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COMPOSITION OF HYDROTHERMAL AND IGNEOUS BIOTITES, AND THEIR OCCURRENCE IN BOREHOLE No 1, DIENG, INDONESIA

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Abstract

Textural relations and mineral chemistry have been used to determine the differences between igneous and hydrothermal biotites from different depths in borehole No. 1, Dieng, Indonesia.

The igneous and hydrothermal biotites occur as coarse and fine grained material respectively. Igneous biotites are homogeneous while hydrothermal biotites change in composition with increasing temperature and depth. Hydrothermal biotites are depleted in Ti, Mg, and K, but enriched in Fe, Si, and Ca relative to igneous ones. The hydrothermal biotites also have sufficient (Si + Al) to fill the tetrahedral sites as indicated in the general structural formula.

Compositional variations of hydrothermal biotite reveal that they have been controlled by temperatures, rock permeability and duration of thermal activity.

Introduction

Borehole **No. 1** is located in the Dieng geothermal area, Indonesia. It was drilled to 1900 m depth. The general sequence of rock types penetrated during drilling were: andesites, tuff breccias, and tuffs. Between **1608** m and **1900** m, the andesite is intruded by diorite. The andesites, tuffs, and tuff breccias have undergone intense hydrothermal alteration but the diorite is relatively fresh..

Hydrothermal biotite first appears in an andesite at **1450** m depth where it completely replaces igneous biotite and partially replaces clinopyroxene and amphibole. Below this depth igneous biotite has undergone partial recrystallization to hydrothermal biotite.

Analytical Methods

Four drillcores sampled from **1450, 1608, 1807,** and **1900** m depth were selected for more detailed study. Polished thin sections were prepared from each sample for petrographic observation and microprobe analysis. A **JEOL** Super Probe **733** with accelerating voltage of **15 KV** and probe current of **1.2** mA was used. Chemical analyses of the mineral standard biotites, **P.S.U.5-110** and **U.M.R-2208,** were compared with biotites from Dieng.

Petrography

Primary igneous biotite occurs with augite, amphibole, ilmenite, rutile, and andesine. Biotite comprises about **5** to **10%** of the host **rocks** and is one of the dominant mafic **minerals** present. The biotites commonly contain magnetite and apatite inclusions (Fig. **1).** Hydrothermal biotite is closely associated with actinolite, adularia, pyrite, chlorite and titanite.

Igneous biotite is deep-brown to medium brown, and occurs as rectangular flakes up to 1 mm in length. The hydrothermal biotite forms fine grained aggregates, and has a faint pale yellowish or greenish-brown pleochroism. It commonly fills fractures or cavities in primary feldspar (Fig. **2).**

Composition of igneous biotite

Analyses of igneous biotite **are** listed in Table **1**, and **are** plotted on an Al-Fe-Mg diagram (Fig. **3A).** The biotites **are** characterized by high TiO_2 **(4-5%** wt.%), and the Fe/Fe+Mg ratios range from **0.38 - 0.41** (Table **1).** Almost all of **the** biotites do not contain enough (Si+Al) to fill their tetrahedral sites. The igneous biotites from different depths and rock **types are** chemically homogeneous.

Composition of hydrothermal biotites

Analyses of hydrothermal biotites **are** presented in Table **2,** and plotted on Fig. 3B. In contrast **to** the igneous biotites, the TiO_2 content of hydrothermal biotites is low and ranges from **0.2 - 3.3** wt.%. **There** is sufficient (Si+Al) to fill the tetrahedral sites and there is additional Al (up to **0.51** atom per formula unit) to fill the octahedral sites. These biotites contain significant CaO, have variable Na_2O, and have lower K_2O than the igneous biotite.

Biotite in diorite (porosity = ϕ<1%) has a wide range in Ti, from **0.02** to **0.33** per formula unit. Fe/Fe+Mg ratios vary from **0.41 to 0.58.** Biotites in altered andesite from **1450** m **(ϕ = 3%)** and **1807** m($ = **1%)** depths hare a narrow range of Ti content; **0.03** to **0.12** and **0.25** to **0.30** respectively, while Fe/Fe+Mg ratios vary between **0.43** to **0.55.**

Biotite composition changes with depth

The composition of igneous biotites varies only slightly with increasing depth, except for the biotite from **1900** m (Table **1).** However, in general these biotites **are** considered to be homogeneous in composition (Fig. **3A).** On the other hand, with increasing depth and decreasing temperature, there is a significant and regular increase in **K** and Al, and a decreases in Si for hydrothermal biotites (Table **2** and Fig. **4). The** average Fe/Fe+Mg **ratios** decrease slightly, but there is a significant increase in average **Ti** content with increasing depth **.** These trends have also been observed in the Salton **Sea** geothermal biotites over a temperature range from **325°C** up to **360°C** in borehole Elmore 1 (McDowell **and** Elders, **1980).**

Table **1.** Representative Electron Microprobe analyses of Igneous Biotites from Borehole **No.** 1, Dieng.

No	AF.6	AF.6	AF 30	AF 30	AF7	AF7
Depth	1608	1608	1807	1807	1900	1900
(m)(°C)	315	315	260	260	235	235
SiO_2	38.8	38.9	39.3	39.2	37.8	39.7
Al_2O_3	11.4	12.1	12.2	11.9	12.0	12.7
TiO_2	4.3	4.8	4.5	4.0	4.3	4.6
FeO	15.7	15.4	16.8	16.3	16.5	16.0
MnO	0.3				0.4	0.3
MgO	14.7	14.4	14.0	14.6	13.5	14.1
CaO						0.1
Na_2O		0.2	0.2	0.3	0.2	
K_2O	9.5	8.9	8.8	8.8	9.3	8.6
Total	94.4	94.7	95.8	95.1	94.0	96.1
Cations Number of ions on the basis **O** = 22						
Si	5.87	5.84	5.83	5.87	5.79	5.86
Al	2.03	2.15	2.13	2.09	2.16	2.20
Ti	0.48	0.55	0.50	0.45	0.50	0.51
Fe	1.99	1.93	2.08	2.04	2.11	1.97
Mn	0.04				0.05	0.04
Mg	3.31	3.22	3.09	3.27	3.08	3.11
Ca						0.01
Na		0.04	0.07	0.08	0.05	
K	1.82	1.70	1.66	1.68	1.81	1.62
Fe/Fe+Mg	0.38	0.38	0.40	0.38	0.41	0.39
AlIV	2.03	2.15	2.13	2.09	2.16	2.14
AlVI						0.06
ΣVI	5.69	5.50	5.67	5.76	5.74	5.69

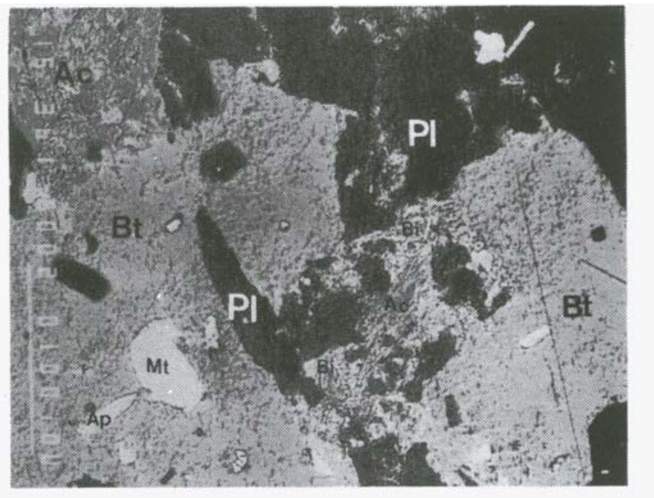

Fig. 1. Backscattered electron image photo **(BEI)** of igneous biotite (Bt) which is partly altered **to** hydrothennal biotite (Bi) **and** actinolite (Ac). Pl = plagioclase (An44), Mt = magnetite, Ap = apatite, **and** bar scale is 100 μ.

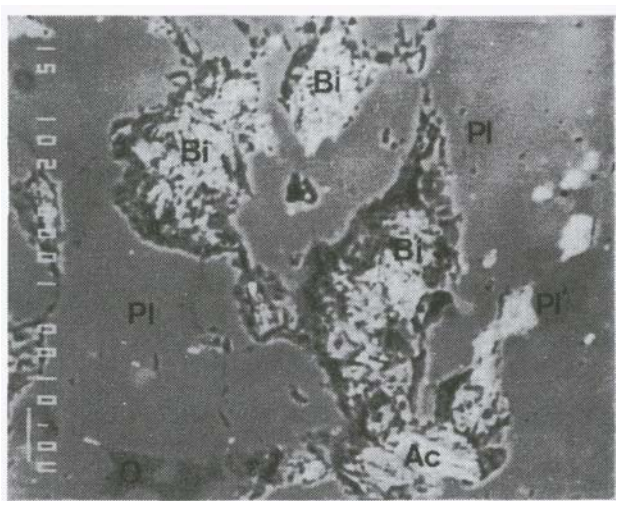

Fig. **2.** Backscattered electron image of hydrothermal biotite (Bi) fills cavities in plagioclase - Pl (An56) and Pl' (An43). Ac = actinolite, Q = quartz, **and bar** scale is 10 μ.

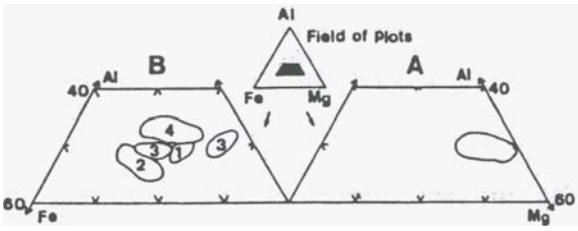

Fig. 3. Compositional variations **of** the **two types** of biotite.
A - Composition of igneous **biotites,**
B - Composition of hydrothermal **biotites,**

1 biotite from 1450 m,
2 biotite from 1608 m
3 biotite from 1807 m
4 biotite from 1900 m.

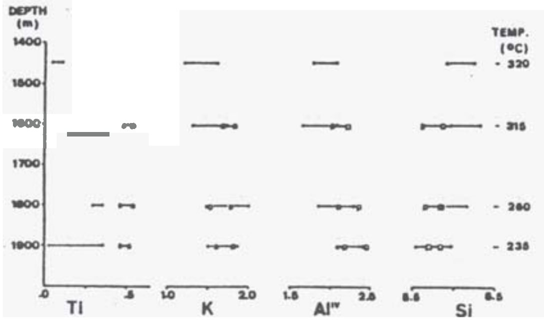

Fig. 4. Compositional variations of biotite versus depth (m) and **temperature (°C).**

Table 2. Representative Electron Microprobe analyses of hydrothermal biotites from Borehole No.- 1, Dieng.

No.	AF4	AF4	AF6	AF6	AF30	AF30	AF7	AF7
Depth (m)	1450	1450	1608	1608	1807	1807	1900	1900
T (°C)	320	320	315	315	260	260	235	235
SiO_2	41.4	38.1	40.7	38.6	39.3	39.8	39.5	39.1
Al_2O_3	12.1	12.7	9.3	11.7	12.3	11.0	14.5	13.4
TiO_2	1.0	0.8	2.3	2.3	2.2	2.3	0.3	2.5
FeO	19.8	23.0	20.0	22.5	20.5	18.6	19.2	21.8
MnO	0.3	0.2	0.3	0.4		0.2	0.3	0.2
MgO	13.1	10.4	10.8	10.1	12.0	11.2	12.3	10.6
CaO	0.6	0.3	2.1	0.4	1.2	2.1	0.2	0.5
Na_2O	0.1	0.2	0.2		0.2		0.2	0.2
K_2O	7.2	7.2	6.8	8.4	8.4	7.5	9.6	8.8
NiO		.	0.5					
Total	95.6	92.9	93.0	94.5	96.1	92.7	96.1	97.1
Cations	Number of ions on the basis O = 22							
Si	6.17	5.99	6.33	6.01	5.94	6.17	5.95	5.87
Al	2.14	2.35	1.70	2.16	2.19	2.00	2.57	2.38
Ti	0.12	0.10	0.27	0.27	0.25	0.27	0.03	0.28
Fe	2.47	3.03	2.60	2.92	2.59	2.41	2.42	2.74
Mn	0.03	0.03	0.03	0.05		0.03	0.03	0.03
Mg	2.91	2.45	2.50	2.35	2.70	2.58	2.77	2.38
Ca	0.10	0.05	0.35	0.07	0.19	0.34	0.04	0.08
Na	0.03	0.05	0.06		0.04		0.05	0.05
K	1.36	1.45	.133	1.66	1.61	1.47	1.84	1.69
Ni			0.06					
Fe/Fe Mg	0.46	5.55	0.51	0.55	0.49	0.48	0.47	0.54
AlIV	1.83	2.01	1.67	1.99	2.06	1.83	2.06	2.13
AlVI	0.31	0.34	0.03	0.15	0.13	0.17	0.51	0.25
ΣVI	5.84	5.95	5.43	5.74	5.67	5.46	5.76	5.68

The temperatures measured in borehole No. 1 (Dieng) decrease from 320°C to 235°C with increasing depth (Fig. 4). This suggests that present day temperatures in this borehole below a depth 1608 m are not those required for hydrothermal biotite crystallization. The first appearance of hydrothermal biotite in the Salton Sea boreholes is at 330°C. Thus it can be concluded that in Dieng No. 1, temperatures have decreased from about 330°C to 235°C below 1608 m depth.

Discussion

Hydrothermal biotites in active geothermal systems are found at temperatures higher than 300°C (McDowell and Elders, 1980; and Schiffman et al., 1985). In rocks with low permeability, equilibrium between the rocks and the fluid is seldom achieved and at high temperatures, primary phases can remain unaltered (Browne, 1978),

In samples with high porosity (t$ = 3.0%), e.g. at 1450 m depth, primary biotite is totally replaced by secondary biotite. This suggests extensive interaction between these rocks and high temperature fluids. The restricted compositional range of hydrothermal biotites (especially Ti contents <1.0%) in these samples suggests that fluid-rock interaction has approached equilibrium. The composition of Dieng biotites are compared to the hydrothermal biotites found in borehole Elmore 1 where Ti02 contents are much less than 1.0 by wt. percent and rock porosity ranges from 5 to 20%. However, the wide range of Ti contents in hydrothermal biotite from Dieng diorite could also result from different compositions of host minerals with which the biotite is associated.

In rocks with low porosity, e.g. diorite (ϕ = <1.0%) at 1608 and 1900 m depths, and andesite (ϕ = 1.0%) at 1807 m depth, igneous biotite still remains unaltered suggesting that the amount of interaction with high temperature fluids in these samples was low. Since the diorite has low porosity and intrudes andesite that has already been hydrothermally altered, it has been interacting with high temperature fluids for a shorter time.

Thus, temperature, rock porosity (effective porosity), and duration of thermal activity have a significant control on the composition of hydrothermal biotites forming in this borehole.

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