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THE FILLING MINERALS IN HYDROTHERMAL SYSTEM OF LAHENDONG, NORTH SULAWESI, INDONESIA

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ABSTRACT

The occurrences of each may be controlled by lithology, temperature, pressure, fluid composition or any combination of these. Minerals may reflect current conditions (mineral at equilibrium), or previous condition (metastable minerals), or they may reflect transition or interm-ediate phases as the mineralogy adjusts to a new temperature, pressure, compositional environment (unstable, transient mineral-s).The mineral assemblages in Lahendong drillholes can be divided into 3 groups : kaolinite-anhydrite, epidote-chlorite and sericite-actinolite group. Each mineral group was formed under somewhat varying physical chemical conditions, the implication from these upon the mineral filling in this geothermal history .

1. INTRODUCTION

The Lahendong hydrothermal field is one of three apparently separate thermal systems in Minahasa at about 32 kilometers to the south of the capital city of North Sulawesi province, Manado, Indonesia (Figure 1). The others are the Tempang hydrothermal system to the south and the Batukolok hydrothermal system to the southwest (Ganda et al, 1982). Presently the seventh exploratory well is being drilled at the same prospect area which is in the Quaternary Lahendong caldera within followed by other two separated basaltic andesite and andesitic volcanic activities which are attributed on the caldera rim. Some shallow microdiorite dykes and sheets related to those volcanic activities were encountered by drilling (Ganda et al, 1986). The Lahendong caldera itself lies on the Tondano rhyolitic formation which overlies on the Pre-Tondano andesitic formation. The Tondano rhyolitic formation seems to be a bigger system which control the three thermal systems above. The Lahendong high tempe-rature field has been conducted by PERTAMINA since 1981 and will be utilized for generating a 30 megawatt electric power plant in the near future,

Most of all exploratory wells are located in the Lahendong caldera and lies on the Kasuratan volcanic formation which is the second youngest volcanic in the area (Figure1). Formation porosity was mostly occurred relating to the caldera activity and also accelerated by later microdiorite intrusions. Fractures and grain porosity are frequently found

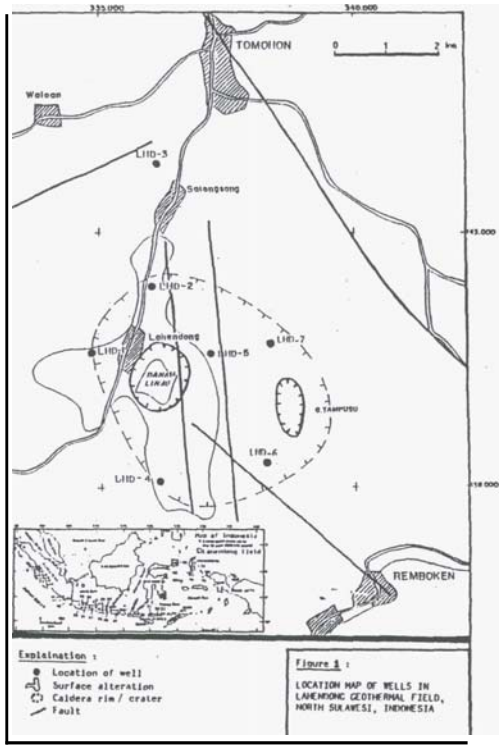


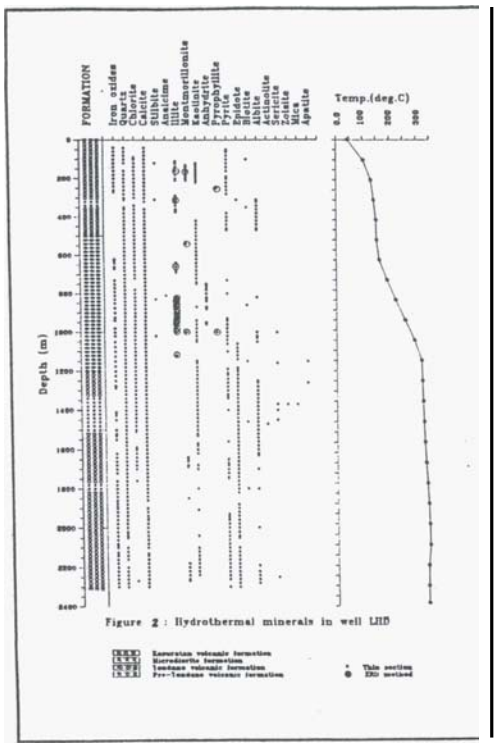
Figure 1 : LOCATION MAP OF WELLS IN LAHENDONG GEOTHERMAL FIELD, NORTH SULAWESI, INDONESIA

rather than primary porosity. All volcanoes in the area are regularly controlled by the subduction activity at the eastern part of North Sulawesi arm and shifted by geological time from east to the west while the recent active volcanoes : Soputan and Lokon are located.

2. FILLING MINERALS ZONATION

In Lahendong drillholes the zoning boundary is not clearly distinctive, although the minerals occurrence implying the physical chemical condition, but perform a superi-mposed zoning through the whole drillholes. Three active hydrothermal zone can be explained furthermore as following (Figure 2) :

Kaolinite-anhydrite zone (100-1060 m) This zone represents the acid alteration effect into the rock formation through argilitization which mostly affects much to a fine grained rock e.g tuff and breccia. As seen at Figure 2, a group of low temperature minerals e.g iron oxides, amorphous quartz, pyrophyllite, montmori-llonite, anhydrite, illite and kaolinite is occurred within this zone. The present measured temperature indicates that the zone appears at a temperature ranging



from 100°-250°C. The lower boundary can only be assumed at the depth of the first appearance of epidote, but kaolinite is found continuously down to the bottom superimposing with the two other zones. Although those reality characterized the effect of two phase fluid with various flashing point depth, but encouraging to be said that the well is supplied by more than one feeding zone. According to the temperature gradient and boiling curve depth, the present fluid is flashed at 250°C, the fluid will favorably precipitate a acid hydrothermal mineral e.g kaolinite, anhydrite are mostly at the upper part of the well. From 310-350 m the relict sericite-actinolite zone appears within this zone which relates to microdiorite intrusion.

Epidote-chlorite zone (1060-2307 m) This zone is indicated by the first appearance of epidote as the upper boundary and the bottom of the well is assumed to be the lower boundary. The sercite-actinolite zone intersects this zone at depth of 1340-1500 m and 1775-1800 m, but the silisification areas have not broadly developed, because it might be as a oldest system encountered within this well. The epidote-chlorite zone has a association of medium temperature minerals such as epidote, crystalline quartz, chlorite, calcite, albite, illite and kaolinite (exceptional). The group of those minerals above represent the temperature of 250°-300°C and perform as the outer influenced ring of contact metamorphism zone. The present water at 300°C is equilibrium with K.mica-illite which indicated that the altering fluid at 300°C is favor in water phase prior to reservoir static pressure (Figure 4).

Sericite-actinolite zone (310-330 m; 1340-1500 r; 1775-1800 m) This zone is indicated by a series of high temperature influencing contact metamorphism minerals e.g actinolite, sericite, mica, biotite, zoisite and apatite. This zone is much influenced by the intrusion of microdiorite which associates with a silisification zone. The occurrence temperature of those minerals are ranging from 300°-350°C which is partly supplied by the microdiorite intrusions which seem to be a partly heat source of the present active hydrothermal system. The surrounding rocks are completely altered, sometimes a relict of primary mineral might be recognized. By comparing with the same appearance in Dieng geothermal field that those minerals were successively applied to a temperature of 350°C in andesitic volcanic environment (Suroto et al, 1981). In Iceland's extinct thermal area (Geitafell) the actinolite zone was also interpreted that was occurred at temperature of 350°C (Fridleifsson, 1983a). Browne 1984, by using the series of biotite-amphiboles indicated as a high permeability rank in New Zealand geothermal field, seems to be applied in Lahendong drillholes somewhere as the main reservoir located at 1775-1800 m and the highest temperature of 350°C.

3. FLUID COMPOSITION

Based on the water chemistry analysis data taken from Lahendong drillholes have been calculated and shows that the altering fluid, there were sufficient $SO4^{=}$ for sulphate minerals depositing in this well, because the well is supplied by two feed zones where the upper feed zone is dominated by steam. Anhydrite, kaolinite and montmorillonite have evidence for the presence of a vapour or a condensate zone. However boiling and twophase condition probably occur where calcite is most abundant. By considering the system $CaO - Al_2O_3 - K_2O - H_2O$ at 250°C, it is possible to estimate the activities of the Ca^{++} and K^{+} ions which respect to pH, presents in the altering fluid; thus the logarithmic of aCa^{++}/aH^{+} is about 5.8 - 6.0 and the logarithmic of aK^{+}/aH^{+} is about 1.9 - 2.1. In similar way, the logarithmic of aNa^{+}/aH^{+} of the fluid is 3.0 - 3.3 approximate calculations based upon reported chemical analysis for Na, K, and Ca in Lahendong water (Suwana, 1987) and using measured discharge enthalpies show that the deep water has a pH of 5.6 slightly acid at 250°C when boiling takes places at about 1000 m depth and become more alkaline due to loss of carbon dioxide. In the phase diagram at 250°C (Figure5) the present fluid is performed within the kaolinite field.

At 300°C the system $CaO - Al_2O_3 - K_2O - H_2O$ represents that the present fluid shifted out from kaolinite field into K.mica-Illite field shows that the deep water ha8 a pH of 6.8; very close to neutral. The fluid seems to be a water dominated which is fed from the lower feeding zone at 1800-2300 m depth.

The concentration of carbon dioxide dissolved in the deep Lahendong fluid is slightly high, about 1430 ppm. This is indicated by the presence of Ca-silicate minerals (Browne, 1984) such as epidote, actinolite and apatite, calcite also present in cuttings recovered from below a depth of about 1300 meter. However, calcite occurs in many shallower samples, mostly in one or two distinct zones across the periphery of the field (about 310-350 m). Calcite may precipitate either where thermal fluids are heated or else lose CO_2, since both non corroded primary and hydrothermal quartz also

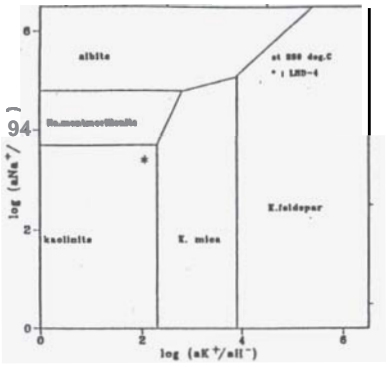


Figure 3 : Ionic activity diagram for the phase In system Na_2O-K_2O-Al_2O_3-H_2O and system CaO-K_2O-Al_2O_3-H_2O at 250°C, in LHD deep water.

occur in the calcite zones, it is likely that fluids here are cooling rather than heating, so it is CO_2 oversaturated with causes calcite to precipitate. Therefore the calcite horizons are interpreted as a zones where water dominated phase prevail, especially it is confirmed at the lower part of the well which relates to the sericite-actinolite hydrothermal zone. The measured pressure gradient also shown that in the static condition the well is filled by a zone of water which at least up to depth of 1000 meter.

4. ALTBRATIOIO HISTORY

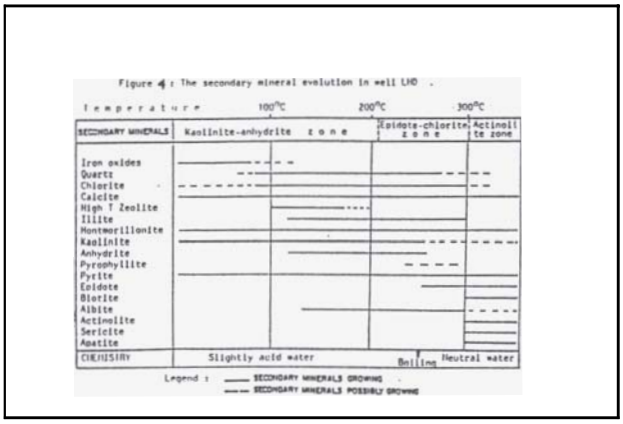
Several of active hydrothermal metamorphism have affected the rock sequence in Lahendong and large displacements have complicated the stratigraphy as well as the secondary mineralogy. Alteration minerals from previous hydrothermal events are juxtaposed over the assemblages due to the present hydrothermal regime. Comparison of data with the Dieng geothermal field and information from Iceland, and other geothermal areas show that some of the assemblages are in disequilibrium with present conditions; such as the relict sericite-actinolite at the upper part of the drillholes.

Hydrothermal activity is often thought of as a process in which geothermal parameters such as temperature, pressure and permeability are diffused away from the source and the reservoir. Mineral assemblages are formed accordingly and exhibit a sequence with respect to temperature and pressure for a given rock type and fluid chemistry.

With increasing temperature, a sequence of montmorillonite to illite to predominantly chlorite had been established in the Dieng geothermal field (Suroto et al, 1981). Similar geological conditions prevail in Lahendong as in Dieng. Furthermore, similar hydrothermal minerals occur in Lahendong drillholes as in the other wells in the Dieng; the same sequence is observed in the drillholes but the first occurrences are at shallower depths and lower temperatures. The boundaries between the various temperature-dependent mineral assemblages are more diffuse (Figure 4). At deeper levels and temperature more than 300°C, however, some of the assemblages in Lahendong grade into "equilibrium" conditions.

Localized zone of pyrophyllite, kaolinite, and/or anhydrite at maximum temperature of 250°C appearing down to a depth of 1340 meter are comparable to the present chemistry water and the occurrences in the geothermal field of Matsukawa and Otake. Studies by Hayashi (1974) and Sumi (1969) show that these preferably form in acidic conditions.

Hydrothermal assemblages show a general trend of increasing grade with depth and temperature. The mineralogy consist of calcite, anhydrite, epidote, actinolite, quartz, chlorite, clays of the illite-montmorillonite group. Sporadic and localized appearances of pyrophyllite, and kaolinite were observed.



5. DISCUSSIONS

Various silica minerals (amorphous and crystalline quartz) are much independently to a temperature changing, and/or environmental changing perform as metastable minerals. Using these minerals as indicator for investigating a hydrothermal history may give a useful interpretation. In low-temperature of less than 150°C, amorphous quartz is favor precipitated, on contrary, crystalline quartz at high-temperature seem to be implied in Lahendong.

6. CONCLUSION

The alteration in Lahendong is not a continuous of increasing intensity with depth. Instead, patches of high alteration may alternate with zones of weakly altered rocks. The intensity of alteration depends on the primary and secondary porosity and permeability of the formations.

The type of secondary mineral assemblages encountered at given depths in Lahendong are governed by the original rock type, permeability, temperature and possibly, by differences in chemical conditions. The temperature and permeability dependence of the hydrothermal minerals is often masked by the complex history of faulting and hydrothermal surges that affected the area. Where temperatures in the hole are high, epidote, illite, and actionolite are found: and where permeability is good, secondary albite occur. Relict mineral assemblages implying high temperatures and permeable zones are found at shallower levels in the hole (depth of 310-350 m). Lithology of the rock seems to play an important role when alteration is low grade. But when alteration grades to high silisification, the lithology of the rock show8 little influence on alteration.

The minerals association of actinolite, apatite, mica, sericite, biotite are observed in contact metamorphism zone, far down the hole, and in the permeable zone implying that : 1) either the hole was drilled through a intrusion(dyke) which seems unlikely or several dykes cut the rock sequence, though less in magnitude than the aforementioned dyke, 2) one of the factors for for the fracturing in the permeable zone is due to dykes.

Chlorite spans the whole length of the hole in sporadic appearances, from near surface to depths of 1800 meter where temperatures of 350°C are found. The anonalous extension of this mixed layer clay to such depths may be resolved by elevating the sequence by across the dyke towards lower temperatures and shallower depths.

Apparently, pyrophyllite + kaolinite + anhydrite + quartz appear at two depth intervals 250 - 300 m and below this 900 - 1000 m. Matching up the formations across the fault shows that the anhydrite and pyrophyllite with associated kaolinite seems to be confined to a narrow zone in the Tondano volcanic sequence. Kaolinite is a supergenetic mineral near and at the surface but maybe hydrothermal at depths where it is associated with pyrophyllite and anhydrite. The assemblage pyrophyllite + anhydrite + kaolinite + quartz was possibly formed before the faulting.

Quartz and anhydrite are the most abundant vein materials, and together with secondary albite and some calcite probably sealed off former aquifers found in the upper regions of the well. The same group of minerals are also found at depth interval of 1000 m to 1340 m indicates that the two phase fluid was occupied the area at 250°C in a nearly acid condition.

Epidote and biotite at shallow levels where temperatures are lower than 250°C are considered relict but at depth, relict of those minerals could not be distinguished from the biotite epidotes presently being formed. Actinolite, sericite, zoisite, mica, and apatite may also being formed at temperature of 300° - 350°C in a neutral water condition.

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