

## Geochemical Study of Ground Waters in the Matsushiro Area

### Part 2 : Chemical Composition of Ground Waters

By Yasushi KITANO\*, Ryuma YOSHIOKA\*,  
Setsuo OKUDA, and Kazuo OKUNISHI

(Manuscript received May 8, 1968)

#### Abstract

The authors carried out a hydrological survey and chemical analysis of ground waters in the Matsushiro area between September 1966 and February 1968.

Water balance and chemical composition of ground waters in the area show that ground waters gush out from a deep source and that they are not influenced by precipitation.

There are several types of time change in the chemical composition, but there is a general tendency for the concentrations of calcium and chloride ions, among dissolved ions, to increase most remarkably with time.

#### Introduction

The Matsushiro swarm earthquakes occurred in and around the Matsushiro town area of Nagano Prefecture in August 1965<sup>1-5)</sup>. A positive relationship between the activity of the swarm earthquakes, the amount and the concentration of the chemical composition of ground waters in the area was observed<sup>6-7)</sup>.

Landslips occurred in the Makiuchi and Nishidairayama areas in September and October 1966, respectively, and tremendous amounts of ground waters gushed out there. A change in the conditions under the ground can be expected through a change in the chemical composition of the ground waters. Knowledge of conditions under the ground is both useful and important for understanding the mechanism of the occurrence of the swarm earthquakes and landslips.

The authors measured the change with time in the chemical composition of ground waters. That is, since September 1966 ground water samples were taken monthly and the chemical composition was determined.

This paper reports on the amount and chemical composition of the ground waters. It is a sequel to a similar study, part 1, made on ground water samples taken between September 1966 and February 1967<sup>8)</sup>. As we completed hydrological and geochemical observations of the ground waters for a whole year in October 1967, we will discuss the hydrochemical features in this area, laying emphasis on the chemical composition of ground water samples taken between March 1967 and February 1968.

#### 1. Hydrological aspect of the spring waters

Many of the springs which gushed out accompanying the heavy earthquakes and landslides disappeared entirely after a decrease in their discharge whereas large amounts of water are still gushing out from some springs. Fig.1 shows

\* Water Research Laboratory, Faculty of Science, Nagoya University, Nagoya.

several examples of the discharge hydrographs of springs with daily precipitation data. The spring at Station 16 is the gush-out from a bore-hole. The hydrograph does not include the leak discharge from the casing of the bore-hole. The

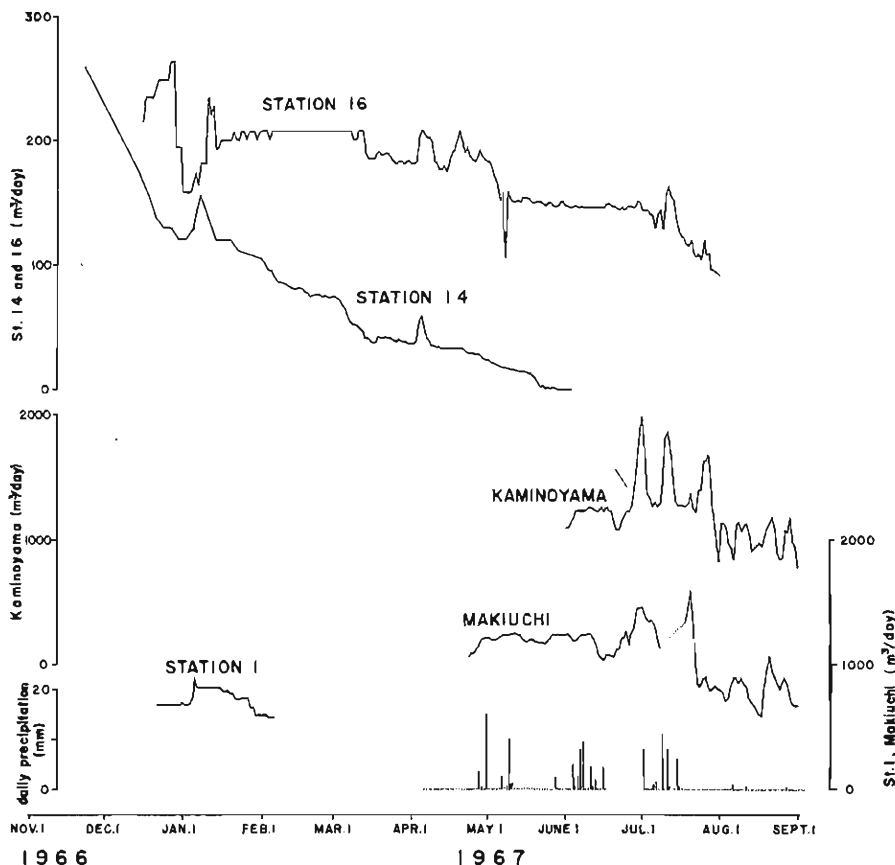


Fig. 1 Discharge hydrographs of major springs.

spring at Station 14 shows a rapid decrease in discharge and it virtually stopped gushing out at the end of May, 1967. The hydrographs of the Kaminoyama and Makiuchi areas represent the total discharge from spring groups in each region. The springs at Makiuchi include the spring at Station 1.

The hydrographs in Fig. 1 show the general tendency of a decrease in discharge, but they also show many peaks of discharge. These peaks often occurred simultaneously, but were not well correlated with precipitation. During the period of observation, twenty rainfalls were experienced with a depth of more than 10mm, among which only five were followed by an increase in discharge of at least one spring. There were nine rises of the hydrograph obviously independent of precipitation.

It was shown in the previous report that the total discharge from the springs in the Makiuchi and Kaminoyama areas was equivalent to the precipitation in these areas over 2.3 years, though the time constant of depletion was about

50 days<sup>8)</sup>. These springs now seem to be in a quasi-steady state, and another examination is needed concerning their water budget. The equation for the water budget can be written as,

$$P = Q_{st} + Q_{gr} + Q_{sp} + E + \Delta S \quad \dots\dots\dots (1)$$

where  $P$  is the precipitation,  $Q_{st}$  the stream runoff,  $Q_{gr}$  the ground water outflow,  $Q_{sp}$  the discharge from the springs,  $E$  the evapotranspiration, and  $\Delta S$  the accretion of the ground water storage over a certain period. Fig.2 shows the mass diagrams of the total spring discharge in the Makiuchi and Kaminoyama areas, and those of precipitation at Shinonoi and Makiuchi.

The specific discharge of the spring groups was calculated as the total discharge divided by the catchment area of each area. A comparison of the gradient of these curves shows that the total spring discharge is about 3.7 times the precipitation at Makiuchi, and about 2.8 times the latter at Kaminoyama. The observation shown in Fig.2 was carried out in the rainy season and the ground water accretion during this period seems to have been positive. The other terms of equation (1) are positive and the precipitation would have been larger than the total spring discharge if the springs had been fed by precipitation during the same period. Therefore it is concluded that this spring water can be said to rise from a deep source other than the normal hydrologic cycle.

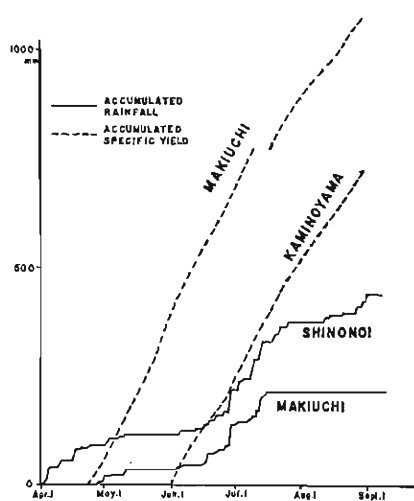


Fig. 2 Mass curves of precipitation and specific discharge from the spring groups in the Makiuchi and Kaminoyama areas.

**2. Experimental aspects**

The locations for sampling ground waters are given in Fig.3. Ground waters were collected monthly. Temperature and pH values were measured in the field and chemical constituents such as  $Na^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Cl^-$ ,  $HCO_3^-$ ,  $SO_4^{2-}$  and soluble  $SiO_2$  were determined in the laboratory of the Disaster Prevention Research Institute, Kyoto University.

**3. Results and Discussion**

- A) The changes with time in the pH value and water temperature of ground waters are shown in Figs.4A and 4B.
  - A-1) At Sts.10, 11, 13 and 24, the seasonal variation in water temperature was very remarkable, but that in pH value was small. It seems that the ground waters of these stations were remarkably influenced by atmospheric temperature and surface water.
  - A-2) At other stations, the seasonal variations in both water temperature and pH value were not so remarkable, in spite of the decrease in the atmospheric

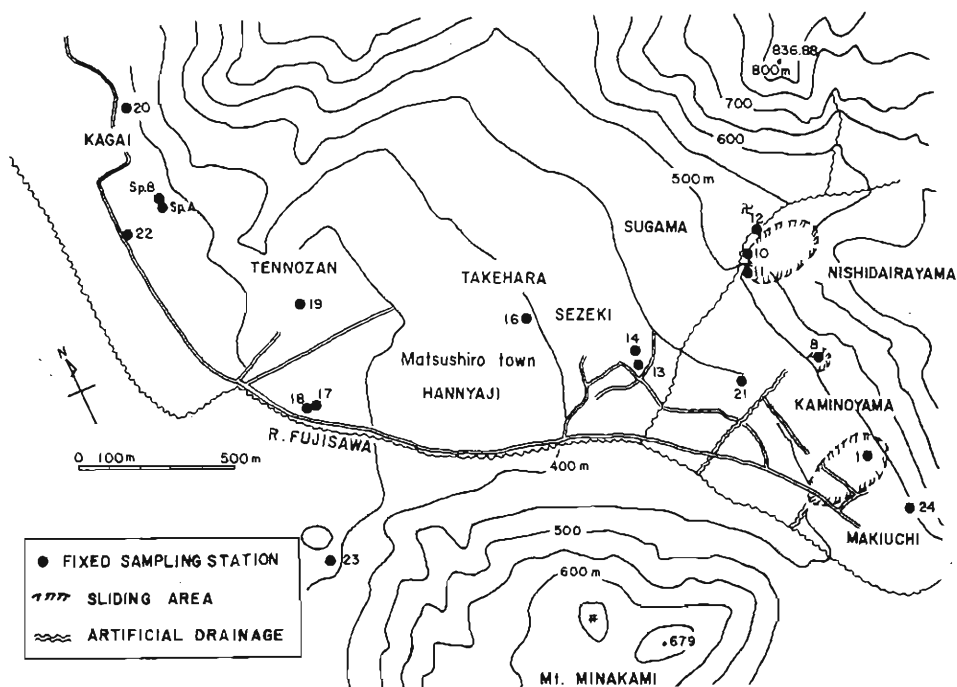


Fig. 3 Location of water sampling stations.

temperature. These phenomena indicate that the ground waters are not influenced directly and greatly by surface water.

B) Figs. 5A to 5E show the percentages of the contents of the major cations and anions of ground waters collected monthly as  $\text{Na}^+$ - $\text{Ca}^{2+}$ - $\text{Mg}^{2+}$  diagram and  $\text{HCO}_3^-$ - $\text{Cl}^-$ - $\text{SO}_4^{2-}$  diagram, respectively.

B-1) At Sps. A and B, and St. 22, the percentages of the contents of magnesium and sulfate ions in the ground waters were very low and steady during our observations. Those of calcium and bicarbonate ions increased with time (Figs. 5A, 5B and 6A).

B-2) At Sts. 17, 18 and 23, the changes with time in the percentages of the contents of dissolved ions were very small, especially in magnesium and sulfate ions (Figs. 5B and 6B).

B-3) At Sts. 8, 13, 14, 16 and 21, the changes with time in the percentages of the contents of dissolved ions in water samples were relatively small. In general, the time change in the percentage of the content of sodium ions, among dissolved ions, became steady at its low value. On the other hand, that of chloride ions gradually became steady at its high value (Figs. 5C and 6A).

B-4) At Sts. 10, 11 and 12, the time change in the percentage of the content of sodium ions in water samples kept relatively low. That of chloride ions, except St. 10, changed irregularly during our observations. It seems reasonable to suppose that the chemical compositions of ground waters in these stations are greatly influenced by surface water, from considering

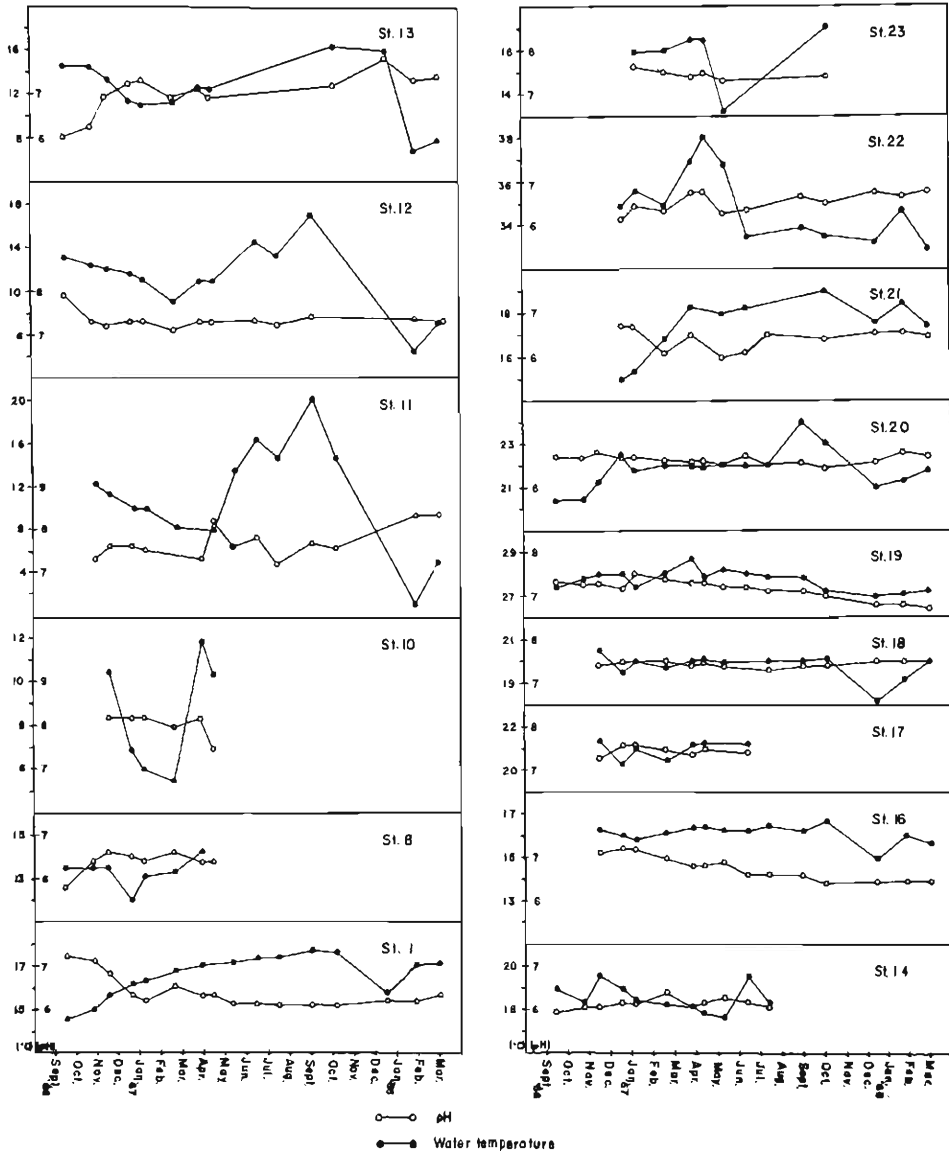


Fig. 4A Time change in pH value and water temperature of ground waters.

that the seasonal variations in water temperature were most remarkable at these stations (Figs. 5D, 6B and 4A).

B-5) At Sts. 1, 24, 19 and 20, the percentage of the content of calcium ions was generally high, and the chemical composition of cations changed irregularly with time. In anions, the percentage of the content of bicarbonate ions was almost unchanged with time, but that of sulfate ions decreased and that of chloride ions increased with time (Figs. 5E, 6A and 6B).

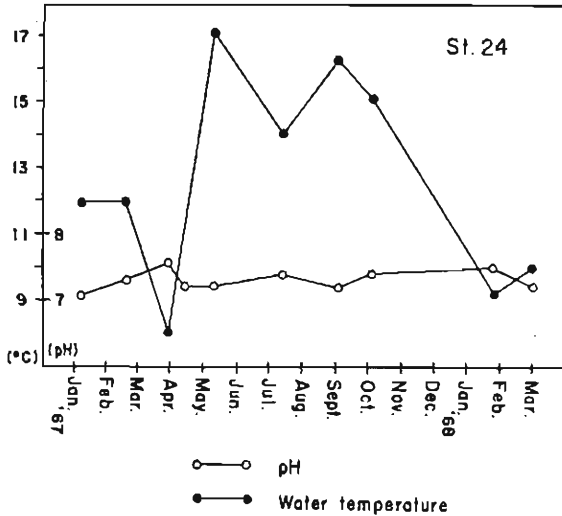


Fig. 4B Time change in pH value and water temperature of ground waters.

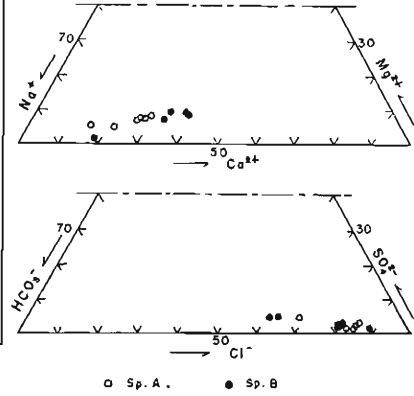


Fig. 5A  $\text{Na}^+\text{-Ca}^{2+}\text{-Mg}^{2+}$  and  $\text{HCO}_3^-\text{-Cl}^-\text{-SO}_4^{2-}$  diagrams of hot springs (Sp. A: Jul. and Nov. '65, Feb. and Oct. '67 and Jan. and Feb. '68; Sp. B: Oct. '30, Nov. '65, Feb. and Oct. '67 and Jan. and Feb. '68)

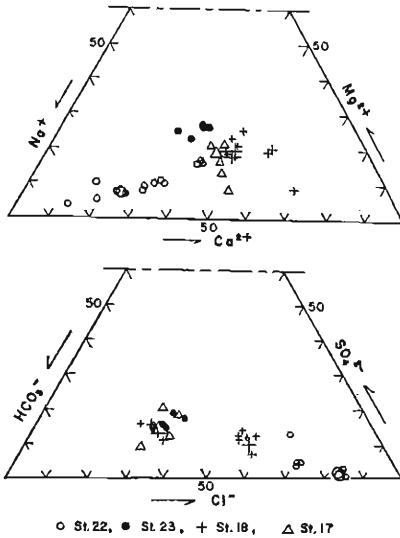


Fig. 5B  $\text{Na}^+\text{-Ca}^{2+}\text{-Mg}^{2+}$  and  $\text{HCO}_3^-\text{-Cl}^-\text{-SO}_4^{2-}$  diagrams of ground waters (St. 17: Nov. '65 and Nov. '66 to Jun. '67; St. 18: Nov. '66 to Feb. '68; St. 22: Mar. '62, Nov. '65 and Dec. '66 to Feb. '68; St. 23: Jan. to Oct. '67).

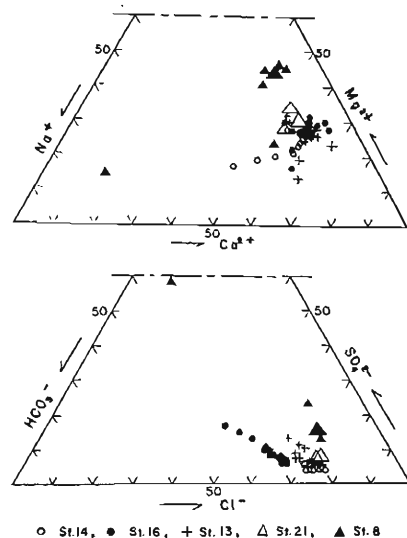


Fig. 5C  $\text{Na}^+\text{-Ca}^{2+}\text{-Mg}^{2+}$  and  $\text{HCO}_3^-\text{-Cl}^-\text{-SO}_4^{2-}$  diagrams of ground waters (St. 8: Sept. '66 to Apr. '67; St. 13: Sept. '66 to Feb. '68; St. 14: Sept. '66 to Jul. '67; St. 16: Nov. '66 to Feb. '68; St. 21: Dec. '66 to Feb. '68).

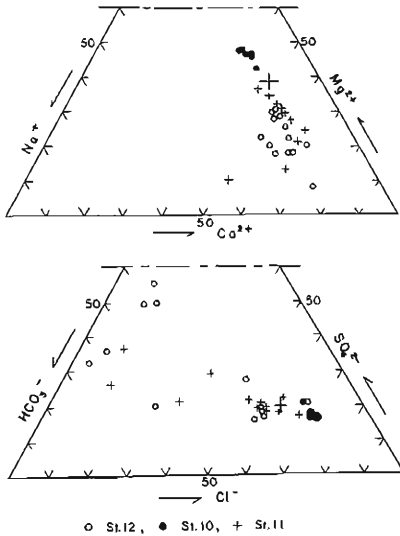


Fig. 5D  $\text{Na}^+$ - $\text{Ca}^{2+}$ - $\text{Mg}^{2+}$  and  $\text{HCO}_3^-$ - $\text{Cl}^-$ - $\text{SO}_4^{2-}$  diagrams of ground waters (St. 10 : Nov. '66 to Apr. '67 ; St. 11 : Oct. '66 to Feb. '68 ; St. 12 : Sept. '66 to Feb. '68).

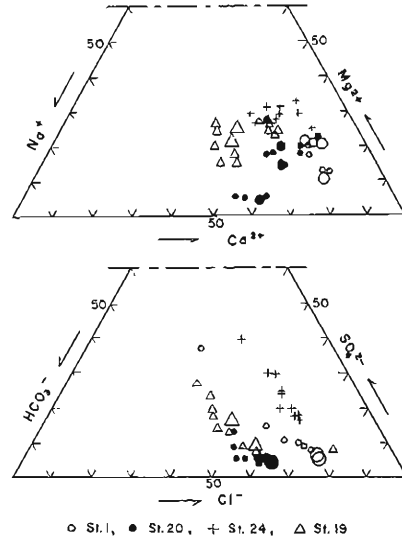


Fig. 5E  $\text{Na}^+$ - $\text{Ca}^{2+}$ - $\text{Mg}^{2+}$  and  $\text{HCO}_3^-$ - $\text{Cl}^-$ - $\text{SO}_4^{2-}$  diagrams of ground waters from Sept. '66 to Feb. '68 (except St. 24 : Jan. '67 to Feb. '68).

C) The change with time in the concentrations of the major cations and anions are shown in Figs. 6A and 6B.

C-1) At St. 22, the concentrations of sodium and chloride ions suddenly increased after March 1967, and the cause is not yet known. At St. 20, the concentrations of the ions dissolved in the ground water, except sulfate ions, gradually decreased after February 1967 (Fig. 6A).

C-2) At Sts. 18 and 21, the concentrations of the dissolved ions kept almost constant during our observations (Figs. 6A and 6B).

C-3) At Sts. 13 and 14, the concentrations of calcium and chloride ions, and of magnesium and bicarbonate ions, among dissolved ions, showed a similar behaviour with time, respectively (Fig. 6A).

C-4) At Sts. 1, 16 and 24, the concentrations of dissolved ions increased most remarkably between September 1966 and December 1967. St. 1 has, however, shown a steady state in the concentrations of dissolved ions in the ground water since January 1968. On the other hand, Sts. 16 and 24 have tended to show a decrease in the concentrations of dissolved ions since January 1968 (Fig. 6A).

C-5) At St. 19, the concentrations of dissolved ions, except sulfate ions, increased after September 1966 during our observations (Fig. 6B).

C-6) At St. 8, the concentrations of chloride, calcium and magnesium ions, among dissolved ions, increased most remarkably between September 1966 and April 1967 (Fig. 6A).

C-7) At Sts. 11 and 12, the concentrations of dissolved ions suddenly decreased

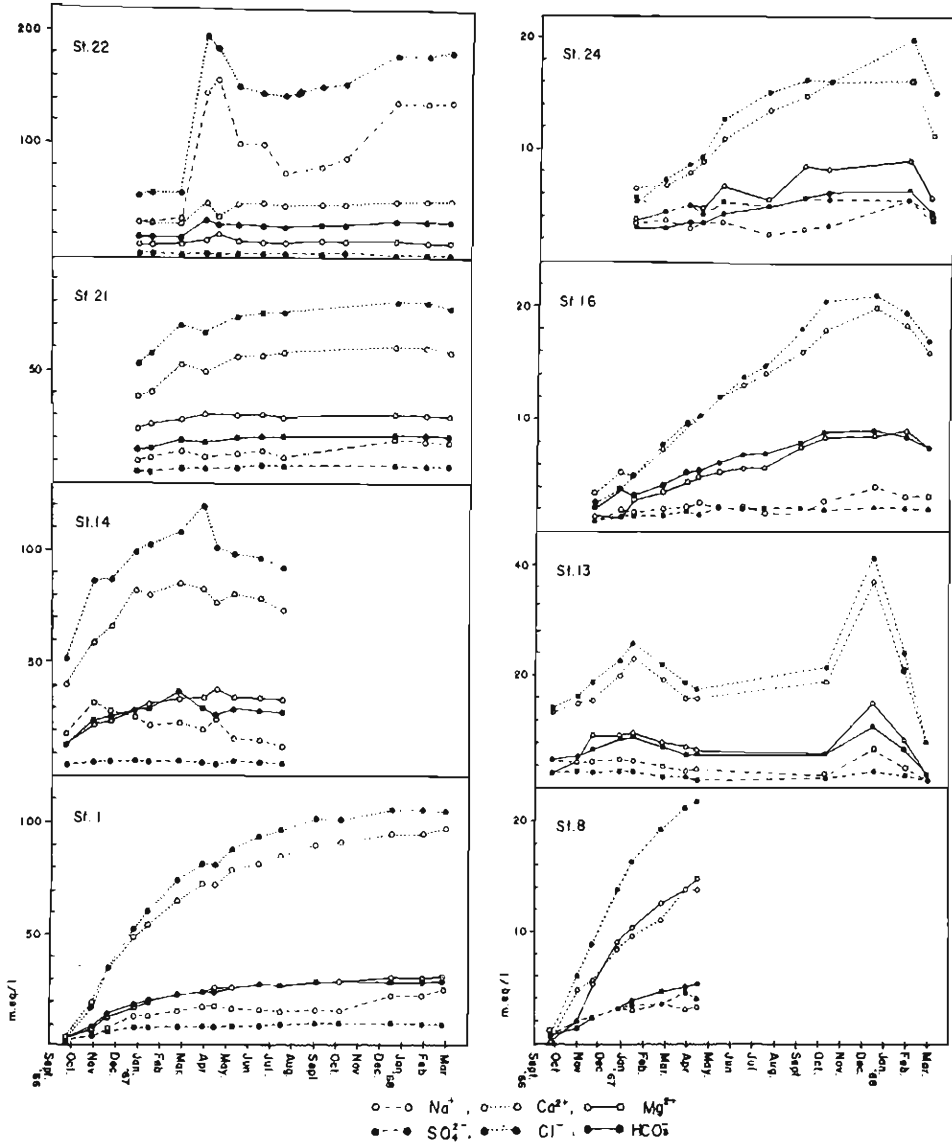


Fig. 6A Time change in concentrations of the major ions in ground waters.

in February 1967 and subsequently continued to change irregularly with time. The minimum value was observed in July 1967. These facts may indicate that the ground waters in the areas are influenced directly and greatly by surface water (Fig. 6B).

- D) The mass of the elements transported by springs to the surface can be calculated as the product of their concentrations and the spring discharge. Fig. 7 shows some typical examples of the time change in the mass transfer of calcium and chloride ions and of water on a logarithmic scale. At Station



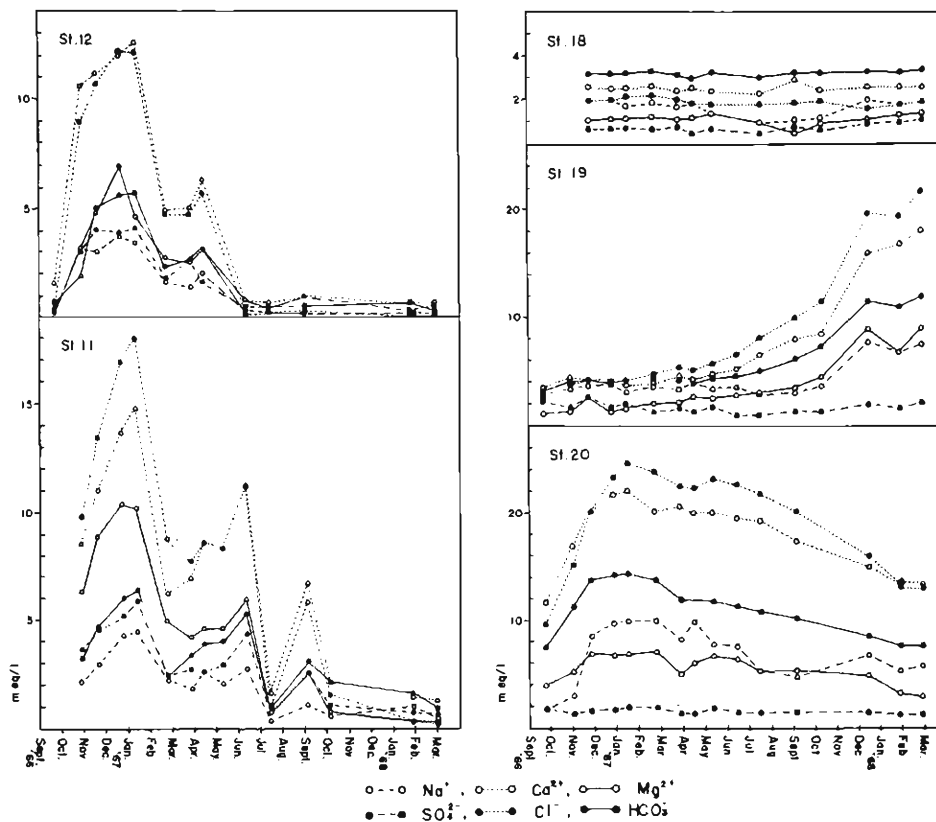


Fig. 6B Time change in concentrations of the major ions in ground waters.

14, the curves are nearly parallel to each other, which shows that the concentrations of the ions had remained unchanged until the spring stopped gushing out. At Station 16, the mass transfer of the ions increased in spite of the decrease in the discharge of water. In the Makiuchi area, a large change in the chemical composition of spring water took place between September 1966 and April 1967 and the mass transfer of  $\text{Cl}^-$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ , and  $\text{SO}_4^{2-}$  increased or decreased to 6.0, 3.9, 1.9, 2.0 and 0.45 times the former values, respectively, during the period. Thereafter the concentrations of the ions were unchanged and the curves are parallel to each other.

These results make it possible to say the following : the bulk of ground waters in the Matsushiro area is derived from a source deep under the ground which is not directly influenced by precipitation and surface water, the saline waters of calcium chloride type gush out with the active swarm earthquakes, and the concentrations of calcium and chloride ions in the gushed ground waters increase with the activity of the swarm earthquakes.

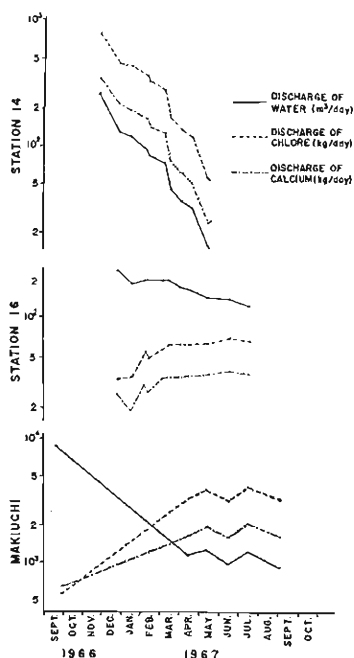


Fig. 7 Time change in the mass transfer of calcium and chloride ions, and of water on a logarithmic scale.

The authors will, in the next report, discuss the reason why ground waters of this chemical composition continuously gush out in this area, taking into consideration of knowledge of deep borings and the distribution of other elements dissolved in the ground waters.

### Acknowledgement

The authors are deeply grateful to Miss. T. Natsukawa of Kyoto University, Mr. T. Shimura of Matsushiro High School and Mr. S. Ogahara of Sarashina Agricultural High School, Nagano Prefecture, who greatly assisted them in carrying out this study.

### References

- 1) The Party for Seismographic Observation of the Matsushiro Earthquakes and others ; Research on the Matsushiro earthquakes (1), Bull. Earthq. Res. Inst., vol. 44, 1966, 307-445.
- 2) Hamada, K., T. Hagiwara, and others ; Research on the Matsushiro earthquakes (2), *ibid.*, Vol. 44, 1966, 1213-1395.
- 3) Nagumo, S. and others ; Research on the Matsushiro earthquakes (3), *ibid.*, vol. 44, 1966, 1623-1792.
- 4) Hamada, K., T. Hagiwara, and others ; Research on the Matsushiro earthquakes(4), *ibid.*, vol. 45, 1967, 159-288.
- 5) Network of JMA during Aug. 1965 to Dec. 1966 (National Res. Center for Disa. Prev.) ; Seismological data of the Matsushiro earthquake swarm, Rev. Res. Disa. Prev. no. 1, 1967, 1-140.
- 6) Noguchi, K. ; The Matsushiro earthquakes and hot springs, Chemistry and Chemical Industry (Kagaku to Kōgyō), vol. 20, 1967, 67-72 (in Japanese).
- 7) Kasuga, I. ; Aspect on the relation of thermal water and Matsushiro earthquakes in Kagai hot spring area, Nagano Prefecture ; Jour. Geography (Chigaku Zasshi), vol. 76, 1967, 76-86 (in Japanese).
- 8) Kitano, Y. and others ; Geochemical Study of Ground Waters in the Matsushiro Area (part 1), Bull. Dis. Prev. Res. Inst. Kyoto Univ., vol. 17, Part 2, (no 123) 1967, 47-71.