CHARACTERIZATION OF HYDROTHERMAL ALTERATION ZONES IN PANTI GEOTHERMAL FIELD, PASAMAN DISTRICT, WEST SUMATERA PROVINCE

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ABSTRACT

Panti geothermal area is located in Pasaman Regency, West Sumatra Province. The survey area is about 200 km away from the city of Padang and about 30 km away from the capital city of Pasaman Regency, Lubuk Sikaping. The purpose of this research activity was to determine the characteristics of hydrothermal alteration in an observed well. The method used was petrological analysis on PNT-1 well core data from the depth of 41.5 m until 533.5 m, petrography analysis of 17 rock samples, and Specterra analysis based on secondary data. The alteration minerals that appeared in the observed well were calcite, sericite, chlorite, secondary quartz, anhydrite, opaque minerals, iron oxide, clay, and epidote minerals; with alteration types in the form of replacement and direct depositional. Two zones were sorted based on the presence of minerals and determination of alteration zones, namely the Smectite-Chlorite zone, and the illit-smectite-chlorite and sericite zone. The smectite-chlorite zone was located at the depth of ± 41- ± 454 m and was characterized by the presence of smectite, ilite-smectite, calcite, and chlorite alteration minerals; which were more dominant than other alteration minerals. This zone according to the alteration zone division comprised of argillic zone with a temperature of 140° C - 220° C. The ilite-smectite-chlorite and sericite zone was located at the depth of ± 454- ± 533 m characterized by the presence of illit-smectite, chlorite, sericite, calcite and quartz minerals. This zone, according to the alteration zone division, was comprised of argillic zone with a temperature of 200° C - 250° C. It was concluded that the alteration rocks in PNT-1 well were estimated to serve as caprock zone of the Geothermal Panti system which formed due to the interaction between rocks and acidic to neutral fluid in temperatures between 140° C - 250° C.

Keywords: *Alteration, Argillic, Caprock, Geothermal.*

INTRODUCTION

Hydrothermal alteration is one of the features that can characterize the prospect of geothermal energy. Hydrothermal alteration is a process of mineralogical changes in rocks caused by interactions between geothermal fluids and rocks. This alteration generally occurs around geothermal manifestations. Alteration understanding is critical in order to learn how the fluid behaves during contact with its surrounding rocks. It is one of the way to analyze sub-surface features. The characteristics of alteration is responsible in the evaluation of both positive and negative potential of a geothermal field. Identifying the presence of alteration minerals can determine the approximate location of prospect zones. Other than locating the zones, the presence of alteration minerals also reflects subsurface temperatures.

Panti geothermal field, East Pasaman District, West Sumatra Province, was chosen as the location of the investigation because, based on the results of previous

investigations, it was known to have a wide area of prospects of 9 km^2, with an estimated reservoir temperature of 180°, and a potential reserves of 30 Mwe (PSDMBP, 2016).

This research was conducted for Geothermal Studies in the research area in order to find out how the geothermal system in Rimbo Panti formed, more specifically in the caprock which serves as the cap in the geothermal system.

LITERATURE REVIEW

The Panti Geothermal area is located in the North of Lubuksikaping. Geologically, Panti is located in the transition area between the magmatic arc and back arc, precisely located in the southern part of the Graben Rao system and is set in the large Sumatran

E-ISSN : 2579 – 3136

fault. The geothermal system in the Sumatra fault is a compelling one to be studied.

The observed area is set within the Lubuksikaping Regional Geology Map (Rock dkk, 1982 dalam Hidayat dkk, 2008) :

a. Kuantan (Puku) Formation consists of metasediment and slate spread over the southwest of the drilling point, this formation was formed in the Paleozoic Perm-Carbon age. It is the oldest rock that is exposed around the drilling area.
b. Dioritic intrusion (Tmid) is an intrusive tertiary rock exposed at the southern of the drilling point
c. Panti Formation, there is only a limited information about this formation, but based on PT. Nusa Palapa Mineral report, this formation consists of Meta-Volcanic rocks, green schists, and Meta-Volkaniklastik. (Hidayat et al., 2008).
d. Indistinguishable volcanic (Tmv) is composed of volcanic rock layers and does not indicate the source of volcanic eruptions, Miocene age, consisting of andesitic lava, basalt and breccia affected by Sumatran tectonic.

The movement of regional geological structures in the study area was affected by three main faults which were part of the Sumatran faults series, namely Lubuksikaping Fault, Gadis Fault, and Pungkut-Barilas Fault. The Lubuksikaping fault has an indication of dextral movement about 40 km. According to Sieh & Natawijaya (2000), this fault is estimated to be no longer active. While the Pungkut-Barilas Fault is characterized by a 20-meter-wide fault zone consisting of a clay zone: sulfide-rich clays and silicated breccias were present with gypsum (Rock dkk., 1983 in Barber et. al, 2015).

The area around drilling is interpreted as a graben, which is an extension due to the dextral movement of the Sumatran Fault called Graben Rao. It formed because of the transitional shifting caused by Lubuksikaping Fault and Pungkut-Barilas Fault.

The Sumatran Fault is characterized by volcanism and high rate of hydrothermal solutions which is associated with extension and compressional regimes. This fault system is interpreted as the magmatic pathway of the Sumatran tectonics. This gave rise to geothermal manifestations along the Sumatran fault on Graben Rao.

The Rimbo Panti area is set within the Panti formation. Characteristically the Panti Formation is set within the Lubuksikaping Regional Geology Map (Rock et al., 1982 in Hidayat et al., 2008). Generally this formation consists of meta volcanic, green schist, and metavolcaniclastic. The distribution of this formation is very small, which is spread across the northwestern of the Sikaping or the southwest of the observed area.

The stratigraphy unit of rocks in Panti geothermal areas inlcudes several rock units, sorted from the oldest to the youngest, as follows:

1. Metasediment rock (slate-quartzite).
2. Metalimestone.
3. Metavolcanic.
4. Metagranite.
5. Diorite.
6. Dacite.
7. Dacite-silicification.
8. Basalt.
9. Polimix breccia (ignimbrite).
10. Conglomerate
11. Aluvium

METHODS

The objects observed in this study were rock core samples (core) and Specterra Mineral Analyzer analysis data. The research was focused to the analysis of rock core data (core) using petrological analysis methods (megascopic observation) from the depth of 41.5 m until 533.5 m, and petrography analysis of 17 rocks and minerals samples from underneath the surface of the observed well.

In addition, secondary data from the Specterra Mineral Analyzer was compiled to understand the characteristics of alteration mineral in the observed well, namely in PNT-01 well.

The research was divided into three stages: the petrological analysis which is done using megascopic observation, petrography analysis, and clay mineral analysis based on secondary data from the Specterra Mineral Analyzer.

Petrology analysis is an analysis done by megascopic description on rock core from drilling well of PNT-01 with loupe, carried out to identify the lithology of each rock. These cores were observed to find out the differences in lithological variations as per each of its depth.

E-ISSN : 2579 – 3136

Petrography analysis was done out of thin sections of each rock. By petrography analysis, rock types was identified microscopically. There, the minerals composing the rock were observed microscopically with polarizing microscope (Olympus CX31). However, with petrography analysis, it was not possible to find out the composition of clay minerals composing of rocks.

The identification of clay minerals was done by using Specterra Mineral Analyzer. This analysis was done out of secondary data obtained from Center for Mineral, Coal and Geothermal Resources (PSDMBP).

RESULTS AND DISCUSSION

Well Lithology

Based on petrology and petrography analysis of the observed area in PNT-1 well, as displayed in Figure 4.2, PNT-1 well was composed of several lithologies:

1. Altered Tuff Breccia

Altered tuff breccia was found at a depths of 8 - 226 m, 278-328 m, and 360-398 m. Based on megascopic analysis, the fresh color of this altered tuff breccia was light grey whereas the weathered color was brownish, grain size of granules to pebble, angular component, matrix supported, medium sorted, the component consisted of andesitic and basaltic igneous rocks whereas the matrix was composed of tuff.

This rock had been slightly altered. The fresh color of this component was blackish grey, hypocrystalline texture, afanitic granularity with identified mineral composition was plagioclase. Matrix was composed of light grey tuff with, grain size of fine ash, grain shape of sub rounded – sub angular, matrix supported, well supported, mineral composition consisted of plagioclase, pyroxene, quartz, biotite, the presence of mineral calcite and clay minerals.

Based on microscopic analysis, the thin section had already been altered with poorly sorted, grain shape sub angular – sub rounded. Composed of primary minerals (plagioclase, k-feldspar, biotite and quartz) and secondary minerals (calcite, sericite, clay minerals and opaque minerals) by 50%. Rock fragments by 15% and ground mass was composed of volcanic glass and clay minerals by 35%. In general, this rock had been slightly altered, i.e. by 22-25% percent. Based on the Schmid classification (1981) the matrix of this rocks was identified as Crystal tuff.

2. Altered Basalt.

Altered basalt was found at a depths of 226-251 m, 278-298 m, 328-360 m and 398-451 m. Based on megascopic analysis, the fresh color of this altered basalt was blackish grey whereas weathered color was brownish grey, afanitic granularity, hypocrystalline texture. The mineral composition consisted of biotite, olivine, pyroxene, plagioclase, pyrite, veins filled with secondary minerals i.e. calcite and quartz.

Based on microscopic analysis, the thin section had grain size of well–medium, altered, inequigranular, porphyritic, hypidiomorph, hypocystalline. It consisted of phenocrises of primary minerals (plagioclase, k-feldspar, biotite and quartz) and secondary minerals (calcite, sericite, clay minerals and opaque minerals) by 40%. Ground mass was composed of volcanic glass and clay minerals by 60%. In general, this rock had been slightly altered by 25%. Based on the Travis classification (1955) this rocks was identified as *Basalt*.

3. Altered Andesite

Altered andesite was found at depths of 251 – 278 m. Based on megascopic analysis, the fresh color of this altered andesite was light grey with with weathered color was brownish, afanitic -porphyritic granularity, hypocystalline. Mineral composition consisted of quartz, plagioclase, clay minerals, and calcite minerals. The calcite and quartz minerals were present, filling the veins.

Microscopically, had grain size well–medium, altered, inequigranular, porphyritic, hypidiomorph, hypocystalline. It consisted of phenocrises of primary minerals (plagioclase, k-feldspar, olivine and quartz) and secondary minerals (calcite, sericite, chlorite, iron oxide, clay minerals and opaque minerals) by 40%. Ground mass was composed of volcanic glass and clay minerals by 60%. In general, this rock had been slightly altered by 22%. Based on the Travis classification (1955) this rocks was identified as Andesite.

4. Altered Granite

Altered granite was found at depths of 451-533 m. Based on megascopic analysis, the fresh color of this altered granite was light grey whereas the weathered color was brownish, afanitic-porphyritic granularity, hypocystalline, this rock had been slightly altered, mineral composition consisted of quartz, plagioclase, clay minerals, and calcite minerals. The quartz minerals were present, filling the veins.

E-ISSN : 2579 – 3136

Based on microscopic analysis, had grain size of medium-coarse, altered, faneritic porphyritic granularity, hypidiomorph, hypocystalline. It consisted of phenocrises of primary minerals (plagioclase, k-feldspar, biotite and quartz.) And secondary minerals (calcite, sericite, chlorite, clay minerals and opaque minerals) by 50%. Ground mass was composed of volcanic glass and clay minerals by 50%. In general, this rock had been slightly altered by 23%. Based on the Travis classification (1955) this rocks was identified as *Granite*.

Alteration Minerals of Research Area

Analysis of alteration minerals in the research area was divided into two methods, namely the method of petrography analysis and secondary data analysis using Specterra Mineral Analyzer.

Identified minerals based on petrography analysis, namely :

1. Calcite

Calcite was present in almost throughout of the PNT 01 well, replacing some of the plagioclase, K-feldspar, sericite, and secondary quartz was also present to fill the veins. Calcite was colorless (PPL), low relief, no pleocroism, refractive index $n_{min} > n_{med}$, interference color was pale yellow orde 1. Calcite was taking some of the plagioclase and K-feldspar (Figure 1) while some were also filling the veins of plagioclase.

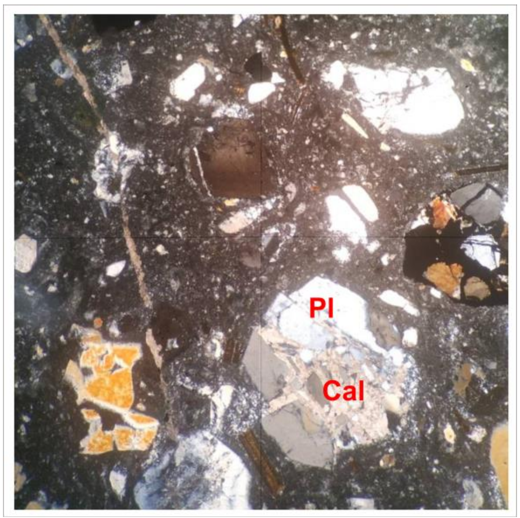


Figure 1. Microscopic photo (magnification 40) at a depth 171 m, the calcite (cal) replaced some of plagioclase.

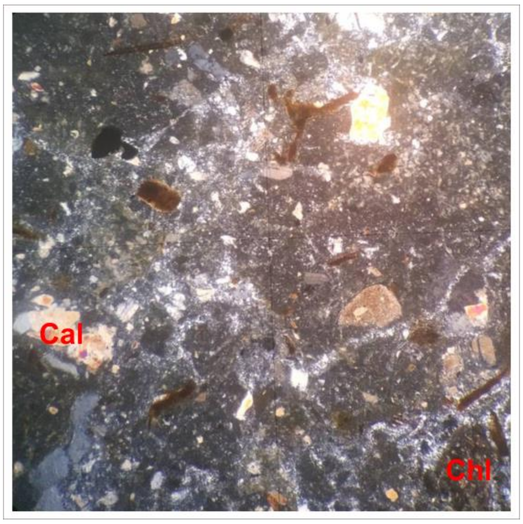
2. Sericite

Sericite was present in almost throughout of the well. Had characteristic of brownish color, low relief, no pleocroism, refractive index $n_{min} < n_{med}$, one direction cleavage, interference color was greenish grey orde 2, sericite replaced some to completely of plagioclase and K-feldspar (Figure 2).

Figure 2. Microscopic photo (magnification 40) at a depth 41.5 m, the sericite (Ser) replaced plagioclase almost entirely.

3. Chlorite

Chlorite was present at the depths of 51,0 m, 249,5 m, 271,6 m, 285,0 m, 298,0 m, 328,0 m, 330,0 m, 341,0 m, 424,4 m, 449,0 m, 491,2 m dan 498,7 m. Chlorite has green color, moderate relief, no pleocroism, refractive index $n_{min} < n_{med}$, interference color was reddish yellow orde 1, replacing some of the plagioclase and the olivine, also replacing biotite and olivine completely (Figure 3). Chlorite was formed at a neutral pH over a wide temperature range, >120ºC (Reyes,1990).



E-ISSN : 2579 – 3136

Figure 3. Microscopic photo (magnification 40) at a depth 341 m, chlorite (Chl) replaced some of plagioclase.

4. Secondary Quartz

Secondary quartz was present at a depths of 51 m, 171 m, 330 m, 341 m, 424.4 m, 449 m dan 498,7 m. Secondary quartz was colorless, low relief, no pleocroism, *mozaic texture*. Secondary quartz was present to fill in the vein (Figure 4.4). Secondary quartz was present at temperature >100°C with neutral pH (Reyes, 1992).

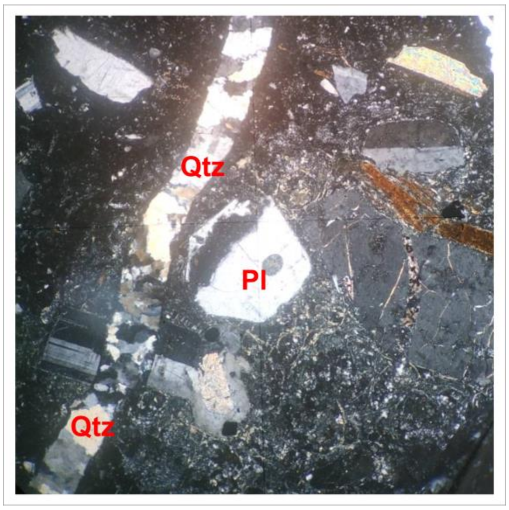


Figure 4. Microscopic photo (magnification 40) at a depth 449 m, quartz vein was present (Qtz) filling the fracture in plagioclase and ground mass.

5. Anhydrite

Anhydrite was present at the depths of 328 m. Anhydrite was colorless, moderate relief, no pleocroism, refractive index $n_{min} < n_{med}$, interference color was bluish-purple orde 2, Anhydrite replaced some of plagioclase (Figure 5).

Figure 5. Microscopic photo (magnification 40) at a depth 328 m, anhydrite (An) and sericite (Ser) were present.

6. Opaque Mineral

Opaque mineral was almost present in all depths of the well. Microscopically (Figure 6) opaque mineral has isotropic characteristics, some were symmetrical like cubic which was estimated to be pyrite, as inclusion minerals in calcite minerals, plagioclase, k-feldspar and ground mass.

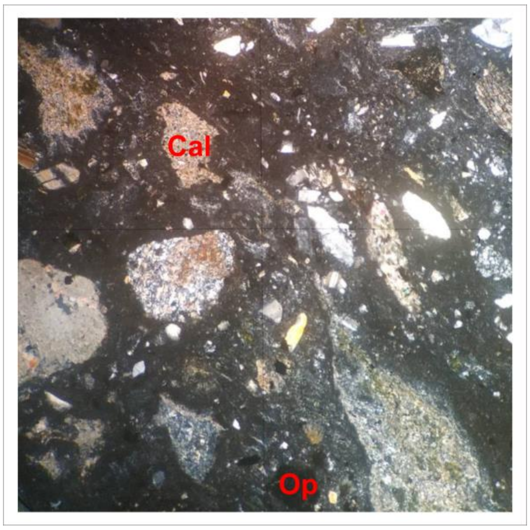


Figure 6. Microscopic photo (magnification 40) at a depth of 328 m, opaque mineral (Op) was present.

7. Iron oxide

Iron oxide was present in depths of 160 m, 171 m, 271.6 m, 285 m dan 341 m. Microscopically (Figure 7) iron oxide had characteristic reddish dark brown color, low relief, fine texture, iron oxide replaced volcanic glass ground mass.

E-ISSN : 2579 – 3136

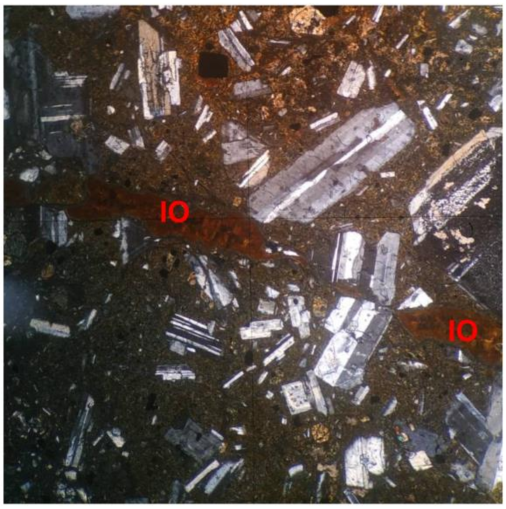


Figure 7. Microscopic photo (magnification 40) at a depth of 160 m, the iron oxide (IO) replaced ground mass and plagioclase (Pl).

8. Epidote

Based on petrography analysis, the epidote had brown color, high relief, anhedral, low pleocroism, interference color was red-green orde 2, sericite replaced some to completely plagioclase (Figure 8).

The epidot there was not dominant at the depth, the presence of the epidote was infered to be originated from fossils as it was only present only at a certain depth.

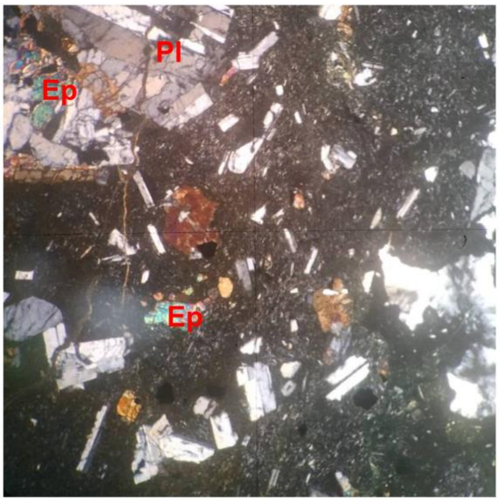


Figure 8. Microscopic photo (magnification 40) at a depth of 330 m, The epidote (Ep) replaced some of plagioclase (Pl).

9. Clay Mineral

Based on petrography analysis, clay minerals couldn't be identified accurately without the support of XRD data. Brown, low relief, replaced some of plagioclase and volcanic glass ground mass (Figure 9). Clay minerals form where air and water interact with silicate minerals, breaking them into clays and other products (Sapiie, 2006).

Clay mineral was present almost throughout the well, starting from a depth of 41.5 m to 533.3 m.

Alteration Mineral of Research Well Based on Specterra Mieral Analyzer Analysis

The alteration minerals were analyzed through Specterra Mineral Analyzer. The analysis were to identify and observe alteration minerals and clay minerals in the observed area.

This analysis showed which mineral was the most dominant and the mineral groups within the depth of 41.5 m to 534 m (Appendix I).

Alteration Zone of Research Well

Based on the abundance of its alteration mineral associations, the observed well was divided into two alteration zones: smectite-chlorite zone and illite-smectite-chlorite-sericite.

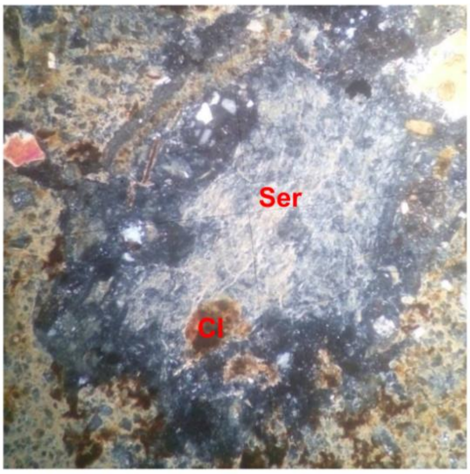


Figure 9 Microscopic photo (magnification 40) at a depth of 41.5 m, The clay mineral (Cl) replaced some of sericite (Ser).

1. Smectite – Chlorite Zone

This zone was characterized by the presence of smectite, illite-smectite, calcite and chlorite alteration minerals which were more dominant than other alteration minerals. In addition, it was also found that the presence of iron oxide and opaque minerals was rare in this zone. This zone had a higher clay mineral intensity than other zones and was estimated as a caprock zone in the geothermal system with a depth of ± 41 ±

E-ISSN : 2579 – 3136

454 m. This zone was included into argilic zone (Corbett and Leach, 1997) with temperatures of 140˚C - 220˚C.

2. Illite-Smectite–Chlorite–Sericite Zone

This zone was characterized by the presence of illite-smectite, chlorite, sericite, calcite and quartz minerals. In addition, it was also found anhydrite, illite and epidote with rare intensity in this zone.

This zone was set at a depth of ± 454- ± 533 m. This zone was included into argilic zone with possible temperature of 200˚C - 250˚C

CONCLUSIONS

Based on petrology and petrography analyzes of the observed area in PNT-1 wells. PNT-1 well was composed of several lithologies, i.e.:

1. Altered Tuff Breccia
2. Altered Basalt.
3. Altered Andesite.
4. Altered Granite.

Two zones were sorted based on the presence of minerals and determination of alteration zones, namely the Smectite-Chlorite zone, and the illit-smectite-chlorite and sericite zone. The smectite-chlorite zone was located at the depth of ± 41- ± 454 m depth and was characterized by the presence of smectite, ilite-smectite, calcite, and chlorite alteration minerals; which were more dominant than other alteration minerals. In addition, it is also found that the presence of iron oxide and opaque minerals wais rare in this zone. This zone was set within the argillic zone with a temperature of 140˚C - 220˚C. The ilite-smectite-chlorite and sericite zone was located at the depth of ± 454- ± 533 m characterized by the presence of illit-smectite, chlorite, sericite, calcite and quartz minerals. Moreover, anhydrite, illite, and epidote were found with rare intensity in this zone. This zone was set within to the argillic zone with a temperature of 200˚C - 250˚C. It could be concluded that alteration rocks in PNT-1 wells were estimated to serve as caprock zones of the Geothermal Panti system which formed due to the interaction between rocks and acidic fluid to weak acids at temperatures between 140˚C to 250˚C.

ACKNOWLEDGMENTS

Thanks Center for Mineral, Coal and Geothermal Resources who have allowed and guided researchers to join the Panti drilling team and obtain this data as an analysis of geothermal studies. Thank you to the lecturer at the Faculty of Geology, Padjadjaran University who has guided the author in completing this research.

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Appendix I. List of alteration minerals by *Specterra Mineral Analyzer* in well PNT-1 (PSDMBP, 2017)

No	Depth (m)	Group of minerals
1.	41,50	Smectite
2.	48,35	Smectite
3.	146,90	Chlorite
4.	150,00	Chlorite
5.	156,00	Smectite
6.	157, 25	Smectite, Chlorite, Silica
7.	151,30-151,50	Chlorite
8.	159,00	Chlorite
9.	161,40	Smectite
10.	164,75	Smectite
11.	171,00	Smectite
12.	173,55	Smectite
13.	178,20	Smectite, Chlorite, Silicat
14.	185,45-186,00	Smectite, Chlorite, Silicat
15.	216,00	Silicat, Smectite
16.	227,00	Smectite
17.	230,00	Silica
18.	235,50	Silica
19.	245,65	Smectite
20.	247,00	Silica
21.	252,00	Chlorite, Silicat, Carbonate
22.	272,00	Carbonate
23.	274,00	Chlorite
24.	276,00	Chlorite
25.	279,50	Chlorite, Smectite, Carbonate
26.	283,00	Oxide
27.	285,00	Oxide
28.	291,00	Oxide
29.	298,00	Carbonate, Kaolinite, Oxide
30.	302,15-303,15	Illite, Smectite
31.	305-305,15	Smectite
32.	307,00	Smectite, Chlorite
33.	313-314,05	Silica, Smectite
34.	318,00	Silica, Chlorite
35.	325,05	Silicat
36.	328,00	Smectite
37.	330,00	Sulphate
38.	338,00	Smectite
39.	348.20	Zeolite
40.	359.50-359.60	Silicat
41.	370.35	Phosphate
42.	380,00	Pyroxene
43.	424.10	Smectite
44.	427.20	Calcite
45.	432,00	Calcite, Smectite
46.	445,00	Dioptase
47.	454.70	Kurnakovite - Solongoite
48.	476.30	Chlorite, Illite, Smectite
49.	491,00	Andalusite
50.	497.90	Chlorite, Illite, Smectite
51.	506,69	Smectite
52.	515,00	Chlorite
53.	522,25	Chlorite, Illite, Smectite
54.	534,00	Chlorite, Illite, Smectite

E-ISSN : 2579 – 3136