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A Hydrothermally Altered Igneous Intrusion: An Additional Heat Source for the Geothermal System of Paipa, Colombia?

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ABSTRACT

The area of Paipa located in the Eastern Cordillera of Colombian Andes, harbor a geothermal system whose main source of heat is associated with the remaining heat of intrusions with ages of the order of 1 MA. To the Northwest of the geothermal area emerges The Durazno, intrusive body characterized by intense hydrothermal alteration and anomalies of radiogenic elements. Hydrothermal alteration is argillic and advanced argillic, suggesting that there was the interaction of the body with fluids pH acid. The anomalies of radiogenic elements were measured in 4 perforations with depths no higher than 100m, in which are reported values of up to 370 ppm of U-238, which would generate a contribution of heat radiogenic maximum to the system of 12.52 uW /m3. This radiogenic heat could heat the surrounding waters, as suggested by the anomalous temperature of 34.8°C in a 97m deep well 3 km from El Durazno. The thermal fluid in the area have a temperature of 75°C and a clear mixture with a salt source, However, in the well near El Durazno, the fluids are sodium bicarbonate and have a temperature of 34°C. These differences could suggest the existence of two different water circuits, where the Durazno would serve as a source of heat to the shallow. It is worth noting that minor concentrations of radiogenic elements to those recorded in the Durazno, they have been considered as sources of heat in the Chena Springs, Alaska area. However, it is required to know the volume and residence time of the water that interacts with El Durazno, As well as the permeability and make water balances to have greater certainty of the radiological heat generated by this body.

1. INTRODUCTION

Geothermal exploration in Colombia has been carried out since the late seventies (OLADE, 1982). One of the areas of interest is Paipa, located in the department of Boyacá in center Colombia. This geothermal system is the only one in the country to be housed in sedimentary rock of the Eastern Cordillera, where thermal spring are found temperatures between 20°C and 76°C, gas discharge at low pressure with a maximum temperature of 71°C (Alfaro et al., 2005) and volcanic geoforms.

Words of geology (Rueda, 2017) and geophysics (Beltrán, 2015) have registered intrusive bodies in the area, whose remaining heat has been associated with the heat source of the system (Alfaro et al., 2017). One of these intrusions located northwest of the area, is characterized by high concentrations of radiogenic elements, whose disintegration could be a source of additional heat to the geothermal system (Rodríguez and Alfaro, 2015). In order to establish this contribution of radiogenic heat, drilling nuclei were evaluated in this body called El Durazno.

2. METHODOLOGY

The four perforations in El Durazno (Figure 1 and 3) are characterized by an intense hydrothermal alteration of argillic and advanced argillic type, which makes these rocks a homogeneous material. For this reason, the sampling for analysis of gamma spectrometry, carried out by Laboratory of Nuclear Techniques of Servicio Geológico Colombiano (SGC), it was carried out systematically every 10 m approximately.

This chemical analysis, allowed to establish the concentrations in the El Durazno drilling of U-238, Th-232 and K-40, with which the contribution of radiogenic heat was calculated with the use of the mathematical calculation proposed by Beardsmore y Cull (2001) (see Equation 1), which states that the rate of radiogenic heat generated within rocks is related to the amount of radioactive material, the rate of decay and the energy of particle emission. Once calculated the contribution of radiogenic heat in the four drillings, the whisker or box diagram was used in order to eliminate extreme values and have less dispersing results.

$$A = Ar * \rho * Cr \qquad (1)$$

where, A: Rate of generation of heat, Ar: Abundance of the rock (ppm U-238, Th-323 o K%-40), ρ: Density of the rock, Cr: Constant heat generation by U, Th y K.

3. GEOLOGIC SETTING

The geothermal area of Paipa is located in the axial zone of the Eastern Cordillera of Colombia. Where is a basement composed of metamorphic and sedimentary rocks of the Paleozoic. On the basement there is a sedimentary sequence with ages from the Cretaceous to the Paleogene, as well as sediments from the Neogene to the Quaternary (Velandia, 2003). In the area, volcanic rocks have also been mapped (Cepeda & Pardo, 2004; Rueda, 2017) of acid composition that make up domes and pyroclastic deposits with a tendency northeast (Alfaro et al., 2017). The intrusive bodies mapped in the sector of Alto de Los Volcanes, Alto de los Godos and Quebrada Honda (Figure 1), they have a domonic shape with a report of ages between1.0± 0.25 Ma (GIANG-SGC, 2016 in Rueda, 2017); 2.71 ±0.0025 Ma (Rueda, 2017) y 1.81±0.024 Ma (Rueda, 2017), respectively. These bodies are characterized by the presence of megacrystals of potassium feldspar, mafic crystals of biotite and amphibole, in a white matrix with leaching resulting from the removal of crystals (Rueda, 2017).

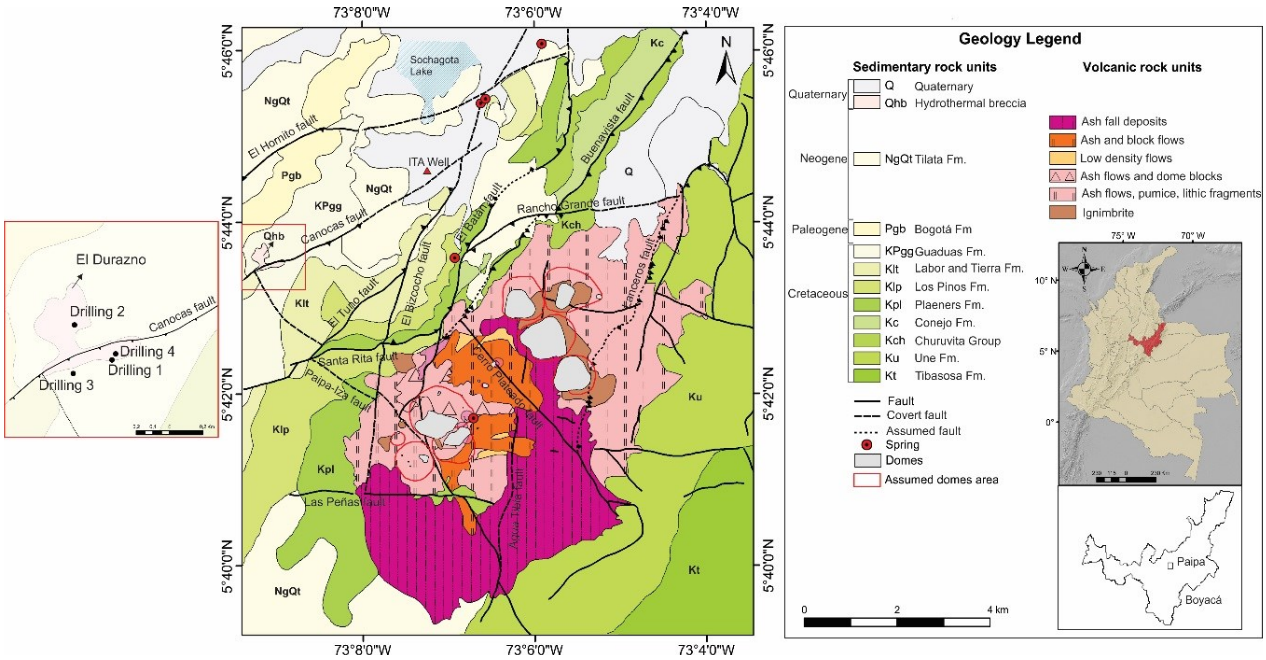

Figure 1. Location and geology of the geothermal area of Paipa, with the location of the four drillings in El Durazno (red square). Modified from Velandia & Cepeda, 2004; Pardo, 2004 y Rueda, 2017.

To the northwest of the area El Durazno, mapped by Velandia (2003) as a hydrothermal breccia at the intersection of the Canocas and Paipa - Iza faults. Interpreted by this author as a result of a steam explosion that crushes and pulls rock fragments from the Plaeners, Los Pinos, Labor y Tierna and Guaduas formations. According to Rodríguez & Alfaro (2015) El Durazno is an intrusive body when observing positive anomalies of gravimetry and magnetometry (Beltrán, 2015). Its igneous origin is supported in its high sanidine contents determined from DRX analysis (Rodríguez & Alfaro, 2015). This body is characterized by an intense hydrothermal alteration of argillic and advanced argillic type (Mojica & Valentino, 2009), therefore, a possible circulation of acid pH fluids is suggested, originating in sulfated steam heated springs, sulphated acid chlorides or fumaroles (Alfaro et al., 2017). In El Durazno, anomalous radiogenic values have also been recorded (Enusa, 1981; González, et al., 2008) that could generate an additional source of heat to Paipa's geothermal system (Rodríguez & Alfaro, 2015).

4. STRUCTURAL GEOLOGY

In the area, reactivated structures and new ones generated under a regime of compressive effort during the Andean Orogeny have been proposed. This effort at the local level has been characterized as transpressive with an effort tensor in a 122 ° direction (Velandia, 2003). This transpression would be responsible for generating overthrusts and strike slip. In the area, longitudinal and transverse faults that generate block rotation were characterized. Longitudinal faults NNE, are parallel to regional structures (fault Boyacá and Soapaga). According to Velandia (2003) structures analysis (Figure 2), the longitudinal faults have two structural styles: one that affects the basement (thick-skinned) and another that affect sedimentary rocks of the covertera (thin-skinned). Those of thick-skinned, are related to reverse faults of Lancero and Agua Tibia. This reverse movement is part of the tectonic inversion, that is, they behaved like normal. The longitudinal faults of thin-skinned, are related to the El Bizcocho and El Batan fault (Velandia, 2003). Among the transversal faults of the northwest, stand out Cerro Plateado and Paipa-Iza, interpreted as basement structures with tectonic inversion, which allowed the emergence of magmas and gave rise to the volcanism of the area (Velandia, 2003). Finally, the transverse faults NE, El Hornito, Canocas, Santa Rita and Rancho Grande are characterized as a hatchway that occasionally displaces the longitudinal ones, which is why they are considered more recent structures.

5. RESULTS

The four drillings in El Durazno do not exceed 100m, they are characterized by the intense hydrothermal alteration of argillic and advanced argillic type (Figure 3), as well as by their high concentration in sanidine characterized by DRX analysis (Rodríguez & Alfaro, 2015). The gamma spectrometry analyzes allowed to establish the concentrations of U-238, Th-232 and K-40, on which the calculation of radiogenic heat contribution was based (Table 1).

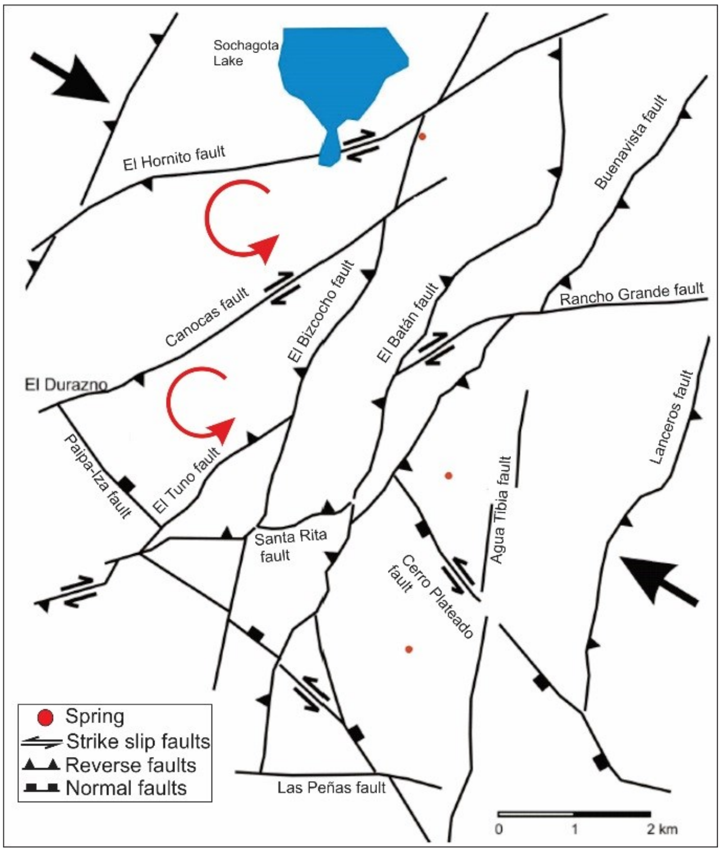

Figure 2. Structural Geology of the study area (Velandia, 2003). The red arrows show the direction of rotation of blocks between transverse failures NE, as a consequence of the direction of compression, approximately 122 ° (Black arrows).

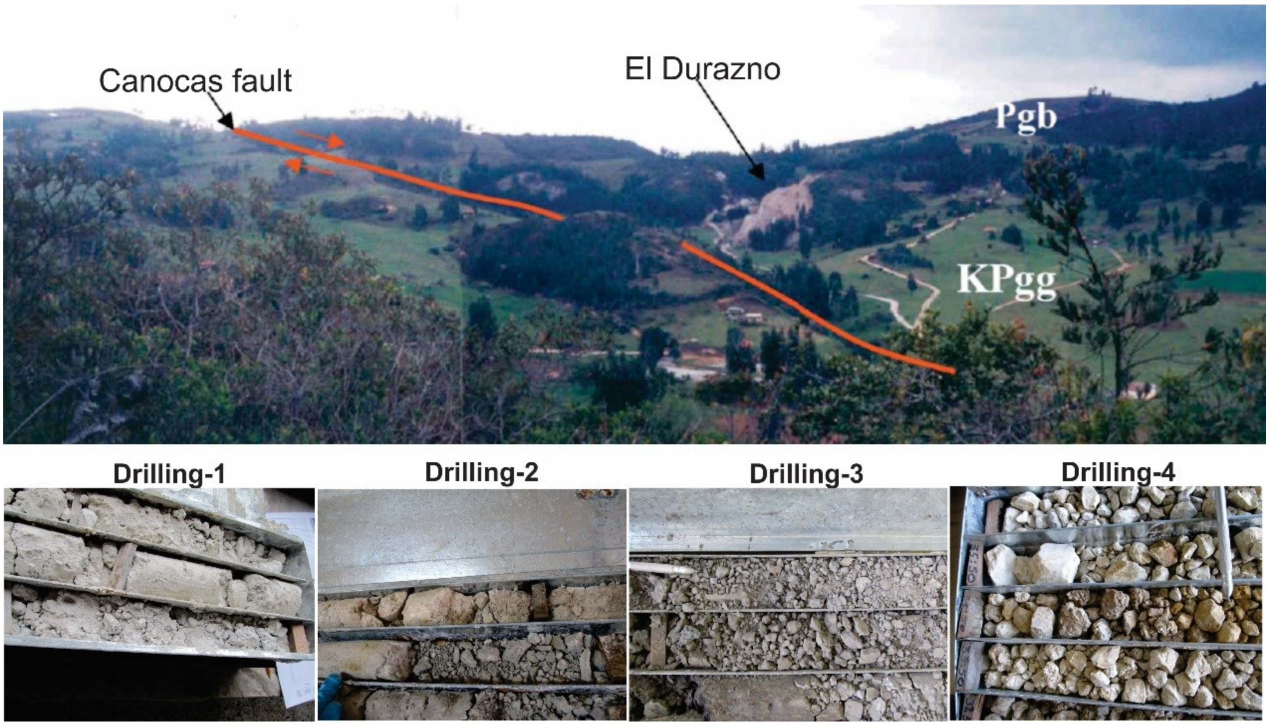

Figure 3. Above. Panoramic in SE direction, where the El Durazno intrusive is observed. Down. Detail of the rocks with intense hydrothermal alterationin the four drillings of El Durazno. (Velandia, 2003 y Rodríguez & Alfaro, 2015).

The highest concentrations of U-238 are found in drillings three and two, with values up to 374 (mg / Kg) and 159 (mg / Kg) respectively, while those of Th-232 are high in drilling two, with values of 133 (mg / Kg). In drillings one, three and four, the K-40 content is similar with concentrations up to 7 (mg / Kg), however, in the perforation of two, this value is significantly lower (up to 1.16 mg / Kg).

The values obtained by gamma spectrometry show great dispersion, for this reason the box or whisker diagram was used to represent this data. Drilling two has the highest average heat generation with a value of 12.52 µWm-3 (Figure 4). This value of heat generation per unit volume is comparable to those referenced in the Cooper sedimentary basin (Australia), where there is a heat flow anomaly attributed to a Proterozoic age granite rich in radiogenic elements that generate an estimated contribution heat of 10.3 µWm -3 (Meixner, 2012 in Rodríguez & Alfaro, 2015). This basin in Australia has projections of geothermal energy development from hot dry rock (Beardsmore, 2004, in Alfaro et al., 2017).

The radiogenic heat provided by El Durazno or other intrusions outcropping and with greater importance those that do not emerge given the confinement of heat by insulating layers, could contribute to the increase in temperature of the infiltrated waters of the area (Alfaro et al., 2017). Plutons rich near surface radiogenic elements have been recorded as a heat source in small geothermal systems, such as the Chena springs system in Alaska. In this geothermal system a generation of radiogenic heat of the order of 7.44 µWm-3 has been reported (Kolker, 2008), attributed to the radioactive decay of a granite of Tertiary age, with extensions of 40 Km2. In this place a binary geothermal plant with a total generating capacity of 400kW is developed (Kolker, 2008).

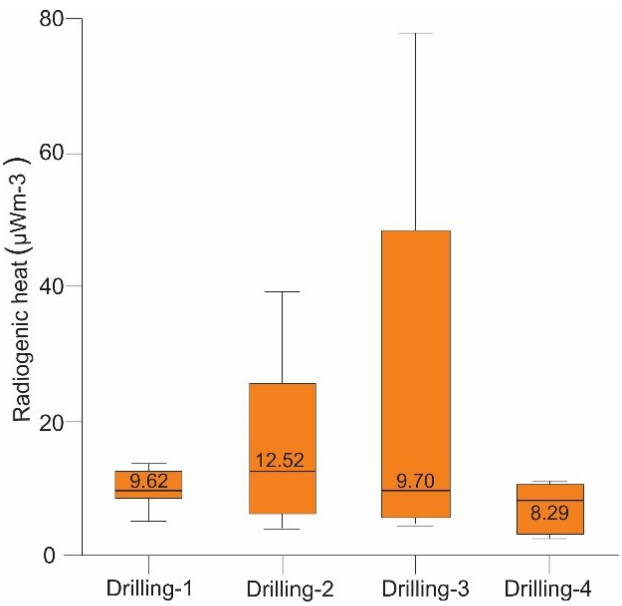

Figure 4. Diagram of boxes or whiskers for the production of radiogenic heat in the four perforations of El Durazno (Rodríguez & Alfaro, 2015).

The thermal sources in the geothermal area of Paipa have a maximum temperature of 75 ° C, they are characterized by presenting a mixture line related to a salty source (Alfaro et al., 2005). This mixture is not found in the 97 m ITA well, drilled 3 km NE of El Durazno (Figure 1), where sodium bicarbonated waters are found at temperatures of 34.5 ° C (Alfaro et al., 2017). This suggests that in Paipa there are two water circuits; a deep one related to the thermal springs of temperatures of up to 75 ° C and mixtures with sources salty, where the source of heat source would be the remnant of the intrusions of ages up to 1 Ma. and another shallow water circuit of better temperature, without the presence of mixtures with the salty source, where El Durazno would be the source of heat. This shallow circuit would be delimited by the faults of Canocas and El Hornito, given the geophysical observations in the area (Alfaro et al., 2017)

Table 1. Estimated radiogenic heat in the four drillings of Paipa (Rodríguez & Alfaro, 2015).

Well-1	Deep (m)	U- 238 (ppm)	Heat contribution U-238 (Wm-3)	Th -232 (ppm)	Heat contribution Th-232 (Wm-3)	K-40 (%)	Heat contribution K-40 (Wm-3)	Radiogenic heat *A* (μ Wm-3)
P1-1	12	15,30	3,06E-06	39,40	2,14E-06	6,29	4,56E-07	5,66
P1-2	23	15,00	3,00E-06	27,90	1,52E-06	6,32	4,58E-07	4,98
P1-3	32	30,60	6,13E-06	38,40	2,09E-06	3,83	2,77E-07	8,49
P1-4	40	48,50	9,71E-06	21,40	1,17E-06	1,22	8,84E-08	10,96
PI-5	50	38,00	7,61E-06	30,60	1,67E-06	4,82	3,49E-07	9,62
P1-6	60	30,40	6,09E-06	37,50	2,04E-06	7,58	5,49E-07	8,68
P1-7	85	50,10	1,00E-05	38,20	2,08E-06	5,31	3,85E-07	12,49
P1-8	95	47,10	9,43E-06	71,00	3,87E-06	5,83	4,22E-07	13,72
P1-9	100	45,10	9,03E-06	30,20	1,64E-06	5,32	3,85E-07	11,06
Well-2	**Deep (m)**	**U- 238 (ppm)**	**Heat contribution U-238 (Wm-3)**	**Th -232 (ppm)**	**Heat contribution Th-232 (Wm-3)**	**K-40 (%)**	**Heat contribution K-40 (Wm-3)**	**Radiogenic heat *A* (μ Wm-3)**
P2-1	1	11,30	2,26E-06	24,00	1,31E-06	5,39	3,91E-07	3,96
P2-2	12	17,40	3,48E-06	30,00	1,63E-06	4,59	3,33E-07	5,45
P2-3	23	134,00	2,68E-05	112,00	6,10E-06	2,05	1,49E-07	33,07
P2-4	32	159,00	3,18E-05	133,00	7,24E-06	1,16	8,40E-08	39,15
P2-5	40	22,50	4,50E-06	33,70	1,83E-06	0,00	0,00E+00	6,34
P2-6	50	100,00	2,00E-05	101,00	5,50E-06	1,66	1,20E-07	25,64
P2-7	60	28,90	5,78E-06	37,50	2,04E-06	1,41	1,02E-07	7,93
P2-8	85	48,00	9,61E-06	59,80	3,26E-06	0,00	0,00E+00	12,86
P2-9	95,0	51,10	1,02E-05	37,60	2,05E-06	0,00	0,00E+00	12,28
P2-10	100	44,60	8,93E-06	70,30	3,83E-06	0,00	0,00E+00	12,75
Well-3	**Depp (m)**	**U- 238 (ppm)**	**Heat contribution U-238 (Wm-3)**	**Th -232 (ppm)**	**Heat contribution Th-232 (Wm-3)**	**K-40 (%)**	**Heat contribution K-40 (Wm-3)**	**Radiogenic heat *A* (μ Wm-3)**
P3-1	7	27,80	5,56E-06	27,20	1,48E-06	3,08	2,23E-07	7,27
P3-2	14	19,90	3,98E-06	0,00	0,00E+00	5,53	4,01E-07	4,38
P3-3	21	19,80	3,96E-06	23,30	1,27E-06	5,96	4,32E-07	5,66
P3-4	28	220,00	4,40E-05	70,00	3,81E-06	6,29	4,56E-07	48,30
P3-5	35	34,70	6,95E-06	16,50	8,98E-07	5,41	3,92E-07	8,24
P3-6	42	43,00	8,61E-06	39,90	2,17E-06	5,45	3,95E-07	11,17
P3-7	49	58,80	1,18E-05	44,20	2,41E-06	5,66	4,10E-07	14,59
P3-8	56	374,00	7,49E-05	47,70	2,60E-06	6,69	4,85E-07	77,94
Well-4	**Deep (m)**	**U- 238 (ppm)**	**Heat contribution U-238 (Wm-3)**	**Th -232 (ppm)**	**Heat contribution Th-232 (Wm-3)**	**K-40 (%)**	**Heat contribution K-40 (Wm-3)**	**Radiogenic heat *A* (μ Wm-3)**
P4-1	6	49,60	9,93E-06	0,00	0,00E+00	6,82	4,94E-07	10,42
P4-2	12	30,30	6,07E-06	80,90	4,40E-06	7,93	5,75E-07	11,04
P4-3	18	24,40	4,88E-06	46,50	2,53E-06	5,96	4,32E-07	7,85
P4-4	24	9,77	1,96E-06	19,70	1,07E-06	5,29	3,83E-07	3,41
P4-5	30	8,11	1,62E-06	20,50	1,12E-06	7,35	5,33E-07	3,27
P4-6	36	8,88	1,78E-06	19,80	1,08E-06	4,53	3,28E-07	3,18
P4-7	42	32,60	6,53E-06	33,80	1,84E-06	5,05	3,66E-07	8,73
P4-8	48	37,80	7,57E-06	29,20	1,59E-06	0,82	5,94E-08	9,22

6. CONCLUSIONS

El Durazno is characterized by its intense hydrothermal alteration of argillic and advanced argillic type, which shows the interaction of the body with acid ph fluids and average temperatures. In addition to the intense hydrothermal alteration, the Durazno is characterized by its abundance in radiogenic elements with maximum values obtained by gamma spectrometry of 374 ppm U-238, 133 ppm of Th-232 and 7.93% K-40.

The radiogenic heat generated by El Durazno would be an additional source of heat in Paipa's geothermal system, which would be heated in a shallow water circuit of lower temperature (34.5 ° C) compared to deep circuits with salt mixture, where registered the maximum maximum 75 ° C.

The production of radiogenic heat generated by the El Durazno perforations presents average values of up to 12.52 µWm -3 (drilling 2). This value is greater than that generated by the Cooper basin (10.3 µWm -3) and Chena Spring (7.44 µWm-3), related to intrusions rich in radiogenic larger than expected in El Durazno, which are not known with precision, It would not exceed 1 Km2.

It is recommended to determine the volume and time of residence of the water that interacts with El Durazno, as well as the permeability and make water balances to have greater certainty of the radiogenic heat generated by this body.

REFERENCES

Alfaro, C., Velandia, P., Cepeda, H., Pardo, N., Vásquez, L. & Espinosa, O. 2005. Modelo conceptual preliminar del sistema geotérmico de Paipa. INGEOMINAS. Informe técnico. 42 p. Bogotá.

Alfaro, C., Matiz, J.C; Rueda, J., Rodríguez, G., González, C. Beltrán, M., Rodríguez, G., Malo, J. 2017. Actualización del modelo conceptual del área geotérmica de Paipa. Servicio Geológico Colombiano. Bogotá.

Beardsmore, G.R., Cull, J.P. 2001. Crustal Heat Flow. Cambridge University. United States of America.

Beltrán, M.A. 2015. Interpretación de anomalías magnetometrías y gravimétricas en el área geotérmica de Paipa-Iza. Servicio Geológico Colombiano. 182 paginas. Bogotá.

Cepeda, H. Pardo, S. 2004. Vulcanismo de Paipa, Informe técnico. 104 paginas. INGEOMINAS. Bogotá.

ENUSA. 1981. Geología y metalogénesis de las principales anomalías uraníferas descubiertas por ENUSA en Colombia. Empresa Nacional del Uranio. 14 paginas. Madrid.

González, L. Vásquez, L. Muñoz, R. Gómez, H. Parrado, G. Vargas S. 2008. Exploración de recursos energéticos exploración de uranio en Paipa, Iza, Pesca, Chivata (Boyacá). Informe Técnico. 177 páginas, INGEOMINAS. Bogotá.

Kolker, A. 2008. Geologic setting of the Central Alaskan hot springs belt: Implications for geothermal resource capacity and sustainable energy production. PhD Thesis. University of Alaska Fairbanks. 189 p. Fairbanks, Alaska.

Mojica, J. & Valentino, M. T. 2009. Alteración hidrotermal del área geotérmica de Paipa. INGEOMINAS. Documento de trabajo. 66 p. Bogotá.

OLADE, ICEL, CONTECOL & GEOTÉRMICA ITALIANA. 1982. Estudio de reconocimiento de los recursos geotérmicos de la república de Colombia. 7 Volúmenes. Pisa.

Rodríguez, G. Z., Alfaro, C., Caracterización de núcleos de perforación en las zonas de El Durazno, Paipa y criptodomo de Iza. Servicio Geológico Colombiano. Bogotá. 97 p

Rueda, J. 2017. Cartografía de los cuerpos dómicos del área geotérmica de Paipa. Servicio Geológico Colombiano. Bogotá.

Velandia, F. 2003. Cartografía geológica y estructural sector sur del municipio de Paipa. Ingeominas, 32 páginas. Bogotá.