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Update to the Conceptual Geologic Model of the Borinquen Geothermal Field, Costa Rica

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ABSTRACT

From October 18, 2016 to December 14, 2018 three deep directional boreholes have been drilled from wellpad PLB-09 located in the northwest sector of the Borinquen Geothermal Field (BGF) in Costa Rica. Previously, four other deep wells had been drilled in this field (two vertical and two deviated) as well as 28 temperature gradient wells. Prior to drilling from pad PLB-09, the geologic, stratigraphic, structural, high temperature alteration mineralogy, hydrogeochemistry, geophysical, and isotope information available from those boreholes and previous field work was compiled by Molina and Martí and published in Geothermics in 2016 where a thermal anomaly is shown within the Cañas Dulces Caldera. This paper shall provide newly obtained information form these three new boreholes in comparison with the already published data to update the existing Conceptual Geologic Model of the Borinquen Geothermal Field.

1. INTRODUCTION

In 2014, West Japan Engineering Consultants, Inc. compiled a report that includes geoscientific data from the Borinquen Geothermal Field (BGF) in northwestern Costa Rica where the Instituto Costarricense de Electricidad (ICE) currently drills deep exploratory wells that are to sustain the operation of two geothermal power plants (north plant and south plant) with a nominal production capacity of 55 MWe each, the first of which is programmed to be commissioned in 2026. Figure 1 shows the lineaments traced in WestJEC (2014) that may be related to the structural geologic framework of the BGF. The total number of production wells necessary for plant start up is shown in table 1.

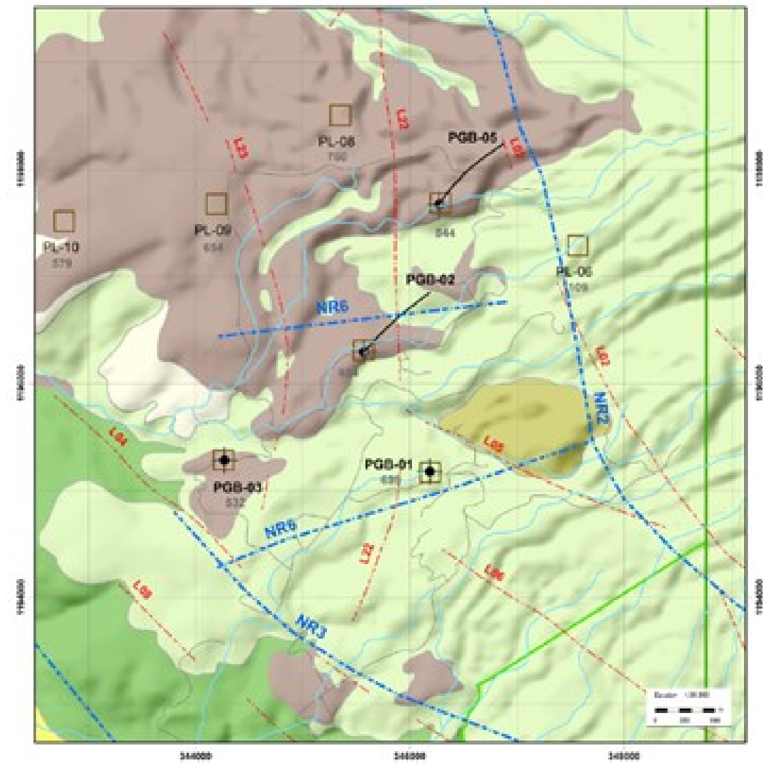

Figure 1. General location map of the Borinquen Geothermal Field that shows the structural geologic framework proposed by WestJEC (2014) as well as drill the pad locations, deviated well traces (prior to drilling at pad PLB-09) and the surface geology.

Table 1: Wells required prior to the commissioning of the north and south 55 MWe powerplants at the Borinquen Geothermal Field (WestJEC, 2014).

	North Plant	South Plant
Total wells needed to start generation	9	9
Replacement wells to be incorporated the following year	11	11
Existing wells	1 (PGB-05)	2 (PGB-01, PGB-02)
Wells yet to be be drilled to begin nominal generation (55 MWe)	10	9

Following that report, Molina y Martí (2016) compiled the existing geologic, stratigraphic, structural, alteration mineralogy, hydrogeochemistry, geophysical, and isotope information available from four deep wells and 28 temperature gradient wells, as well as previous field work and published in Geothermics, where they show a thermal anomaly within the Cañas Dulces Caldera. This paper shall provide newly obtained information form the three new boreholes at pad PLB-09 in comparison with the already published data to update the existing Conceptual Geologic Model of the Borinquen Geothermal Field.

2. NEWLY DRILLED WELLS

From October 18, 2016 to December 14, 2018 three deep directional boreholes were drilled from pad PLB-09 located in the northwest sector of the BGF, taking the total number of deep wells to 7 (5 deviated and 2 vertical), in addition to the 28 already drilled temperature gradient wells.

The Instituto Costarricense de Electricidad began drilling at PLB-09 on October 18, 2016 with well PGB-09 and culminated on December 14 2018 with the completion of well PGB-59. During this time three deep deviated wells were drilled from pad PLB-09 for the reinjection of hot geothermal brine in the operation of the Borinquen I power plant which will be located approximately 525 meters to the south (Table 1, Figure 2). During these 26 months, 7358.81 meters were drilled, reaching lengths between 2325 – 2521 meters and final elevations between -1601.11 and -1736.22 m a.s.l. (for a range of 135.11 m) and an angular separation of 86 to 158° to explore the possible existence of permeability within the Bagaces Group, which is modeled to be below -1535 m b.s.l. As part of the development plan of the BGF well PGB-02 was changed to PGB-22.

Table 2: Starting and ending dates of the new wells drilled at PLB-09.

Well	Elevation (m a.s.l.)	Starting Date	Completion Date
PGB-09	654	Octubre 18, 2016	March 17, 2017
PGB-29	654	March 10, 2018	July 18, 2018
PGB-59	654	August 26, 2018	December 14, 2018

Table 3: General characteristics of the three new wells drilled at PLB-09.

Well	Measured depth (m)	Azimuth (°)	Inclination (°)	Final elevation (m b.s.l.)
PGB-09	2512.1	355	33.8	-1656.8
PGB-29	2521.14	269.5	27.4	-1736.22
PGB-59	2325.57	111.1	18.1	-1601.11

2. TEMPEATURE GRADIENTE DISTRIBUTION AND STRUCTURAL FRAMEWORK

Considering the temperature gradient distribution model presented in Molina & Martí (2016), pad PLB-09 is located in a moderate to high temperature zone where the temperature gradient is from 45 - 50°C/100 m. According to this scenario, both wells PGB-09 and PGB-29 were drilled towards areas of lower geothermal gradient to the north and west respectively, while well PGB-59 was drilled towards an area of higher geothermal gradient modelled to the east (Figure 2).

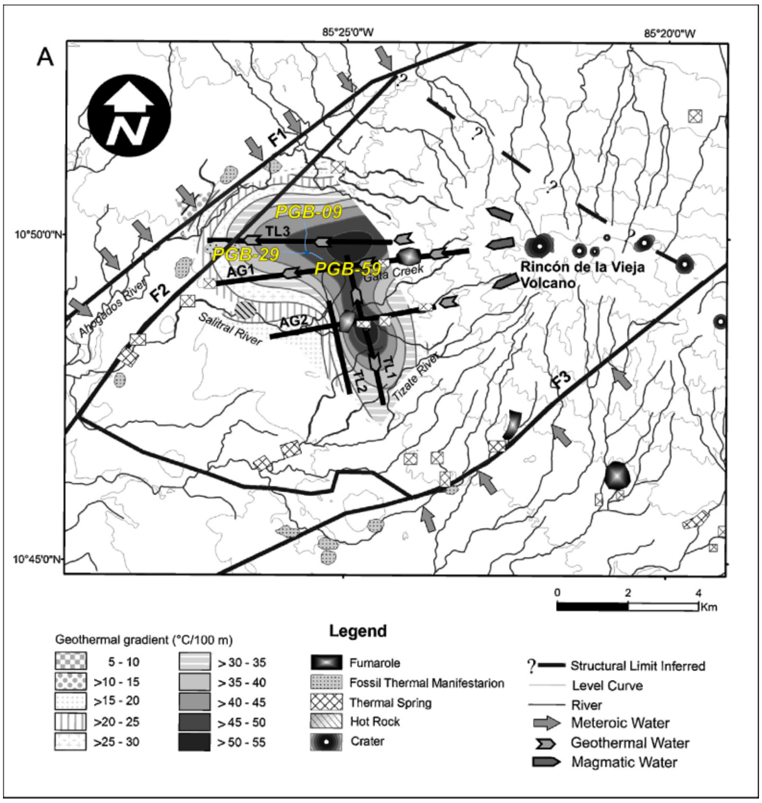

Figure 2. Distribution of the geothermal gradient at the Borinquen Geohtermal Field, within the Cañas Dulces Caldera (Molina & Martí, 2016) showing the newly drilled wells from PLB-09.

The structures AG1 and AG2 are oriented nearly parallel to some of the Resistivity lineaments traced by WestJEC (2014) while the thermal lineaments TL1 and TL2 are somewhat parallel to the photo-lineaments shown in WestJEC (2014). Viewing these structural orientations from the perspective of focal mechanisms helps to understand the possible controlling factors associated.

DeMets (2001) reports that in general the focal mechanisms on the pacific coast of Costa Rica show a northwest trending right lateral strike slip fault movement (Figure 3), which is consistent with the orientation of the Middle American Trench, the Guanacaste Volacnic mountain chain and to a lesser degree the orientation of the photo-lineaments traced by WestJEC.

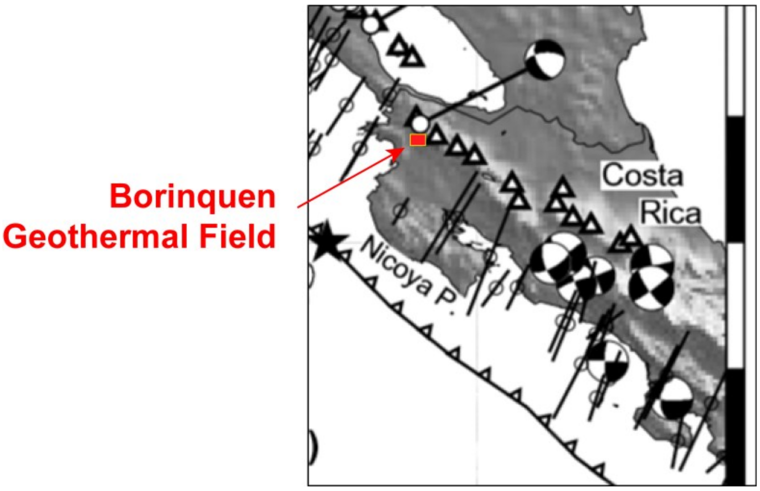

Figure 3. Location of the Borinquen Geothermal field with respect to focal mechanisms reported on the pacific coast of Costa Rica (DeMets, 2001).

On the other hand, to the the north of Rincón de la Vieja there is a focal mechanism that suggests a possible northeast trending right lateral movement which may be related to the Hess escarpment or possibly the Santa Elena suture zone, reported by James in Bundschuh and Alvarado (2012). Figures 4 and 5 show that the northeast trending structure revealed by the focal mechanism is consistent with the strike of faults AG1 and AG2, reported by Molina and Martí (2016).

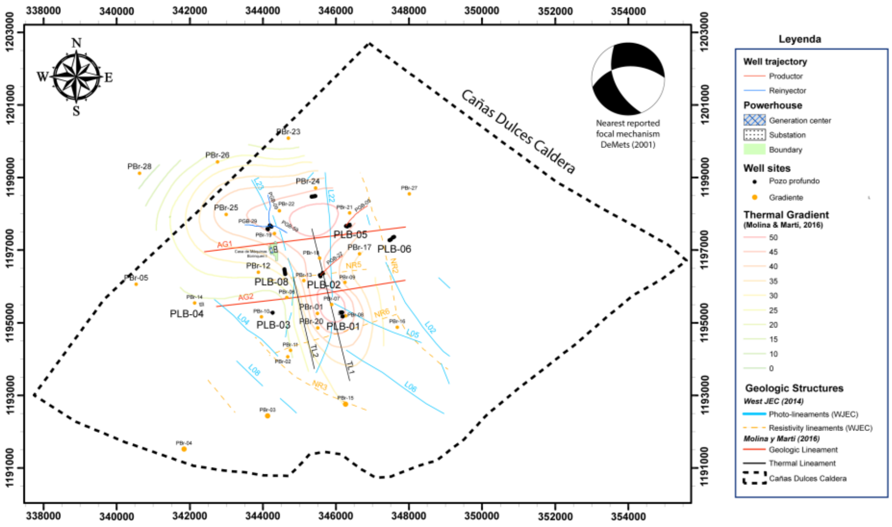

Figure 4. Location map of the Borinquen Geothermal Field that shows the structural framework within the Cañas Dulces Caldera, the thermal gradient distribution (Molina & Martí, 2016) and the nearest focal mechanism reported (DeMets, 2019).

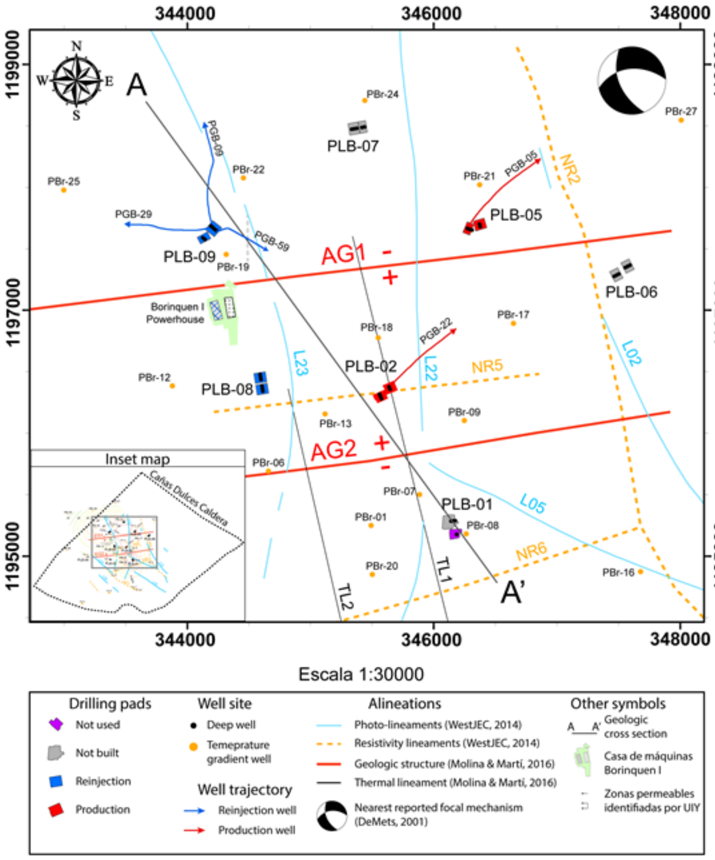

Figure 5. Structural synthesis map of the Borinquen Geothermal Field.

3. BOREHOLE STRATIGRAPHY, CLAY ZONES AND STRUCTURAL INTERPRETATION

The borehole stratigraphic and clay zone column for PLB-09 was described from rock cuttings obtained in intervals of 3, 5 and 10 meters from the surface down to -829 m a.s.l. for a total thickness of 1483 m. At lower elevations the lithostratigraphy was compiled from the description of rock cores taken at intervals 257 m +/- 45 m (including a reverse-circulation junk basket sample in PGB-09) and complemented by junk sub samples collected between cores 3 and 4 in well PGB-29 and below core 3 in well PGB-59. Figure 7 shows a stratigraphic and clay zone comparison as well as a possible structural interpretation between wellpads PLB-09 and PLB-01 while figures 7 and 8 are NW-SE cross sections that show the stratigraphy and clay zones, respectively.

3.1 Recent Products Unit (RPU)

This unit extends from the surface down to about 500 m a.s.l. for an average thickness of 155 meters, which is congruent with the thickness of nearly 200 meters of reported for this unit (Molina, 2014) and intermediate with respect to the measured depths in other deep boreholes in BGF suggesting a decrease in thickness from east to west, in comparison to well PGB-05, as distance from the main volcanic edifice increases.

3.2 Pital Formation (PF)

This unit is described from 500 to nearly 300 m a.s.l. with a reported thickness of 159 to 199 m. This suggests that the Pital Formation thins out as distance from the main volcanic edifice increases.

3.3 Liberia Formation (LF)

From 339 to -1535 m a.s.l. the Liberia Formation is described with a total estimated thickness of more than 1870 m. The top of this unit is highest at PLB-09 and deepens towards the east. Likewise, it has the greatest described thickness in the field at PLB-09.

3.4 Bagaces Group (BG)

The top of the Bagaces Group was estimated from stratigraphic information from PGB-01 (2594 m, -1895 m a.s.l.) as well as from drilling parameters. This unit is only reported at pads PLB-01 and PLB-09.

Table 4: Elevation of the top and thickness of stratigraphic units at pads PLB-09 and PLB-01.

Unit	PGB-09		PGB-29		PGB-59		PGB-01	
	Elevation (m a.s.l.)	Thickness (m)	Elevation (m a.s.l.)	Thickness (m)	Elevation (m s.n.m.)	Thickness (m)	Elevation (m a.s.l.)	Thickness (m)
UPR	654	154	654	154	654	350	699	234
FP	500	161	499	170	506	224	465	312
FL	339	1879	329	1860	307	1585	153	1704
GB	-1540	115	-1531	204	-1506	94	-1551	344

3.5. Clay zones and high temperature mineralogy

In the BGF the three main zones identified with X-Ray diffraction methods are the smectite, transition and illite zones (table 4). Occasionally chlorite and corrensite are observed. The appearance of these clay zones is consistent with the high temperature alteration mineralogy identified in the boreholes (table 5).

Specifically, at PLB-09 the smectite zone is up to 350 meters thick, extending from the surface down to 304 m a.s.l. (PGB-59). The transition zone (interlayered illite and smectite) is found between the smectite zone and the illite zone which is described from 79 m elevation at PLB-09. This puts the top of the illite zone at nearly 215 meters higher elevation than than that reported in the other deep wells of the Borinquen Geothermal Field. Locally within the illite zone chlorite is reported and may be related to intrusive bodies described in the Liberia Formation below sea level. In wells PGB-29 and PGB-59 the deepest part of the well is reported to have regressed to the transition zone (interlayered illite and smectite), possibly coinciding with Liberia Formation-Bagaces Group contact.

Table 4: Elevation of the top and thickness of the clay zones identified at well pads PLB-09 and PLB-01.

Clay Zone	PGB-09		PGB-29		PGB-59		PGB-01	
	Elevation (m a.s.l.)	Thickness (m)	Elevation (m a.s.l.)	Thickness (m)	Elevation (m a.s.l.)	Thickness (m)	Elevation (m a.s.l.)	Thickness (m)
Sm	654	300	654	334	654	350	699	348
I/Sm	354	482	320	306	304	224	351	369
I	-128	1527	14	1062	79	1585	-18	208*

*Below the illite layer in PGB-01, intercalated layers of chlorite and illite/smectite were reported (Figure 6).

Table 5: Elevation of the first appearance of high temperature mineralogy at wellpads PLB-09 and PLB-01.

Pozo	PGB-59	PGB-29	PGB-09	PGB-01
Leucoxene	54	-89	173	246
Epidote	-123	-89	489*; -55	303
Pennine	-123	-722	137**; -441	28
Sericite	204	229**	255**; 165	267
Wairakite	4	---	-118	-818

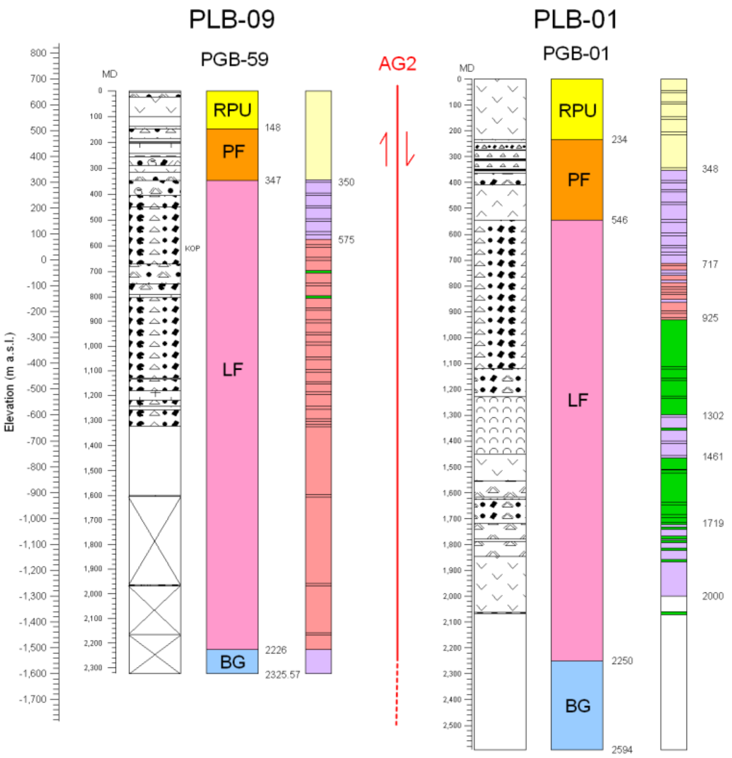

Figure 6. Lithology, stratigraphy and clay zones from wellpads PLB-09 and PLB-01 showing vertical offset, possibly along AG2 (Molina & Martí, 2016). RPU: Recent Products Unit; PF: Pital Formation; LF: Liberia Formation; BG: Bagaces Group.

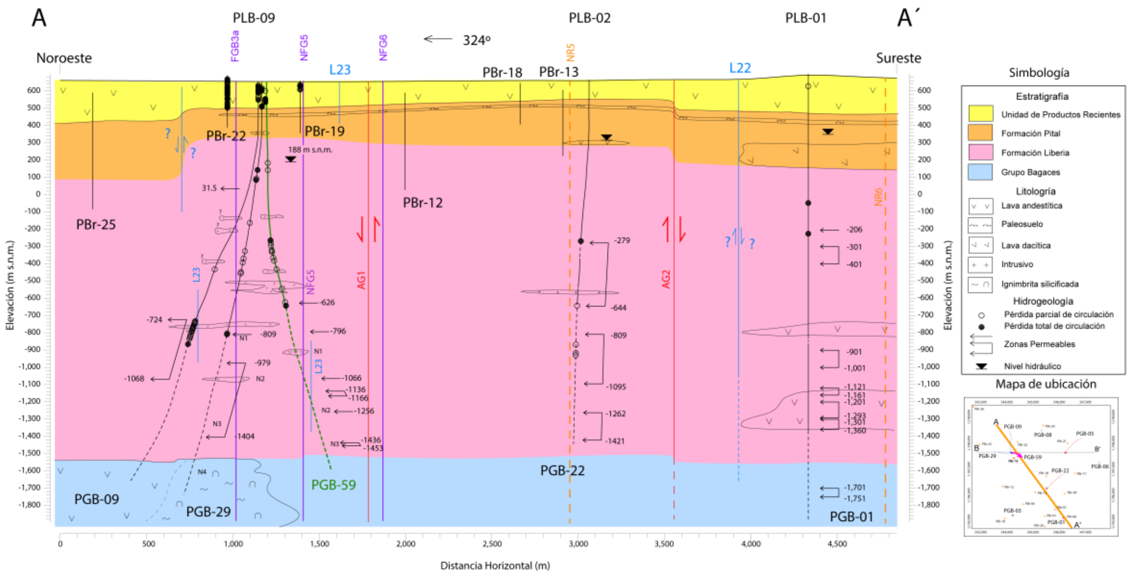

Figure 7. Geologic cross section A-A' orientaded NW-SE showing stratigraphy lithology, permeability and proposed structures, passing through the wells at PLB-09, PLB-02 and PLB-01.

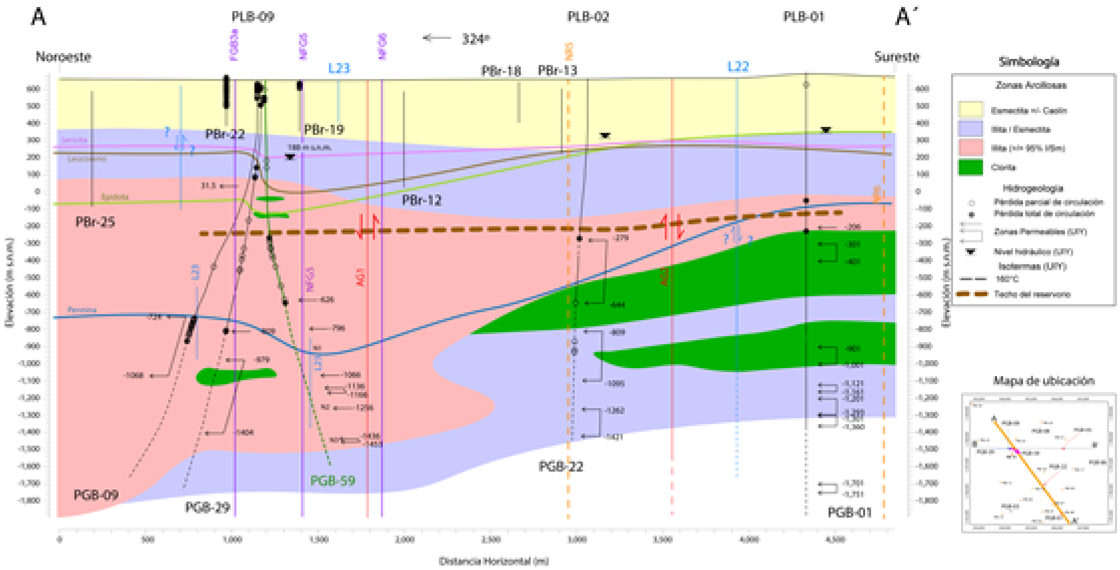

Figure 8. Geologic cross section A-A' orientado NW-SE showing clay zones, high temperature mineralogy, top of reservoir, permeability and proposed structures, passing through the wells at PLB-09, PLB-02 and PLB-01.

5. CONCLUSIONS

The Borinquen Geothermal Field is scheduled to commsion Borinquen 1 (the north plant) in 2026 for which it is necessary the drilling and completion of ten more production wells.

The thermal anomaly and structural framework proposed by Molina and Martí 2016 are consistent with a nearby focal mechanism reported by DeMets (2001) and may be influenced by the Hess escarpment or the Santa Elena suture zone mentioned in Bundschuh & Alvarado (2012).

There may be a correlation between the photo-lineaments and resistivity lineaments reported by WestJEC (2014) with regard to the nearby focal mechanism reported by DeMets (2001), notwithstanding these photo-lineaments are oblique to AG1 and AG2 and near parallel to the thermal lineaments TL1 and TL2 (Molina and Martí, 2016).

Borehole stratigraphy suggests vertical movement along AG2 (Molina & Martí, 2016), although there is no clear evidence for AG1. Likewise, it is uncertain what influence the thermal lineaments TL1 and TL2 might have on stratigraphic unit offset. The pattern of alteration mineralogy does not seem to have been directly affected by the proposed structural framework.

REFERENCES

Bundschuh, J. & Alvarado, G. 2012. Central America: Geology, Resources and Hazards. Taylor and Francis Group. pp. 1436.

Molina, F., Martí, J., Aguirre, G., Vega. E., & Chavarría, L. 2014. Stratigraphy and structure of the Cañas Dulces caldera (Costa Rica). Geological Society of America Bulletin. doi: 10.1130/B31012.1

Molina, F. & Martí, J. 2016. The Borinquen geothermal system (Cañas Dulces caldera, Costa Rica). Geothermics. Vol. **64**. pp. 410-425.

West Japan Engineering Company, Inc. 2014. Estudio preparatorio para el proyecto del desarrollo geotérmico en Guanacaste, Costa Rica. Borinquen, Informe Final.