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The Contents and Distributions of Arsenic, Antimony, and Mercury in Geothermal Waters

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The contents and distributions of arsenic, antimony, and mercury in geothermal water samples taken from various geothermal areas in Japan were investigated. Since the existing forms of arsenic, antimony, and mercury in geothermal waters are complex and can change during sample storage, it is difficult to determine all of the chemical forms. In this study, therefore, the arsenic(III+V), antimony(III+V), and total mercury contents were determined. In geothermal water, there is a high positive correlation between the contents of arsenic and antimony. However, there is no correlation at all between the contents of mercury and arsenic, or between those of mercury and antimony. It can be assumed that mercury behaves differently from either arsenic or antimony in geothermal water.

In keeping pace with the development of geothermal energy, attention has been paid to the various components of geothermal water, such as that of thermal water or hot spring water. Arsenic, antimony and mercury are included in these components. However, information on the contents, existing forms and distributions of these elements are insufficient. Investigations concerning arsenic have been continuing in view of the environmental contamination caused by the drainage of hot spring water[1] and the use of hot spring water for drinking.[2,3] In some sources of thermal well water obtained for geothermal power generation, there are high concentrations of arsenic; such thermal water is being recharged into underground regions as a counterplan. Investigations into the exclusion treatment of arsenic have also begun.[4]

Since antimony, the homologous element of arsenic, is found in relatively low content, compared to arsenic, and is difficult to analyze, there have not been many reports on antimony in geothermal water compared to those on arsenic. After Holak[5] developed atomic absorption spectrometry for arsenic hydroguret in 1969, determinations of arsenic and antimony in ppb-ppt levels became possible through the work of Fernandedz et al.[6] and Yamamoto et al.[7]

To determine the mercury content, cold vapor atomic absorption spectrometry has been widely employed.[8,9]

Nakagawa[10] and Awaya et al.[11] produced data concerning the mercury content in hot spring water at various locations in Japan.

There have been many reports concerning the arsenic and antimony contents in hot spring water at various specific areas.[12-18] There have also been reports by Watanuki et al.[19] and Sato[20] concerning the arsenic and antimony contents in acidic thermal water. However, there have been no reports concerning measurements of the contents of arsenic, antimony and mercury in the geothermal water found over a wide range of geothermal areas. In this study, we determined the contents of arsenic, antimony and mercury in geothermal water (thermal water, hot spring water and condensed water) sampled at various geothermal areas in Japan. We discuss their existing forms, mutual relations and distributions.

Experimental

Preservation of Sample. Geothermal water samples used for determining arsenic and antimony contents were kept in polyethylene bottles(1 l), which were exuded beforehand by approximately 3 mol dm^{-3} nitric acid for two weeks and then washed thoroughly with water. 10 ml of 35% hydrochloric acid was added to each 1 l of sample at the sampling place as quickly as possible. Samples were then brought back to the laboratory and analyzed.

The samples used in determinations of the mercury content were taken in hard glass bottles, which had been washed in a manner similar to that of the polyethylene bottles used for arsenic and antimony, equipped with Teflon packing. For every 1 l of sample, 10 ml of (1 : 1) (97%) sulfuric acid was added. Samples were then brought back to the laboratory and analyzed. When a sample containing much chloride, such as geothermal water, was preserved at less than pH 1, the loss of mercury was hardly observable. However, for samples containing much sulfide, the loss of arsenic, antimony, and mercury could be observed. In this case, the sulfide and its related compounds were oxidized by a sulfuric acid-potassium permanganate solution and determinations of arsenic, antimony, and mercury were quickly undertaken.

The acids(hydrochloric acid, sulfuric acid) and the potassium permanganate, which were used for measurements of arsenic, antimony and mercury were all analytical, special-reagent grade.

The present investigation aimed to provide a practical method for determining the contents of arsenic and antimony. Regarding arsenic and antimony determination we used the method of Yamamoto et al.,[7] and applied a differential determination of arsenic and antimony to geothermal waters. The procedures are as follows.

Determination of Arsenic. One method for a differential determination of arsenic(III+V) and arsenic(III) is described.

A sample solution (≦40 ml), containing less than 0.5 μg of arsenic(III+V), was placed in a reaction vessel and diluted with water, bringing it to 40 ml. Into this solution, 10 ml of

35% hydrochloric acid and 5 ml of 40% potassium iodide solution were added and the reaction vessel was then put into a hydroguret generator. Then, 1 ml of 3% sodium borohydride in 0.01 mol dm^{-3} sodium hydroxide solution was injected with a syringe over a period of 20 s while stirring with a bar. Arsine was evolved by passing nitrogen through the reaction vessel 70 s after injecting 3% sodium borohydride. The arsine was atomized in a hydrogen-nitrogen flame of an atomic absorption spectrometer and the arsenic(III+V) was determined at a wavelength of 193.7 nm. By using a calibration curve prepared in the same way as the sample, the arsenic(III+V) content could be determined.

In order to determine the content of arsenic(III), the sample solution was diluted with water, bringing it to 40 ml, in a reaction vessel. This solution was adjusted to pH 5—6 by the addition of 1 ml of 40% citric acid and 5 ml of 1 mol dm^{-3} sodium citrate tribasic, set into the hydroguret generator, and treated in the same way as in the procedure for arsenic(III+V).

Determination of Antimony. One method for a differential determination of antimony(III+V) and antimony(III) is described. A sample solution (≦40 ml), containing less than 0.5 μg of antimony(III+V), was placed in a reaction vessel and diluted with water, bringing it to 40 ml. Then, 5 ml of 35% hydrochloric acid and 2.5 ml of 40% potassium iodide solution were added. The vessel was then put into a hydroguret generator and the antimony(III+V) was treated in the same way as during the determination of arsenic(III+V). The amount of antimony(III+V) was determined by a hydrogen-nitrogen flame. The atomic absorption was done at a wavelength of 217.6 nm.

In order to determine the content of antimony(III), a 40 ml sample solution containing less than 0.5 μg was placed in a reaction vessel as in the determination of antimony(III+V). The sample solution was then adjusted to pH 2 by the addition of 2.5 ml of 40% citric acid solution; the antimony(III) was treated in the same way as treating antimony(III+V).

Determination of Mercury. The determination of mercury was achieved according to the method described previously.[9]

Results and Discussion

Existing Forms of Arsenic and Antimony in Geothermal Waters. Geothermal water was sampled and brought back to the laboratory. Then, the change in the arsenic(III) and arsenic(III+V) contents were examined during storage.

The analytical results are shown in Table 1. The contents of arsenic(III) in some samples decreased rapidly while standing after sampling; however, the contents of arsenic(III+V) remained almost constant. A similar result was obtained for antimony.

The underground regions where geothermal water exists are strongly reductive and the abundance ratios of arsenic(III) to arsenic(III+V) and antimony(III) to antimony(III+V) are higher than those of surface

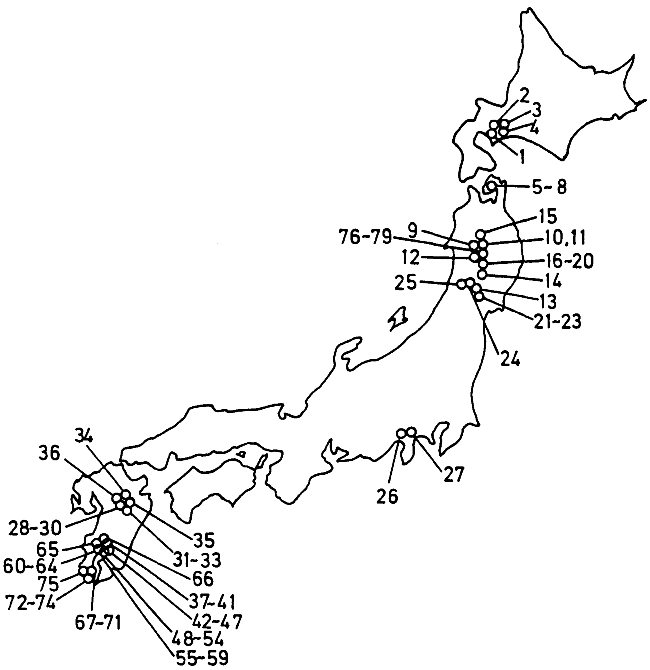

Fig. 1. Map of sampling locations for geothermal waters. 1: Usu, 2, 3: Tōya, 4: Noboribetsu, 5—8: Osorezan, 9: Tamagawa, 10, 11: Ōnuma, 12: Kuroyu, 13: Doroyu, 14: Oyasukyō, 15: Sumikawa, 16—20: Kakkonda, 21—23: Onikoube, 24: Onikoube Arayu, 25: Katayamajigoku, 26: Ōwakudani, 27: Miyanoshita, 28—30: Sujiyu, 31—33: Hattyoubaru, 34: Mizuwaketōge, 35: Takigami, 36: Ōtake, 37—41: Ebino rotenburo, 42—47: Ebino iwōyamashita, 48—54: Iwōdani, 55—59: Maruo, 60—64: Tearai, 65: Kurino, 66: Kurinodake onsen, 67—71: Ibusuki, 72—74: Yamagawa, 75: Kaimon, 76—79: Matsukawa.

Table 1. Change of Arsenic(III) and Arsenic(III+V) Concentration in Hot Spring Waters

Sample[f]	Standing after sampling					
	1 days Content/$\mu g\, l^{-1}$		10 days Content/$\mu g\, l^{-1}$		30 days Content/$\mu g\, l^{-1}$	
	As(III)	As(III+V)	As(III)	As(III+V)	As(III)	As(III+V)
A[a]	0.0	12.$_4$	0.0	12.$_6$	0.0	12.$_4$
B[b]	80.$_4$	225	7.0	224	5.0	218
C[c]	31.$_4$	60.$_8$	2.4	60.$_4$	2.0	59.$_4$
D[d]	0.9	1.8	1.0	2.0	0.9	1.7
E[e]	5.6	6.3	4.4	6.2	3.8	6.3

a) Ebino rotenburo. b) Iwōdani miyōban onsen. c) Ebino iwōyamashita (1). d) Kirishima kokusaihoteru. e) Ebino iwōyamashita (2). f) 10ml of 35% hydrochloric acid was added to each 1 liter of sample.

Table 2. Analytical Results of Mercury in Various Geothermal Waters

Sampling station	Inorg. Hg $\mathrm{ng\,l^{-1}}$	Inorg. Hg+Org. Hg $\mathrm{ng\,l^{-1}}$	Total Hg $\mathrm{ng\,l^{-1}}$	Remarks
Unagionsen(Yamagawa)	3.7	6.3	6.3	Hot spring water
Miyōban(Iwōdani)	0.7	5.0	4.7	Hot spring water
Rotenburo(Ebino)	2.9	4.9	5.0	Hot spring water
Iwōyamashita(Ebino)	1.7	2.2	$18._5$	Hot spring water
Kankyō-chōsasei(Tearai)	2.9	3.2	$10._5$	Thermal water
Fushime(Yamagawa)	8.7	9.9	$11._0$	Thermal water
Ōtake(Ōita)	$10._6$	$13._3$	$14._7$	Thermal water
Matsukawa No. 6 (Matsukawa)	0.1	9910	13700	Condensed water
Matsukawa No. 7 (Matsukawa)	0.1	9020	11400	Condensed water
Kankyō-chōsasei(Tearai)	2.3	4640	4600	Condensed water

Table 3. Analytical Results of Arsenic, Antimony, and Mercury in Geothermal Waters

No.	Sampling location	Date	Temp °C	pH	As(III+V) $\mu\mathrm{g\,l^{-1}}$	Sb(III+V) $\mu\mathrm{g\,l^{-1}}$	Hg(Total) $\mathrm{ng\,l^{-1}}$
1	Usu(Ginnumakakō)	Nov. 13. '82	90	3.0_6	1.7	0.0_5	$89._8$[a)]
2	Tōya(Soubetsu onsen) (1)	Nov. 14. '82	59.7	6.5_9	910	0.3_8	$10._8$
3	Tōya(Soubetsu onsen) (2)	Nov. 14. '82	67.0	6.4_9	1160	0.2_5	$10._2$
4	Noboribetsu onsen	Oct. 25. '83	87.5	2.5_4	$23._2$	0.8_6	$10._1$
5	Osorezan (1)	Nov. 15. '82	58.0	2.1_6	$16._0$	0.2_0	7.5
6	Osorezan (2)	Nov. 15. '82	59.6	2.0_5	1.4	0.0_5	$37._0$
7	Osorezan (3)	Nov. 15. '82	62.6	2.0_2	1430	0.1_5	$30._8$
8	Osorezan (4)	Nov. 15. '82	61.5	2.0_0	$20._0$	0.0_5	$10._2$
9	Tamagawa onsen Ōubuki	Sept. 8. '82	98.0	1.2_0	3050	7.8	$22._6$
10	Ōnuma (1)	Sept. 8. '82	—	7.9_1	9500	163	$18._7$
11	Ōnuma (2)	Sept. 8. '82	—	7.8_2	8050	153	$19._1$
12	Kuroyu	Sept. 9. '82	86.0	2.9_9	0.3_5	0.0_8	—
13	Doroyu	Sept. 10. '82	97.2	8.1_3	7.0	0.7_5	—
14	Oyasukyō Ōubukiyu	Sept. 10. '82	—	8.3_8	160	$14._7$	$26._5$
15	Dowa kōgyō(Sumikawa)	Sept. 10. '82	93.5	9.3_8	211	$22._6$	$21._1$
16	Kakkonda (1)	Oct. 30. '81	—	8.3_5	3350	146	$43._0$
17	Kakkonda (2)	Oct. 30. '81	87.5	8.6_0	2610	119	$16._6$
18	Kakkonda (3)	Oct. 15. '82	—	8.4_4	4500	147	$13._6$
19	Kakkonda (4)	Oct. 15. '82	—	8.7_8	2100	111	$15._2$
20	Kakkonda(Damushita onsen)	Oct. 30. '81	98.1	8.8_3	435	$26._7$	—
21	Onikoube (1)	Jun. 19. '82	93.0	4.7_0	1310	$17._2$	$21._3$
22	Onikoube (2)	Jun. 19. '82	97.3	7.1_8	1610	$55._2$	$19._0$
23	Onikoube (3)	Jun. 19. '82	97.4	3.4_6	1540	$26._2$	$14._8$
24	Onikoube Arayu	Jun. 19. '82	91.0	1.9_9	215	0.5_1	—
25	Katayamajigoku	Jun. 19. '82	92.1	2.5_0	8.6	1.4_7	—
26	Hakone(Ōwakudani)	Jul. 15. '83	—	2.3_9	1.8_6	0.0_4	$65._5$
27	Hakone(Miyanoshita-jakotsu)	Jul. 15. '83	86.0	8.0_6	1150	9.6_6	$12._7$
28	Sujiyu(Utaseyu)	Aug. 5. '83	55.3	3.4_9	306	5.1_0	$19._2$
29	Sujiyu(Yakushiyu)	Aug. 5. '83	55.0	3.5_1	330	5.9_0	$4._5$
30	Sujiyu(Ōyu)	Aug. 5. '83	44.0	3.8_7	288	5.9_0	$6._3$
31	Hattyoubaru (1)	Aug. 5. '83	97.0	7.3_0	3660	119	$6._8$
32	Hattyoubaru (2)	Aug. 5. '83	96.5	7.1_7	4290	244	$31._6$
33	Hattyoubaru (3)	Aug. 5. '83	92.0	7.4_5	3670	$70._5$	$4._6$
34	Mizuwaketōge	Aug. 6. '83	96.2	8.9_8	480	$21._8$	$2._6$
35	Takigami	Aug. 3. '83	—	9.0_8	332	$13._6$	—
36	Ōtake	Nov. 9. '81	90	8.3_3	2590	$88._8$	$14._7$
37	Ebino rotenburo	Nov. 1. '81	40.5	2.2_3	$15._4$	0.1_5	9.7
38	Ebino rotenburo	Mar. 14. '82	39.0	2.2_5	$41._5$	0.7_0	5.0
39	Ebino rotenburo	Sept. 12. '82	40.5	2.3_1	$10._4$	0.1_5	$11._7$
40	Ebino rotenburo	Aug. 26. '83	39.5	2.3_5	$12._4$	0.3_4	$13._5$
41	Ebino rotenburo	Nov. 25. '83	37.5	2.3_9	7.3	0.2_0	7.1
42	Ebino iwōyamashita	Nov. 1. '81	56.0	1.8_5	$60._5$	0.9_7	$12._2$
43	Ebino iwōyamashita	Jan. 27. '82	45.8	1.8_5	$47._3$	1.0_3	9.8
44	Ebino iwōyamashita	Mar. 14. '82	49.0	1.7_0	$45._7$	1.4_2	9.2
45	Ebino iwōyamashita	Sept. 12. '82	58.5	1.8_4	$60._8$	0.9_3	9.4
46	Ebino iwōyamashita	Aug. 26. '83	57.8	1.8_8	$73._7$	1.0_1	9.7
47	Ebino iwōyamashita	Nov. 25. '83	46.0	1.9_7	$75._6$	0.8_0	6.8

Table 3. (Continued)

No.	Sampling location	Date	Temp °C	pH	As(III+V) $\mu g\,l^{-1}$	Sb(III+V) $\mu g\,l^{-1}$	Hg(Total) $ng\,l^{-1}$
48	Iwōdani miyouban	Jan. 27. '82	58.3	3.0_0	$86._3$	0.0_8	8.5
49	Iwōdani miyouban	Mar. 13. '82	58.5	3.1_2	$88._2$	0.4_5	4.7
50	Iwōdani miyouban	Sept. 12. '82	60.0	3.1_5	225	0.1_3	3.6
51	Iwōdani miyouban(Iwōsen)	Aug. 26. '83	45.8	3.3_3	$77._7$	0.3_8	$10._8$
52	Iwōdani miyouban(Iwōsen)	Nov. 25. '83	50.7	3.3_0	$43._2$	0.0_8	3.4
53	Iwōdani miyouban(Tetsusen)	Aug. 26. '83	61.6	3.1_6	154	0.4_1	8.4
54	Iwōdani miyouban(Tetsusen)	Nov. 25. '83	61.3	3.1_8	104	0.1_3	9.6
55	Maruo 3 gōsen	Dec. 6. '81	76.0	6.4_5	3.8	0.1_8	7.7
56	Maruo 3 gōsen	Jan. 27. '82	77.2	6.5_8	1.7	0.0_5	$54._6$
57	Maruo 3 gōsen	Mar. 13. '82	73.8	6.9_1	2.3	0.0_8	$72._5$
58	Maruo 3 gōsen	Apr. 14. '82	75.5	6.7_1	2.0	0.1_5	$51._7$
59	Maruo 3 gōsen	Sept. 12. '82	76.8	7.7_0	1.3	0.1_0	$61._3$
60	Tearai (1)	Feb. 17. '82	92.5	8.6_8	4410	193	$37._4$
61	Tearai (2)	Feb. 25. '82	93.0	8.3_7	5800	205	$65._5$
62	Tearai (3)	Mar. 10. '82	94.0	8.1_7	7150	231	$10._5$
63	Tearai (4)	Oct. 6. '82	94.2	2.9_4	4450	$92._3$	8.4
64	Tearai (5)	Oct. 23. '82	96.5	2.7_2	5350	$81._0$	$12._9$
65	Kurino KEI-3	Jan. 27. '82	93.5	8.5_4	2650	145	$21._7$
66	Kurinodake onsen	Mar. 13. '82	64.1	1.9_5	1.7	0.1_5	$17._0$
67	Sunaburo(Ibusuki)	Jul. 9. '82	51.8	6.8_1	$77._4$	4.2_0	$11._6$
68	Shokubutsushikenjō(Ibusuki)	Jul. 9. '82	52.0	6.6_2	$32._6$	0.3_0	$16._4$
69	Nigatsuden(Ibusuki)	Jul. 9. '82	59.5	7.0_8	$46._4$	0.3_3	$11._8$
70	Hakusuikan(Ibusuki)	Jul. 9. '82	69.0	6.8_7	155	4.5_0	$13._7$
71	Kokuritsubyōin(Ibusuki)	Jul. 9. '82	78.0	7.8_0	$62._4$	3.6_0	$11._7$
72	Okachogamizu(Yamagawa)	Jul. 9. '82	52.5	7.0_6	$74._0$	1.8_3	9.8
73	Masuda onsen(Yamagawa)	Jul. 9. '82	76.0	8.0_8	109	7.5_8	3.8
74	Fushime(Yamagawa)	Jul. 9. '82	89.5	6.5_7	1540	$73._6$	$27._9$
75	Kaimonsou(Kaimon)	Jul. 9. '82	39.2	7.7_1	$30._6$	1.1_0	$10._7$
76	Matsukawa (1)[b)]	Oct. 28. '81	—	—	121	0.4_8	15900
77	Matsukawa (2)[c)]	Oct. 28. '81	—	—	$97._3$	0.5_3	13700
78	Matsukawa (3)[d)]	Oct. 28. '81	—	—	320	0.4_2	11400
79	Matsukawa (4)[e)]	Oct. 29. '81	—	—	114	0.3_5	—

a) Stored in a polyethylene bottle. b), c), d), e): Condensed water.

water. After sampling, the arsenic(III) and antimony(III) were exposed to an oxidative atmosphere and may have been converted to arsenic(V) and antimony(V), respectively.

Since arsenic(III) and antimony(III) in geothermal water can change, depending on the storage conditions of the sample, any determination of arsenic(III) and antimony(III) must be carried out in as short a time as possible after sampling.

Existing Forms of Mercury in Geothermal Waters. The analytical results of the existing chemical forms are shown in Table 2.

In thermal water and hot spring water, there is no great difference in the contents of soluble inorganic mercury, soluble inorganic plus organic mercury, and total mercury. It may be noted that mercury in thermal water and hot spring water exists in almost soluble inorganic mercury. However, for volcanic gas condensed water, which contains much hydrogen sulfide, the amount of soluble inorganic plus organic mercury and the total amount of mercury is more than that of soluble inorganic mercury. This does not suggest that there is not much soluble inorganic mercury in volcanic gas condensed water, but implies that the reduction of soluble inorganic mercury is difficult because of the interference of sulfide ion. Therefore, it is difficult to determine the amount of soluble inorganic mercury and organic mercury in geothermal water samples which contain much sulfide ion.

Table 4. Arsenic, Antimony, and Mercury Contents in Geothermal Waters

Element	Range[a)]	n[b)]	$\bar{X}_A$[c)]	$\bar{X}_G$[d)]
As	0.35—9500	75	1230	141
Sb	0.05— 244	75	$35._4$	2.5_0
Hg	2.6 — $89._8$	69	$19._1$	$13._8$

a—c) in $\mu g\,l^{-1}$ for As, Sb and $ng\,l^{-1}$ for Hg. b) Number of samples. c) Arithmetic mean. d) Geometric mean.

The Arsenic, Antimony, and Mercury Contents in Geothermal Waters. The arsenic(III+V), antimony(III+V), and total contents of mercury were determined for geothermal water sampled from various geothermal areas in Japan. The sampling stations are illustrated in Fig. 1 and analytical results are tabulated in Table 3. Below, we discuss the data listed in Table 3.

The range, arithmetic and geometric mean of the arsenic, antimony, and mercury contents and the number of samples measured, except for gas condensed water, are shown in Table 4.

Using the mean content of arsenic, antimony, and mercury in igneous rocks, accepted to be 1.5,[21] 0.2,[22] and 0.08[23] ppm, respectively, the gravimetric ratios of As/Sb, Sb/Hg, and As/Hg can be calculated as being 7.5, 2.5, and 19, respectively. From the values listed in Table 4, the gravimetric ratios of As/Sb, Sb/Hg, and As/Hg in geothermal water were calculated to be 56, 179 and 10000, respectively. Watanuki et al.[19] have reported that the gravimetric ratio of As/Sb in the Tamagawa and Kusatsu hot springs to be 100 and 50, respectively.

The antimony and mercury contents in geothermal water are smaller compared to the arsenic content. The reasons involve (assuming the differences of the composition of thermal water which comes into contact with igneous rock) the ease of sulfide precipitation and gas scattering in the atmosphere.

Mutual Relation of Arsenic, Antimony, and Mercury in Geothermal Waters. The mutual relation among arsenic, antimony and mercury contents in geothermal waters is shown in Figs. 2—4.

In geothermal water, there is a high positive correlation between the arsenic and antimony contents (correlation coefficient, 0.87). However, the correlation coefficients between the contents of arsenic and mercury or between that of antimony and mercury were 0.065 and 0.15, respectively, showing no correlation between arsenic and mercury or between antimony and mercury. This suggests that mercury behaves differently from arsenic and antimony in geothermal water.

Distributions of Arsenic, Antimony, and Mercury in Geothermal Waters. The frequency distributions of the arsenic, antimony, and mercury contents in geothermal water are shown in Figs. 5—7.

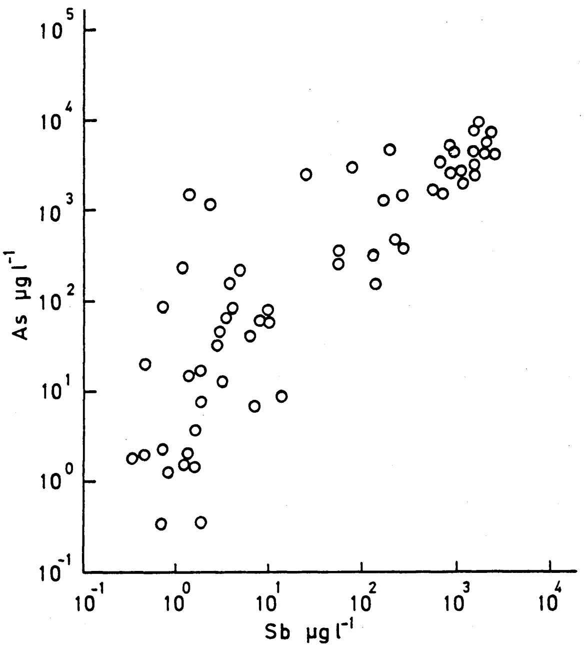

Fig. 2. Relation between arsenic and antimony in geothermal waters.

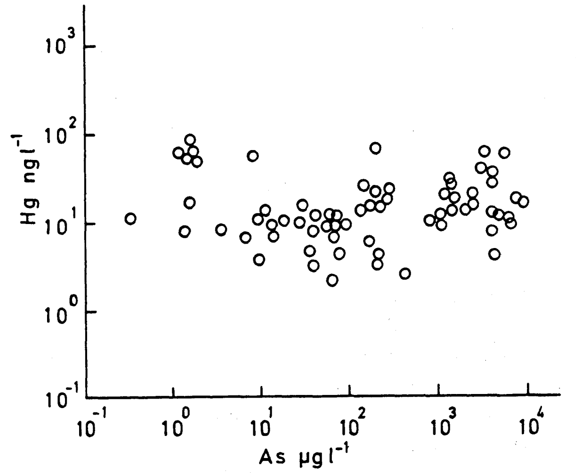

Fig. 3. Relation between mercury and arsenic in geothermal waters.

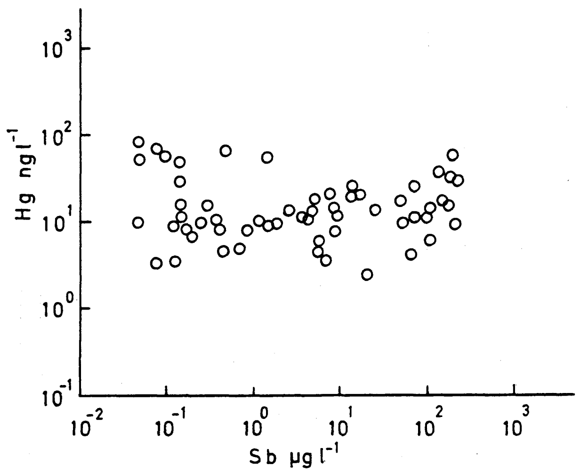

Fig. 4. Relation between mercury and antimony in geothermal waters.

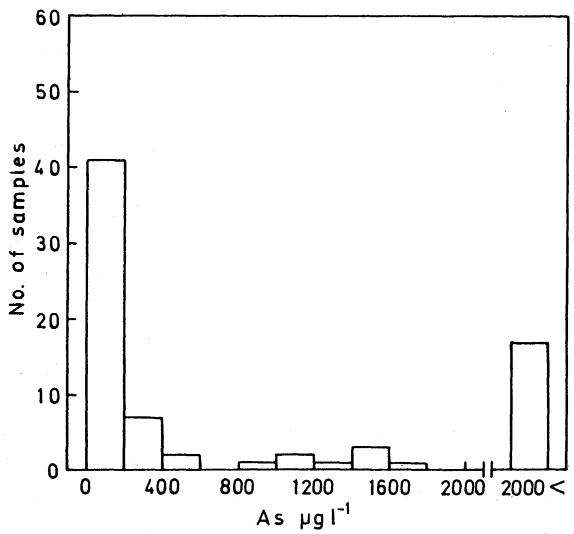

Fig. 5. Frequency for arsenic content distributions of geothermal waters.

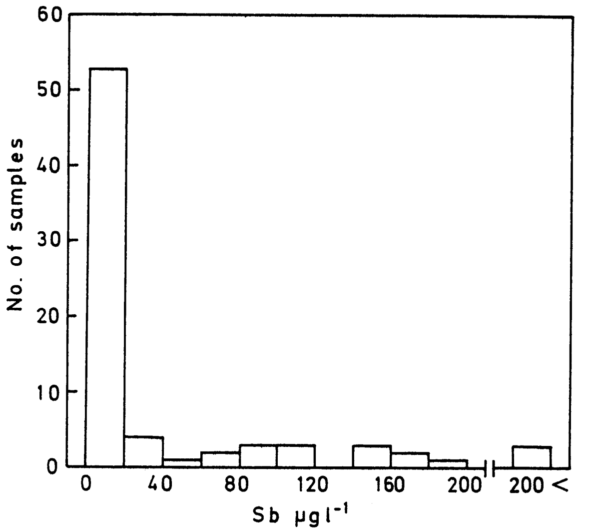

Fig. 6. Frequency for antimony content distributions of geothermal waters.

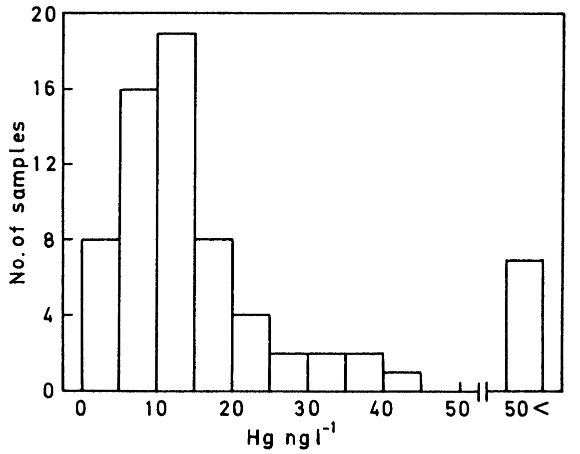

Fig. 7. Frequency for mercury content distributions of geothermal waters.

The distributions of arsenic and antimony are similar in the sense that they are spread over wide concentration range. On the other hand, except for a few of the samples, the mercury is limited to an extremely narrow concentration range.

One of the specificities of arsenic and antimony contents (cf. Table 3) in geothermal water is that the arsenic and antimony contents in a thermal water system (Ōnuma, Kakkonda, Onikoube, Ōtake, and others) tend to be larger than those in a vapor dominated system (Matsukawa).

The arithmetic and geometric means of the total mercury content in geothermal water for 69 samples, except for gas condensed water, are $19._1$ ng l^{-1} and $13._8$ ng l^{-1} respectively. Except for a few samples, there was no great difference in the mercury content from different geothermal areas; the mercury content in geothermal water was smaller than that of the arsenic and antimony contents. The range of the mercury content in the gas condensed water at Matsukawa was 11400—15900 ng l^{-1}; this concentration in gas condensed water is as much as a 1000 times higher than that found in general thermal waters. This seems to correlate with the fact that mercury is a component which changes easily to the gas phase.

No correlation between pH and the content of arsenic, antimony or mercury in geothermal water could be observed.

Conclusion

We have determined the arsenic, antimony, and mercury contents in geothermal water. The range of arsenic(III+V), antimony(III+V), and the total contents of mercury in geothermal water were 0.35—9500 μg l^{-1}, 0.05—244 μg l^{-1}, 2.6—$89._8$ ng l^{-1}, respectively, their arithmetic means were 1230 μg l^{-1}, 35.4 μg l^{-1}, and $19._1$ ng l^{-1}, respectively, and their geometric means were 141 μg l^{-1}, 2.5_0 μg l^{-1}, and $13._8$ ng l^{-1}, respectively.

There is a high positive correlation between the arsenic and antimony contents in geothermal water, but there is no correlation between the mercury and arsenic contents or between the mercury and antimony contents. It is assumed that mercury behaves differently from arsenic or antimony in geothermal water.

The arsenic and antimony contents in geothermal water tend to be larger in the thermal water of thermal water systems compared to the thermal water (condensed water) of vapor dominated systems.

On the other hand, except for a few cases, there is not much difference in the total mercury content of geothermal water in different geothermal areas. Mercury is thought to be a component which can not exit in high concentrations in geothermal water (thermal water and hot spring water).

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