MINERALOGICAL AND GEOCHEMICAL CHARACTERISTICS OF HYDROTHERMALLY ALTERED BASALT IN THE KUROKO MINING AREA, JAPAN: COMPARISON WITH RIDGE BASALT ALTERATION

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The hydrothermally altered basalt in the Kuroko mining area can be mineralogically divided into two types; chlorite-rich and epidote-rich one. The chlorite-rich type is characterized by chlorite, albite, calcite, pyrite, quartz and small amounts of iron-poor epidote and actinolite, and they occur as replacement of groundmass and phenocrysts, and vesicle is filled with chlorite. The epidote-rich type is characterized by iron-rich epidote, quartz, calcite and small amounts of hematite and magnetite, occurring as vesicle filling. Generally, brecciated rock suffered the chlorite-rich type alteration, while massive rock is changed to the epidote-rich one. Fluid inclusion studies show that alteration of basalt to the chlorite-rich and epidote-rich assemblages occurred at the temperature range of 230-250°C and 250-280°C, respectively, implying that generally temperature increased from chlorite stage to epidote stage. The above data indicate that permeability and temperature are important factors causing different type of alteration (epidote and chlorite alterations). Texture of alteration minerals suggests that chlorite formed earlier than iron-rich epidote. With proceeding of hydrothermal alteration, iron content of epidote increases and CaO content of feldspar decreases. MgO/FeO ratio of chlorite depends on the coexisting minerals; that coexisting with pyrite is low (1.1), while that coexisting with hematite and epidote is high (1.4).

CaO, Na_2O, and SiO_2 contents of hydrothermally altered Kuroko basalt inversely correlate to MgO and $H_2O(+)$ contents. The chlorite-rich one is rich in MgO and $H_2O(+)$, while the epidote-rich one is suffered hydrothermal alteration under the high seawater/basalt mass ratio (up to 40). Oxygen isotopic compositions of calcite in the chlorite-rich rock containing albite, epidote and actinolite suggest that calcite formed at seawater/basalt mass ratio of 0.1-1.8, which is similar to that for epidote-actinolite-albite-quartz rock of ridge basalt. Thus, it is inferred that the seawater/rock ratio decreased from early to late stage of alteration. The basalt having high K_2O and variable Fe content overlies the Kuroko ore. This type of alteration is caused by the hydrothermal activity at the discharge zone and at waning stage of the Kuroko sulfide mineralization.

As summarized in Table 1, the characteristic features of the alteration mineralogy, stable isotopes, fluid inclusions and bulk rock compositions of the Kuroko basalt are generally similar to those of the ridge basalt altered to greenschist facies. For example, δD, $\delta^{18}O$, and $\delta^{13}C$ of hydrothermal solution responsible for the Kuroko basalt alteration are similar to those of hydrothermal solution issuing at oceanic ridge. However, some differrences between the Kuroko and ridge basalt alterations exist. They are; (1) late stage iron-rich epidote and hematite filling vesicules are common in the Kuroko basalt but not in the ridge basalt, (2) CaO content of bulk rock is relatively low and Fe_2O_3 and Na_2O contents are relatively high for the Kuroko basalt. The rock enriched in CaO content compared with original rock is not present in the Kurko mining area, (3) Na_2O content of the Kuroko basalt inversely correlates with MgO content, and (4) MgO/FeO ratios of chlorite and actinolite and Fe_2O_3 content of epidote from the Kuroko basalt are relatively high.

The possible factors causing these differences are, temperature, water/rock ratio, original solution composition, and original rock composition. Among them, the original rock composition is considered to be the most important one; Higher Fe_2O_3/FeO and MgO/FeO of chlorite and actinolite than those in the ridge basalt. High Fe_2O_3 content of epidote and the presence of hematite in the Kuroko basalt are considered to have been caused by high Fe_2O_3 content of original rock in the Kuroko mining area. High Na_2O content and low CaO content of the hydrothermally altered Kuroko basalt can be explained by the different CaO and Na_2O contents of original rocks.

The vesicle volume % of the Kuroko basalt is high (average 20 %) and vesicles are filled with alteration minerals (dominantly epidote, calcite, chlorite, pyrite, quartz) which formed at late-stage hydrothermal activity. The abundant vesicles also strongly control the bulk rock compositions, stable isotope compositions, and alteration mineralogy of hydrothermally altered basalt. Such vesicular basalt (vesicle volume %: 20-40) has been reported from back arc basin and island arcs: Lau basin, Shikoku basin, and Mariana trench. In contrast, vesicle volume % of mid-ocean ridge basalt is very low, less than 10 %.

Table 1. Characteristics of Kuroko basalt and ridge basalt alterations

	Kuroko basalt	Ridge basalt
Petrography		
Chlorite-quartz -rich rock	absent	present
Vesicle	abundant (20 volume%)	poor (less than 10 volume %)
Mineralogy		
Chlorite	MgO/FeO;high (1.1-1.6)	MgO/FeO: variable, usually low (0.5-1.7)
Epidote	Fe_2O_3 content: high (11-16 wt.%)	Fe_2O_3 content: low (5-15 wt.%)
Actinolite	MgO/FeO: high (1.3-2.0)	MgO/FeO: variable,usually low (0.7-1.2)
Hematite	common	rare
Bulk Compositions		
Positive correlation with MgO and H_2O(+)	FeO, ΣFe	FeO
Negative correlation with MgO	CaO, SiO_2, Na_2O	CaO, SiO_2
Original compositions	CaO: 4-6 wt.% Na_2O: 3-6 wt.% MgO: 6 wt.% FeO: 5 wt.%	CaO: 9-13 wt.% Na_2O: 2-3 wt.% MgO: 7-8 wt.% FeO: 7-9 wt.%
Stable Isotopes	$\delta^{13}C$ of calcite: -8 - -3 ‰ $\delta^{18}O$ of calcite: +6 - +12 ‰ δD of epidote: about -40 ‰	$\delta^{13}C$ of calcite: -7 - -3‰ $\delta^{18}O$ of calcite: +7 - +12‰
Temperature	Chlorite stage: 230-250°C Epidote stage: 250-280°C	250-350°C (epidote-actinolite-albite-quartz--chlorite assemblage)
Seawater/Basalt Ratio	Chlorite stage: high (up to 40) Calcite: low (0.1-1.8)	Chlorite-quartz rich rock: high more than 50 Epidote-actinolite-albite-quartz-chlorite assemblage: low (1.6)