A 20-yr Record of Sr-90 and Heavy Metals off the Third Nuclear Power Plant in Southern Taiwan

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Abstract

Porites, a species of coral with annual growth bands plays an ideal role for the reconstruction of past marine environments. Here, porites samples were collected off the Third Nuclear Power Plant in southern Taiwan. The Sr-90 activities have maintained the decreasing trend which peaked in the Northern Hemisphere in the early 60's. This suggests that Sr-90 has come mainly from atmospheric fallout. On the other hand, trace metals are mostly from land sources. Further, peaks of Cd, Cu, Rb, and Cs were found in the 1985 and 1986 growth bands, likely because of the dumping of dirt into the ocean at the site in 1985.

Introduction

Traditionally, scientists have compared recent data with data collected in previous years in order to illustrate a secular change of a certain physical or chemical parameter in the marine environment. But few early data exist and those that are available are sometimes inaccurate. As a result, the secular trend obtained is often unreliable, as evidenced by the decreasing trace metal concentrations in seawater reported in different years (Fig. 1). Investigators have also used sediments to obtain the secular change by analyzing properties of interest at various depths and by dating each sediment layer. Sediments, however, are often re-worked by physical turbulences and bioturbation. Consequently, the signal is often blurred. Banded corals may provide an alternative in recording the past environment.

The order Scleractinia, more commonly known as corals, secreted the calcium carbonate skeleton within the ectoderm of the coral polyp. Bands of varying density form within the carbonate skeleton of reef-building corals. These band pairs have been described and confirmed to be mostly, although not always, annual by Knutson et al., (1972), Patzold (1984) and Wang and Huang (1987), among others. The annual timing of the narrow high density band and a wide low density band has been used as an environmental indicator in both contemporary and paleo-communities. For example, patterns of annual banding has been used to assess the impact of long-term changes or perturbations involving sedimentation, temperature, and nutrients (Barnard et al., 1974 ; Dodge and Vaisnys, 1975 ; Hudson et al., 1976 ; Dodge and Vaisnys, 1975 ; Dodge, 1978 ; Wellington and Glynn, 1983 ; Kawahata and Suzuki, 1999).

Several investigators have also attempted, to varying degrees of success, to use banded coral skeletons to document the chronology of coastal pollution (Dodge and Gilbert, 1984 ; Dodge et al., 1984 ; Shen and Boyle, 1987, 1988 ; Shen et al, 1987 ; Chakraborty, 1993). Here we document the annual variation of trace metals and Sr-90 in coastal waters near a nuclear power plant in southern Taiwan using porites, a species of banded coral.

Material and Methods

Banded Porites samples were collected off the cooling water outlet of the Third Nuclear Power Plant, located at a pristine site at the southern tip of Taiwan. The collected coral skeletons were immersed for a week in a solution of 5% Ca (OCl) and 30% H_2O_2 to remove the soft tissue, next they were cleaned with water, sliced with a diamond-headed rock saw, X-rayed, and repeatedly ultrasonically cleaned in distilled water and soaked in dilute distilled, metal-free acid. Samples were then ground in an agate mortar and rinsed with clean acid to dissolved away half of the samples by weight in order to remove the outer layers of the particles.

A Hitachi Zeeman-Effect Z-8000 Atomic Absorption Sectrophotometer and an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) were used to measure trace metals. A Perkin-Elmer Model 2380 Atomic Absorption Spectrophotometer and the neutron activation method were used to double check part of the data. In addition, the anoxic stripping voltammeter method was used to check the accuracy of Pb measurements (Chen et al., 1986 ; Cheng, 1988). Sr-90 was measured by the Taiwan Radioactivity Detection Center.

Results

Porites show clear density bands. Within each band are clear δ C-13 and δ O-18 variations with distinct annual periodicity (Chen et al., 1999). It is interesting to note that trace metal concentrations have not shown a clear trend in the prinstive environment near Nanwan (Fig. 2). Although the Black Stream (the Kuroshio) primarily flows northward, the coastal current and eddies frequently move water southward. Semi-diurnal tidal currents in the Taiwan Strait move water northward during flood tide but southward during ebb tide. These currents may have carried the polluted water as far south as the Third Nuclear Power Plant, where the degree of contamination was lower because of the longer distance involved. Airborne particles from coal-burning power plants and heavy industry, and construction of the nuclear power plant may also have partially contributed to the measured trace metal concentrations in the local corals. Notably on Fig. 2, however, are the high values in the 1985, 1986 bands. These anomalies are probably due to dumping of dirt near the sampling site (Su et al., 1985). Sr-90 activities are plotted in Fig. 3.

Discussion

Literature of trace metals in whole corals is widely scattered and the results vary. Perhaps the most comprehensive studies were those Livingston and Thompson (1971). Their results for coastal corals are generally slightly higher than ours except for Zn where the agreement is good. The concentrations, however, show a large jump in 1985 (Fig. 2). We attribute this to dumping of dirt near the sampling site, as reported by Su et al. (1986). The concentrations returned to normal after 1987. Dodge and Gilbert (1984), Shen and Boyle (1987,1988) and Shen et al. (1987) demonstrated a significant increase in Cd towards the present based on corals collected from the North Atlantic, Pacific and Indian Oceans. Our Cd and Cu data show a significant increase only in 1985 and 1986. Since two nonpollution-ralated metals, Rb and Cs, also increased in 1985 or 1986, we believe that these peaks are due to dumping of dirt, rather than from industrial sources.

Shen and Boyle (1988) measured Ba, Cd, Mn, and V in a banded coral collected at Bermuda. They did not expect these metals to change concentration over time and indeed did not detect any change. They did, however, expect Zn concentration to increase but did not detect the increase. Zinc is one of the most commonly used metals in the industrial world and our observed increase no doubt reflects the recent industrial activities in Taiwan. Scrapping of ships, acid cleaning of imported scrapped metal, burning of waste cable, combustion of lubricating oil, emissions from rubber tire wear and smelters, and dumping of slags in heavily polluted coastal waters in the Tainan/Kaohsiung area (Bureau of Environmental Protection of Taiwan, 1986；Wang, 1987). The latest Zn concentration in the coral is approximately 4 ppm. Taking an aragonite/seawater partition coefficient of 5.5 (Pingitore, 1978), we estimated a local seawater Zn concentration of 2.2 ppb. The estimated local seawater concentration two decades ago would be about 0.04 ppb. These values are much higher than the open ocean surface water Zn concentration of 0.004 ppb. (Bruland, 1983；Environmental Protection Bureau, 1985；Guo and Huang, 1986), and still higher than measured local seawater value of 0.9 ppb. Such discrepancies may indicate that much of the zinc we measured is not lattice-bound. Accumulation of non-skeletal zinc can not be ruled out. As a comparison, Shen and Boyle (1988) reported values between 50 and 160 ppb with an average of 100 ppb for their sample collected at Bermuda. It should also be kept in mind, however, sampling and analysis of Zinc at low concentrations (ppb level) is prone to contamination (Shiller and Boyle, 1985).

In terms of radionuclides we attempted to measure 29 species but only Sr-90, a fission product, was above the detection limit (Table 1). Fig. 3 shows the Sr-90 activities measured in this study along with those reported in the Pacific Ocean. In general, the higher the latitude the higher the activities because most atomic bombs were tested in the high latitude regions of the Northern Hemisphere. The peak appears in 1964 soon after these tests peaked. Our data continues the decreasing trend found at Oahu, which is of the same latitude. Since other major fission products, such as Cs-134 and Cs-137, or major activation products, such as Mn-54, Fe-55 and Co-60 could not be detected, the implications are that the Sr-90 found off the Third Nuclear Power Plant was from atmospheric fallout. There is no indication of any significant leaking from the Plant.

Conclusion

We have measured heavy metals and radioisotopes from banded corals collected in southern Taiwan. Our preliminary data indicate a steady increase of Zn since 1965 but a sudden jump in 1985, 1986 because of dumping of dirt nearby. The concentration returned to normal after 1987. Other metals such as Cd, Cu, Rb and Cs also show such a peak in 1985 and 1986. Sr-90 probably comes from the atmospheric fallout rather than from the Third Nuclear Power Plant. The activities continue to fall since 1978. Other man-made radioisotopes could not be detected.

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References

Ahrland, S. (1988)：*Trace metal complexation by inorganic ligands in sea water,* in "The determination of trace metals in national waters" ed. T. S. West and H. W. Nurnberg, Backwell Sci. Pde. Oxford, 233-253.

Barnard, L.A., I.G. Macintyre and J.W. Pierce (1974)：Possible environmental inde in tropical reef corals, *Nature,* 252, 219-220.

Bertine, K.K. and R.G. Venon Clark (1996)：Elemental composition of the colloidal phase isolated by cross-flow filtration from coastal seawater samples, *Mar. Chem.,* 55, 189-204.

Chakraborty, S. (1993)：*Environmental significance of isotopic and trace elemental variations in banded corals,* dissertation, Physical Research Lab. Ahmedabad, India, 88pp.

Chen, C. T. A., B. J. Wang and H. I. Huang (1996)：A 20-year Seawater temperature record at Nanwan, Southern Taiwan, this volume.

Dodge, R.E. and J.R. Vaisnys (1975)：Hermatypic coral growth banding as environmental recorder, *Nature,* 258, 707-708.

Dodge, R.E. and T.R. Gilbert (1984)：Chronology of lead pollution contained in banded coral skeletons, *Mar. Biol.,* 82, 9-13.

Dodge, R.E., T.D., Jickells, A.H. Knap and R.P.M. Bak (1984)：Reef-building coral skeletons as chemical pollution (phosphorus) indicators, *Mar. Pollut. Bull.,* 15, 178-187.

Goldberd, E.D. (1963)：*The oceans as a chemical system, in "The Sea",* Vol. 2, ed. M.N. Hill, Interscience, New York, 3-25pp.

Goldberd, E.D. (1975)：*Marine pollution, in "Chemistry Oceanography"* eds. J.P. Riley and G. Skirrow, Academic Press, London, 39-89pp.

Hamilton, T. F., J. C. Milles-Lacroix and G. H. Hong (1996)：*Cs-137 (Sr-90) and Pu isotopes in the Pacific Ocean：Sources and trends,* in Radionuclides in the Oceans eds. P. Guegueniat, P. Germain and H. Metivier, les Editions de Physique, Les Ulis, France, 29-58pp.

Horne, R.A. (1969)：*"Marine Chemistry",* Wiley-Interscience, New York, 568pp.

Hudson, J.H., E.A. Shinn, R.B. Halley and B. Lidz (1976)：Sclerochronology: a tool for interpreting past environments, *Geology,* 4, 361-364.

Kawahata, H. and A. Suzuki (1999)：High resolution environmental analysis based upon coral annual banding — Reconstruction of past fluctuation in sea surface features in relation to asian monsoon and ENSO, *Journal of Oceanogr.,* 8, 141-156.

Knutson, D.W., R.W. Buddemeier and S.V. Smith (1972)：Coral chronometers: seasonal growth bands in reef corals, *Science,* 177, 270-272.

Livingston, H.D. and G. Thompson (1971)：Trace element concentrations in some modern corals, *Limnol. and Oceanogr.,* 16, 786-796.

Patzold J. (1984)：Growth rhythms recorded in stable isotopes and density bands in the reef coral Porites lobata (Cuba, Philippines), *Coral Reefs,* 3, 87-90.

Shen, G.T. and E.A. Boyle (1987)：Lead in corals：reconstruction of historical industrial fluxes to the surface ocean, *Earth Planet Sci. Lett.,* 82, 289-304.

Shen, G.T. and E.A. Boyle (1988)：Determination of lead, cadmium and other trace metals in annually-banded corals, *Chem. Geol.,* 67, 47-62.

Shen, G.T., E.A. Goyle and D.W. Lea (1987)：Cadmium in corals as a tracer of historical upwelling and industrial fallout, *Nature,* 328, 794-796.

Sverdrup, H.U., M.W. Johnson and R.H. Fleming (1942)：*The Oceans, Prentice Hall,* Inc. Englewood Cliffs, N.J., 1087pp.

Su, J.C., C.C. Hung, Y.M. Jiang et al.(1986)：Ecological research off the Nuclear Power Plant in southern Taiwan V1, The 6th year report, SCOPE, Academia Sinica, 164pp.

Toggweiler, J.R. and S. Trumbore (1985)：Bomb-test Sr-90 in Pacific and Indian Ocean surface water as recorded by banded corals, *Earth Planet Sci. Lett.,* 74, 306-314.

Wang, C.H. and C.Y. Huang (1987)：Oxygen and carbon isotope records in the coral Favia speciosa of Nanwan Bay, southern Taiwan, *Acta Oceanogra. Taiwan.,* 18, 150-157.

Wellington, G.M. and P.W. Glynn (1983)：Environmental influences on skeletal banding in Eastern Pacific (Panama) corals, *Coral Reefs,* 1, 215-222.

Table 1. Detection limit of various radionuclides (Bq/kg)

radioclides	Detection limit
Total β	34
K-40	0.6640
Sc-46	0.0602
Mn-54	0.0919
Fe-55	0.5920
Co-57	0.0414
Co-60	0.0658
Se-75	0.0588
Kr-81	19.10
Kr-85	0.3140
Sr-85	0.0835
Y-88	0.0644
Cd-109	1.290
Sn-113	0.0667
Tn-123	0.0114
I-125	461.0
Cs-134	0.0668
Cs-136	0.0595
Cs-137	0.0618
Cs-138	5.050
Ce-139	0.0432
Eu-154	0.0884
Eu-155	0.1490
Hg-203	0.0499
Tl-208	0.1790
Pb-210	24.40
Pb-214	0.1440
Bi-214	0.1250
Ac-228	0.1790

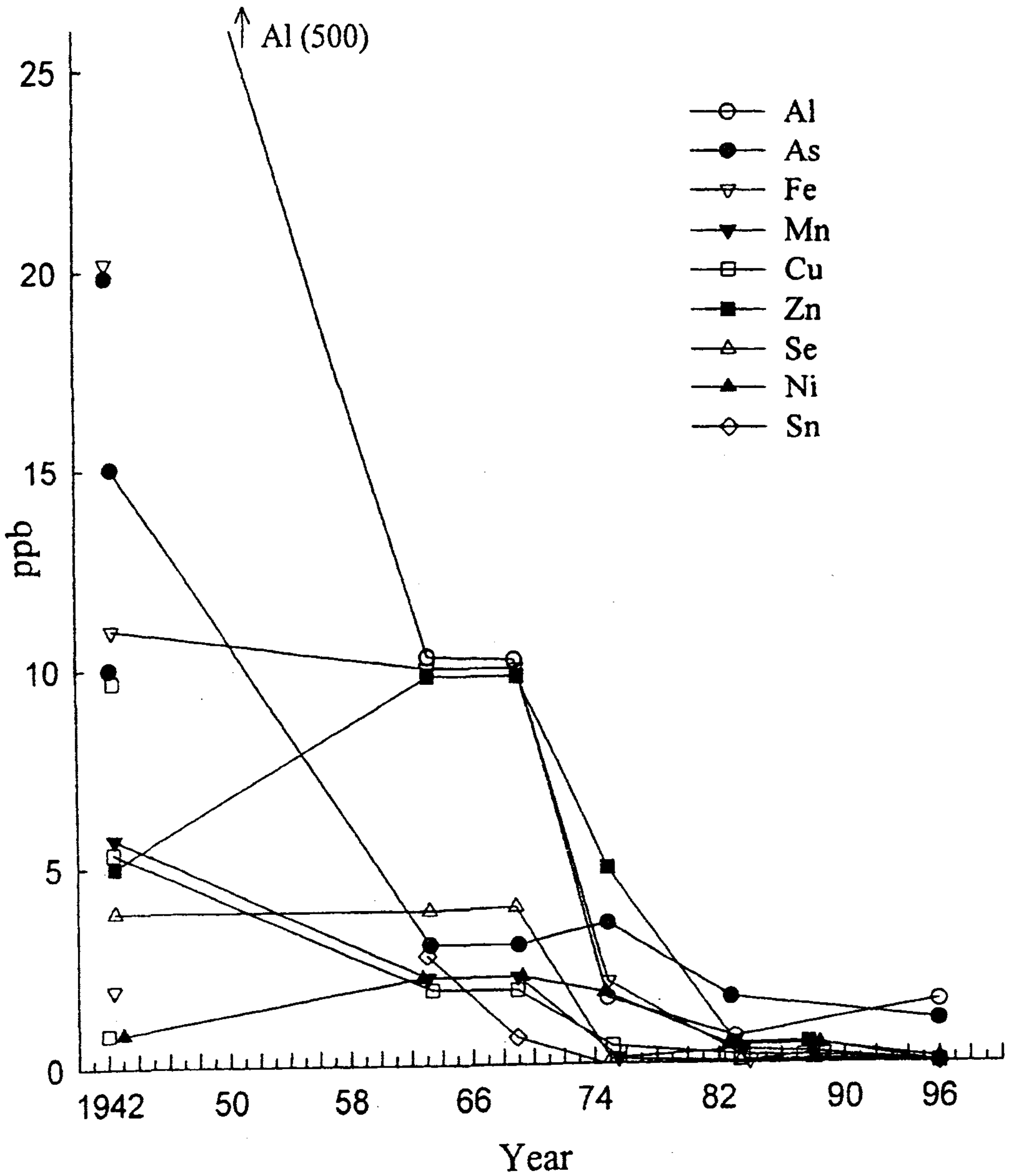

Figure 1. Concentrations of selected trace metals in seawater reported in different years (data from Sverdrup et al., 1942, Goldberg, 1963 ; Horne, 1969; Brewer, 1975 : Bruland, 1983 ; Ahrland, 1988 ; Bertine and Vernon Clark, 1996).

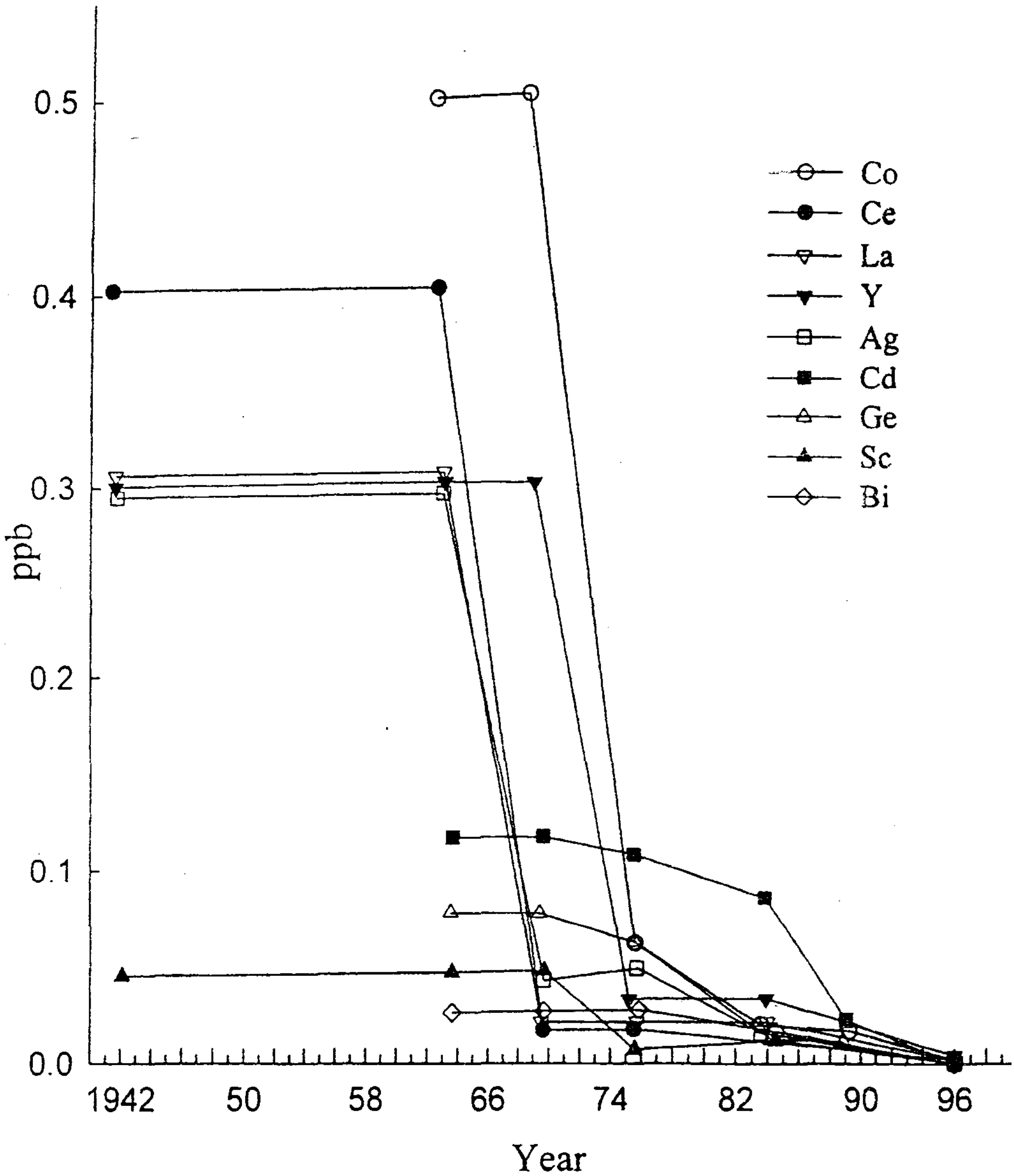

Figure 1. (continued).

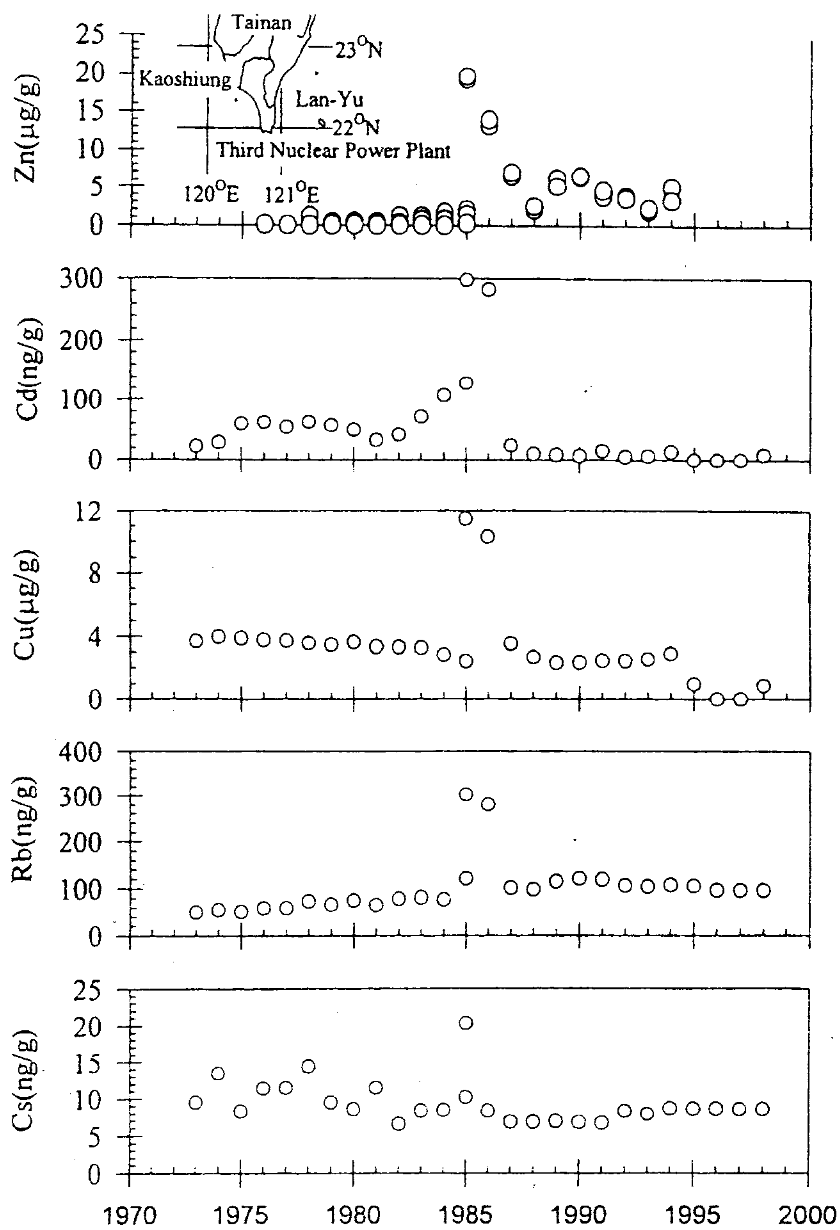

Fig. 2. Annual variations of Zn, Cd, Cu, Rb and Cs concentrations in corals collected at the thirc Nuclear Power Plant.

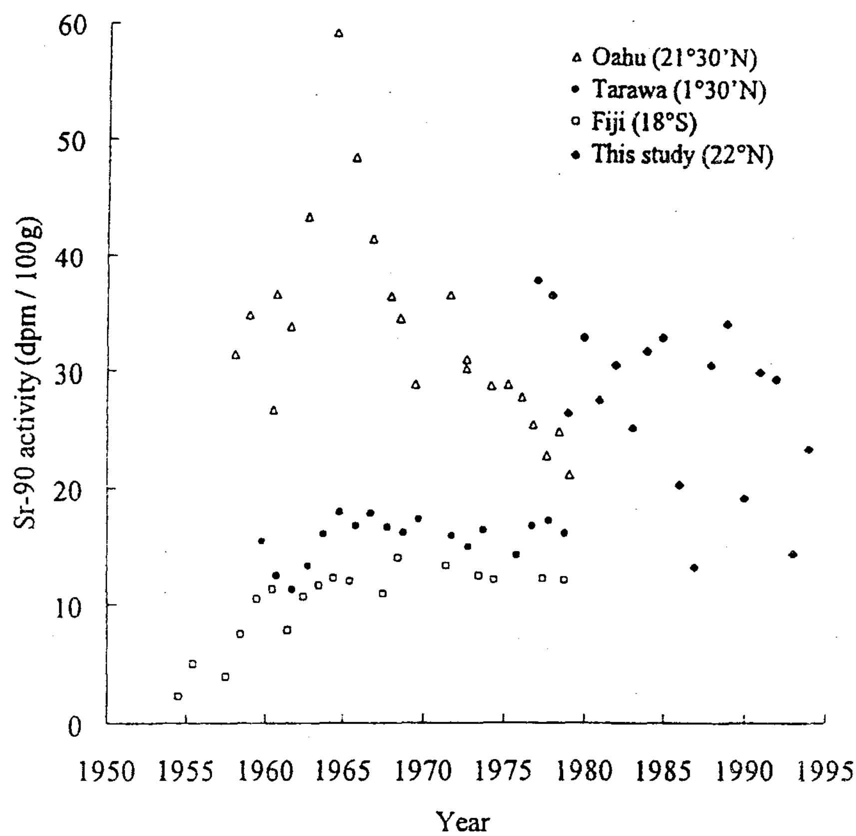

Fig. 3. Annual variations of Sr-90 concentration in corals collected from Oahu, Tarawa, Fiji and the Third Nuclear Power Plant in Taiwan. Data at Oahu, Tarawa and Fiji are from Toggweiler and Trumbore (1985).