Preliminary Study on the Hotspring Waters in the Ladolam Gold Deposit Area, Lihir Island, Papua New Guinea

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Abstract

The hotspring waters from the Ladolam gold deposit on Lihir Island, New Ireland Province, Papua New Guinea, are preliminarily studied to consider the origin of hydrothermal solution.

Lihir Island is on the Tabar-Feni volcanic chain of Pliocene to Quaternary age, and is characterized by the association with a hydrous subvolcanic system and with activities of fumaroles and hotsprings.

From chemical and isotopic compositions, the hotspring waters can be divided into three groups as follows. Group 1 is an acid sulfate solution, of which the δD and $\delta^{18}O$ values (relative to SMOW) lie along the evaporation line of meteoric water. Group 2 is the brine of NaCl and Na_2SO_4 with the molal ratio of 2:1, and the amount of dissolved ions is proportional to the δD and $\delta^{18}O$ values. The amount of dissolved ions of group 3 waters is inversely proportional to the δD and $\delta^{18}O$ values.

Although data are limited, the following hypotheses could be derived. The waters of group 1 are produced from meteoric water by evaporation. An endmember water in this region may be the least concentrated water of group 2. The highly concentrated water of group 2 are derived from the endmember water by evaporation. The waters of group 3 are the mixture of the endmember water and evaporated meteoric waters of group 1.

Key words: Ladolam deposit, Papua New Guinea, hotspring, geochemistry, δD and $\delta^{18}O$

Introduction

The Ladolam gold deposit on Lihir Island, New Ireland Province, Papua New Guinea, is one of the biggest epithermal gold deposits in the world. This deposit is characterized by the association with a hydrous subvolcanic system and with activities of fumaroles and hotsprings. This is a preliminary study, from the chemical and isotopic compositions of the hotspring waters, to consider the relationship between porphyry copper mineralization, epithermal gold mineralization, and geothermal activity, especially in view of the continuity of hydrothermal solution.

Lihir island is on the 250km long Tabar-Feni volcanic chain, parallel to the elongated direction of New Ireland Island, as shown in Fig. 1. This island consists of five volcanic units of Pliocene to Quaternary age and recently raised coral reef limestone

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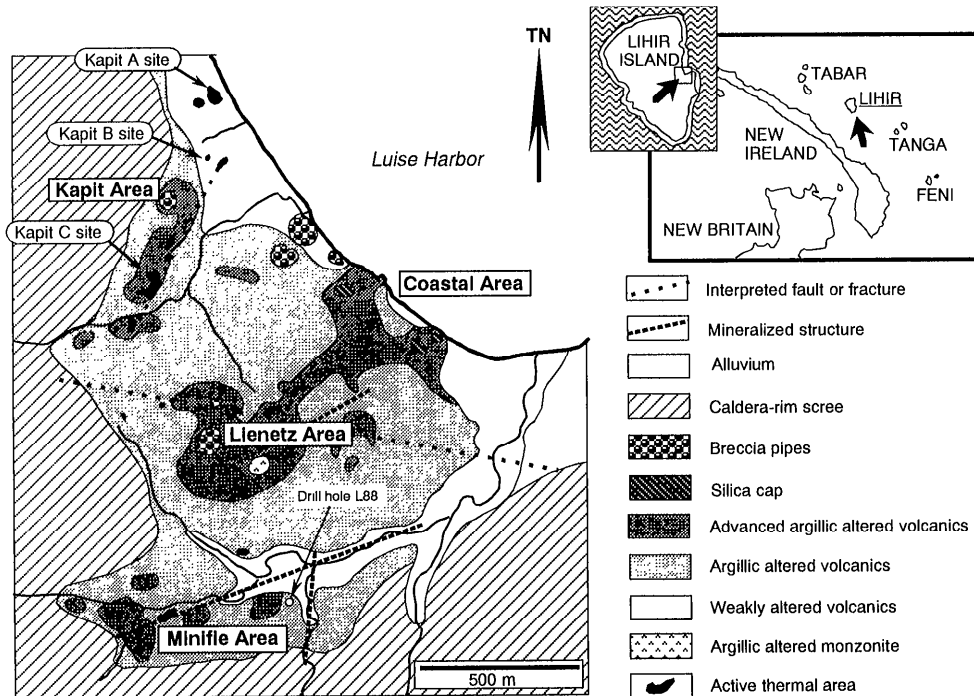3) Geological Laboratory, Faculty of Sciences, Fukuoka University, Fukuoka 814-01, Japan.

Fig. 1   Geological map of the Ladolam gold ore deposit, Lihir Island, Papua New
          Guinea (after MOYLE et al., 1990)

(WALLANCE et al., 1983).   All volcanic units are high-potassic basalts.   The Ladolam
gold ore deposit is situated in the 4km x 6km Luise caldera in the youngest volcano,
Luise Volcano, which was emplaced about 0.35 to 0.9 Ma (DAVIES and BALLANTYNE,
1987 ; MOYLE et al., 1990).   The subvolcanic syenite and monzonite intrude about
200m below the present bottom of the caldera.   The Cl^- / OH^- ratio of biotite and
apatite in the intrusive rocks are rather high, suggesting the high f_{HCl}/f_{H_2O} ratio of the
monzonitic magmatism.   This feature is similar to those in the porphyry copper sys-
tems in Papua New Guinea (NEDACHI et al., 1990 ; 1991).

The alteration and mineralization were described in detail by DAVIES and BALLAN-
TYNE (1987), and MOYLE et al. (1990).   The stage of hydrothermal alteration is close to
that of the monzonitic magma activity.   A potassic (K-feldspar and/or biotite) altera-
tion occurs at the depth of more than 100m below the surface.   The chemical composi-
tions of biotite and apatite in the potassic alteration stage are similar to those in the
subvolcanic activity stage.   Propylitic alteration occurs from the periphery to the area
of potassic alteration.   The latter epithermal type alteration occurs at the shallower
depth, and the bottom of the caldera is widely altered.   The argillic-phyllic alteration
(kaolinite, smectite, illite, K-feldspar and silica) develops extensively around the acid-
sulfate type alteration.   The Ladolam gold ore deposit is composed of four mineralized
areas: Kapit, Coastal, Lienetz and Minifie (Fig. 1).

Other important evidences for the mineralization are an anhydrite sealed zone and a boiling zone.   Anhydrite ($\pm$ quartz $\pm$ calcite) occurs in veins and in breccia matrix below the argillic alteration zone.   Boiling and siliceous breccia zones occur as horizontal layers between the argillic and anhydrite sealed zones.   Gold mineralization of ore grade is principally hosted by the argillic alteration zone, siliceous breccia zone, boiling zone, and the upper part of the anhydrite sealed zone.   The mineralization stage was estimated to be 0.1 to 0.35 Ma by DAVIES and BALLANTYNE (1987).

Eight fluid inclusions of the quartz in the anhydrite sealed zone of 221.8m depth in the drill hole core L88 are examined (Fig. 1).   All inclusions consist of liquid and gas phases.   The filling temperatures and salinities (equivalent Wt.% NaCl) for each inclusion are 223℃-3.1%, 221℃-3.1%, 205℃-3.0%, 224℃-3.1%, 212℃-3.3%, 199℃-3.1%, 226℃ -3.0%, and 217℃ -2.3%, respectively. MOYLY *et al.*(1990) reported similar temperature and salinity ranges.   HARRISON (unpublished, referred by MOYLE *et al.,* 1990) reported supersaline inclusions with many daughter minerals, and gaseous inclusions which suggest boiling at about 300 to 700m depth.

Hotspring water

Hotspring and fumarole activity can be seen some places in the bottom of the caldera.   Thirteen hotspring waters were collected from the Coastal and Kapit mineralized areas.

Sea water washes over the area of fumarole activity in the Coastal area, and the hotspring water flows directly into the harbor.   The water samples of PW01 and PW02 were collected during the retreat of the waves.   No sinter material is observed.   No smell of H_2S gas is detected.

We surveyed three hotspring sites in the Kapit mineralized area; Kapit A, B and C sites from the beach side (Fig. 1).   Four water samples, PW10 to PW13, were collected from the Kapit A site.   PW10 is from a very small pond which slightly changes water level every few minutes.   Rocks around the pond are covered by thin sulfide precipitates.   PW11 is quite limpid water, and PW12 and PW13 are slightly muddy and strongly acid waters.

Three hotspring waters, PW03 to PW05, were collected from the Kapit B site. PW03 is boiling limpid water coexisting with precipitates consisting of amorphous silica, pyrite, halloysite and illite.   PW04 is also clear water with precipitates of kaolinite, pyrite, alunite and smectite.   PW05 is muddy acid water with sulfur - alunite precipitates.

Four water samples, PW06 to PW 09, were collected from the Kapit C site.   All the samples from this site show low pH and contain precipitates such as amorphous silica, alunite, free sulfur, gypsum and pyrite.   PW08 is from a highly condensed muddy pond, and PW09 is the most limpid water from the stagnating pool near a small riverlet.

For comparison, a sample of sea water was collected from the Luise harbor.

Chemical composition of hotspring waters

The water samples were analyzed for major chemical composition and for isotopic compositions of δD and $\delta^{18}O$ (relative to SMOW). MOHR's method was used for Cl^- and gravimetry for SO_4^{2-}, and atomic absorption for alkali and alkali earth elements. The results are shown in Table 1 and are illustrated in Figs. 2 to 4.

The hotspring waters collected from the Coastal area are near-neutral pH brine. They contain Na^+ as predominant cation, some amount of K^+, and minor amounts of Ca^{2+} and Mg^{2+}. Cl^- and SO_4^{2-} also are contained as major anions. The content of Cl^- is almost twice of that of SO_4^{2-} (Fig. 3b), and are about one-fourth of that of sea water. The δD and $\delta^{18}O$ values shift slightly from the meteoric water line (Fig. 2).

The pH of waters from Kapit A site vary from 1.6 to 7.2, and the contents of major components increase with increasing pH. The δD and $\delta^{18}O$ values increase with decreasing pH. The ratios among the major ions of PW10 and PW11 are almost the same as those from the Coastal area, but PW12 and PW13 contain mainly SO_4^{2-} ion.

The waters collected from Kapit B site show two different characteristics. PW03 and PW04 are neutral and are highly concentrated in dissolved ions (Table 1). Na^+ content is about two times higher (Fig.4a), and SO_4^{2-} and K^+ contents are much higher than that of sea water. The Cl^- content is almost the same as that of sea water (Fig.4b). However, the $Na^+ : Cl^- : SO_4^{2-}$ ratio is similar to those from the Coastal area. The δD and $\delta^{18}O$ values are uniformly high compared to the meteoric water of this region (Figs. 2 and 4). On the other hand, PW05 is acid and contains only a small amount of SO_4^{2-} and other components, and similar to PW12 and PW13 of

Table 1   Chemical compositions of hotspring waters of the Ladolam gold ore deposit

| Sample	Coastal area		Kapit A site				Kapit B site			Kapit C site				Luise harbor
	PW01	PW02	PW10	PW11	PW12	PW13	PW03	PW04	PW05	PW06	PW07	PW08	PW09	PW14
Temp (℃)	93.5	94.0	98.3	91.7	82.4	91.3	99.4	76.7	66.2	97.7	90.1	91.2	73.9	31.0
pH	6.9	7.8	7.2	3.2	1.6	1.6	7.4	6.0	2.3	1.3	1.6	2.1	2.1	8.1
δD_{SMOW} (‰)	-29.1	-29.5	-12.3	-1.3	4.0	5.4	-2.0	4.3	-1.4	-10.6	-10.8	10.1	-24.6	0.6
$\delta^{18}O_{SMOW}$ (‰)	-3.1	-3.2	2.3	6.3	7.3	8.2	8.2	11.5	7.4	2.3	2.7	11.0	-1.4	0.3
Mg^{2+} (mmol/l)	1.9	1.9	0.9	1.3	0.8	1.0	0.1	0.1	0.1	0.2	0.2	tr	0.4	63
Ca^{2+} (mmol/l)	2.8	3.0	1.5	1.5	0.7	0.8	0.6	0.8	0.2	0.1	0.1	0.1	0.8	10.1
Na^+ (mmol/l)	242.7	247.5	125.7	79.6	2.0	1.0	904.8	791.7	1.3	0.2	0.2	0.1	0.2	513.3
K^+ (mmol/l)	32.7	32.7	14.6	8.9	0.4	0.3	61.4	61.4	0.4	0.8	0.9	0.7	0.6	11.9
SO_4^{2-} (mmol/l)	71.2	73.5	32.8	28.4	19.3	14.7	239.4	195.7	7.5	10.3	10.5	9.7	9	29.1
Cl^- (mmol/l)	143.3	143.6	82.6	51.6	1.3	0.5	527.5	459.8	0.7	tr	tr	tr	tr	555.7
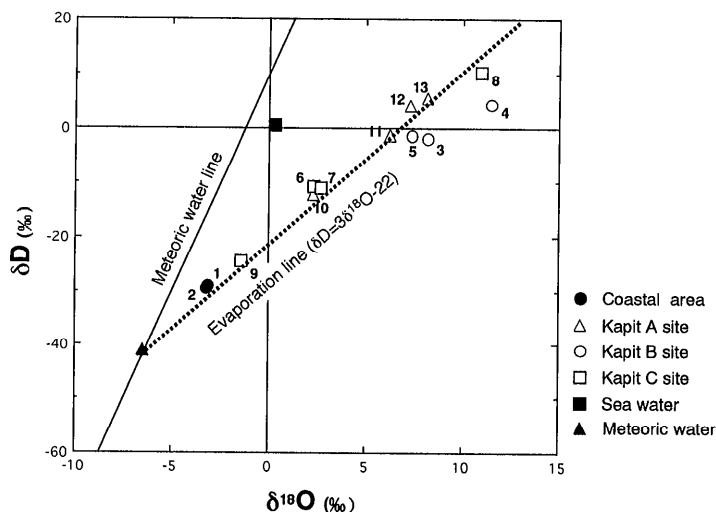
Fig. 2　δD-δ^{18}O of hotspring waters from the Ladolam gold ore deposit.
Numbers attached to symbols, for example 1, 2 and 13, are sample numbers, PW01, PW02 and PW13, respectively.

Kapit A site.

All water samples from the Kapit C site are acid sulfate as shown in Table 1 and Fig. 3. The δD and δ^{18}O vary widely along the line of δD $=$ 3 δ^{18}O - 22 which is an evaporation trajectory of meteoric water (Craig, 1963), as shown in Fig. 2. More muddy water is richer in deuterium and ^{18}O. WILLIAMSON (1983) and MOYLE *et al.* (1990) have reported waters of similar characteristic from the Kapit and Minifie mineralized areas.

As a whole, the waters from the Ladolam gold deposit area in this study might be divided into three groups, 1, 2 and 3 on the basis of the ratio of dissolved ions. The group 1 waters are acidic sulfate dilute solutions showing the wide variation in δD and δ^{18}O values along the evaporation line (Fig. 2), including PW13 from the Kapit A site, PW05 from the Kapit B site, and PW06 to PW09 from the Kapit C site. The group 2 waters, PW01 to PW04, are near-neutral pH and sulfate-chloride solutions containing concentrated solutes, of which major components are NaCl and Na_2SO_4 with the ratio of 2:1. These waters also are roughly on the evaporation line (Fig. 2). The amounts of dissolved components are proportional to the δD and δ^{18}O values. The group 3 waters include PW10 to PW12. Although these waters show the wide variation in δD and δ^{18}O values along the evaporation line, the amounts of dissolved components and pH values of the waters are inversely proportional to the δD and δ^{18}O values.
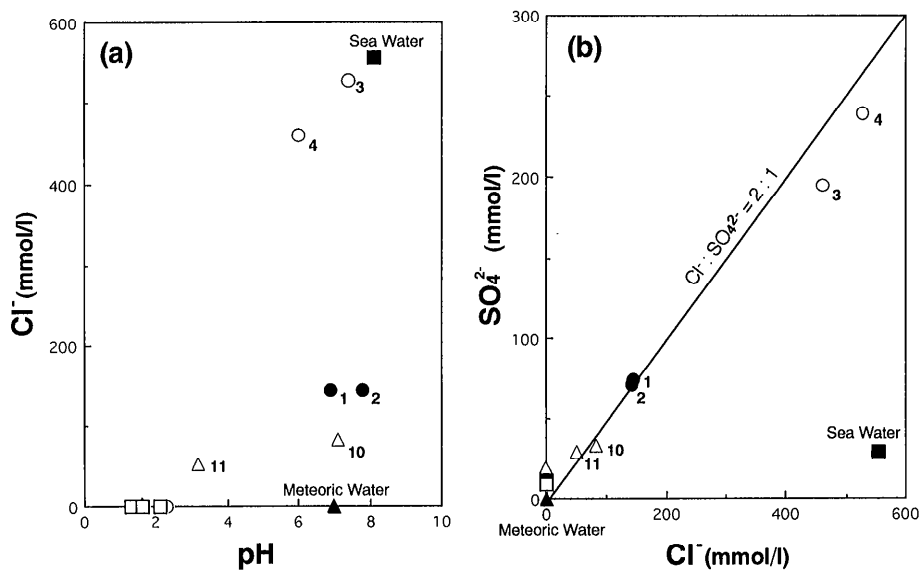
Fig. 3   Cl⁻- pH (a) and SO_4^{2-} - Cl⁻ (b) of hotspring waters from the Ladolam gold ore deposit.   Symbols are the same as those in Fig. 2.
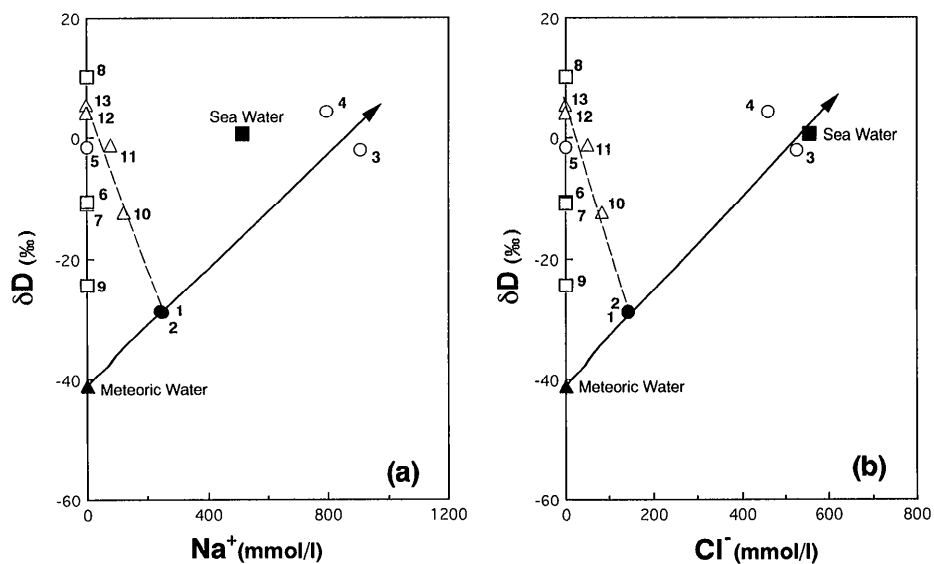

Fig. 4 δD-Na⁺ (a) and δD-Cl⁻ (b) of hotspring waters from the Ladolam gold ore deposit.   Symbols are the same as those in Figs. 2 and 3.

Evolution of hydrothermal fluid

To discuss the origin and evolution of the hotspring waters, the most basic information necessary is the isotopic composition of the meteoric water of Lihir Island, but we have failed to collect it. NEDACHI *et al.* (1994) reported $\delta D = -41.1‰$ and $\delta^{18}O = -6.5‰$ for the meteoric water collected in Wewak (latitude 4.0°S). TAGUCHI *et al.* (1991) reported $\delta D = -40.5‰$ and $\delta^{18}O = -6.14‰$ for the meteoric water from the Kapiura river (latitude 5.5°S), Kasiloli, New Britain Island (Fig.1). These data suggest that -40.0‰ for δD and -6.5‰ for $\delta^{18}O$ are the reasonable values for the meteoric water in Lihir Island (latitude 3.1°S). This is just on the cross point of meteoric water line and the evaporation line in δD - $\delta^{18}O$ diagram.

Although there are no informations from the deeper part and other thermally active areas in the Luise caldera, we at least could presume the possible evolution process as in Fig. 5. Mixing of waters, evaporation and water-rock interaction might occur in this field.

The isotopic compositions of the waters of group 1 lie on the evaporation line of meteoric water. They hardly contain dissolved ion except slight amount of SO_4^{2-}. Hence, the group 1 is interpreted by the simple evaporation (CRAIG, 1963) of meteoric water. Field observation seems to support this interpretation; more limpid water has lighter isotopic composition and more muddy water has heavier composition. Through evaporation, water may become muddier, and heavier in isotopic composition than
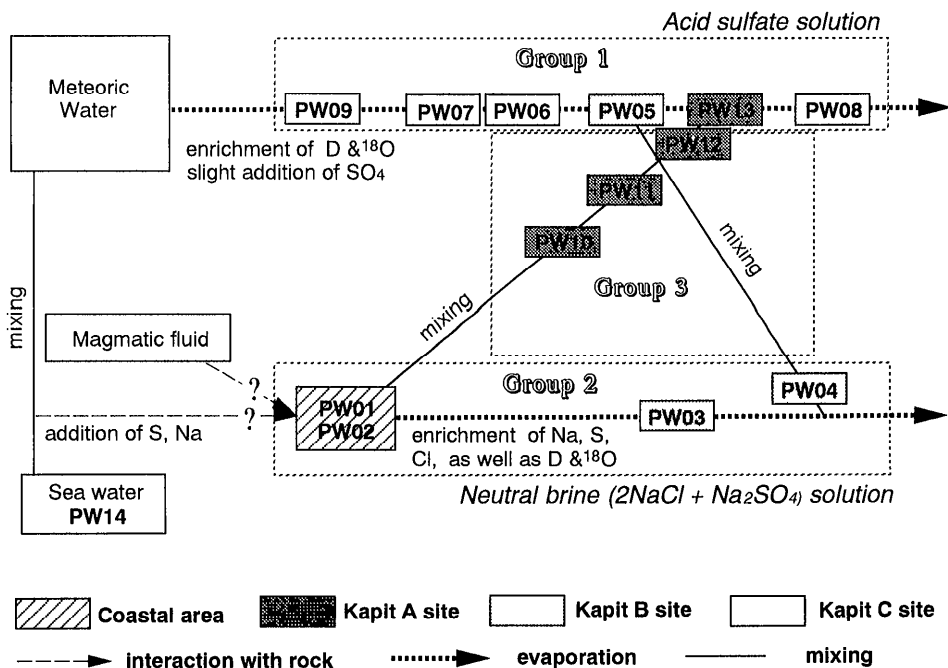

Fig. 5   The evolution of hotspring waters in the Ladolam gold ore deposit.

meteoric water.   The SO_4^{2-} might be produced by oxidation of pyrite or H_2S near the surface.   Sulfide minerals (mainly pyrite) of epithermal alteration stages are recognized underground.   PLIMER et al. (1988) suggested that the H_2S gas was derived by the boiling of neutral chloride brine, which leached sulfur from alkaline basalts.   As H_2S gas is not recognized at the sampling sites on the surface, H_2S may be oxidized at shallow depth under the surface.

The same ratio of dissolved ions among the waters of group 2 suggests that the waters are derived from the same endmember water. PW01 and PW02 might play an important role as an endmember water in this region.   The amounts of dissolved ions are proportional to δD and $\delta^{18}O$ values for four water samples of group 2, and PW3 and PW04 are richer in the dissolved ions than PW01 and PW02.   These indicate that PW03 and PW04 are formed by evaporation from PW01 or PW02.   The chemical and isotopic compositions of PW04 can not be explained only by simple evaporation process (Fig. 4).   PW04 might be produced by mixing an evaporated meteoric water, PW05, and the highly evaporated water from PW01 or PW02 (Fig. 5).   The content of dissolved ions in the group 3 is inversely proportional to the δD and $\delta^{18}O$ values. They might be formed by mixing the endmember water (PW01 or PW02) and the evaporated meteoric water of the group 1, such as PW13.

The origin of the endmember water might be explained by water-rock interaction, if the water was formed by mixing sea water and meteoric water with a ratio of about 3:1.   The Cl^- content and the isotopic composition of PW01 and PW02 are well explained by this process.   However, extremely high Na_2SO_4 content and rather low Ca^{2+}/Cl^- ratio are not consistent with the results of the previous studies (MOTTL and HOLLAND, 1978 ; REED, 1983).   An exceptional condition and/or the chemical compositions of rocks should be considered (e.g., existence of a special mineral such as thenardite).   In addition, there is a possibility that a hydrothermal fluid of hydrous subvolcanic magmatism has contributed as a source of PW01 and PW02: the biotite and apatite chemistry of the rocks in this field suggests the existence of supersaline brines similar to those observed in the ordinal porphyry copper districts in Papua New Guinea.   The process to form group 2 water will be discussed in detail in the next paper (NEDACHI et al., in preparation).

In conclusion, neutral brines of $NaCl$ and Na_2SO_4 ($NaCl : Na_2SO_4 = 2:1$) as well as the meteoric water, are endmembers in the active geothermal system around the Ladolam gold ore deposit.   The meteoric water has been heated and evaporated in various degrees to produced waters of group 1 in Kapit area.   Also, the neutral brine has evaporated to produced waters of group 2 in Coastal and Kapit areas.   The waters produced in these ways have mixed together to produce the waters of group 3.   The origin of the endmember brine has still remained unanswered.   Again, it should be noted that this study is based on limited data, and that comprehensive information, especially the data from a deeper sample from the Kapit and Coastal areas and from other geothermal areas in the Luise caldera are necessary for better understanding of the origin of water in the Ladolam gold mineralization area.

Acknowledgements

The authors wish to thank Mr. B. DUCK of the Bremar Minerals Pty. Ltd., Prof. H.L. DAVIES of UPNG, Mr. N. KONDO of RTZ (Japan) Ltd., Mr. J. OHSAKO of MMAJ, Prof. E. IZAWA of Kyushu University, Dr. H. SAKAMOTO of Kagoshima University, Dr. Y. MATSUHISA of GSJ, and Prof. H. OHMOTO of The Pennsylvania State University for their kind guidance, advice, and valuable information.

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