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PETROGRAPHY AND MINERAL ALTERATION IN BERLIN GEOTHERMAL FIELD

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ABSTRACT

A total of eighty-five thin sections of cores in 15 wells of Berlin geothermal field was re-analyzed using the petrographic microscope. Most of the cores were taken at different depths from 519 m to 2347.4 m in andesitic and lithic tuff formations. However, recent drilling (2006) of well TR-14A cored the first intrusive rock, granodiorite at 2063 m, while wells TR-19B and TR-19C successively obtained another intrusive rock which is more acidic, a granite.

Two additional hydrothermal alteration minerals were identified: actinolite and prehnite. Actinolite is one of the high temperature amphibole minerals (300ºC) and mostly observed in well TR-2, while prehnite is usually associated with epidote in veins and vesicles of the rocks.

Facies zones include argillitic-phyllitic zone to propyllitic zone, with increasing depth. Mineralogical temperature ranges from 150º to 300ºC.

INTRODUCTION

The Berlin geothermal field is located 110 km ESE of the city of San Salvador, El Salvador (Figure 1). The first exploratory well, TR-1 was drilled in 1968 and intercepted the geothermal reservoir at 1400m depth, with a reservoir temperature of 230ºC. Exploratory drilling continued in 1978 and with the aid of Interamerican Development Bank (IDB) and Electroconsult (ELC), feasibility studies were carried out for a possible exploration and development of the area.

In 1992, two 5 MW back-pressure units were commissioned in Berlín. Expansion of the geothermal field was a priority to address the growing demand of electrical energy of the country. In 1999, two 27.5 MW condensing unit went on-line, contributing to the 22% of the total geothermal electricity generation. At present, a 40 MW plant is being constructed by ENEL Produzione S.p.A, the company's strategic partner.

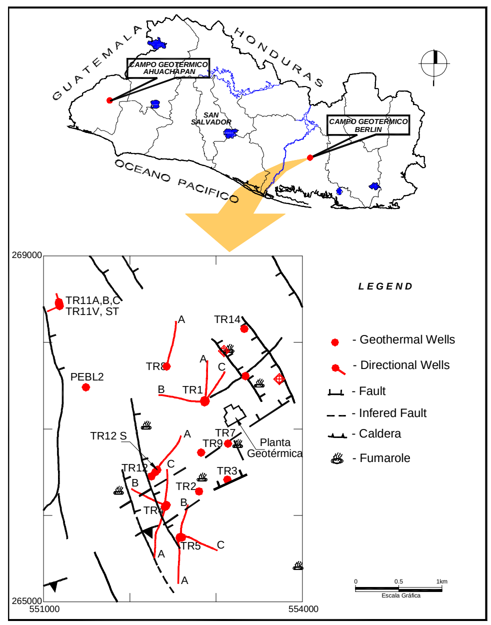

Figure 1: Location Map of Berlìn Geothermal Field

This study presents information on the hydrothermal alteration minerals found in wells and their distribution with depth. Four mineralogical alteration zones at increasing depths have been identified based on the abundance and appearance of characteristic hydrothermal minerals.

The hydrothermal minerals occur as replacement minerals on most primary igneous minerals (e.g. replacement of plagioclase by epidote + albite) and as fillings of vesicles/cavities or fractures present in the rock.

METHODOLOGY

Core samples were studied using microscopic observation of thin sections, with the petrographic microscope LEICA model DMLSP. Some of the clay minerals and zeolites were identified using the XRD machine SIEMENS D5000.

GEOLOGY

The Berlin geothermal field is located at the northern flank of the Berlin-Tecapa Quaternary volcanic complex, which is characterized by basaltic to andesitic lava flows, lithic tuffs and scoria, and andesitic to dacitic ignimbrites. Volcanic-tectonic activities started 1.4 million years ago. Recent volcanic activities (0.1 million years ago) brought large amounts of ignimbritic products produced by the collapse of the volcano and consequently formed the Berlín caldera. The last event (700 years) is represented by the "El Hoyon" phreatic explosion.

Four basic lithological units were identified during drilling and are presented in Table 1.

Table 1 shows a brief description of the lithological units found in Berlín geothermal field.

RESULTS AND DISCUSSION

Studies included the identification of hydrothermal alteration minerals, textural relation, occurrence and distribution and microstructures observed in some samples.

Table 2 presents a summary of hydrothermal minerals present in each core. However, a complete table where occurrence, lithology, depth, etc is found at the original report of Berlin cores (Garcìa et al, 2003).

Microstructures/permeability

In the structural analysis of cores in Berlín (García et al, 2003), it was observed that joints and faults are mostly of high angle from 60° to 90°. It is also evident the predominance of sealed fractures mainly by calcite, epidote, quartz, chlorite and iron oxides.

In the production area, normal faults have higher angle (60° -90°) than those at the reinjection area (30°-60°). The southern part of the field shows very few inverse faults, while the northern part has an intense compressive stress, which are mostly observed in well TR-8, where inverse faults of high and low angles predominate. Transcurrent or lateral faults were also observed at the northern part of the field.
Petrographic analysis showed that microstructures include displacement (or microfaulting) in plagioclase crystals, veins and other lithic fragments. Almost all veins are sealed with calcite, epidote, quartz, prehnite, wairakite and sometimes pyrite. Thickness of veins varies form <0-04 mm upto 3mm. Some stylolites are also observed filled with calcite.

Vesicles or cavities are usually filled with calcite, quartz, epidote, chlorite, chalcedony, clay minerals and wairakite, the first three minerals being well-formed in most vesicles. Epidote and prehnite are usually radial. Chalcedony is usually observed along the rims of the vesicles.

Partial fillings of open spaces (cavities or veins) reduces the permeability but does not completely eliminate the passage of water through the rocks. However, in most of the reinjection wells, cavities predominate and usually filled with quartz and calcite.

A. Occurrence

The volcanic products are affected by intensity of hydrothermal alteration, from slightly altered to totally replaced volcanic rocks. Hydrothermal minerals not only replace the original igneous minerals, the volcanic groundmass and the breccia matrix, but also fill small cavities and microfractures crosscutting the volcanic rocks

Epidote usually replaces the matrix and crystals of plagioclases. At higher depth, it is usually associated with albite ± quartz ± chlorite ± calcite. It is also found in veins and filling vugs and vesicles and cavities.

Furthermore, calcite, quartz and chlorite are the most abundant hydrothermal phases. Calcite replaces plagioclase and forms veins or fills cavities. Quartz is also found in veins and in matrix of volcanic rocks.

Different types of chlorite (penninite and chlinoclore) are observed under the microscope. Penninite is bluish, while clinochlore is sometimes greenish, brownish and yellowish depending on the amount of Fe. They are mostly observed in vesicles, altering pyroxenes and along the fissures of plagioclase crystals and matrix of the rocks.

Leucoxene was also observed as alteration mineral to TiO2 - bearing opaque minerals (sphene).

Two additional minerals were identified in the analysis: actinolite and prehnite. Prehnite forms together with epidote in veins and vesicles. Actinolite is a high temperature amphibole mineral, indicating a temperature of 300ºC and usually replaces plagioclases and pyroxenes and forms together with epidote. This mineral was found in well TR-2.

Most of the plagioclase at depth are albitized and replaced by calcite, chlorite, epidote and sericite/illite.

Matrix

The matrix of most rocks are glassy to devitrified with some chlorite, clay minerals and opaque minerals. Andesitic and basaltic lavas mostly show microlites of feldspar in their matrix.

Lithic tuffs usually have silicified matrix.

Mineralogical Zones

Table 3 shows the different facies zones present in the cores studied.

The shallowest alteration zone found in the cores, argillitic-phyllitic facies is characterized by the presence of relatively low-temperature minerals (i.e. saponite, montmorillonite, heulandite etc.), whereas, at greater depth, hydrothermal phases, such as epidote, wairakite, prehnite, anhydrite, typical of higher temperature conditions, are present. Quartz, calcite and chlorite are also widespread in most of these zones.

DISCUSSION

Several factors influence the distribution and kind of mineral assemblages in hydrothermal systems, which include permeability, temperature and fluid composition (Browne and Ellis, 1970).

a. Permeability

Permeability of the rocks controls the access of thermal fluids, which cause hydrothermal alteration of the rocks and precipitation of secondary minerals in open spaces. Rocks that have very restricted permeability or are completely impervious to fluids will only be slightly altered.

There were at least two types of permeability observed in different cores in Berlìn: porosity and fractures. Most of the pores/cavities and fractures are filled up by secondary minerals such as calcite, quartz, chlorite and epidote, which reduced permeability and the passage of water. Porosity was mostly observed in reinjection wells.

b. Temperature

Temperature may be the most significant factor in hydrothermal alteration because many of the chemical reactions require elevated temperatures.

Some measured temperatures (present day temperatures) have lower values than past temperatures as observed in fluid inclusion homogenization temperature, while others are in equilibrium of the present day temperature.

In well TR-5, homogenization temperatures (T_h) of fluid inclusions in anhydrite veins at 1620 and 1650 m ranged from 275-297°C with an average value of 286°C These T_h values closely agree with the stable measured temperature of 287°C at this depth, as well as with prophyllitic alteration observed within the deep aquifer horizon in TR-5 (Henriquez, 2001). The exact agreement of rock alteration, fluid inclusion data, and stable measured temperatures within the deep aquifer of TR-5 indicates thermal stability in the area drilled by this well.

c. Fluid composition

Chemical composition of the host rocks determines the availability of cations to form alteration minerals. Similarly, the cation and anion content of the fluids interacting with the rocks influences the composition of alteration minerals.
Most of the hydrothermal minerals found belong to neutral waters with the presence of mineral assemblage such as epidote-quartz-wairakite-calcite-illite-chlotite.

CONCLUSION

The petrographic study of cores identified the occurrence of different hydrothermal minerals predominant at higher depths such as epidote-quartz-wairakite-calcite-illite-chlorite, all indicating neutral chloride waters.

Primary and secondary permeabilities are present in Berlìn geothermal field, cavities (vugs and vesicles) and microfractures which reduces the permeability of the rock.

Temperature influences a lot the hydrothermal alteration process. Changing to secondary minerals provided the mineralogical temperature seen at Table 4.

REFERENCES

When references are used in the text, tie them to an alphabetical (by principal author) list of references to be included as the last item of your paper. The format commonly used in scientific literature follows:

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Table 1:

Unit	Lithology	Characteristics
1	Andesite to basaltic andesite	Recent deposits
2	Ignimbrite intercalated with scoria and thin layers of andesite	Where intermediate aquifer is located
3	Fine silicified lithic tuff	Serves as the caprock
4	Andesite to basaltic andesite with intercalation of lithic tuff and presence of volcanic dykes, also with presence of granodiorite in TR-14 and granite in TR-19B and TR-19C.	Where reservoir is located

Table 2:

A. Neutral pH	**V**	**C**	**P**	**F**	**OM**	**M**
Smectite (Nont-Mont)*	x	x	x			x
Illite*	x	x	x			x
Chloritic Clays	x	x	x	x		x
Chlorite	x	x	x	x		x
Penninite	x	x	x	x		x
Cristobalite	x	x				x
Tridymite	x	x				
Chalcedony	x	x				
Quartz	x	x	x			x
Heulandite	x	x	x			
Laumontite	x	x	x			
Wairakite	x	x	x			
Prehnite	x	x				x
Epidote	x	x	x			x
Iddingsite				x		
Hematite	x	x	x	x	x	x
Leucoxene					x	x
Actinolite			x	x		
Caclite	x	x	x	x		x
Albite			x			
B. Acid pH	**V**	**C**	**P**	**F**	**OM**	**M**
Kaolinite*			x			x
Halloysite*			x			x
Alunite/Natroalunite*	x					x
Anhydrite	x	x	x			x
Pyrite	x	x			x	x

Table 3:

Facies	Lithology	Alteration Minerals	% TA	Temp. (°C)	Depth (m)	Observation
Argillitic-phyllitic	Porphyritic andesite	Ca, Cl, Qz, Hem, Cl clays, OM, Clay minerals	3-60	150-180	590-1035	Few veins with Ca, Cl T =0.08mm tuffs; 0.025- 0.12 in andesites
Phyllitic	Porphyritic andesite, porphyritic basaltic andesite, lithic tuff and ignimbrite	Ca, Ser, Cl, OM, Qz, Pen	14-85	1 80-220	1035-1455	Veins with Ca, Cl, Qz, Wai, Py, Cl clays ; T = 0.04-0.4 mm in andesites; 0.01mm in ignimbrites
Phyllitic-Propyllitic	Very altered lithic tuff and andesite	Wai, Ca, Qz, Ser, Cl, Anhy, Preh	40-98	220-250	1455-1765	Veins with Ca, Ep, Cl, Qz, Preh, Wai; T = 0.04-0.24 mm in tuff,; 0.08-0.12 mm in andesite
Propyllitic	Basaltic andesite, porphyritic andesite very altered lithic tuff and ignimbrite and granodiorite	Ep, Qz, Preh, Actinolite, Cl, Qz	14-76	250-300	1765-2325.4	Veins with Ep, Qz, Preh, OM, Wai; T = 0.02-0.08 mm ignimbrite; 0.4-1 mm in andesite

Table 4:

Temperature (°C)