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Anomalous Levels of Heavy Metals in Sediments from Guaymas Bay, Mexico

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Guaymas Bay (27°55'N, 110°52'W) is located in the state of Sonora on the eastern shores of the Gulf of California, México. The harbor contains many urban activities. There are about 1000 types of boats and 63 effluents from industrial and municipal wastewater supplying pollutants into the marine environment (Arreola-Lizárraga et al. 2001). Dock activities that cause accidental contamination of the bay include copper, fuel, pesticides, and industrial additives. There are 25 fish processing plants along the bay, which over many years, discharged wastewater with contaminants that contribute to eutrophication of the marine sediment and bioavailability of metals (Méndez et al. 2002). This study evaluated the degree of contamination by heavy metals in marine sediments in Guaymas Bay using a geo-accumulation index.

MATERIALS AND METHODS

Sediment samples at 25 stations were obtained with a Van Veen grab (Figure 1), using a GPS Magellan 315 for locating stations, which were chosen for their proximity to potential pollution sources. The samples taken were stored in polyethylene bottles previously decontaminated with nitric acid and kept frozen until chemical analysis. Grain size distribution was evaluated using calibrated sieves (Folk 1974).

For heavy metal analysis, the sample fraction smaller than 65μm was used. Total digestion was carried out in Teflon beakers using nitric and hydrofluoric acids (proportion 3:1) (Van Loon 1985). An atomic spectrophotometer (BUCK Scientific #200A) using flame air/acetylene was used to determine the amount of copper, zinc, nickel, cadmium, manganese and lead present. Metal recovery was between 95 and 102%. Validation of the analytical procedure was determined with samples of marine sediments from the National Research Council of Canada and reference (BCSS-1, MESS-2, and PACS-1), which are from the Gulf of St. Lawrence, Beaufort Sea, and Esquimalt Bay, B.C., respectively.

These standards were also used to evaluate the level of contamination of the sediment samples. BCSS-1 and MESS-2 are sediments with low and moderate pollution, while PACS-1, is considered as polluted area. A second approach for

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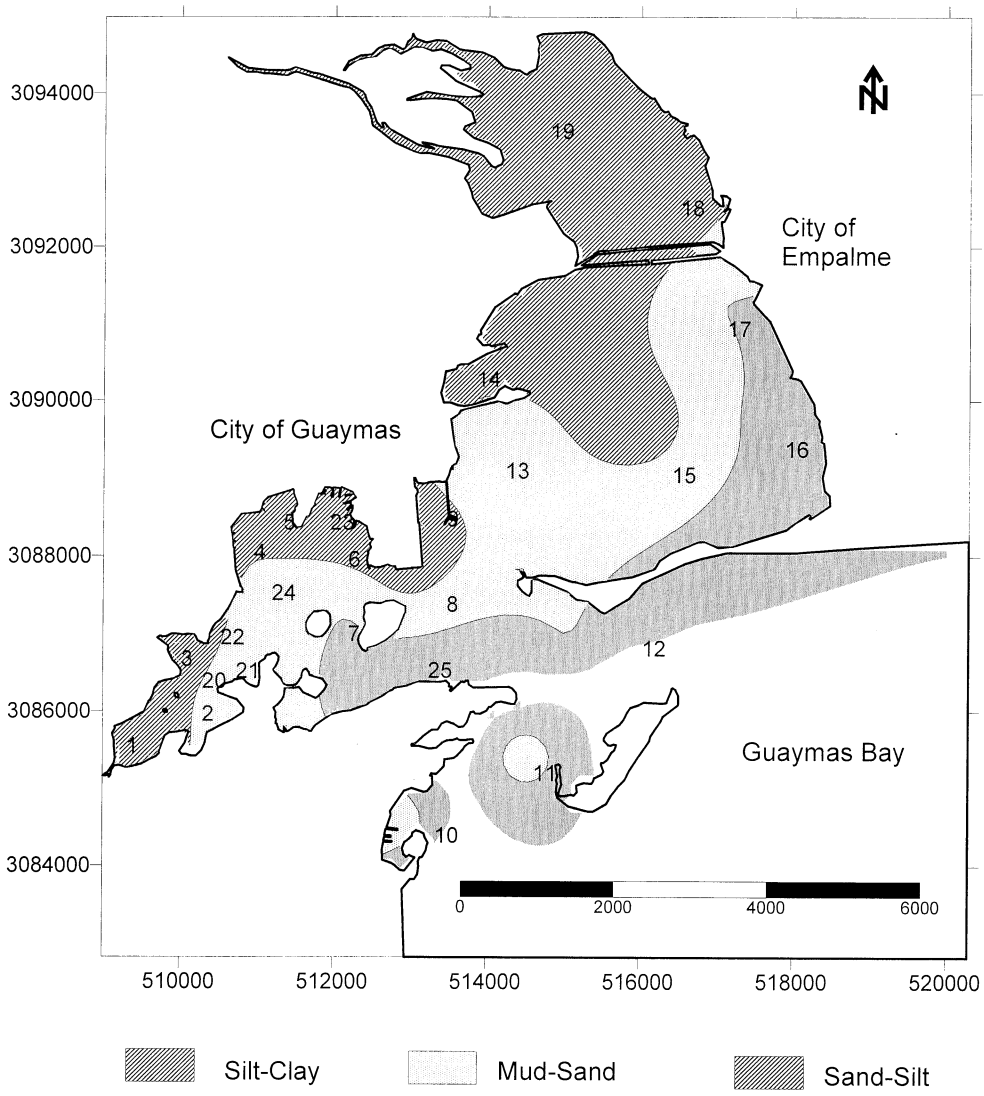

Figure 1. Location of sampling stations in Guaymas Bay, Sonora, México and texture of sediments (UTM grid coordinates used).

evaluating the level of heavy metal contamination is the geo-accumulation index (Müller 1979), which is:

$$Igeo = \log ([M]i/(1.5([M]r)$$

where, [M]i and [M]r are concentrations of heavy metals in the area studied and the mean of the element in the terrestrial matrix.

RESULTS AND DISCUSSION

Levels of copper, manganese, zinc, lead, nickel, and cadmium are shown in Table 1.

The highest concentrations of copper were 295, 339, and 275 μg/g at stations 6, 8, and 9, respectively (Figure 1). Station 8, is in front of the main dock in which several types of materials as copper, grain, and various chemical compounds are unloaded. The BCSS-1 and MESS-2 standards have copper concentrations between 18.5 and 39.3 μg/g, lower than the concentrations in Guaymas Bay. The PACS-1 standard has 452 ± 16 μg/g copper, higher than any sample in this study.

According to the index of geo-accumulation (I_{geo}; Müller 1979), only the area surrounding station 8 (I_{geo} = 2.03) would be classified as moderately to highly polluted with copper. Stations 4, 5, 6, 9, 21, and 25, with I_{geo} between 1.08 and 1.83, have moderate pollution with copper.

Copper is associated with fine sediment particles and organic matter (Green-Ruiz 2000). High levels of copper are associated with dumping of municipal wastewater, hydrocarbons, and boat repairs (Leoni and Sartori 1996; Shriadah 1998; Gibbs and Guerra 1997). The highest copper concentrations were found in silt and clay sediments.

The highest concentrations of zinc were recorded at stations 5, 10, and 24 (Figure 1), with 476, 359and 366 μg/g, respectively. Remaining stations show zinc concentrations close at those reported for MESS-2 and BCSS-1 (172 ± 16 and 119 ± 12 μg/g). The concentrations reported for PACS-1 is 824±22 μg/g, almost double the highest concentrations obtained in this study. Stations 5 and 24 are near dumping sites of municipal wastewater and station 10 is an important area of industrial activities (Green 2000; Ruelas-Inzunza 1998).

Only station 5 (I_{geo} = 2.18) is classified as an area with moderate to strong zinc pollution, and stations 4, 6, 10, and 24 are classified as moderately polluted with zinc (I_{geo} of 1.05 to 1.80). No relationship was found between particle size and concentration of zinc.

The highest concentration of manganese was recorded at station 9 (247 μg/g). All other stations recorded manganese typical of sediments with low to moderate levels of pollution, according the MESS-2 and BCSS-1 standard, (365 and 229 μg/g zinc, respectively). None station is considered by I_{geo} as being contaminated with manganese.

The highest concentration of nickel (58.5μg/g) was recorded at station 14 near the dock serving CFE and PEMEX (Electricity Federal Commission and Mexican Petroleum). Remaining stations recorded similar or lower concentrations of nickel than the MESS-2, BCSS-1, and PACS-1 standards (49.3 ± 1.8, 55.3 ± 3.6, and 44.1 ± 2.0 μg/g, respectively). With the low concentrations in PACS-1, it was now

Table 1. Concentrations of copper, manganese, zinc, lead, nickel, and cadmium (μg/g dry weight) in sediments from Guaymas Bay, Sonora.

Station	Cu	Mn	Zn	Pb	Ni	Cd
1	18.9	81.2	54.7	25.7	4.9	0.4
2	129	120	192	49.9	11	0.3
3	69.8	92.8	126	48.2	7.0	1.8
4	175	120	219	14.5	14.9	1.8
5	235	130	477	81.0	28.5	4.8
6	295	146	229	46.3	26.9	4.9
7	77.6	115	109	36.6	15.4	0.60
8	339	177	135	36.3	26.5	1.8
9	275	247	111	30.8	28.4	0.70
10	90.8	151	360	56.5	32.3	5.1
11	45.9	144	35.5	23.7	17.0	2.5
12	4.7	45.7	19.7	6.4	10.2	1.6
13	107	179	87	26.6	31.0	3.9
14	78.0	135	72.7	26.3	58.5	2.9
15	41.8	192	59.9	20.3	28.1	2.5
16	5.1	12.2	3.4	11.4	11.3	1.2
17	32.9	203	40.2	25.1	26.7	2.8
18	25.7	156	32.9	27.2	24.6	2.3
19	25.9	138	37.8	20.3	23.2	2.2
20	93.6	134	202	47.4	16.3	0.88
21	219.6	95.8	206	70.0	18.1	0.87
22	124	114	195	59.8	17.8	ND
23	76.7	183	100	29.9	14.9	0.92
24	138	177	367	49.9	25.4	4.1
25	183	104	199	50.2	17.6	1.18

ND= Not Detected

used for comparison with our results. No station was considered as contaminated with nickel using the I_{geo}.

The highest concentration of lead (81 μg/g) was recorded at station 5, close to the dumping out of municipal wastewater. This value is higher than the highest concentration reported by Hosch (1996), which was 69.19μg/g. The PACS-1 standard (404 ± 20 μg/g) was almost five times higher than the highest concentration in Guaymas Bay. The remaining stations are in agreement with levels reported by Hosch (1996), but are higher than the concentrations of lead reported in the MESS-2 and BCSS1 standards (21.9 ± 1.2 and 22.7 ± 3.4 μg/g, respectively).

The three stations with the highest concentrations of zinc are the same ones with the highest concentrations of lead. A significant correlation ($r = 0.81$; $P < 0.001$) was found between these elements.

According to the I_{geo}, station 5 is moderately to strongly contaminated by lead (I_{geo}=2.10). Stations 2, 3, 6, 10, 20, 21, 22, 24, and 25 are moderately polluted by lead (I_{geo} = ranging from 1.33 to 1.90).

The highest concentration of cadmium (5.1 μg/g) was recorded at station 10, near the canning factories. This concentration is higher than the PACS-1 standard (2.38 ± 0.20μg/g). Stations 5, 6, 13, 14, and 24 also have higher concentrations than PACS-1. The values reported by MESS-2 and BCSS-1 (0.24 ± 0.01 and 0.25 ± 0.04 μg/g, respectively) are 10 times lower than the highest level of cadmium measured in this study. Hosch (1996) did not analyze sediments near the canning factories and reported a site near the main dock having 2.36μg/g. This area (station 6) is the second most polluted station, after station 5. Both stations have the twice of the levels reported by Hosch (1996) (Table 1). Most of the high concentrations of cadmium were found in areas with the fine particle size.

Stations 5, 6, and 10, with an I_{geo} = 4, 4.04, and 4.09, respectively, are very strongly polluted by cadmium. Stations 11, 13, 14, 15, and 17, with I_{geo} = ranging from 3.04 to 3.76, are strongly to very strongly polluted by cadmium. Stations 3, 4, 8, 12, 16, 18, and 19, with I_{geo} ranging from 2.37 to 2.96, moderately to strongly polluted, and stations 9, 20, 23, and 25 with I_{geo} ranging from 1.15 to 1.97 are moderately polluted by cadmium. Further studies are required to evaluate the origin of this element. Several studies have reported elevated levels of cadmium in sediments (Méndez et al. 1998), mussels (Méndez et al. 2002) plankton (Martín and Broenkow 1975), and insects (Cheng et al. 1976) collected along the Baja California Peninsula.

According to the Geo-accumulation Index, the level of pollution with copper, zinc, and lead in some areas of Guaymas Bay are from moderate to high, while the level of cadmium in the bay is very high.

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