

Water geochemistry of the Wewak region, East Sepik Province, Papua New Guinea

Munetomo NEDACHI¹⁾, Akio INOUE²⁾ and Sachihiko TAGUCHI³⁾

Abstract

Geochemistry of the hot spring, meteoric and sea waters in the Wewak region, East Sepik Province, Papua New Guinea, was preliminarily described. δD and $\delta^{18}O$ of the groundwater in this region are -41.1% and -6.5% , respectively. The river water is much lighter. They are well on the meteoric water line (CRAIG, 1961). δD of the hot spring water in Kairiru Island is -20.0% , and the Cl- content is 9630 mg/l. The data suggest that the hot spring water originated from the 1:1 mixture of the meteoric water and sea water in this region. Mg^{2+} and SO_4^{2-} were found strongly depleted from the original mixed water. Na^+ and K^+ were moderately removed to low concentration. Ca^{2+} was leached from rocks and resulted in the high concentration in the water. Removal of Mg^{2+} and other cations from the hot spring water was supplimented largely by leaching of Ca^{2+} from rocks. However, the $\delta^{18}O$ shift by water-rock interaction is not observed. The water temperature at the depth might be about $140^\circ C$, and the similarity of $\delta^{34}S$ between the hot spring water and sea water suggests that the water-convection was performed under oxidation condition.

It is suggested that both sea water and meteoric water were mixed together with the ratio of about 1 : 1, that the mixed water reacted mainly with the surrounding beach rock at shallow depth, and that the rate of water-rock interaction was not so high to shift the $\delta^{18}O$, or the water/rock ratio was rather high not to affect the $\delta^{18}O$ value.

Key words: Geochemistry, Hot spring water, Wewak, Papua New Guinea

Introduction

Consideration on heated underground water has contributed to the discussion on water-circulation system around magmatic activity. During the comprehensive survey in Papua New Guinea, organized by the Research Center for the South Pacific, Kagoshima University, in 1991, the authors visited Wewak, the capital of East Sepik Province, and collected groundwater from plantation field, river water from Sepik River, sea water, and hot spring water from Kairiru Island. In this preliminary study, those waters are geochemically analyzed, and the obtained results were compared with each other, and also with those in the other regions in Papua New Guinea reported by TAGUCHI *et al.* (1991).

1) Department of Geology, College of Liberal Arts, Kagoshima University, Kagoshima 890, Japan

2) Research Center for the South Pacific, Kagoshima University, Kagoshima 890, Japan

3) Geological Laboratory, Faculty of Science, Fukuoka University, Fukuoka 814-01, Japan

Sampling Sites

The Wewak region occupies the northeast of the Sepik River basin, and is partly composed of calc-alkaline volcanic rocks of Paleocene, and marine and terrestrial clastic sediments of Quaternary. The region is situated in the back arc side of the Bismarck active volcanic chain in Bismarck Sea (BAIN *et al.*, 1972).

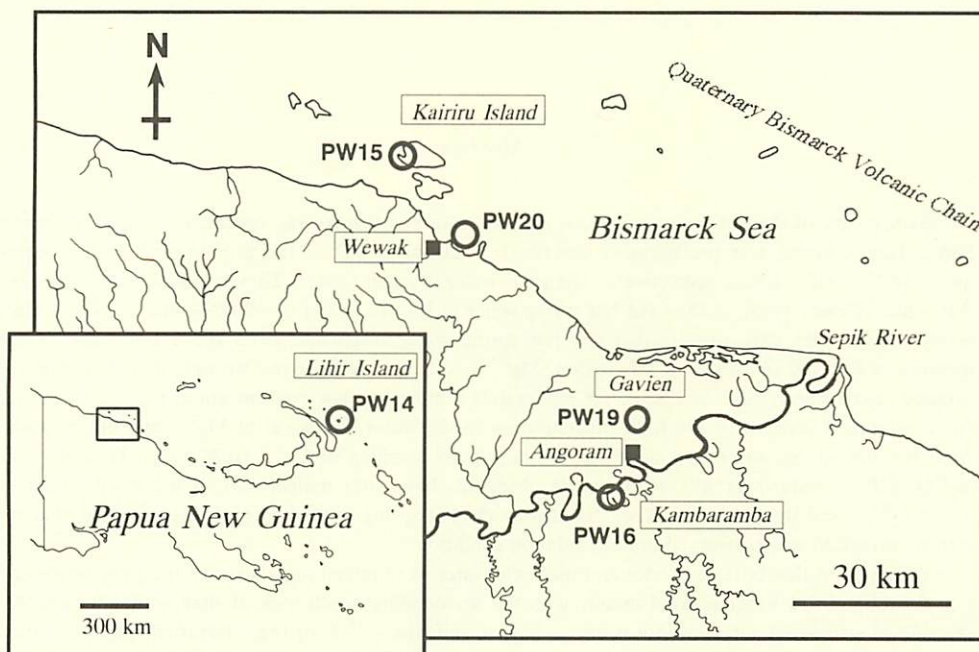


Fig. 1 Map of Wewak region, Papua New Guinea, showing sampling sites.

Sampling sites of water are shown in Fig. 1. Numerals (PW14-20) are the sample numbers in Table 1. Groundwater and river water were collected from the eastern end of the Sepik River basin. The former (PW19) was collected from a natural pool in the rubber plantation field of Gavien, 7 km north of the Angoram village and 60 km southeast from Wewak, the capital of East Sepik Province. The soil is originated from marine and terrestrial clastic sediments. The temperature and pH were 26.8°C and 7.1, respectively. River water (PW16) of Sepik River was collected at the Kambaramba village, 12 km southwest of the Angoram village and 70 km southeast from Wewak. Sea water (PW20) was collected from Bismarck Sea at the Wewak harbour. The temperature and pH were 28.5°C and 8.3, respectively. For comparison, sea water was collected from Luise Harbour, Lihir Island (PW14; NEDACHI *et al.*, unpublished)

Kairiru Island is situated in the northwest 30 km of Wewak, and is mainly composed of the calc-alkaline volcanic rocks of Paleocene (BAIN *et al.*, 1972). The coast is composed of beach rock and coral beach sand. The fragments of amezist and rock crystals are often observed among the beach sand and beach rocks, which suggest the exist-

ence of hydrothermal veining in Kairiru Island. Some hot springs are located in the southern end of Victoria Bay, 1 km southwest of the Purawa village, Kairiru Island, and the sample, PW15, was collected from this hot spring. The temperature and pH were 100.0°C and 7.0, respectively. H₂S gas was not observed.

Analytical Method and Results

The collected water samples were analyzed for Na⁺, K⁺, Ca²⁺, Mg²⁺ using Hitachi Zeeman atomic absorption, and precipitation titrimetry method was used for the analyses of Cl⁻ and SO₄²⁺. δ D and $\delta^{18}\text{O}$ were determined using Finnigan Mat mass spectrometer. H₂ gas for δ D analysis was obtained by uranium reduction method and CO₂ gas for $\delta^{18}\text{O}$ by the conventional CO₂-H₂O equilibrium method. The standards are SMOW (Standard Mean Ocean Water). The accuracies are $\pm 0.2\%$ for oxygen and $\pm 2\%$ for hydrogen. SO₄²⁻ for $\delta^{34}\text{S}$ was precipitated as BaSO₄ and the SO₂ was prepared by the extraction procedure proposed by SAKAI *et al.* (1979), with the conversion process from ZnS to Ag₂S, and to SO₂. The mass spectrometry for $\delta^{34}\text{S}$ was carried out by VG Prism Series mass spectrometer. The standard is CDT (Canyon Diablo Troilite). The accuracy is $\pm 0.1\%$. The chemical compositions of water are shown in Table 1, and Figs. 2 and 3.

δ D and $\delta^{18}\text{O}$ of the groundwater collected from a natural pool in the rubber plantation field are -41.1% and -6.5% , respectively. The river water of Sepik River (δ D = -60.3% ; $\delta^{18}\text{O}$ = -9.1%) is lighter than the meteoric water, and heavier than those from the Highland region (TAGUCHI *et al.*, 1991), which is the southern ridge of the Sepik River basin. The data can be well understood by the empirical rule: As shown in Fig. 2, those data are plotted on the meteoric water line of δ D = $8 \delta^{18}\text{O} + 10$ (CRAIG, 1961). The contents of the dissolved ions are higher than the average of ordinal meteoric water. The groundwater might be enriched in those elements from the soil, fertilizer and others in the plantation field.

The chemical compositions of sea waters from Bismarck Sea and Lihir Island are almost same with the mean value of oceanic water. The Cl⁻ contents are slightly higher, and the similar data was reported from Rabaul Harbour by TAGUCHI *et al.* (1991). The Na⁺ content also is slightly higher. The $\delta^{34}\text{S}$ is 20.0%.

δ D and $\delta^{18}\text{O}$ of the hot spring water in Kairiru Island are -20.0% and -3.4% , respectively. Those values are almost half of those of the groundwater of this area. The Cl⁻ content is 9630mg/l, which also is the half of the sampled sea water (19400mg/l) at Wewak Harbour. On the other hand, Mg²⁺, Ca²⁺, Na⁺, K⁺ and SO₄²⁻ do not show the same feature. Mg²⁺ and SO₄²⁻ contents of the hot spring water are very low compared to the sea waters (PW14, PW20). The contents of Na⁺ and K⁺ also are low, but moderately. On the other hand, The Ca²⁺ is quite higher than those of the meteoric water and sea water. The $\delta^{34}\text{S}$ is similar to that of the sampled sea water.

Table 1. Chemical composition of waters from the Wewak region, Papua New Guinea.

Sample	PW15	PW19	PW16	PW20	PW14
Locality	Kairiru	Gavien	Kambaramba	Wewak	Lihir
Water	Hot spring	Groundwater	River water	Sea water	Sea water
Temp. (°C)	100.0	26.8	26.1	28.5	31.0
pH	7.0	7.1	7.3	8.3	8.1
Na ⁺ (mg/l)	3610	12	nd	10800	11800
K ⁺ (mg/l)	133	1	nd	380	366
Ca ²⁺ (mg/l)	2300	5	nd	421	403
Mg ²⁺ (mg/l)	52	2	nd	1240	1230
Cl ⁻ (mg/l)	9630	10	nd	19400	19700
SO ₄ ²⁻ (mg/l)	308	3	nd	2460	2600
δ D _{SMOW} (‰)	-20.0	-41.1	-60.3	0.0	0.6
δ ¹⁸ O _{SMOW} (‰)	-3.4	-6.5	-9.1	0.1	0.3
δ ³⁴ S _{CDT} (‰)	21.3	nd	nd	20.0	19.4

nd: not determined

Discussion on the Hot Spring Water

The hot spring water in Kairiru Island is compared with the meteoric water and sea water in the Wewak region, and the circulation of water is discussed in this section. In the discussion, no shift of δ D and δ ¹⁸O of meteoric water by latitude is assumed between Kairiru Island and Gavien. δ D value and Cl⁻ content of the hot spring water in Kairiru Island are almost mid between those of the groundwater and the sampled sea water. Water-rock interaction has been considered by many workers, and it is said that δ D value of water has remained almost constant and the Cl⁻ content has hardly changed during water-rock interaction (CRAIG, 1963; 1966). Hence, the hot spring water in Kairiru Island can be considered to originate from the simple mixture of meteoric water and sea water in this region, with the ratio of about 1: 1.

The exchanges by water-rock interaction are observed in the following ions. Mg²⁺ and SO₄²⁻ contents of the hot spring water are lower than those of the ideally mixed water as shown in Fig. 3. Mg²⁺ and SO₄²⁻ were strongly removed from the water into rocks. On the other hand, Ca²⁺ was leached from beach rocks and enriched in the water. The present data well coincide with the previous conclusions. Many workers agreed on the rapid depletion of Mg²⁺, moderate depletion of SO₄²⁻, and the enrichment of Ca²⁺ (e.g., MATSUBAYA *et al.*, 1973; MIZUKAMI *et al.*, 1977; MOTTLE and HOLLAND, 1978; MIZUKAMI and OHMOTO, 1983; SHIRAKI, *et al.*, 1987). Especially in this region, the beach rock rich in coral materials, through which the hot spring water gushed out, might have played an important role for the enrichment of Ca²⁺.

The Na⁺ content also is less than that of the ideally mixed water. Na⁺ were mod-

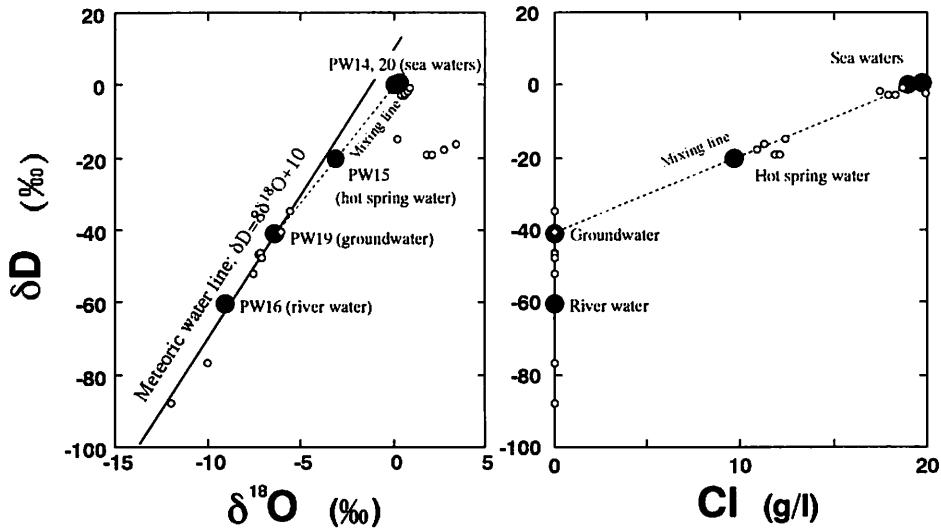


Fig. 2 Relationship of $\delta D - \delta^{18}O$ and $\delta D - Cl^-$ of waters from the Wewak region, Papua New Guinea. Large closed circles indicate meteoric water, sea water and hot spring water in present study. Small open circles are from TAGUCHI *et al.* (1991).

erately removed to low concentration. SHIRAKI *et al.* (1987) reported the enrichment from the experiments of rhyolite- and andesite-water interactions. MOTTLE and HOLLAND (1978) reported the depletion from the experiments of basalt-water interaction at low water/rock ratios. MIZUKAMI and OHMOTO (1983) reported the chemical compositions of the coastal thermal waters discharged from andesitic volcanic rocks along some coastal areas of Japan. Some data well coincide with the present results. SHIRAKI *et al.* (1987) discussed the differences between their experimental results and the field evidences by previous workers. K^+ was slightly depleted. MOTTLE and HOLLAND (1978), and SHIRAKI *et al.* (1987) reported the enrichment of K^+ . On the other hand, MIZUKAMI *et al.* (1977) and MIZUKAMI and OHMOTO (1983) described the depletion. These data suggest that the exchanges of dissolved ions in water are affected by the compositions of source materials (rock and/or water), by its mixing ratio, and by the P-T conditions. The temperature of water-rock equilibrium for this hot spring water was estimated from the $Na^+ - K^+ - Ca^{2+}$ geothermometer proposed by FOURNIER (1981), and the calculated result was about $140^\circ C$. The water might have circulated under rather low temperature condition, or at shallow depth if the water would be near the boiling temperature.

$\delta^{34}S$ of the hot spring water is almost same or slightly higher than that of the sampled sea water. As SO_4^{2-} content of the meteoric water is negligible, if SO_4^{2-} of the hot spring water originated from sea water, the resemblance of $\delta^{34}S$ values suggests that the depletion of SO_4^{2-} was performed by precipitation of sulfate minerals, such as

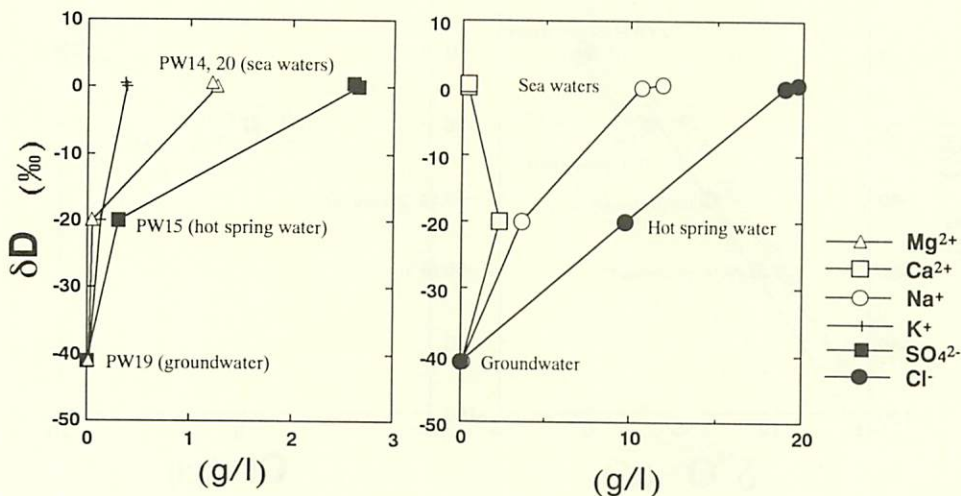


Fig. 3 Relationship of δD and dissolved ions in waters from the Wewak region, Papua New Guinea.

gypsum and anhydrite. If sulfide would be precipitated, $\delta^{34}S$ values of the hot spring water should be extremely higher than that of sea water. Because the fractionation factor, $\Delta \delta^{34}S$, between sulfide and sulfate is over than about 30‰ at the estimated temperature, and the three fourth of SO_4^{2-} in the ideally mixed water were depleted into solid phases. It means that SO_4^{2-} species was more dominant than the other dissolved sulfide species, such as HS^- and H_2S , and also that the water-convection might be performed under rather oxidation condition at shallow depth, compared to the ordinal epithermal mineralization.

Although $\delta^{18}O$ shift is often observed in the waters of typical geothermal fields in Papua New Guinea (TAGUCHI *et al.*, 1991), δD and $\delta^{18}O$ of the hot spring water in Kairiru Island are plotted on the simple mixing line between the meteoric water and sea water (Fig.2). There is no $\delta^{18}O$ shift associated with water-rock interaction.

We conclude that the hot spring water in Kairiru Island originated from the 1 : 1 mixture of the meteoric water and sea water, that SO_4^{2-} was removed from the water into rocks under SO_4^{2-} predominant condition, and that removal of Mg^+ and other cations in the water was supplemented largely by leaching of Ca^{2+} from beach rocks. The calculated water temperature at the depth is about 140°C. It is suggested that the rate of water-rock interaction was not so high to cause $\delta^{18}O$ shift, or water/rock ratio was rather high not to affect the $\delta^{18}O$ of the hot spring water.

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