

Geologic Model of the Pailas Geothermal Field, Guanacaste, Costa Rica

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ABSTRACT

The Pailas Geothermal Field is located on the southern flank of the Rincón de la Vieja volcanic complex, fifteen kilometers north of Liberia, Guanacaste, Costa Rica. Based on the data obtained from nine deep wells, surficial geology and temperature gradient wells, a geologic model is presented. This model includes lithologic and mineralogic correlations that show the general geothermal scope of the field. According to the data available we consider that the heat source is located towards the north-northeast and is associated with the Rincón de la Vieja volcanic complex, and declines towards the south-southwest.

1. INTRODUCTION

The Pailas Geothermal Field is located on the southern flank of the Rincón de la Vieja volcanic complex, which forms part of the Quaternary Guanacaste volcanic cordillera in northwestern Costa Rica, approximately 250 km northwest of San José, Costa Rica (Figure 1). The local coordinates of this project in the Costa Rica Lambert North coordinate system are: 302-306 N, 386-389 E on the Curubandé 1:50000 topographic base map. Initial field studies began in the 1970's as part of a regional geothermal reconnaissance study, at which time the first temperature gradient wells were installed. At present 18 temperature gradient wells have been drilled with an average of 300 m depth. From 2001 to 2002, as part of a geothermal feasibility study the first deep well drilling campaign was completed with the conclusion of five deep wells (1418-1856 m deep) which confirmed the existence of a commercially exploitable geothermal reservoir. Since that time, four more deep wells have been drilled as part of the development phase. A directional deep well drilling program is planned to begin in June, 2009 which will help to explore the area north and northeast of the present deep well field.

Geological studies, including remote imagery analysis, field reconnaissance studies, down-hole lithologic descriptions and alteration mineralogy studies in deep wells and geothermal gradient wells have been used to create a geothermal model of the Pailas Geothermal Field including structural, lithologic, mineralogical and temperature data.



Figure 1: Location map of Las Pailas Geothermal Field.

2. STRUCTURAL SETTING

From a structural point of view this part of the country is characterized by E-W regional lineaments which extend from Santa Elena peninsula towards the volcanic arc, ending against a NW-SE regional system that could be related with the extension of the Nicaragua Graben (Figure 2). Other important lineaments show a NE-SW trend and, some of them extend from the Pacific coast to the volcanic arc. A N-S system is also observed that shows lineaments that cut across the Quaternary volcanic edifices.

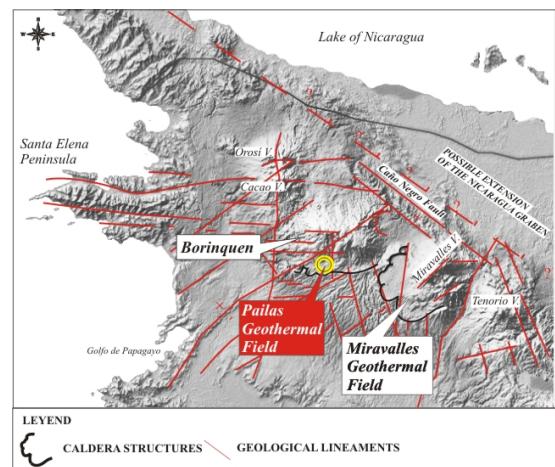


Figure 2: Regional lineaments and location of Pailas Geothermal Field. Caldera structures correspond to the black curved lines. (Background image taken from <http://photojournal.jpl.nasa.gov/catalog/PIA0336>).

Within the geothermal field inferred faults and lineaments (figure 3) were defined by a combination of factors including: morphology, field evidence (fractures), of hydrothermal alteration, gravimetric data, and electric resistivity data.

3. LITHOSTRATIGRAPHY

The local geological history is related to the evolution of the Cañas Dulces and Guachipelín calderas and more recently with the activity of the Rincón de la Vieja volcanic complex. A lithostratigraphic column can be interpreted from the deep wells that includes six separate volcano-stratigraphic units. These six units can be correlated to regional formations dating from the Miocene to the Holocene: (1) Aguacate Group; (2) Bagaces Group; (3) Liberia Formation; (4) Domes Unit; (5) Pital Formation; and (6) Recent Products Unit. Of these formations, the only unit not represented in an area outcrop is the Aguacate Group. From deep well data the geothermal reservoir is restricted to the basal section of the Bagaces Group and the Aguacate Group.

The Cañas Dulces Caldera is easily traced to the southwest and south of the Pailas Geothermal field and is buried by younger units to the east and north. The Guachipelín Caldera is much smaller and lies within the Cañas Dulces Caldera, completely enclosing the current deep well field. To the west of the geothermal field there is a dacitic to rhyo-dacitic dome field that rises above lahar deposits and the Post Pleistocene pyroclastic rocks of the Pital Formation.

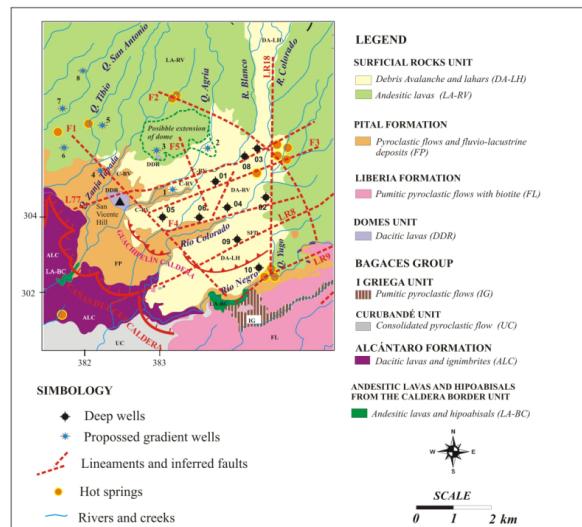


Figure 3: Geologic map of the Pailas Geothermal Field.

The stratigraphic units found at depth in the Pailas Geothermal Field have a good correlation with the outcropping units. This includes diverse volcanic and volcaniclastic material deposited in explosive and effusive phases, as well as during periods of volcanic quiescence.

The regional geological formations have been correlated by utilizing the Liberia Formation (dated at 1.6 Ma) as a marker bed in the drilled lithologies. This rock formation widely distributed throughout Guanacaste.

A brief description of the main rock units from oldest to youngest is presented as follows (Figure 3).

3.1 Aguacate Group

This unit includes andesitic lava sequences interbedded with pyroclastic rocks, sedimentary rocks, reworked material, andesitic dykes and hypabyssal rocks. There are no outcrops of these rocks at the Pailas Geothermal Field, although due to the stratigraphic location of the Aguacate Group suggests that the deepest rock units encountered during drilling at the Pailas Geothermal Field belong to this rock group. The thickness of the Aguacate Group is estimated between 251 to 790 m in the deep wells (the base of this unit has not been encountered). These lavas are characterized by their secondary permeability along fractures, where intense alteration has been observed.

3.2 Bagaces Group

This unit corresponds to a pyroclastic flow and tuff sequence (ash, lithic, pumiceous and crystal lithic tuffs) with alternating lavas, reduced thicknesses of dacitic lava and ignimbrites (Alcántaro Formation), lake deposits and scattered dykes. The Alcántaro Formation is thickest in the western part of the well field at PGP-05 and we consider that these lavas mark Cañas Dulces caldera border. The Bagaces Group is confined above by the Liberia Formation and below by the Aguacate Group. The thickness of this unit varies from 360 m (PGP-03) to 710 m (PGP-04). Permeability in the upper part of the Bagaces Group is associated with lithologic contacts while permeability in the basal section is associated with fractures in lavas and highly consolidated tuffs.

3.3 Liberia Formation

This formation has been drilled in the deep wells and has been correlated with an extensive pyroclastic rock sequence that outcrops at the surface. This rhyolitic tuff is formed by various explosive events that contain lithic, pumiceous, crystal lithic pyroclasts and characteristic biotite and primary quartz crystals. It has been encountered with thicknesses ranging from 3 m (PGP-06) to 231 m (PGP-01). We have observed that within the caldera the thickness of this unit thins out towards wells PGP-06, PGP-09 and PGP-10, and thickens towards the north and northwest.

3.4 Domes Unit

This unit consists of several dacitic domes that outcrops mainly at the border of the Cañas Dulces caldera, but there are also two dome structures towards the inner part: one near the Guachipelín caldera border to the northwest of PGP 05 (San Vicente hill) and the other to the northwest of PGP-01 (Figure 3). The latter has dacitic lavas at the base and andesitic lavas at the top, indicating different emplacement episodes, probably along the Guachipelín caldera ring fractures or possibly a NE-SW fracture system parallel to the Zanja Tapada Creek. The dacitic lavas are rich in hornblende and plagioclase and locally contain biotite. In contrast, the andesitic lavas are similar to those of the modern Rincón de la Vieja volcano, and have large plagioclase, orthopyroxene, and clinopyroxene crystals in a partially silicified to argillitic glassy matrix.

3.5 Pital Formation (Guachipelín)

This formation consists mainly of pumiceous pyroclastic deposits and few lacustrine deposits. It has been found in all of the deep wells with thicknesses varying from 180 m (PGP-05) to 347 m (PGP-03). It is dacitic to rhyolitic in composition and was formed from pyroclastic events with high white pumice content. Also found in this formation are lithic to crystal-lithic tuffs. Primary minerals locally observed in these flows are green or brown hornblende, and

reworked biotite. The rock cuttings that correspond to this lithology have been correlated with outcrops of the Pital Formation to the east and south of the Pailas Geothermal Field. In some deep wells, a lacustrine deposit, composed of reworked material from the underlying rocks, was observed capping this formation.

3.6 Rincón de la Vieja volcano Products

This unit consists of a sequence of debris avalanches and lavas from the Rincón de la Vieja volcanic complex. Within the caldera the thickness of this unit varies due to paleotopography and proximity to the source vent. This unit is thickest near PGP-03 and thins out towards deep wells PGP-05 and PGP-10, which have been interpreted as forming part of the inner limit of the caldera border.

4. GEOLOGICAL CROSS SECTIONS

The distribution and extention of the volcano-stratigraphic units at Pailas Geothermal Field are shown in cross sections oriented NNW-SSE (cross section 1) and WSW-ENE (cross section 2).

In general the lateral extention of the rock units at Pailas Geothermal Field allows a correlation between the deep wells with reasonable differences in unit thickness and lithologic types.

Based on the types of rock units found in the deep wells the following conclusions can be made from the cross sections.

In cross section 1 (Figure 4) andesitic lava flows from the Aguacate Group are slightly deeper towards the central and northern part of the field (PGP-1 and PGP-04) and shallower to the south (PGP-10). At well PGP-10 the thickness of these lavas is approximately 1400 m. Unfortunately, drilling stopped at shallower depths.

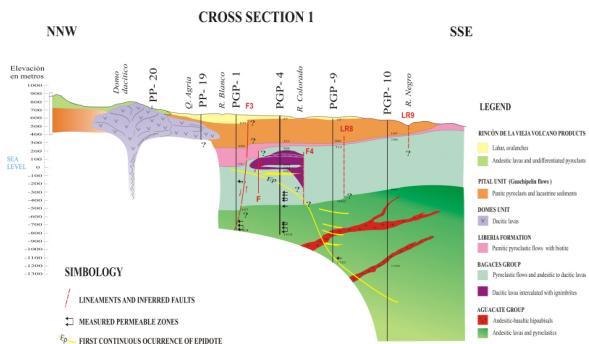


Figure 4: NW-SSE cross section.

The upper limit of the Aguacate Group it is a few tens of meters deeper at PGP-01, which may possibly be explained by a fault interpreted as dipping towards the northwest (F3). It is also observed the presence of dacitic lavas in well PGP-04 probably emplaced through a NE-SW fracture system (F4). To the NNW a rhyo-dacitic dome structure, observed in the temperature gradient well PP-19, interrupts the sequence present in the deep wells.

The Bagaces Group is dominated by pyroclastic deposits, where the unit thickness across the field is relatively constant with some NNW thinning (towards PGP-01). The upper limit of this unit is approximately 250 m deeper in PGP-01 than in PGP-04. This vertical displacement is supporting evidence for fault F2 at depth although it does not affect the younger units. Locally, there are lacustrine deposits capping the Bagaces Group which suggests a period of volcanic quiescence in which various local basins

may have formed prior to deposition of the Liberia Formation.

The Liberia Formation is thicker to the NNW and tends to thin to the south (within the caldera) and is only 6 meters thick in well PGP-10. This may be explained by the fact that pyroclastic flows tend to fill the paleotopography.

The Pital Formation correlates well between all of the deep wells and demonstrates a relatively constant thickness throughout the well field. This pyroclastic sequence was deposited on a paleotopography that does not appear to have been affected by fault displacement.

The first continuous occurrence of epidote (Figure 4; yellow line) is related to temperatures around 200°C and is used as an indicator of the temperature in the reservoir. In figure 4 it is clear that the presence of this high temperature mineral deepens towards the SSE.

Figure 5 shows a WSW-ENE cross section between deep wells PGP-05 and PGP-02. The Aguacate Group basement rocks show a deepening towards the ENE (PGP-02) probably caused a paleotopography associated with erosion, fault displacements and/or proximity to the source vent. The mainly pyroclastic flow, which comprises the Bagaces Group, tended to fill the surface. Small displacements in the formation can be related to faults affecting the region around well PGP-02. In this vicinity a small basin seems to have formed that was later filled by the pyroclastic flows of the Liberia Formation. Similar to cross section 1, the Pital Formation exhibits a subdued topography with no major vertical displacements.

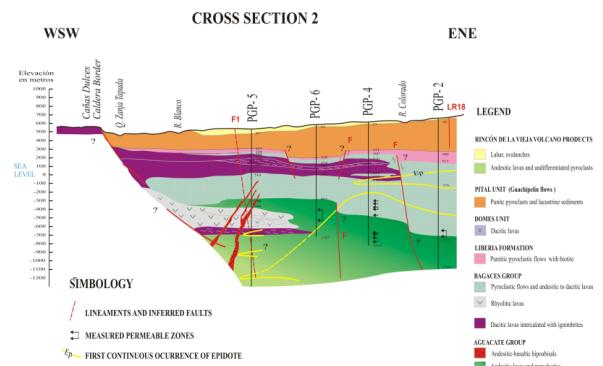


Figure 5: WSW-ENE cross section.

It is evident that the emplacement of dacitic and rhyolitic lavas towards the Cañas Dulces caldera border (PGP-05) probably occurred along caldera ring fractures.

The line of continuous epidote occurrence indicates a decrease in the temperature conditions towards the WSW. This condition was most evident in the borehole temperature measurements in deep well PGP-05. Once again the hotter zones are located towards the ENE sector of the field near the recent Rincón de la Vieja Volcanic edifice.

5. CONCLUSIONS

The Pailas geothermal field is located inside the Guachipelín caldera structure, which is inside an older and bigger caldera structure known as Cañas Dulces Caldera. The drilled sequences vary from andesitic-basaltic to rhyolitic composition and are associated to pyroclastic and effusive activity from ancient volcanic edifices.

The geological cross sections show noticeable vertical displacements especially in the older units, which may be explained by old faults movements, erosion, or even proximity to the paleo-vent sources. The recent units show no significant vertical displacement which suggests that the caldera fill is relatively young. However, field evidences reveals fracturing of most of the recent units.

The behavior of the continuous occurrence of epidote (yellow line) could be used as an indicator of the thermal

conditions in the borehole field. This parameter clearly indicates that the hotter zone is located towards the NE sector and a clear decrease is observed to the SW, S and SE sectors. It seems that the heat source of the Pailas reservoir is associated with the Rincón de la Vieja volcano.