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Lead contamination in the Mexican Caribbean recorded by the coral *Montastraea annularis* (Ellis and Solander)

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Evidence from worldwide environmental contamination by lead, as a result of anthropogenic emissions, has been documented. According to lead measurements made in Greenland's ice and snow in the mid 1960s, over 99% of the lead in the global troposphere of the Northern hemisphere was anthropogenic (Murozomi et al., 1969; Robinson and Robbins, 1971). However, Boutron et al. (1991) found that, as a result of recent limited use of leaded gasoline by the US, Canada, and the European countries, lead concentrations in recently deposited Greenland snow decreased by a factor of 7.5 since the 1970s. Shen and Boyle (1987) found the same decreasing trend in North Atlantic sea water. During the seventies the northeastern coast of the Yucatan Peninsula experienced explosive human development resulting from growth of the tourist center, Cancun. Since its establishment, dredging and land clearing activities have been continually performed, and Cancun Island, the hotel center, has been expanded with large amounts of sand taken from nearby localities, and from the sea, to foster development (Marti, 1985; Dachary and Burne, 1986). The coastal population increased from one family to more than 357,000 inhabitants, with nearly 2.3 million visitors annually, in three decades (INEGI, 1997).

To assess lead contamination resulting from this explosive human development in the northeastern part of the Yucatan Peninsula, a lead chronology based on the analysis of lattice-bound lead concentrations in an annually banded scleractinian coral from Cancun, was determined. A similar chronology was obtained from coral collected in a pristine area located on the southeast coast of the Peninsula.

Specimens of the scleractinian coral *Montastraea annularis*, *sensu* Weil and Knowlton (1994), were collected from Cancun (21°02′ N–86°45′ W) in September 1998, and Majahual's fishermen village (18°42′ N; 87°42′ W). Both were analysed for annual Pb/Ca ratios (Fig. 1).

Specimens were cut with a water lubricated diamond saw along the coral's maximum growth axis to obtain slices 6–8 mm thick. The slices were X-rayed following Buddemeier et al. (1974) and Hudson (1981) to expose the annual growth bands (Fig. 2). The upper growth band was assigned to the year 1998 for both specimens. Coral annual samples were obtained with a Dremel drill. In order to eliminate contamination from handling and coral-detritus, samples were washed with 0.1 N ultrapure nitric acid in an ultrasonic bath, heated to 50 °C and rinsed with distilled water. Losses due to dissolution of the sample and decantation of the supernatant, were less than 30%.

Samples were dissolved with concentrated ultrapure nitric acid to a final pH of 4, and made up to volume

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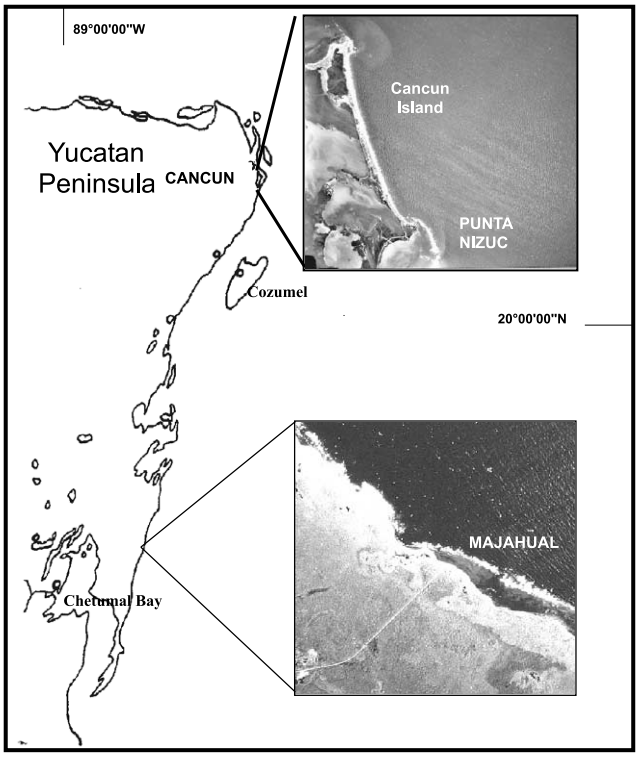

Fig. 1. Sampling sites of the coral specimens. Aerial Photogtraphs provided by INEGI.

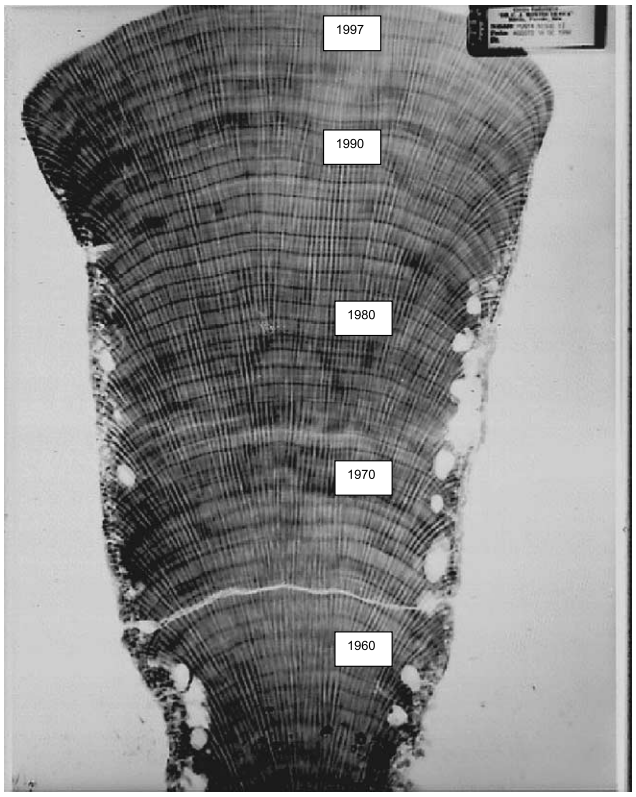

Fig. 2. Positive of a X-ray from the Cancun coral slice. Each annual growth band consists of a dark and a white adjacent band.

with 1% ultrapure nitric acid. Calcium was determined by EDTA titration using Murexide as color indicator (APHA, 1998). Lead was analyzed by chelation with ammonium pyrrolidine dithiocarbamate (APDC) and extracted with methyl isobutyl ketone (MIBK) (APHA, 1998). Standard solutions and blanks were extracted and the absorbancies (three readings from each one) were compared with those of the non-extracted standard and blank solutions. Extractions were 100% efficient in these solutions. Recovery of the coral samples was $77.3 \pm 13.2\%$ ($n = 10$). The coefficient of within-sample variation was $< 6\%$ ($n = 60$).

Fig. 3 shows the Pb/Ca mole ratio values for the colonies collected in Cancun (1960–1998) and in Ma-

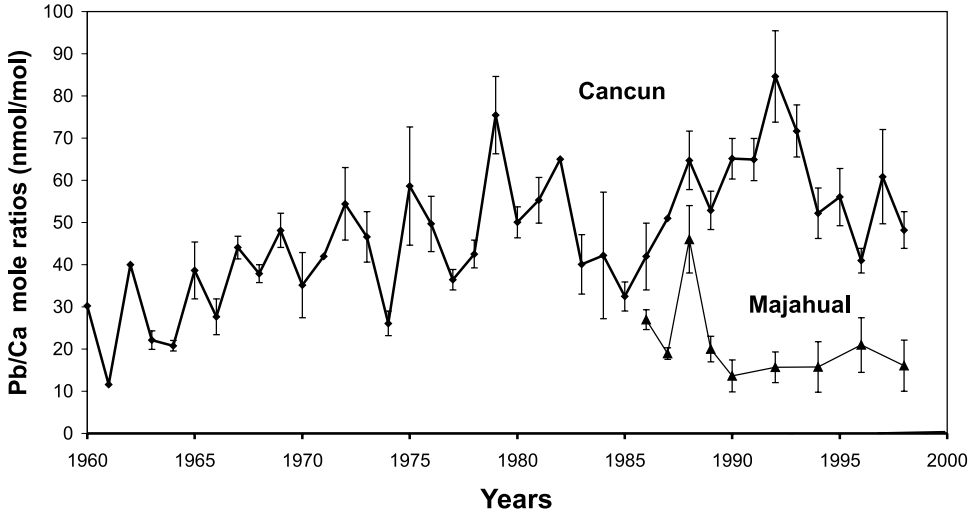

Fig. 3. Analytic results of the Pb/Ca mole ratio of each dated sample from the Cancun's (1960–1998) and Majahual's (1986–1998) specimens. In most cases the points represent duplicate measurements. Bars represent the standard error and the absence in certain years is due to failed extractions.

jahual (1986–1998). Cancun showed values consistently higher than those registered in Majahual for the same period of time (from 1986 to 1998). This difference is significative statistically (Kruskal–Wallis $H = 14.29$; $p = 0.0005$). Lead concentrations in Cancun increased significantly with time, from 1960 to 1992, according to the following regression:

$$\text{nmol Pb/mol Ca} = -1701.01 + 0.8834\ (\text{year})$$
$$(p < 0.01; r^2 = 0.64).$$

From 1992 to 1998 lead concentrations decreased. The average value obtained in Majahual (21 nmol Pb/mol Ca) was smaller than that obtained in Cancun for the 1960s (32 nmol Pb/mol Ca) (Kruskal–Wallis $H = 4.3$; $p = 0.0369$).

Since the measured Pb/Ca mole ratio values in the Cancun sample are greater than those measured in Majahual during the same period of time, we suggest that the northeastern coast of the Yucatan Peninsula is contaminated with lead, resulting from the explosive human development since the early seventies. Several human activities with potential to cause the observed contamination are: (1) dredging and filling activities to accommodate urban services and to enlarge Cancun island (Marti, 1985); (2) land clearing activities, and burning, to create the city of Cancun, and the other tourist centers being developed along the northeastern coast (Dachary and Burne, 1986); (3) huge population increase, resulting in a increased aquatic activities and number of automobiles (INEGI, 1997; Muñoz-Chaguín et al., 1998), and (4) sewage discharges known to contain heavy metals, particularly lead and copper (Clark, 1993). An observed decrease after the maximum in 1992 (85 nmol Pb/mol Ca) way be the result of the introduction of unleaded gasolines in Mexico since the early 1990s.

The lower values obtained in Cancun in the 1960s (12–15 nmol Pb/mol Ca) and Majahual (21 nmol Pb/mol Ca) compare well with concentrations obtained in the Florida Keys (Shen and Boyle, 1987), 10 nmol Pb/mol Ca; Buck Island, St. Croix, Virgin Islands (Dodge and Gilbert, 1984), 10 nmol Pb/mol Ca in 1954 to 18 nmol Pb/mol Ca in 1980.

A decrease in the Pb/Ca ratio in corals from Cancun after 1992, from a maximum of 85 nmol Pb/mol Ca, may be the result of the introduction of unleaded gasoline in Mexico in the early 1990s, and a prohibition on the use of leaded gasoline in the mid 1990s. Similar trends have been observed in the Florida Keys and Bermuda (Shen and Boyle, 1987).

To determine the spatial dispersion of the observed contamination in Cancun, and to trace the origin of the measured lead, chemical analysis of more coral specimens from different locations within the northeastern coast of the Peninsula, together with an isotopic analysis of the coral lattice-bound lead, would be required.

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