# The Distribution of Mercury, Arsenic, and Antimony in Sediments of Kagoshima Bay

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Mercury, arsenic, and antimony were determined in marine sediments collected from Kagoshima Bay, and their distribution was investigated. The contents of mercury, arsenic, and antimony in surface sediments were higher than those in the marine sediments of the open ocean. The average contents of mercury, arsenic, and antimony in surface sediments in the northern part of the bay were higher than in the southern part. The high-temperature sediments (about 200 °C) in the vicinity of a sea bottom fumarole, located at a depth of about 200 m in the northern part of the bay, showed abnormal concentrations of mercury, arsenic, and antimony derived from the fumarole gas; the contents of these components decreased sharply with an increase in the distance from the fumarole. A high degree of positive correlation was found among the contents of the three components (mercury, arsenic, and antimony) over the northern part of the bay. In contrast, no such correlation was observed in the southern part of the bay. This is in accord with the fact that volcanic activity is more vigorous in the northern than in the southern part of the bay.

In November, 1973, high pollution with mercury exceeding the "provisional permissible level for mercury contained in fishes and shellfishes (0.4 mg kg$^{-1}$)" was found[1] in some of the *Trichiurus lepturus* caught in the northern part of Kagoshima Bay.

Investigations of other types of fish then followed, and autonomous regulation was extended to include ten other types of fish (*Trachurus japonicus, Nemipterus bathybius, Conger myriaster, etc.*) by August, 1975. Concurrently, extensive studies[2-4] of the mercury pollution of fishes living in Kagoshima Bay, investigation of possible pollution sources,[5-7] and medical checks[8-10] of the local inhabitants have been carried out by the aid of the central and local governments. In spite of these efforts, however, the mechanism of the pollution of fish with mercury is not yet absolutely clear.

Mercury, arsenic, and antimony are elements of special interest in connection with volcanic activity[11,12] because of the volatility they exhibit as elements and in the form of compounds.

This study will concentrate on the volatile components (mercury, arsenic, and antimony) derived from volcanic activity based on the notion that volcanic activity must be related to the marine environment of Kagoshima Bay. The horizontal and vertical distributions of the mercury concentration in sea water of Kagoshima Bay have previously been reported.[13] This paper describes the results of concentrations on mercury, arsenic, antimony in marine sediments collected from Kagoshima Bay.

## Experimental

*General Circumstances of Kagoshima Bay.* Kagoshima Bay is a narrow inner bay (about 75 km long and about 25 km wide)—an arm of the sea penetrating far into the land from south to north.

Its bottom has unique topographic features, as may be seen from the vertical section shown in Fig. 1. Sakurajima Volcano, standing between the central and northern parts of the bay, separates the two sea areas, which communicate

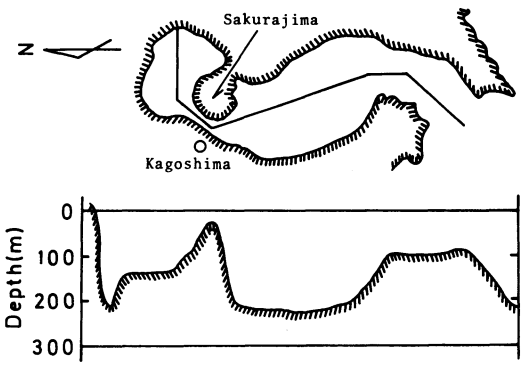


Fig. 1. Vertical section of Kagoshima Bay.

with each other only through Nishi Sakurajima Suidō, a shallow area about 40 m deep. Thus, sea-water exchange between the northern part (140 to 200 m deep) and the open ocean is not easy. The progress of pollution in the whole bay caused by human activities, both connected with daily living and industrial, is also dictated by the sea-water exchange because of the intricate topography of the bay's bottom. Considerable fumarolic activity is observed around Points **A** and **B** in the northern part of Kagoshima Bay (Fig. 2); this activity influence the marine environment in a number of ways. On the other hand, the speed of sediment accumulation in Kagoshima Bay is high due to the emissions from Minamidake of Sakurajima Volcano, which has continued to be active since October, 1955. The effects of the volcano emissions upon the sediments will be reported in a separate paper.

*Methods of Collecting and Preserving Sedimentary Samples.* A Smith-McIntyre spring-loading grab was used to collect surface sediments, and a Fhleger bottom sampler, equipped with a plastic inner tube 3.3 cm in inside diameter, was employed for the investigation of the vertical distribution. The sediment sample collected was immediately cut at 10 cm intervals; each fragment was enclosed in a polystyrene bottle, refrigerated at the site, and then brought back to our laboratory. Each sample was then suction-filtered with a 0.45 μm Millipore filter, air-dried (taking care to avoid any extraneous contamination), and ground in an agate mortar. The uniform sediment samples thus obtained were preserved for the subsequent determination of mercury, arsenic, and antimony.

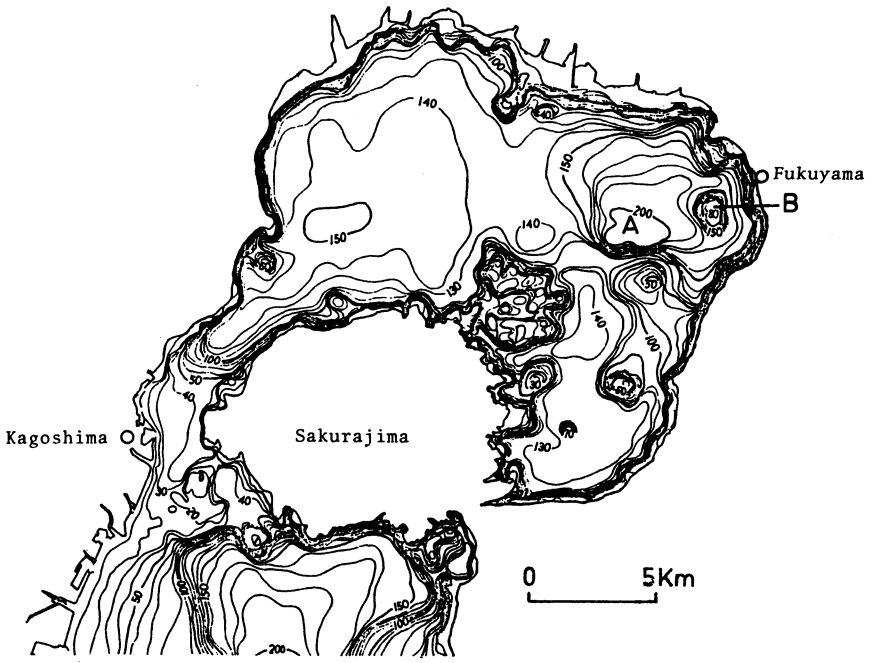


Fig. 2. Topographical map of northern Kagoshima Bay and the locations (A and B) where the submarine fumarolic activities were found.

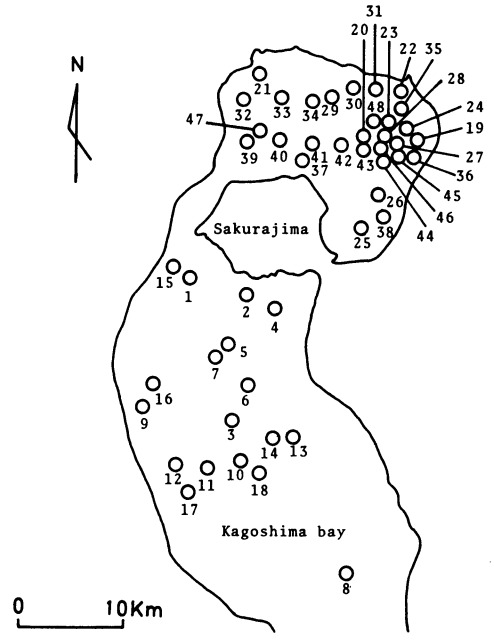


Fig. 3. Sampling stations of marine sediments in Kagoshima Bay.

*Sampling Stations in Kagoshima Bay.* The sediment sampling stations in Kagoshima Bay are shown in Fig. 2 and Fig. 3; the station numbers are tabulated in Table 1.

*Apparatus.* The apparatus used included a Rigaku Mercury SP (this apparatus was connected to an Ohkura recorder); a Hitachi spectrophotometer Model 101; an Iwaki-KM (Model V-D) shaker, and a Shimadzu-MAF atomic-absorption spectrophotometer.

*Reagents.* *Standard Solution of Mercury(II), 1 mg cm$^{-3}$*: Dissolve 1.354 g of mercuric chloride in 10 cm$^3$ of 5 mol dm$^{-3}$ sulfuric acid, and dilute to 1000 cm$^3$ with water.

*Standard Solution of Arsenic(III), 1 mg cm$^{-3}$*: Dissolve 1.320 g of diarsenic trioxide in 10 cm$^3$ of 10 mol dm$^{-3}$ sodium hydroxide, and dilute to 1000 cm$^3$ with water.

*Standard Solution of Antimony(III), 1 mg cm$^{-3}$*: Dissolve 1.874 g of antimony trichloride in water, and dilute to 1000 cm$^3$ with water.

The acids used (sulfuric acid, nitric acid, hydrochloric acid, hydrofluoric acid, perchloric acid) and potassium permanganate were all analytical-special-reagent-grade for the measurements of the toxic metals.

*Procedure for the Determination of Mercury.* A sediment sample (0.02 to 0.20 g), homogenized as much as possible under wet or air-dried conditions, was weighed out into a porcelain boat previously ignited to exclude any trace of mercury that might be left adhered, and covered with an addition agent (calcium hydroxide and sodium carbonate, both ignited at 700 °C and then mixed in a 1:1 volume ratio). The analytical sample thus prepared was heated in the furnace of a mercury analyzer at about 300 °C for three minutes, and then at about 700 °C for four minutes to complete the decomposition; the mercury vapor thus evolved was caught in a potassium permanganate solution acidified with sulfuric acid[14] or with a porous gold collector.[15] In the method using a porous gold collector, once the collector heating time is properly set on the timer, the evolution of mercury vapor and its measurement by cold vapor atomic-absorption spectrometry are performed automatically, giving results of a high reproducibility in a short time.

*Procedure for the Determination of Arsenic.* A sediment sample (0.05 to 0.20 g) was weighed out into a Teflon beaker; 4 cm$^3$ of perchloric acid (60%), 3 cm$^3$ of sulfuric acid (96 to 98%), 8 cm$^3$ of hydrofluoric acid (46%), and 2 cm$^3$ of potassium permanganate solution (2%) were then added, and the mixture was heated on a hot plate (100 °C) to effect decomposition and subsequently evaporated to dryness. After cooling, 3 cm$^3$ of 12 mol dm$^{-3}$ hydrochloric acid and 6 cm$^3$ of

redistilled water were added to dissolve the residue, and the solution was transferred into an arsine generator, where the arsenic was separated as arsine ($AsH_3$) by the addition of arsenic-free zinc and determined by the Ag–DDTC method.[16] The results of this method showed good agreement with those obtained by atomic-absorption spectrometry.[17]

*Procedure for the Determination of Antimony.* A sediment sample (0.05 to 0.50 g), weighed out into a porcelain crucible, was fused with 2.5 g of potassium pyrosulfate. After cooling to room temperature, 10 $cm^3$ of 6 mol $dm^{-3}$ hydrochloric acid, 10 $cm^3$ of 6 mol $dm^{-3}$ sulfuric acid, and 5 $cm^3$ of redistilled water were added to dissolve the fusion product, the solution was transferred into a separating funnel, and the antimony was determined by the Rhodamine B method.[18]

The contents of mercury, arsenic, and antimony in the marine-sediment samples were measured according to the methods described above. Actual analysis was made on air-dried samples. Separately, part of each sample was heated at 110 °C for 6 h to determine the weight loss; the measurements were then converted to the values on a bone-dry basis.

## Results and Discussion

*Contents of Mercury, Arsenic, and Antimony in Surface Sediments (0 to 10 cm deep).* The analytical results for the contents of mercury, arsenic, and antimony in surface sediments (0 to 10 cm deep) of Kagoshima Bay are shown in Table 1. In the following discussion,

Table 1. Mercury, arsenic, and antimony contents in surface sediments of Kagoshima Bay

| Station No. | Depth/m | Sampling Date | Content/mg $kg^{-1}$ [a] | | | Remarks |
|---|---|---|---|---|---|---|
| | | | Hg | As | Sb | |
| 1 | 144 | Sept. 21, '76 | 0.034 | $8.1_2$ | 0.62 | Southern Kagoshima Bay |
| 2 | 170 | Sept. 22, '76 | 0.042 | $7.2_3$ | 0.59 | Southern Kagoshima Bay |
| 3 | 226 | Sept. 21, '76 | $0.10_8$ | $7.4_8$ | $1.4_5$ | Southern Kagoshima Bay |
| 4 | 160 | Sept. 21, '76 | 0.017 | $4.5_7$ | $1.2_5$ | Southern Kagoshima Bay |
| 5 | 217 | Oct. 12, '76 | 0.063 | $6.7_4$ | $1.3_7$ | Southern Kagoshima Bay |
| 6 | 226 | Oct. 30, '76 | 0.034 | $7.6_4$ | $2.0_5$ | Southern Kagoshima Bay |
| 7 | 218 | Dec. 5, '76 | 0.055 | $7.3_4$ | $1.2_7$ | Southern Kagoshima Bay |
| 8 | 185 | Dec. 5, '76 | 0.040 | $7.3_9$ | $1.1_6$ | Southern Kagoshima Bay |
| 9 | 13 | Mar. 10, '77 | $0.008_4$ | $8.0_6$ | 0.66 | Southern Kagoshima Bay |
| 10 | 210 | Mar. 10, '77 | 0.060 | $6.9_7$ | $1.0_8$ | Southern Kagoshima Bay |
| 11 | 110 | Mar. 10, '77 | 0.040 | $6.3_2$ | $1.2_0$ | Southern Kagoshima Bay |
| 12 | 36 | Mar. 10, '77 | 0.016 | $7.6_1$ | $1.4_9$ | Southern Kagoshima Bay |
| 13 | 100 | Mar. 10, '77 | 0.014 | $5.4_8$ | 0.54 | Southern Kagoshima Bay |
| 14 | 200 | Mar. 10, '77 | 0.030 | $7.7_3$ | 0.56 | Southern Kagoshima Bay |
| 15 | 80 | Nov. 6, '77 | 0.014 | $7.2_2$ | $1.7_4$ | Southern Kagoshima Bay |
| 16 | 40 | Nov. 6, '77 | 0.050 | $8.3_5$ | $1.8_4$ | Southern Kagoshima Bay |
| 17 | 150 | Nov. 6, '77 | 0.047 | $6.2_7$ | 0.81 | Southern Kagoshima Bay |
| 18 | 215 | Nov. 6, '77 | 0.095 | $4.7_5$ | $1.2_0$ | Southern Kagoshima Bay |
| 19 | 78 | Aug. 12, '76 | $0.002_4$ | $6.5_3$ | $1.3_5$ | Northern Kagoshima Bay |
| 20 | 140 | Oct. 12, '76 | $0.10_7$ | 10.6 | $1.7_4$ | Northern Kagoshima Bay |
| 21 | 25 | Oct. 29, '76 | $0.14_3$ | 12.0 | $4.3_9$ | Northern Kagoshima Bay |
| 22 | 38 | Oct. 30, '76 | 0.030 | 15.8 | $2.7_5$ | Northern Kagoshima Bay |
| 23 | 190 | Oct. 30, '76 | 0.092 | 19.1 | $4.9_7$ | Northern Kagoshima Bay |
| 24 | 180 | Oct. 30, '76 | 0.026 | $8.6_4$ | $4.1_6$ | Northern Kagoshima Bay |
| 25 | 140 | Oct. 30, '76 | 0.016 | $8.4_3$ | $3.2_3$ | Northern Kagoshima Bay |
| 26 | 118 | Dec. 6, '76 | 0.017 | $9.3_4$ | $1.2_2$ | Northern Kagoshima Bay |
| 27 | 202 | Jan. 21, '77 | $0.37_0$ | 16.2 | $3.1_4$ | Northern Kagoshima Bay |
| 28 | 210 | Apr. 17, '77 | $0.24_0$ | 17.3 | $2.8_0$ | Northern Kagoshima Bay |
| 29 | 115 | Oct. 29, '77 | 0.060 | $9.6_5$ | $2.9_2$ | Northern Kagoshima Bay |
| 30 | 104 | Oct. 29, '77 | 0.069 | 22.0 | $3.3_6$ | Northern Kagoshima Bay |
| 31 | 40 | Oct. 29, '77 | $0.17_4$ | 20.0 | $4.1_6$ | Northern Kagoshima Bay |
| 32 | 135 | Oct. 29, '77 | 0.099 | 10.6 | $1.3_1$ | Northern Kagoshima Bay |
| 33 | 145 | Nov. 6, '77 | 0.078 | $9.5_0$ | $1.5_1$ | Northern Kagoshima Bay |
| 34 | 140 | Nov. 6, '77 | $0.20_0$ | $9.5_4$ | $1.2_1$ | Northern Kagoshima Bay |
| 35 | 140 | Nov. 6, '77 | $0.24_7$ | 13.3 | $2.2_7$ | Northern Kagoshima Bay |
| 36 | 195 | Nov. 6, '77 | $0.24_0$ | $9.6_8$ | $2.3_7$ | Northern Kagoshima Bay |
| 37 | 30 | Nov. 6, '77 | 0.032 | $5.8_0$ | $1.0_0$ | Northern Kagoshima Bay |
| 38 | 100 | Nov. 6, '77 | 0.034 | $6.1_9$ | $1.4_5$ | Northern Kagoshima Bay |
| 39 | 150 | Sept. 20, '79 | 0.058 | 7.7 | $1.6_6$ | Northern Kagoshima Bay |
| 40 | 155 | Sept. 20, '79 | 0.096 | 5.8 | $1.1_7$ | Northern Kagoshima Bay |
| 41 | 140 | Sept. 20, '79 | $0.10_3$ | 5.5 | $3.7_6$ | Northern Kagoshima Bay |
| 42 | 140 | Sept. 20, '79 | $0.11_5$ | 8.1 | $3.9_4$ | Northern Kagoshima Bay |
| 43 | 190 | Sept. 20, '79 | $0.21_9$ | 8.8 | $3.4_0$ | Northern Kagoshima Bay |
| 44 | 195 | Sept. 20, '79 | $0.19_8$ | 6.8 | $2.8_7$ | Northern Kagoshima Bay |
| 45 | 200 | Sept. 20, '79 | $0.73_1$ | 14.1 | $4.4_1$ | Northern Kagoshima Bay |
| 46 | 192 | Oct. 5, '79 | $0.52_9$ | 18.0 | $4.8_2$ | Northern Kagoshima Bay |
| 47 | 150 | Sept. 21, '76 | 0.030 | $7.3_3$ | $2.8_3$ | Northern Kagoshima Bay |

| | | | | | | |
|---|---|---|---|---|---|---|
| 48 | 205 | Nov. 6, '77 | $0.34_0$ | $8.2_5$ | $1.3_0$ | Northern Kagoshima Bay |
| A-1 | 200 | Sept. 9. '77 | $0.66_8$ | $18._8$ | $10._7$ | Vicinity of a sea bottom fumarole |
| A-2 | 200 | Sept. 11. '77 | $0.32_4$ | $12._5$ | $9.2_2$ | Vicinity of a sea bottom fumarole |
| A-3 | 200 | Sept. 11. '77 | 267 | 297 | 1080 | Vicinity of a sea bottom fumarole |
| A-4 | 200 | Sept. 11. '77 | $1.4_3$ | $20._2$ | $11._2$ | Vicinity of a sea bottom fumarole |
| A-5 | 200 | Sept. 11. '77 | 256 | 113 | 276 | Vicinity of a sea bottom fumarole |
| A-6 | 200 | Sept. 13. '77 | 116 | 464 | 11200 | Vicinity of a sea bottom fumarole |
| A-7 | 200 | Sept. 15. '77 | $0.45_9$ | $15._5$ | $8.7_3$ | Vicinity of a sea bottom fumarole |
| A-8 | 200 | Sept. 15. '77 | $0.63_5$ | $7.9_0$ | $6.6_1$ | Vicinity of a sea bottom fumarole |
| A-9 | 200 | Sept. 15. '77 | $0.34_4$ | $12._9$ | $7.4_8$ | Vicinity of a sea bottom fumarole |
| A-10 | 200 | Aug. 25. '78 | $0.61_0$ | $12._6$ | $7.6_1$ | Vicinity of a sea bottom fumarole |
| A-11 | 200 | Aug. 25. '78 | $1.3_9$ | $38._2$ | $33._2$ | Vicinity of a sea bottom fumarole |
| A-12 | 200 | Aug. 25. '78 | $2.1_5$ | $48._5$ | $48._8$ | Vicinity of a sea bottom fumarole |
| A-13 | 200 | Aug. 26, '78 | $0.96_1$ | $16._1$ | $12._8$ | Vicinity of a sea bottom fumarole |
| A-14 | 200 | Aug. 27. '78 | $76._7$ | 200 | 121 | Vicinity of a sea bottom fumarole |
| A-15 | 200 | Aug. 27. '78 | $37._0$ | 105 | 131 | Vicinity of a sea bottom fumarole |
| B-1 | 100 | Sept. 12. '77 | $0.10_5$ | $15._5$ | $2.5_0$ | Vicinity of a sea bottom fumarole |
| B-2 | 100 | Sept. 12. '77 | 0.015 | $13._0$ | $1.5_2$ | Vicinity of a sea bottom fumarole |
| B-3 | 100 | Sept. 14. '77 | 0.042 | 7.6 | $1.5_5$ | Vicinity of a sea bottom fumarole |
| B-4 | 100 | Aug. 24. '78 | 0.012 | 8.5 | $1.4_1$ | Vicinity of a sea bottom fumarole |

a) The contents of mercury, arsenic, and antimony are coverted to these values when samples are heated at 110 °C for 6h.

TABLE 2. MERCURY, ARSENIC, AND ANTIMONY CONTENTS IN SURFACE SEDIMENTS OF KAGOSHIMA BAY

| | | Content/mg kg$^{-1}$(110 °C, 6 h dry basis) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Hg | | As | | Sb | | |
| Sampling station | | $\overline{X_A}$[d] | $\overline{X_G}$[e] | $\overline{X_A}$[d] | $\overline{X_G}$[e] | $\overline{X_A}$[d] | $\overline{X_G}$[e] | n[f] |
| Northern Kagoshima Bay | A[a] | $50._8$ | $4.0_3$ | $92._1$ | $39._6$ | 864 | $43._7$ | 15 |
| | B[b] | $0.04_4$ | $0.03_0$ | $11._2$ | $10._7$ | $1.7_5$ | $1.7_0$ | 4 |
| | C[c] | $1.5_7$ | $0.09_1$ | $11._0$ | $10._2$ | $2.7_2$ | $2.4_2$ | 30 |
| Southern Kagoshima Bay | | $0.04_3$ | $0.03_5$ | $6.9_6$ | $6.8_7$ | $1.1_6$ | $1.0_7$ | 18 |

a) A is the area 200 m-deep within *ca.* 100 m from the center of the fumarole group. b) B is the area 78 m-deep within *ca.* 50 m from the center of the fumarole group. c) C is the area excluding A and B. d) $\overline{X_A}$ is the arithmetic mean. e) $\overline{X_G}$ is the geometric mean. f) n is the number of determined samples.

Kagoshima Bay is divided into two sections by the line connecting Kagoshima City and Sakurajima: The southern part (Stn. 1 to 18) and the northern part (Stn. 19 to 48, A and B). The results for the northern part are summarized in Table 2, in which data are separately shown for the 200 m station (A), the 78 m station (B), and the other stations (C). $\overline{X_A}$ represents the arithmetic mean; $\overline{X_G}$ the geometric mean, and n; the number of samples collected. It is apparent from the table that the contents of mercury, arsenic, and antimony at the 200 m station (A) are abnormally high. The data for the 200 m and 78 m stations are those of sediment samples collected in a past survey; (an investigation by the government and Kagoshima prefecture, in which the author paticipated as a member, which was carried out to determine if the mercury derived from volcanic activity is responsible for the mercury pollution of fishes and shellfishes).

These samples were collected by means of a submarine boat (HAKUYO; displacement, 6.6 tons) while visually observing the sea-bottom fumarole. No abnormal values, such as those seen at the 200 m station, were found at the 78 m station. This difference may probably be correlated to the fact that the fumarole gas at the 78 m station is relatively low in temperature and has a composition similar to that of natural gas, while the fumarole gas at the 200 m station is considerably high in temperature (the max. was 215 °C) and contains much hydrogen *etc.*[6] The average values of mercury, arsenic, and antimony in the surface sediments collected from the southern part, in which volcanic activity is milder, are lower than those in the northern part.

*Horizontal Distribution of Mercury, Arsenic, and Antimony in Surface Sediments of Kagoshima Bay.* Figures 4—6 show the horizontal distribution on mercury, arsenic, and antimony in surface sediments collected at 48 stations over the entire area of Kagoshima Bay.

Higher contents of these compositions are observed in the northern part, particularly in the vicinity of the 200 m-deep fumarole and in the area near the estuary of the river Amori, flowing down from the Kirishima Volcano region. This suggests a close correlation of the mercury, arsenic, and antimony components to volcanic activity.

Sedimentary samples with abnormally high concentrations of mercury, arsenic, and antimony, as collected near the 200 m deep fumarole, have never been found in any ship survey from sea level.

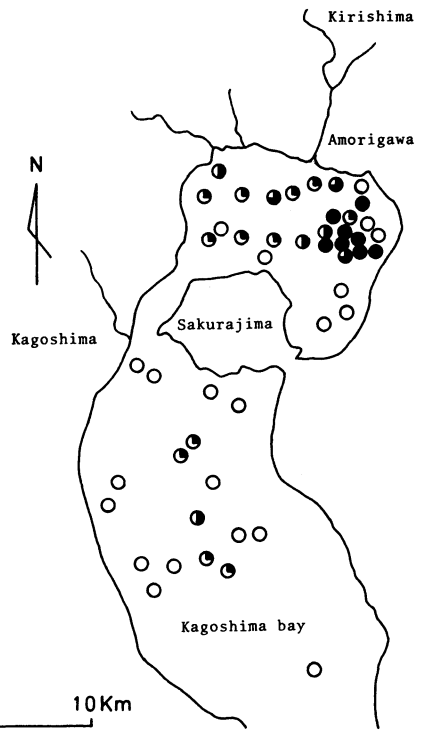


Fig. 4. Horizontal distribution of mercury in surface sediments of Kagoshima Bay.

| Hg mg kg$^{-1}$ [a] | No. of samples |
|---|---|
| ○ ≦0.05 | 21 |
| ◔ 0.06—0.10 | 12 |
| ◑ 0.11—0.15 | 4 |
| ◕ 0.16—0.20 | 3 |
| ● 0.21≦ | 8 |

a) 110°C, 6h dry basis.

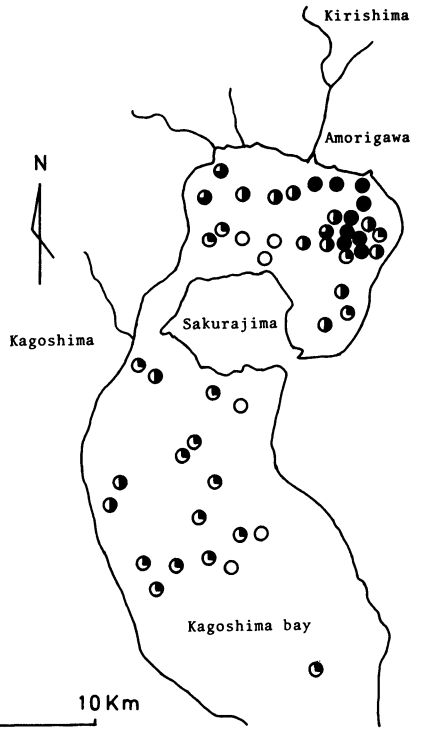


Fig. 5. Horizontal distribution of arsenic in surface sediments of Kagoshima Bay.

| As mg kg$^{-1}$ [a] | No. of samples |
|---|---|
| ○ ≦ 6.0 | 6 |
| ◔ 6.1— 8.0 | 17 |
| ◑ 8.1—10.0 | 13 |
| ◕ 10.1—12.0 | 3 |
| ● 12.1≦ | 9 |

a) 110°C, 6h dry basis.

Let us now compare the mercury content in surface sediments collected in Kagoshima Bay with those in other inner bays.

Already reported are 0.12—0.33 mg kg$^{-1}$ for Funka Bay,[19] 0.115—0.794 mg kg$^{-1}$ for Tokyo Bay,[20] 0.190—0.550 mg kg$^{-1}$ for Osaka Bay,[19] and 0.1—0.2 mg kg$^{-1}$ for Tokuyama Bay[21] (20 cm deep). Compared with these values, the range of mercury concentrations observed in the southern and northern parts of Kagoshima Bay are lower (except for the vicinity of the 200 m-deep fumarole); 0.008—0.10$_8$ mg kg$^{-1}$ (geometric mean: 0.033 mg kg$^{-1}$) and 0.002—0.73$_1$ mg kg$^{-1}$ (geometric mean: 0.087 mg kg$^{-1}$) respectively.

However, an unusually high concentration range of 0.45$_9$—267 mg kg$^{-1}$ (geometric mean: 4.0$_3$ mg kg$^{-1}$) is found in the limited area in the vicinity of the 200 m-deep fumarole.

*Vertical Distribution of Mercury, Arsenic, and Antimony in Sediments of Kagoshima Bay.* Figure 7 shows the vertical distribution of mercury, arsenic, and antimony contained in sediments of the northern (Stn. 48) and southern (Stn. 18) parts of Kagoshima Bay. In this figure, the contents of mercury, arsenic, and antimony (abscissa) are plotted against the depth (ordinate) (10 cm-interval vertical sections from the surface of the sediment to a depth of 100 cm).

In the southern part (Stn. 18), little change is observed in the contents of mercury, arsenic, and antimony with the depth. In the northern part (Stn. 48), on the other hand, the vertical distribution is uneven for mercury and arsenic. This figure also shows higher contents for all of the components in the northern than in the southern part. This tendency is also the case with the other sampling stations.

*Relationship between Mercury and Arsenic Contents in Surface Sediments Around the Fumarole in the Northern Part.* Figure 8 shows the relationship between the mercury and arsenic contents in the surface sediments collected at the 200 m-deep station around the fumarole in the northern part of Kagoshima Bay. As can be seen from the figure, a fairly high degree of positive correlation exists between the two (correlation coefficient: 0.65).

*Relationship between Arsenic and Antimony Contents in Surface Sediments Around the Fumarole in the Northern Part.* Figure 9 shows the relationship between the contents of arsenic and antimony in the same samples as have been used to describe the relationship between mercury and arsenic. Here, also, there is a high degree of positive correlation (correlation coefficient: 0.83).

*Relationships of Mercury, Arsenic, and Antimony Contents to the Distance from the Fumarole (200 m-Deep*

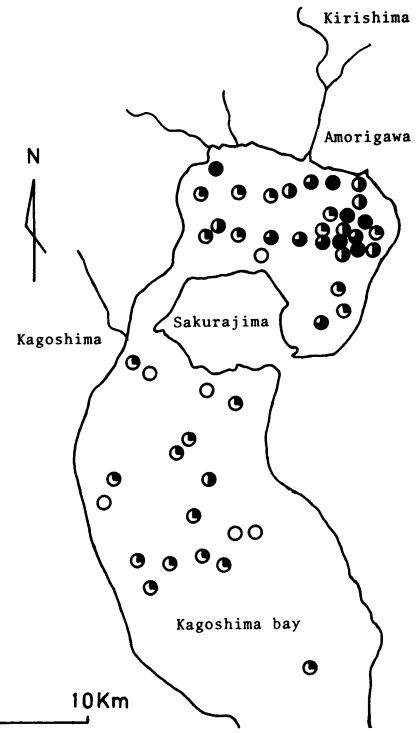


Fig. 6. Horizontal distribution of antimony in surface sediments of Kagoshima Bay.

| Sb mg kg$^{-1}$ a) | No. of samples |
|---|---|
| ○ ≦1.0 | 6 |
| ◔ 1.1—2.0 | 22 |
| ◑ 2.1—3.0 | 8 |
| ◕ 3.1—4.0 | 6 |
| ● 4.1≦ | 6 |

a) 110°C, 6h dry basis.

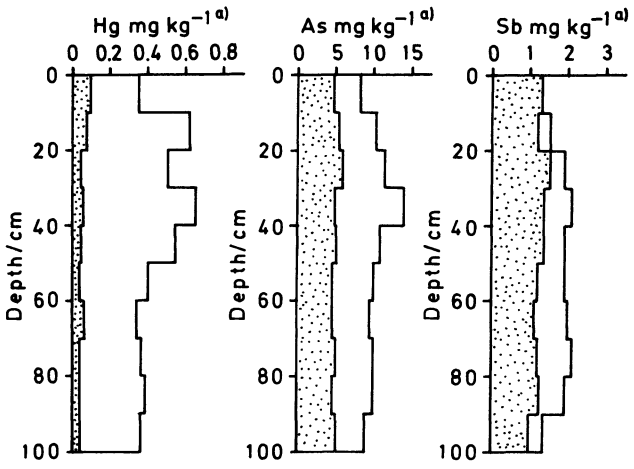


Fig. 7. Vertical profiles of mercury, arsenic, and antimony in sediments of Kagoshima Bay.
□: Stn. 48 (Northern Kagoshima Bay)
▨: Stn. 18 (Southern Kagoshima Bay)
a) 110°C, 6h dry basis.

*Locations in the Northern Part).* Figure 10 shows the relationships between the contents of mercury, arsenic, and antimony in surface sediments and the distance from the fumarole. It is apparent from these figures that abnormal concentrations of mercury, arsenic, and antimony are observed only at hot positions near the

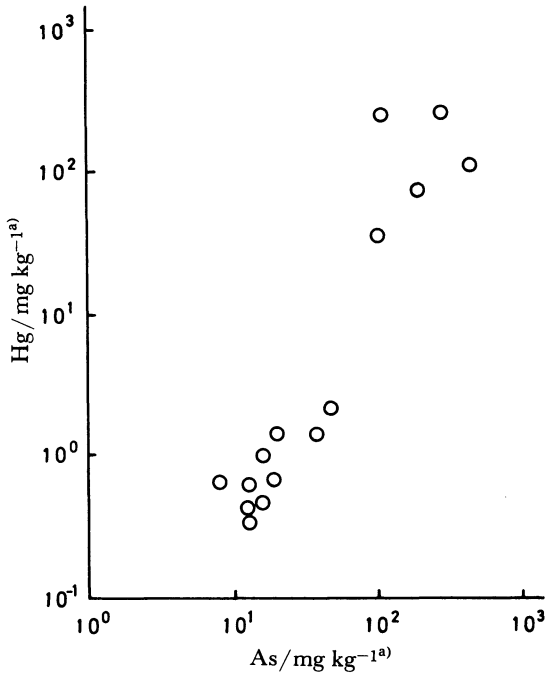


Fig. 8. Relationship between the mercury and arsenic contents in surface sediments around the fumarole at the 200m-deep locations.
a) 110°C, 6h dry basis.

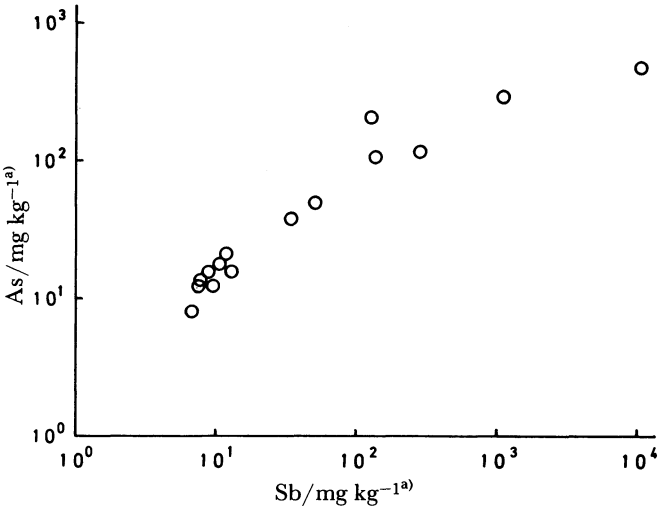


Fig. 9. Relationship between the arsenic and antimony contents in surface sediments around the fumarole at the 200m-deep locations.
a) 110°C, 6h dry basis.

fumarole. The contents of these components sharply decrease with the distance between the sampling position and the fumarole, gradually approaching the background level of the open ocean.

*Correlations among Mercury, Arsenic, and Antimony Contents in Surface Sediments in Kagoshima Bay.* Table 3 shows the correlation coefficients among the contents of mercury, arsenic, and antimony in surface sediments in the northern and southern parts of Kagoshima Bay. As may be apparent from this table, a higher degree of positive correlation is found among

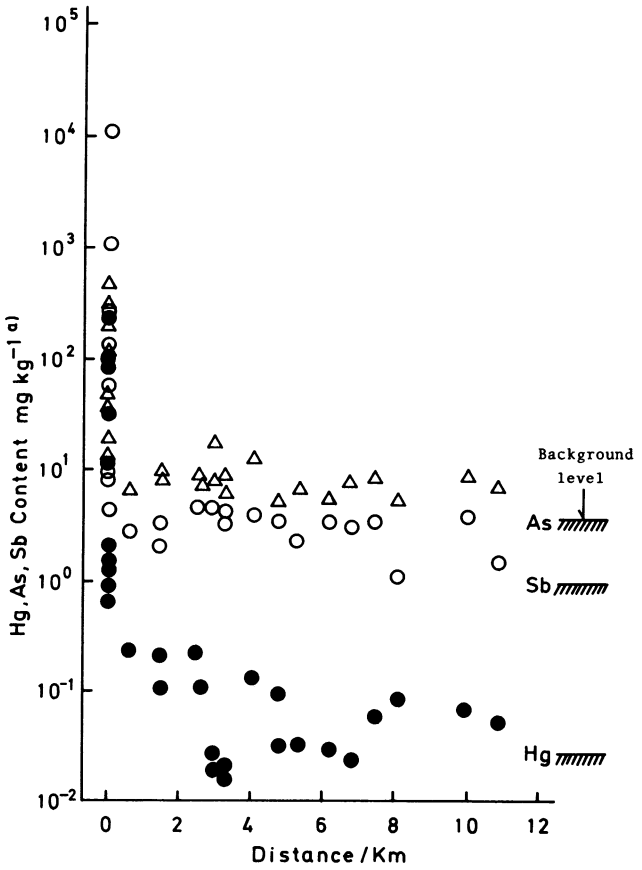


Fig. 10. Relationships between the mercury, arsenic, antimony, and the distance from the fumarole at the 200m-deep locations.
a) 110°C, 6h dry basis.
●: Mercury, △: Arsenic, ○: Antimony.

TABLE 3. MUTUAL CORRELATION COEFFICIENTS OF MERCURY, ARSENIC, AND ANTIMONY IN MARINE SURFACE SEDIMENTS OF KAGOSHIMA BAY

(I)[a]

| | As | Sb | Hg |
|---|---|---|---|
| As | | | |
| Sb | 0.13 | | |
| Hg | −0.12 | 0.19 | |

($n^{c}$)=18)

(II)[b]

| | As | Sb | Hg |
|---|---|---|---|
| As | | | |
| Sb | 0.88 | | |
| Hg | 0.81 | 0.89 | |

($n^{c}$)=39)

a) (I) is southern Kagoshima Bay. b) (II) is northern Kagoshima Bay. c) (n) is the number of determined samples.

the contents of mercury, arsenic, and antimony in the northern than in the southern part. This is in accord with the more vigorous volcanic activity in the former than in the latter part.

It may be considered that factors such as geological circumstances (Kirishima and Sakurajima) and the intricate submarine topography of the northern part.

## Conclusion

The horizontal and vertical distributions of the contents of mercury, arsenic, and antimony in the sediments collected from Kagoshima Bay have been studied. The results may be summarized as follows: (1) The distribution of mercury, arsenic, and antimony contents in the surface sediments of Kagoshima Bay revealed high concentrations of these components in a limited area in the northern part. (2) The vertical distribution of these components in sediments of Kagoshima Bay clearly showed higher concentrations in the northern than in the southern part. Little change was observed in the contents with the depth in the sediments of the southern part, but apparent changes with depth were noticed in the sediments of the northern part. (3) A high degree of correlation was found among the three components (mercury, arsenic, and antimony) in surface sediments of the northern part, but no such close correlation existed among those in the southern part. (4) Abnormal concentrations of mercury, arsenic, and antimony were found at a hot position, 200 m deep, near the center of volcanic activity in the northern part, and a sharp decrease in the contents of these components was observed with the increasing distance from the fumarole. This suggests that these components have been deposited as a result of volcanic activity which both took place in the past and are under way at present. (5) It has already been demonstrated[6] that all sediments containing mercury, arsenic, and antimony in markedly high concentrations are also rich in montmorillonite, stibnite, and dolomite.

It may thus be concluded that the abnormally high concentrations of mercury, arsenic, and antimony found in surface sediments at the hot position 200 m deep near the fumarole in the northern part of Kagoshima Bay is derived from natural volcanic activity at the sea bottom and is not caused by human activities.

Studies of the mechanism of mercury concentration in fishes are under way in various fields of research, but a satisfactory explanation has not yet been reached. For a complete elucidation, it would be essential to continue monitoring of water quality, sediments, living things, volcanic activity, and other phenomena in the bay.

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