Review of Geothermal Tenements Held by Hot Rock in Peru and Early Exploration Results

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ABSTRACT

Hot Rock Limited (ASX Code: HRL) a public company listed on the Australian Stock Exchange successfully established Hot Rock Peru SA (HRP) in 2009, to explore for prospective high enthalpy geothermal prospects throughout Peru. The volcanic geothermal setting in Peru is very similar to Chile and presents excellent potential for the discovery of geothermal reservoirs suitable for electricity generation.

Subduction of the Nazca tectonic plate beneath the South American plate has produced an almost continuous line of active and dormant volcanoes along most of the length of both Chile and Peru. Within the volcanic belt of Peru, more than 500 geothermal springs have been identified. It is clear that Peru has high potential for the development of volcanic geothermal resources for both electricity generation and direct use in the same manner as has been undertaken over the past 50 years around the Circum Pacific Rim in countries such as New Zealand, PNG, Indonesia, Philippines, Japan, Russia, the western US, Mexico and Central America, where approximately 7,000 MWe of geothermal power has been installed and is now operating.

An initial desktop analysis of geothermal prospects by HRL in 2009 and a series of subsequent reconnaissance field investigations located a number of high to moderate temperature geothermal fields in the south-central area of Peru. These prospects have extensive surface geothermal activity with chemistries typical of large volcanic geothermal systems which have been developed elsewhere in the world. The evidence from chemical geothermometry studies to evaluate subsurface temperatures suggests minimum reservoir temperatures ranging between 180 to 250°C.

At the time of writing, HRP is preparing detailed exploration surveys including geochemical studies, magneto-telluric resistivity surveys and is continuing land access investigations and community education programs in all granted and soon to be granted concessions.

1. Introduction

Since late 2009, HRP has filed 10 exploration applications in Peru, covering 9 prospect areas for undertaking detailed surface exploration studies (Fig. 1). Table 1 shows the concession details for all 10 concessions applications made by HRP. Four of these applications (Quellaapacheta, Chocopata, Turu and Rupha) have now been granted and the others are at an advanced stage of evaluation by the Peruvian authorities. HRP expects at least two further concessions to be awarded during 2012 (Ocururane, and

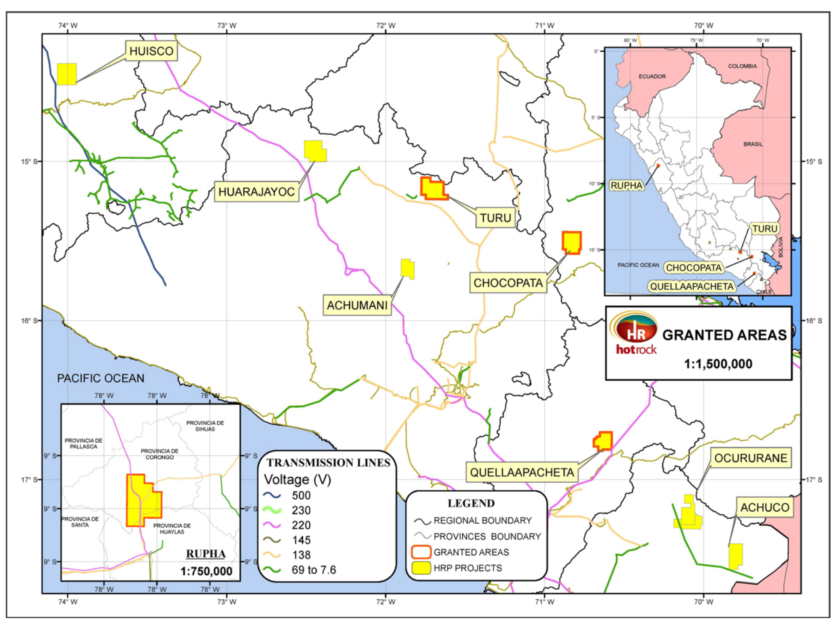

Figure 1. Transmission lines and Hot Rock concessions to May 2012. Granted concessions are outlined in red.

Achumani). The HRL applications are all well located with respect to delivering geothermal electricity into both major transmission grid facilities and to off-grid mine sites (Fig. 1).

This paper provides a description of the four granted areas that HRL hold in Peru and summarizes recent reconnaissance field work undertaken by HRP. Preliminary conceptual models of the geothermal reservoirs are presented, which are the basis for planning future exploration work programs.

2. Peru – A Rapidly Developing Economy

The regulatory and commercial environment in Peru has been progressively developing over the past decade and Peru is now seen by the international community as a rapidly modernizing economy following a similar pathway to that which has led Chile to make spectacular economic and social advances over the past two decades. From 2008 to 2010 Peru has sustained a GDP growth rate in excess of 8%. GDP growth for 2012 is predicted to be 4.5%, down from 6.8% in 2011, and to increase to 5% in 2013 (Figure 2).

Peru is now enjoying its longest economic expansion on record, with low inflation, a solid external position and declining indebtedness ratios. Public expenditure has been reduced through the abolition of subsidies and the privatization of state owned companies. Trade barriers have been cut, direct subsidies to exporters and domestic producers have been eliminated, and equal treatment has been granted to foreign and domestic investors.

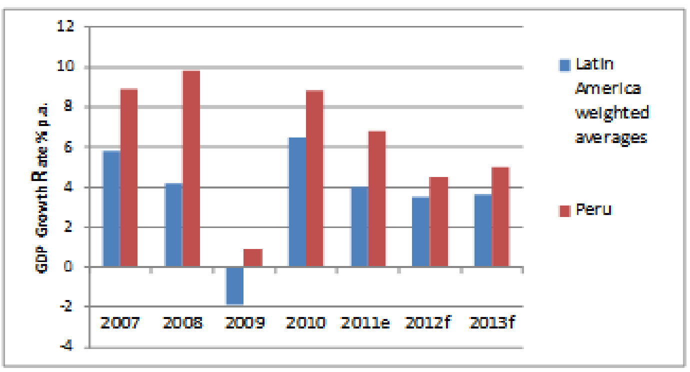

Figure 2. High GDP growth in Peru. Figures for 2011 are estimated, and for 2102 and 2013 are projected (Source: Standard and Poors, 2012).

From a country risk perspective, Peru represents an improving and increasingly attractive commercial environment. It has a current Fitch investment rating of BBB with a "Stable" outlook (Figure 3).

A number of Government and major mining and energy projects, particularly relating to the Camisea natural gas field, combined with growing exports of minerals, textiles and agricultural produce, are continuing to sustain high investment levels in Peru.

COUNTRY	Moodys RATING	Moody OUTLOOK	Fitch RATING	Fitch OUTLOOK	S and P RATING	S and P OUTLOOK
Chile	Aa3	STABLE	A+	STABLE	A+	POSITIVE
Mexico	Baa1	STABLE	BBB	STABLE	BBB	STABLE
Brazil	Baa2	POSITIVE	BBB	STABLE	BBB	STABLE
Peru	Baa3	POSITIVE	BBB	STABLE	BBB	STABLE
Colombia	Baa3	STABLE	BBB-	STABLE	BBB-	STABLE
Panama	Baa3	POSITIVE	BBB	STABLE	BBB-	POSITIVE
Uruguay	Ba1	STABLE	BB	POSITIVE	BB+	STABLE
Paraguay	B1	STABLE			BB-	STABLE
Venezuela	B2	STABLE	B+	STABLE	B+	STABLE
Argentina	B3	STABLE	B	STABLE	B	STABLE

Figure 3. Investment ratings for South American countries.

3. The Peru Electricity Sector

Electricity generation in Peru currently comes largely from thermal and hydroelectric sources. The country has a total installed generation of 7,200 MW in terms of plant capacity, from which some 32,500 GWh of generation p.a. is achieved. Approximately 45 % of generation comes from hydroelectric sources and 55% from thermal fuel sources. Some 85% of present generation enters the electricity market, with the remaining 15% generated for self-consumption. The National Interconnected Grid System (SEIN) (as shown in Figure 1) serves 85% of the connected population, with several "isolated" systems covering the rest of the country (Urzua, 2009).

Since 2006, with increased awareness of global climate change, the impact of gas-fired thermal electricity generation on the environment, and estimates that that electricity demand will increase between 6.1 to 8.5 % per annum between 2010 to 2017, Peru has been vigorously promoting the generation of electricity through non-traditional renewable energy generation processes (geothermal, wind, solar etc.). This interest has been formalized in Government Decree 1058 (of June 27, 2008) which aims to promote the generation of renewable power through providing significant tax incentives (Urzua, 2009). This new law, along with other new legislation, provides a favourable governmental as well as legal and regulatory framework for geothermal exploration and geothermal power production in Peru.

HRL's entry into the Peru geothermal power market is very strategic and builds upon the strong technical, logistics and knowledge base that HRL has developed in Chile over the past four years. Of particular significance with this is the first mover advantage that HRL has achieved for securing and developing geothermal prospects that appear to be as good as some of the best volcanic geothermal systems anywhere in the world.

These factors together with the rapidly developing and modernizing Peru economy; a high demand for new power generation to support, in particular, a very large mining industry; recognition by the Government of Peru that the development of renewable power sources is essential to the future well being of the country, given the finite nature of the countries gas reserves, and considerable uncertainty with hydropower given the rate of deforestation in the Amazon forest catchments; all auger well for HRP becoming a major long term renewable energy company in Peru.

4. Granted Prospects and Exploration Work

To date four of the HRP applications (Quellaapacheta, Chocopata, Turu and Rupha) have been granted. Details are given in Table 1.

4.1 Quellaapacheta

The Quellaapacheta exploration concession is located 120 km north of Tacna, near the town of Calacoa along the Putina river in the province of Moquegua. It covers 126 km^2 of highly prospective ground for high enthalpy volcanic geothermal systems. Access is through a paved road from Moquegua to Carumas.

The Quellapacheta project is associated with the Ticsani Volcano in the Peruvian Southern Cordilleran Volcanic Zone. The suite of springs around which this concession is located consist of more than 15 springs discharging along the Putina and Cuchumbaya rivers, tributaries of the Rio Tambo with temperatures ranging from 54°C to 89°C and with pH levels from 5 to 8.

Geochemically, the springs are described as chloride and bicarbonate waters indicating the presence of benign geothermal reservoir fluids at depth. Carbonate and silica sinter are reported as deposition products around the surface thermal features (Steinmuller and Nunez, 1998; Urzua and Vargas, 2011). Steaming ground and fumaroles have recently been discovered by HRP near the summit of the Ticsani volcano (Figure 4).

Table 1. Summary details on HRP's geothermal concessions in Perú.

Concession	Location	Area (Km2)	Lodgement Date	Status	Grant Date	Term (yrs)
Achumani	Region of Arequipa	108	Submitted: 4/12/2009 Resubmitted: 6/08/2010	Processed. To be granted in October 2011		
Quellaapacheta	Region of Moquegua	126	Submitted: 5/12/2009 Resubmitted: 6/08/2010	Granted	6/04/2011	3
Ocururane	Region of Tacna	153	Submitted: 5/12/2009 Resubmitted: 6/08/2010	Application resubmitted and under process		
Achuco	Region of Tacna	153	Submitted: 5/12/2009 Resubmitted: 6/08/2010	Application resubmitted and under process		
Rupha	Region of Ancash	171	Submitted: 15/02/2010 Resubmitted: 6/08/2010	Granted	12/02/2011	3
Turu	Regions of Arequipa/ Cuzco	198	Submitted: 15/02/2010 Resubmitted: 6/08/2010	Granted	05/12/2011	3
Huarajayoc	Region of Arequipa	198	Submitted: 2/09/2010	Under publication process from 05/11/10		
Chocopata	Region of Puno	171	Submitted: 10/09/2010	Granted	18/03/2011	3
Huisco	Region of Ayacucho	195	Submitted: 07/2011	under process		
Ocururane sur	Region of Tacna	126	Submitted: 07/2011	under process		

An initial hydro geological conceptual model for the Quellapacheta prospect is for a geothermal system to be most likely located at depth near the Ticsani fumaroles. This deep primary water being hot and thermally buoyant most likely flows upwards and outwards from the centre of the system, with a long lateral outflow reaching the surface in the Carumas river area (Putina, Secolaque springs) and likely other locations, yet to be discovered (Urzua and Vargas 2011).

Shallow reservoir temperatures have been estimated from silica geothermometers at 181°C to 184°C and temperatures in the deep primary geothermal water are indicated from cation geothermometry to be 240°C (Urzua and Vargas, 2011).

The discovery of the steam fed surface manifestations at high elevation combined with the presence of chloride rich springs waters actively depositing silica sinter in peripheral basal portions of the Ticsani volcano together with good geochemical evidence for high reservoir temperatures, provide strong evidence that Quellaapacheta is a classic steep terrain, high temperature geothermal volcanic system.

4.2 Chocopata

The Chocopata exploration concession is located 120 km north east of Arequipa and 90 km North West of Puno at an average altitude of 4370 meters amsl. It covers 171 km^2 of ground that is highly prospective for high enthalpy volcanic geothermal systems. The tenement is flanked to the North, East and West by three 138 kV transmission lines all of them located at about 70 km from the centre of the tenement.

Geologically, the area lies between the Andean Volcanic belt and the Altiplano plateau in the Lampa province, Department of Puno. Intrusives and volcanic deposits associated with the Turputa Caldera located inside the tenement area are suggested as potential heat sources.

The main thermal area is called Pinaya which is close to the southern edge of the tenement. This is characterized by numerous hot springs with temperatures ranging between 40 to 90 °C, with neutral pH chemistry and relativity high flow rates of about 10 l/s (Huamani A., 2001; Urzua and Vargas, 2011). Two further thermal areas have been identified inside the tenement at Quebrada Jarpaña and Chupahuito. Thermal springs at Quebrada Jarpaña have measured temperatures above 50 °C and show active silica sinter deposition. Chupahuito is located to the north of Jarpaña and has hot springs with measured temperatures exceeding 60 °C (Figure 5).

The chemistries of the springs at Chocopata together with their geological setting suggest deep primary geothermal water likely located near the Chupahuito thermal features. This primary water would flow both upwards and outwards from the centre of the system, reaching the surface at Jarpaña, Pinaya and likely other locations, yet to be discovered. From cation geothermometry considerations temperatures in the deep primary geothermal water are expected to be at least 210°C (Urzua and Vargas 2011).

The geological setting of the Chocopata prospect, the very prospective indications from spring geochemistry and proximity to the national grid highlight the excellent potential this prospect has for commercial development.

4.3 Turu

The Turu project is located in the volcanic area of the Andes covering several districts - Caylloma, Sibayo and Cabanaconde, province of Caylloma in Arequipa Region and the district of Suyckutambo, province of Espinar in Cusco Region. It covers 198 km^2 of prospective ground for high to moderate temperature geothermal system. Access is by paved road from Arequipa to the town of Sibayo and then unpaved road to the project area near the town of Caylloma.

The reconnaissance and sampling work undertaken by (HRP in Turu confirms INGEMMET's previous findings on the presence of 3 thermal features within the concession (Steinmuller and Bilberto, 1997; Urzua and Vargas, 2012). In 2011, personnel from HRP collected water samples from these springs (Coñicmayo, Cencuyo and Pusa Pusa) and two additional cold springs: Mario Catasi and Quecarahui.

The geological setting provides good indications for primary and secondary permeability for geothermal fluid flow. Primary permeability can be expected in the volcanic formations of Orcompampa (lavas and tuffs) Fm Ichicollo (tuffs interfingered with agglomerates) and deposits associated with the Caylloma Caldera. Secondary permeability is likely in the Mesozoic rocks affected by NE-SW stresses generating local faults and structures. In the northern part of the concession, many Paleocene - Pleistocene volcanic formations are affected by normal faults and lineaments with NW-SE direction (i.e., the regional Andean structural trend). A major structure within the concession is the Caylloma Caldera which surrounds Cosana hill and appears to control the location of the three main hot springs in the concession (Urzua and Vargas, 2012).

Cl/B ratios and Cl-Li-B relationships in spring waters from the three main hot springs at Turu suggest they all originate from a common source of hot water/rock interaction i.e. from a single geothermal reservoir (Urzua and Vargas, 2012). On the other hand, Mario Catasi and Quecarahui likely originate from a different source, most likely associated with rain water interacting with Miocene altered deposits.

The field evidence suggests that there is a hot geothermal reservoir of primary chloride water at depth in the Turu prospect area. This upflows and outflows to surface springs at Coñicmayo, Cencuyo and Pusa Pusa after mixing with shallow cold water (Urzua and Vargas, 2012). This would explain both the relatively high Cl levels (approx. 1000 ppm) content in these features and the sub boiling temperatures at the discharge points (Steinmuller and Bilberto, 1997; Urzua and Vargas, 2012).

The hot springs at Pusa Pusa are geochemically mature water and are thus well suited to application of cation geothermometry to estimate potential deep geothermal temperatures. In addition, geothermometers gives some indication of local geothermal temperatures around the hot spring surface discharge points at Conicmayo and Cencuyo in spite of these being less geochemically mature. In contrast, the Mario Catasi and Quecarahui springs are geochemically classified as waters of secondary, near surface origin and thus provide no indications of geothermal conditions at depth. The indications from cation geothermometry for the Turu springs are for temperatures in deep primary geothermal water of at least 180°C.

On the basis of the available information, two preliminary conceptual models can be proposed for Turu (Urzua and Vargas, 2012):

(1) A primary geothermal upflow from a geothermal system most likely located near the main heat source (Cerro Cosana? or Cerro Ichocollo? or Cerro Chiticocha?), which reaches the surface after near surface shallow mixing and cooling at the Coñicmayo, Cencuyo and Pusa Pusa springs and likely at other locations, yet to be discovered .

(2) An alternative conceptual model is for a medium enthalpy system (≤180°C) associated with a deep fracture(s) (Caylloma Caldera?) that allow groundwater to circulate to depth. Upon heating at depth, the water flows upwards within the fractures and outwards, probably within shallower aquifers with primary permeability. In this model, the heat source would most likely be associated with the Pliocene-Pleistocene volcanic deposits of the Caylloma Caldera.

4.4 Rupha

Rupha is located in the central-north Andean Mountain, in part of the districts of Yuracmarca, province of Huyalas and the districts of Aco, Yupan, La Pampa, Cusa, Yanac and Corongos, province of Corongos in Region of Ancash. It covers 171 km^2 of ground that is prospective for high to moderate temperature geothermal systems. Access is by paved road from the city of Huaraz to the town of Caraz, and then to the area of Rupha via an unpaved road.

The project is directly associated with the Neogene tonalite-granodiorite batholith of the Cordillera Blanca in central Peru. It is considered that this batholith hosts either a deep and/or shallow geothermal reservoir from which the thermal features in the area originate. The most likely heat source is young intrusions (≤ 2 Ma) within the batholith system providing direct or remnant heat to the current, active geothermal system (Urzua and Vargas, 2012).

There are three areas of springs within the concession, Aticara, La Pampa and Pacatqui-Aquilina (Figure 6). These emanate from quaternary deposits or directly from the Neogene tonalite-granodiorite. The range in temperature from 25°C to 83°C with pH levels ranging from 3.2 to 9 (Huamani A., 2000; Urzua and Vargas, 2012). The springs can be classified as sulphate and chloride-bicarbonate waters suggesting the presence of a benign geothermal reservoir at depth. Additionally, the Pacatqui-Aquilina springs deposit carbonate and silica sinter? while La Pampa springs deposit sulphur (Huamani A., 2000; Urzua and Vargas, 2012).

Geothermometry temperature estimates using the chalcedony quartz geothermometer indicate near surface temperatures in the steam heated water beneath the springs at Pacatqui-Aquilina ranging up 112°C; while cation geothermometers estimate temperatures at greater depth/ distance from the steam heated feature could be as high as 226°C (Urzua and Vargas, 2012).

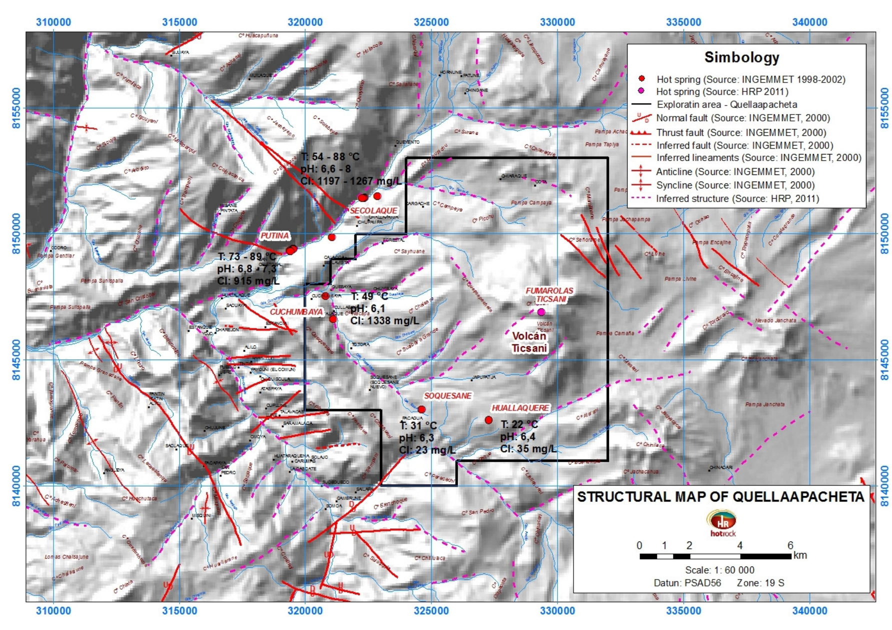

Figure 4. Quellaapacheta key elements map (Urzua and Vargas, 201l).

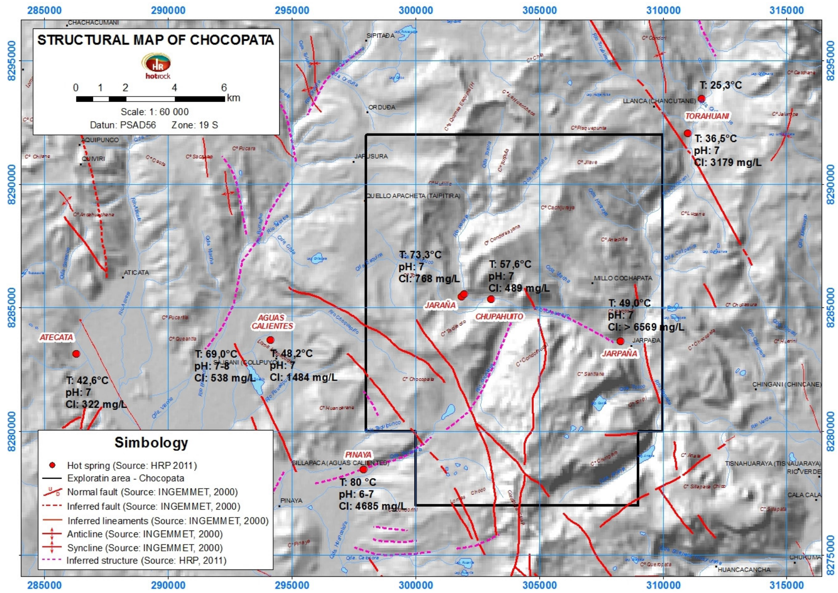

Figure 5. Chocopata key elements map (Urzua and Vargas, 2011).

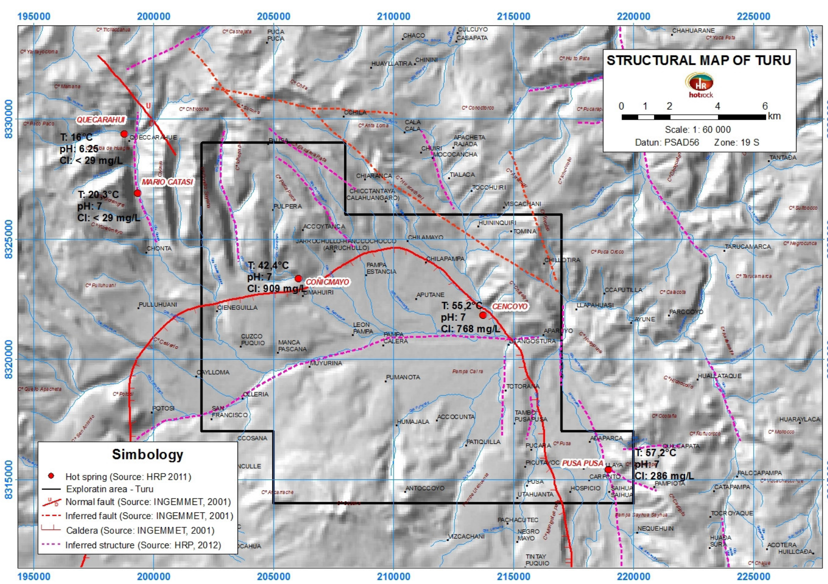

Figure 6. Turu, key elements map (Urzua and Vargas, 2012).

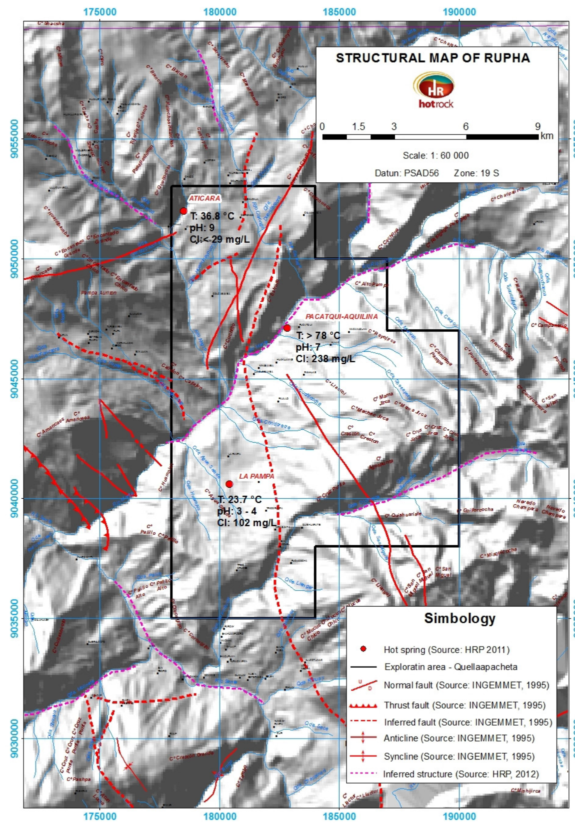

Figure 7. Rupha, Key elements map (Urzua and Vargas, 2011).

Based on the available information, two conceptual models are proposed for Rupha (Urzua and Vargas, 2012):

(1) A high enthalpy model in which a primary geothermal water upflow from a geothermal system located near La Pampa reaches the surface after mixing and cooling at the Pacatqui – Aquilina and Aticara springs.

(2) A medium enthalpy model in which deep fractures within the tonalite allow groundwater to circulate to depth where heating generates a rising hot fluid which rises and flows upwards within fracture and outwards within shallow aquifers providing lateral primary permeability.

In both cases the heat source would likely be associated with a recently emplaced intrusives and/or remnant heat from late stage intrusions within the Neogene tonalite.

The presence of almost boiling chloride - bicarbonate water actively depositing travertine and silica sinter? combined with potential high reservoir temperature estimates, suggest that Rupha is an attractive high to moderate temperature geothermal system.

5. Conclusions

HRL's entry into the Peru geothermal power market is very strategic and builds upon the strong technical, logistics and knowledge base that HRL has developed in Chile over the past two years. Of particular significance is the strong first mover advantage that HRL has gained for securing and developing geothermal prospects that appear to be as good as some of the best volcanic geothermal systems anywhere in the world.

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