GEOTHERMAL EXPLORATION IN THE AYSÉN REGION, CHILEAN PATAGONIA

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ABSTRACT

During 2014, a team of researchers from CEGA, along with the Aysén ministry of mining, won a public bidding to develop a 2 year geothermal exploration campaign encompassing the whole region (PGA for the Spanish acronym). In January of 2015, CEGA began an exploration campaign focused on two main objectives: i) To develop a regional geothermal resource assessment and ii) the proposal of a pilot project for the direct use of geothermal energy.

The Aysén region, located in southern Chile, has favorable conditions for the formation of geothermal systems: the existence of shallow magmatic processes, abundant rainfall and active fault systems, along with the occurrence of many high temperature (> 50ºC) geothermal spring waters. Its capital Coyhaique, with ~63,000 inhabitants, is one of the most polluted areas in the country, mainly due to a high amount of wood heating.

Since the onset of the project, there has been an approach on outreach to the general public and the development of scientific documentation. This work documents the main achievements of the campaign so far and elaborates on the importance of a clear state strategy for geothermal progress, as economic feasibility by itself has not been an effective tool for the development of geothermal power plants. The role of outreach in local communities is of paramount importance for the development of direct uses in isolated areas, as it allows a positive feedback between researchers looking for data and potential users looking for solutions.

1. INTRODUCTION

1.1 Geology and geothermal features in the Aysén region.

The geology of western Patagonia, between the latitudes 43.5°S to 47°S, is strongly affected by the subduction of the Nazca and Antarctic plates beneath the South American plate. The main structural feature in the Aysén Region is the Liquiñe Ofqui Fault System (LOFS; Hervé 1976), which runs from the 39°S to 48°S latitude, controlling the location of volcanism and thermal areas. The long-term dextral transpressional regime appears to be driven by oblique subduction. The short-term deformation is in turn controlled by ridge collision from 6 Ma to present day. (Cembrano et al. 2002).

The region has favorable condition for the formation of geothermal systems: the existence of magmatic processes, abundant rainfall (~1200 mm/year) and active fault systems that can allow the circulation and rising of deep fluids. These features are supported by the occurrence of many geothermal spring waters distributed from Raul Marin Balmaceda port to the north until General Carrera Lake in the south, in both coastal and continental zones (Negri et al. 2015). Geothermal springs are located along the Liquiñe-Ofqui fault system (LOFS; Hauser 1997; Hauser 1989) and other distant fractures, with thermal fluids generally emerging from the intrusive host rock of the North Patagonian Batholith, indicating that structural features are controlling the thermal springs while aquifer storage capacity must be controlled by fluid circulation through the fractured zones. This is consistent with a strong interaction between recent tectonic activity and fluid flow in the LOFZ (Legrand et al. 2011).

1.2 Electricity market

Chile pioneered electricity market liberalization in the 1980s. It has changed in part over the years, but maintained its main design features including: (i) independent, private electricity generators; (ii) centralized dispatch; (iii) a generator-only wholesale market to 'trade' short-term differences and (iv) long-term contracts with large users (especially mining companies). Average 2010-2014 contract prices for regulated customers in the central electrical grid (26.5°S to 43.5°S) were US $82.6/MWh with future contract prices varying from US $93 to $125/MWh (Sanchez-Alfaro et al. 2015).

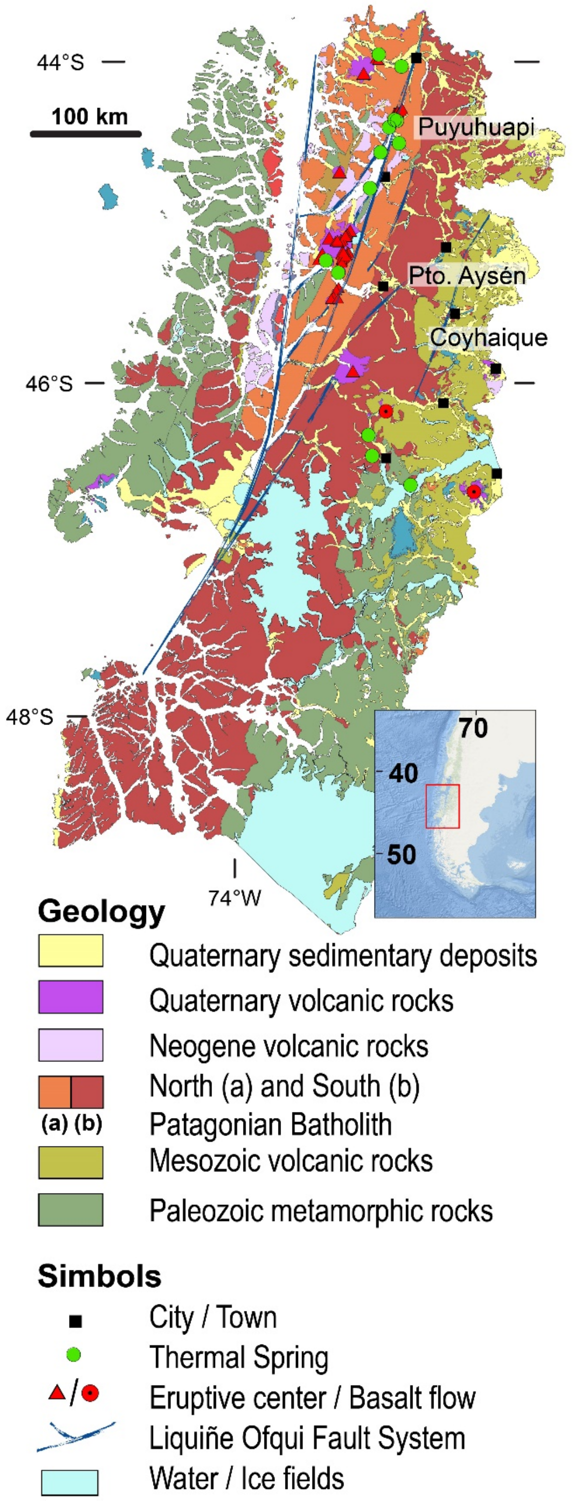
Electricity market in the Aysén region began in a similar context in 1986, when a joint project by the Chilean Development Corporation (CORFO), the national electricity company (ENDESA) and the private company EDELAYSEN started the construction of a complex of small hydropower plants and transmission lines in the soon to be opened Austral road. In 1998, the private company SAESA acquired over 90% of EDELAYSEN and, since then, has controlled the generation, distribution and transmission of electricity in the region throughout five independent small systems: Cisnes, Huichas, Villa O'Higgins, Amengual-La Tapera and Santa Bárbara (Nueva Chaitén); and three median systems: Aysén, Palena and General Carrera, serving over 42 thousand people.

Table 1: Number of power plants, installed capacity and gross production per year in the Aysén region.

	Nº of power plants	Installed capacity (MWe)	Gross production (MWh/year)
Wind	1	1.98	6600
Hydro	7	25.1	112.272
Diesel	18	28.2	42.019
Total	26	55.3	160.891

In November of 2001, the 1.98 MWe wind power plant "Alto Baguales" became the first non-conventional renewable energy power plant in the Aysen region (Table 1). Average 2015-2016 prices for regulated customers in the region varies from US $250/MWh to US $420/MWh (Maripangui et al., this workshop).

Figure 1. Regional geological map. Location of eruptive centers, sampled thermal springs (Table 1) and main cities. Geology modified from (SERNAGEOMIN 2003). Main structures modified from (Cembrano, Hervé, and Lavenu 1996)

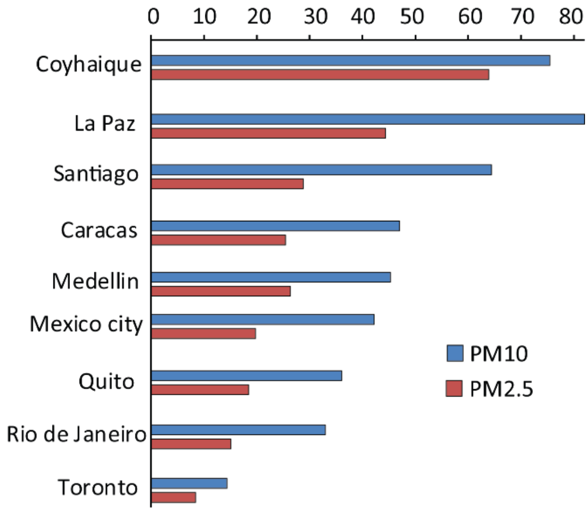


1.3 Heating in Aysén

Wood heating is the major source of particulate matter (PM2.5-PM10) in many cities in southern Chile. This is mainly due to three causes: i) Deficient heating technology, ii) low quality fuel (wet wood) and iii) poor insulation of houses. At least 45% of emissions is related to poor equipment operation. (De La Maza 2010).

The city of Coyhaique is one of the most polluted in South America (Figure 2). In 2012 it was announced as a PM10 saturated area. From 2010 to 2013, the annual and daily concentrations of PM10 were 70%, and 135% higher than the norm, respectively (Maripangui et al., This workshop). On March the 28th of 2016, the decontamination plan for Coyhaique city and surroundings was enacted. It promotes thermal efficiency of houses, replacement of inefficient heating devices and the use of wood with a moisture content below 25%. However, this plan does not refer to replacing polluting wood heating with any renewable source of energy.

Figure 2. Annual concentration of Particulate matter in highly polluted American cities (µg/m^3). Data from (WHO 2016).



2. THE AYSÉN GEOTHERMAL EXPLORATION PROJECT (PGA)

During 2014, a team of researchers from CEGA, along with the Aysén ministry of mining, won a public bidding to develop a 2 year geothermal exploration campaign encompassing the whole region (PGA for the Spanish acronym). In January of 2015, CEGA began an exploration campaign focused on developing a regional geothermal resource assessment.

In two years, some of the main cities of the region have been subjected to hydro-geological, geochemical and geophysical surveys (Table 2). The collected data focusses on 3 targets: i) Exploration of high enthalpy geothermal systems, ii) direct uses of thermal springs and iii) soil thermal properties for the implementation of ground-source heat pumps (GsHP).

For the exploration of high enthalpy geothermal systems we focused on the composition of thermal springs, gravity, magnetotellurics (MT) and transient electromagnetic (TEM) methods (Table 2). The same data coupled with electrical resistivity tomography (ERT) surveys, temperature logging of shallow wells and measurements of soil thermal properties allows a much better understanding of underground water flow in the studied cities, a factor of paramount importance when implementing ground-source heat pump technology.

Table 1. Data collected during the first 18 months of the PGA. *reinterpreted from previous data.

City / Town	Survey / Sample
Coyhaique	Gravity, ERT, TEM, ground temperature, ground thermal conductivity, well temperature gradient.
Puerto Aysén	Gravity, seismic reflection *, fluid sample.
Puyuhuapi	Gravity, TEM, natural seismicity, ground temperature, ground thermal conductivity, fluid sample.
La Junta (El Sauce)	MT, fluid sample.
Puerto Raúl Marín Balmaceda, Puerto Cisnes, Puerto Murta.	Fluid sample.

2.1 Main results

Favored by early gathering of data, after 1 year, many of the original objectives of the PGA were achieved. Three areas show potential for exploration of high enthalpy geothermal resources:

i) Puyuhuapi Figure 5) and ii) Puerto Aysén Figure 3) are located near the coastline, and just east of the LOFS (Cembrano et al. 2002 and references therein). Thermal springs have temperatures above 80 ºC, are Na-Cl water types with dissolved ions contributed by input of marine waters and hydrothermal processes (Negri et al. 2015). The gravity survey shows a negative anomaly on the western side of the Puyuhuapi Fjord, which could be related to less dense fractured rock at shallow depths. In order to understand fluid paths and the geometry of the fault zone, a natural seismicity network was installed around the Puyuhuapi area. Results of this survey will be included in the development of a conceptual model that helps understand the origin and processes of thermal features.

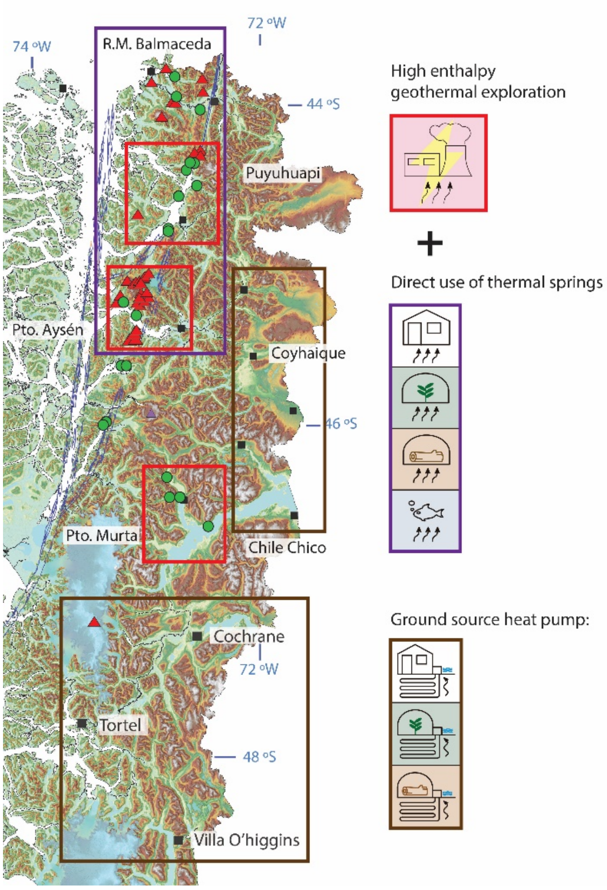
iii) Puerto Murta (Figure 3) is located inland, above the northern end of the slab window segment (Lagabrielle et al. 2004 and references therein). Thermal springs reach 54 ºC on the north shore of the General Carrera Lake. They are Na-Cl-HCO3 water types with dissolved ions only contributed by hydrothermal processes (Negri et al. 2015).

Although most of the hot springs are intervened, only three thermal areas are being used as a spa. Spring temperatures and flow are suitable for heating houses, heating greenhouses, lowering the moisture of wood and even aquaculture (Figure 3). Conventional aqueous geothermometers cannot be used because of seawater influence. Nevertheless, silica geothermometry suggests equilibrium temperatures ranging from 100 to 150 ºC.

Cities located inland and far from thermal activity include Coyhaique, Cochrane, Tortel and Villa O`Higgins. Subsurface temperature measured in Coyhaique allows a technical and economic assessment of a closed loop GsHP functioning for 9 types of houses. The Coefficient of Performance (COP) estimated with the measured temperature at 1.45m depth is 3.97. The operation cost of GsHP systems in Coyhaique city is even lower than the operation cost of pellet stoves, which is the main option of the decontamination plan for Coyhaique city (Maripangui et al. 2016, this workshop).

Some of the results of the PGA were included in a public document that helps explain, in a simple way, the geothermal potential of the region: the iconography used for such purpose is shown in Figure 3. Results also encouraged regional authorities and researchers to develop a pilot project. CEGA is currently bidding for several publically funded projects that are aimed at designing and building prototypes, which would bring the technology closer to the community.

Figure 3. Iconography used in the outreach program to show areas suitable for high enthalpy exploration, direct use of thermal springs and use of ground source heat pumps.



2.2 Scientific publications

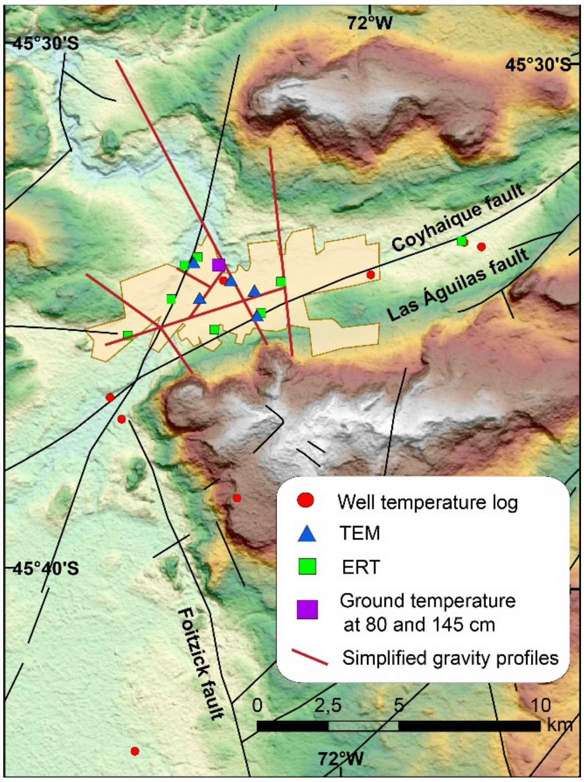
In October 2015, nine months after the beginning of the PGA, the XIV Chilean geological congress was the perfect opportunity to display preliminary results in the form of 4 documents regarding: i) ERT prospection in Coyhaique

(García and Aravena 2015), ii) Evaluation of a Binary power plant in Palena province (Muñoz et al. 2015), iii) thermal properties of sediments in the Coyhaique basin (Aravena et al. 2015) and iv) hydro-geochemistry of thermal springs in the region (Negri et al. 2015).

Four MSc. theses were derived from the PGA involving i) the processing of magnetotelluric data in La Junta and Lago Atravesado (Uribe, 2015), ii) the hydro-geochemistry of thermal springs (Negri, 2016, in prep), iii) the design of district heating network in Puyuhuapi (Valtinke 2016) and iv) modeling of geothermal heat pumps with a borehole heat exchanger in Coyhaique (Muñoz, 2016. In prep).

Three papers are currently been developed by CEGA researchers. They include the main results encountered in thermal springs throughout the region, geochemical and geophysical exploration in Puyuhuapi and an economic and feasibility analysis for direct uses in Coyhaique.

Figure 4. Data collected in Coyhaique city (shaded area) and surroundings during the first 18 months of the PGA.

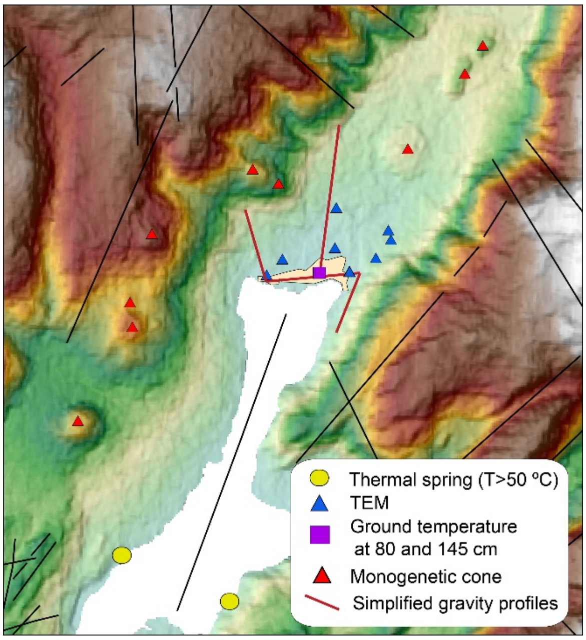


3. THE ROLE OF PUBLIC POLICIES IN GEOTHERMAL DEVELOPMENT

Chile has recently strengthened its '20/25' NCRE-law, which is likely to lead to steadily rising incentives for renewable sources of energy. In Chile, in order to apply for a public bidding regarding innovation, the candidate must have very specific knowledge, which is hardly achieved outside the academy. From the onset, the wide variety of organizations involved in geothermal development at a governmental level have worked more against geothermal growth than for it, as most of these organizations are new and still working on being consolidated as valid state institutions. Responsibilities are scattered and unclear (Otero 2015 and references therein).

CEGA is state funded project (Fondap-Conicyt) hosted at the Universidad de Chile that began operations during the first half of 2011. This initiative is aimed at improving geothermal knowledge and promoting its use in the Andean countries. CEGA comprises a team of researchers from national and international institutions. This publically funded center has an active outreach program for geothermal energy. However, the very existence of CEGA depended on winning competitive state funding and the motivation of a research group to apply for the money. It was not the product of a state strategy for geothermal progress, as has occurred in most of the countries where geothermal is now a developed source of energy (Otero, S., 2015).

Figure 5. Data collected in Puyuhuapi (shaded area) and surroundings during the first 18 months of the PGA.



The lack of researcher in a given scientific area immediately undermines its progress. In 2015, the Chilean government enacted the creation of the first public university founded in 68 years. The Universidad de Aysén aims to promote local, regional and national development. Preliminary analysis of tendencies in engineering careers (Valdes 2016) point to geothermal energy as one of the research lines that is best perceived by public functionaries in the region. This may have an important influence in the development of geothermal energy projects, reflecting a direct link between academic research and policy makers. Despite being considered as one of ten candidates, the university will initially focus on five careers which do not include the study of geothermal systems and their potential applications to the region.

4. THE ROLE OF OUTREACH IN GEOTHERMAL DEVELOPMENT

CEGA stands as the only public funded organization with a constant effort to popularize geothermal information and create outreach materials about this energy source. Increasing public awareness and promoting geothermal as a renewable, clean alternative energy is one of CEGA's founding objectives, and the Centre's outreach work during its first five years has been focused on bridging this information gap on geothermal energy for a diverse range of non-scientific audiences.

CEGA's Outreach programme aims to share and inspire the community with the geothermal knowledge generated by researchers at the Centre. Since the onset of the project, there has been an approach on outreach to the general public and the development of scientific documentation. By including public talks in every campaign, we were able to address the community directly and incorporate their needs in the analysis of data and planning of surveys. Public presentations included television, radio and webcast conferences. An additional outreach effort was done in Puyuhuapi, were we provided the public with easy-to-read handouts answering a list of common questions and referring them to the CEGA website. Community leaders were initially engaged through regional authorities. Nevertheless, after 6 to 8 months the roles reversed and most leaders engaged us.

A core element that influences the lack of social awareness on geothermal is that there are very few close experiences about this energy alternative. Opinions around geothermal are still being molded and that is an opportunity. There are two fields that need to be addressed in order to influence in the opinion of the different audiences, these are technical issues and convictions. Most of technical issues, about what geothermal is, and how does it work have been taken care of during CEGA's first five years of operations. In this new stage, we will focus more on the arena of people's convictions, showing how geothermal energy (both high and low enthalpy) and the work CEGA has been doing and will keep carrying on in this area, can contribute to solve problems: provide clean, local, affordable and renewable energy for personal and community demands on top of contributing to clean the national energy matrix which has been building a series of health and pollution problems to several cities and villages in the country. In brief, we aim to target the benefits that geothermal can trigger at a personal level (individuals), group level (organized communities and interest groups) and macro level (policy makers) for the benefit of people's lifestyle and society's quality of life.

5. CONCLUSIONS

The Aysén region has a high favorability for the occurrence of geothermal systems. Surveys in Puyuhuapi, Puerto Aysén and Puerto Murta indicate high enthalpy resources at drillable depth. Additionally, the cost of electricity in the region is among the highest in the country, making geothermal energy a viable alternative.

In most cities located on the coastline, spring temperatures and flow are suitable for several direct uses, including heating houses, heating greenhouses, lowering the moisture of wood and aquaculture. Cities located inland and far from thermal activity could benefit greatly from the use of GsHP, reaching a COP of ~4 with a low operation cost

Data obtained in the PGA will be used for further research, nevertheless, a clear state policy is needed in order to do so. Linking researchers, policy makers and community generates a positive feedback. This is of paramount importance for the positioning of geothermal energy as a strategic resource.

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Figure 6. Outreach activities done by local authorities and CEGA researchers. A: Local news program, B: Public presentation in Puyuhuapi. C: Local radio station interview in Puerto Aysén city.

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