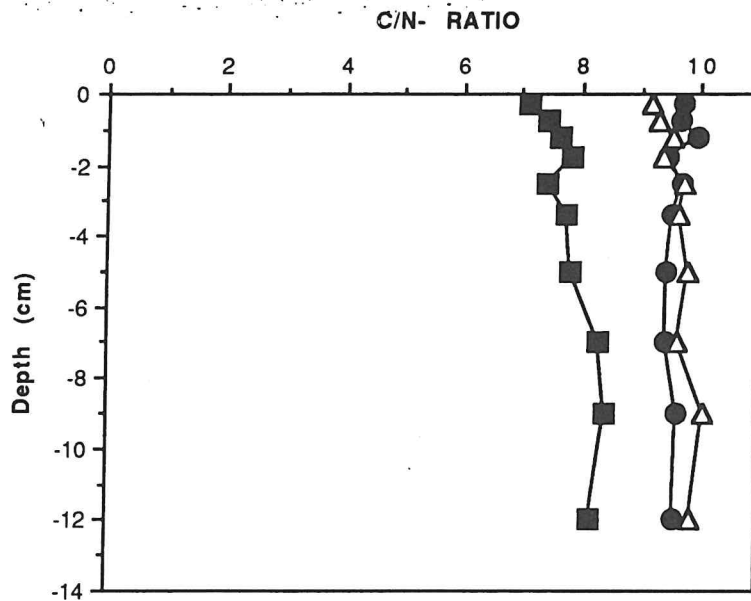


Figure 8: C/N-ratio against depth (cm) in sediment at stations 306 ● , 311 Δ and 352 ■ .

4.1.4 Distribution of the major elements

In figure 9 the mean percentage major elements (Ca, Al, Si and Fe) in the top 2 centimeters of the sediment were plotted against the water depth at the different stations. The major elements are expressed in their most abundant form: CaCO_3 , Al_2O_3 , Fe_2O_3 and SiO_2 . Found values of horizontal and vertical distribution are listed in appendix 8 to 11.

The calcium carbonate content in the sediments increased slightly from 45 to 55 % when moving from shallow to deeper water. This is probably caused by the same processes which caused an increase in the organic carbon content in the top two centimeters of the sediments. Further offshore at the deepest stations the calcium carbonate content in the sediment showed a large decrease from approximately 60 % to 25 % at a water depth of 4815 meters and less than 1 % at 5170 meters. This decrease is caused by the dissolution of calcium carbonate at

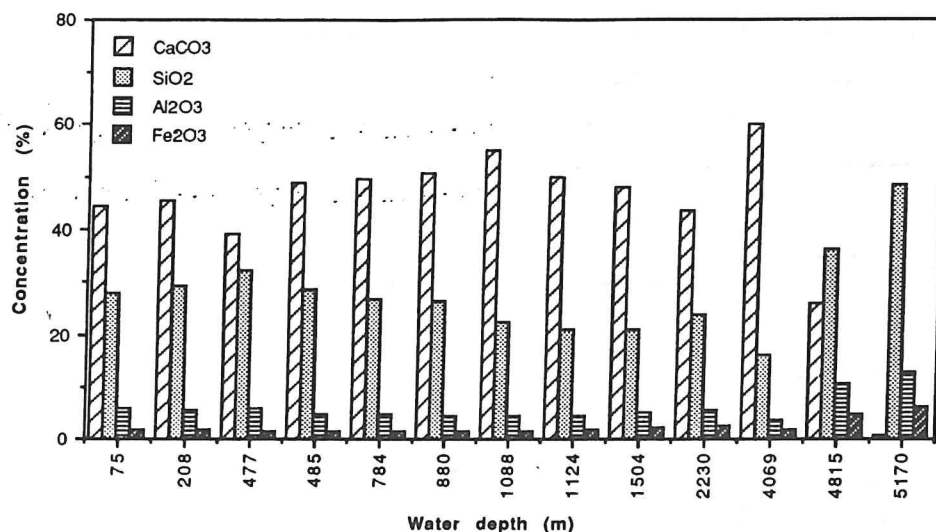


Figure 9: Major element concentration presented as carbonate and oxides (% CaCO₃, Al₂O₃, Fe₂O₃ and SiO₂) in the first two centimeter of the sediment in the northern Indian Ocean plotted against water depth (m)

the deeper stations which are beneath the compensation depth of calcium carbonate. This is also reported by Sirocko (1989).

The silicium oxide content showed an opposite behaviour compared to the calcium carbonate content in the sediment. First it slightly decreased from approximately 30 % to 20 %. This decrease can be explained by a lower supply of terrigenous silicium oxide by wind transport. At the two deepest stations a sharp increase took place. This is caused by the dissolution of calcium carbonate in the sediment and creates a relative increase in the SiO₂ content. This is also reported by Sirocko (1989).

The percentage iron oxide in the sediment is rather uniform when moving from shallow to deeper water, approximately 1.5-2.5 %. Except at the deepest stations (351 and 352) an increase was observed, to values of approximately 5.5-6.5 %. This is partly due to the lower calcium carbonate content in these sediments. Such an increase is also found for aluminiumoxide.

The sum of the major elements in the upper 2 centimeter of the sediment is approximately 70 to 85% (figure 10). The remainder part consists probably of TiO_2 , Na_2O , K_2O , P_2O_5 , MgO , NaCl , organic matter and H_2O .

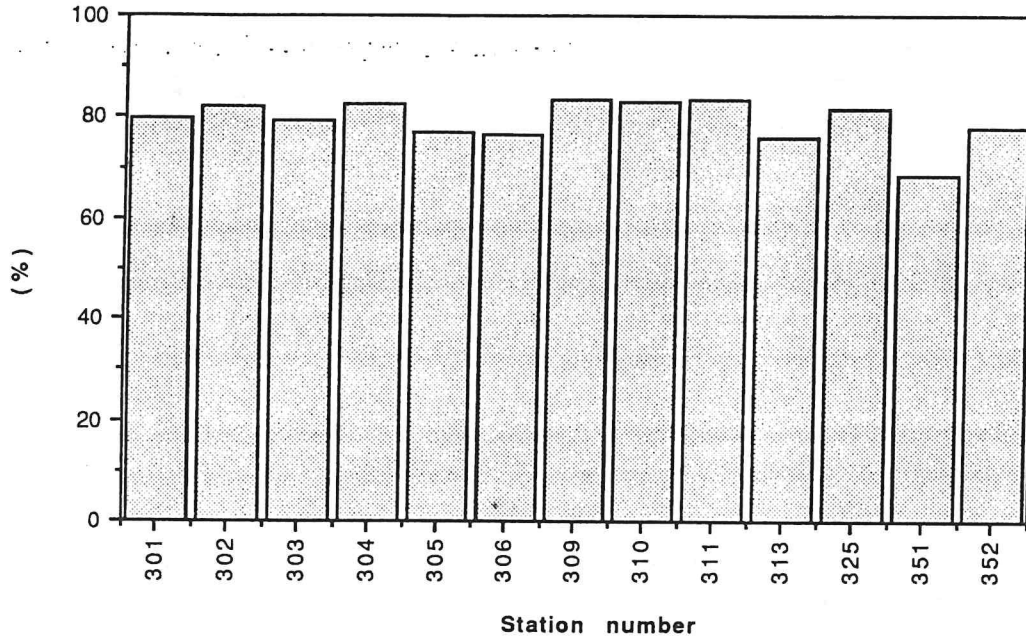


Figure 10: Sum of the major elements presented as CaCO_3 , Al_2O_3 , Fe_2O_3 and SiO_2 in the upper 2 centimeter of the sediment plotted against water depth (m)

4.2 Oxygen penetration in the sediment

The course of diagenesis is dominantly defined by the oxygen concentration in the sediment. Oxygen is used for oxidation of organic matter and reduced forms of trace metals, like Fe and Mn. The penetration depth of oxygen in the sediment is mainly dominated by the amount of organic matter in the sediment.

In figure 11 some typical oxygen-depth profiles are shown for station 306 and 313. These profiles are obtained by insitu measurement at the ocean floor with a so called TROL bottom launder (Temperature, Resistivity, Oxygen Launder) [Helder et al.,1993]. The penetration depth of oxygen is very small, respectively 15 and 20 mm, compared to values in the literature where penetration depths are mentioned of several centimeters in near shore sediments to more than a meter in pelagic (deep sea) sediments [Chester, 1990]. Probably the undeeep oxygen penetrations are caused by the enhanced supply of organic matter due to the

increase in primary production. Due to technical problems it was not possible to determine in situ oxygen-depth profiles at the other stations. Oxygen profiles determined on board are not reliable due to the oxygen pressure that exists when sediments are transported from the ocean floor to the surface. These measurements gave other results than those of the TROL. However, with help of the nitrate (the first electron acceptor after depletion of oxygen) concentration-depth profiles a good indication of the oxygen penetration depth can be obtained, which will be shown later.

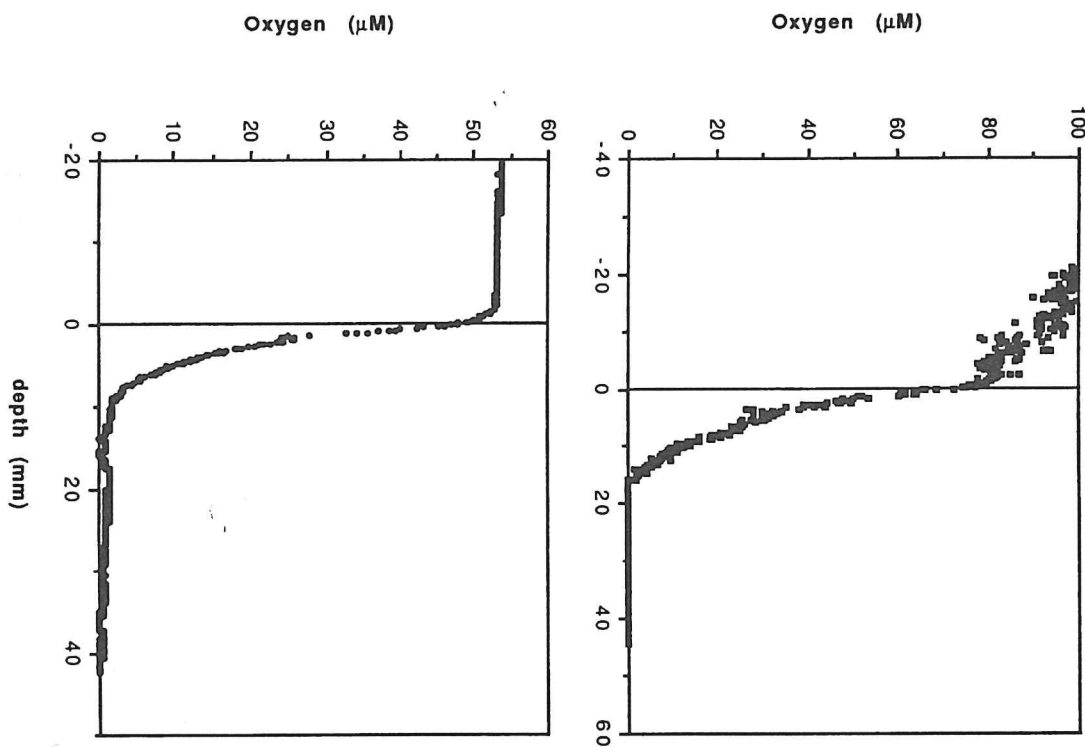


Figure 11: Some typical oxygen concentration (μM) -depth (mm) profiles are shown for stations 306 (left) and 313 (right).

4.3 Horizontal distribution of trace metals in sediments

In this chapter the horizontal distribution of Mn, Cu, Zn, Ni, Pb, Cr and Cd will be discussed. The trace metal concentration was calculated on a CaCO_3 free basis, with the mean value in the first two centimeters surface sediment. The horizontal distributions of Mn, Pb, Cu, Zn and Ni are shown in figure 12 and those of Cr and Cd in figure 13. Found values are listed in appendix 12. A detailed description of the forming of marine sediments can be found in Chester (1990) and a lot of our recent observations for the Indian Ocean can be explained by this presentation.

Manganese

The concentration of manganese shows in general an increase with increasing water depth. In the coastal area till 1500 meters water depth the concentration is almost constant (approximately $400 \mu\text{g/g}$), followed by an increase to $5656 \mu\text{g/g}$ at 4069 meters (station 325). After this maximum is reached, a decrease follows to approximately $4000 \mu\text{g/g}$ at 5000 meters. An increase of the manganese concentration with increasing water depth is reported before in the Laptev sea (Russia) by van Dalen and Nolting (1992), before the Mauritania coast by Ramkema (1992) and in the Mediterranean deep sea by Fernex et al. (1992). A decrease in the percentage of the leachable fraction was found, of approximately 40-50 % at the shallow stations to approximately 20 % at the deeper stations.

Copper

The copper concentration shows a steadily increase with increasing water depth from approximately $15 \mu\text{g/g}$ at the shallow stations to almost $195 \mu\text{g/g}$ at 4815 meters water depth. Followed by a decrease to almost $90 \mu\text{g/g}$ at 5170 meters. This increase with increasing water depth is found before, for example in the Laptev sea (Russia) by van Dalen and Nolting (1992), before the Mauritania coast by Ramkema (1992), in the Mediterranean deep sea by Fernex et al. (1992) and in the north-west Mediterranean by den Das and Nolting (1993). The proportion between the leachable fraction and the total amount of copper increases with depth, approximately 10-20 % to 60 %. So it looks that the increase in the copper concentration with depth is mainly dictated by the easy exchangeable fraction. Which means that uptake of dissolved copper from the water phase to small particles and scavenging from the water phase can play an important role.

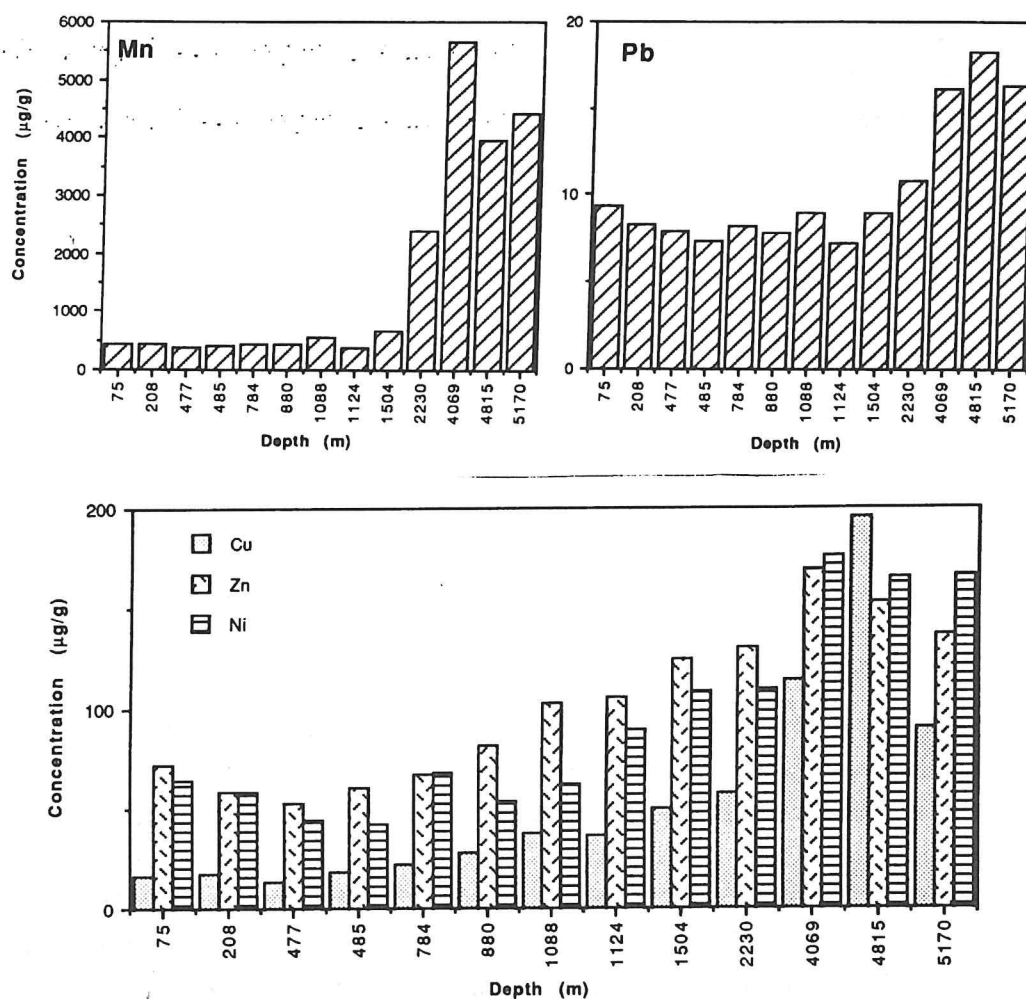


Figure 12: Mean concentration of calciumcarbonate corrected Mn and Pb (upper figure) and Cu, Ni and Zn (lower figure) in the upper 2 centimeter of the sediment in the northern Indian Ocean plotted against water depth.

Zinc

Zinc shows in general the same horizontal distribution as the preceding metals. At almost 1000 meters water depth the zinc concentration increases from approximately 60 µg/g to 170 µg/g at 4069 meter with increasing water depth. At 5000 meters water depth the zinc concentration decreases to approximately 140 µg/g. In harmony with the preceding trace metals, also this trend in

horizontal distribution is found before in the Laptev sea (Russia) by van Dalen and Nolting (1992), before the Mauritania coast by Ramkema (1992) and in the Mediterranean deep sea by Fernex et al. (1992). The percentage of the leachable fraction shows an increase from approximately 30 % in the shallow stations to 40-60 % in the deeper stations.

Nickel

Nickel shows almost the same trend in horizontal distribution as the preceding trace metals. First an increase is found from approximately 60 $\mu\text{g/g}$ at the shallow stations to almost 176 $\mu\text{g/g}$ at 4069 meters water depth, followed by an almost constant value of approximately 165 $\mu\text{g/g}$ at stations 351 and 352. This trend in horizontal nickel distribution and also the resemblance with manganese, copper and lead is found before in the Laptev sea (Russia) by van Dalen and Nolting (1992) and before the Mauritania coast by Ramkema (1992). The percentage of the leachable fraction in the total amount of nickel increases steadily from 15 % at the shallow stations to almost 60 % at the deepest stations.

Lead

The horizontal distribution of lead shows a good resemblance with that of copper and manganese. After a more or less constant concentration at the shallow stations (<1500 meters water depth) of approximately 8 $\mu\text{g/g}$ Pb, the concentration increases with increasing water depth to approximately 18 $\mu\text{g/g}$. Followed by a decrease at 5170 meters (station 351) to approximately 16 $\mu\text{g/g}$. This trend in horizontal distribution of Pb is found before, for instance in the Laptev sea (Russia) by van Dalen and Nolting (1992), before the Mauritania coast by Ramkema (1992) and in the Mediterranean deep sea by Fernex et al. (1992). The percentage leachable of the total solid phase fluctuates between 25 % and 65 %.

All these elements show an equal behaviour which is consistent with the distributions described by Chester (1990) for oceanic basins.

Chromium

The concentration of chromium shows, in confirmation with cadmium in general a decrease with increasing water depth. Concentrations of approximately 175 $\mu\text{g/g}$ chromium are found in the shallow waters, followed by a small increase

between 500 and 1000 meter water depth to approximately 140 $\mu\text{g/g}$. Then a decrease is found to approximately 100 $\mu\text{g/g}$ in the deeper waters. The solid phase of Cr is for a great part of the not reactive (residual) phase.

Cadmium

In contrast to the horizontal distributions of the preceding trace metals, cadmium shows in general a slightly decrease with increasing water depth. Concentrations of approximately 0.75 $\mu\text{g/g}$ in the shallow stations and less than 0.25 $\mu\text{g/g}$ cadmium in the deepest stations are found. The resemblance in horizontal distribution of trace metals with the results in the Laptev sea by van Dalen and Nolting (1992) holds with cadmium. Cadmium is for a great part of the leachable fraction, 80 to 95 %.

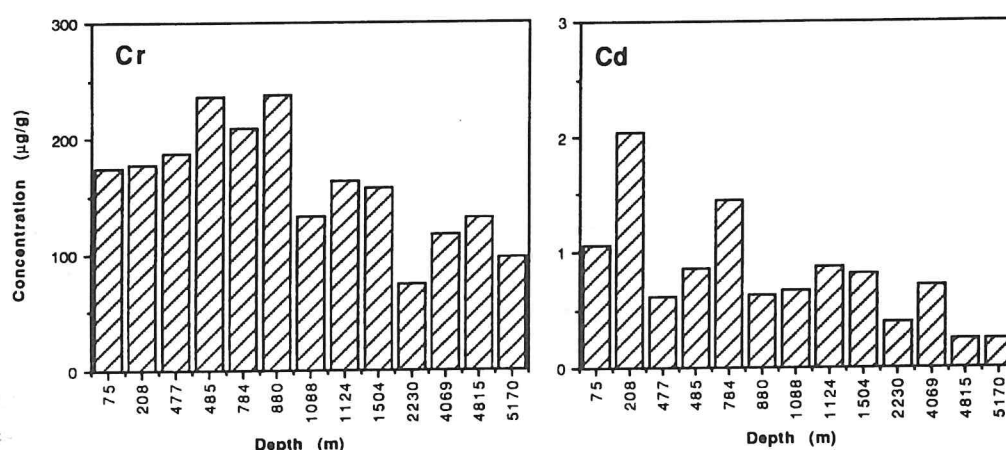


Figure 13: Mean concentration of calcium carbonate corrected Cr and Cd in the upper 2 centimeter of the sediment in the northern Indian Ocean plotted against water depth.

Suggested explanations for the trends found in the horizontal distribution of these trace metals, are:

1) Differences in particle size: small particles have a higher adsorption capacity for trace metals compared to bigger particles, due to their larger specific surface area. This theory is supported by the increase of the leachable fraction of Cu, Zn, Ni and Pb with increasing water depth. Probably this also explains the differences in horizontal distribution found between Cr and Cd, and Mn, Cu, Ni, Pb and Zn. Chromium is mainly found in the residual fraction, so less chromium

is dissolved in the porewaters and is not able to precipitate on sediment particles. Gobeil et al. (1987) described the cadmium diagenesis in Laurentian through sediments (Canada), which was found to be very complex. The solid phase concentration-depth profiles for cadmium showed low concentrations in the oxygen layer of the sediments. Cadmium, released from oxidised organic matter, diffused out of the upper sediment to the water column or deeper into the sediment. This can explain the lower concentrations in the stations at greater water depth. Because at these stations oxygen penetration is often deeper.

2) Co-precipitation with Mn and Fe: Fernex et al. (1992) suggested that co-precipitation with Mn and Fe could be the cause of higher trace metal concentrations in deep sea sediments compared to those in shallow waters. Lateral transport of manganese rich particles or hydrothermal vents (underwater vulcanism) [Burton and Statham, 1988] can cause a higher manganese content in deep sea sediments, so more trace metals can be precipitated. Figure 14 shows a schematic representation of the trace metal trapping process in surface sediments during Mn precipitation. Mn and organic matter are buried in the sediment, followed by a release of Mn^{2+} (used as electron acceptor) and trace metals which were present in the organic matter. After the Mn^{2+} diffused upwards to the surface layer of the sediment, it is oxidised and precipitated as manganese oxides together with the trace metals.

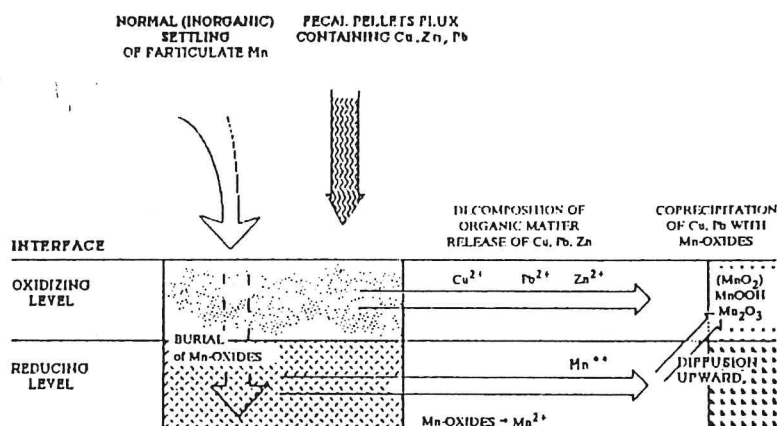


Figure 14: Schematic representation of the trace metal trapping process in surface sediments during Mn precipitation [Fernex et al., 1992].

3) Atmospheric transport: Atmospheric transport of particles can supply considerable amounts of trace metals to the sediment. Martin et al., (1989) found that the annual atmospheric input of red dust to the Western Mediterranean is of the same order of magnitude as the annual discharge by rivers. As far as trace metals are concerned, the atmospheric flux of Cu, Pb and Cd exceeds river input by one to two orders of magnitude. Buat-Menard and Chesselet (1978) found in the Tropical North Atlantic high enrichments for several trace metals in the marine atmosphere. The easy leachable trace metal contents of aerosols in the Western Mediterranean atmosphere are higher in European urban-dominated aerosols compared to Saharan crust-dominated aerosols [Chester et al., 1990]. Because the northern Indian Ocean is situated near a dry area without large cities and no river input it is expected that the atmospheric input is mainly of the crust-dominated origin. Aerosols can also adsorb dissolved trace metals out of the water column during their way to the sediment [Chester, 1990].

In this project no research is done for horizontal differences in particle size, so no conclusions can be drawn for the first option. Also the second and third option are difficult to check. For answering the raised questions further research will be necessary.

It is however clear, that the longitudinal metal distribution pattern compares very well with those patterns found in the Pacific and Atlantic Oceans (Chester, 1990). The actual concentrations are however different, especially the Pb concentrations are very low in the Indian Ocean sediments. In general all these metal concentrations are rather low, compared to urbanised areas, and comparable with those found near Mauritania [Ramkema, 1992].

4.4 Vertical distribution of trace metals in sediment

In this chapter the concentration-depth profiles of Mn, Fe, Cu, Zn, Ni, Pb, Cr and Cd in the sediments will be discussed. These profiles are influenced by biogeochemical processes in the sediment, for example reduction, oxidation, dissolution etc. The solid phase is divided in two fractions, the easy exchangeable and the residual fraction. The first one can reflect anthropogenic influences, such as pollution of lead and zinc. Also precipitation due to oxidation of trace metals, which were in solution in the porewaters of the sediment leave traces behind in

this fraction of the solid phase of the sediment [Macdonald et al., 1991]. The residual fraction is the autochthonous part of the solid phase, these trace metals were already present in the solid rock from which the sediment was formed. In the concentration-depth profiles given, the residual and total fraction are plotted in one graph. In this way a variation in the leachable fraction can easily be observed [den Das and Nolting, 1993]. Shallow stations are 301, 302, 303, 304, 309 and 310. Deeper stations are 305, 306, 311 and 313. The deepest stations are 325, 351 and 352. For each of these groups a representative example of the concentration-depth profile is given, because in most cases profiles within one group show the same trend. Representative stations are respectively: 303, 311, 325 and 351.

Manganese

Concentration-depth profiles of solid phase Mn are shown in figure 15. Found values for each station are listed in appendix 13. The reduction/oxidation processes of Mn are mainly discussed in the interstitial water paragraph.(4.5). Both residual and total Mn concentrations in the sediment at the shallow stations and at station 352 are very constant with depth. This indicates a low oxidation of organic matter due to manganese reduction and/or high bioturbation and/or sedimentation rates. The Mn concentrations at the shallow stations are also rather low, compared to concentrations in the deeper stations and in other research areas, for instance: in the Laptev sea (2000-5000 $\mu\text{g/g}$) [van Dalen and Nolting, 1992] and in the N.W. Mediterranean sea (500 to 2000 $\mu\text{g/g}$) [den Das and Nolting, 1993]. At the deeper stations the concentration of the residual fractions are constant with depth and equal to those at the shallow stations, but the leachable Mn fraction has higher concentrations in the first centimeter, followed by a constant concentration deeper down the sediment. At these stations dissolved manganese in the porewaters, coming from reduction of solid Mn deeper in the sediment, diffuses upwards to the oxic layer where it is oxidised and precipitates. These are normal Mn concentration-depth profiles in steady-state systems where a maximum in the leachable Mn fraction is found at the border between the oxic and anoxic layers. The diagenesis of Mn is extensively described by a variety of authors, for example Froelich et al. (1979), Sundby et al., (1981), Sundby and Silverberg (1985), Sundby et al. (1986) and Shaw et al., (1990). At station 325 an increase with depth of the concentration of the residual fraction in the first four centimeters of the sediment is found, followed by a decrease with

depth from approximately 3500 $\mu\text{g/g}$ at 4 centimeters depth to 80 $\mu\text{g/g}$ at 9 centimeters depth. This trend in the concentration-depth profile is also found at station 351. Because the trend is found in the residual fraction of the solid phase, it can not be explained by normal diagenesis. Probably these changes in Mn contents in the sediment are caused by turbidites. Fresh material is covered by older material, higher in MnO_x , caused by a slide of sediment from higher situated sediments. The profile of station 325 also shows a clear boundary between the anoxic and oxic layer, as seen by the sharp increase of exchangeable Mn at 4 centimeters depth, due to the upward diffusion of Mn^{2+} and subsequent precipitation of MnO_x . See chapter 3.5. The Mn concentrations at the deepest stations 325, 351 and 352 near the equator are remarkably higher (3000 to 6500 $\mu\text{g/g}$) compared to those in the shelf waters near Oman and Somalia (approximately 200 $\mu\text{g/g}$). This is probably caused by the previously mentioned transport of Mn from shallow to deeper waters. Due to reduction of Mn at the shallow stations, the Mn dissolves in the porewaters, escapes through the sediment-water layer to the water column and is transported to deeper waters where it precipitates again. Because there are no rivers in the neighbourhood of these stations to supply new Mn, the stock of Mn in the sediment is exhausted. This theory is supported by the higher leachable fraction at the deepest stations. Also the fact that CaCO_3 dissolves at stations beneath the compensation depth for CaCO_3 , cause a relative higher content of trace metals. This applies also for the remaining trace metals.

Iron

Concentration-depth profiles of solid phase Fe are shown in figure 15. Found values for all stations are listed in appendix 14. Profiles at the shallow stations and at station 352 are very constant. No signs that Fe is used for oxidation of organic matter can be observed. Just like Mn, higher Fe concentrations in the first one or two centimeters of the sediments are found at the deeper stations. This implies, comparable to Mn, precipitation of dissolved Fe due to oxidation. However, no evidence for reduction of Fe is found in the porewater concentration-depth profiles at these stations [Froelich et al., 1979; Shaw et al., 1990]. At station 325 and 351 an increase with depth of the residual fraction in the first two centimeters of the sediment is found, comparable to Mn. The relative higher Fe concentrations in the deeper stations are partly caused by the dilution effect of CaCO_3 , which is for a great part dissolved at the deeper stations.

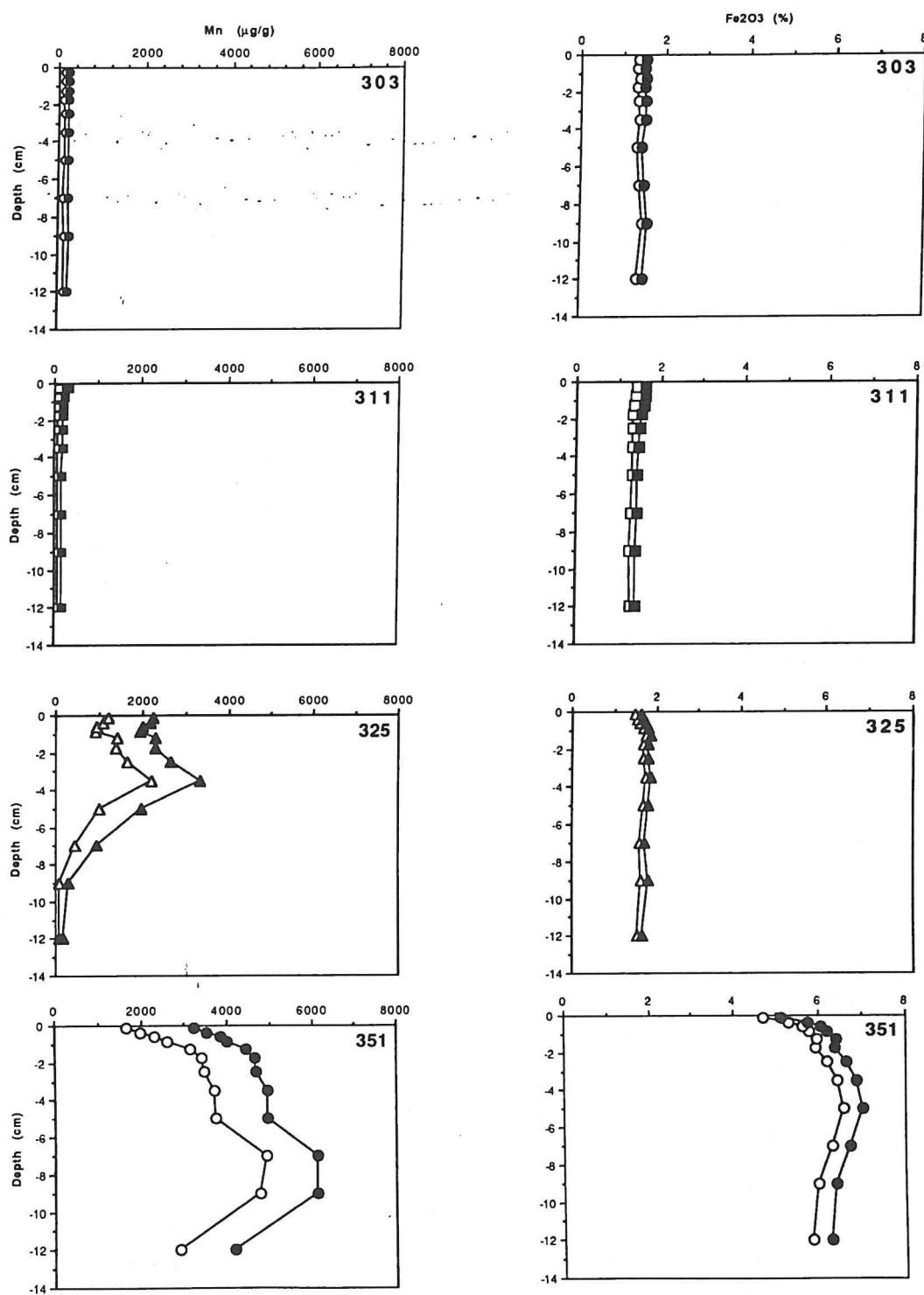


Figure 15: Concentration-depth profiles of residual (open symbols) and total (filled symbols) solid phase Mn (μg/g) and Fe₂O₃ (%) at stations 303, 311, 325 and 351.

Copper

Concentration-depth profiles of solid phase Cu are shown in figure 16. Found values for all stations are listed in appendix 15. The depth profiles of copper in the sediments are at all stations more or less constant with depth. This is found before in, for instance, the Laptev sea [van Dalen and Nolting, 1992] and for the coast of Mauritania [Ramkema, 1992]. As exception station 351 shows a lower concentration in the first centimeter of the sediment, as is found before at this station for Mn and Fe. This decrease is maybe caused by the somewhat higher CaCO₃ contents in the top layer compared to that below 1 centimeter. The total Cu concentration increases from less than 10 µg/g at the shallow stations to approximately 130 µg/g in the deepest stations. It is also mentionable that the easy exchangeable copper fraction increases remarkably with water depth, while this is around 10 % in the shallow sediments it is around 60 % in the sediments at 5000 meter water depth. This indicates that the absorption of copper on particles in these last sediments is much higher than in the exhausted coastal sediments.

Zinc

Concentration-depth profiles of solid phase Zn are shown in figure 16. Found values for all stations are listed in appendix 16. The zinc concentration in the solid phase of the sediments at the shallow and deeper stations are all constant with depth. This indicates non anthropogenic polluted sediments [Nolting and Helder, 1991]. Comparable to Mn, Fe and Cu, total Zn concentrations of the solid phase at station 325 and 351 show an increase with depth in the first few centimeters, followed by a decrease deeper into the sediment. This is caused by turbidites.

Nickel

Concentration-depth profiles of solid phase Ni are shown in figure 17. Found values for all stations are listed in appendix 17. In the shallow and deeper stations the concentrations of nickel in the sediment are constant with depth. Except in stations 311 and 313 the leachable fraction shows a small decrease with depth in the first 1.5 centimeter of the sediment. Two of the deepest stations, 325 and 351, have an increase of the total nickel concentration with depth in the first few centimeters of the sediment, followed by a large decrease in both the leachable and residual fraction at respectively 4 and 7 centimeters depth in the sediment. The same phenomena is found in the Mn, Fe, Cu and Zn profiles and is

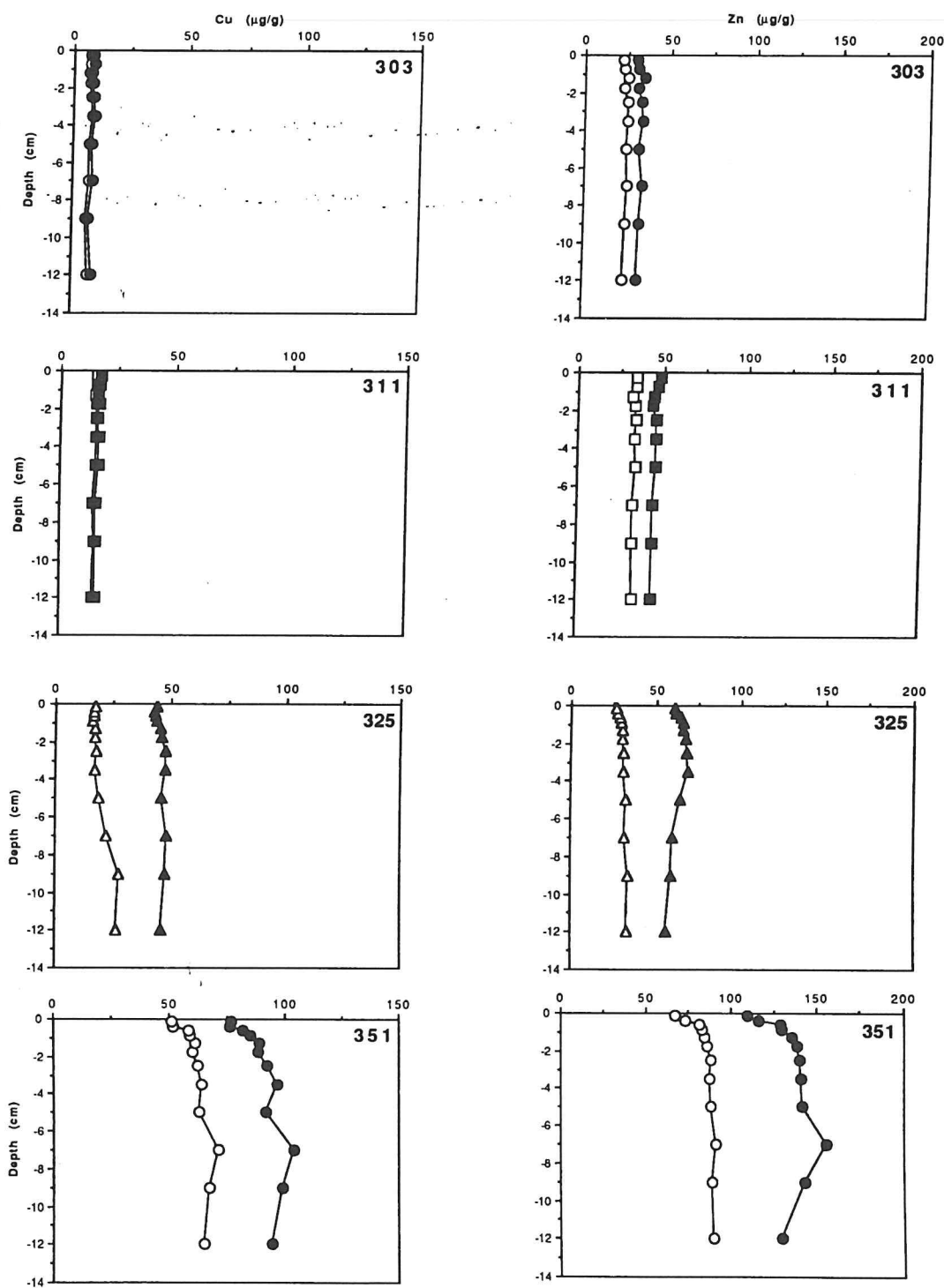


Figure 16: Concentration-depth profiles of residual (open symbols) and total (filled symbols) solid phase Cu and Zn ($\mu\text{g/g}$) at stations 303, 311, 325 and 351.

probably also caused by turbidites, as is explained in the Mn part.

Lead

Concentration-depth profiles of solid phase Pb are shown in figure 17. Found values for all stations are listed in appendix 19. In almost all of the stations the concentrations of Pb in the sediment are constant with depth. Except at stations 311 and 313 where a higher concentration in the first centimeter is found, which can indicate an increase of recent Pb supply and at the stations 325 and 351, where lower total Pb concentrations in the upper layer of the sediment are found, comparable to the concentration-depth profiles of Mn, Fe, Zn and Ni. At station 325, at 4 centimeters depth, also a large decrease in the concentration of the residual fraction is found. Absence of higher lead concentrations in the upper layer of the sediment is an indication that these sediments are not influenced by anthropogenic sources or due to the low sedimentation rates at the deep stations (1-2 cm / 1000 years) not traceable. Anthropogenic influence was found for instance in the N.W. Mediterranean Sea by den Das and Nolting (1993), in the Gulf of Lion by Nolting and Helder (1991), in the north-east Atlantic by Veron et al., (1987) and in the Sargasso Sea and the US Continental shelf by Hamelin et al., (1989).

Chromium

Concentration-depth profiles of solid phase Cr are shown in figure 18. Found values for all stations are listed in appendix 19. Concentration-depth profiles of chromium are in a patchy way constant in the shallow stations. In contrast with the preceding trace metals, the concentration of Cr at station 325 is higher in the first centimeter of the sediment instead of lower. The Cr found in the sediment is almost completely incorporated in the residual fraction, only a small part, less than 10 %, is of the reactive form and shows no difference with water depth.

Cadmium

Concentration-depth profiles of the solid phase for Cd are shown in figure 18. Found values for all stations are listed in appendix 20. Cadmium concentration-depth profiles are rather different for each station. The profiles of stations 301 and 302 are rather constant with depth. The profiles of station 303 and 304 are rather patchy with a decrease with depth of the residual fraction in the first 2 centimeters. The deeper stations (305, 306, 309, 310, 311 and 313) show a constant

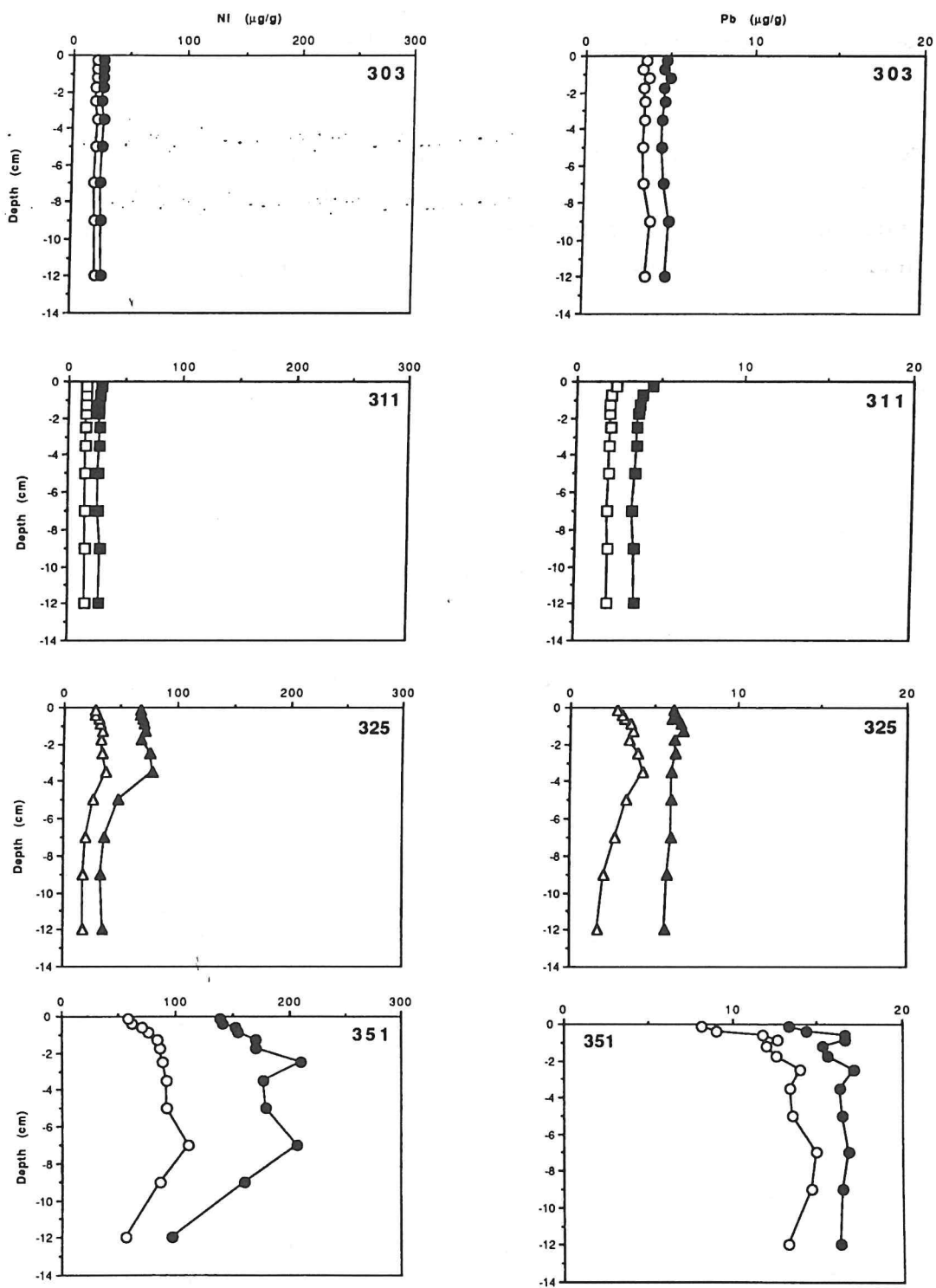


Figure 18: Concentration-depth profiles of residual (open symbols) and total (filled symbols) solid phase Cr and Cd ($\mu\text{g/g}$) at stations 303, 311, 325 and 351.

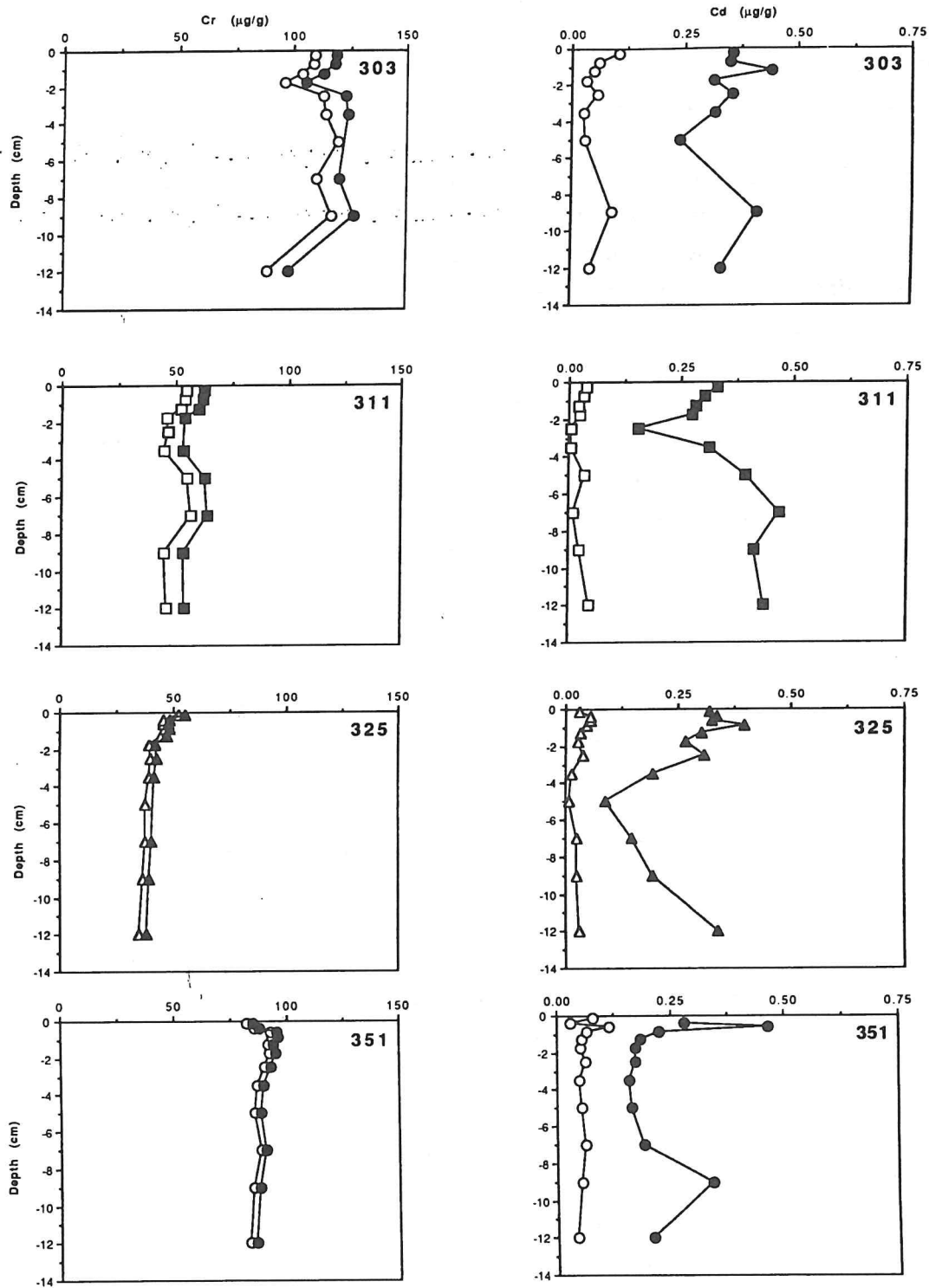


Figure 17: Concentration-depth profiles of residual (open symbols) and total (filled symbols) solid phase Ni and Pb ($\mu\text{g/g}$) at stations 303, 311, 325 and 351.

concentration with depth of the residual fraction and increasing leachable cadmium concentrations deeper in the sediment. This is caused by the release of Cd in the oxygenated layer due to oxidation of organic matter, to which it was probably initially bound, followed by precipitation of Cd in the anoxic layer. This is shown previously by Gobeil et al. (1987) for Laurentian Through sediments. The deepest stations show higher leachable Cd concentrations in the upper layer of the sediment. It is evident that the majority of the cadmium content exists in the exchangeable fraction.

It is clear that vertical profiles of trace metals found at the stations in the upwelling area (301 to 313) near Oman, Yemen and Somalia differ completely from those outside that area (325 to 352) near the equator. Not only in concentration of trace metals, but also in shape of the profiles and thus processes in the sediment. This applies for all mentioned metals.

4.5 Vertical trace metal distribution in porewaters

In this chapter the trace metal concentration of Mn, Fe, Cu, Zn, Ni, Pb and Cd in the porewaters will be discussed. Also the relation between Mn and Fe and nitrate will be discussed (nitrate concentrations for each station are listed in appendix 21). With help of solid phase trace metal depth profiles it is possible to describe processes which take place in the sediment, for instance oxidation of organic matter by reduction. When describing shallow stations, stations 301 to 304, 309 and 310 are meant. Deeper stations are 305, 306, 311 and 313. Deepest stations are 325, 351 and 352. For each group of stations some representative examples for concentration-depth profiles are given. Respectively: 1) 303, 305 and 306, 2) 309, 311 and 313, 3) 325, 351 and 352.

Manganese

Concentration-depth profiles of manganese are shown in figure 19. Found values for all stations are listed in appendix 22. The manganese porewater concentrations of stations 302 to 305, 309 to 311, 351 and 352 are very constant with depth and most probably at these stations the oxidation of organic matter by manganese within the first 14 centimeters of the sediment is minor. Also the concentrations are very low, mostly less than 2 μM , compared to other shelf areas where sediment is reducing, for instance in Laurentian Through sediments

concentrations of 50 to 400 μM are found [Sundby and Silverberg, 1985]. This was also seen in the solid phase, where also low concentrations of Mn were found. Probably due to the high supply of organic matter Mn is extensively used as electron acceptor and so leached from the sediment. However, enough organic matter is present (1 to 3.5 %) to cause reduction of Mn and Fe, no signs of reduction of these elements are found due to the simple fact that there is no more Mn and Fe to be reduced. Also the supply of new Mn and Fe, which is low due to the absence of rivers in this area, accounts for this phenomenon. Transport of Mn from continental margin sediments was observed by Johnson et al. (1992) in the California margin.

At stations 301, 306, 313 and 325 the porewater concentration-depth profiles show evidence for manganese reduction. Found Mn concentrations at station 301 are rather low due to the low Mn content in the solid phase, however at 5 centimeters depth an increase in the dissolved Mn concentration is found. At stations 306 and 313 an increase of dissolved manganese (respectively from 1.2 μM to 2.8 μM and from 1.3 μM to 11 μM) starts immediately under the upper layer of the sediment and levels out at 2 centimeters depth. This increase is caused by reduction of MnO_x due to oxidation of organic matter, where Mn^{2+} dissolves in the porewaters. The increase of the dissolved manganese starts at the same depth where the concentration nitrate decreases, when nitrate is completely used as electron acceptor, Mn takes over, indicated by the increase of dissolved Mn. This trend is also found at station 325. This indicates a high supply of organic matter to the sediment and so an undeeper oxygen penetration. The found porewater profiles are in agreement with the depth profiles of the solid phase Mn, where the leachable fraction showed also an higher concentration in the first centimeter, due to upward diffusion of Mn and subsequent precipitation of MnO_x . After the manganese concentration in station 313 reached a maximum of 11 μM it decreases with depth to values of approximately 7 μM . Probably dissolved manganese is precipitated by sulphides or carbonates, the former are formed due to the oxidation of organic matter by sulphates.

At station 325 the manganese concentration is constant in the first 4 centimeter, deeper in the sediment an increase is found from 1.5 μM to 11 μM . In the solid phase depth profile of this station also an increase of the leachable fraction was found. In contrary with the preceding stations, this increase in the leachable

fraction does not start at approximately the same depth as the increase in the porewater concentration of manganese. This implies an upward moving of the oxygen layer caused by a higher supply of organic matter. Because the less deep penetration of oxygen, MnO_2 is used earlier as electron acceptor. However, the sediment of station 325 was heavily disturbed by turbidites. Manganese diagenesis is extensively described by several authors, for instance: Froelich et al. (1979), Sawlan and Murray (1983), Klinkhammer (1980), Klinkhammer et al. (1982), Sundby et al. (1981) and Heggie et al. (1987).

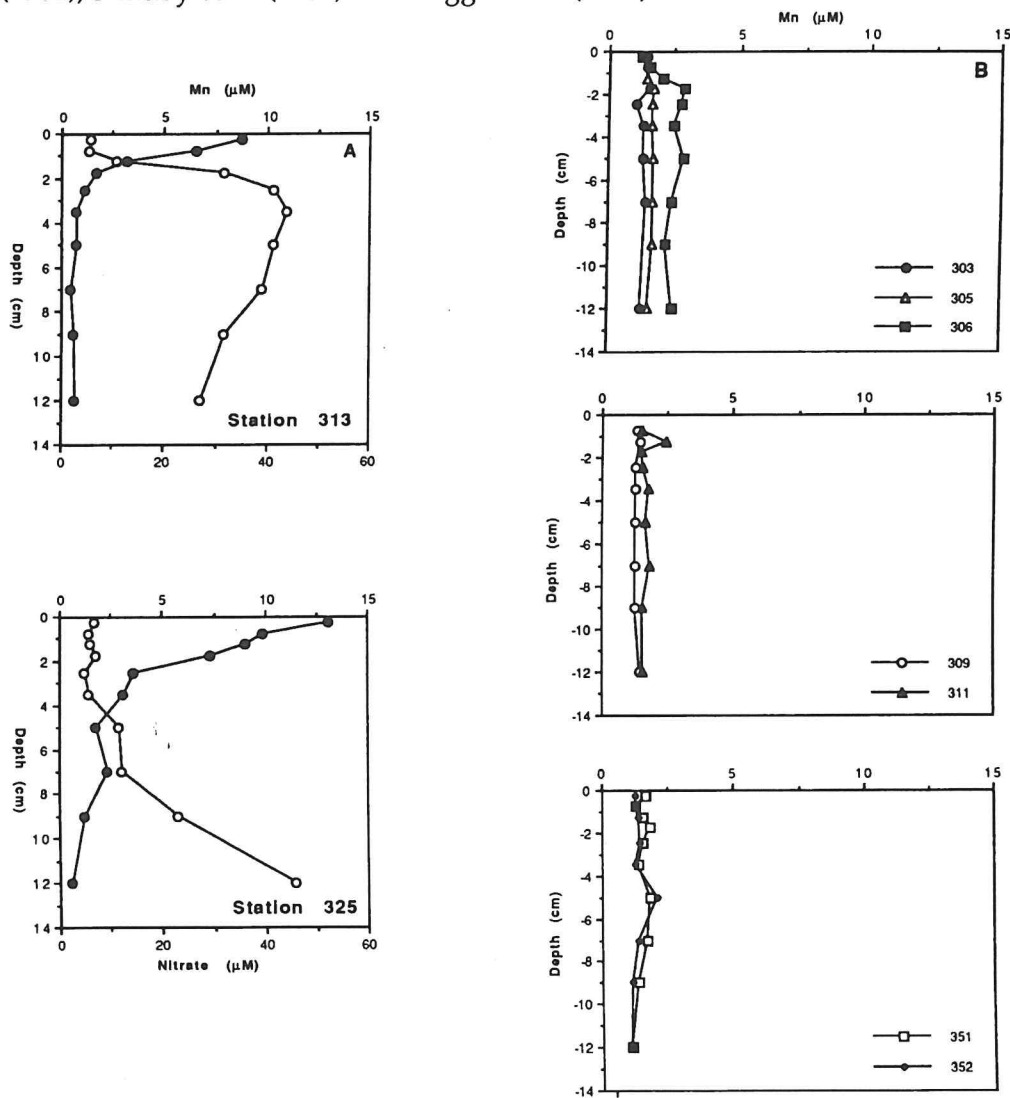


Figure 19: Concentration-depth profiles of Mn (μM) $\circ$ and nitrate (μM) $\bullet$ in porewater at stations 313 and 325 (A) and Mn (μM) at stations 303, 305, 306, 309, 311, 313, 325, 351 and 352 (B.)

Iron

Concentration-depth profiles of Fe are shown in figure 20. Found values for all stations are listed in appendix 23. The porewater Fe concentration increases from shallow to deeper water. However, all concentrations are very low. Iron concentrations in porewater are constant with depth in almost all stations, except in station 352 where a decrease with depth is found, starting at 5 centimeters depth from approximately 16 μM to 10 μM . At stations 311 and 313 also a decrease with depth is found, however not as clear as the one at station 352. This implies that at all stations the use of Fe as electron acceptor for oxidation of organic matter is negligible. The decrease with depth at station 352 is probably caused due to precipitation by sulphides. Fe diagenesis is extensively described by several authors, for example: Sawlan and Murray (1983), Froelich et al. (1979) and Klinkhammer (1980).

Copper

Concentration-depth profiles of Cu are shown in figure 20. Found values for all stations are listed in appendix 24. Generally seen the concentration-depth profiles of Cu are rather patchy and high at the deepest stations. The overall trend, which can be observed, is a higher concentration at the water/sediment interface and a decrease of the Cu concentration deeper in the sediment. This trend is caused by release of copper which was present in the oxidised organic matter and precipitation of Cu on sediment particles deeper in the sediment. This is observed before by several authors, for instance: Klinkhammer (1980), Sawlan and Murray (1983) and Klinkhammer et al. (1982).

Zinc

Concentration-depth profiles of Zn are shown in figure 21. Found values for all stations are listed in appendix 25. In contrast to Mn, Fe and Cu, the Zn concentrations are almost equal in the shallow and deeper stations. Almost all of the concentration-depth profiles of zinc show low concentrations in the upper layer, followed by a sharp increase with depth and further a steadily decrease to approximately the same values as in the upper layer. Probably zinc is also released in the porewaters due to oxidation of organic matter to which it was initially bound, followed by diffusion into the sediment and upwards to the overlying water. This process is described for Cu by, for example, Shaw et al. (1990).

Nickel

Concentration-depth profiles of Ni are shown in figure 21. Found values for all stations are listed in appendix-26. Usually nickel shows the same concentration-depth profiles as manganese [Chester, 1990; Sawlan and Murray, 1983; Shaw et al., 1990 and others]. Which in this case won't fit. The stations which showed evidence for reduction of MnO_2 (301, 306, 313 and 325) have a fairly constant nickel concentration with depth (station 306) or show an one to three fold

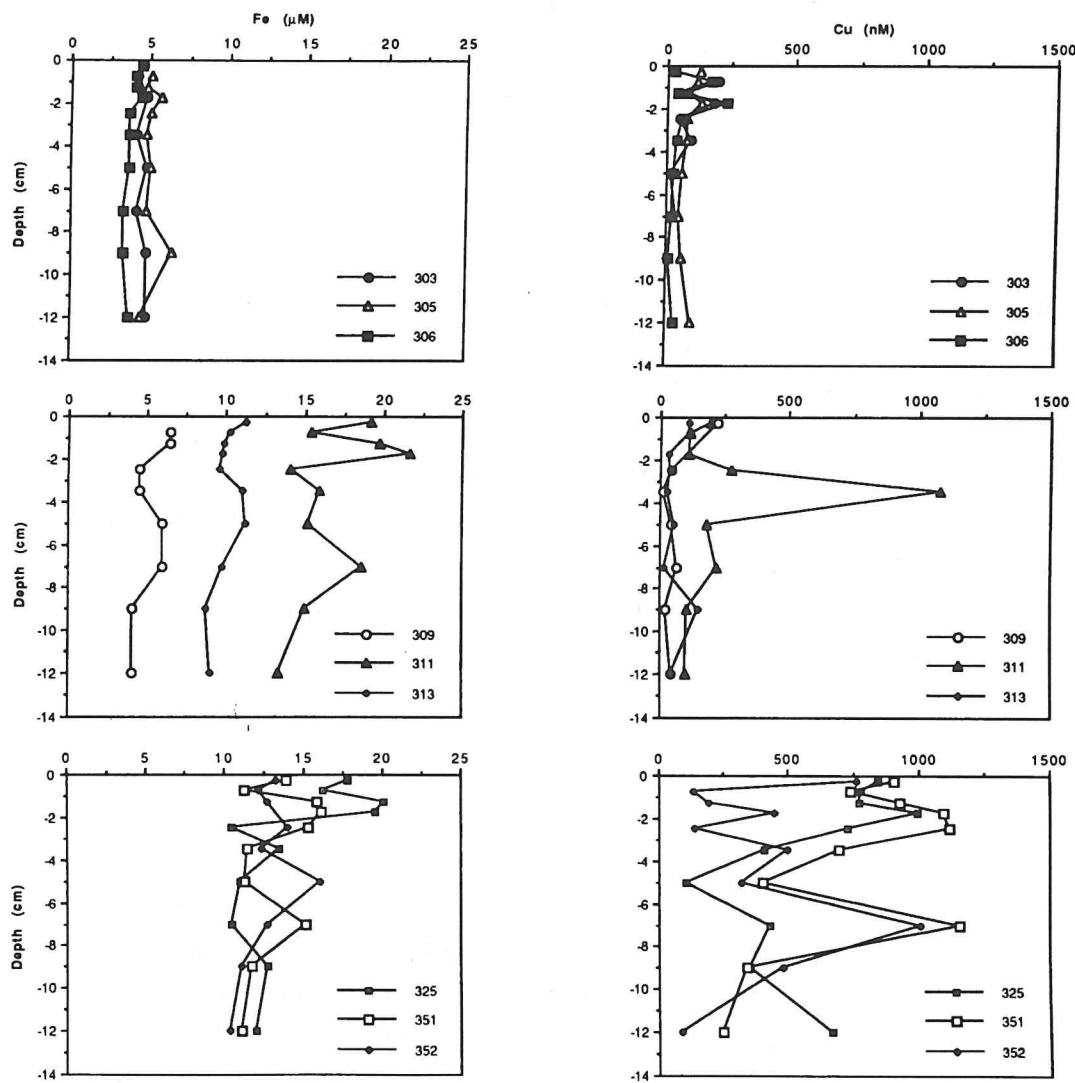


Figure 20: Concentration-depth profiles of Fe (μM) and Cu (nM) in porewater at stations 303, 305, 306, 309, 311, 313, 325, 351 and 352.

enrichment in the first centimeters. This pattern is usually found for copper concentration-depth profiles, when oxidation of organic matter causes dissolution of organic bound copper. This trend is found for the stations 301, 305, 310, 311, 313, 325 and 352.

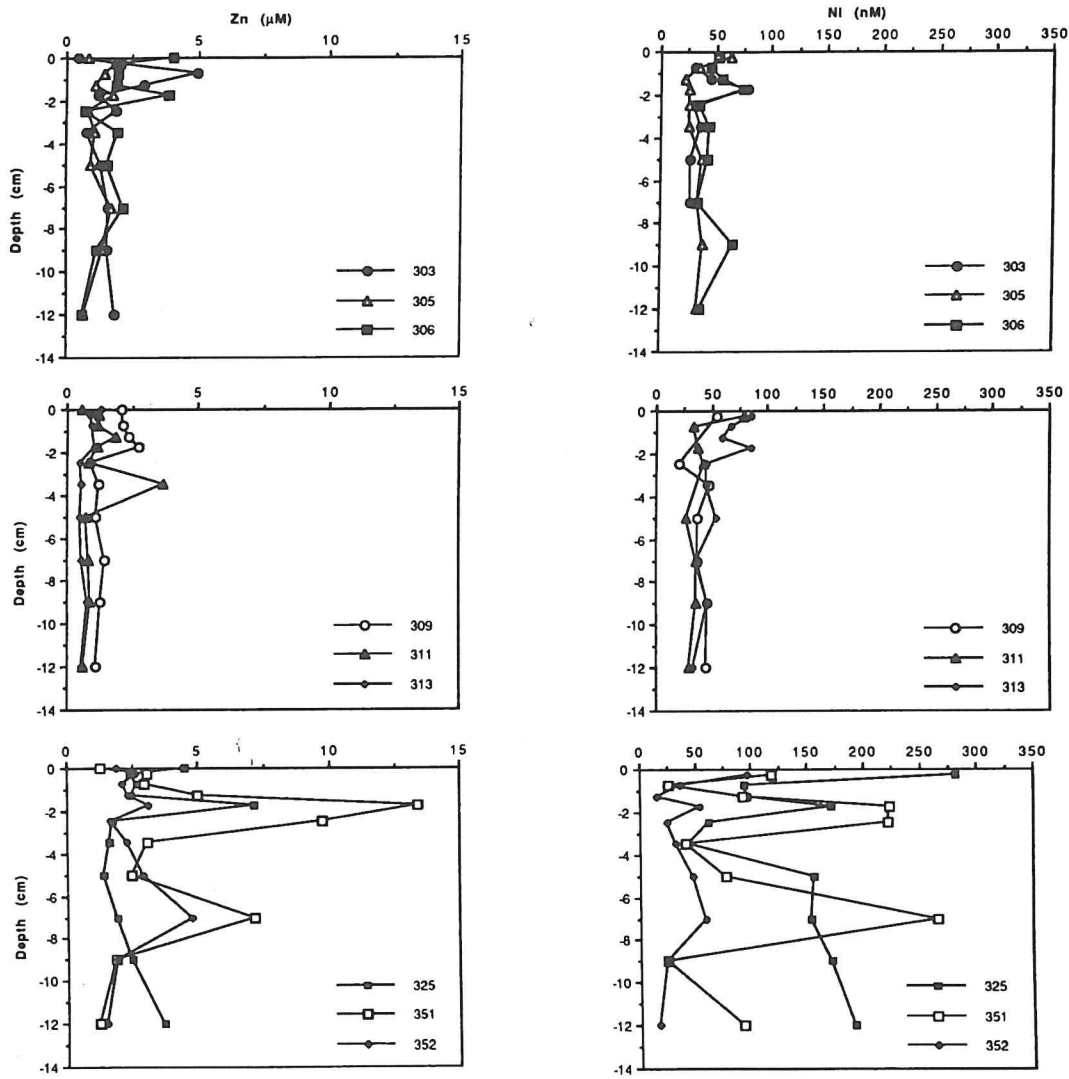


Figure 21: Concentration-depth profiles of Zn (μM) and Ni (nM) in porewater at stations 303, 305, 306, 309, 311, 313, 325, 351 and 352.

Lead

Concentration-depth profiles of Pb are shown in figure 22. Found values for all stations are listed in appendix 27. Found concentration-depth profiles of Pb at the shallow and deeper stations are rather uniform with depth in the shallow stations. Only the profile of station 301 shows a clear trend, with high concentrations in the surface layer (biogenic mineralisation). The deepest stations show a more patchy pattern. Previous research reported also rather patchy profiles, but also consistent patterns among the concentration-depth profiles of

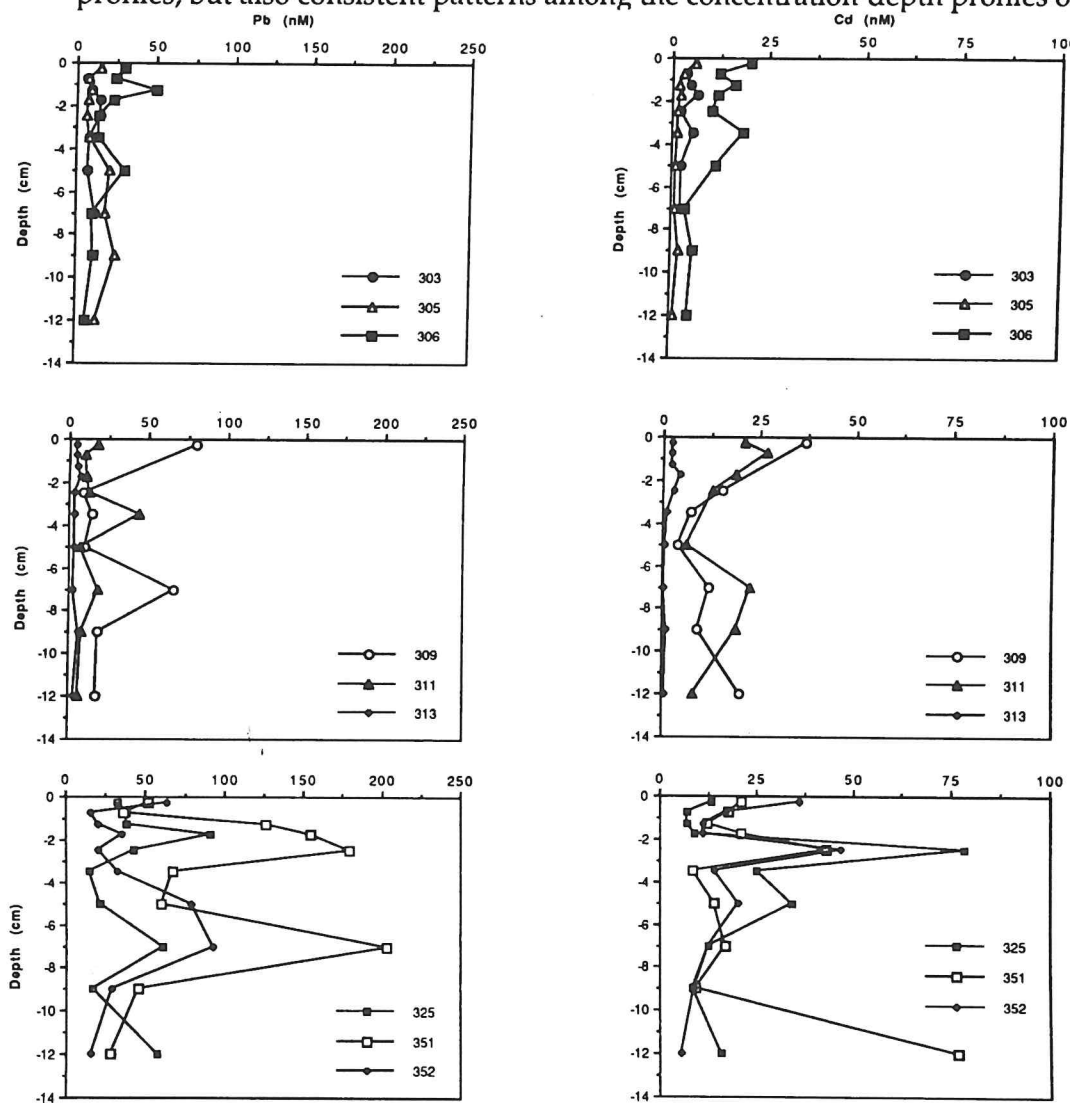


Figure 22: Concentration-depth profiles of Pb and Cd (nM) in porewater at stations 303, 305, 306, 309, 311, 313, 325, 351 and 352.

dissolved Cd and Fe were found [Gobeil and Silverberg, 1989; Nolting and Helder, 1991]. Remarkably is the high Pb concentration at station 351, which is situated beneath the CaCO_3 depth, which can indicate the Pb is released from sediments during dissolution of CaCO_3 .

Cadmium

Concentration-depth profiles of Cd are shown in figure 22. Found values for all stations are listed in appendix 28. Almost all concentration-depth profiles of cadmium show high concentrations in the upper layer of the sediment, followed by a decrease with depth. This trend is probably caused by release of organic bound cadmium, which dissolved due to oxidation of the organic matter, followed by migration upwards to the overlying water and downwards into the sediment [Gobeil et al., 1987; Gobeil and Silverberg, 1989; Wallman, 1992].

All of the interstitial water profiles show that at the shallow continental stations processes regulating the release of trace metals from sediments are less hectic than those at the deepest stations, which one expect would be the reverse.

4.6 Kd-values of trace metals in the sediment

The mobility of trace metals in sediments depend, among others, on the partitioning between the dissolved and the particulate phase. The ratio between the solid ($\mu\text{g/kg}$) and the dissolved phase ($\mu\text{g/L}$) is called the distribution coefficient K_d . The K_d is influenced by several processes: solution, (co-) precipitation, adsorption and biological uptake.

The transport process of Mn from shallow to deeper waters, which is mentioned before, is supported by the K_d values. As can be seen in figure 23, the K_d values for Mn are low in the shallow stations (2000-4000) and increase with increasing water depth (almost 50.000). At the shallow stations relatively more Mn dissolves in the porewaters compared to the deeper stations. This implies a higher mobility of Mn at the shallow stations, which can cause a transport of Mn to the deeper waters where it will precipitate. Calculated K_d values of manganese are in the same order of magnitude as those mentioned by van der Loeff and Waijers (1985) for north-west Atlantic sediments:

-aerobic sediments: 90.000

-suboxic sediment: 110

Thus coastal sediments are more suboxic and deep ocean sediments are oxic.

K_d values of other trace metals show no clear pattern. But Cd and Zn are more mobile than Cu, Pb and Ni. Found values for all stations and all determined trace metals are listed in appendix 29.

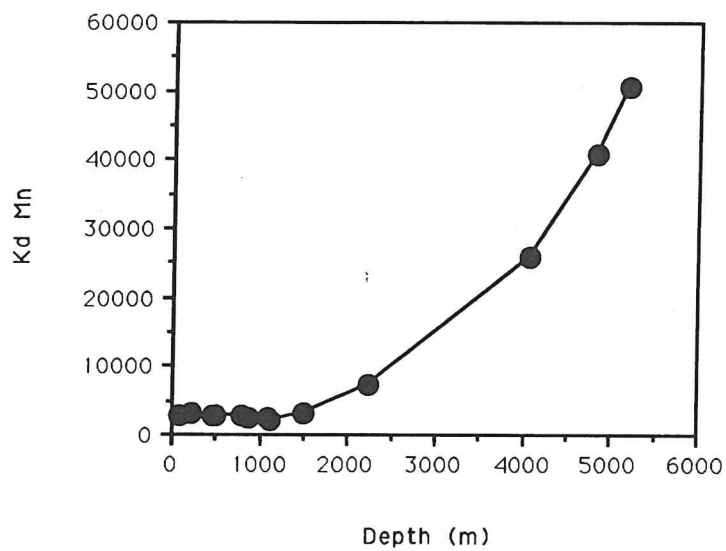


Figure 23: K_d values for Mn plotted against water depth.

CONCLUSIONS

From the obtained results several conclusions can be drawn.

The results for trace metals as well as for major elements are in good agreement with the certified values given for the BCR reference material. With help of Sheward charts a good precision could be obtained during the whole analytical procedure. According to the duplo's, the accuracy proved to be good.

The oxygen concentration of the bottom water increases with water depth, due to the fact that at greater water depth less organic matter reaches the ocean floor.

The stations near the margin between upwelling and open ocean water have the highest organic carbon and nitrogen content. Probably because the highest primary production is found at this margin. The C/N-ratio decreases with increasing water depth. Pelagic formed organic matter has a ratio of approximately 6.2 and terrestrial formed organic matter a ratio of approximately 90, so it can be concluded that the contribution of pelagic formed organic matter increases with increasing water depth.

The horizontal distribution of the major elements are rather uniform with depth at the stations in the upwelling area, but shows a large decrease in the calcium carbonate content at the deeper stations (near the equator) caused by dissolution beneath the calcium carbonate compensation depth.

The horizontal distribution of the trace metals shows, generally seen, two trends:

- 1) The concentration of Mn, Cu, Zn, Ni and Pb increases with increasing water depth.
- 2) The concentration of Cd and Cr decreases with increasing water depth.

Several explanations are given in the literature for this phenomena: difference in grain size, co-precipitation with Mn and Fe and atmospheric transport.

Vertical concentration-depth profiles of the solid phase Mn and those of the porewaters, show Mn redox processes at station 306, 313 and 325. Absence of higher Pb and Zn concentration in the top layer of the sediment can indicate that the sediments are not influenced by anthropogenic sources or at least not traceable. Generally seen the porewater profiles of Mn, Fe, Cu Zn, Ni and Pb do not show great variations with depth and have rather low concentrations at the stations in the upwelling area (near Somalia, Yemen and Oman) and are more patchy with higher concentrations at the deepest stations (near the equator).

K_d values of most of the trace metals do not show a clear trend with water depth. Manganese is an exception and shows increasing K_d values with increasing water depth. This implies a higher mobility of Mn in shallow waters, compared to its mobility at greater water depth. This can cause the higher amount of Mn at the deeper stations and exhaustion of Mn in the shallow sediments due to the lack of freshly supplied Mn by for instance rivers.

Concluding it can be said that sediments in the upwelling area of the northern Indian Ocean show great differences with those more offshore, which means that the upwelling zone has a great impact on the underlying sediment. The huge amount of organic material supplied to the sediment during the upwelling period causes a depletion of oxygen and other electron acceptors. This causes a situation that newly supplied organic matter can not be mineralised completely, resulting in a build up of this material indicated by the high organic carbon content.

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APPENDICES

- 1) Used apparatus for analysis of trace- and major elements in the sediments and porewaters.
- 2) Experimental conditions for Flame AAS analysis of major elements in sediments and porewaters.
- 3) Experimental conditions for the analysis of trace metals in sediments and porewaters.
- 4) Porosity in the sediments of the northern Indian Ocean.
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- 10) Silicium oxide concentrations in sediments of the northern Indian Ocean.
- 11) Aluminium oxide concentrations of the leachable, residual and total fraction and percentage leachable in sediments of the northern Indian Ocean.
- 12) Mean trace metal concentration in the top 2 centimeter of the sediments in the northern Indian Ocean, calculated on a calcium carbonate free basis.

- 13) Manganese concentrations of the leachable, residual and total fraction and percentage leachable in sediments of the northern Indian Ocean.
- 14) Iron concentrations of the leachable, residual and total fraction and percentage leachable in sediments of the northern Indian Ocean.
- 15) Copper concentrations of the leachable, residual and total fraction and percentage leachable in sediments of the northern Indian Ocean.
- 16) Zinc concentrations of the leachable, residual and total fraction and percentage leachable in sediments of the northern Indian Ocean.
- 17) Nickel concentrations of the leachable, residual and total fraction and percentage leachable in sediments of the northern Indian Ocean.
- 18) Lead concentrations of the leachable, residual and total fraction and percentage leachable in sediments of the northern Indian Ocean.
- 19) Chromium concentrations of the leachable, residual and total fraction and percentage leachable in sediments of the northern Indian Ocean.
- 20) Cadmium concentrations of the leachable, residual and total fraction and percentage leachable in sediments of the northern Indian Ocean.
- 21) Nitrate concentration in sediments of the northern Indian Ocean.
- 22) Manganese concentrations in porewaters of all stations in the northern Indian Ocean.
- 23) Iron concentrations in porewaters of all stations in the northern Indian Ocean.
- 24) Copper concentrations in porewaters of all stations in the northern Indian Ocean.

- 25) Zinc concentrations in porewaters of all stations in the northern Indian Ocean.
- 26) Nickel concentrations in porewaters of all stations in the northern Indian Ocean.
- 27) Lead concentrations in porewaters of all stations in the northern Indian Ocean.
- 28) Cadmium concentrations in porewaters of all stations in the northern Indian Ocean.
- 29) Mean K_d values of Cu, Cd, Zn, Ni, Pb, Mn and Fe of the sediments in the northern Indian Ocean.

APPENDIX 1: Used apparatus for analysis of trace-and major elements in sediments and porewaters

Flameless Absorption Spectrophotometry

- (1) * Perkin Elmer 5100 PC Atomic Absorption Spectrophotometer
 * Perkin Elmer HGA-600 graphite furnace
 * Perkin Elmer AS-60 autosampler
 * Zephyr watercooling Unit ZEM 750
 * Epson PC-AX2 Personal computer
 * Epson EX-80 printer

- (2) * Perkin Elmer 5000 Atomic Absorption Spectrophotometer
 * Perkin Elmer HGA-500 graphite furnace
 * Perkin Elmer AS-40 autosampler
 * Zephyr watercooling Unit ZEM 750
 * Perkin Elmer PRS-10 Printer Sequencer
 * Perkin Elmer Recorder 56

Flame Absorption Spectrophotometry

- (1) * Perkin Elmer 2380 Atomic Absorption Spectrophotometer
 * Perkin Elmer PRS-10 Printer Sequencer
 * Perkin Elmer Recorder 56

Lamps

- (1) * Perkin Elmer Hollow Cathode Lamps (HCL) for Cu, Ni, Cr, Zn, Mn, Fe, Mg, Ca, Al and Si
- (2) * Perkin Elmer Electrodeless Discharge Lamp (EDL) for Cd and Pb together with a Perkin Elmer EDL Power Supply

APPENDIX 2: Experimental conditions for Flame AAS analysis of major elements in sediments and porewaters

Element	Wave-length (nm)	Split setting (nm)	Oxidant*
Ca	422.7	0.7	Air
Mg	485.2	0.7	Air
Fe	248.3	0.2	Air
Mn	279.5	0.2	Air
Zn	213.9	0.7	Air
Al	309.3	0.7	N ₂ O [#]
Si	251.6	0.2	N ₂ O

* = The fuel for all analysis was C₂H₂

[#] =Reducing flame

APPENDIX 3: Experimental conditions for the analysis of trace metals in porewaters and sediments

Parameters	Cd	Pb	Cr	Cu	Ni
Wave-length (nm)	228.8	283.8	357.9	324.8	232.0
Split setting (nm)	0.7	0.7	0.7	0.7	0.2
Injection volume (μl)	20	10/20	20	20	10
Measurement type	area	area	area	area	area
Step 1 :Temperature (°C)	180	160	180	180	150
Ramp time (sec)	1	1	1	1	1
Hold time (sec)	40	30	50	40	30
Internal Flow (ml/min)	300	300	300	300	300
Step 2:Temperature (°C)	700	750	1650	1300	1400
Ramp time (sec)	10	10	10	10	10
Hold time (sec)	15	15	10	15	15
Internal Flow (ml/min)	50	50	50	50	50
Step 3:Temperature (°C)	1800	1800	2500	2400	2500
Ramp time (sec)	0	0	0	0	0
Hold time (sec)	5	5	3	5	5
Internal Flow (ml/min)	0	0	0	0	0
Integration time (sec)	5	5	3	5	5
Read delay (sec)	0	0	0	0	0
Baseline offset corr.	-2	-2	-2	-2	-2
Step 4:Temperature (°C)	2300	2500	2600	2500	2600
Ramp time (sec)	1	1	1	1	1
Hold time (sec)	3	3	3	3	3
Internal Flow (ml/min)	300	300	300	300	300

APPENDIX 4: Porosity in the sediments of the northern Indian Ocean.

Depth (cm)	301	302	303	304	305	310	311
-0.45	64.0	67.1	67.2	78.2	75.4	79.4	75.4
-1.35	65.4	69.7	66.2	74.6	78.2	71.2	79.2
-2.25	68.3	71.0	70.4	70.4	86.0	77.8	85.2
-3.15	67.2	66.3	65.3	77.6	70.6	69.4	69.9
-4.05		69.9	69.8	88.6	82.0	75.8	74.4
-4.95	65.0	72.4	66.9		79.0	71.2	49.4
-6.75	67.7	59.2	76.4		75.8	80.6	
-7.65	72.8	59.1	59.9		52.2	69.4	
-8.55	46.0		43.6			76.6	
-9.45						79.4	
-10.35					39.2		

Depth (cm)	313	325	351	352
-0.45	71.8	85.4	80.0	88.2
-1.35		82.2	99.0	91.6
-2.25	82.4	83.0	80.6	83.1
-3.15	91.4	88.6	74.8	86.2
-4.05	82.8	73.6	83.4	82.2
-4.95	83.4	86.4	83.4	97.6
-6.75	39.6	88.8	80.6	87.8
-7.65		73.4	95.6	88.8
-8.55		99.0		67.2
-9.45		35.4	78.2	69.4
-10.35			47.0	

**APPENDIX 5: Bottomwater oxygen concentration (μM) at each station in
the northern Indian Ocean.**

Depth (m)	Oxygen conc. (mM)	Station
75	9.0	301
208	8.0	302
477	9.0	303
784	10.0	304
1124	19.0	305
1504	52.0	309
880	13.0	311
2230	108.0	313
5170	192.0	351
4815	190.0	352

APPENDIX 6: Mean of the carbon and nitrogen content (%) and C/N-ratio in the first 2 centimeter of the sediments in the northern Indian Ocean.

Station	Depth (m)	C (%)	N (%)	C/N
301	75	1.01	0.08	12.43
302	208	1.06	0.12	8.62
303	477	0.98	0.09	10.74
309	485	1.47	0.14	10.46
304	784	1.45	0.14	10.70
310	880	1.96	0.20	9.70
311	1088	2.38	0.26	9.34
305	1124	3.11	0.34	9.25
306	1504	3.53	0.37	9.69
313	2230	2.56	0.30	8.61
325	4069	0.99	0.11	9.19
352	4815	0.80	0.11	7.51
351	5170	1.35	0.20	6.89

APPENDIX 7: Carbon and nitrogen contents (%) and C/N-ratio in sediments of the northern Indian Ocean.

Depth (cm)	301 N	301 C	301 C/N	302 N	302 C	302C/N
-0.25	0.09	1.06	11.82	0.12	0.97	7.90
-0.75	0.08	1.07	13.14	0.12	1.10	8.88
-1.25	0.07	0.87	11.89	0.11	1.05	9.33
-1.75	0.08	1.04	12.85	0.13	1.10	8.38
-2.50	0.08	1.21	15.74	0.10	1.01	9.97
-3.40	0.06	0.71	12.14	0.11	1.01	9.31
-5.00	0.06	1.28	19.88	0.11	1.05	9.69
-7.00	0.06	0.62	10.17	0.11	1.14	9.97
-9.00	0.06	0.66	10.68	0.08	0.88	10.65
-12.00	0.07	0.75	10.91	0.10	1.00	10.51

Depth (cm)	303 N	303 C	303 C/N	304 N	304 C	304 C/N
-0.25	0.09	1.02	10.96	0.16	1.70	10.59
-0.75	0.09	0.95	11.17	0.11	1.36	12.42
-1.25	0.09	0.98	11.01	0.13	1.31	9.78
-1.75	0.10	0.97	9.81	0.14	1.44	10.02
-2.50	0.09	0.97	10.81	0.13	1.45	10.80
-3.40	0.11	1.10	10.18	0.14	1.56	10.95
-5.00	0.09	0.93	10.40	0.14	1.50	11.05
-7.00	0.08	0.84	10.79	0.12	1.32	10.56
-9.00	0.03	0.44	12.96	0.11	1.41	12.94
-12.00	0.07	0.85	11.32	0.11	1.17	10.32

Depth (cm)	305 N	305 C	305 C/N	306 N	306 C	306 C/N
-0.25	0.33	3.21	9.81	0.41	3.96	9.71
-0.75	0.33	3.00	9.00	0.36	3.46	9.65
-1.25	0.34	3.19	9.34	0.34	3.40	9.96
-1.75	0.34	3.03	8.86	0.35	3.31	9.45
-2.50	0.35	3.11	8.95	0.35	3.39	9.70
-3.40	0.35	3.17	9.12	0.36	3.41	9.55
-5.00	0.36	3.15	8.80	0.34	3.25	9.44
-7.00	0.33	3.04	9.15	0.35	3.28	9.46
-9.00	0.33	3.08	9.45	0.33	3.21	9.66
-12.00	0.33	2.98	8.99	0.33	3.15	9.62

Depth (cm)	309 N	309 C	309 C/N	310 N	310 C	310 C/N
-0.25	0.19	1.88	9.74	0.20	1.84	9.17
-0.75	0.14	1.44	10.00	0.20	1.98	9.78
-1.25	0.11	1.25	11.20	0.20	1.95	9.74
-1.75	0.12	1.30	10.88	0.20	2.06	10.09
-2.50	0.15	1.51	10.35	0.18	1.87	10.53
-3.40	0.12	1.38	11.42	0.19	1.94	9.96
-5.00	0.13	1.34	10.37	0.20	2.00	10.04
-7.00	0.11	1.15	10.58	0.18	1.98	10.81
-9.00	0.11	1.16	10.57	0.16	1.62	10.27
-12.00	0.12	1.28	10.49	0.17	1.73	10.40

Depth (cm)	311 N	311 C	311 C/N	313 N	313 C	313 C/N
-0.25	0.28	2.54	9.16	0.31	2.61	8.33
-0.75	0.27	2.48	9.29	0.29	2.55	8.74
-1.25	0.24	2.27	9.52	0.30	2.63	8.77
-1.75	0.24	2.21	9.38	0.28	2.44	8.60
-2.50	0.23	2.29	9.76	0.30	2.68	8.90
-3.40	0.23	2.21	9.67	0.28	2.58	9.18
-5.00	0.21	2.11	9.83	0.29	2.57	8.87
-7.00	0.22	2.11	9.65	0.29	2.61	8.96
-9.00	0.21	2.16	10.11	0.26	2.46	9.29
-12.00	0.20	2.00	9.92	0.25	2.43	9.78

Depth (cm)	325 N	325 C	325 C/N	351 N	351 C	351 C/N
-0.25	0.12	1.04	8.84	0.25	1.73	6.93
-0.75	0.11	0.98	9.11	0.20	1.39	6.90
-1.25	0.10	0.98	9.56	0.17	1.16	6.68
-1.75	0.10	0.95	9.23	0.16	1.10	7.06
-2.50	0.09	0.93	9.98	0.16	1.08	6.92
-3.40	0.09	0.79	9.13	0.15	1.05	6.92
-5.00	0.08	0.82	9.66	0.14	0.95	6.95
-7.00	0.08	0.96	11.41	0.13	0.94	7.00
-9.00	0.08	0.85	10.17	0.13	0.91	6.89
-12.00	0.08	1.16	13.78	0.12	0.88	7.57

Depth (cm)	352 N	352 C	352 C/N
-0.25	0.14	1.01	7.12
-0.75	0.11	0.78	7.42
-1.25	0.10	0.74	7.64
-1.75	0.09	0.68	7.84
-2.50	0.09	0.70	7.43
-3.40	0.09	0.70	7.75
-5.00	0.09	0.67	7.83
-7.00	0.08	0.65	8.34
-9.00	0.06	0.53	8.43
-12.00	0.06	0.46	8.21

APPENDIX 8: Mean concentration (%) of major elements (CaCO_3 , SiO_2 , Al_2O_3 , Fe_2O_3) in the top 2 centimeter of the sediments in the northern Indian Ocean.

Station	Depth (m)	Ca (%)	Si (%)	Al (%)	Fe (%)
301	75	44.4	27.8	5.78	1.95
302	208	45.5	29.5	5.48	1.74
303	477	39.4	32.3	5.85	1.52
309	485	48.8	28.6	4.69	1.32
304	784	49.6	26.7	4.68	1.53
310	880	50.8	26.4	4.56	1.49
311	1088	55.1	22.4	4.48	1.60
305	1124	49.9	20.9	4.31	1.70
306	1504	48.0	20.8	5.25	2.25
313	2230	43.7	23.9	5.58	2.61
325	4069	60.0	16.0	3.60	1.81
352	4815	25.9	36.3	10.71	4.87
351	5170	0.7	48.6	12.82	6.36

APPENDIX 9: Mean trace metal concentrations ($\mu\text{g/g}$) in the top 2 centimeter of the sediments in the northern Indian Ocean, calculated on a calcium carbonate free basis.

Station	Depth (m)	Cu	Cd	Zn	Ni	Pb	Cr	Mn
301	75	16.2	1.05	71.3	64.6	9.33	175.2	434
302	208	17.5	2.05	58.5	58.4	8.27	177.0	421
303	477	13.8	0.60	52.2	44.1	7.89	187.8	378
304	784	22.1	1.44	67.3	67.7	8.17	209.1	375
305	1124	36.2	0.86	105	89.2	7.29	162.5	446
306	1504	49.7	0.81	125	108	8.95	157.6	434
309	485	18.4	0.86	60.3	42.6	7.36	236.3	424
310	880	27.8	0.62	81.5	53.3	7.82	237.6	654
311	1088	37.1	0.66	102	62.1	8.94	132.6	404
313	2230	57.7	0.40	130	109	10.8	73.2	2396
325	4069	114	0.71	170	177	16.2	116.2	5656
351	5170	89.7	0.25	137	167	16.3	97.2	4405
352	4815	195	0.25	153	166	18.3	130.7	3953

APPENDIX 10: Silicium oxide concentration (%) in sediments of the northern Indian Ocean. R = residual fraction.

Depth (cm)	301R	302R	303R	304R	305R	306R	309R
-0.250	26.5	29.7	33.7	28.3	21.4	20.6	28.3
-0.750	28.4	30.0	32.4	27.0	21.1	21.5	28.0
-1.250	28.7	28.7	32.8	25.2	21.2	20.4	29.3
-1.750	27.5	29.4	30.3	26.4	19.9	20.5	28.7
-2.500	28.6	26.5	32.5	24.1	20.4	19.8	30.0
-3.500	28.5	30.1	32.6	24.6	20.2	20.4	27.0
-5.000	28.1	28.6	31.9	24.8	19.5	19.9	28.8
-7.000	28.0	28.9	31.4	24.7	20.1	19.1	29.3
-9.000	26.9	26.2	34.9	25.6	20.7	18.6	28.8
-12.000	27.5	29.5	32.9	25.5	20.3	20.8	29.3

Depth (cm)	310R	311R	313R	325R	351R	352R
-0.250	27.1	23.1	25.1	16.4	50.2	36.2
-0.750	26.5	22.9	25.1	15.6	49.2	37.2
-1.250	26.4	21.9	23.9	16.2	47.2	36.0
-1.750	25.7	21.9	21.4	15.7	47.7	36.0
-2.500	25.4	23.0	23.6	15.5	48.5	35.7
-3.500	24.8	22.0	23.3	15.5	49.0	37.3
-5.000	28.7	22.8	20.3	15.9	47.0	35.1
-7.000	23.9	22.6	22.8	14.0	47.9	35.0
-9.000	24.1	21.3	22.0	13.9	46.4	30.1
-12.000	22.6	20.7	21.6	12.9	46.1	28.4
-0.125				14.9	39.7	
-0.375				14.5	44.1	
-0.625				14.8	48.1	
-0.875				15.2	48.2	

APPENDIX 11: Aluminium oxide concentration of the leachable, residual and total fraction (% as Al₂O₃) and percentage leachable in sediments of the northern Indian Ocean. L = leachable fraction, R = residual fraction, T = total, L' = percentage leachable.

Depth (cm)	301L	301R	301T	301L'	302L	302R	302T	302L'
-0.250	0.21	5.65	5.86	3.6%	0.19	5.50	5.69	3.3%
-0.750	0.21	5.75	5.96	3.5%	0.22	5.35	5.57	3.9%
-1.250	0.21	5.53	5.74	3.7%	0.21	5.02	5.23	4.0%
-1.750	0.20	5.34	5.54	3.6%	0.18	5.24	5.42	3.3%
-2.500	0.19	5.36	5.55	3.4%	0.21	5.05	5.26	4.0%
-3.500	0.18	5.40	5.58	3.2%	0.20	5.19	5.39	3.7%
-5.000	0.18	5.35	5.53	3.3%	0.19	5.18	5.37	3.5%
-7.000	0.16	5.42	5.58	2.9%	0.18	5.31	5.49	3.3%
-9.000	0.19	5.01	5.20	3.7%	0.19	4.81	5.00	3.8%
-12.000	0.21	5.57	5.78	3.6%	0.19	5.29	5.48	3.5%

Depth (cm)	303L	303R	303T	303L'	304L	304R	304T	304L'
-0.250	0.16	5.74	5.90	2.7%	0.16	4.69	4.85	3.3%
-0.750	0.16	5.68	5.84	2.7%	0.13	4.55	4.68	2.8%
-1.250	0.16	5.75	5.91	2.7%	0.16	4.32	4.48	3.6%
-1.750	0.18	5.55	5.73	3.1%	0.15	4.57	4.72	3.2%
-2.500	0.15	5.72	5.87	2.6%	0.16	4.39	4.55	3.5%
-3.500	0.15	5.78	5.93	2.5%	0.15	4.33	4.48	3.3%
-5.000	0.13	5.70	5.83	2.2%	0.16	4.44	4.60	3.5%
-7.000	0.13	5.70	5.83	2.2%	0.13	4.39	4.52	2.9%
-9.000	0.16	6.24	6.40	2.5%	0.13	4.43	4.56	2.9%
-12.000	0.13	5.90	6.03	2.2%	0.13	4.42	4.55	2.9%

Depth (cm)	305L	305R	305T	305L'
-0.250	0.16	3.92	4.08	3.9%
-0.750	0.16	4.21	4.37	3.7%
-1.250	0.16	4.36	4.52	3.5%
-1.750	0.18	4.08	4.26	4.2%
-2.500	0.19	4.32	4.51	4.2%
-3.500	0.18	4.40	4.58	3.9%
-5.000	0.16	4.20	4.36	3.7%
-7.000	0.18	4.27	4.45	4.0%
-9.000	0.16	4.39	4.55	3.5%
-12.000	0.16	4.34	4.50	3.6%

Depth (cm)	309L	309R	309T	309L'	310L	310R	310T	310L'
-0.250	0.15	4.60	4.75	3.2%	0.18	4.31	4.49	4.0%
-0.750	0.15	4.49	4.64	3.2%	0.19	4.48	4.67	4.1%
-1.250	0.18	4.52	4.70	3.8%	0.19	4.42	4.61	4.1%
-1.750	0.15	4.52	4.67	3.2%	0.21	4.24	4.45	4.7%
-2.500	0.15	4.52	4.67	3.2%	0.20	4.31	4.51	4.4%
-3.500	0.15	4.59	4.74	3.2%	0.20	4.40	4.60	4.3%
-5.000	0.12	4.53	4.65	2.6%	0.19	4.30	4.49	4.2%
-7.000	0.13	4.57	4.70	2.8%	0.20	4.25	4.45	4.5%
-9.000	0.13	4.48	4.61	2.8%	0.18	4.28	4.46	4.0%
-12.000	0.10	4.43	4.53	2.2%	0.19	4.17	4.36	4.4%

Depth (cm)	311L	311R	311T	311L'	313L	313R	313T	313L'
-0.250	0.21	4.39	4.60	4.6%	0.30	5.52	5.82	5.2%
-0.750	0.21	4.31	4.52	4.6%	0.30	5.56	5.86	5.1%
-1.250	0.23	4.20	4.43	5.2%	0.29	5.39	5.68	5.1%
-1.750	0.19	4.17	4.36	4.4%	0.24	4.72	4.96	4.8%
-2.500	0.19	4.43	4.62	4.1%	0.31	5.41	5.72	5.4%
-3.500	0.21	4.24	4.45	4.7%	0.29	5.44	5.73	5.1%
-5.000	0.19	4.24	4.43	4.3%	0.28	4.94	5.22	5.4%
-7.000	0.19	4.10	4.29	4.4%	0.28	5.27	5.55	5.0%
-9.000	0.19	4.17	4.36	4.4%	0.27	5.36	5.63	4.8%
-12.000	0.19	4.24	4.43	4.3%	0.26	5.32	5.58	4.7%

Depth (cm)	325L	325R	325T	325L'	351L	351R	351T	351L'
-0.250	0.39	3.19	3.58	10.9%	1.11	11.36	12.47	8.9%
-0.750	0.41	3.20	3.61	11.4%	1.15	12.01	13.16	8.7%
-1.250	0.41	3.22	3.63	11.3%	1.13	11.84	12.97	8.7%
-1.750	0.38	3.20	3.58	10.6%	1.12	11.54	12.66	8.8%
-2.500	0.36	3.18	3.54	10.2%	1.10	11.68	12.78	8.6%
-3.500	0.38	3.19	3.57	10.6%	1.13	11.69	12.82	8.8%
-5.000	0.33	3.16	3.49	9.5%	1.11	11.44	12.55	8.8%
-7.000	0.35	3.03	3.38	10.4%	1.06	11.58	12.64	8.4%
-9.000	0.34	2.83	3.17	10.7%	1.10	11.55	12.65	8.7%
-12.000	0.31	2.68	2.99	10.4%	1.12	11.56	12.68	8.8%
-0.125	0.34	2.95	3.29	10.3%	1.03	8.08	9.11	11.3%
-0.375	0.37	3.01	3.38	10.9%	1.08	9.39	10.47	10.3%
-0.625	0.37	3.10	3.47	10.7%	1.15	11.16	12.31	9.3%
-0.875	0.38	3.18	3.56	10.7%	1.13	10.91	12.04	9.4%

Depth (cm)	352L	352R	352T	352L'
-0.250	1.06	9.41	10.47	10.1%
-0.750	1.26	10.11	11.37	11.1%
-1.250	1.07	9.47	10.54	10.2%
-1.750	1.05	9.40	10.45	10.0%
-2.500	1.06	9.25	10.31	10.3%
-3.500	1.03	9.64	10.67	9.7%
-5.000	1.03	9.21	10.24	10.1%
-7.000	1.00	9.32	10.32	9.7%
-9.000	0.82	7.83	8.65	9.5%
-12.000	0.78	7.26	8.04	9.7%

APPENDIX 12: Calcium carbonate concentrations (%) in sediments of the northern Indian Ocean. L = leachable fraction.

Depth (cm)	301L	302L	303L	304L	305L	306L	309L
-0.250	42.6	43.6	39.1	46.7	8.7	46.8	49.7
-0.750	45.0	45.8	39.8	50.1	49.8	50.3	48.9
-1.250	44.9	46.8	38.0	52.2	49.6	47.6	47.3
-1.750	45.1	45.6	40.9	49.3	51.6	47.5	49.3
-2.500	46.3	44.5	39.4	50.5	49.1	47.1	50.1
-3.500	45.9	45.3	40.5	49.0	51.3	49.7	49.2
-5.000	43.8	45.4	39.4	49.4	50.7	49.3	49.4
-7.000	45.2	44.7	40.4	50.1	51.5	49.7	47.4
-9.000	45.8	46.3	37.8	48.5	50.0	49.3	47.2
-12.000	45.1	44.7	41.4	47.5	51.0	48.3	47.0

Depth (cm)	310L	311L	313L	325L	351L	352L
-0.250	49.8	53.2	42.9	58.5	0.92	25.4
-0.750	50.9	55.5	45.4	61.5	0.64	25.1
-1.250	51.4	56.0	45.1	60.2	0.58	26.0
-1.750	50.9	55.9	41.4	59.8	0.53	27.0
-2.500	51.2	56.4	46.2	61.4	0.50	26.9
-3.500	52.6	56.4	45.7	63.6	0.52	26.9
-5.000	51.0	57.0	42.1	60.4	0.52	26.8
-7.000	50.8	54.8	46.3	62.3	0.54	29.3
-9.000	51.6	56.6	44.6	62.9	0.59	34.6
-12.000	51.9	56.7	45.9	62.7	0.61	40.4
-0.125				60.7	1.15	
-0.375				59.7	0.75	
-0.625				60.1	0.56	
-0.875				59.4	0.56	

APPENDIX 13: Manganese concentrations of the leachable, residual and total fraction in $\mu\text{g/g}$ and percentage leachable of the sediments in the northern Indian Ocean. L = leachable fraction, R = residual fraction, T = total, L' = percentage leachable.

Depth (cm)	301L	301R	301T	301L'	302L	302R	302T	302L'
-0.25	119.3	124.4	243.7	49.0%	105.6	123.3	228.9	46.1%
-0.75	119.5	122.3	241.8	49.4%	113.6	118.1	231.7	49.0%
-1.25	121.2	121.9	243.1	49.9%	110.1	116.7	226.8	48.5%
-1.75	115.9	120.5	236.4	49.0%	113.4	117.8	231.2	49.0%
-2.50	116.3	123.8	240.1	48.4%	103.7	114.8	218.5	47.5%
-3.50	115.8	122.7	238.5	48.6%	104.5	123.5	228.0	45.8%
-5.00	112.0	121.4	233.4	48.0%	99.4	123.8	223.2	44.5%
-7.00	115.9	127.1	243.0	47.7%	102.2	121.9	224.1	45.6%
-9.00	115.3	128.8	244.1	47.2%	95.3	110.8	206.1	46.2%
-12.00	111.2	126.6	237.8	46.8%	97.6	126.6	224.2	43.5%

Depth (cm)	303L	303R	303T	303L'	304L	304R	304T	304L'
-0.25	89.8	135.9	225.6	39.8%	101.0	122.6	223.6	45.2%
-0.75	91.8	135.5	227.3	40.4%	96.9	120.9	217.8	44.5%
-1.25	96.5	141.0	237.5	40.6%	92.3	112.6	204.9	45.1%
-1.75	93.8	130.7	224.5	41.8%	89.9	119.8	209.7	42.9%
-2.50	93.6	137.9	231.5	40.4%	82.2	97.0	179.2	45.9%
-3.50	94.8	140.7	235.5	40.3%	77.7	113.3	191.0	40.7%
-5.00	85.7	137.1	222.8	38.5%	82.3	118.5	200.9	41.0%
-7.00	93.8	130.5	224.3	41.8%	76.7	113.5	190.2	40.3%
-9.00	105.0	146.4	251.4	41.8%	80.8	118.5	199.3	40.5%
-12.00	94.5	141.4	235.9	40.1%	76.6	118.5	195.1	39.3%

Depth (cm)	305L	305R	305T	305L'	306L	306R	306T	306L'
-0.25	105.4	95.2	200.6	52.5%	453.8	105.9	559.7	81.1%
-0.75	92.3	98.0	190.3	48.5%	319.0	107.9	426.9	74.7%
-1.25	81.3	102.9	184.2	44.1%	87.3	104.8	192.1	45.4%
-1.75	80.3	95.7	176.0	45.6%	75.7	105.2	180.9	41.9%
-2.50	82.2	104.6	186.8	44.0%	69.8	104.9	174.7	39.9%
-5.00	81.9	96.7	178.6	45.9%	69.1	106.2	175.3	39.4%
-7.00	82.5	100.6	183.1	45.1%	68.4	1030	1098	6.2%
-9.00	76.6	102.9	179.5	42.7%	70.3	100.9	171.2	41.1%
-12.00	75.8	101.8	177.6	42.7%	67.8	108.6	176.4	38.4%

Depth (cm)	309L	309R	309T	309L'	310L	310R	310T	310L'
-0.25	104.5	99.9	204.4	51.1%	119.1	101.1	220.2	54.1%
-0.75	113.7	97.4	211.1	53.9%	118.0	105.9	223.9	52.7%
-1.25	109.9	97.3	207.2	53.0%	115.6	104.4	220.0	52.5%
-1.75	110.7	94.9	205.6	53.8%	111.0	102.8	213.8	51.9%
-2.50	107.3	103.5	210.8	50.9%	113.4	100.2	213.6	53.1%
-3.50	105.2	101.5	206.7	50.9%	109.5	99.8	209.3	52.3%
-5.00	109.2	100.2	209.4	52.1%	112.7	98.2	210.9	53.4%
-7.00	110.1	100.1	210.2	52.4%	107.3	93.0	200.3	53.6%
-9.00	107.9	99.7	207.6	52.0%	110.8	96.9	207.7	53.3%
-12.00	109.4	104.6	214.0	51.1%	109.4	96.8	206.2	53.1%

Depth (cm)	311L	311R	311T	311L'	313L	313R	313T	313L'
-0.25	226.4	98.1	324.5	69.8%	1493	724.0	2217	67.3%
-0.75	137.4	98.9	236.3	58.1%	1536	739.0	2275	67.5%
-1.25	103.7	98.1	201.8	51.4%	494.6	131.0	625.6	79.1%
-1.75	100.3	94.8	195.1	51.4%	176.1	102.0	278.1	63.3%
-2.50	97.4	98.3	195.7	49.8%	84.9	117.0	201.9	42.0%
-3.50	96.6	95.6	192.2	50.3%	87.1	110.0	197.1	44.2%
-5.00	95.6	93.8	189.4	50.5%	66.7	105.0	171.7	38.9%
-7.00	93.9	90.5	184.4	50.9%	59.8	117.0	176.8	33.8%
-9.00	94.9	86.7	181.6	52.3%	62.0	112.0	174.0	35.6%
-12.00	94.7	90.6	185.3	51.1%	68.9	99.5	168.4	40.9%

Depth (cm)	325L	325R	325T	325L'	351L	351R	351T	351L'
-0.25	934.2	1193	2127	43.9%	1666	2267	3933	42.4%
-0.75	951.8	1353	2305	41.3%	1490	2992	4482	33.2%
-1.25	886.3	1416	2302	38.5%	1298	3141	4439	29.2%
-1.75	918.1	1398	2316	39.6%	1238	3411	4649	26.6%
-2.50	1022	1639	2661	38.4%	1226	3462	4688	26.2%
-3.50	1133	2209	3342	33.9%	1251	3710	4961	25.2%
-5.00	958.5	1016	1974	48.5%	1222	3733	4955	24.7%
-7.00	499.2	438.7	937.9	53.2%	1215	4915	6130	19.8%
-9.00	191.4	92.1	283.5	67.5%	1362	4778	6140	22.2%
-12.00	102.7	83.4	186.1	55.2%	1267	2912	4179	30.3%
-0.125	1034	1220	2254	45.9%	1565	1660	3225	48.5%
-0.375	1098	1078	2176	50.5%	1537	1985	3522	43.6%
-0.625	1069	952.4	2021	52.9%	1528	2318	3846	39.7%
-0.875	1048	909.4	1957	53.5%	1373	2615	3988	34.4%

Depth (cm)	352L	352R	352T	352L'
-0.25	974.0	1819	2793	34.9%
-0.75	870.1	2180	3050	28.5%
-1.25	763.3	2188	2951	25.9%
-1.75	746.7	2175	2922	25.6%
-2.50	749.6	2170	2920	25.7%
-3.50	765.5	2210	2976	25.7%
-5.00	755.7	2085	2841	26.6%
-7.00	711.1	2153	2864	24.8%
-9.00	617.4	1984	2601	23.7%
-12.00	605.7	2191	2797	21.7%

APPENDIX 14: Iron concentrations of the leachable, residual and total fraction (% as Fe₂O₃) and percentage leachable in sediments of the northern Indian Ocean. L = leachable fraction, R = residual fraction, T = total, L' = percentage leachable.

Depth (cm)	301L	301R	301T	301L'	302L	302R	302T	302L'
-0.250	0.034	1.75	1.78	1.9%	0.259	1.48	1.73	14.9%
-0.750	0.303	1.72	2.02	15.0%	0.241	1.52	1.76	13.7%
-1.250	0.344	1.70	2.04	16.8%	0.228	1.46	1.69	13.5%
-1.750	0.329	1.64	1.97	16.7%	0.217	1.54	1.76	12.3%
-2.500	0.290	1.75	2.04	14.2%	0.233	1.38	1.61	14.4%
-3.500	0.286	1.74	2.03	14.1%	0.221	1.54	1.76	12.5%
-5.000	0.274	1.75	2.02	13.5%	0.217	1.53	1.75	12.4%
-7.000	0.244	1.78	2.02	12.1%	0.206	1.54	1.74	11.8%
-9.000	0.242	1.72	1.96	12.3%	0.221	1.47	1.69	13.1%
-12.000	0.259	1.79	2.05	12.7%	0.210	1.54	1.75	12.0%

Depth (cm)	303L	303R	303T	303L'	304L	304R	304T	304L'
-0.250	0.184	1.35	1.53	12.0%	0.191	1.38	1.57	12.2%
-0.750	0.170	1.33	1.50	11.4%	0.191	1.36	1.55	12.3%
-1.250	0.152	1.39	1.54	9.9%	0.181	1.30	1.48	12.2%
-1.750	0.169	1.32	1.49	11.4%	0.158	1.34	1.50	10.6%
-2.500	0.154	1.36	1.52	10.2%	0.139	1.30	1.44	9.7%
-3.500	0.150	1.38	1.53	9.8%	0.137	1.27	1.41	9.7%
-5.000	0.128	1.33	1.45	8.8%	0.138	1.28	1.42	9.7%
-7.000	0.129	1.37	1.50	8.6%	0.126	1.23	1.35	9.3%
-9.000	0.139	1.46	1.60	8.7%	0.122	1.22	1.34	9.1%
-12.000	0.132	1.36	1.49	8.8%	0.125	1.20	1.32	9.5%

Depth (cm)	305L	305R	305T	305L'	306L	306R	306T	306L'
-0.250	0.188	1.46	1.65	11.4%	0.223	1.97	2.19	10.2%
-0.750	0.198	1.57	1.76	11.2%	0.267	2.08	2.35	11.4%
-1.250	0.152	1.58	1.73	8.8%	0.222	2.02	2.24	9.9%
-1.750	0.153	1.50	1.66	9.2%	0.183	2.03	2.21	8.3%
-2.500	0.145	1.58	1.72	8.4%	0.154	1.96	2.12	7.3%
-3.500	0.140	1.57	1.71	8.2%	0.155	1.94	2.10	7.4%
-5.000	0.148	1.49	1.63	9.1%	0.140	1.90	2.04	6.9%
-7.000	0.143	1.58	1.72	8.3%	0.136	1.88	2.02	6.7%
-9.000	0.138	1.58	1.72	8.0%	0.145	1.81	1.95	7.4%
-12.000	0.134	1.55	1.68	8.0%	0.134	1.90	2.04	6.6%

Depth (cm)	309L	309R	309T	309L'	310L	310R	310T	310L'
-0.250	0.225	1.19	1.41	15.9%	0.233	1.27	1.50	15.5%
-0.750	0.190	1.12	1.31	14.5%	0.232	1.27	1.50	15.4%
-1.250	0.169	1.11	1.27	13.3%	0.206	1.31	1.52	13.6%
-1.750	0.162	1.11	1.27	12.8%	0.176	1.27	1.45	12.1%
-2.500	0.140	1.16	1.30	10.8%	0.157	1.24	1.40	11.2%
-3.500	0.150	1.07	1.22	12.3%	0.138	1.26	1.40	9.9%
-5.000	0.142	1.09	1.24	11.5%	0.141	1.18	1.32	10.7%
-7.000	0.146	1.08	1.23	11.9%	0.141	1.17	1.32	10.7%
-9.000	0.145	1.10	1.25	11.6%	0.129	1.22	1.35	9.6%
-12.000	0.133	1.10	1.23	10.8%	0.132	1.16	1.29	10.2%

Depth (cm)	311L	311R	311T	311L'	313L	313R	313T	313L'
-0.250	0.194	1.43	1.62	11.9%	0.232	2.50	2.73	8.5%
-0.750	0.225	1.41	1.63	13.8%	0.247	2.44	2.69	9.2%
-1.250	0.226	1.36	1.59	14.2%	0.303	2.35	2.66	11.4%
-1.750	0.211	1.33	1.54	13.7%	0.233	2.14	2.37	9.8%
-2.500	0.160	1.34	1.50	10.6%	0.195	2.34	2.54	7.7%
-3.500	0.152	1.34	1.49	10.2%	0.171	2.25	2.42	7.1%
-5.000	0.131	1.32	1.45	9.0%	0.145	2.07	2.21	6.6%
-7.000	0.147	1.31	1.46	10.1%	0.143	2.20	2.34	6.1%
-9.000	0.130	1.28	1.41	9.2%	0.148	2.16	2.31	6.4%
-12.000	0.123	1.30	1.42	8.6%	0.158	2.22	2.38	6.6%

Depth (cm)	325L	325R	325T	325L'	351L	351R	351T	351L'
-0.250	0.144	1.61	1.75	8.2%	0.459	5.79	6.24	7.4%
-0.750	0.144	1.67	1.81	7.9%	0.466	5.99	6.45	7.2%
-1.250	0.135	1.74	1.87	7.2%	0.432	5.96	6.39	6.8%
-1.750	0.139	1.68	1.82	7.6%	0.438	6.20	6.64	6.6%
-3.500	0.122	1.74	1.86	6.5%	0.447	6.44	6.88	6.5%
-5.000	0.123	1.69	1.81	6.8%	0.440	6.59	7.03	6.3%
-7.000	0.141	1.59	1.73	8.1%	0.403	6.31	6.72	6.0%
-9.000	0.166	1.64	1.81	9.2%	0.414	6.00	6.41	6.5%
-12.000	0.114	1.54	1.65	6.9%	0.428	5.85	6.27	6.8%
-0.125	0.137	1.49	1.63	8.4%	0.417	4.71	5.13	8.1%
-0.375	0.138	1.53	1.67	8.3%	0.443	5.30	5.74	7.7%
-0.625	0.139	1.59	1.73	8.0%	0.435	5.62	6.06	7.2%
-0.875	0.135	1.68	1.81	7.4%	0.426	5.77	6.20	6.9%

Depth (cm)	352L	352R	352T	352L'
-0.250	0.388	4.43	4.81	8.1%
-0.750	0.388	4.65	5.03	7.7%
-1.250	0.367	4.42	4.79	7.7%
-1.750	0.367	4.47	4.84	7.6%
-2.500	0.380	4.31	4.69	8.1%
-3.500	0.368	4.53	4.90	7.5%
-5.000	0.379	4.35	4.73	8.0%
-7.000	0.348	4.27	4.62	7.5%
-9.000	0.296	3.68	3.98	7.4%
-12.000	0.277	3.50	3.78	7.3%

APPENDIX 15: Copper concentrations in the leachable, residual, total fraction in $\mu\text{g/g}$ and percentage leachable in sediments of the northern Indian Ocean. L = leachable fraction, R = residual fraction, T = total, L' = percentage leachable.

Depth (cm)	301L	301R	301T	301L'	302L	302R	302T	302L'
-0.250	2.00	7.41	9.41	21.3%	2.10	7.66	9.76	21.5%
-0.750	1.93	7.37	9.30	20.8%	1.95	7.48	9.43	20.7%
-1.250	1.36	7.09	8.45	16.1%	1.66	7.60	9.26	17.9%
-1.750	2.00	6.85	8.85	22.6%	1.54	8.18	9.72	15.8%
-2.500	1.34	7.32	8.66	15.5%	1.70	7.32	9.02	18.8%
-3.500	1.50	7.10	8.60	17.4%	1.52	8.22	9.74	15.6%
-5.000	1.45	6.55	8.00	18.1%	1.47	8.11	9.58	15.3%
-7.000	1.53	6.88	8.41	18.2%	1.54	7.30	8.84	17.4%
-9.000	1.64	6.62	8.26	19.9%	1.52	7.53	9.05	16.8%
-12.000	1.52	6.90	8.42	18.1%	1.39	7.45	8.84	15.7%

Depth (cm)	303L	303R	303T	303L'	304L	304R	304T	304L'
-0.250	1.40	7.07	8.47	16.5%	1.38	10.04	11.42	12.1%
-0.750	1.30	7.31	8.61	15.1%	1.27	9.86	11.13	11.4%
-1.250	1.23	6.70	7.93	15.5%	1.11	9.73	10.84	10.2%
-1.750	1.03	7.30	8.33	12.4%	1.09	10.20	11.29	9.7%
-2.500	1.05	7.55	8.60	12.2%	1.03	9.90	10.93	9.4%
-3.500	1.10	8.23	9.33	11.8%	0.96	10.38	11.34	8.5%
-5.000	1.01	7.13	8.14	12.4%	1.34	10.19	11.53	11.6%
-7.000	1.12	7.46	8.58	13.1%	1.20	9.72	10.92	11.0%
-9.000	1.19	6.24	7.43	16.0%	1.01	9.24	10.25	9.9%
-12.000	1.67	7.07	8.74	19.1%	1.00	9.37	10.37	9.6%

Depth (cm)	305L	305R	305T	305L'	306L	306R	306T	306L'
-0.250	1.65	16.04	17.69	9.3%	4.33	21.21	25.54	17.0%
-0.750	1.29	17.01	18.30	7.0%	4.18	21.73	25.91	16.1%
-1.250	1.22	17.16	18.38	6.6%	3.16	22.78	25.94	12.2%
-1.750	1.46	16.72	18.18	8.0%	3.19	22.64	25.83	12.3%
-2.500	1.58	17.26	18.84	8.4%	3.66	22.39	26.05	14.0%
-3.500	1.75	17.48	19.23	9.1%	4.25	22.42	26.67	15.9%
-5.000	1.63	16.55	18.18	9.0%	4.61	22.59	27.20	16.9%
-7.000	1.75	17.01	18.76	9.3%	4.22	22.11	26.33	16.0%
-9.000	1.88	16.95	18.83	10.0%	5.04	21.22	26.26	19.2%
-12.000	1.95	16.84	18.79	10.4%	4.78	21.08	25.86	18.5%

Depth (cm)	309L	309R	309T	309L'	310L	310R	310T	310L'
-0.250	1.19	8.57	9.76	12.2%	1.36	12.37	13.73	9.9%
-0.750	1.19	8.02	9.21	12.9%	0.99	12.50	13.49	7.3%
-1.250	1.19	7.98	9.17	13.0%	0.90	12.85	13.75	6.5%
-1.750	1.34	8.12	9.46	14.2%	0.87	12.85	13.72	6.3%
-2.500	1.32	8.19	9.51	13.9%	1.03	12.20	13.23	7.8%
-3.500	1.18	8.21	9.39	12.6%	0.98	12.62	13.60	7.2%
-5.000	1.38	8.28	9.66	14.3%	1.04	12.27	13.31	7.8%
-7.000	1.20	7.91	9.11	13.2%	1.10	12.57	13.67	8.0%
-9.000	1.19	7.84	9.03	13.2%	1.16	11.96	13.12	8.8%
-12.000	1.14	7.57	8.71	13.1%	1.08	12.34	13.42	8.0%

Depth (cm)	311L	311R	311T	311L'	313L	313R	313T	313L'
-0.250	1.64	15.39	17.03	9.6%	10.17	23.14	33.31	30.5%
-0.750	1.28	15.45	16.73	7.7%	10.00	23.92	33.92	29.5%
-1.250	1.24	15.13	16.37	7.6%	7.30	25.64	32.94	22.2%
-1.750	0.84	15.60	16.44	5.1%	6.55	23.15	29.70	22.1%
-2.500	0.84	15.36	16.20	5.2%	7.88	25.64	33.52	23.5%
-3.500	0.87	15.82	16.69	5.2%	8.71	25.42	34.13	25.5%
-5.000	1.07	15.35	16.42	6.5%	8.78	22.93	31.71	27.7%
-7.000	1.10	14.40	15.50	7.1%	9.12	24.54	33.66	27.1%
-9.000	1.02	14.76	15.78	6.5%	10.09	23.75	33.84	29.8%
-12.000	1.08	14.66	15.74	6.9%	10.20	23.67	33.87	30.1%

Depth (cm)	325L	325R	325T	325L'	351L	351R	351T	351L'
-0.250	25.78	17.57	43.35	59.5%	26.20	62.38	88.58	29.6%
-0.750	29.28	17.39	46.67	62.7%	28.13	62.67	90.80	31.0%
-1.250	28.42	17.26	45.68	62.2%	27.50	61.26	88.76	31.0%
-1.750	28.88	17.49	46.37	62.3%	28.24	59.99	88.23	32.0%
-2.500	29.83	17.68	47.51	62.8%	30.00	61.96	91.96	32.6%
-3.500	30.72	17.08	47.80	64.3%	33.05	63.73	96.78	34.1%
-5.000	26.98	19.02	46.00	58.7%	28.48	63.02	91.60	31.1%
-7.000	26.09	22.37	48.46	53.8%	32.47	71.28	103.8	31.3%
-9.000	19.63	28.04	47.67	41.2%	31.57	67.41	98.98	31.9%
-12.000	19.35	26.67	46.02	42.0%	29.63	64.73	94.36	31.4%
-0.125	26.59	17.10	43.69	60.9%	25.98	50.87	76.85	33.8%
-0.375	26.26	16.57	42.83	61.3%	24.26	51.73	75.99	31.9%
-0.625	26.55	16.77	43.32	61.3%	23.46	58.40	81.86	28.7%
-0.875	28.06	15.91	43.97	63.8%	26.22	58.80	85.02	30.8%

Depth (cm)	352L	352R	352T	352L'
-0.250	80.67	59.37	140.0	57.6%
-0.750	88.77	61.42	150.2	59.1%
-1.250	89.89	55.28	145.2	61.9%
-1.750	89.68	53.95	143.6	62.4%
-2.500	89.59	55.94	145.5	61.6%
-3.500	90.99	55.21	146.2	62.2%
-5.000	87.34	51.62	139.0	62.9%
-7.000	88.23	50.22	138.4	63.7%
-9.000	81.91	42.52	124.4	65.8%
-12.000	78.90	39.18	118.1	66.8%

APPENDIX 16: Zinc concentrations of the leachable, residual, total fractions in $\mu\text{g/g}$ and percentage leachable in sediments of the northern Indian Ocean. L = leachable fraction, R = residual fraction, T = total, L' = percentage leachable.

Depth (cm)	301L	301R	301T	301L'	302L	302R	302T	302L'
-0.250	12.6	28.3	40.9	30.8%	9.46	22.6	32.1	29.5%
-0.750	12.2	27.3	39.5	30.9%	8.86	22.2	31.1	28.5%
-1.250	12.1	27.2	39.3	30.8%	8.59	22.8	31.4	27.4%
-1.750	12.4	26.5	38.9	31.9%	9.38	23.7	33.1	28.4%
-2.500	13.4	27.9	41.3	32.4%	9.49	22.0	31.5	30.1%
-3.500	12.9	28.1	41.0	31.5%	8.99	24.0	33.0	27.3%
-5.000	13.8	26.7	40.5	34.1%	9.50	24.0	33.5	28.4%
-7.000	13.8	29.3	43.1	32.0%	9.35	25.0	34.3	27.2%
-9.000	14.0	27.6	41.6	33.7%	9.53	24.1	33.6	28.3%
-12.000	13.7	29.8	43.5	31.5%	9.54	24.8	34.3	27.8%

Depth (cm)	303L	303R	303T	303L'	304L	304R	304T	304L'
-0.250	8.14	22.3	30.4	26.7%	8.71	26.0	34.7	25.1%
-0.750	8.12	22.9	31.0	26.2%	7.88	24.9	32.8	24.0%
-1.250	9.31	25.1	34.4	27.1%	7.95	25.2	33.1	24.0%
-1.750	7.70	23.0	30.7	25.1%	8.19	27.0	35.2	23.3%
-2.500	7.87	24.9	32.8	24.0%	8.02	26.1	34.1	23.5%
-3.500	8.47	25.3	33.8	25.1%	7.84	26.2	34.0	23.0%
-5.000	7.49	23.9	31.4	23.9%	9.47	26.8	36.3	26.1%
-7.000	8.79	24.9	33.7	26.1%	8.73	26.1	34.8	25.1%
-9.000	8.23	23.9	32.1	25.6%	8.58	24.9	33.5	25.6%
-12.000	7.95	23.8	31.8	25.0%	9.11	26.4	35.5	25.7%

Depth (cm)	305L	305R	305T	305L'	306L	306R	306T	306L'
-0.250	15.1	36.6	51.7	29.2%	20.0	42.9	62.9	31.8%
-0.750	13.1	40.7	53.8	24.3%	20.2	45.2	65.4	30.9%
-1.250	12.8	40.5	53.3	24.0%	18.0	46.1	64.1	28.1%
-1.750	12.2	39.9	52.1	23.4%	19.0	47.3	66.3	28.7%
-2.500	13.6	41.5	55.1	24.7%	19.0	48.7	67.7	28.1%
-3.500	13.9	42.1	56.0	24.8%	19.5	47.5	67.0	29.1%
-5.000	14.3	38.8	53.1	26.9%	20.7	49.1	69.8	29.7%
-7.000	13.2	40.3	53.5	24.7%	19.9	47.4	67.3	29.6%
-9.000	13.3	39.7	53.0	25.1%	24.7	46.5	71.2	34.7%
-12.000	13.8	40.5	54.3	25.4%	22.4	72.2	94.6	23.7%

Depth (cm)	309L	309R	309T	309L'	310L	310R	310T	310L'
-0.250	9.5	22.1	31.6	30.0%	10.7	27.8	38.5	27.8%
-0.750	8.8	20.7	29.5	29.8%	12.4	28.4	40.8	30.4%
-1.250	9.5	21.4	30.9	30.7%	11.1	29.4	40.5	27.4%
-1.750	9.9	21.5	31.4	31.6%	11.3	29.5	40.8	27.7%
-2.500	9.1	22.5	31.6	28.8%	11.1	28.2	39.3	28.2%
-3.500	9.4	20.5	29.9	31.4%	11.0	29.3	40.3	27.3%
-5.000	10.0	22.2	32.2	31.0%	11.0	31.2	42.2	26.1%
-7.000	8.8	22.1	30.9	28.5%	11.5	28.8	40.3	28.5%
-9.000	9.5	21.3	30.8	30.8%	11.0	27.9	38.9	28.3%
-12.000	9.4	22.6	32.0	29.4%	10.8	29.4	40.2	26.9%

Depth (cm)	311L	311R	311T	311L'	313L	313R	313T	313L'
-0.250	13.5	34.4	47.9	28.2%	31.8	45.2	77.0	41.3%
-0.750	13.2	33.8	47.0	28.1%	29.2	45.2	74.4	39.2%
-1.250	12.1	32.0	44.1	27.4%	26.4	48.8	75.2	35.1%
-1.750	10.9	33.0	43.9	24.8%	21.7	43.9	65.6	33.1%
-2.500	11.7	34.0	45.7	25.6%	22.9	47.3	70.2	32.6%
-3.500	12.1	33.7	45.8	26.4%	24.9	49.9	74.8	33.3%
-5.000	12.2	34.0	46.2	26.4%	23.1	44.5	67.6	34.2%
-7.000	11.7	32.7	44.4	26.4%	25.7	47.4	73.1	35.2%
-9.000	12.1	32.4	44.5	27.2%	28.0	47.8	75.8	36.9%
-12.000	11.6	33.0	44.6	26.0%	29.4	47.9	77.3	38.0%

Depth (cm)	325L	325R	325T	325L'	351L	351R	351T	351L'
-0.250	40.1	29.8	69.9	57.4%	49.8	81.9	131.7	37.8%
-0.750	37.4	30.9	68.3	54.8%	53.3	85.9	139.2	38.3%
-1.250	35.8	30.3	66.1	54.2%	51.2	84.4	135.6	37.8%
-1.750	36.8	30.5	67.3	54.7%	52.5	85.9	138.4	37.9%
-2.500	37.0	31.4	68.4	54.1%	51.9	88.1	140.0	37.1%
-3.500	37.7	31.2	68.9	54.7%	53.3	87.2	140.5	37.9%
-5.000	32.0	32.4	64.4	49.7%	53.7	87.8	141.5	38.0%
-7.000	28.3	31.7	60.0	47.2%	64.6	91.3	155.9	41.4%
-9.000	25.0	34.4	59.4	42.1%	54.0	89.0	143.0	37.8%
-12.000	23.1	33.3	56.4	41.0%	39.6	89.9	129.5	30.6%
-0.125	33.9	26.9	60.8	55.8%	42.5	67.4	109.9	38.7%
-0.375	34.1	27.1	61.2	55.7%	42.7	73.4	116.1	36.8%
-0.625	35.7	28.6	64.3	55.5%	47.6	81.4	129.0	36.9%
-0.875	36.2	29.7	65.9	54.9%	46.6	82.7	129.3	36.0%

Depth (cm)	352L	352R	352T	352L'
-0.250	41.2	70.1	111.3	37.0%
-0.750	42.7	73.8	116.5	36.7%
-1.250	41.1	71.1	112.2	36.6%
-1.750	41.9	71.0	112.9	37.1%
-2.500	42.4	71.0	113.4	37.4%
-3.500	42.9	73.0	115.9	37.0%
-5.000	42.2	70.0	112.2	37.6%
-7.000	40.1	70.1	110.2	36.4%
-9.000	39.8	62.7	102.5	38.8%
-12.000	39.7	61.5	101.2	39.2%

APPENDIX 17: Nickel concentrations of the leachable, residual, total fraction in $\mu\text{g/g}$ and percentage leachable in sediments of the northern Indian Ocean. L = leachable fraction, R = residual fraction, T = total, L' = percentage leachable.

Depth (cm)	301L	301R	301T	301L'	302L	302R	302T	302L'
-0,250	5,37	31,47	36,84	14,6%	6,14	26,12	32,26	19,0%
-0,750	4,61	31,91	36,52	12,6%	6,08	26,45	32,53	18,7%
-1,250	5,32	31,22	36,54	14,6%	5,76	24,96	30,72	18,8%
-1,750	5,03	28,63	33,66	14,9%	5,54	26,30	31,84	17,4%
-2,500	4,37	30,89	35,26	12,4%	6,58	23,02	29,60	22,2%
-3,500	4,63	31,14	35,77	12,9%	5,71	25,21	30,92	18,5%
-5,000	5,03	30,00	35,03	14,4%	6,17	25,40	31,57	19,5%
-7,000	4,57	29,30	33,87	13,5%	5,53	24,31	29,84	18,5%
-9,000	4,93	29,38	34,31	14,4%	6,19	25,20	31,39	19,7%
-12,000	5,14	30,09	35,23	14,6%	5,36	24,81	30,17	17,8%

Depth (cm)	303L	303R	303T	303L'	304L	304R	304T	304L'
-0,250	5,64	21,19	26,83	21,0%	7,02	26,06	33,08	21,2%
-0,750	6,05	20,92	26,97	22,4%	7,91	26,69	34,60	22,9%
-1,250	6,11	20,83	26,94	22,7%	7,78	25,53	33,31	23,4%
-1,750	5,94	20,25	26,19	22,7%	8,49	26,98	35,47	23,9%
-2,500	5,66	20,28	25,94	21,8%	8,45	24,53	32,98	25,6%
-3,500	5,80	22,09	27,89	20,8%	7,87	23,80	31,67	24,9%
-5,000	5,27	21,38	26,65	19,8%	8,06	25,39	33,45	24,1%
-7,000	5,39	19,99	25,38	21,2%	8,04	23,73	31,77	25,3%
-9,000	5,70	20,77	26,47	21,5%	7,31	23,13	30,44	24,0%
-12,000	5,09	22,35	27,44	18,5%	6,26	23,97	30,23	20,7%

Depth (cm)	305L	305R	305T	305L'	306L	306R	306T	306L'
-0,250	13,96	27,75	41,71	33,5%	19,22	36,48	55,70	34,5%
-0,750	14,71	30,44	45,15	32,6%	18,20	37,81	56,01	32,5%
-1,250	14,42	33,27	47,69	30,2%	18,09	39,59	57,68	31,4%
-1,750	15,10	28,89	43,99	34,3%	18,17	37,28	55,45	32,8%
-2,500	14,94	32,63	47,57	31,4%	18,11	36,15	54,26	33,4%
-3,500	15,66	33,16	48,82	32,1%	18,21	38,46	56,67	32,1%
-5,000	14,52	31,91	46,43	31,3%	18,45	39,83	58,28	31,7%
-7,000	15,11	29,01	44,12	34,2%	17,23	38,97	56,20	30,7%
-9,000	13,91	30,11	44,02	31,6%	18,89	38,72	57,61	32,8%
-12,000	14,36	29,05	43,41	33,1%	17,82	36,41	54,23	32,9%

Depth (cm)	309L	309R	309T	309L'	310L	310R	310T	310L'
-0,250	8,19	14,56	22,75	36,0%	10,17	15,45	25,62	39,7%
-0,750	7,90	13,30	21,20	37,3%	10,54	15,32	25,86	40,8%
-1,250	8,04	13,20	21,24	37,9%	10,81	15,79	26,60	40,6%
-1,750	8,57	13,38	21,95	39,0%	10,96	15,90	26,86	40,8%
-2,500	8,30	13,45	21,75	38,2%	10,54	15,03	25,57	41,2%
-3,500	8,41	12,86	21,27	39,5%	10,93	15,73	26,66	41,0%
-5,000	8,59	13,28	21,87	39,3%	11,17	14,52	25,69	43,5%
-7,000	8,06	12,64	20,70	38,9%	11,28	14,85	26,13	43,2%
-9,000	7,58	13,09	20,67	36,7%	10,75	15,11	25,86	41,6%
-12,000	7,70	13,25	20,95	36,8%	11,01	14,99	26,00	42,3%

Depth (cm)	311L	311R	311T	311L'	311L	313R	313T	313L'
-0,250	13,39	16,05	29,44	45,5%	13,39	39,67	65,52	39,5%
-0,750	12,28	15,72	28,00	43,9%	12,28	39,33	63,65	38,2%
-1,250	11,73	15,08	26,81	43,8%	11,73	39,63	61,14	35,2%
-1,750	11,69	15,39	27,08	43,2%	11,69	34,70	54,64	36,5%
-2,500	11,58	15,92	27,50	42,1%	11,58	38,24	60,11	36,4%
-3,500	11,92	16,09	28,01	42,6%	11,92	40,83	62,52	34,7%
-5,000	11,27	15,39	26,66	42,3%	11,27	35,05	55,07	36,4%
-7,000	11,81	15,12	26,93	43,9%	11,81	37,74	58,79	35,8%
-9,000	12,97	15,42	28,39	45,7%	12,97	36,97	58,20	36,5%
-12,000	12,14	15,39	27,53	44,1%	12,14	37,50	59,78	37,3%

Depth (cm)	325L	325R	325T	325L'	351L	351R	351T	351L'
-0,250	37,58	32,01	69,59	54,0%	83,99	69,24	153,2	54,8%
-0,750	37,53	34,16	71,69	52,4%	85,77	82,90	168,7	50,9%
-1,250	37,81	34,72	72,53	52,1%	86,24	84,20	170,4	50,6%
-1,750	35,52	33,12	68,64	51,7%	83,02	87,15	170,2	48,8%
-2,500	42,25	34,97	77,22	54,7%	121,2	89,23	210,4	57,6%
-3,500	41,40	38,02	79,42	52,1%	83,97	92,17	176,1	47,7%
-5,000	22,49	26,66	49,15	45,8%	87,21	92,13	179,3	48,6%
-7,000	16,20	20,21	36,41	44,5%	95,72	111,2	206,9	46,3%
-9,000	15,82	17,53	33,35	47,4%	73,01	86,82	159,8	45,7%
-12,000	17,73	17,78	35,51	49,9%	40,30	56,88	97,2	41,5%
-0,125	40,21	27,67	67,88	59,2%	79,96	58,82	138,8	57,6%
-0,375	40,45	27,86	68,31	59,2%	78,96	62,61	141,6	55,8%
-0,625	39,81	30,60	70,41	56,5%	80,40	71,55	151,9	52,9%
-0,875	39,22	32,35	71,57	54,8%	77,80	76,51	154,3	50,4%

Depth (cm)	352L	352R	352T	352L'
-0,250	59,22	58,62	117,8	50,3%
-0,750	63,10	63,88	127,0	49,7%
-1,250	61,93	62,07	124,0	49,9%
-1,750	59,84	62,51	122,3	48,9%
-2,500	59,75	62,48	122,2	48,9%
-3,500	59,87	63,80	123,7	48,4%
-5,000	58,62	60,71	119,3	49,1%
-7,000	56,90	61,38	118,3	48,1%
-9,000	54,19	56,73	110,9	48,9%
-12,000	51,40	56,04	107,4	47,8%

APPENDIX 18: Lead concentrations of the leachable, residual, total fraction in $\mu\text{g/g}$ and percentage leachable in sediments of the northern Indian Ocean. L = leachable fraction, R = residual fraction, T = total, L' = percentage leachable.

Depth (cm)	301L	301R	301T	301L'	302L	302R	302T	302L'
-0.250	2.20	3.01	5.21	42.2%	1.48	3.13	4.61	32.1%
-0.750	2.17	3.31	5.48	39.6%	1.53	2.98	4.51	33.9%
-1.250	2.14	3.02	5.16	41.5%	1.41	2.63	4.04	34.9%
-1.750	2.19	2.73	4.92	44.5%	1.64	3.24	4.88	33.6%
-2.500	2.25	3.12	5.37	41.9%	1.36	2.85	4.21	32.3%
-3.500	1.96	3.32	5.28	37.1%	1.47	3.13	4.60	32.0%
-5.000	1.78	3.05	4.83	36.9%	1.52	3.20	4.72	32.2%
-7.000	2.22	3.14	5.36	41.4%	1.58	3.02	4.60	34.3%
-9.000	1.95	2.83	4.78	40.8%	1.39	2.89	4.28	32.5%
-12.000	1.87	3.26	5.13	36.5%	1.39	3.35	4.74	29.3%

Depth (cm)	303L	303R	303T	303L'	304L	304R	304T	304L'
-0.250	1.14	3.65	4.79	23.8%	1.47	2.92	4.39	33.5%
-0.750	1.22	3.42	4.64	26.3%	1.38	2.86	4.24	32.5%
-1.250	1.26	3.74	5.00	25.2%	1.22	2.59	3.81	32.0%
-1.750	1.22	3.45	4.67	26.1%	1.39	2.66	4.05	34.3%
-2.500	1.20	3.54	4.74	25.3%	2.64	1.44	4.08	64.7%
-3.500	1.05	3.52	4.57	23.0%	1.24	2.63	3.87	32.0%
-5.000	1.06	3.48	4.54	23.3%	1.28	2.86	4.14	30.9%
-7.000	1.17	3.57	4.74	24.7%	1.42	2.85	4.27	33.3%
-9.000	1.12	3.98	5.10	22.0%	1.51	2.72	4.23	35.7%
-12.000	1.14	3.79	4.93	23.1%	1.20	2.71	3.91	30.7%

Depth (cm)	305L	305R	305T	305L'	306L	306R	306T	306L'
-0.250	1.70	1.84	3.54	48.0%	2.85	1.91	4.76	59.9%
-0.750	2.12	1.79	3.91	54.2%	2.66	1.91	4.57	58.2%
-1.250	1.90	1.70	3.60	52.8%	2.66	1.93	4.59	58.0%
-1.750	1.76	1.79	3.55	49.6%	2.82	1.84	4.66	60.5%
-2.500	1.71	1.73	3.44	49.7%	2.38	1.86	4.24	56.1%
-3.500	1.75	1.76	3.51	49.9%	2.68	1.99	4.67	57.4%
-5.000	1.89	1.70	3.59	52.6%	2.53	1.91	4.44	57.0%
-7.000	1.79	1.72	3.51	51.0%	2.36	1.91	4.27	55.3%
-9.000	1.97	1.90	3.87	50.9%	2.37	1.82	4.19	56.6%
-12.000	1.90	1.70	3.60	52.8%	2.38	4.24	6.62	36.0%

Depth (cm)	309L	309R	309T	309L'	310L	310R	310T	310L'
-0.250	1.44	2.35	3.79	38.0%	1.49	2.38	2.38	38.5%
-0.750	1.21	2.64	3.85	31.4%	1.46	2.37	2.37	38.1%
-1.250	1.24	2.34	3.58	34.6%	1.58	2.28	2.28	40.9%
-1.750	1.42	2.42	3.84	37.0%	1.54	2.31	2.31	40.0%
-2.500	1.30	2.41	3.71	35.0%	1.39	2.44	2.44	36.3%
-3.500	1.11	2.39	3.50	31.7%	1.44	2.25	2.25	39.0%
-5.000	1.11	2.83	3.94	28.2%	1.34	2.50	2.50	34.9%
-7.000	1.26	2.53	3.79	33.2%	1.32	2.19	2.19	37.6%
-9.000	1.10	2.43	3.53	31.2%	1.42	2.21	2.21	39.1%
-12.000	1.24	2.52	3.76	33.0%	1.39	2.21	2.21	38.6%

Depth (cm)	311L	311R	311T	311L'	313L	313R	313T	313L'
-0.250	2.13	2.40	4.53	47.0%	3.35	3.09	6.44	52.0%
-0.750	1.90	2.06	3.96	48.0%	3.38	2.86	6.24	54.2%
-1.250	1.81	2.00	3.81	47.5%	3.62	2.56	6.18	58.6%
-1.750	1.76	1.98	3.74	47.1%	3.28	2.15	5.43	60.4%
-2.500	1.52	2.10	3.62	42.0%	3.49	2.41	5.90	59.2%
-3.500	1.61	1.99	3.60	44.7%	3.57	2.35	5.92	60.3%
-5.000	1.57	1.97	3.54	44.4%	3.46	2.01	5.47	63.3%
-7.000	1.47	1.94	3.41	43.1%	3.64	2.30	5.94	61.3%
-9.000	1.52	2.00	3.52	43.2%	3.70	2.14	5.84	63.4%
-12.000	1.65	1.98	3.63	45.5%	3.86	2.26	6.12	63.1%

Depth (cm)	325L	325R	325T	325L'	351L	351R	351T	351L'
-0.250	2.98	3.38	6.36	46.9%	5.82	11.11	16.93	34.4%
-0.750	2.87	3.68	6.55	43.8%	4.60	12.31	16.91	27.2%
-1.250	2.95	3.81	6.76	43.6%	3.33	12.01	15.34	21.7%
-1.750	2.65	3.57	6.22	42.6%	3.03	12.64	15.67	19.3%
-2.500	2.25	4.05	6.30	35.7%	3.19	14.01	17.20	18.5%
-3.500	1.69	4.40	6.09	27.8%	2.99	13.41	16.40	18.2%
-5.000	2.70	3.40	6.10	44.3%	2.95	13.55	16.50	17.9%
-7.000	3.36	2.71	6.07	55.4%	1.90	14.97	16.87	11.3%
-9.000	3.72	2.10	5.82	63.9%	1.83	14.67	16.50	11.1%
-12.000	3.97	1.73	5.70	69.6%	3.12	13.26	16.38	19.0%
-0.125	3.35	2.78	6.13	54.6%	5.23	8.16	13.39	39.1%
-0.375	3.21	3.10	6.31	50.9%	5.36	9.05	14.41	37.2%
-0.625	2.84	3.24	6.08	46.7%	4.86	11.82	16.68	29.1%
-0.875	2.98	3.60	6.58	45.3%	3.94	12.73	16.67	23.6%

Depth (cm)	352L	352R	352T	352L'
-0.250	6.17	7.18	13.35	46.2%
-0.750	5.92	8.37	14.29	41.4%
-1.250	5.27	8.10	13.37	39.4%
-1.750	5.40	7.74	13.14	41.1%
-2.500	5.10	8.55	13.65	37.4%
-3.500	5.36	13.60	18.96	28.3%
-5.000	5.52	7.54	13.06	42.3%
-7.000	5.12	7.77	12.89	39.7%
-9.000	4.24	7.10	11.34	37.4%
-12.000	3.99	7.36	11.35	35.2%

APPENDIX 19: Chromium concentrations of the leachable, residual, total fraction in $\mu\text{g/g}$ and percentage leachable in sediments of the northern Indian Ocean. L = leachable fraction, R = residual fraction, T = total, L' = percentage leachable.

Depth (cm)	301L	301R	301T	301L'	302L	302R	302T	302L'
-0,250	11,46	77,3	88,7	12,9%	12,40	84,5	96,9	12,8%
-0,750	10,74	97,0	107,8	10,0%	12,75	84,4	97,2	13,1%
-1,250	12,17	87,3	99,5	12,2%	12,07	85,4	97,5	12,4%
-1,750	12,57	81,0	93,6	13,4%	12,24	82,4	94,6	12,9%
-2,500	10,80	86,3	97,1	11,1%	12,48	80,3	92,8	13,4%
-3,500	11,88	82,0	93,9	12,7%	12,33	78,2	90,5	13,6%
-5,000	11,85	83,3	95,1	12,5%	12,89	86,8	99,7	12,9%
-7,000	11,09	88,5	99,6	11,1%	12,20	89,8	102,0	12,0%
-9,000	10,99	98,9	109,9	10,0%	11,99	91,0	103,0	11,6%
-12,000	12,49	84,9	97,4	12,8%	11,91	80,8	92,7	12,9%

Depth (cm)	303L	303R	303T	303L'	304L	304R	304T	304L'
-0,250	9,09	109,3	118,4	7,7%	8,86	107,0	115,9	7,6%
-0,750	9,40	108,4	117,8	8,0%	8,11	92,5	100,6	8,1%
-1,250	9,51	103,7	113,2	8,4%	8,99	84,0	93,0	9,7%
-1,750	9,76	95,8	105,6	9,2%	8,55	103,8	112,3	7,6%
-2,500	9,97	113,0	123,0	8,1%	8,70	83,4	92,1	9,4%
-3,500	9,77	114,4	124,2	7,9%	8,60	89,0	97,6	8,8%
-5,000	119,8				8,86	104,1	113,0	7,8%
-7,000	9,81	110,4	120,2	8,2%	8,88	93,2	102,1	8,7%
-9,000	10,08	116,7	126,8	8,0%	9,04	93,5	102,6	8,8%
-12,000	9,73	88,5	98,3	9,9%	77,7			

Depth (cm)	305L	305R	305T	305L'	306L	306R	306T	306L'
-0,250	7,56	69,2	76,8	9,8%	6,02	75,2	81,2	7,4%
-0,750	8,24	74,6	82,8	9,9%	6,01	77,2	83,2	7,2%
-1,250	7,72	79,5	87,2	8,9%	5,97	76,2	82,2	7,3%
-1,750	8,03	70,5	78,5	10,2%	6,08	74,7	80,8	7,5%
-2,500	8,54	81,2	89,7	9,5%	5,98	81,9	87,9	6,8%
-3,500	8,56	80,4	89,0	9,6%	6,19	76,9	83,1	7,4%
-5,000	8,45	79,4	87,8	9,6%	6,04	79,0	85,0	7,1%
-7,00	8,42	75,8	84,2	10,0%	5,91	76,3	82,2	7,2%
-9,000	8,39	74,9	83,3	10,1%	6,46	72,8	79,3	8,2%
-12,000	8,21	75,8	84,0	9,8%	6,14	69,3	75,4	8,1%

Depth (cm)	309L	309R	309T	309L'	310L	310R	310T	310L'
-0,250	10,78	110,6	121,4	8,9%	9,30	98,2	107,5	8,7%
-0,750	11,07	88,6	99,7	11,1%	9,64	100,3	109,9	8,8%
-1,250	11,43	110,6	122,0	9,4%	9,89	101,4	111,3	8,9%
-1,750	11,42	129,5	140,9	8,1%	9,72	129,7	139,4	7,0%
-2,500	10,80	106,2	117,0	9,2%	9,56	94,9	104,5	9,2%
-3,500	11,36	98,6	110,0	10,3%	9,61	105,0	114,6	8,4%
-5,000	11,44	97,3	108,7	10,5%	9,94	89,3	99,3	10,0%
-7,000	11,64	88,7	100,3	11,6%	9,94	82,3	92,3	10,8%
-9,000	11,08	110,4	121,5	9,1%	9,31	104,6	113,9	8,2%
-12,000	10,91	121,1	132,0	8,3%	9,94	99,1	109,0	9,1%

Depth (cm)	311L	311R	311T	311L'	313L	313R	313T	313L'
-0,250	7,76	54,7	62,5	12,4%	5,62	33,9	39,5	14,2%
-0,750	7,84	53,8	61,6	12,7%	5,86	36,5	42,4	13,8%
-1,250	8,15	52,0	60,2	13,5%	6,05	45,3	51,3	11,8%
-1,750	7,68	46,0	53,7	14,3%	5,40	26,2	31,6	17,1%
-2,500	46,4				6,46	44,0	50,5	12,8%
-3,500	7,99	45,1	53,1	15,0%	6,16	45,1	51,3	12,0%
-5,000	7,78	55,2	63,0	12,4%	5,84	33,9	39,7	14,7%
-7,000	7,48	56,4	63,9	11,7%	6,06	44,1	50,2	12,1%
-9,000	7,86	45,2	53,1	14,8%	6,53	35,9	42,4	15,4%
-12,000	7,86	46,0	53,9	14,6%	6,81	35,0	41,8	16,3%

Depth (cm)	325L	325R	325T	325L'	351L	351R	351T	351L'
-0,250	3,15	46,2	49,3	6,4%	2,68	95,0	97,7	2,7%
-0,750	3,07	44,0	47,1	6,5%	2,60	96,8	99,4	2,6%
-1,250	2,81	44,2	47,0	6,0%	2,57	91,5	94,1	2,7%
-1,750	2,79	39,6	42,4	6,6%	2,66	92,5	95,2	2,8%
-2,500	2,71	40,1	42,8	6,3%	2,80	90,0	92,8	3,0%
-3,500	2,48	39,2	41,7	6,0%	2,72	86,5	89,2	3,0%
-5,000		37,6			2,78	85,3	88,1	3,2%
-7,000	2,77	37,6	40,4	6,9%	2,54	88,1	90,6	2,8%
-9,000	3,10	36,5	39,6	7,8%	2,69	85,0	87,7	3,1%
-12,000	3,61	35,0	38,6	9,3%	2,82	83,5	86,3	3,3%
-0,125	2,95	52,1	55,0	5,4%	2,52	82,4	84,9	3,0%
-0,375	2,67	45,8	48,5	5,5%	2,62	85,3	87,9	3,0%
-0,625	2,23	45,5	47,7	4,7%	2,46	92,9	95,4	2,6%
-0,875	2,17	46,1	48,3	4,5%	2,56	93,4	96,0	2,7%

Depth (cm)	352L	352R	352T	352L'
-0,250	3,23	69,8	73,0	4,4%
-0,750	2,99	71,4	74,4	4,0%
-1,250	2,70	62,9	65,6	4,1%
-1,750	2,75	63,7	66,4	4,1%
-2,500	2,78	62,9	65,7	4,2%
-3,500	2,58	65,8	68,4	3,8%
-5,000	2,53	61,5	64,0	4,0%
-7,000	2,48	63,9	66,4	3,7%
-9,000	2,08	50,0	52,1	4,0%
-12,000	1,94	47,3	49,2	3,9%

APPENDIX 20: Cadmium concentrations of the leachable, residual and total fraction in $\mu\text{g/g}$ and percentage leachable in the sediments of the northern Indian Ocean. L = leachable fraction, R = residual fraction, T = total, L' = percentage leachable.

Depth (cm)	301L	301R	301T	301L'	302L	302R	302T	302L'
-0.250	0.470	0.060	0.530	88.7%	0.930	0.105	1.035	89.9%
-0.750	0.610	0.053	0.663	92.0%	1.010	0.085	1.095	92.2%
-1.250	0.520	0.062	0.582	89.3%	0.910	0.145	1.055	86.3%
-1.750	0.480	0.086	0.566	84.8%	1.050	0.235	1.285	81.7%
-2.500	0.530	0.093	0.623	85.1%	0.870	0.080	0.950	91.6%
-3.500	0.580	0.036	0.616	94.2%	0.900	0.105	1.005	89.6%
-5.000	0.540	0.059	0.599	90.2%	0.940	0.115	1.055	89.1%
-7.000	0.550	0.073	0.623	88.3%	0.920	0.155	1.075	85.6%
-9.000	0.600	0.028	0.628	95.5%	0.960	0.115	1.075	89.3%
-12.000	0.600	0.130	0.730	82.2%	0.880	0.315	1.195	73.6%

Depth (cm)	303L	303R	303T	303L'	304L	304R	304T	304L'
-0.250	0.250	0.105	0.355	70.4%	0.320	0.800	1.120	28.6%
-0.750	0.290	0.060	0.350	82.9%	0.340	0.380	0.720	47.2%
-1.250	0.390	0.050	0.440	88.6%	0.360	0.240	0.600	60.0%
-1.750	0.280	0.034	0.314	89.2%	0.330	0.140	0.470	70.2%
-2.500	0.300	0.057	0.357	84.0%	0.310	0.190	0.500	62.0%
-3.500	0.290	0.027	0.317	91.5%	0.290	0.350	0.640	45.3%
-5.000	0.210	0.031	0.241	87.1%	0.440	0.100	0.540	81.5%
-7.000	0.330				0.300	0.260	0.560	53.6%
-9.000	0.320	0.092	0.412	77.7%	0.370	0.150	0.520	71.2%
-12.000	0.290	0.043	0.333	87.1%	0.200	0.024	0.224	89.3%

Depth (cm)	305L	305D	305T	305L'	306L	306R	306T	306L'
-0.250	0.340	0.014	0.354	96.0%	0.340	0.025	0.365	93.2%
-0.750	0.380	0.036	0.416	91.3%	0.320	0.010	0.330	97.0%
-1.250	0.410	0.045	0.455	90.1%	0.360	0.005	0.365	98.6%
-1.750	0.470	0.033	0.503	93.4%	0.440	0.185	0.625	70.4%
-2.500	0.500	0.060	0.560	89.3%	0.570	0.036	0.606	94.1%
-3.500	0.600	0.058	0.658	91.2%	0.720	0.031	0.751	95.9%
-5.000	0.510	0.020	0.530	96.2%	0.750	0.030	0.780	96.2%
-7.000	0.580	0.019	0.599	96.8%	0.860	0.030	0.890	96.6%
-9.000	0.600	0.010	0.610	98.4%	0.760	0.026	0.786	96.7%
-12.000	0.610	0.038	0.648	94.1%	0.730	0.020	0.750	97.3%

Depth (cm)	309L	309R	309T	309L'	310L	310D	310T	310L'
-0.250	0.360	0.030	0.390	92.3%	0.260	0.030	0.290	89.7%
-0.750	0.500	0.010	0.510	98.0%	0.260	0.010	0.270	96.3%
-1.250	0.370	0.015	0.385	96.1%	0.280	0.041	0.321	87.2%
-1.750	0.430	0.045	0.475	90.5%	0.310	0.034	0.344	90.1%
-2.500	0.500	0.014	0.514	97.3%	0.360	0.019	0.379	95.0%
-3.500	0.500	0.015	0.515	97.1%	0.380	0.033	0.413	92.0%
-5.000	0.480	0.020	0.500	96.0%	0.390	0.015	0.405	96.3%
-7.000	0.460	0.025	0.485	94.8%	0.420	0.014	0.434	96.8%
-9.000	0.410	0.035	0.445	92.1%	0.470	0.033	0.503	93.4%
-12.000	0.430	0.045	0.475	90.5%	0.440	0.040	0.480	91.7%

Depth (cm)	311L	311R	311T	311L'	313L	313R	313T	313L'
-0.250	0.290	0.040	0.330	87.9%	0.260	0.019	0.279	93.2%
-0.750	0.270	0.034	0.304	88.8%	0.210	0.010	0.220	95.5%
-1.250	0.260	0.023	0.283	91.9%	0.150	0.010	0.160	93.8%
-1.750	0.250	0.025	0.275	90.9%	0.210	0.025	0.235	89.4%
-2.500	0.150	0.005	0.155	96.8%	0.330	0.014	0.344	95.9%
-3.500	0.310	0.005	0.315	98.4%	0.420	0.010	0.430	97.7%
-5.000	0.360	0.035	0.395	91.1%	0.390	0.019	0.409	95.4%
-7.000	0.460	0.010	0.470	97.9%	0.490	0.024	0.514	95.3%
-9.000	0.390	0.025	0.415	94.0%	0.640	0.020	0.660	97.0%
-12.000	0.390	0.046	0.436	89.4%	0.660	0.044	0.704	93.8%

Depth (cm)	325L	325R	325T	325L'	351L	351R	351T	351L'
-0.250	0.250	0.029	0.279	89.6%	0.300	0.055	0.355	84.5%
-0.750	0.250	0.030	0.280	89.3%	0.220	0.061	0.281	78.3%
-1.250	0.270	0.033	0.303	89.1%	0.130	0.054	0.184	70.7%
-1.750	0.240	0.028	0.268	89.6%	0.120	0.053	0.173	69.4%
-2.500	0.270	0.039	0.309	87.4%	0.110	0.064	0.174	63.2%
-3.500	0.180	0.015	0.195	92.3%	0.110	0.051	0.161	68.3%
-5.000	0.081	0.009	0.090	90.0%	0.110	0.056	0.166	66.3%
-7.000	0.120	0.026	0.146	82.2%	0.130	0.063	0.193	67.4%
-9.000	0.170	0.025	0.195	87.2%	0.290	0.054	0.344	84.3%
-12.000	0.310	0.030	0.340	91.2%	0.170	0.043	0.213	79.8%
-0.125	0.290	0.030	0.320	90.6%	1.780	0.079	1.859	95.8%
-0.375	0.280	0.055	0.335	83.6%	0.250	0.030	0.280	89.3%
-0.625	0.270	0.055	0.325	83.1%	0.350	0.117	0.467	74.9%
-0.875	0.350	0.046	0.396	88.4%	0.160	0.066	0.226	70.8%

Depth (cm)	352L	352R	352T	352L'
-0.250	0.250	0.036	0.286	87.4%
-0.750	0.140	0.035	0.175	80.0%
-1.250	0.110	0.028	0.138	79.7%
-1.750	0.120	0.024	0.144	83.3%
-2.500	0.120	0.040	0.160	75.0%
-3.500	0.150	0.025	0.175	85.7%
-5.000	0.110	0.030	0.140	78.6%
-7.000	0.110	0.025	0.135	81.5%
-9.000	0.150	0.036	0.186	80.6%
-12.000	0.180	0.025	0.205	87.8%

APPENDIX 21: Nitrate concentrations in sediments of the northern Indian Ocean.

Depth (cm)	301	302	303	304	305	306	309
0.00	23.6	25.5	25.7	32.2	35.5	37.6	28.9
-0.25	13.0	10.0	12.0	22.3	31.0	22.1	25.8
-0.75	6.3	15.4	17.0	13.9	21.2	11.3	11.5
-1.25	9.1	9.4	7.5	12.0	11.7	4.0	11.4
-1.75	4.5	8.8	9.7	11.3	4.6	2.8	10.0
-2.50	3.9	4.4	7.3	8.6	2.6	1.7	6.6
-3.50	2.0	2.6	6.7	50.2	3.8	1.6	4.6
-5.00	1.6	1.6	1.9	1.7	5.0	1.6	2.0
-7.00	1.3	1.6	1.9	6.7	3.5	1.1	3.3
-9.00	7.9	1.6	6.2	1.6	3.1	1.2	2.8
-12.00	3.3	2.7	1.8	1.7		1.3	3.9

Depth (cm)	310	311	313	325	351	352
0.00	34.4	33.6	35.1	52.1	42.7	32.0
-0.25	10.5	103.3	26.3	39.5	43.9	45.6
-0.75	6.9	57.6	12.9	36.1	46.8	45.9
-1.25	6.0	53.0	6.8	29.4	43.2	46.6
-1.75	5.1	32.0	4.5	14.4	48.2	45.8
-2.50	3.0	55.4	2.9	12.4	42.8	52.9
-3.50	3.3	54.9	2.8	7.1	50.7	48.5
-5.00	1.8	24.6	1.6	9.3	38.7	57.4
-7.00	1.8	33.4	2.3	4.8	35.4	51.7
-9.00	1.4	30.2	2.6	2.2	33.7	49.7
-12.00	1.7	45.0	2.5	32.7	30.7	47.9

APPENDIX 22: Manganese concentrations (μM) in porewaters of all stations in the northern Indian Ocean.

Depth (cm)	301	302	303	304	305	306	309
-0.25		1.44	1.44	1.53		1.20	
-0.75	1.85		1.44	1.53	1.53	1.57	1.34
-1.25	1.38	1.16		1.26	1.44	2.04	1.43
-1.75			1.53	1.44	1.72	2.87	
-2.50	1.38	1.35	1.07	1.35	1.63	2.78	1.25
-3.50	1.57	1.26	1.35	2.82	1.63	2.50	1.25
-5.00	1.29	1.35	1.35	1.44	1.72	2.87	1.25
-7.00	1.85	1.26	1.44	1.35	1.72	2.41	1.25
-9.00	2.13	1.26		1.26	1.72	2.22	1.25
-12.00	2.04	1.35	1.26	1.26	1.53	2.50	1.43

Depth (cm)	310	311	313	325	351	352
-0.25	1.48		1.43	1.68	1.64	1.28
-0.75	1.48	1.48	1.34	1.41	1.28	1.28
-1.25	1.85	2.41	2.72	1.50	1.55	1.37
-1.75	1.57	1.48	7.88	1.77	1.82	
-2.50	1.38	1.57	10.28	1.24	1.55	1.46
-3.50	1.48	1.76	10.92	1.41	1.37	1.28
-5.00	1.29	1.66	10.28	2.94	1.82	2.10
-7.00	1.29	1.85	9.72	3.03	1.73	1.37
-9.00	1.38	1.57	7.88	5.73	1.37	1.19
-12.00	1.38	1.57	6.78	11.48	1.10	1.10

APPENDIX 23: Iron concentrations (μM) in porewaters of all stations in the northern Indian Ocean.

Depth (cm)	301	302	303	304	305	306	309
-0.25	4.46	4.46	6.73		4.44		
-0.75	10.98		4.14	5.09	5.09	4.06	6.46
-1.25	7.13	6.35		4.10	4.76	4.06	6.46
-1.75		5.72	4.78	4.76	5.74	4.44	28.71
-2.50	4.44	6.35		4.43	5.09	3.67	4.56
-3.50	7.13	5.09	4.14	10.35	4.76	3.67	4.56
-5.00	5.98	6.67	4.78	6.07	5.09	3.67	5.98
-7.00	7.13	4.14	4.14	5.74	4.76	3.29	5.98
-9.00	7.90	4.78	4.78	5.74	6.40	3.29	4.09
-12.00		4.14	4.78	5.09	4.43	3.67	4.09

Depth (cm)	310	311	313	325	351	352
-0.25	9.97	19.16	11.27	17.77	13.92	13.27
-0.75	9.27	15.37	10.27	16.23	11.22	12.17
-1.25		19.70	9.87	20.07	15.85	12.72
-1.75	10.07	21.69	9.77	19.52	16.14	
-2.50	8.97	14.11	9.57	10.42	15.27	14.04
-3.50	9.47	15.92	11.07	13.49	11.42	12.39
-5.00	8.87	15.19	11.27	10.97	11.22	16.01
-7.00	9.17	18.62	9.77	10.42	15.17	12.72
-9.00	9.37	15.01	8.77	12.72	11.70	11.07
-12.00	8.77	13.39	9.07	11.95	11.03	10.31

APPENDIX 24: Copper concentrations (μM) in porewaters of all stations in the northern Indian Ocean.

Depth (cm)	301	302	303	304	305	306	309
-0.25	85.0	19.0			130.0	28.0	220.0
-0.75	69.0	22.0	200.0	42.0	116.0	170.0	
-1.25	22.0	12.0	79.0	34.0	78.0	38.0	
-1.75	267.0	22.0	185.0	130.0	135.0	231.0	
-2.50	68.0	40.0	50.0	82.0	75.0	59.0	43.0
-3.50	13.0	25.0	92.0	213.0	76.0	41.0	11.0
-5.00	258.0	18.0	18.0	9.0	63.0	27.0	42.0
-7.00	11.0	85.0	36.0	23.0	52.0	21.0	67.0
-9.00	9.0	26.0		60.0	60.0	9.0	24.0
-12.00	119.0	13.0		48.0	100.0	32.0	47.0

Depth (cm)	310	311	313	325	351	352
-0.25	105.0	195.0	111.0	846.0	907.0	762.0
-0.75	69.0	114.0	111.0	780.0	744.0	131.0
-1.25	72.0			777.0	930.0	195.0
-1.75	100.0	112.0	33.0	997.0	1095	447.0
-2.50	75.0	277.0	40.0	730.0	1117	136.0
-3.50	76.0	1079	27.0	410.0	698.0	496.0
-5.00	56.0	180.0	58.0	103.0	405.0	322.0
-7.00	69.0	224.0	16.0	430.0	1157	1008
-9.00	33.0	105.0	151.0	354.0	344.0	482.0
-12.00	139.0	98.0	47.0	670.0	251.0	88.0

APPENDIX 25: Zinc concentrations (μM) in porewaters of all stations in the northern Indian Ocean.

Depth (cm)	301	302	303	304	305	306	309
-0.25	13.00	1.06	2.06	2.37	1.84	2.01	
-0.75	18.90	1.33	4.96	3.23	1.45	1.93	2.11
-1.25	11.60	8.56	2.95	1.69	1.12	1.86	2.34
-1.75	10.80	6.62	1.22	3.48	1.78	3.87	2.72
-2.50	7.24	3.65	1.90	1.76	0.80	0.74	0.86
-3.50	11.66	1.87	0.79	5.47	1.09	1.91	1.21
-5.00	3.61	2.43	1.30	1.40	0.93	1.53	1.11
-7.00	6.65	1.46	1.59	1.59	1.71	2.17	1.42
-9.00	1.29	3.09	1.53	1.10	1.39	1.16	1.30
-12.00	0.82	1.68	1.80	0.69	0.64	0.63	1.09

Depth (cm)	310	311	313	325	351	352
-0.25	2.14	1.24	0.91	2.38	3.06	2.59
-0.75	1.87	1.16	0.95	2.67	2.94	2.09
-1.25	1.34	1.81		2.45	5.00	2.34
-1.75	1.47	1.18	1.07	7.14	13.38	3.09
-2.50	0.91	0.84	0.49	1.73	9.72	1.66
-3.50	1.13	3.63	0.55	1.62	3.02	2.25
-5.00	0.96	0.74	0.51	1.38	2.41	2.87
-7.00	1.07	0.84	0.53	1.89	7.13	4.77
-9.00	0.96	0.91	0.80	2.41	1.83	1.90
-12.00	1.04	0.59	0.55	3.68	1.22	1.48

APPENDIX 26: Nickel concentrations (μM) in porewaters of all stations in the northern Indian Ocean.

Depth (cm)	301	302	303	304	305	306	309
-0.25	126.2	34.6			63.0	52.3	54.2
-0.75	124.1	44.1	31.5	82.2	34.4	44.7	
-1.22	101.7	30.8	45.3	27.0	21.8	55.6	
-1.75		35.4	78.3	31.0	25.5	74.3	
-2.50	59.1	22.1	29.2	25.7	25.2	34.7	20.9
-3.50	40.9	40.0	36.1	180.6	25.8	43.6	48.3
-5.00	43.6	26.9	27.4	24.1	37.5	43.3	38.0
-7.00	51.9	19.3	26.6	24.4	34.2	33.2	37.2
-9.00		39.8		21.0	38.3	65.9	46.0
-12.00	39.3	45.6			33.6	36.0	45.4

Depth (cm)	310	311	313	325	351	352
-0.25	49.7	79.4	85.7	281.4	119.0	97.4
-0.75	62.4	34.2	66.9	94.1	26.3	35.6
-1.22	29.5		60.0	97.4	93.2	15.6
-1.75	27.0	38.1	85.0	171.2	223.9	54.7
-2.50	20.3	42.6	45.6	62.2	222.1	24.9
-3.50	29.0		45.0	43.5	41.0	32.5
-5.00	22.7	27.7	53.8	156.9	77.0	47.6
-7.00	41.7	36.0	35.6	153.1	265.6	59.8
-9.00	34.0	36.6	46.3	171.2	24.7	24.4
-12.00	43.2	29.5	34.1	192.5	92.9	16.8

APPENDIX 27: Lead concentrations (μM) in porewaters of all stations in the northern Indian Ocean.

Depth (cm)	301	302	303	304	305	306	309
-0.25	28.27	9.25			15.06	29.32	79.58
-0.75	47.78	6.73	6.77	9.13	7.54	23.68	
-1.25	26.86	16.45	8.94	8.98	9.19	49.60	
-1.75	79.82	8.05	14.46	25.62	7.64	23.18	
-2.50	38.21	10.02	14.61	6.22	6.53	14.12	8.84
-3.50	42.38	9.39	8.48	92.15	8.69	13.82	14.85
-5.00	30.78	6.86	7.51	5.74	20.71	30.67	10.17
-7.00	28.62	7.91	12.34	13.29	18.66	10.31	66.55
-9.00		15.15		19.19	25.10	11.46	18.12
-12.00	14.77	16.70		8.89	12.57	6.89	17.37

Depth (cm)	310	311	313	325	351	352
-0.25	7.01	17.15	4.44	31.77	51.50	63.70
-0.75	7.22	10.31	4.15	37.34	35.50	15.30
-1.25	5.96		5.14	37.64	126.3	20.00
-1.75	4.98	11.25	7.28	90.93	154.0	34.60
-2.50	2.88	13.24	3.76	41.82	179.0	20.30
-3.50	7.80	44.53	3.26	14.86	67.00	32.60
-5.00	4.47	7.07	3.88	20.79	59.80	79.40
-7.00	5.44	18.40	3.00	60.69	202.7	93.10
-9.00	4.25	8.62	6.66	16.30	45.40	28.60
-12.00	4.05	6.36	3.97	56.58	27.90	15.60

APPENDIX 28: Cadmium concentrations (μM) in porewaters of all stations in the northern Indian Ocean.

Depth (cm)	301	302	303	304	305	306	309
-0.25	6.23	10.68			5.77	20.21	36.92
-0.75	17.08	17.60	3.75	3.68	2.86	12.24	
-1.25	6.76	13.35	4.86	1.73	1.90	16.09	
-1.75	13.17	15.46	6.80	2.19	2.12	11.73	
-2.50	4.98	23.04	2.28	1.60	1.51	10.23	15.44
-3.50	3.56	8.26	5.71	23.72	1.65	18.45	7.44
-5.00	2.14	11.80	2.53	1.21	1.07	11.58	4.22
-7.00	3.91	6.10	2.56	1.26	0.94	3.77	12.06
-9.00		7.47		0.77	2.10	6.01	9.36
-12.00	1.96	5.71		0.69	0.93	4.68	20.43

Depth (cm)	310	311	313	325	351	352
-0.25	5.78	20.93	2.19	13.17	21.00	36.26
-0.75	2.90	27.03	2.15	7.12	17.62	16.83
-1.25	2.72		2.22	6.94	12.10	11.01
-1.75	2.26	18.97	4.36	8.90	21.00	11.19
-2.50	1.32	12.78	3.08	78.11	43.06	47.01
-3.50	1.76	155.0	1.05	24.91	8.36	14.13
-5.00	1.65	6.19	0.71	34.34	14.06	20.25
-7.00	1.26	22.76	0.50	12.46	17.08	12.62
-9.00	1.30	19.06	1.09	8.54	9.25	8.72
-12.00	2.72	8.15	0.69	15.84	76.69	5.68

APPENDIX 29: Mean Kd values of Cu, Cd, Zn, Ni, Pb, Mn and Fe of the sediments in the northern Indian Ocean.

Station	Depth (m)	Kd Cu	Kd Cd	Kd Zn	Kd Ni
301	75	1277	480	45	6942
302	208	7950	699	111	14948
303	477	848	629	173	8822
304	784	2556	2600	193	12453
305	1124	2488	1200	521	21057
306	1504	3478	249	409	16880
309	485	1126	150	197	9905
310	880	2485	805	360	10623
311	1088	1861	119	519	9370
313	2230	6024	723	1144	14014
325	4069	843	277	284	7472
351	5170	1526	123	342	24393
352	4815	5933	88	685	41205

Station	Depth (m)	Kd Pb	Kd Mn	Kd Fe
301	75	548	2719	26969
302	208	2148	3216	39548
303	477	2298	2833	42678
304	784	1364	2705	37066
305	1124	1789	2187	41000
306	1504	713	2722	11912
310	880	2962	2505	19097
311	1088	1502	2434	10558
313	2230	5569	7345	31748
325	4069	632	25903	12320
351	5170	852	50652	55776
352	4815	1957	40698	47949

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