Chemical Composition of Natural Waters and Rock Weathering in the Izu Peninsula Area as an Index to Earthquake-Caused Landslides

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Abstract

Natural waters in the Izu Peninsula area were analyzed in connection with earthquake predictions and ground stability in the area.

No relationship was observed between earthquakes and the chemical composition of natural waters. From the chemical composition of natural waters, the amount of rock forming minerals chemically weathered and also the amount of clay minerals formed were estimated. Chemical analyses of natural waters were found to be a valuable and useful index to ground stability in connection with earthquake-related landslides.

1. Introduction

Recently many studies have been carried out to find a method to predict earthquakes. Some geochemists have reported that radon, helium, argon and hydrogen gases in ground waters are good indicators (WAKITA *et al.*, 1980). Others have proposed that chemical analyses of anions in ground waters are useful for earthquake prediction (YOSHIOKA, 1978). Various kinds of monitoring are now being attempted for the prediction of earthquakes in the Izu Peninsula area of Japan, where earthquakes have been frequent since 1974 (see Table 1). The authors collected natural water samples three times in this peninsula area and analysed their major chemical constituents. No clear relationship between the chemical composition of natural water and the occurrence of earthquakes was established, but the analytical data on the natural waters may serve as a basis for future earthquake prediction studies in this area.

The present investigators consider that the chemical composition of natural water may be related to earthquake occurrence in the following two ways. First, an earthquake might be predictable on the basis of the anion concentration (volatile

materials) in natural water. Some anions in natural water are supplied from subterranean parts of the area. And the concentrations of some anions may give some information on certain events occurring in subterranean parts of the area. A second point concerns the ground stability in connection with landslides, as determined mainly from the cation concentration in natural water. Water-rock interaction causes the dissolution of cations from rock forming minerals into natural water and the transformation from rock forming minerals into clay minerals. Thus, the chemical composition of natural water may indicate the extent of the chemical weathering of rocky materials, the formation of clay minerals and the ground stability (KITANO and NAKAMURA, 1973; KITANO, 1980a, b). One of the most serious disasters resulting from earthquakes is the damage from landslides. Therefore, it is important to have detailed and accurate information on ground stability. In this study, the chemical analysis of groundwater did not provide a means to predict earthquakes, but the analytical result of natural water indeed is an index to ground stability which is a key indicator for landslides triggered by earthquakes.

2. Experimental

Collection of water samples: Natural water samples were collected three times for the chemical analysis of water quality at the various stations shown in Fig. 1, before and after the earthquakes shown in Table 1: Irozaki, Iruma and Nakagi in Nov. 1976; various stations throughout the peninsula in July 1977; and various stations in the Inatori area, where the Izu-Ohshima earthquake occurred, in March 1978. Chemical analyses: pH, glass electrode pH meter; HCO_3^- , titration with hydrochloride standard solution and bromcresol purple indicator; Cl^- , colorimetry with mercury thiocyanate; SO_4^{2-} , colorimetry with thorium-morin complex (NASU, 1969); Ca^{2+} and Mg^{2+} , atomic absorption spectrophotometry; Na^+ and K^+ , flame emission spectrophotometry; and soluble SiO_2 , colorimetry with ammonium molybdate.

3. Results and Discussion

As pointed out earlier, the analytical results in natural waters seem very important and useful for future studies on earthquake prediction in this area. These analytical results are presented in Tables A, B and C as an Appendix.

(A) Relationship between earthquakes and chemical composition of natural water.

Anions are volatile materials, and some anions in natural water originate in deep parts of the earth. However, some Cl^- ions

come from sea water, some SO_4^{2-} ions through the oxidation of iron sulfide, and some HCO_3^- ions from oxidation of organic material. Therefore, the concentrations of anions in natural water do not always indicate a geochemical change and events occurring in deep parts of the earth. Cations are supplied into natural water mostly through the chemical weathering processes of rocks. Therefore, the change in the anion concentration in natural water could be expected to have a more significant connection with earthquakes than that of cations. Western and southern Izu Peninsula areas are covered with Neogene rocks. The eastern part has Quaternary pyroclastic rocks. The authors examined the relationship between earthquakes and anion concentrations in natural water using data shown in Tables A, B and C (Appendix). However, no clear relationship could be found between the occurrence of earthquakes and the change in anion concentrations in natural water. It was noted that natural waters in the southern part of Izu Peninsula (St. 27) and in the Inatori area (Sts. 74 and 92) exhibited very high concentrations of dissolved constituents. These waters flow out through a fault.

Table 2 shows the chemical compositions of two representative natural waters in the individual sampling area. The natural water at St. 27 in the Yumigahama area is very interesting (see Table 2), because

Table 1. Occurrence of earthquake and water sampling in the Izu Peninsula area.

Occurrence of earthquake		Sampling of waters for chemical analyses	
Date	Name of earthquake (magnitude)	Date	Numbers of water sample
May 9, 1974	Off-Izu Peninsula earthquake (M 6.9)	Nov., 1976 Jul., 1977 May, 1978	18 98 90
Aug. 18, 1976	Kawazu earthquake (M 5.4)		
Jan. 4, 1978	Izu-Ohshima earthquake (M 7.4)		
Dec. 3, 1978	Itoh-Kawanasaki earthquake (M 5.4)		
Jun. 29, 1980	Off-east part of Izu Peninsula earthquake (M 6.7)

Fig. 1. Locations of natural water sampling in the Izu Peninsula area. (Figure in map denotes station number).

it is a calcium-chloride type water. This type of water has been found only at special stations such as Don Juan Pond in Antarctica, the deep seawater layer in the Red Sea, and the brine waters in oil fields. The major chemical constituents in these waters are calcium and chloride ions, and usually the high concentrations range from 300 to 400 g·l⁻¹. KITANO and his coworkers found this calcium-chloride type water in the ground water of the Matsushiro swarm earthquake area in Japan (KITANO *et al.*, 1968; YOSHIOKA *et al.*, 1970). The authors discussed the processes involved in the formation of the calcium-chloride type water. A calcium-chloride type water was also

found here in Izu Peninsula at St. 27. It should be noted that St. 27 is situated in a typical fault area.

The key diagram classification of natural waters from these chemical compositions is shown in Table 3, which indicates the types of natural waters.

(B) *Estimation of the amounts of silicate minerals weathered, clay minerals formed, and calcium carbonate and silica dissolved.*

In order to estimate the above-mentioned amounts from the chemical composition of natural water, the amounts of Na⁺, K⁺, Ca²⁺, and Mg²⁺, dissolved into natural water from rocky materials for one year,

Table 2. Chemical composition of natural waters and amounts of minerals weathered, dissolved and formed in the Izu Peninsula area.

Station No.	pH	HCO ₃ ⁻ mg./l. ⁻¹	Cl ⁻ mg./l. ⁻¹	SO ₄ ²⁻ mg./l. ⁻¹	Na ⁺ mg./l. ⁻¹	K ⁺ mg./l. ⁻¹	Ca ²⁺ mg./l. ⁻¹	Mg ²⁺ mg./l. ⁻¹	Soluble SiO ₂ mg./l. ⁻¹	1*1	2*2 ton·km ⁻² ·year ⁻¹	3*3	4*4	Region	Remarks
25	6.3	54	70	48	42	6.0	21	12	37	120	60	10	30	Irozaki, Sitaru	Well
26	7.0	137	82	74	74	47	31	15	32	940	520		320		Well
27	7.6	265	680	23	270	17	950	150	26	770	240	3000	220	Yumigahama	Well
28	7.4	117	64	14	33	1.7	28	13	27	60	20	80	30		Well
29	7.6	147	78	14	99	1.6	8.6	3.4	35	970	640	50	270	Simogamo	Well
30	6.5	46	8.5	9.7	9.2	3.7	7.1	3.7	16	120	70	30	40		Well
46	6.3	54	9.0	15	6.7	1.9	19	4.8	13	60	30	40	20	Kawazu, Simosagano	Well
48	6.5	61	10	8.9	11	1.6	15	4.1	16	120	70	30	30		Well
63	6.6	47	55	51	45	29	13	5.2	34	520	280		180	Mitaka	Well
66	7.9	63	8.5	5.8	9.5	0.7	12	2.6	35	90	60	30	30		Well
101	6.9	48	14	29	12	2.2	28	7.0	33	120	60	50	30	Ito, Kamata	Spring
102	6.8	43	69	76	40	1.7	34	9.3	36	70	30	10	20		Spring
127	6.7	109	28	15	25	5.8	30	4.4	27	240	140	70	70	Shuzenji	Well
128	6.6	46	8.5	11	9.8	1.4	10	3.6	19	120	70	10	30		Well
132	6.5	56	9.5	13	8.2	3.8	21	4.8	22	100	50	50	30	Yugashima, Ichiyama	Spring
133	7.2	49	3.4	6.8	6.5	0.8	10	1.7	21	100	60	20	30		

*1—1: Amount of rock forming silicate minerals weathered, (ton·km⁻²·year⁻¹).*2—2: Amount of clay minerals formed, (ton·km⁻²·year⁻¹).*3—3: Amount of CaCO₃ dissolved, (ton·km⁻²·year⁻¹).*4—4: Amount of SiO₂ dissolved, (ton·km⁻²·year⁻¹).

Table 3. Types of the chemical composition of natural waters in the Izu Peninsula area.

Region	Type of water quality
Irohazaki	NaCl, NaHCO ₃
Yumigahama	CaCl ₂
Matsuzaki	(Ca, Mg) (HCO ₃) ₂
Kawazu	Ca(HCO ₃) ₂ , MgCl ₂ , CaSO ₄ , NaCl
Inatori	CaSO ₄ , CaCl ₂ , MgCl ₂ , Na ₂ SO ₄
Shirata, Naramoto	Ca(HCO ₃) ₂
Katase	Ca(HCO ₃) ₂ , CaCl ₂ , CaSO ₄
Itoh	Ca(HCO ₃) ₂ , NaHCO ₃ , CaCl ₂ , CaSO ₄
Sawakuchi	(Ca, Mg) (HCO ₃) ₂
Nakaizu	Ca(HCO ₃) ₂ , CaCl ₂ , CaSO ₄ , Na ₂ SO ₄
Toi	Ca(HCO ₃) ₂

Fig. 2. Relation between HCO₃⁻ concentration and Ca²⁺+Mg²⁺ concentration in natural waters.

(×, ○, ●: data in 1976, 1977 and 1978, respectively).

must be estimated, and the important chemical reactions to dissolve these cations from rocky materials must be identified.

By introducing the estimated amounts of Na^+ , K^+ , Ca^{2+} and Mg^{2+} into the above-noted important chemical reactions, the equations of the chemical reactions are solved. These detailed procedures were reported previously by KITANO (1980 a, b). The following two processes are expected to occur in the chemical weathering of rocky materials: weathering only by carbonic acid; weathering by both carbonic

acid and sulfuric acid.

Sulfuric acid is formed through the oxidation of iron sulfides. When the SO_4^{2-} concentration in ground water is low, the weathering is considered to occur only through carbonic acid; and when it is high, the weathering occurs through both carbonic and sulfuric acids. The chemical weathering of rock forming silicate minerals causes the transformation of silicate minerals into clay minerals (GARRELS and MACKENZIE, 1967; KITANO and NAKAMURA, 1973; KITANO, 1980 a, b). HCO_3^-

Fig. 3. Relation between $\text{HCO}_3^- + \text{SO}_4^{2-}$ concentration and $\text{Ca}^{2+} + \text{Mg}^{2+}$ concentration in natural waters.

(x, o, ●: data in 1976, 1977 and 1978, respectively).

Fig. 4. Relation between HCO_3^- concentration in the natural waters and amount of chemically weathered silicate minerals.

(×, ○, ●: data in 1976, 1977 and 1978, respectively).

ions in ground water are supplied through the interaction between carbonic acid and rocky materials, and SO_4^{2-} ions through the interaction between sulfuric acid formed through the oxidation of sulfides and rocky materials. When chemical elements are dissolved from rocky materials through the carbonic and/or sulfuric acid process, calcium and magnesium are dissolved preferentially. This suggests that HCO_3^- concentration, $\text{HCO}_3^- + \text{SO}_4^{2-}$ concentration and $\text{Ca}^{2+} + \text{Mg}^{2+}$ concentration in natural water indicate the degree of chemical weathering of rocky material and also the degree of ground stability. This was confirmed earlier (KITANO and NAKAMURA, 1973; KITANO, 1980 b; ISAGAI and ISAGAI, 1981).

The amounts of silicate minerals weathered, clay minerals formed, and carbonate and silica dissolved were estimated by solving the equations, as shown in Tables A, B and C (Appendix).

Figure 2 shows the relationship between the HCO_3^- concentration and the $\text{Ca}^{2+} + \text{Mg}^{2+}$ concentration in the natural waters of the Izu Peninsula area.

Figure 3 shows the relationship between the $\text{HCO}_3^- + \text{SO}_4^{2-}$ concentration and the $\text{Ca}^{2+} + \text{Mg}^{2+}$ concentration in the natural waters in the same area.

Figure 4 presents the relationship between the HCO_3^- concentration in the natural waters and the amount of silicate minerals

Fig. 5. Relation between $\text{HCO}_3^- + \text{SO}_4^{2-}$ concentration in the natural waters and amount of chemically weathered silicate minerals.

(×, ○, ●: data in 1976, 1977 and 1978, respectively).

chemically weathered.

Figure 5 gives the relationship between the $\text{HCO}_3^- + \text{SO}_4^{2-}$ concentration in the natural waters and the amount of silicate minerals chemically weathered.

Figure 6 gives the relationship between the HCO_3^- concentration in the natural waters and the amount of clay minerals formed plus carbonate and silica dissolved.

Figure 7 presents the relationship between the $\text{HCO}_3^- + \text{SO}_4^{2-}$ concentration in the natural waters and the amount of clay minerals

formed plus carbonate and silica dissolved.

Figure 8 shows the relationship between the HCO_3^- concentration in the natural waters and the amount of silicate minerals weathered plus carbonate and silica dissolved.

Figure 9 gives the relationship between the $\text{HCO}_3^- + \text{SO}_4^{2-}$ concentration in the natural waters and the amount of silicate minerals weathered plus carbonate and silica dissolved.

When Figs. 2, 4, 6 and 8 are compared

Fig. 6. Relation between HCO_3^- concentration in the natural waters and amount of (clay minerals formed) + (carbonate and silica dissolved).
($\times$, $\circ$, $\bullet$: data in 1976, 1977 and 1978, respectively).

with Figs. 3, 5, 7 and 9, respectively, the latter figures show a better correlation in values than the former. This may suggest that the chemical weathering of rocks is effected by both carbonic acid and sulfuric acid. It is well known that ground stability decreases with increasing amounts of weathered silicate minerals, formed clay minerals and dissolved carbonate and silica. The formation of clay minerals extremely

decreases the ground stability. The dissolution of silica (quartz and amorphous silica) has little influence on the ground stability as compared with the formation of clay minerals, but the carbonate dissolution has a significant role. In practise, the concentration of HCO_3^- plus SO_4^{2-} in the natural waters in Izu Peninsula may well indicate the degree of ground stability in the area and thereby predicts the size

Fig. 7. Relation between $\text{HCO}_3^- + \text{SO}_4^{2-}$ concentration in the natural waters and amount of (clay minerals formed) + (carbonate and silica dissolved).

($\times$, $\circ$, $\bullet$: data in 1976, 1977 and 1978, respectively).

and extent of landslides.

Estimation of the amounts of clay minerals formed and rock forming minerals weathered is thus valuable and useful for the prediction and prevention of earthquake disasters.

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摘要

地震予知の観点から、また地盤の安定性を判断するために伊豆地方の天然水を分析した。

地震と天然水の水質との間には明確な関係はみられなかった。分析結果から化学的に風化される岩石量、生成される粘土鉱物の量を推定した。その結果、天然水を分析することは地震の際の地盤災害に関係ある地盤の安定性を判断するのに有効であることがわかった。

Fig. 8. Relation between HCO_3^- concentration in the natural waters and amount of (silicate minerals weathered) + (carbonate and silica dissolved).
($\times$, $\circ$, $\bullet$: data in 1976, 1977 and 1978, respectively).

Fig. 9. Relation between $\text{HCO}_3^- + \text{SO}_4^{2-}$ concentration in the natural waters and amount of (silicate minerals weathered) + (carbonate and silica dissolved).

($\times$, $\circ$, $\bullet$): data in 1976, 1977 and 1978, respectively).

References

- GARRELS, R.M. and F.T. MACKENZIE (1967) : Origin of the chemical compositions of some springs and lakes. *Equilibrium Concepts in Natural Water Systems, Advances in Chemistry Series, 67, Am. Chem. Soc.*, 222-242.
- ISAGAI, K. and K. ISAGAI (1981) : Chemical composition of ground water in the Hirayama landslide area in Nagasaki Prefecture. *Chikyu Kagaku* (Geochemistry), 15: 33-44.
- KITANO, Y. (1980 a) : Water-rock interaction and geochemical balance of major chemical elements-With emphasis of geochemical balance of calcium and carbon dioxide. *Acta Oceanographica Taiwanica*, 11: 40-48.
- KITANO, Y. (1980 b) : The formation of clay in land area. p.63-74. In: Y. KITANO and T. MATSUNO (ed.), *Chemistry of Earth and Environment (Modern Chemistry 22*, pp.261). Iwanami Co.
- KITANO, Y. and S. NAKAMURA (1973) : Landslide and water quality. *Sekogijutsu*, 6: 17-24.
- KITANO, Y., R. YOSHIOKA and S. OKUDA (1968) : Geochemical study of ground waters in the Matsushiro area. Part 2. *Bull. Disas. Prev. Inst., Kyoto Univ.*, 18: 49-58.
- KITANO, Y., R. YOSHIOKA, S. OKUDA and K. OKUNISHI (1967) : Geochemical study of ground waters in the Matsushiro area. Part 1. *Bull. Disas. Prev. Res. Inst., Kyoto Univ.*, 17: 47-71.
- NASU, T. (1969) : Spectrophotometric determination of micro amounts of sulfate using thorium-morin complex. *Bunseki Kagaku*, 18: 1183-1188.
- WAKITA, H., Y. NAKAMURA, I. KITA, N. FUJII and K. NOTSU (1980) : Hydrogen release: New indicator of fault activity. *American Association for the Advancement of Science*, 210: 188-190.
- YOSHIOKA, R. (1978) : On the relation between chloride ions content of Shiota hot spring and earthquake at the Yamasaki fault. *Disas. Prev. Res. Inst. Nenpo*, Kyoto Univ., 21, B-1: 37-41.
- YOSHIOKA, R., S. OKUDA and Y. KITANO (1970) : Calcium chloride type water discharged from the Matsushiro area in connection with swarm earthquakes. *Geochem. J.*, 4: 61-74.
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Appendix A

Chemical composition of natural waters and amounts of minerals weathered, dissolved and formed in the Izu Peninsula area. Nov. 1976

Station No.	pH	HCO ₃ ⁻ mg./l. ⁻¹	Cl ⁻ mg./l. ⁻¹	SO ₄ ²⁻ mg./l. ⁻¹	Na ⁺ mg./l. ⁻¹	K ⁺ mg./l. ⁻¹	Ca ²⁺ mg./l. ⁻¹	Mg ²⁺ mg./l. ⁻¹	Soluble SiO ₂ mg./l. ⁻¹	1* ¹	2* ² ton·km ⁻² ·year ⁻¹	3* ³	4* ⁴	Region	Remarks
1	6.6	73	76	16	44	5.6	15	7.6	48	80	40	30	30	Irozaki (Irozakiso)	Well
2	6.8	114	93	31	65	15	20	12	50	370	210	10	120	(Setoya)	Well
3	7.0	104	83	16	53	9.1	18	11	56	210	110	40	60	(Tanaka)	Well
4	6.8	85	82	24	47	8.6	20	10	61	110	50	40	40	(Suzuki)	Well
5	7.2	94	100	27	43	5.6	29	15	48	60	20	70	20	(Ozawa)	Well
6	7.2	39	42	27	36	8.0	8.7	5.0	34	300	180		90	(Akamon)	Well
7	7.0	88	104	16	42	4.1	31	14	64	50	20		20		Well
11	7.5	98	45	8.4	34	2.6	18	6.4	43	180	120	40	50	Nakagi	Spring
12	7.3	47	58	26	44	1.8	11	7.7	22	220	140		60		Spring
13	7.6	93	38	8.6	32	2.6	17	6.2	46	220	130	30	70		Spring
14	7.5	62	29	7.0	24	3.3	10	4.1	50	170	100	10	50	Iruma	Drainage
15	7.2	60	51	12	33	2.3	13	6.9	54	110	60	20	30	(Mishima shrine)	Spring
16	7.4	78	43	8.8	37	1.5	9.3	5.4	50	240	150	5	70	(Kaizoji temple)	Well
17	6.5	69	92	21	59	4.8	14	7.9	74	180	110	20	50	(Sotooka)	Well
18	7.9	87	33	5.8	33	3.4	12	4.4	59	290	180	10	80	(Eel nursery)	Well
19	8.1	95	33	5.6	37	6.5	11	2.3	60	380	240	5	110		City water
20	8.3	95	34	5.4	37	5.6	14	2.6	58	360	230	20	110	(Fujinoya)	Spring
21	8.3	94	34	5.6	37	5.3	13	2.6	57	360	230	10	110	(Fujinoya)	Drainage

*¹—1: Amount of rock forming silicate minerals weathered, (ton·km⁻²·year⁻¹).

*²—2: Amount of clay minerals formed, (ton·km⁻²·year⁻¹).

*³—3: Amount of CaCO₃ dissolved, (ton·km⁻²·year⁻¹).

*⁴—4: Amount of SiO₂ dissolved, (ton·km⁻²·year⁻¹).

Chemical composition of natural waters and amounts of minerals weathered, dissolved and formed in the Izu Peninsula area. Jul. 1977

Station No.	pH	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	Soluble SiO ₂	1*1	2*2	3*3	4*4	Region	Remarks
		mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹						
1	6.4	77	80	13	39	5.8	22	12	50	60	20	60	20	Irozaki (Irozakiso)	Well
2	6.7	96	95	26	57	11	22	12	51	180	90	40	60	(Setoya)	Well
3	6.9	113	62	10	53	9.0	26	10	60	410	250	50	120	(Tanaka)	Well
4	6.7	87	93	10	48	8.3	28	8.4	68	60	30	80	30	(Suzuki)	Well
5	7.0	96	110	13	46	4.0	40	15	70	60	20	120	20	(Ozawa)	Well
6	6.8	55	73	20	42	7.6	17	9.0	41	100	50	30	30	(Akamon)	Well
7	7.1	89	134	9.3	40	3.5	39	12	72	20	10	120	10		Well
8	7.0	88	175	11	38	2.4	35	18	72	40	10	110	10		
9	6.8	71	28	48	41	3.4	21	7.9	28	490	300		130	(Irozaki bekkon)	Well
10	6.5	62	64	14	33	2.3	20	7.2	47	20	10	50	10	(Hashimotoya)	Well
11	7.3	98	50	3.8	31	1.4	21	5.8	50	70	40	60	20	Nakagi (Fish pond)	Drainage
12	7.3	63	100	21	48	1.4	19	10	26	20	10	40	10		Spring
14	7.7	74	35	11	26	4.3	12	2.8	61	150	90	20	50	Iruma (Shrine)	City water
15	6.9	64	49	11	29	2.0	11	6.9	56	60	30	20	20	(Shrine)	Spring
16	7.1	77	43	8.7	36	1.2	10	5.6	50	220	140	10	60	(Kaizoji temple)	Well
17	6.4	68	100	15	57	3.3	15	6.8	83	50	30	40	10	(Sotooka)	Well
18	7.5	84	43	2.0	28	2.3	14	4.4	63	90	60	40	30	(Nursery, Eel)	Well
19	7.6	94	33	5.7	37	7.1	11	1.9	60	390	240	4	120		City water
22	6.5	77	89	35	67	4.4	25	12	46	350	220	20	100	Oose (Morishita)	Well
23	7.0	66	67	26	37	5.6	17	15	18	80	20	30	20	(Jyoseiji temple)	Well
24	6.7	132	75	53	67	1.4	31	12	29	460	290		120	(S. Watanabe)	Well
25	6.3	54	70	48	42	6.0	21	12	37	120	60	10	30	Sitaru (H. Hirayama)	Well
26	7.0	137	82	74	74	47	31	15	32	940	520		320	(Yoshida)	Well
27	7.6	265	680	23	270	17	950	150	26	770	240	3000	240	Yumigahama (T. Yokoyama)	Well
28	7.4	117	64	14	33	1.7	28	13	27	60	20	80	30	(Iwata)	Well
29	7.6	147	78	14	99	1.6	8.6	3.4	35	970	640	50	270	Shimogamo (Yamamoto)	Well
30	6.5	46	8.5	9.7	9.2	3.7	7.1	3.7	16	120	70	30	40	(Hoya)	Well
31	6.2	37	31	24	21	15	8.8	4.4	20	210	110	30	80	Sashita (Katsuta)	Well
32	7.0	78	64	7.5	27	1.2	18	3.5	47			50		(Shimada)	Well
33	6.5	64	27	6.9	18	3.0	11	4.7	79	80	50	50	30	Kitsijyo (M. Yamamoto)	Well
34	9.1	99	22	6.6	45	1.1	0.9	0.2	79	580	380	20	160	(S. Kuroda)	Well
35	7.1	86	57	5.0	33	2.2	15	7.6	49	50	30	70	10	Mera (Sawada)	Well
36	7.0	77	61	24	37	4.5	20	9.2	52	100	50	70	30	(Zenpukuji temple)	Well
37	6.5	66	12	4.2	13	3.2	12	7.4	20	160	90	30	40	Matsuzaki (Tennenji temple)	Well
38	6.8	42	14	6.6	8.7	0.9	14	10	21	80	30	40	20	Matsuzaki (N. Nakamura)	Well
39	6.8	21	4.3	7.9	5.1	0.5	6.2	1.4	15	50	30	6	20	Nashimoto (Tsuribashiso)	Spring
40	7.1	41	5.8	6.4	5.3	0.5	11	1.3	17	40	30	30	10	(Tsuribashiso)	Piped water
41	6.9	32	5.0	5.6	4.6	0.7	7.4	1.6	21	40	20	10	10	Izumiokuhara (Wasabisawa)	Spring
42	6.5	17	8.0	10	6.2	0.3	8.3	2.7	14	50	20	10	10	Konabe (T. Hirakawa)	Well
44	6.7	23	5.3	5.6	4.9	0.3	5.3	1.6	17	40	20	7	10	Yugano (M. Matsunaga)	Spring
46	6.3	54	9.0	15	6.7	1.9	19	4.8	13	60	30	40	20	Shimosagano (Kagoya)	Well
48	6.5	61	10	8.9	11	1.6	15	4.1	16	120	70	30	30	(Inaba denki)	Well
49	7.0	47	5.8	6.5	5.9	0.7	11	2.8	23	60	30	20	20	(Inamoto)	Well
50	7.2	38	3.0	3.4	5.6	0.8	7.3	2.2	26	80	50	10	20	Kamisagano (Hospital)	Well
51	6.9	30	3.8	5.6	3.7	0.9	6.5	1.7	19	40	20	10	10		Spring
52	5.8	4.6	7.3	1.8	6.6	0.7	6.3	4.3	12	70	40	20	20	Ikadaba (H. Misawa)	Well
53	6.1	8.9	9.0	1.7	8.0	2.4	7.3	5.7	8	90	40	20	20	(T. Koyama)	Well
56	6.9	27	5.8	1.9	5.1	0.5	2.8	2.2	22	40	20	4	10	Sawada (T. Goto)	Spring
57	6.4	27	10	15	7.4	1.3	11	4.8	17	60	30	10	20	(M. Suzuki)	Well
62	6.4	65	9.5	24	8.6	1.0	19	6.6	26	100	50	30	30	Tanaka (K. Iida)	Well
97	6.6	22	5.0	6.0	5.3	0.9	5.1	2.0	24	60	40	6	20	Ito (Source of city water)	
99	6.9	35	7.0	4.2	8.2	0.4	6.3	0.6	21	90	60	10	20	Okuno	Spring
100	7.1	46	12	20	13	1.0	21	5.5	21	150	90	40	40	Kamata	Well
101	6.9	48	14	29	12	2.2	28	7.0	33	120	60	50	30		Spring
102	6.8	43	69	76	40	1.7	34	9.3	36	70	30	10	20	(Yokikan, Hotel)	Spring
103	6.9	38	5.0	3.6	5.2	1.0	8.0	2.8	34	60	40	20	20	(Suidoyama orifice of water)	
104	7.1	58	11	8.5	9.0	1.6	15	4.5	40	80	40	40	20	(Yamadaya)	Spring
105	7.0	45	14	3.2	6.8	14	17	2.2	14	140	60	60	50	Sawaguchi (M. Sato)	Well
106	6.0	12	10	1.2	3.9	1.2	3.6	2.9	11	20	5	10	5	(Ikeda)	Well
107	7.1	42	8.0	2.0	4.6	0.7	7.1	2.8	33	20	10	20	10	Nakaizu (Golf course)	Well
108	6.2	20	8.0	1.8	3.9	0.8	3.6	2.6	19	20	10	10	5	(Komatsu Besso)	Well
109	6.7	14	5.8	0.8	3.7	0.4	2.5	1.3	15	20	10	10	4	Hiyakawa	Stream
110	6.0	12	8.3	8.5	4.8	0.7	6.3	3.3	17	30	10	10	10		Well
111	6.1	32	8.3	7.1	5.7	1.6	9.6	2.5	18	40	20	20	10	(Oonaga store)	Well
112	6.7	25	5.5	2.4	4.5	0.7	4.5	1.7	29	40	20	10	10	(I. Sugiyama)	Spring
113	6.6	25	5.3	2.8	4.5	0.7	3.7	1.6	33	40	20	7	10	(Seki)	City water
114	6.8	26	7.3	3.2	4.5	1.0	3.6	1.5	35	20	10	10	10	(Banreiji temple)	Spring
115	6.3	28	5.5	6.6	7.0	1.5	5.7	1.8	22	90	60	5	30	Tokunaga (H. Fugiwara)	Well
116	7.4	37	6.0	5.6	8.8	0.5	8.4	0.1	15	110	70	10	30	(Suikoen)	Well
117	7.1	53	5.0	8.6	7.7	1.0	14	0.9	21	100	70	30	30	(Hiyakawa tunnel)	Drainage
118	6.8	29	5.5	8.1	5.1	0.5	7.6	1.3	18	50	30	10	10	(Itirin Bridge)	Spring
119	6.3	34	9.0	5.6	7.7	3.2	6.6	2.4	22	90	50	10	30	Hatiman (S. Sato)	Well
120	6.8	21	7.8	1.9	3.2	0.8	3.6	1.1	24	10	3	10	3	(Banjonotaki)	Spring
121	6.8	21	5.8	0.6	2.8	1.0	3.8	1.1	25	10	4	10	4		Spring
122	7.0	37	4.8	2.6	4.0	0.9	6.7	2.1	28	40	20	20	10	Shuzenji (Toshikawa orifice of water)	
123	6.7	45	19	6.0	6.0	3.0	8.8	3.8	17	30	10	30	10	(Y. Ishikawa)	Well
124	6.3	20	9.5	9.9	5.2	1.1	6.1	2.8	21	20	10	10	5	Oohira (Okina store)	Well
125	6.5	45	8.3	13	7.2	0.6	13	3.6	22	70	40	20	20	Shuzenji (Namakon)	Well
126	6.7	102	26	8.4	14	1.8	21	8.3	29	50	20	70	20	(Akitsucamera shop)	Well
127	6.7	109	28	15	25	5.8	30	4.4	27	240	140	70	70	(Endo store)	Well
128	6.6	46	8.5	11	9.8	1.4	10	3.6	19	120	70	10	30	Matsugase (Y. Iida)	Well
129	6.6	45	9.8	16	10	5.2	13	5.7	23	150	80	20	50	Aobane (Hasegawa)	Well
130	6.3	34	6.5	8.6	5.9	1.0	11	2.9	20	60	30	20	20	Deguchi (Suzuki)	Well
131	6.1	17	9.8	3.6	5.2	0.8	4.6	2.2	18	10	4	10	4	Tsukigase (T. Uchida)	Well
132	6.5	56	9.5	13	8.2	3.8	21	4.8	22	100	50	50	30	Ichiyama (Y. Horii)	Well
133	7.2	49	3.4	6.8	6.5	0.8	10	1.7	21	100	60	20	30	(Meitokuji temple)	Spring
134	6.5	33	3.9	3.9	4.5	0.8	7.8	1.9	15	60	30	20	20	(Tsuchiya)	Well
135	6.1	22	9.9	20	8.7	3.9	8.6	3.1	19	110	50		30	Yugashima (Akizuki cake shop)	Well
136	6.2	21	5.8	10	4.6	1.0	6.6	2.2	16	40	20	7	10	Nishihira (T. Ando)	Well
137	6.1	22	4.4	10	5.5	1.0	7.3	2.5	16	70	40	7	20		Well
138	6.8	22	3.4	3.4	5.1	0.5	3.6	1.1	22	70	40	3	30	Shuku (Kodoji temple)	Spring
142	5.9	7.9	8.0	2.5	3.8	2.3	5.6	1.2	19	20	10	20	10	Yugashima (Okada)	Well
143	6.7	25	3.7	2.0	4.0	1.1	4.2	1.1	30	50	30	10	20	Amagi (Hatsikubo)	City water
144	6.4	29	4.9	7.4	5.7	1.2	6.9	2.3	24	70	40	10	20	Funahara (M. Tateiwa)	Well
145	7.1	16	2.7												

Appendix C

Chemical composition of natural waters and amounts of minerals weathered, dissolved and formed in the Izu Peninsula area. Mar. 1978

Station No.	pH	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	Soluble SiO ₂	1*1	2*2	3*3	4*4	Region	Remarks	
		mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	mg·l ⁻¹	ton·km ⁻² ·year ⁻¹	ton·km ⁻² ·year ⁻¹	ton·km ⁻² ·year ⁻¹	ton·km ⁻² ·year ⁻¹			
1	6.5	54	56	17	34	5.2	17	6.8	40	100	50	30	30	Irozaki (Irozakiso, Hotel)	Well	
2	6.8	94	92	24	60	10	21	11	51	250	140	30	80		(Setoya)	Well
3	7.0	115	90	18	58	8.9	22	12	59	230	130	50	70		(Tanaka)	Well
4	6.8	83	81	21	49	7.7	21	10	65	140	80	40	50		(Suzuki)	Well
5	7.2	96	120	23	51	4.8	36	16	65	60	20	100	20		(Ozawa)	Well
6	7.3	45	58	23	41	8.3	12	6.6	38	230	130	1	70		(Akamon)	Well
7	7.3	87	96	15	44	3.7	30	13	71	50	20	90	10		(Leisure land)	Well
8	7.3	88	97	16	45	4.1	30	13	71	50	20	90	10		(Inquiry office, Bus)	Well
9	7.2	77	26	12	49	3.0	19	7.6	26	640	400		180		(Irozaki Bekkan, Hotel)	Well
10	6.5	59	60	14	35	2.0	17	7.0	50	50	30	40	10		(Hashimotoya, Hotel)	Well
11	7.7	95	40	8.8	33	2.2	17	6.3	50	210	130	30	60	Nakagi	Drainage	
12	7.5	80	69	19	49	2.2	18	8.7	35	210	130	20	60		(Fish pond)	Spring
14	6.5	68	78	24	58	4.3	14	6.9	78	290	180		80	Iruma	City water	
15	7.4	64	43	10	31	1.5	12	6.6	58	140	90	20	40		(Shrine)	Spring
16	7.6	78	41	8.6	38	1.2	9.3	5.3	55	280	180		80	(Kaizoji temple)	Well	
18	7.9	83	33	5.4	32	3.5	13	4.6	61	270	170	20	80	(Nursery, Eel)	Well	
19	8.3	92	32	6.9	39	7.2	12	2.2	64	430	270	1	130	(Source of city water)		
22	7.0	80	92	37	73	5.8	23	11	50	440	270	1	120	Oose	Well	
23	7.6	87	52	26	42	6.1	13	12	23	300	170		80		(Morishita)	Well
25	6.5	50	63	48	50	6.8	13	10	38	330	200		100	Sitaru	Well	
26	7.1	134	75	76	79	47	26	13	33	1100	620		360		(H. Hirayama)	Well
28	7.4	118	60	13	38	1.4	26	12	30	140	70	70	40	Yumigahama	Well	
31	6.2	35	32	24	25	19	9.2	4.9	23	300	160		110		(Iwata)	Well
32	7.6	79	25	9.9	33	0.7	12	3.0	49	340	220		90	Sashita	Well	
35	7.6	85	43	9.6	35	2.1	12	7.2	50	220	130	10	60	Mera	Well	
36	7.5	74	60	13	33	3.4	18	8.5	54	30	10	50	10		(Shimada)	Well
40	7.9	42	4.8	9.0	6.8	0.2	11	1.3	17	80	50	20	20	(Sawada, Hotel)	Well	
41	7.3	34	4.6	5.1	6.2	0.4	7.4	1.6	23	70	40	10	20	(Zenpukuji temple)	Well	
42	7.6	41	6.1	5.1	6.6	0.1	9.2	2.0	19	60	40	20	20	Nashimoto	Pipe water	
43	7.1	41	6.8	6.9	7.6	0.3	11	2.5	23	80	50	20	20	(Tsuribashiso)	Spring	
45	6.6	50	12	10	10	2.2	16	4.2	25	90	50	30	20	(Wasabisawa)	Well	
47	7.5	86	8.7	12	12	0.5	24	4.2	26	150	90	50	40	Konabe	Spring	
48	6.6	62	10	9.7	10	1.8	14	3.7	21	100	60	30	30	(T. Hirakawa)	Well	
49	7.8	56	6.6	7.6	9.3	0.8	13	2.7	26	110	70	20	30	(Daito Kagoya)	Well	
50	7.7	38	4.4	5.4	6.3	0.5	7.9	2.5	31	80	50	10	20	Yugano	Well	
51	7.4	30	3.5	7.1	4.7	0.5	7.4	1.8	20	60	30	10	20	(Souma)	Well	
52	5.8	2	9.8	1.4	7.4	0.3	6.0	4.3	9	60	30	20	20	(Shimosagano)	Well	
53	6.4	13	13	11	12	4.0	10	7.4	9	230	110	10	80	(M. Hiram)	Well	
54	7.1	31	7.1	34	10	0.5	17	2.6	16	110	70	1	30	(Inaba Denki)	Well	
55	6.5	28	16	17	13	9.0	9.1	4.5	21	160	80	2	50	(Inamoto)	Well	
56	7.5	24	6.7	2.2	5.4	0.2	4.9	2.5	21	40	20	10	10	Kamisagano	Well	
58	7.0	30	7.4	12	6.4	0.9	7.9	2.7	16	50	30	10	10		(Kawazuham hospital)	Well
59	7.2	46	10	16	10	1.2	13	3.2	19	90	60	20	30		Spring	
60	7.5	38	6.7	9.1	7.8	0.4	8.3	2.7	27	80	50	10	20		Spring	
61	6.5	77	12	11	11	1.0	15	6.0	39	110	60	30	30		Well	
62	6.5	70	12	22	11	1.0	19	6.5	30	110	60	30	30	Tanaka	Well	
63	6.6	47	55	51	45	29	13	5.2	34	520	280		180	(K. Iida)	Well	
64	6.7	30	38	31	33	14	12	5.3	18	340	190		110	Kawazu,	Well	
65	6.9	20	18	3.6	11	1.7	5.2	3.6	21	40	20	10	10	(Mitaka, Nagano)	Well	
66	7.9	63	8.5	5.8	9.5	0.7	12	2.6	35	90	60	30	30	(I. Nakamura)	Well	
67	7.4	50	11	5.2	9.7	0.4	10	3.6	33	80	50	20	20	(M. Imamura)	Well	
68	7.9	56	8.5	5.5	9.3	0.7	13	2.7	35	90	60	30	20	Iriya	Spring	
69	7.3	28	7.9	210	34	0.9	110	4.7	30	530	340	30	140	(I. Endo)	Spring	
70	7.7	20	7.2	1.7	5.5	0.3	3.5	2.2	22	40	20	10	10	(S. Saito)	Spring	
71	7.4	21	16	2.9	10	0.5	9.0	6.6	25	60	30	30	20	Inatori,	Spring	
72	7.5	26	18	3.0	11	1.0	11	5.7	28	50	20	20	10		Iriya	Spring
73	7.0	17	7.8	56	13	0.9	17	3.0	25	160	100		40	(Tamura)	Spring	
74	6.3	43	400	78	137	6.9	87	48	24	150	50	220	40	(Izukyu, tunnel)	Spring	
75	7.5	23	20	19	14	0.7	13	7.2	21	90	50	10	30	(Nekoya, Tailor)	Spring	
76	6.1	22	14	38	14	1.7	11	4.9	23	130	80		40	(Hirose, store)	Well	
77	6.6	19	12	9.4	11	1.0	8.3	4.2	21	90	60	10	30	(Yamadaso, hotel)	Spring	
78	6.6	19	16	7.3	13	0.8	8.6	5.1	23	100	50	10	30	(U. Nakada)	Well	
79	7.7	34	19	17	13	0.9	13	6.8	34	80	40	20	20	(Katahira, hospital)	Spring	
80	7.2	29	12	7.3	9.3	0.5	8.2	3.9	30	70	40	10	20	(Saikoji)	Well	
81	6.7	35	100	86	84	3.9	24	3.0	33	520	340		150	(I. Endo)	Spring	
82	7.4	36	10	5.6	8.3	0.5	6.7	3.3	30	60	40	10	20	(S. Saito)	Spring	
83	7.7	39	7.7	6.7	7.7	0.5	10	3.2	30	80	40	20	20	Shirata	Well	
84	7.0	34	31	33	19	2.7	16	5.9	39							