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Comparative Anatomy of the Hydrothermal Alteration of Chonnam and Kyongsang Hydrothermal Clay Alteration Areas in Korea

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ABSTRACT : Chonnam and Kyongsang clay alteration areas are distributed in volcanic fields of the Yuchon Group in late Cretaceous period. The host rock of the Chonnam alteration area is generally acidic and that of the Kyongsang alteration area is acidic to dominantly intermediate volcanics. The important difference of two alteration areas is source of fluid; the Chonnam alteration area is characterized by dominantly meteoric water and the Kyongsang alteration area is characterized by dominantly magmatic water. Accordingly, the high temperature minerals such as pyrophyllite and andalusite, and boron bearing minerals such as dumortierite and tourmaline are common in the Kyongsang alteration area. In contrast to this, the lower temperature minerals such as kaolin and alunite are common in the Chonnam alteration area. The mineralogical difference of two alteration areas were depended on the difference of the formation temperature of clay deposits. The other important geochemical difference is the chemistry of hydrothermal solution such as pH. The alteration of "acid-sulfate type" with alteration mineral assemblage of alunite-kaolin-quartz is dominant in the Chonnam alteration area, which was caused by the attack of strong acid and acid solution. In contrast to this, the that of "quartz-sericite type" with the mineral assemblage of sericite-quartz is dominant in the Kyongsang alteration area, which was caused by the attack of neutral or weak acid solution. Also, the Kyongsang and Chonnam alteration areas show the difference in structural setting; the Chonnam alteration area is commonly associated with silicic domes and the Kyongsang alteration area is commonly associated with calderas.

INTRODUCTION

Hydrothermal alteration areas which consisted of many pyrophyllite-kaolin-sericite-alunite deposits are spatially divided into two alteration regions of the Kyongsang (Kyongju-Milyang-Yangsan) and Chonnam (Haenam-Jindo-Wando) areas (Fig. 1). They are all the volcanic-hosted clay deposits distributed in Cretaceous volcanic field of the Yuchon Group.

In regions of anomalously high heat flow, thermal convection dominates the behaviour of ground water in permeable crust and generates geothermal systems where hot upflow waters approach the surface. The region with high heat flow generating geothermal system in late Cretaceous period would perhaps be of the volcanic fields of the Yuchon Group characterized by the climactic volcanic activity of late Cretaceous period in Korea (Koh, 1996). The distribution of volcanic-hosted pyrophyllite-kaolin-sericite deposits and volcanic rocks of the Yuchon Group supports the above hypothesis.

The epithermal alteration of acid-sulfate and adularia-sericite (quartz-sericite) types occurs in similar tectonic setting on a continental scale with subduction zones at plate boundaries (Silbermann *et al.*, 1976; Sillitoe, 1977). The most common regional structural setting is the caldera (Heald *et al.*, 1987). Many epithermal deposits are spatially related to margins of a caldera. The other common regional structural setting is associated with silicic domes (Heald *et al.*, 1987). The association with silicic domes may be more significant. In general, hydrothermal wallrock alteration and ore deposition took place close to the end of volcanism (Heald *et al.*, 1987). Most of the epithermal deposits are dominant in the tectonic environment of island arc. This study attempts to compare two alteration areas on the basis of geological, mineralogical and geochemical characteristics of the hydrothermal clay deposits.

GEOLOGICAL ENVIRONMENT

The geological environment which formed the hydrothermal kaolin-alunite-pyrophyllite deposits such as Bukok(Seongsan), Okmae, Haenam, Gushi,

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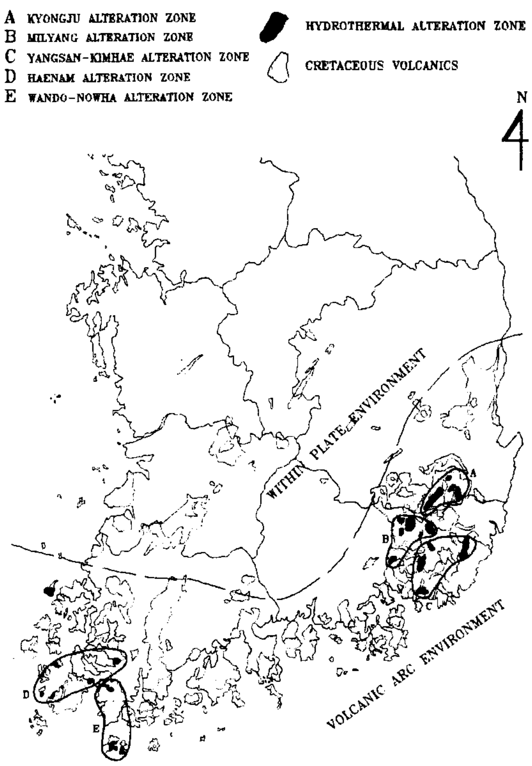

Fig. 1. Distribution map of the Cretaceous volcanic rocks of Yuchon Group and volcanic-hosted clay deposits in hydrothermal alteration zone (after Koh, 1996). A; Kyongju alteration zone, B; Milyang alteration zone, C; Yangsan-Kimhae alteration zone, D; Haenam alteration zone, E; Wando-Nowha alteration zone.

Dokchon, Nowha and Wando deposits in the Chonnam alteration area is characterized by the following explosive acidic volcanic activities in the region with the sequence of wet sediments (lacustrine sedimentary deposit: Uhangri Formation), intermediate volcanics (Hwawon Formation), and Precambrian metamorphic basement.

The volcanic host rock of the Chonnam alteration area is characterized by high-K calc-alkaline series, which occurs at the volcanic arc environment in continental margin (Koh, 1996). The host rock of the clay deposits is mostly acidic lava and pyroclastics of rhyodacite to rhyolite compositions, and related sediments (Koh, 1996). Most of the clay deposits in this alteration area show the close association with silicic domes.

Kyongsang alteration area which are distributed within the Kyongsang Basin contains many hydrothermal clay deposits such as Milyang, Bobae, Sangdong, Cheonbulsan, Yukwang, Bulkuksa, Kyongju and Bunam deposits (sericite-pyrophyllite and porcelain deposits). The host rock of the hydrothermal clay deposits is acidic (mostly rhyodacite) to intermediate lava (andesite) and pyroclastics. These volcanic rocks in the Yuchon Group are characterized by high-K calc-alkaline series, which occur at the volcanic arc environment in continental margin like those of Chonnam alteration area (Hwang, 1990; Hwang, Kim, 1994a, b). Some clay deposits are probably related to caldera. For example, Sangdong sericite deposits are distributed within the Wondong caldera named by Hwang (1990).

ALTERATION MINERALOGY

The alteration mineral constituent of clay deposits in the studied area is summarized in Table 1.

The most abundant alteration mineral assemblages of Chonnam alteration area are alunite-kaolin-quartz and pyrophyllite-illite. These alteration mineral assemblages were formed by advanced argillic and argillic alteration. Hydrothermal solution which formed these mineral assemblages would be characterized by acidic solution.

The characteristic mineral assemblages of Kyongsang alteration area are sericite-quartz and pyrophyllite-sericite. These mineral assemblages were formed by sericitic (phyllic) and argillic (advanced argillic) alteration. Particularly, high temperature alteration minerals such as andalusite and corundum, and boron bearing minerals such as dumortierite and tourmaline are also occasionally associated. These alteration minerals indicate that the hydrothermal solution which formed clay deposits was characterized by dominant magmatic fluid and weak acid (or neutral) solution.

ALTERATION AGE

K-Ar age of alteration minerals such as sericite and alunite occurring in the studied areas is listed in Table 2.

The age of alteration minerals in Chonnam and Kyongsang alteration areas ranges from 71.8 to 81.4 Ma and 65.9 to 79.4 Ma, respectively. This indicates that Cretaceous hydrothermal system of the Kyongsang alteration area was maintained for longer period than that of Chonnam alteration area.

FORMATION TEMPERATURE

Formation temperature measured by fluid inclusion study of the Bukok deposit in Chonnam alteration area ranged from 120 to 360°C with mean temperature of

Table 1. Alteration mineral constituents of clay deposits in the Haenam-Jindo-Wando and Kyongju-Milyang-Yangsan area.

Haenam-Jindo-Wando area				
*Location	Deposits	Major constituents	Minor constituents	References
D	Bukok	Alunite, Dickite, Quartz	Kaolinite, Illite, **I/S, Barite, Pyrite, Chlorite	Koh (1996)
D	Okmae	Alunite, kaolinite, Quartz	Dickite, Illite, Gibbsite, Chlorite	Kim (1990)
D	Haenam	Pyrophyllite, Illite	Kaolinite, Smectite, Chlorite, Corundum, Quartz, Andalusite, Diaspore, Pyrite	Jeong (1990)
D	Dokchon	Alunite, Kaolinite, Quartz	Illite, Pyrite	Kim (1991)
E	Gushi	Pyrophyllite, Dickite, I/S	Chlorite, ***C/S, Quartz, Pyrite, Epidote	Roh (1989)
E	Nowha	Pyrophyllite	Illite, Diaspore, Alunite, Quartz, Pyrite	Koh *et al.* (1994)
E	Wando	Pyrophyllite	Diaspore, Quartz, Pyrite	Koh *et al.* (1994)
Kyongju-Milyang-Yangsan area				
Location		Major constituents	Minor constituents	References
C	Bobae	Sericite, Quartz	Andalusite, Pyrophyllite, Rutile, Chlorite, Sphene, Pyrite	Moon (1994)
C	Sangdong	Sericite, Quartz	Pyrite	Moon (1990)
A	Taewoong	Sericite, Quartz	Chlorite, Pyrite	Kim *et al.* (1990)
B	Dongkok	Sericite, Quartz	Pyrite	Kim *et al.* (1990)
C	Yukwang	Sericite, Quartz	Pyrite	Kim *et al.* (1990)
B	Sungjin	Sericite, Quartz	Pyrite	Kim *et al.* (1990)
B	Milyang	Pyrophyllite	Quartz, Diaspore, Dumortierite, Pyrite	Moon (1994)
A	Kyongju	Pyrophyllite	Kaolin, Sericite, Pyrite, Diaspore, Corundum,	Kim *et al.* (1990)
C	Dongrae	Pyrophyllite Sericite	Andalusite, Kaolin, Dumortierite	Kim *et al.* (1990)
A	Sanne	Pyrophyllite Sericite	Dumortierite	Kim *et al.* (1990)
C	Cheonbul -san	Sericite Pyrophyllite	Tourmaline, Pyrite, Kaolin, Diaspore, Hematite	Kim *et al.* (1990)

* Location : A, B, C, D and E symbols are same as Fig. 1.
** I/S : Illite-smectite interstratified mineral
*** C/S : Chlorite-smectite interstratified mineral

210°C (Koh, 1996). Gushi, Okmae and Haenam deposits show the range of formation temperatures from 255 to 265°C (Roh, 1989), 250 to 300°C (Kim, 1990) and 240 to 290°C (Jeong, 1990), respectively. Kim (1990) predicted the temperature of the Okmae deposit by the alteration mineral assemblage on the assumption that the pressure is from 300 to 500 bars. Accordingly, the formation temperature of clay deposits in the Chonnam area shows the range from 120 to 360°C and the mean temperature of about 250°C.

Formation temperatures of sericite of Sangdong and Milyang deposits in Kyongsang alteration area are from 315 to 350°C (Moon, 1994) and about 290°C (Moon, 1994), respectively. Also, the temperature measured by fluid inclusion of quartz in the Bobae deposit ranged from 240 to 390°C (Moon, 1994). Accordingly, the formation temperature of the clay deposits in the Kyongsang area ranged

Table 2. K-Ar alteration ages of sericite and alunite occurring in Chonnam and Kyongsang alteration areas.

Locality and deposit name	Mineral	K-Ar age (Ma)	References	Locality and deposit name	Mineral	K-Ar age (Ma)	References
Chonnam area				Chonnam area			
Bukok deposit	Sericite	78.1±1.1	Kim (1991)	Haenam deposit	Sericite	79.6±1.1	Kim (1991)
	Sericite	79.7±1.0	Kim (1991)		Sericite	78.9±1.0	Kim (1991)
	Alunite	80.8±0.9	Kim (1991)		Sericite	74.5±2.8	Moon *et al.* (1990)
	Alunite	80.9±1.2	Kim (1991)	Dokchon deposit	Sericite	78.8±4.8	Kim (1991)
	Alunite	76.6±2.9	Moon *et al.* (1990)		Alunite	80.4±3.8	Kim (1991)
	Alunite	78.3±2.7	Kim *et al.* (1993)		Alunite	80.6±1.9	Kim (1991)
Okmae deposit	Sericite	79.0±1.1	Kim (1991)	Kyongsang area			
	Sericite	80.2±1.1	Kim (1991)	Bobae deposit	Sericite	79.4±2.1	Moon (1994)
	Alunite	80.8±1.0	Kim (1991)		Sericite	67.5±1.7	Moon (1994)
	Alunite	81.4±1.0	Kim (1991)		Sericite	65.9±1.7	Moon (1994)
	Alunite	71.8±2.8	Moon *et al.* (1990)		Sericite	67.5±1.3	Park (1994)
					Sericite	79.4±2.0	Park (1994)

Table 3. Sulfur isotopic compositions of pyrite in clay deposits of the Haenam-Jindo-Wando and the Kyongju-Milyang-Yangsan areas.

Deposit name	$\delta^{34}S$ (n=frequency)	References	Deposit name	$\delta^{34}S$ (n=frequency)	References
Bukok	-3.5~+3.6 (n=14)	Koh (1996)	Bobae	-3.7~+8.2 (n=7)	Moon (1994)
Bukok	-3.8~+3.7 (n=16)	Kim (1991)	Sangdong	+1.9~+4.5 (n=5)	Moon (1994)
Okmae	-4.3~+3.9 (n=8)	Kim (1991)	Milyang	-3.7~-0.2 (n=15)	Chon *et al.* (1991)
Okmae	-3.6~+2.9 (n=3)	Kim (1990)	Milyang	+1.7 (n=1)	Moon (1994)
Dokchon	-11.3~-5.2 (n=5)	Kim (1991)	Sungjin	-5.8~+3.3 (n=5)	Chon *et al.* (1991)
Haenam	-11.4~-6.0 (n=6)	Kim (1991)	Sungjin	-0.2 (n=1)	Moon (1994)

from 240 to 390°C with the mean temperature of about 300°C.

STABLE ISOTOPE

Sulfur isotope

The sulfur isotopic compositions ($\delta^{34}S$) of pyrite in the Bukok, Okmae, Dokchon, and Haenam deposits which distributed in Chonnam alteration area ranged from -3.8 to +3.7‰, -4.3 to +3.9‰, -11.3 to -5.2‰, and -11.4 to -6.0‰, respectively (Table 3). The isotopic ratios of the Bukok and Okmae deposits show the similar range with igneous sulfide (Fig. 2). However, the isotopic ratios of the Dokchon and Haenam deposits were lighter than the Bukok and Okmae deposits. They might show the negative value by the effect of contamination of sedimentary or biogenic sulfide (Fig. 2).

The sulfur isotopic compositions of pyrite in the Bobae, Sangdong, Milyang and Sungjin deposits which loated in the Kyongsang alteration area ranged from -3.7 to +8.2‰, +1.9 to +4.5‰, -3.7 to +1.7‰, and -5.8 to +3.3‰, respectively (Table 3). These isotopic compositions were almost near 0‰, which indicates magmatic sulfur (Fig. 2).

Oxygen and hydrogen isotopes

The oxygen and hydrogen isotopic compositions of kaolin and sericite (illite) of clay deposits in the Chonnam and Kyongsang alteration areas are summarized in Table 4.

The $\delta^{18}O$ and δD isotopic ratios of kaolin and illite in the Bukok and Okmae deposits of the Chonnam alteration area are similar. In the δD vs. $\delta^{18}O_{H_2O}$ diagram, they are almost plotted between magmatic water box of Taylor (1974) and meteoric water line (Fig. 3). This indicates that the hydrothermal fluids formed clay deposits were originated from the mixing of magmatic and meteoric waters, and dominantly meteoric water (Fig. 3).

The oxygen and hydrogen isotopic compositions of sericite in the Sangdong and Bobae deposits which located in the Kyongsang alteration area are summarized in Table 4. In the δD vs. $\delta^{18}O_{H_2O}$ diagram, the sericite of the Sangdong and Bobae deposits is plotted within magmatic water box and near the magmatic water box of Taylor (1974), respectively (Fig. 3). This indicates that the hy-

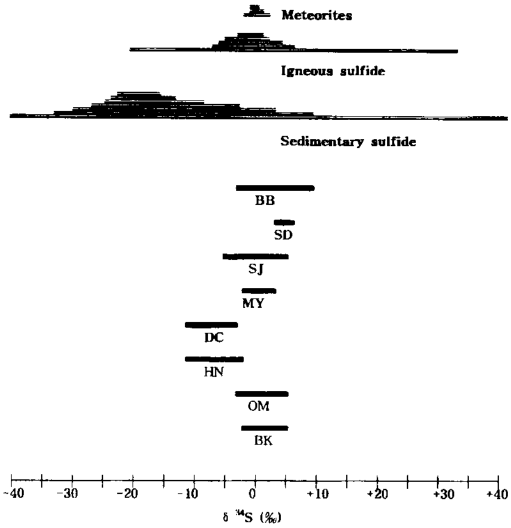

Fig. 2. $\delta^{34}S$ compositions of pyrite in the clay deposits of the Haenam-Jindo-Wando and Kyongju-Milyang-Yangsan areas.

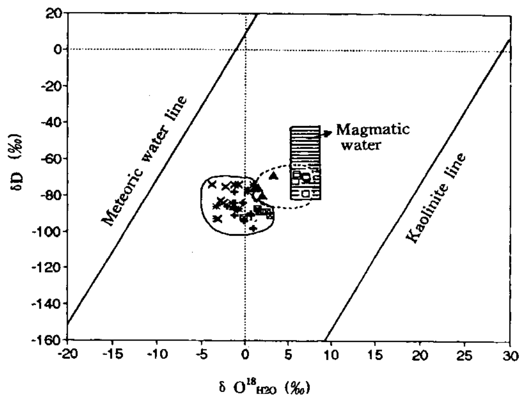

Fig. 3. δD-$\delta^{18}O_{H_2O}$ diagram of kaolin, illite, and sericite for the clay deposits of the Haenam-Jindo-Wando (solid line) and the Kyongju-Milyang -Yangsan areas (dashed line). +; Bukok-Kaolin, ×; Bukok-Illite, □; Sangdong-Sericite, ▲; Bobae-Sericite, ∗; Okmae-kaolin, ⊠; Okmae-Illite

Table 4. Oxygen and hydrogen isotopic compositions of dickite and illite in clay deposits of the Haenam-Jindo-Wando and the Kyongju-Milyang -Yangsan areas.

Haenam-Jindo-Wando area						
Deposit name	Mineral	$\delta^{18}O$	$*\delta^{18}O_{H_2O}$	δD	Data frequency	Reference
Bukok	Dickite	2.8~4.6	-0.3~-2.1	-91~-78	n=7	Koh (1996)
	Illite	1.8~4.1	-3.8~-2.2	-75~-74	n=2	Koh (1996)
Bukok	Kaolin	3.6~5.4	-0.1~1.0	-98~-90	n=4	Kim (1991)
	Illite	4.8~5.8	-3.1~-0.8	-93~-74	n=4	Kim (1991)
Okmae	Kaolin	2.8~6.7	-3.3~1.0	-87~-74	n=4	Kim (1991)
	Illite	4.8~8.4	-3.3~0.3	-91~-77	n=3	Kim (1991)
Kyongju-Milyang-Yangsan area						
Deposit name	Mineral	$\delta^{18}O$	$*\delta^{18}O_{H_2O}$	δD	Data frequency	References
Sangdong	Sericite	7.8~9.1	5.9~7.2	-79~-68	n=6	Moon (1994)
Bobae	Sericite	0.6~5.2	-1.3~3.3	-86~-76	n=5	Moon (1994)

* $\delta^{18}O_{H_2O}$ values of dickite, kaolin and sericite are calculated from fractionation facter (kaolinite-water and sericite-water) of Kulla and Anderson (1978), and Eslinger and Savin (1973).

Table 5. Summary of characteristics of hydrothermal alteration between the Haenam-Jindo-Wando and Kyongju-Milyang-Yangsan areas.

	Haenam-Jindo-Wando alteration area	Kyongju-Milyang-Yangsan alteration area
Tectonic setting	Volcanic arcs in continental margin	Volcanic arcs in continental margin
Structural setting	Silicic domes	Commonly in calderas
Host rock	Acidic volcanics (Yuchon Group)	Acidic to intermediate volcanics (Yuchon Group)
Alteration minerals	Kaolin, pyrophyllite and alunite abundant, diaspore common, andalusite poor, rarely toumaline and dumortierite	Pyrophyllite and sericite abundant, andalusite, tourmaline, and dumortierite common, rarely alunite
Alteration	Advanced argillic to argillic	Sericitic to argillic (advanced argillic)
Alteration age	72~81 Ma.	66~79 Ma
Formation temperature	130~360°C (mean 250°C)	240~390°C (mean 300°C)
Source of fluid (H_2O)	Dominantly meteoric	Dominantly magmatic
Source of sulfide sulfur	Probably magmatic (partly sedimentary or biogenic)	Dominantly magmatic
Alteration and deposit type	Dominantly acid-sulfate type	Dominantly adularia-sericite type (quartz-sericite)
Acidity of hydrothermal fluid	Strong acidic	Acidic to neutral

drothermal fluids were originated from dominantly magmatic and partly mixed with meteoric water.

CONCLUSION

Detailed comparison of the mineralogical, lithotectonic, and geochemical data from two alteration areas shows the difference of hydrothermal systems in two areas (Table 5).

The host rock of the Haenam alteration area is almost acidic volcanics of the Yuchon Group. And the host rock of the Kyongsang alteration area is from acidic to intermediate volcanics of the Yuchon Group. This feature indicates that the Cretaceous volcanic activity which formed the Yuchon Group was related to the formation of the Cretaceous hydrothermal systems in Korea. Also, the volcanic fields of the Yuchon Group contain the sedimentary deposits which the hydrothermal solution and ground water could be circulated easily.

The source of fluid is of important difference between the two areas; the Kyongsang area is characterized by dominantly magmatic water and the Chonnam area is characterized by dominantly meteoric water. Accordingly, the high temperature minerals such as pyrophyllite, andalusite and corundum, and boron bearing minerals such as dumortierite and tourmaline are common in the Kyongsang alteration area. In contrast to this, the lower temperature minerals such as kaolin and alunite are common in the Chonnam alteration area. This feature corresponds to the formation temperature of each alteration minerals (Table 5).

The geochemical environments which formed hydrothermal system would be depended on the differences of solution chemistry such as temperature, pH, oxygen activity, sulfur fugacity and sulfur concentration. The most important geochemical parameter is pH of the hydrothermal solution. The alteration of acid-sulfate type with the alteration mineral assemblage of alunite-kaolin-quartz and the acid leaching characterized by leached residual silica with vuggy appearance are dominant in the Haenam area, which was formed by the attack of strong acid and acid solution. In contrast to this, that of adularia-sericite (quartz-sericite) type with the mineral assemblage of sericite-quartz is dominant in the Kyongsang area, which was formed by the attack of neutral to weak acid solution.

Also, the clay deposits of the Kyongsang and Chonnam areas show the difference in structural setting; that of the Kyongsang area are commonly associated with calderas and that of the Haenam area with silicic domes.

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전남 및 경상 열수변질 점토광상의 생성환경 비교

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요　약: 전남 및 경상점토열수변질지역은 백악기 유천층군의 화산암지대내 분포한다. 전남 변질지역의 모암은 산성화산암류이며 경상 변질지역의 모암은 산성 및 중성화산암류이나 중성화산암류가 우세하다. 두 변질지역의 열수변질작용을 비교 하였을 때 중요한 차이는 열수용액의 기원으로 생각된다. 경상 열수변질지대는 마그마수가 열수의 주 기원으로서 고온성 변질광물인 엽납석이나 홍주석이 우세하게 산출되며 마그마수에서 특징적인 붕소 함유 광물인 듀모티어라이트와 전기석의 산출이 특징적이다. 이에 반해서 전남 열수변질지역은 천수와 열수의 혼합용액이 열수의 주 기원으로 천수가 중요한 역할을 하였으며, 저온성 광물인 카오린, 명반석 등이 우세하게 산출된다. 또 다른 중요한 차이는 pH 와 같은 열수용액의 화학성 차이이다. 전남 열수변질지역의 명반석-카오린-석영 변질광물군은 저온의 강산성 열수용액으로서 "산-황산염형" 으로 특징되며 이에 반해 경상 열수변질지역의 견운모-석영 변질광물군은 "석영-견운모형" 에 해당되며 고온의 중성 내지 약산성 열수용액에 의한 변질특성을 나타낸다. 또한 두 지역은 열수변질대 모암인 화산암류의 지질구조 환경에서 차이를 찾아 볼 수 있다. 전남 열수변질지역은 산성암질 돔과 성인적으로 관련되나 경상 열수 변질지역은 칼데라와 관련된 특성을 보인다.