Study of Hydrothermal Alteration Based on Analysis of X-Ray Diffraction at Cisolok Geothermal Area, Sukabumi District, West Java

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ABSTRACT

Cisolok geothermal area, Sukabumi District, West Java, Indonesia is an area having substantial potential geothermal reserves. Several studies have been carried out in the area, from geology, geochemistry as well as geophysical study and analysis. A geochemical study has been performed by conducting hydrothermal alteration studies that have been carried out using X-Ray Diffraction and petrographic analysis. The study was performed by field mapping and rocks as well as fluids sampling. Further, the lab analysis was performed on 16 rock samples from 77 observation locations. The analysis results show there are two alteration hidrotermal zones in this research area: epidot-chlorite-illite-smectite-quartz-calcite zone and smectite-illite-kaolinite-calcite zone.

1. INTRODUCTION

Indonesia is a collision area of three earth crust plates namely the Eurasian plate, the Indo-Australian plate and the Pacific plate. In this area, Java Island is above a subduction zone of the Eurasian plate and Pacific plate located in the south and stretches from west to east. Subduction zones in the south of Java trigger the development of volcanic activity and also the formation of geological structures of folds, faults, and burrows. These geological structures become the hydrothermal fluid paths appearing on the surface and producing hydrothermal alterations.

Geothermal research has been conducted in the Cisolok area, Sukabumi district, West Java. Administratively it is located in Cisolok Village and its surroundings, Cisolok District, Sukabumi Regency, West Java Province. Geographically the research location is located at 106 ° 26 '9.60 "E - 106 ° 27' 48.60" E and 6 ° 55 '1.20 "S - 6 ° 56' 40.20" S, in an area of 9 km^2.There is geothermal activity forming surface manifestations of hot springs, geysers, traventines, and quartz veins (Figure1). Those geothermal activities could cause hydrothermal alteration.

Figure 1: Surface manifestation at Cisolok geothermal area, A. Geyser and surrounding altered minerals, B. Hot water spring (T~100 degr C), C. Surface outcroped quartz vein, D. Natural bathpool using hot water spring

Hydrothermal alteration is a change in the mineralogical composition of a rock due to the interaction between the hydrothermal solution and the surrounding rock. It is a complex process because of changes in mineralogy, chemistry and texture that occur in certain physical and chemical conditions (Pirajno, 1992). The replacement process occurs at a high temperature of 250 ° -400 ° C, this replacement process records the interaction between host rock and hydrothermal fluid (Browne, 1995 in Utami, 2011).

The purpose of this study is to find out the types of alteration minerals found in the study area through petrographic analysis and X-Ray Diffraction (XRD Analysis), and the objective was to determine the zone of distribution of alteration minerals.

2. REGIONAL GEOLOGY

2.1 Regional Physiography

Van Bemmelen (1949) divided West Java into four physiographic zones which traversed east-west, namely the Plain of Jakarta Beach zone, Bogor zone, Bandung zone and the southern mountains of West Java. The research area is in the Central Depression Zone of West Java (See Figure 2). This zone is located between the Dome and Mountains in the zone of the Central Depression and the Southern Mountain Zone of West Java.

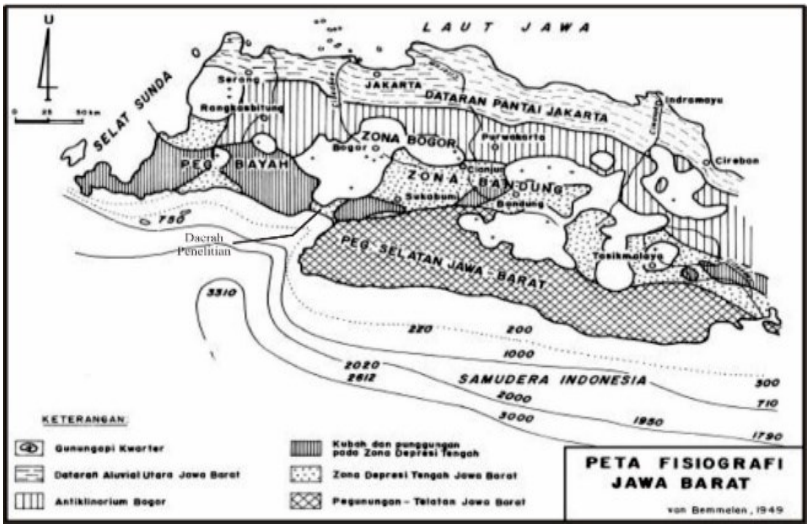


Figure 2: Physiography of West Java (Van Bemmelen, 1949)

2.2 Regional Geology

Geologically, Cisolok area is a part of the Bayah Dome (Bemmelen, 1949). Figure 3 shows the geology map of Cisolok area. The Bayah Dome is constructed by Cikotok Formation as the oldest formation having Oligocene age with rock units comprised of volcanic breccias, tuff and lava deposits. These units are exposed in the west of Cisolok (Sujatmiko and Santosa, 1992). By Early Miocene, rock units consist of Citarete and Cimapag Formation. The Andesite and Dacite intrusion of Late Miocene was exposed at the south of this area (Sujatmiko and Santosa, 1992). Finally, the area is covered by Citorek Tuff, breccias of Tapos Formation and basaltic lava of Quaternary age (Figure 3).

The basic rocks in Cisolok area which are dominantly occupied by lava andesite, volcanic breccia, and volcanic alluvial may have a strong influence to form geothermal resource due to volcanic and magma activity in the regional area of Cisolok. With the existence of caldera and fluid flow in the lake investigation of geology found volcanic rocks that experienced alteration. Mielke et al (2015) performed research in the Tauhara geothermal area, Iceland. Lithologically the rocks in the area are andesite lava and breccia, rhyolite lava breccia, sandstone, siltstone, mudstone, breccia and tuff. They found that with hydrothermal alteration intensity that has been investigated, variations in permeability, porosity, thermal conductivity and specific heat capacity are related to lithology and intensity and nature of the hydrothermal alteration.

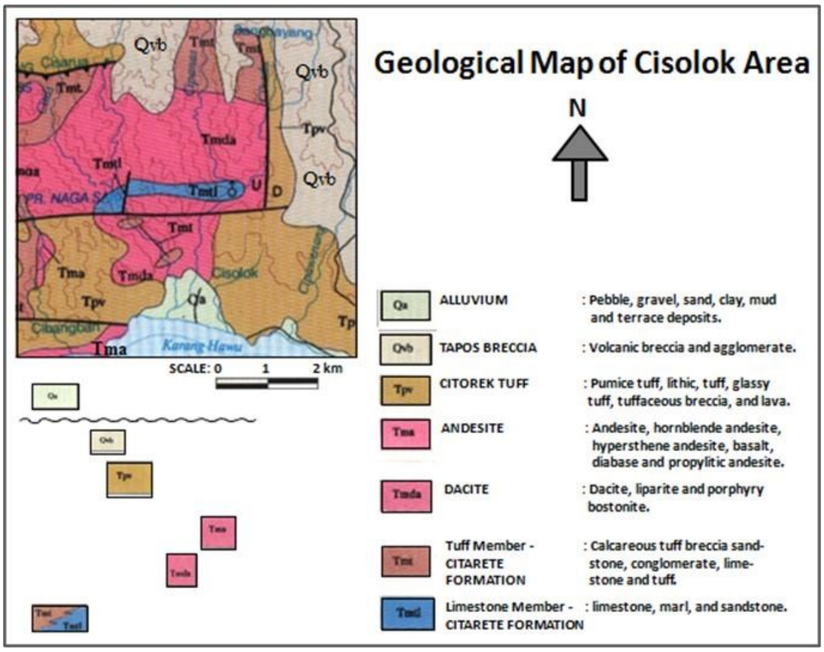


Figure 3: Geology Map of Cisolok area (modified from Sujatmiko and Santosa, 1992)

2.3 Regional Geological Structures

The structural pattern that developed in the western part of Java Island is the Meratus pattern, Javanese pattern and Sundanese pattern (see Figure 4). The geological map of southern Leuwidamar has a complex geological structure, caused by the presence of a tectonic disturbance (Van Bemmelen, 1949). Especially the Bayah mountain complex is a meeting area between the Java geanticline and the Bukit Barisan geanticline in Sumatra. This area has a fault pattern with the general direction of north-south and some have northeast-southwest direction. There is a folding axis with a direction of west-east to northwest-southeast.

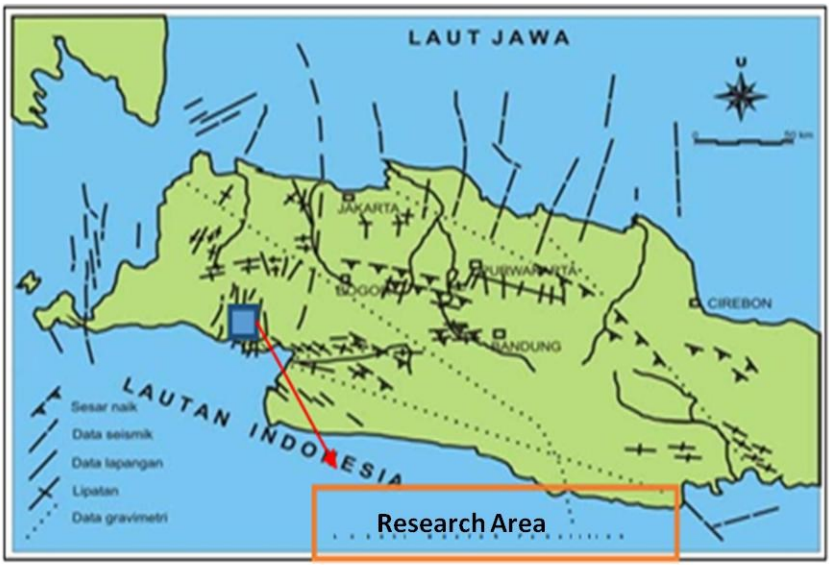


Figure 4: West Java Regional Structure Pattern (Pulunggono and Martodjojo, 1984)

In the Early Tertiary, the Indian Plate movement has a direction of N10°-30°E and has a rate of 18cm/year which is compressive. Towards the Oligocene era, the speed of movement of the plates decreases to 3-4 cm/year. However, ahead of the Late Miocene, there was an acceleration of plate motion so that tectonic compression resumed intensely. At the time of the Oligocene to the Miocene, there was a morphology formation in the Bayah area known as the Bayah Dome, which was formed due to the intrusion of the Granodiorite Cihara rocks into the Cikotok Formation. This Granodiorite Cihara tunneling takes place in the south.

During the Middle Miocene, there was a lifting process that caused folding with the east - west direction towards the formation of old age and normal fault and the horizontal fault with the northeast - southwest direction. Especially in the Cikotok Formation several quartz veins occurred. Mainly in the Late Miocene, there was a movement of plates so that compression tectonics continued intensely. During the Late Miocene arcs folding occurred in the Citarate Formation and the Cimapag Formation and were followed by normal faults and horizontal faults with east - west or northeast – southwest directions.

During the Middle Pliocene to the Late Pliocene, there was a lift which caused the formation of folding with east - west and northeast - southwest directions of normal faults and north - south and southwest – northeast directions of horizontal faults. Then in the south, there was a further change in the Bayah Dome. (Sujatmiko et al, 1992). In Plio-plistosen which is the peak of the compression period of all sedimentary rocks which are increasingly folded, raised and raised to form thrust fold belt through a horizontal and upward fault mechanism represented by Cimandiri Fault, Pelabuhan Ratu Fault, Baribis Fault, and Ciletuh Fault (Hilmi et al, 2008).

2.4 Regional Stratigraphy

The sequence of stratigraphy of the study area is based on the geological map of Leuwidamar (Sujatmiko et al, 1992) (see Figure 5) sorted from old to young, namely:

- Member of Limestone Citarate Formation (Tmtl)
  Consisting of limestone, marl and sandstone. Located at the bottom of the Citerate formation, Early Miocene. Owns reef limestones, containing fragments of quartz and feldspar deposited in the marine environment.
- Members of Tuffaceous Formation Citarate (Tmt)
  Consisting of tuff brackets, sandstones, conglomerates, limestones and tuffs. This unit is located at the top of the Citerate formation. Deposited in the litoral-land environment, characterized by epiclastic tuff rock.
- Dasite (Tmda)
  Late Miocene age, with dacite or liparite in the form of cracks or small breakthroughs such as stock.
- Citorek Tuff (Tpv)
  Consisting of pumice tuffs, intermittent tuffs, glass tuffs, breccia tuff and lava.

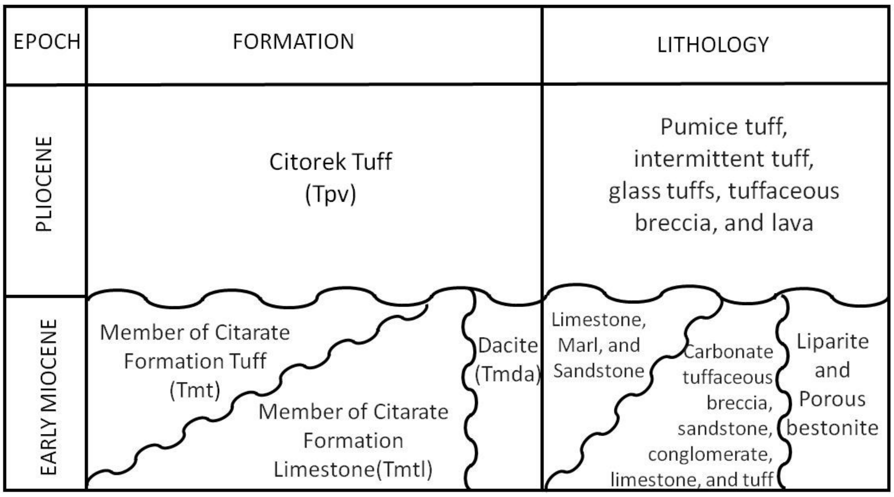


Figure 5: Stratigraphy of Research Areas Based on Geological Maps of Leuwidamar (Sujatmiko et al, 1992)

3. RESEARCH METHOD

The method used in this study begins with a literature study from previous researchers. The primary data collection stage in the study area was used to identify rocks and alteration minerals according to megascopic geology, the position of rock stratigraphy and the geological structure found in the study area. The next stage is the selection of rock samples that will be used for petrographic analysis to determine the type of lithology and primary and secondary mineral content in rocks. After describing the thin incision, to obtain more accurate identification of clay minerals, further analysis was carried out by X-Ray Diffraction analysis. The results of the petrographic analysis and X-Ray Diffraction can determine the alteration zones found in the study area.

4. BASIC THEORY

Hydrothermal alteration is a change in the mineralogical composition of a rock due to the interaction between hydrothermal solution and the rock. The alteration process will cause the transformation of primary minerals into secondary minerals, which are then referred to as altered minerals. Hydrothermal alteration is a complex process because of changes in mineralogy, chemistry and texture that occur in certain physical and chemical conditions (Pirajno, 1992).

Lagat (2009) describes that rock alteration simply means changing the mineralogy of the rock. The primary minerals are replaced by the secondary minerals because there has been a change in the prevailing conditions subjected to the rock. These changes could be caused by changes in temperature, pressure, or chemical conditions or any combination of these. Hydrothermal alteration is a change in the mineralogy as a result of the interaction of the rock with hot water fluids, called "hydrothermal fluids". The fluids carry metals in solution, either from a nearby igneous source or from leaching out of some nearby rocks.

There are 7 factors that influence the formation of alterations in the hydrothermal system (Browne, 1978 in Corbett and Leach, 1997), namely:

- Temperature
- Chemical fluid composition
- Concentration
- Composition of Host Rock
- Kinetics of change
- Duration
- Permeability

Although the above factors influence hydrothermal alteration processes, the temperature factor and chemical composition of the fluid are the most influential factors (Corbett and Leach, 1997). Mayer and Hemley, 1967 (in Corbett and Leach, 1997) classify alteration zones into 5 types, namely the propylitic zone, the intermediate intermediate, the advanced argrilik, the sericite, and the potasic zone. Then the sericite zone can be identified as a phyllic alteration zone.

- Advanced argrillic
  Alteration zone consisting of mineral phases formed under low pH conditions <4 such as silica and alunite mineral groups. In addition, high temperature kaoline groups such as dickite and pyrophyllite without the alunite mineral group can be included in this zone.
- Argrillic (intermediate argrillic)
  Alteration zone consisting of minerals that form at relatively low temperatures of 200-250°C and moderate pH 4-5. This alteration zone is dominated by kaolinite and smectite minerals. Although groups of low temperature minerals such as kaoline (halloysite) and illite (interlayered illite-smektite, illite) which cannot be included in the phyllic zone, are grouped into the argrillic zone.
- Phyllic
  The zone formed at pH of almost the same as the Argrillic zone, but has a higher temperature> 200-250°C, characterized by the presence of sericite or muscovite. This zone can also consist of members of the high temperature kaoline group (pyrophyllite-andalusite) and chlorite group minerals where they are adjacent to sericite or muscovite.
- Propylitic
  Zones formed in conditions close to neutral to alkaline are characterized by the presence of epidote and/or chlorite. Formed at relatively low temperatures, <200-250°C. these alteration assemblages are dominated by zeolite minerals instead of the epidote,

sub-propylitic terms in this condition can be used. The presence of secondary amphibol minerals (generally actinolites) at temperatures> 280-300°C, can be used to indicate the inner propylitic zone. Secondary and/or K-Felspar minerals are generally found in the propylitic alteration zone.

- Potassic
  The alteration zone is formed at high temperatures> 300°C and when pH conditions are neutral to alkali and characterized by the presence of biotite and/or K-Feldspar ± magnetite ± actinolite ± clinopyroxene.

5. DISCUSSION

As already mentioned that in Cisolok geothermal area there is geothermal activity forming surface manifestations of hot springs, geysers, and traventines. Those geothermal activities could cause hydrothermal alteration. Herdianita et al (2010) found that the Cisolok geothermal system is considered as a geothermal prospect area. The result of geothermal activities is its intense geothermal surface manifestations including hot spring and surface alteration. Thermal water discharging in the Cisolok River has a very high temperature reaching the boiling point. The thermal water also has a neutral pH and a very high discharge rate. Hydrothermal alteration occurs at the surface and the bank of the Cisolok River showing very high alteration intensity that is dominated by the occurrence of thick silica sinter and travertine. The type and characteristic of this surface manifestation indicate that the geothermal system of Cisolok and Cisukarame has a shallow, high temperature reservoir.

As described shortly above, in Cisolok geothermal area, in general, could be found quartz veins with heavy metals/minerals. In the Middle Miocene, there was an earth crust lifting process where several quartz veins occurred especially in the Cikotok Formation. Similar quartz veins also found in north Pacitan geothermal area. Sudarsono et al (2012) performed a study about mineral petrogenesis as a result of hydrothermal alteration in Kluwih, Pacitan. Altered zones are characterized by the presence of secondary minerals like silica, chlorite, sericite, epidote, calcite and argilit. Based on differences in character and mineral associations alteration, it can be distinguished several types of alteration, namely argillic type (argilite + microquartz), propylitic type (chlorite) + epidote + calcite + quartz), and type of silicification (dominant quartz ± calcite ± adularia ± ore).

From Cisolok geothermal area, the petrographic analysis was carried out on 16 rock samples and X-Ray Diffraction analyzes on 6 rock samples from 77 observation locations. In the rock samples of the study area are found alteration minerals of smectite, illite, kaolinite, calcite, quartz, chlorite, and epidote. According to the presence of alteration minerals, the study area can be grouped into 2 alteration zones based on mineral alteration zones (referring to Corbett and Leach classification, 1992), namely (1) Epidote-Chlorite-Illite-Smectite-Quartz-Calcite Alteration Zone, (2) Smectite-Illite-Kaolinite-Quartz-Calcite Alteration Zone (Figure 6).

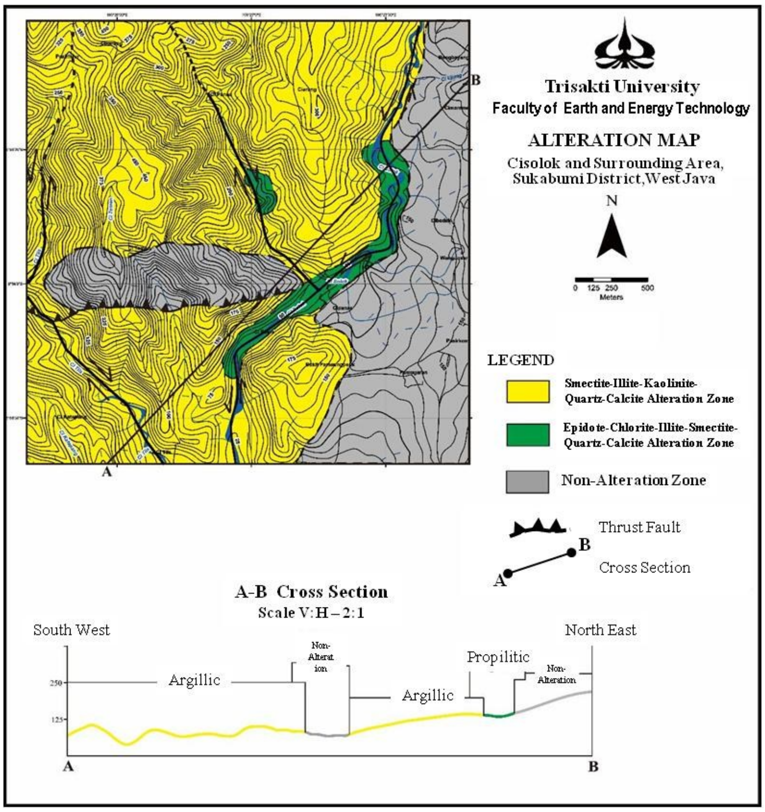


Figure 6: Map of alteration zones in Cisolok and surrounding geohermal area (Irawan, 2018)

5.1 Epidote-Chlorite-Illite-Smectite-Quartz-Calcite Alteration Zone

In XRD analysis of rock sample from a location (for example LP 64), this shows the mineral set of Epidote-Chlorite-Illite-Smectite-Quartz-Calcite. Propylitic alteration types occupy 20% of the total area of the study area, found in the middle part of the study area. Epidote-Chlorite-Illite-Smectite-Quartz-Calcite Alteration Zone is withdrawn based on the interpretation of the similarity of rock characteristics found in outcrops, alteration mineral sets seen in petrographic incisions (Figure 7) and X-Ray Diffraction results (Figure 8). Based on the characteristics of the field, petrographic analysis and X-Ray Diffraction analysis, this alteration zone is comparable to the Propylitic type alteration zone with pH close to neutral (Corbet and Leach, 1997), having temperature proportions ranging from 190°C - 250°C (Table 1). With the existence of epidote mineral, it could have a higher temperature in rocks at the deeper subsurface location.

According to several geothermal experts, it is known that epidote is an indicator of mineral formed by high temperature hydrothermal alteration. Nyandigisi et al (2016) performed the study in high temperature of the active geothermal field who classify altered mineral as High Temperature Hydrothermal Alteration Minerals (HTAMs). HTAMs are known to occur at stable pressure and temperature regimes for example epidote occur at a temperature of over 250°C.

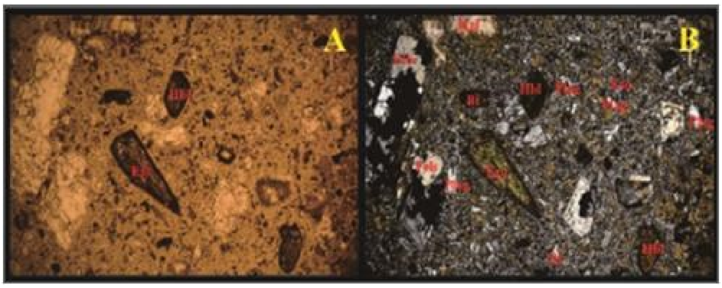
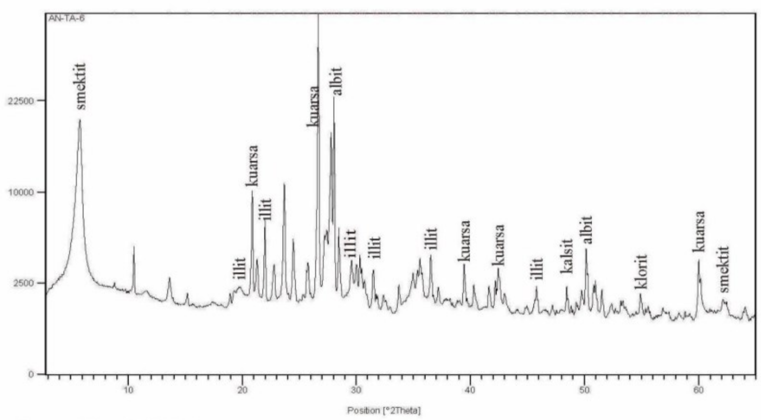


Figure 7: Photomicrograph of Epidote-Chlorite-Illite-Smectite-Quartz-Calcite Alteration Zone

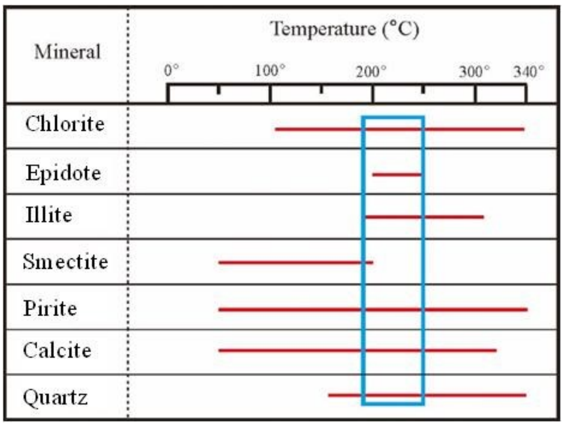


Pattern List: AN-TA-6

Visible	Ref. Code	Compound Name	Chemical Formula
*	00-013-0135	Montmorillonite-15A	Ca0.2 (Al , Mg)2 Si4 O10 (O H)2 !4 H2 O
*	00-026-0911	Illite-2\ITM\RG#1 [NR]	(K , H3 O) Al2 Si3 Al O10 (O H)2
	00-046-1323	Clinochlore-1\ITM\RG#I#I\IT#b\RG	(Mg , Al , Fe)6 (Si , Al)4 O10 (O H)8
*	01-085-0796	Quartz	Si O2
*	00-019-1227	Sanidine	(K , Na) (Si3 Al) O8
*	00-020-0572	Albite, disordered	Na Al Si3 O8
*	01-089-7282	Magnesiohornblende	Ca2 Mg4 (Al , Fe +3) Si2 Al O22 (O H)2
*	01-073-2147	Epidote	Ca2 Fe Al2 Si3 O12 O H

Figure 8: Results of X-Ray Diffraction at LP 64 Analysis

Table 1. Comparative Range of Propylitic-type Mineral Alteration temperatures (Irawan, 2018)



5.2 Smectite-Illite-Kaolinite-Quartz-Calcite Alteration Zone

Argrillic alteration types occupy 50% of the total study area, found in the north, south and west. Smectite-Illite-Kaolinite-Quartz-Calcite Alteration Zone boundary is drawn based on the interpretation of the similarity of rock characteristics found in outcrops, alteration mineral sets seen in petrographic incisions (Figure 9), and X-Ray Diffraction results (Figure 10). Based on the characteristics in the field, petrographic analysis, and X-Ray Diffraction results, this alteration zone can be compared to the Argrillic type alteration zone with a pH of 4-5 (Corbet and Leach, 1997), having comparable temperatures ranging from 160°C - 200°C (Table 2). Supriadi et al (2018) who performs petrology and petrography analysis found alteration of subsurface rock to form smectite-chlorite and illite-smectite-chlorite and sericite zone predicting 140°C - 220°C.

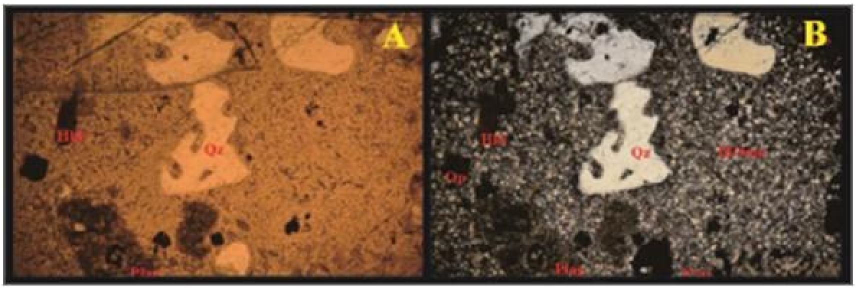
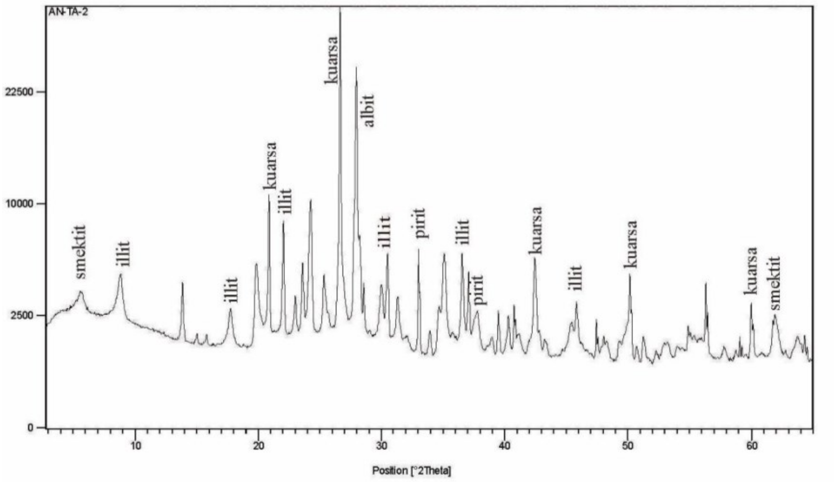


Figure 9: Photomicrograph of Smectite-Illite-Kaolinite-Quartz-Calcite Alteration Zone

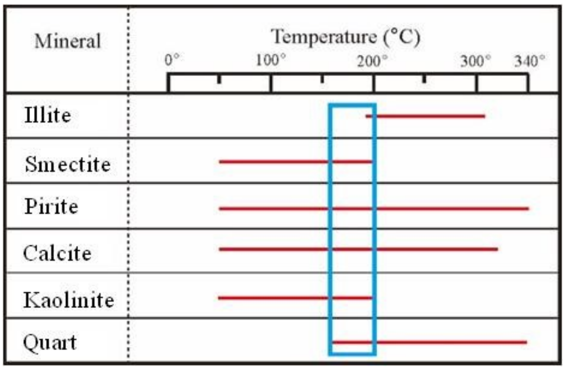


Pattern List: AN.TA-2

Visible	Ref. Code	Compound Name	Chemical Formula
	00-003-0015	Montmorillonite (bentonite)	(Na , Ca)0.3 (Al , Mg)2 Si4 O10 (O H)2 !x H2 O
	00-026-0911	Illite-2\ITM\RG#1 [NR]	(K , H3 O) Al2 Si3 Al O10 (O H)2
	01-085-0796	Quartz	Si O2
	00-020-0554	Albite, ordered	Na Al Si3 O8
	01-071-1680	Pyrite	Fe S2

Figure 10: Results of X-Ray Diffraction of Smectite-Illite-Kaolinite-Calcite Alteration Zone

Table 2. Comparative Range of Argrilik Type Alterated Mineral Temperatures (Irawan, 2018)



6. CONCLUSION

Based on the discussion on the results of the study, it can be concluded as follows:

(1) In the Cisolok research area, there are two alteration zones, namely Epidote-Chlorite-Illite-Smectite-Quartz-Calcite Zone alteration with a temperature range of 190°C-250°C and Smectite-Illite-Kaolinite-Quartz-Calcite alteration zones with a temperature range of 160°C-200°C.
(2) More detailed and accurate analysis and evaluation of identification of alteration minerals have been performed using the X-Ray Diffraction method to find two alterations zone i.e. Propylitic alteration type Zone and Argrillic alteration type Zone.
(3) From this geologial and geochemical research in Cisolok gethermal area, it is predicted that Cisolok geothermal area has the subsurface high temperature to be followed by further the such as geophysical and geothermal exploration deep well surveys.

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