Preliminary assessment of Nevado del Ruiz geothermal potential from laboratory measurements of thermal properties

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INTRODUCTION

Colombia is an attractive country for geothermal energy production due to the presence of recent volcanic activity, in the central and western Andes mountain ranges, where occurs the convergence of Nazca and South American tectonic plates (Figure 1).

The Nevado del Ruiz is an active stratovolcano located in Los Nevados Natural National Park, in the middle of the central mountain range (Figure 2).

Geothermal research in this region began in 1968 with a geothermal regional reconnaissance study. (Alfaro et al., 2000).

Figure 1. Geothermal development in Colombia from Mejia et al., 2014

The first exploratory well was drilled in 1997, at the West side of the volcano. The well could not reach the planned depth of 2000 m because it deviated, up to 42 degrees, and reached only a depth of 1466 m. Nevertheless, seven lithological units with hydrothermal alterations were identified and the measured bottom-hole temperature was about 200 °C.

Recent researches concerned hydrothermal alteration (Forero, 2012), kinematic characteristics of westward faults (Mejia, 2012), geochemical and thermal evolution (Rayo, 2012), and geoelectrical resistivity surveys (Rojas, 2012). Other studies showed that faults may act as preferential flow paths for geothermal fluids (Mejia et al., 2012). Nevertheless, there are no published studies about rock thermal properties.

This work focuses on the evaluation of thermal properties (thermal conductivity and specific heat) of 62 rock samples collected in surface outcrops during a field trip in November 2014. These thermal properties coupled to heat flow values, allowed to estimate temperatures at depth and to provide a preliminary assessment of the geothermal resources.

Figure 2. Nevado del Ruiz from Servicio Geológico Colombiano (2014).

GEOLOGICAL SETTING

Metamorphic and igneous formations with different deformation degrees dominate the sector (Figure 3) (Mejia et al., 2012).

Pes (Cajamarca complex): ensemble of metamorphic rocks.
Kvc – Ksc (Quebrada Grande complex): group of volcanic and sedimentary rocks.
Kpgcdm (Manizales stock): granitoids rock with an intense jointing.
NgQa (Andesitic lava flows): thick layer of extrusive rocks

Also there are several superficial deposits, product of the volcanic activity in the quaternary period:

Qto: pyroclastic rocks
Qfl: volcanic mud flow deposits
Qg: glacial deposits
Qar: recent alluvial deposits

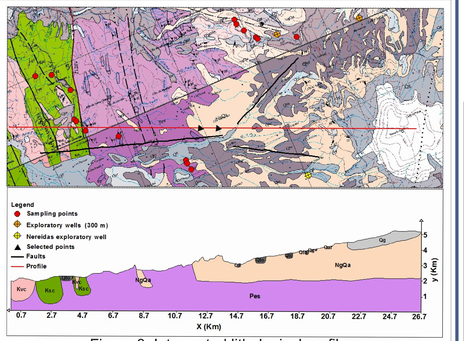

Figure 3. Interpreted lithological profile

THERMAL CONDUCTIVITY AND SPECIFIC HEAT DATA

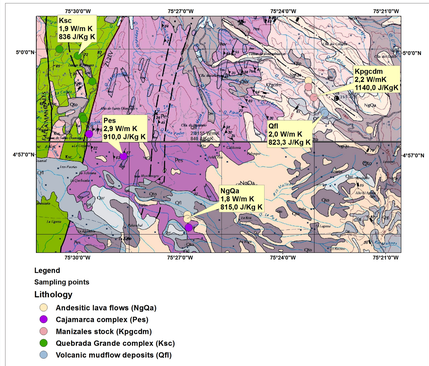

Figure 4. Results of thermal conductivity and heat capacity analysis

The thermal conductivity was measured in 62 rocks samples collected from the north and western flank of Nevado del Ruiz Volcano, using the thermal properties analyzer, KD2 Pro (Figures 4 and 5). The probe consists of a needle with a heater and a temperature sensor inside. Electric current is passed through the heater and the temperature of the probe is monitored over time. An analysis of the probe temperature is used to determine thermal conductivity (Decagon Devices Inc., 2008).

The specific heat of rock samples was estimated from values published by Waples and Waples (2004), for different types of rocks.

The thermal conductivity values obtained for the different formations did not show a large variation: most of these values were close to 2.0 $Wm^{-1}K^{-1}$. Only the Cajamarca complex showed a greater value of 2.9 $Wm^{-1}K^{-1}$ (Figure 4). The heat capacity ranged between 815 and 1140 $JKg^{-1}K^{-1}$, with an average value of 916 $JKg^{-1}K^{-1}$.

TEMPERATURE AT DEPTH

The temperature at depth was estimated according to Fourier's law

$q = -\lambda * dT/dz$

$T_z = T_0 + q*(dz/-\lambda)$

q: heat flow ($W\,m^{-2}$)
$-\lambda$: rock thermal conductivity ($W\,K^{-1}\,m^{-1}$)
z: depth (m)
T_z: reservoir temperature (K)
T_o: surface temperature (K)

The heat flow value (q) for the area was calculated according to the temperature gradients from two exploration wells reaching a depth of 300 meter (Rojas, 2012). The average heat flow equals to 187.3 $mW\,m^{-2}$ was used to estimate the temperature at depth (Figure 6).

Figure 5. KD2 Pro probe during a measurement of thermal conductivity of a rock sample

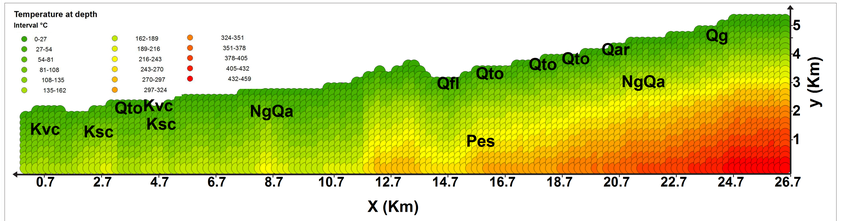

Figure 6. Temperature at depth along the selected lithological profile

RESSOURCE ASSESSMENT

A geothermal resource assessment was carried out to establish the amount of heat that is available underground to produce electricity or some other form of work.

The heat content was initially determined with:

$Q_r = \rho * C * A * (T_r - T_o)$
Q_r: heat available in the reservoir ($J\,m^{-1}$)
ρ: density of the reservoir rock ($Kg\,m^{-3}$)
C: heat capacity of the reservoir rock ($J\,Kg^{-1}\,K^{-1}$)
A: area of the reservoir (m^2)
T_r: reservoir temperature (K)
T_o: surface temperature (K)

The reservoir width was difficult to determine for the study area; therefore the amount of heat available in the reservoir was estimated by unit length (MJ/m).

The geothermal potential was estimated according to a recovery factor since it is not possible to extract the total heat content of the underground. This recovery factor is defined by the ratio between the utilizable energy versus the available energy (Calcagano et al., 2014) and it depends on the porosity and permeability of the reservoir formation (Walsh, 2013).

In this study, a recovery factor (R) of 2.4% has been used, this value is reported by Calcagano et al., (2014) as the minimum recovery factor for fractured aquifers. The power generation potential (Table 1; Gp (MW)) was calculated according to the next equation:

$Gp = R * (Q_r/t) * h$

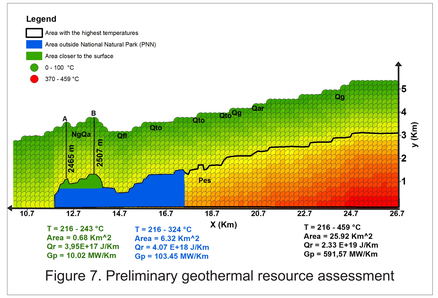

Figure 7. Preliminary geothermal resource assessment

assuming an exploitation period (t) of 30 years and a reservoir width (h) of 5 Km.

The resource assessment was made in the region with temperatures over 216 °C, nevertheless a large portion of this area belongs to the Los Nevados Natural National Park (NNP) and it cannot be exploited. Therefore the evaluation focused on the area outside the NNP (figure 7), and finally on a smaller area where exploitation of geothermal resources can be economical and environmental feasible.

Table 1. Estimation of the power generation potential

	Area with T>216 °C	Area outside NNP	Area closer to surface
Power generation potential (MW)	**2958**	**517**	**50**

CONCLUSIONS

The temperature estimated at depth allowed to identify an area of 25.9 Km^2 with temperatures between 216 and 459 °C, ranging from 2200 to 5300 meters below the surface. These temperatures occur in the andesitic lava flows (NgQa) and Cajamarca complex (Pes) formations. A large part of the area is located inside Los Nevados Natural National Park, therefore only an area of about 6.3 km^2 can be considered like a potential geothermal reservoir.

Currently, the main source of power generation in the region is hydropower. This area has 3 main hydroelectric power plants: San Francisco (135 MW), Esmeralda (30 MW) and Insula (20 MW). Considering the above information, the estimated geothermal potential (50 MW), constitute a significant contribution to the diversification of the power generation sources in the region.

Geothermal resource assessment depends on reservoir volume and recovery factor; in consequence, an improved estimation of Nevado del Ruiz geothermal potential will require further studies to determine reservoir volume and to provide a better estimation of the recovery factor.

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