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THE RECENT DISTRIBUTION OF LEAD IN THE INDIAN OCEAN REFLECTS THE IMPACT OF REGIONAL EMISSIONS

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Abstract

Humans have injected lead (Pb) massively into the earth surface environment in a temporally and spatially evolving pattern. A significant fraction is transported by the atmosphere into the surface ocean where we can observe its transport by ocean currents and sinking particles. This study of the Indian Ocean documents high Pb concentrations in the northern and tropical surface waters, and extremely low Pb levels in the deep water. North of 20°S, dissolved Pb concentrations decrease from 42-82 pmol/Kg in surface waters to 1.5-3.3 pmol/Kg in deep waters. South of 20°S, surface water Pb concentrations decrease from 21 pmol/Kg at 31°S to 7 pmol/Kg at 62°S. This surface Pb concentration gradient reflects a southward decrease in anthropogenic Pb emissions. The upper waters of the north and central Indian Ocean have high Pb concentrations resulting from recent regional rapid industrialization and a late phase-out of leaded gasoline, and these concentrations are now higher than currently seen in the central North Pacific and North Atlantic Oceans. The Antarctic sector of the Indian Ocean shows very low concentrations due to limited regional anthropogenic Pb emissions, high scavenging rates, and rapid vertical mixing, but Pb still occurs at higher levels than would have existed centuries ago. Penetration of Pb into the northern and central Indian Ocean thermocline waters is minimized by limited ventilation. Pb concentrations in the deep Indian Ocean are comparable to the other oceans at the same latitude, and deep waters of the central Indian Ocean match the lowest observed oceanic Pb concentrations.

Significance Statement:

Humans have altered the earth surface environment by massive injection of certain chemicals into our air and water. Although in some cases these injections are detrimental to environmental health and must be monitored to limit the damage (e.g. freons and the ozone layer), in other cases (e.g. freon dissolving into the ocean) there are no harmful consequences, but the chemicals are actually useful as tracers of ocean circulation patterns. Although lead remains a major hazard when it is proximate to humans (e.g. plumbing, housepaint, contaminated soils), in the open ocean lead serves as an inadvertent experiment demonstrating how metals move through the marine environment. This study is the first to examine the fate of human lead in the Indian Ocean.

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Introduction

Although naturally occurring at trace levels throughout the environment, lead (Pb) in the modern ocean is dominated by anthropogenic sources (from leaded gasoline and high temperature industrial activities). As such, it represents one of the great "global geophysical experiments" performed on the earth, comparable to fossil fuel CO_2, nuclear bomb fallout, and atmospheric trace gases: thus we have massively injected Pb into the surface ocean in a time-and-space dependent pattern, and we can now observe where and when it has gone. Although Pb concentrations in the open ocean are low and are not hazardous to marine life or humans, oceanic Pb illustrates the evolving extent of the human footprint upon the natural environment. The first valid oceanic Pb data was obtained for samples collected in 1976-77[1], and subsequently there have been numerous studies documenting concentrations and isotope ratios of Pb in seawater[2-7]. Most of these studies report data from the North Atlantic and North Pacific Oceans. There has only been very limited information from elsewhere in the ocean, with almost no useful data from the entire Indian Ocean. Indian Ocean Pb data are crucial to understanding the impact of anthropogenic Pb on the global scale environment because: (1) large scale economic development in recent decades and limited environmental regulation results in very high fluxes of Pb from the south Asian subcontinent into the Indian Ocean[8], and (2) Southern Asia and Oceania eliminated leaded gasoline later than other industrial countries. Hence the flux of lead to the northern and central Indian Ocean during the

past 20 years is likely to have been higher than elsewhere in the world. Here we present Pb concentration data from a Japanese GEOTRACES cruise in a North-South transect throughout the Indian Ocean that demonstrates that the surface of the Indian Ocean has higher Pb concentrations than representative sites in the North Atlantic and North Pacific Oceans, despite very low concentrations in old deep waters with Southern Ocean sources.

GEOTRACES is an international program directed at understanding the global-scale distribution of trace elements and their isotopes in the marine environment[9]. Here we show data from 11 stations from the 2009-2010 Japanese GEOTRACES transect in the Indian Ocean between 18°N and 65°S (Figure 1). This is the first study of Pb in the Indian Ocean with a detection limit capable of documenting the extremely low levels in the deep water of this basin that defines and refines the significance of the global Pb distribution.

Results and discussion

Surface water Pb concentrations in the northern and central Indian Ocean (53-82 pmol/Kg north of 20°S, Figure 2) are now higher than in the central North Atlantic and North Pacific oceans near Bermuda and Hawaii[10,11]. Given no northern deep water formation and limited upper water ventilation, anthropogenic Pb in the Indian Ocean has not penetrated as deeply as in the Atlantic Ocean, where those waters influenced by anthropogenic emissions are carried to the north, cool and become dense in the winter, then circulate to the south at depth moving into the

96 South Atlantic and Antarctic. In contrast, in the Indian Ocean there is insignificant
97 cooling and limited transport of northern waters to the south. In the northern
98 Indian Ocean, both thermocline and intermediate water CFC (ChloroFluoroCarbon)
99 concentrations are relatively lower and CFC ages are older in the Bay of Bengal than
100 in the Arabian Sea[12]. In the upper waters, at a given density, CFC-derived ages
101 increase and concentrations decrease from the south to north, with lowest
102 concentrations and oldest ages in Bay of Bengal[13].

103 Dissolved Pb concentrations along the north-south transect exhibit strong
104 vertical and horizontal gradients (Figure 2). North of 20°S, dissolved Pb
105 concentrations decrease from 42-82 pmol/Kg in surface waters (with the highest
106 concentration seen at 10°N in the Arabian Sea) to extremely low concentrations of
107 1.5-3.3 pmol/Kg in deep waters. South of 20°S, surface water Pb concentrations
108 further decrease from 21 pmol/Kg at 31°S to 7 pmol/Kg at 62°S. This surface Pb
109 concentration gradient reflects a southward decrease in anthropogenic Pb
110 emissions that are carried by atmospheric aerosols and deposited into the sea
111 surface.

112 The southwest and the northeast monsoons over the northern Indian Ocean
113 drive strongly directional winds with a dominant period in wind stress variability of
114 one year[14]. For oligotrophic open-ocean upper waters the residence time of lead is
115 around 2 years[15-20]. Hence Pb concentrations that we observe for surface waters of
116 the Arabian Sea and the Bay of Bengal derive from sources sampled by the mixture
117 of the different atmospheric flows during the year. During winter (northeast)

monsoon (November-February), the weak (~5 m/s) northeast trade wind brings cool, dry continental air, but during the summer (southwest) monsoon (June-September) the strong (~15 m/s) southwest wind brings humid maritime air into the Arabian Sea[21]. The Arabian Sea has high salinity (usually in the range 35 to 37 pss) due to excess of evaporation over rainfall. In contrast, the Bay of Bengal has much lower salinity due to the large influx of fresh water from river discharge and high amount of rainfall. Wind directions over the Indian Ocean, which is the main forcing function, reverse twice during the year[22]. Gaseous and particulate pollutants emitted by the Indian sub-continent and the south Asian region are transported over the entire north Indian Ocean by the persistent northeastern low-level monsoonal flow reaching as far south as 5° to 10°S[23,24]. Although southwest monsoon winds are stronger, atmospheric aerosol transport into the Arabian Sea during this time comes mostly from marine sources and from less industrialized areas in Africa. In the Arabian Sea atmospheric trace element fluxes are one to two orders of magnitude larger than in the tropical and southern Indian Ocean[25]. Our data show Pb surface concentrations for the Arabian Sea (stations 5-7) (60-82 pmol/Kg) and in the Bay of Bengal (76 pmol/Kg) that are significantly higher than in the Western Equatorial Indian Ocean, reflecting higher inputs by atmospheric deposition. Arabian Sea station 7 (10°N) has the highest surface lead concentration (82 pmol/Kg) in the Indian Ocean.

The increase in lead concentrations at ~1000 meters for stations 11 and 12 (20-25 pmol/Kg) with respect to the northern stations (10-15 pmol/Kg) is in

140 proximity to a salinity minimum attributable to the presence of the Antarctic
141 Intermediate Water (AAIW). This is a low salinity water mass that in the Indian
142 Ocean sinks at around 45-55°S that spreads northwards at a depth of 1000-1800
143 meters. This feature disappears near a hydrographic front at 10°S[26], which is
144 consistent with lower lead concentrations at 1000 meters (9 pmol/Kg) for station 9
145 (5°S). A weak Pb maximum also corresponds to the salinity minimum at a depth of
146 800 m at station 10 (Fig. 2 and Fig. 3). These Pb maxima corresponding to mid-
147 depth AAIW imply that the Pb supply to the surface water of AAIW formation region
148 ~20 years ago was higher than it is now.

149 Dissolved lead concentrations (1.5 pmol/Kg) in the bottom water at 4000m
150 at station 8 (4°N) are similar to that obtained in deep water at 7°S in the Pacific
151 Ocean[6]. Here, both sites are 2-3 fold lower than the lowest dissolved Pb
152 concentration reported elsewhere for the world ocean. At station 14 (62°S), the
153 closest station to Antarctica, there is scant vertical gradient with lead
154 concentrations between 4-7 pmol/Kg at all depths except for a slight maximum of
155 13 pmol/Kg at ~200m.

156 Lead concentrations in old deep waters in the stations around and above the
157 equatorial zone (1.5-3.3 pmol/Kg) are lower than seen in contemporary Antarctic
158 source waters. Two processes account for this observation: (1) although
159 anthropogenic Pb fluxes to the Antarctic are low, they are not zero, and hence
160 modern Pb concentrations are bound to be higher in the modern Antarctic than in
161 the waters that sank centuries ago to form the present-day Northern Indian deep

waters, and (2) ^{210}Pb-^{226}Ra studies have established that Pb is removed from the deep ocean on a time scale of decades to a century by "scavenging" onto sinking particulate matter and "boundary scavenging" onto bottom sediments[15-19, 27]. So it is expected that much of the Pb that may have been present in the north and central Indian Ocean deep waters at the time they sank from the surface will have been removed by scavenging by the time the water reaches the deep northern Indian Ocean. Abyssal waters of the Indian Ocean are occupied by Antarctic Bottom water (AABW) with two significant flows. One flow originates from the Weddell Sea, filling the western basins of the Indian Ocean. The other flow originates from the Adelie Land coast/Ross Sea and filling the eastern basins[28,29]. Both waters flow northward, and in the northern basin, they gradually upwell to form the overlying Indian Deep Water (IDW), which occupies the depths between AAIW and AABW. Unlike AAIW and AABW, IDW is not formed in the Southern Ocean. Rather, it is a mixture of NADW carried from the Atlantic sector with Antarctic Bottom Water, forming Circumpolar Deep Water along the path into the Indian Ocean. The details of these two flow paths and mixing could create differences in the source Pb between eastern and western Indian Ocean, which are not apparent in Pb concentrations but may influence isotopic compositions which will be reported elsewhere.

In contrast, comparing the CFC concentrations from the subtropical bottom Indian Ocean[12] with those in the South Pacific and South Atlantic oceans at comparable latitudes, Indian Ocean bottom water CFC concentrations are lower, consistent with its high dissipation rates from tidal mixing and current fluctuations.

The generally high dilutions and low CFC concentrations in bottom water of the Indian Ocean result from their distance to the water mass source regions and the relative effectiveness of mixing. In contrast, for Pb in the Southern Indian Ocean, near-bottom Pb concentrations are comparable to those observed in the South Pacific and South Atlantic at similar latitudes. At 23°S and 4000m we observe 5.2 pmol/Kg in the Indian Ocean and 4.6 pmol/Kg in the Pacific Ocean (28°S, 88°W) and at 20°S and 4000m we observe 7.3 pmol/Kg in the Indian Ocean and the same concentration in the Western Atlantic Ocean (19°S, 34°W).

In conclusion, at this time, the upper waters of the north and central Indian Ocean show extremely high Pb concentrations resulting from anthropogenic emissions from recent regional rapid industrialization and a late phase-out of leaded gasoline. The contemporary Antarctic sector of the Indian Ocean shows very low concentrations due to limited regional anthropogenic Pb emissions, high scavenging rates, and rapid vertical mixing, although these concentrations are probably somewhat higher than they would have been in preindustrial times. There is only limited penetration of anthropogenic Pb into the northern and central Indian Ocean upper waters because of limited ventilation dominated by water derived from the low-Pb Southern Hemisphere, although there is a small Pb maximum associated with the Antarctic Intermediate water. Pb concentrations in the deep Indian Ocean are comparable to those in the South Atlantic and South Pacific at the same latitude, and the deep waters of the central Indian Ocean match the lowest Pb concentrations observed anywhere in the ocean, due to low initial Pb concentrations in the source waters and scavenging of Pb along the flow path. It should be expected

that the continued evolution of human activities around the Indian Ocean will lead to a continuing evolution of the anthropogenic footprint of Pb on the ocean.

Material and Methods

Sample collection information: samples were obtained during the Japanese Indian Ocean GEOTRACES cruise (KH09-5, November to December 2010), which collected Pb samples from 11 stations from the Bay of Bengal, Arabian Sea, to the Antarctic Circumpolar water (62°S, Figure 1). Seawater samples for Pb analysis were collected from 11 stations using a CTD carousel with an Epoxy-coated Al frame and Teflon-coated Niskin-X bottles (General Oceanics, 12 L-type), which were thoroughly cleaned by soaking in 1.5% Extran MA01 (EMD Millipore), 0.1M HCl, and high-purity water. Upon retrieval, Niskin-X bottles were transferred into a HEPA-filtered air "bubble", and seawater samples were pressure-filtered through 0.2 μm-size capsule filters (Pall Scientific, AcroPak 200). Filtered samples were acidified to pH 2.0 on board with clean HCl and shipped to MIT for analysis.

Pb analysis: Total Pb concentration was analyzed by the NTA ID-ICPMS method described by Lee et al.[11]. Acid-leached 1.5 mL vials were used. The acidified seawater sample was poured into the vial and 1.3 mL of the sample was pipetted out using a clean pipette tip. The 1.3 mL sample in the pipette tip was pipetted back into the same vial after quickly emptying the vial. Then, the sample was spiked with 25 μL of stable ^{204}Pb isotope spike and left for a few minutes to establish equilibrium between added isotope spikes with their natural isotopes in the samples. Then, the

pH of the sample was adjusted to pH=5.3 using ammonium acetate buffer solution (pH= 7.9-8.0). Finally, 150 μL of a NTA resin suspension (2400 beads) were added to the vial and it was shaken on an orbital table at 2000 rpm for 4 days to allow the Pb and resin to bind. After 4 days, the sample vial was centrifuged (for 45 seconds at 14,500 rpm) and the overlying seawater was siphoned off carefully, leaving the resin beads at the bottom. The resin beads were then rinsed three times with high purity H_2O to remove seasalt. In each rinse, the vial was filled with high purity water, centrifuged down, and the supernatant was siphoned off. After rinsing, 150 μL of 0.5 M HNO_3 were added to the vial, and then two days allowed for Pb to be released into solution. The final solution was then brought to the ICPMS for measurement of the isotope ratio ($^{208}Pb/^{204}Pb$) of this solution (after on-peak zero acid blank correction) which is used to calculate the Pb concentration. Exactly 0.3 mL of low-Pb seawater was used to determine the procedure blank. At least three replicates of each sample were measured. Above the detection limit, the precision of the data is about 3% based on a long-term standard with 32 pmol/Kg. The detection limit (3σ of the std. dev. of low concentration samples) is about 1.5 pmol/Kg. By comparison, of the only other publications reporting Pb data from the Indian Ocean, one only reported data as low as 0.01 nM[30], a concentration that exceeds that found in 40% of the samples in this data set, and the other publication only plotted overlain profiles from some stations in a supplementary figure with no discussion of the data[31].

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FIGURE LEGENDS

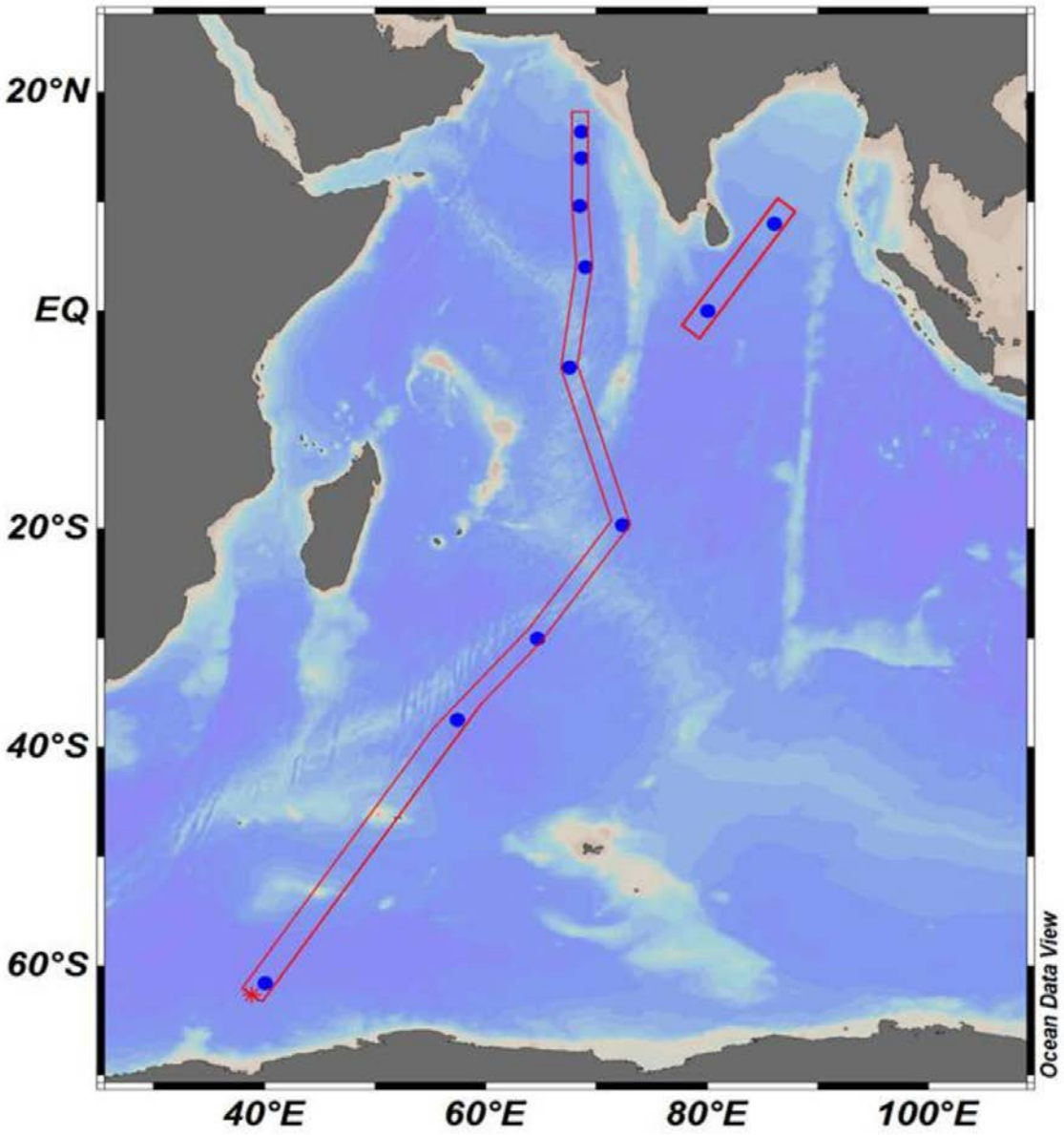
Figure 1: Map showing station positions and indicating section segments.

Figure 2: Seawater dissolved Pb section (north-south transects) in the Indian Ocean.

Figure 3: Vertical Pb profile data from stations in the Indian Ocean.

Figures

Figure 1: Map showing station positions and indicating section segments



358 Figure 2: Seawater dissolved Pb section (north-south transect) in the Indian

359 Ocean.

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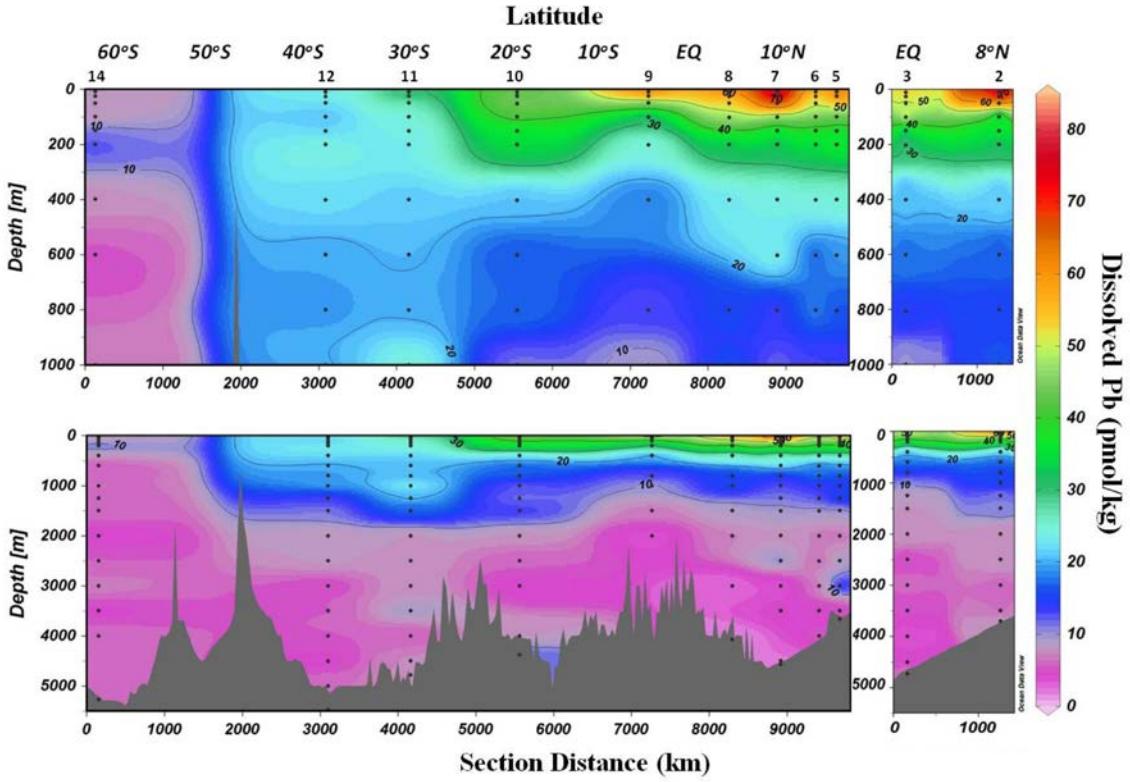

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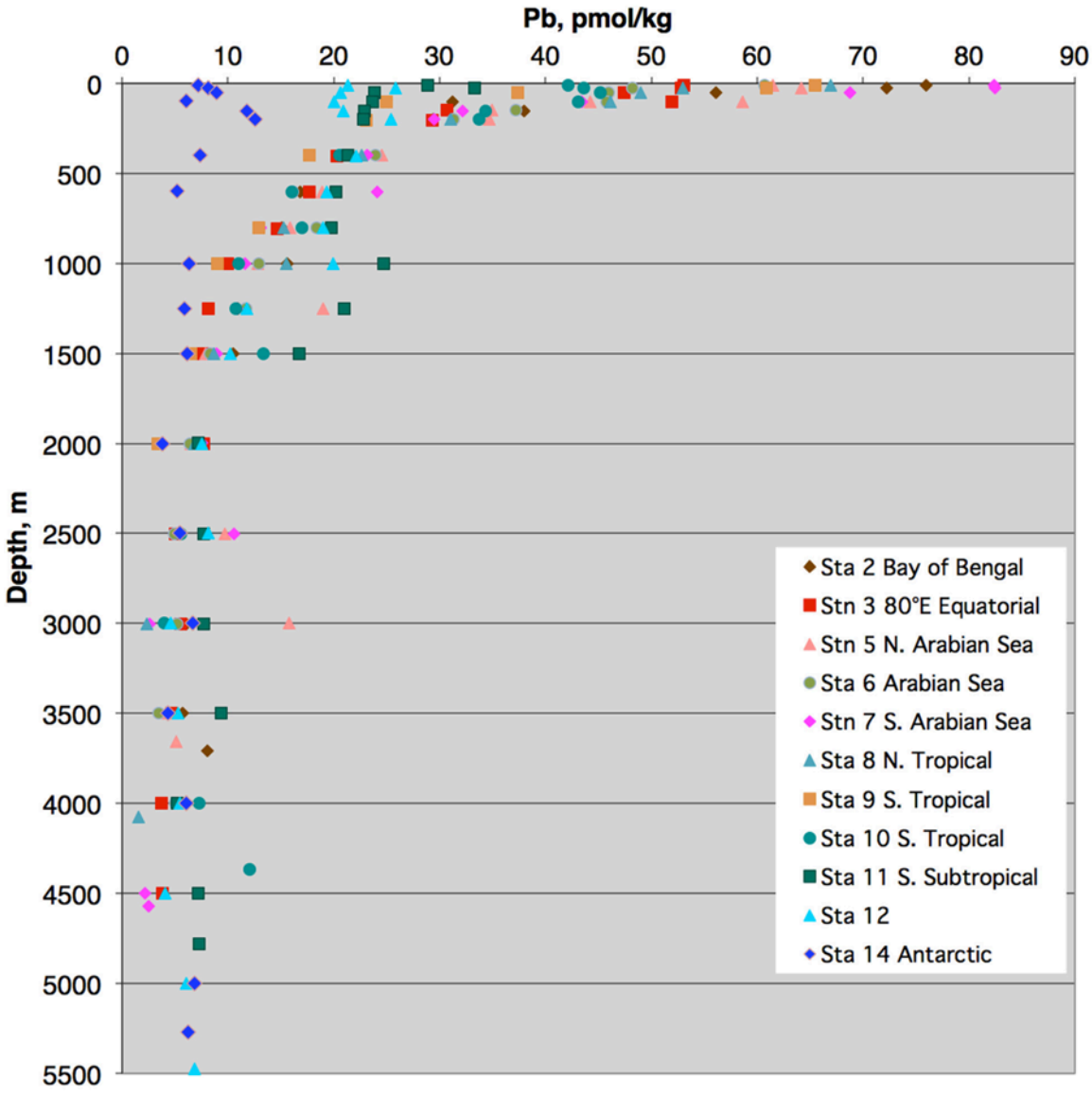
363 Figure 3: Vertical Pb profile data from stations in the Indian Ocean.



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Station	"Latitude, Longitude"	"pressure, dbar"	"Pb, pmol/kg"		
	s.d.	n			
2	"08°31.10'N, 86°01.55'E"	11	75.9	1.2	3
2		26	72.2	1.4	3
2		50	56.1	1.2	3
2		100	31.2	0.6	2
2		151	38	0.7	3
2		201	29.4	0.2	2
2		401	21.2	0.1	2
2		601	16.8	0.3	3
2		802	15.1	1.2	3
2		999	15.6	4.1	2
2		1250	10.9	0.6	3
2		1500	10.5	0.3	2
2		2000	7.2	1.2	3
2		2501	7.7	0.3	3
2		3001	6.1	0.2	3
2		3500	5.8	0.4	2
2		3706	8.1	0.4	2

Station	"Latitude, Longitude"	"pressure, dbar"	"Pb, pmol/kg"		
	s.d.	n			
3	"00°00.34'S, 80°00.38'E"	11	53	1.3	3

389	**3**		**26**	**52.8**	**0.3**	**2**
390	**3**		**51**	**47.4**	**1.1**	**3**
391	**3**		**101**	**51.9**	**0.3**	**3**
392	**3**		**150**	**30.7**	**1.6**	**3**
393	**3**		**203**	**29.3**	**1**	**3**
394	**3**		**403**	**20.3**	**0.4**	**2**
395	**3**		**601**	**17.6**	**1.6**	**3**
396	**3**		**808**	**14.6**	**0.2**	**3**
397	**3**		**1002**	**10**	**0.3**	**3**
398	**3**		**1251**	**8.1**	**0.3**	**2**
399	**3**		**1504**	**7.6**	**0.5**	**3**
400	**3**		**2001**	**7.7**	**0.6**	**2**
401	**3**		**2501**	**5.1**	**1.6**	**2**
402	**3**		**3002**	**5.6**	**0.2**	**2**
403	**3**		**3501**	**4.7**	**0.1**	**2**
404	**3**		**4000**	**3.7**	**0.8**	**3**
405	**3**		**4500**	**3.8**	**0.9**	**3**
406	**3**		**4730**	**7**	**1.4**	**3**
407						
408	**Station**		**"Latitude, Longitude"**		**"pressure, dbar"**	**"Pb, pmol/kg"**
409		**s.d.**	**n**			
410	**5**		**"16°44.58'N, 68°59.72'E"**	**10**	**61.5**	**2.6** **2**
411	**5**		**25**	**64.2**	**2.9**	**2**

412	**5**		**100**	**44.2**	**6.2**	**3**
413	**5**		**150**	**34.9**	**0.7**	**3**
414	**5**		**100**	**58.6**	**1.8**	**3**
415	**5**		**201**	**34.7**	**1.5**	**3**
416	**5**		**400**	**24.6**	**0.2**	**2**
417	**5**		**602**	**18.9**	**0.9**	**3**
418	**5**		**803**	**15.9**	**0.9**	**3**
419	**5**		**1002**	**12.9**	**3.5**	**2**
420	**5**		**1250**	**19**	**0.6**	**2**
421	**5**		**1500**	**7.9**	**0.6**	**3**
422	**5**		**2001**	**6.5**	**0.8**	**2**
423	**5**		**2501**	**9.7**	**0.7**	**2**
424	**5**		**3000**	**15.8**	**1**	**2**
425	**5**		**3500**	**4.3**	**0.4**	**2**
426	**5**		**3658**	**5.1**	**0.4**	**3**
427						
428	**Station**		**"Latitude, Longitude"**		**"pressure, dbar"**	**"Pb, pmol/kg"**
429		**s.d.**	**n**			
430	**6**	**"14°00.12'N, 68°59.45'E"**		**1**	**60.7**	**0.5**	**3**
431	**6**		**2**	**48.2**	**1.4**	**2**
432	**6**		**5**	**45.9**	**1.3**	**3**
433	**6**		**100**	**45.8**	**0.7**	**3**
434	**6**		**150**	**37.2**	**0.8**	**2**

435	**6**		**200**	**31.3**	**0.8**	**4**
436	**6**		**401**	**23.9**	**0.6**	**3**
437	**6**		**604**	**16.1**	**1.2**	**2**
438	**6**		**801**	**18.4**	**0.5**	**2**
439	**6**		**1000**	**12.9**	**0.3**	**2**
440	**6**		**1253**	**11.7**	**1.1**	**3**
441	**6**		**1504**	**8.3**	**1.3**	**2**
442	**6**		**2004**	**6.4**	**0.7**	**3**
443	**6**		**2501**	**4.9**	**0.7**	**3**
444	**6**		**3001**	**5.2**	**0.6**	**3**
445	**6**		**3501**	**3.4**	**0.4**	**2**
446	**6**		**4001**	**5**	**0.4**	**3**
447						
448	**Station**	**"Latitude, Longitude"**		**"pressure, dbar"**		**"Pb, pmol/kg"**
449		**s.d.**	**n**			
450	**7**	**"09°59.88'N, 68°44.79'E"**	**11**	**82.4**	**0.1**	**2**
451	**7**		**26**	**82.4**	**2**	**2**
452	**7**		**51**	**68.7**	**3.2**	**2**
453	**7**		**101**	**43.5**	**1.9**	**3**
454	**7**		**151**	**32.1**		**1**
455	**7**		**201**	**29.4**	**1.2**	**3**
456	**7**		**400**	**23.1**	**1.4**	**2**
457	**7**		**601**	**24.1**	**1.9**	**3**

458	**7**		**802**	**13.1**	**0.1**	**2**
459	**7**		**1003**	**11.6**	**1.1**	**3**
460	**7**		**1251**	**10.9**	**0.7**	**2**
461	**7**		**1504**	**8.9**	**1.5**	**2**
462	**7**		**1997**	**7.6**	**1.8**	**2**
463	**7**		**2501**	**10.6**	**0.7**	**2**
464	**7**		**3004**	**2.6**	**0.3**	**3**
465	**7**		**3501**	**4.2**	**0.6**	**2**
466	**7**		**4000**	**6**	**1.5**	**2**
467	**7**		**4500**	**2.1**	**0.4**	**2**
468	**7**		**4570**	**2.5**	**0.2**	**2**
469						
470	**Station**		**"Latitude, Longitude"**		**"pressure, dbar"**	**"Pb, pmol/kg"**
471		**s.d.**	**n**			
472	**8**	**"04°00.83'N, 69°00.42'"**	**1**	**66.9**	**2.5**	**3**
473	**8**		**2**	**53**	**1.1**	**3**
474	**8**		**5**	**49**	**0.4**	**2**
475	**8**		**100**	**46.1**	**2.8**	**3**
476	**8**		**200**	**31**	**3.7**	**3**
477	**8**		**401**	**22.6**	**2.4**	**2**
478	**5**		**602**	**18.4**	**0.4**	**2**
479	**8**		**801**	**15.3**	**2.1**	**2**
480	**8**		**1001**	**15.5**	**2.4**	**4**

8		**150**	**8.7**	**0.9**	**3**
8		**200**	**6.8**	**0.8**	**2**
8		**300**	**2.3**	**0.2**	**3**
8		**407**	**1.5**	**0.3**	**2**

Station	**"Latitude, Longitude"**	**"pressure, dbar"**	**"Pb, pmol/kg"**		
	s.d.	**n**			
9	**"05°16.01'S, 67°54.25'E"**	**1**	**65.4**	**5.2**	**2**
9		**2**	**60.9**	**1.4**	**3**
9		**5**	**37.4**	**0.9**	**2**
9		**10**	**24.9**	**0.4**	**3**
9		**20**	**23.1**	**0.9**	**3**
9		**40**	**17.6**	**2.7**	**2**
9		**80**	**12.9**	**1.1**	**2**
9		**100**	**9**	**2.4**	**2**
9		**150**	**6.5**	**1.4**	**2**
9		**200**	**3.3**	**0.9**	**2**

Station	**"Latitude, Longitude"**	**"pressure, dbar"**	**"Pb, pmol/kg"**		
	s.d.	**n**			
10	**"19°59.63'S, 72°32.67'E"**	**11**	**42.1**	**1.1**	**2**
10		**25**	**43.6**	**2**	**3**
10		**51**	**45.2**	**1.2**	**2**

504	**10**		**101**	**43.1**	**1.7**	**2**
505	**10**		**151**	**34.3**	**0.7**	**2**
506	**10**		**200**	**33.7**	**0.8**	**2**
507	**10**		**400**	**20.5**	**1.1**	**4**
508	**10**		**601**	**16.1**	**0.2**	**2**
509	**10**		**800**	**17**	**0.2**	**2**
510	**10**		**1001**	**11**	**0.2**	**3**
511	**10**		**1251**	**10.8**	**1.1**	**2**
512	**10**		**1501**	**13.3**	**2**	**3**
513	**10**		**2000**	**7.4**	**0.6**	**2**
514	**10**		**2502**	**5.6**	**1.6**	**2**
515	**10**		**3000**	**4**	**1.6**	**3**
516	**10**		**3500**	**12.1**		**1**
517	**10**		**4001**	**7.3**	**1.6**	**2**
518	**10**		**4367**	**12**	**2**	**2**
519						
520	**Station**	**"Latitude, Longitude"**		**"pressure, dbar"**		**"Pb, pmol/kg"**
521		**s.d.**	**n**			
522	**11**	**"30°00.02'S, 64°59.93'E"**	**10**	**28.8**	**1.6**	**3**
523	**11**		**25**	**33.3**	**1**	**3**
524	**11**		**50**	**23.8**	**1.3**	**3**
525	**11**		**100**	**23.7**	**2.2**	**2**
526	**11**		**151**	**22.8**	**1.3**	**2**

527	**11**		**199**	**22.8**	**1**	**3**
528	**11**		**400**	**21.3**	**0.5**	**2**
529	**11**		**601**	**20.2**		**1**
530	**11**		**800**	**19.8**	**0.1**	**2**
531	**11**		**1001**	**24.7**	**6**	**2**
532	**11**		**1252**	**21**	**3.2**	**2**
533	**11**		**1500**	**16.7**	**2**	**2**
534	**11**		**1999**	**7.2**	**0.3**	**2**
535	**11**		**2501**	**7.7**	**2.8**	**2**
536	**11**		**3001**	**7.7**	**3.2**	**2**
537	**11**		**3501**	**9.4**	**0.2**	**2**
538	**11**		**4001**	**5.2**	**1.4**	**2**
539	**11**		**4500**	**7.2**	**0.3**	**2**
540	**11**		**4782**	**7.3**	**2.2**	**2**
541						
542	**Station**	**"Latitude, Longitude"**		**"pressure, dbar"**		**"Pb, pmol/kg"**
543		**s.d.**	**n**			
544	**12**	**"37°45.14'S, 57°37.13'E"**	**11**	**21.3**	**3.1**	**2**
545	**12**		**25**	**25.9**	**1.4**	**2**
546	**12**		**50**	**20.6**	**0.7**	**2**
547	**12**		**100**	**20**	**1.1**	**2**
548	**12**		**151**	**20.9**	**1.6**	**2**
549	**12**		**200**	**25.4**	**3**	**2**

550	**12**		**402**	**22.1**	**4**	**2**
551	**12**		**601**	**19.3**	**2.6**	**2**
552	**12**		**801**	**19**	**0.9**	**4**
553	**12**		**1000**	**20**	**1.8**	**3**
554	**12**		**1251**	**11.8**	**1.6**	**2**
555	**12**		**1500**	**10.2**	**0.2**	**2**
556	**12**		**2001**	**7.6**	**0.6**	**2**
557	**12**		**2500**	**8.1**	**3**	**2**
558	**12**		**3000**	**4.5**	**2.8**	**2**
559	**12**		**3499**	**5.3**	**3.5**	**2**
560	**12**		**4001**	**5.4**	**0.7**	**3**
561	**12**		**4499**	**?32.3**	**4.6**	**2**
562	**12**		**4501**	**4.1**		**1**
563	**12**		**5001**	**6.1**	**0.9**	**3**
564	**12**		**5473**	**6.8**	**1.3**	**2**
565						
566	**Station**	**"Latitude, Longitude"**		**"pressure, dbar"**		**"Pb, pmol/kg"**
567		**s.d.**	**n**			
568	**14**	**"61°59.95'S, 40°05.98'E"**	**10**	**7.2**	**0.7**	**2**
569	**14**		**26**	**8.1**	**2.4**	**4**
570	**14**		**51**	**8.9**	**1.8**	**3**
571	**14**		**99**	**6**	**0.2**	**2**
572	**14**		**152**	**11.7**	**1**	**2**

573	**14**	**201**	**12.6**	**0.9**	**2**
574	**14**	**399**	**7.3**	**2.3**	**2**
575	**14**	**599**	**5.2**	**1.5**	**2**
576	**14**	**1001**	**6.3**	**0.5**	**2**
577	**14**	**1250**	**5.9**	**0.8**	**2**
578	**14**	**1500**	**6.2**	**1.7**	**2**
579	**14**	**2002**	**3.8**	**1.2**	**2**
580	**14**	**2500**	**5.5**	**4.4**	**2**
581	**14**	**2999**	**6.7**	**0.2**	**2**
582	**14**	**3501**	**4.3**	**1.5**	**2**
583	**14**	**4001**	**6.1**	**1.1**	**2**
584	**14**	**4499**	**?32.4**	**3.2**	**3**
585	**14**	**5000**	**6.9**	**0.6**	**2**
586	**14**	**5271**	**6.2**	**1.7**	**3**