Geothermal Exploration at Irruputuncu and Olca Volcanoes: Pursuing a Sustainable Mining Development in Chile

Nicolás Reyes[1], Ariel Vidal[2], Ernesto Ramirez[2], Knutur Arnason[3], Bjarni Richter[3], Benedikt Steingrimsson[3], Orlando Acosta[1], Jorge Camacho[1]

[1]Compañía Minera Doña Inés de Collahuasi
[2]Geohidrología Consultores Ltda.
[3]ISOR Iceland GeoSurvey

Keyword

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ABSTRACT

Doña Inés de Collahuasi Mining Company which is the third major copper producer in Chile is pursuing a sustainable development by exploring geothermal resources. Currently the mining operation requires 180MW of electric power, which is derived from fossil fuels. However, the company´s objective is to obtain at least 35MW from renewable energy sources by 2015. The geothermal exploration is focused around the Olca and Irruputuncu volcanoes in the Chilean Altiplano at 4000-5000 m a.s.l. in the vicinity of the copper mine.

Irruputuncu is an active dacitic stratovolcano, with fumaroles at the top crater and one acid-sulphate hot spring at the base of the volcano. Two slim boreholes (~800 and ~1430 m depth) evidenced a sequence dominated by tuffs, breccias and minor lava flows, with bottom hole temperatures close to 150ºC and 195ºC (at ~3350 and 3000 m a.s.l., respectively). Both wells are dominated by argillic alteration assemblages and conductive temperature profiles, pointing to a potential deeper reservoir (>220ºC), as suggested by TEM-MT data.

Olca is an andesitic volcano with fumaroles at the crater and one neutral warm spring at the base. The 3D inversion of TEM-MT data evidences two conductive layers intercalated with resistive zones. Shallow drilling at the base of the volcano confirms the occurrence of hot water aquifers (up to 70ºC) and a zone dominated by smectite clays which is coincident with the shallow conductor layer. Preliminary results suggest a potential of electric generation between 75 and 450 MWe. Deep drilling is planned for late 2011 to characterize the potential deep reservoir, below the deep conductor.

Introduction

Doña Inés de Collahuasi Mining Company (CMDIC) is the third largest copper producer in Chile. In its commitment to sustainable development, and its need for safe and clean energy as part of its energy matrix, CMDIC has chosen to explore and evaluate geothermal resources in the proximity of its copper mining in the north of Chile (Figure 1). Currently the mining operation requires 180MW of electric power, which is mainly derived from fossil fuels. The company objective is to obtain at least 35MW from renewable energy sources by 2015.

CMDIC has a set of geothermal exploration permits in the proximity of the mine around the Irruputuncu and Olca volcanoes.

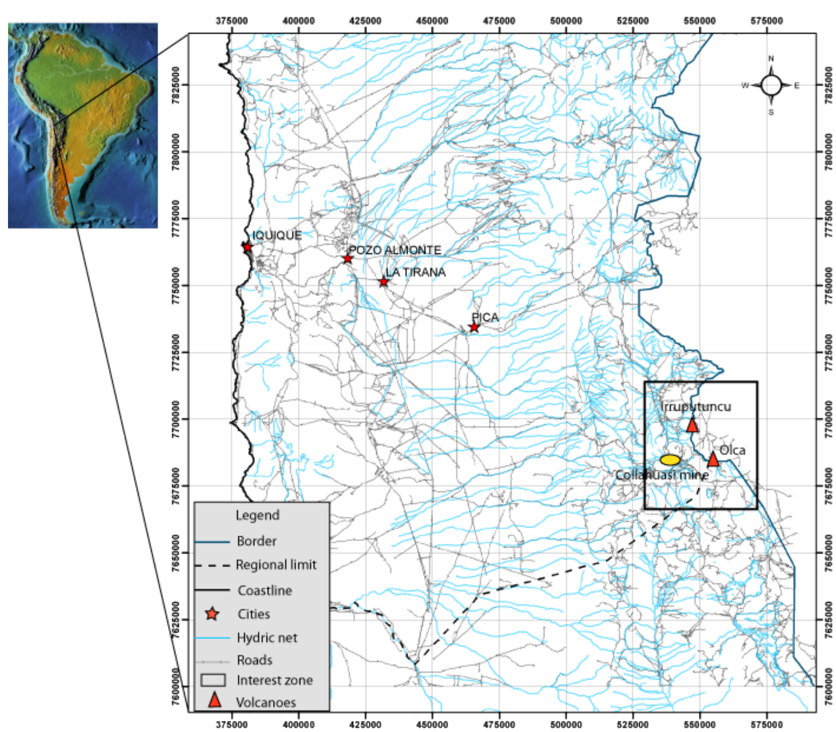

Figure 1. Location map of the Irruputuncu and Olca volcanoes.

Beside electric generation, the company is also considering the possibility of direct uses of the geothermal resources. This initiative contributes to achieving sustainable growth and reducing carbon emissions.

This paper presents the results obtained from the first exploration stage on those permit areas, which included geological and structural studies, resistivity surveys and exploration well drilling.

Geological Background

The CMDIC mine area is located close to the border between Chile and Bolivia, in the volcanic front of the Altiplano plateau. The rocks are dominated by volcanic products like andesitic-dacitic lava flows, ignimbrites and volcanogenic sediments, and non-consolidated glacial deposits. The area is also characterized by the presence of salt flats and evaporitic sequences in the lowest parts of the basins (Gardeweg & Salas, 2011a, 2011b).

The Irruputuncu volcano (5,163 m a.s.l.; 16,939 f a.s.l.) is a stratovolcano composed mainly of a succession of dacitic lava flows intercalated with minor tuffs and breccias. It is located at the north part of an N-S-trending chain of volcanic centers dating from the Miocene to the present (Gardeweg & Salas, 2011a). Irruputuncu is the youngest volcano of this N-S chain, and was constructed within the collapse scarp of a debris avalanche whose deposit extends to the SW. Subsequent eruptions partially filled this scarp and produced thick, viscous dacitic lava flows down the western flank of the volcano. The summit complex contains two craters, but only the southernmost has active fumaroles. The first unambiguous historical eruption from Irruputuncu took place in November 1995, when phreatic explosions produced dark ash clouds (Smithsonian Institution, Global Volcanism Program), although others authors have reported volcanic activity in 1960 and 1989 (Petit-Breuilh, 1995). At the base of the volcano it is located one acid-sulphate hot spring.

The Olca volcano (5,407 m a.s.l.; 17,740 f a.s.l.) lies in the westernmost part of a 15-km-long E-W lineament of several stratovolcanoes with Holocene lava flows, located ~25 km to the south of Irruputuncu. Olca is flanked on the west by Volcán Michincha and on the east by Volcán Candelaria Este, which is immediately to the west of the higher pre-Holocene Paroma volcano. Olca volcano is mainly composed of andesitic lava flows that extend as far as 5 km from the active crater, and minor volcanic debris, avalanches and glacial deposits (Gardeweg & Salas, 2011b). Olca volcano has displayed persistent fumarolic activity in recent years and has one neutral warm spring at the base.

The only known historical volcanic activity from the Olca-Paruma complex was a flank eruption of unspecified character between 1865 and 1867 (Smithsonian Institution, Global Volcanism Program).

The regional structural pattern is governed by N-S to NW-SE structures, with local E-W trends, that contributed to the Altiplano uplift and deformation of the basement rocks. However, the recent volcanic and sedimentary cover has obscured some of the main structural lineaments. The basement of the Pliocene-Holocene volcanic activity is composed by a Miocene sequence of ignimbrites, tuffs, breccias and lava flows, that overlays Paleozoic volcanic rocks with local Cretaceous-Eocene intrusive bodies.

Exploration Results

Irruputuncu

The Irruputuncu project is characterized by the scarce occurrence of surface hydrothermal manifestations, but geological and structural surveys suggest favourable conditions for the presence of an active hydrothermal system below Irruputuncu volcano.

The alteration zones observed at the surface are dominated by native sulphur, dickite, alunite with minor cristobalite, and locally opal and gypsum. The mentioned associations suggest an acid-sulphate character of the shallow circulating fluids, which is in agreement with the chemistry and low pH registered in the unique warm spring of the area.

Two magnetotelluric (MT)-transient electromagnetic (TEM) campaigns were done, composed of 45 stations (Figure 2). The first one, conducted between March and April 2009, shows a resistive structure that likely reflects the existence of a high temperature geothermal reservoir (Eysteinsson et al., 2010). The second survey complemented the existing net of stations and was conducted between September and October 2010. The MT-TEM joint 1-D inversion shows that beneath the easternmost part of the survey area, under the western slopes of Irruputuncu volcano, a high resistivity core lies below the low resistivity cap (Figure 3; Hersir & Árnason, 2011).

Two exploratory slim wells have been drilled in the Irruputuncu project (Figure 2). Well PGC01B reached a depth of ~800 m and drilled into a sequence of crystal and lapilli tuffs in the upper part and volcano-sedimentary breccias in the lower part. The alteration mineralogy observed in thin sections and complemented by XRD, is composed mainly of phillosilicates of the smectite group with local subordinate interlayered illite-smectite and illite.

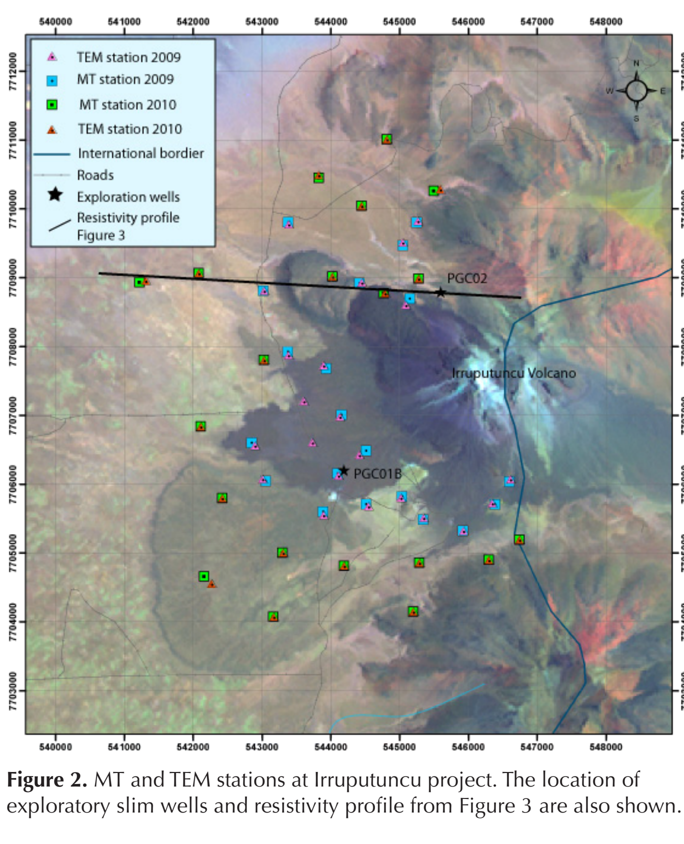

Figure 2. MT and TEM stations at Irruputuncu project. The location of exploratory slim wells and resistivity profile from Figure 3 are also shown.

Several temperature-pressure profiles have been recorded, with a maximum temperature of ~150ºC at 700 m, which is in agreement with the dominance of smectite. The local presence of interlayered illite-smectite and illite at some intervals could be indicative of higher temperature conditions in the past. The dominance of smectite is in agreement with the low resistivity layer evidenced by the MT-TEM survey.

Well PGC02 reached 1430 m deep, and crossed a sequence of volcanic and volcano sedimentary rocks, mainly crystalline and lithic tuffs, with breccia intervals and minor dacitic lava flow in the upper and lower sections. The well formations are characterized by a zoning of alteration minerals with depth, mainly by a progression in the phillosilicates from smectite to interlayered smectite-illite to illite at the bottom of the well. Locally, epidote has been recognized in the deepest part. The temperature profiles recorded a maximum temperature of 193ºC at 1371 m depth, which suggests cooling of the system when compared with the observed alteration mineralogy. The well seems to reach the bottom of the low resistivity layer observed on the MT-TEM 1D inversion, just short of the westernmost part of a characteristic high resistivity core (Figure 3).

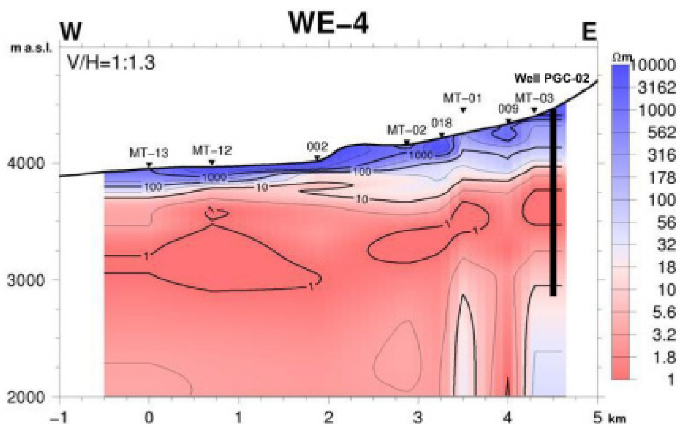

Figure 3. Resistivity cross-section WE-4 from surface to 2 km above sea level (for location see Figure 2). Black vertical line shows well PGC-02.

Both wells are dominated by argillic alteration assemblages and conductive temperature profiles, indicating a potential deeper reservoir (>220ºC), as suggested by TEM-MT data.

Olca

The Olca area is characterized by a scarcity of superficial manifestations and fumaroles are only found at the crater and a single warm spring at the base. Geological and structural characterization of the area has revealed favourable conditions for the development of a geothermal system in the proximity of Olca volcano.

Several alteration zones can be recognized in the field, composed of alunite, dickite, kaolinite, quartz and cristobalite, suggesting the acid character of the fluids at shallow levels. Some abandoned mines for the extraction of native sulphur are present in the area. The alteration zones are

Two MT-TEM campaigns (Figure 4) were conducted at the same time as those at Irruputuncu. The 1-D and 3-D joint inversion of the MT-TEM data shows similar results at shallow depth. The 1-D inversion revealed a shallow low resistivity layer which

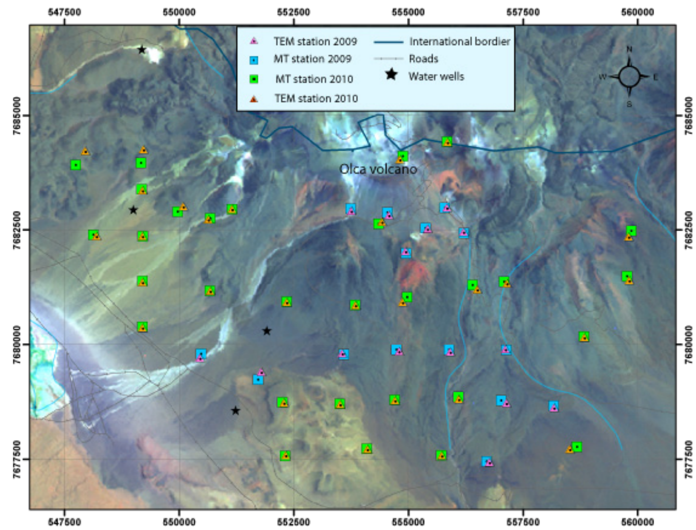

Figure 4. MT and TEM stations at Olca project. The location of exploratory water wells is also shown.

seems, in some places, to have some internal structure which might indicate two layers. The 3D inversion seems to resolve the shallow structure better and shows two shallow low resistivity layers in the central part of the survey area. It also sharpens the picture and reveals extended high resistivity at depth under the Olca volcanic complex below the shallow low resistivity area (Figure 5; Árnason, 2011).

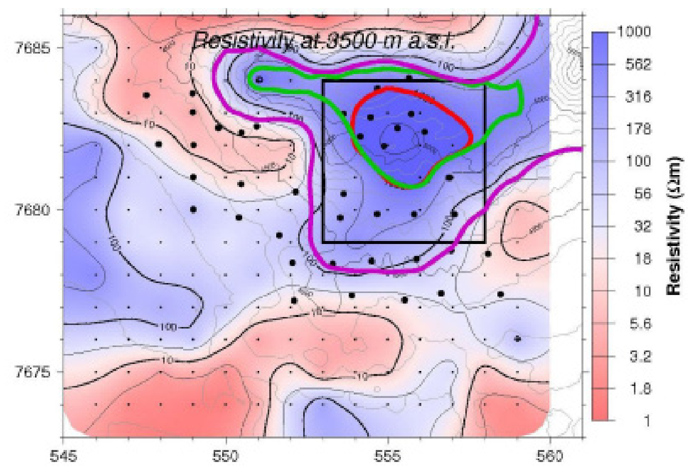

Figure 5. Resistivity at 3500 meters above sea level according to MT-TEM 3D inversion. Three estimates of reservoir size are shown. See text for details.

Exploration water wells (<700m) drilled at the base of the Olca volcano (Figure 4) revealed the existence of an extensive clay cap in a zone characterized by the presence of smectite, locally interlayered smectite-illite, illite and chlorite, along with calcite, anhydrite, laumontite and chalcedony, recognized by thin sections descriptions and XRD analysis. Temperature profiles in these wells recorded temperatures up to 70ºC. This may be the location of a possible outflow zone coming from Olca volcano. This data also suggests that cooling has occurred in some parts of the system as compared to hydrothermal alterations temperature indicators.

Based on the assumption that high resistivity at depth in Olca reflects high temperature alteration, the areal extent of the reservoir can be estimated. Figure 5 shows three estimates, conservative (red–7.5 km^2), likely (green–15 km^2) and optimistic (purple–45 km^2). The depth to the high resistivity is 1500-2000 m and a possible thickness of the reservoir is 2.000 to 3.000 m (Árnason, 2011).

Assuming up to 10 MWe per km^2, depending on the reservoir temperature (230-300°C), which is uncertain at this stage. It is possible to suggest:

1. The smallest area may yield 75MWe
2. The intermediate area may yield 150 MWe
3. The largest area may yield 450 MWe

These numbers are highly hypothetical and should be treated as such. Most of the input parameters are guesswork at this stage. The biggest uncertainty at this stage is the reservoir temperature.

Deep drilling (~2 km) is planned for the end of 2011 to confirm the presence of a high temperature hydrothermal system in Olca and constrain the reservoir temperature and resistivity data.

Concluding Remarks

Doña Inés de Collahuasi Mining Company is conducting an exploration program for geothermal resources in the proximity of the Olca and Irruputuncu volcanoes. This includes the option of power generation and direct uses as well.

Present exploration results suggest the presence of active hydrothermal systems below the Olca and Irruputuncu volcanoes. At Irruputuncu the bottom hole temperatures recorded and the subsurface resistivity structure are in fairly good agreement. The deepest well (PGC02) reach the bottom of the low resistivity layer, which is in agreement with the presence of phyllosilicates like smectite and interstratified illite-smectite. The presence of illite and epidote at the deepest part of the well suggests cooling of the system when compared with the recorded bottom hole temperatures. No information is, however, available on the permeability below the Irruputuncu volcano.

The resistivity structure in the Olca area show similar results from the 1D and 3D joint inversion. The 3D inversion seems to resolve the shallow structure better and shows two shallow low resistivity layers in the central part of the survey area. Existing shallow water wells in the zone shows abundant smectite which is in agreement with the observed geo-electrical structure. The local presence of interlayered illite-smectite and illite suggests hotter previous conditions in the outflow area. Preliminary results suggest a potential of generation between 75 and 450 MWe, however the biggest uncertainty at this stage is the reservoir temperature.

At Olca, deep drilling (~2 km) is planned for the end of 2011 to confirm the presence of a hydrothermal system and constrain the reservoir temperature and electromagnetic data.

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