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May 25th 2021

CEGA
CENTRO DE EXCELENCIA EN GEOTERMIA DE LOS ANDES

Chilean Geothermal Power Potential: An overview after one century of exploration

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Geothermal Resources Council

GRC

Why Geothermal?

- **Reliability:** Baseload power production 24 hours a day, 7 days a week, 365 days a year regardless of how much wind or sunlight is available.
- **Versatility:** Geothermal energy can be used to produce power in utility-scale facilities or for a wide variety of direct use applications, such as heating greenhouses, de-icing sidewalks and dehydrating agricultural products.
- **Small Environmental Footprint:** Geothermal power plants emit lower levels of emissions than fossil fuel plants, and use less land per megawatt than other renewable energy sources.

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CENTRO DE EXCELENCIA EN GEOTERMIA DE LOS ANDES

?

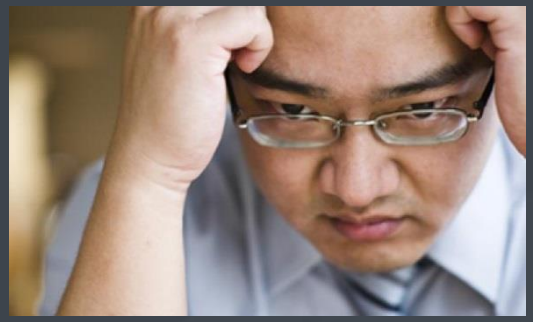
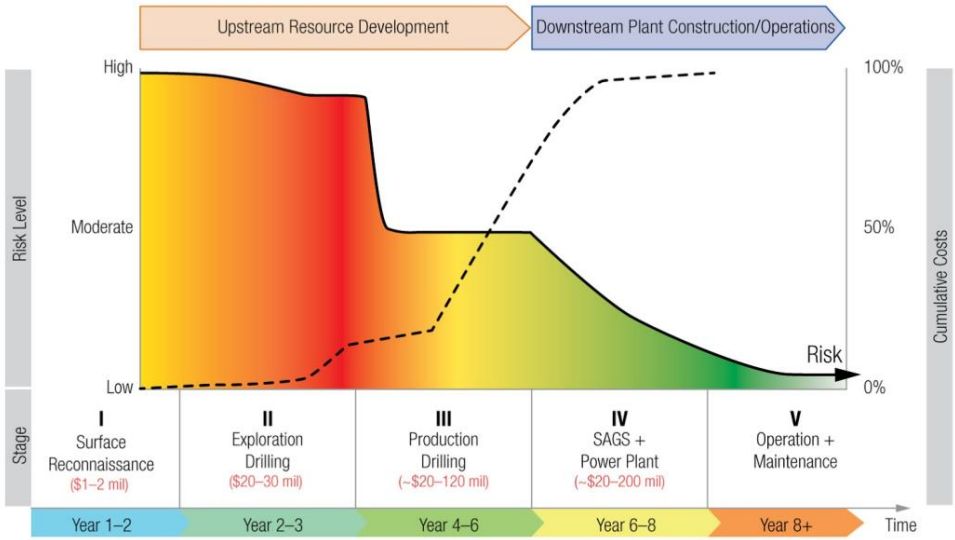


Figure 1 | A Conceptual Representation of Risks and Costs during the Different Stages of a Geothermal Development

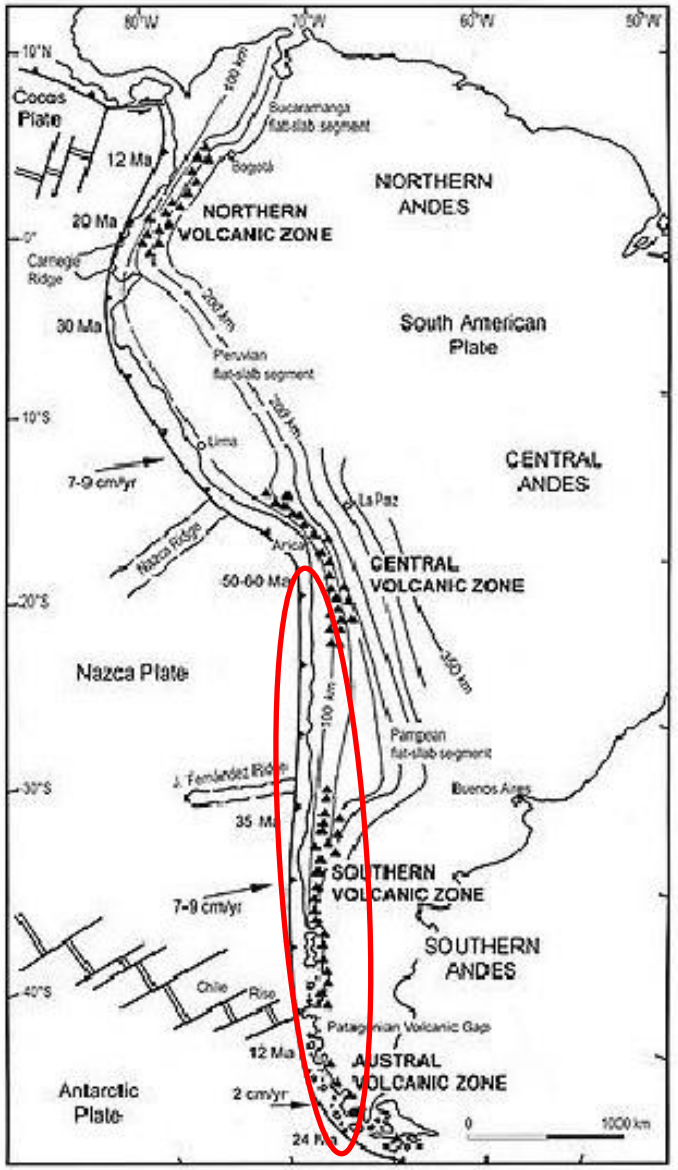


Source: Adapted from Geothermal Handbook (ESMAP 2012).

Geology Background

SUbduction zones

- The **North Volcanic Zone** (NVZ) that includes the volcanoes of northern Colombia, Ecuador and northern Peru.
- The **Central Volcanic Zone** (CVZ) compromising the volcanoes of southern Peru, Bolivia, and northern Chile and Argentina
- The **South Volcanic Zone** (SVZ), spanning from Central Chile to the Chile Triple Junction
- The **Austral Volcanic Zone** (AVZ) begins south of the Chile Triple Junction and is caused by the subduction of the Antarctic Plate



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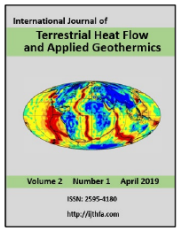

Assessment of Geothermal Resources of South America - A New Look

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Abstract

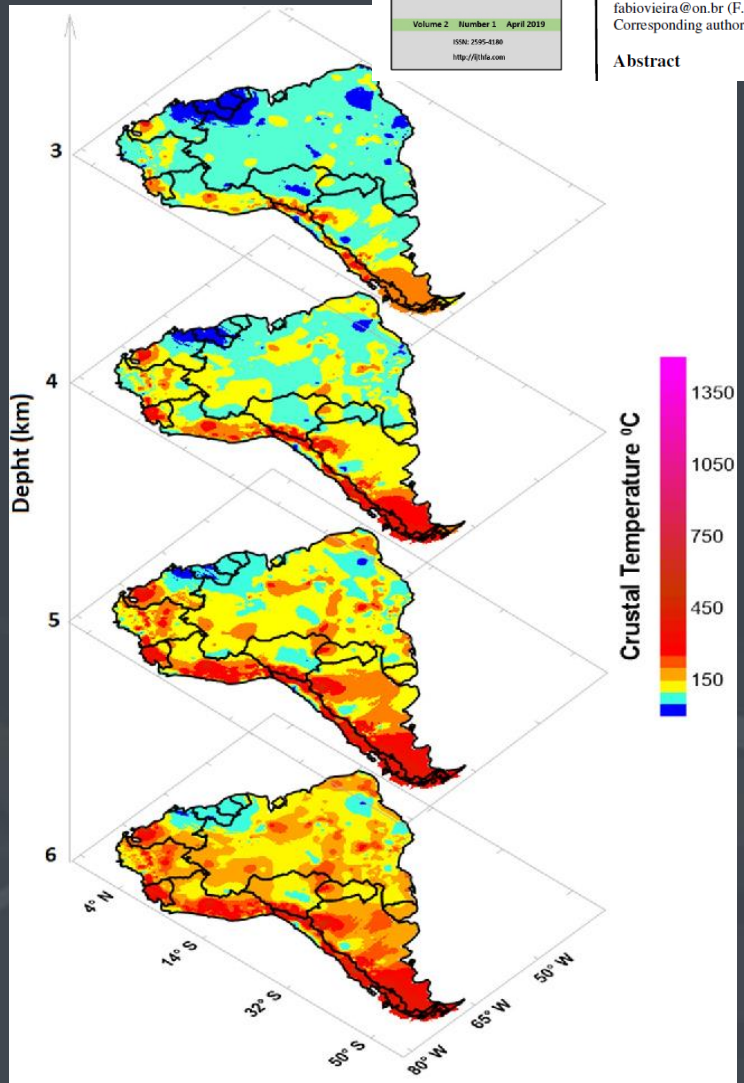


Figure 6 – Stack of maps providing a 3D perspective of crustal

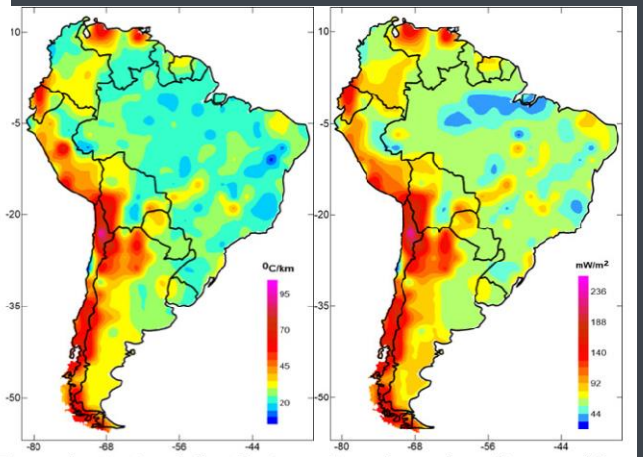
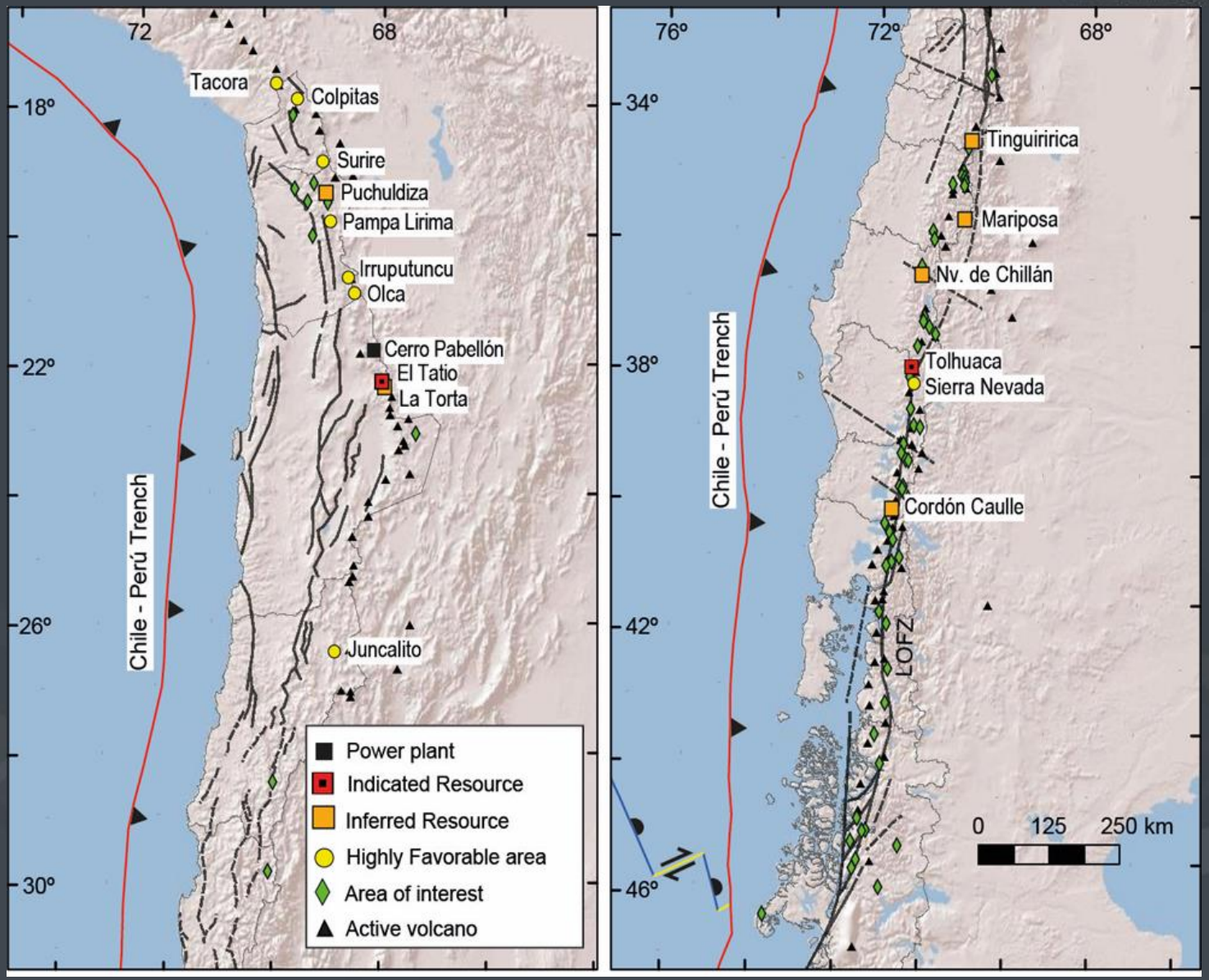


Figure 5 - Regional distributions of geothermal gradients and heat flux in South America.

Table 9 - Summary of resource estimates for geothermal systems in South American continent. RB – Resource base; RBUA – Resource base per unit area; N - number of localities.

Resource Type	T (°C)	N	RB (10^{21}J)	RBUA (GJ/m^2)
Hot Dry Rock	> 150	318	1329	513
Hot Wet Rock	90 - 150	352	586	409
Low Enthalpy 1 (agro-industry)	60 - 90	3273	240	240
Low Enthalpy 2 (Balneology)	< 60	4188	210	212

Main Geothermal areas



A brief overview of the principal (today active) geothermal projects in Chile….

“Prehistory” of the geothermal research in Chile:

ANÁLISIS DE LAS AGUAS DE APOQUINDO. 51

MEDICINA.—Aguas, minerales de Apoquindo, analizadas por don Ignacio Domeyko i don Manuel José Dominguez.

58 ANALES.—ENERO DE 1866.

Parece indudable que constituyendo las sustancias cloruradas casi la totalidad de las sales disueltas, es a estas sales a quienes deb en las aguas de que nos ocupamos su accion medicinal; sus aplicaciones en jeneral deben ser, por consiguiente, las mismas que las que han sido reconocidas en las demas de su especie. Pero no habiéndose encontrado hasta el presente, ni en Europa ni en ninguna otra parte que en Chile, aguas minerales cloruradas que ofrezcan como elemento predominante el cloruro de calcio, i esto aun en dósis tan considerable, ¿cuál será el modo de obrar de este último? ¿Cuáles las aplicaciones especiales que este carácter da a las de Apoquindo? Hé aquí una

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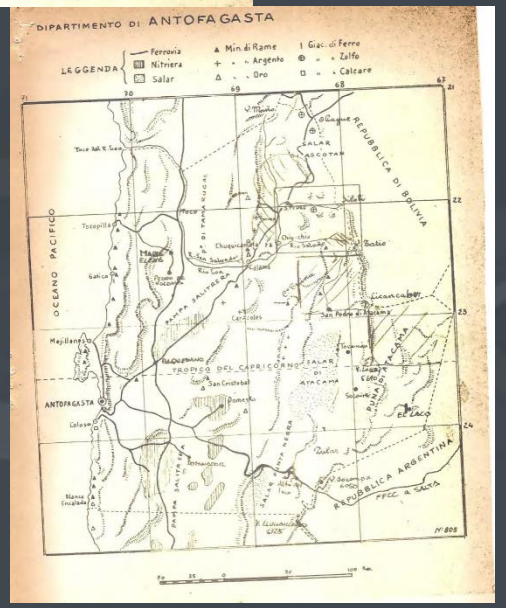
Castiglioncello, Gennaio 1923

UFFICIO GEOLOGICO

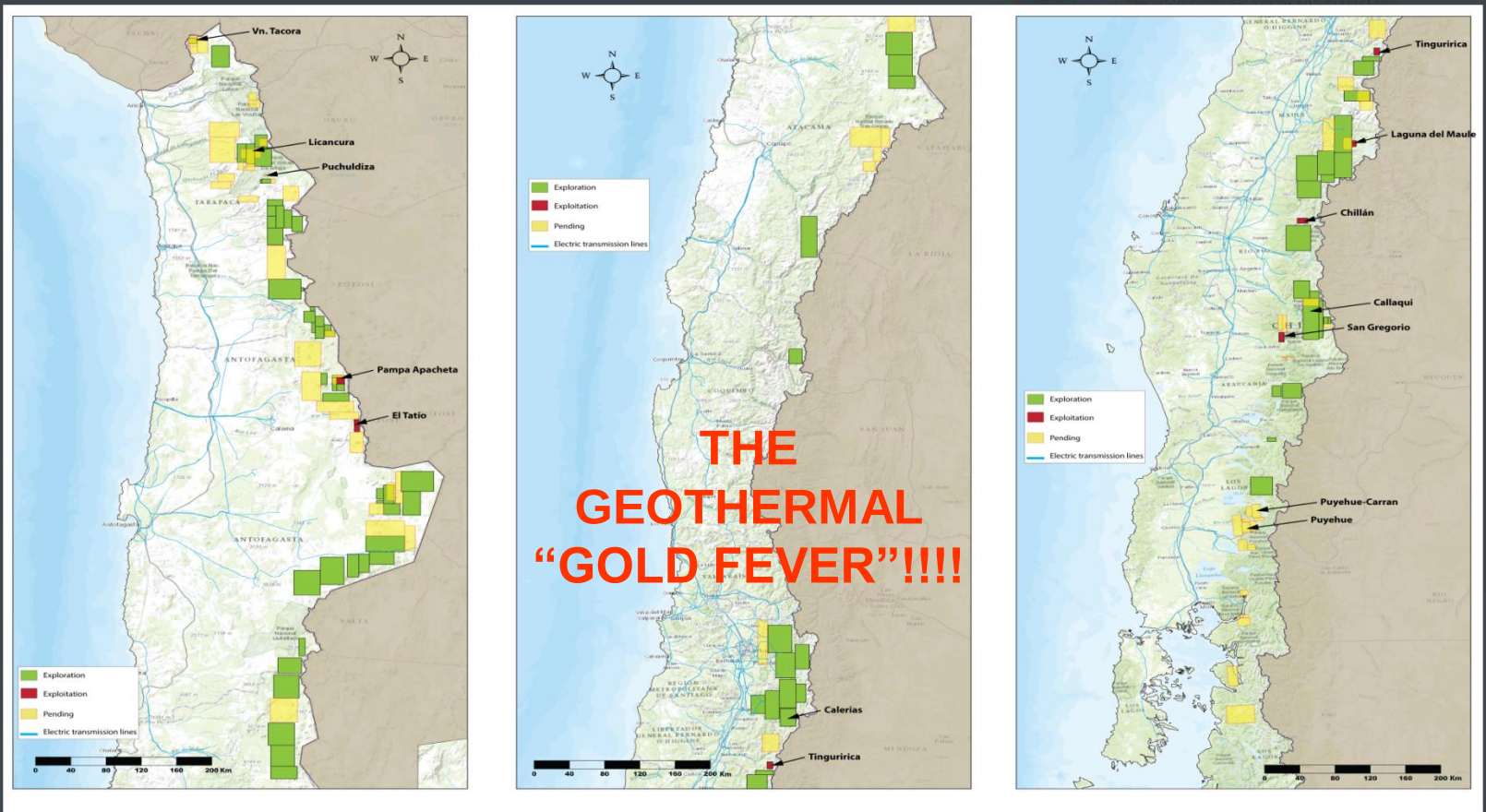
Ing. E. TOCCHI

I L T A T I O

Essendomi occorso, in altra occasione di dover tradurre in cifre ad uso di persone d'affari le mie impressioni sul Tatio, parlai della possibilità di installarvi una centrale di 50.000 kW, ritenendo, come ritengo ancora in base alle cose sopra dette, che tale potenza vi sia perfettamente raggiungibile, purché la proseguzione dei così bene avviati lavori di sondaggio, confermi la pratica possibilità di ottenervi il vapore nelle volute condizioni di temperatura e composizione chimica.



Exploration concessions in Chile (2014)



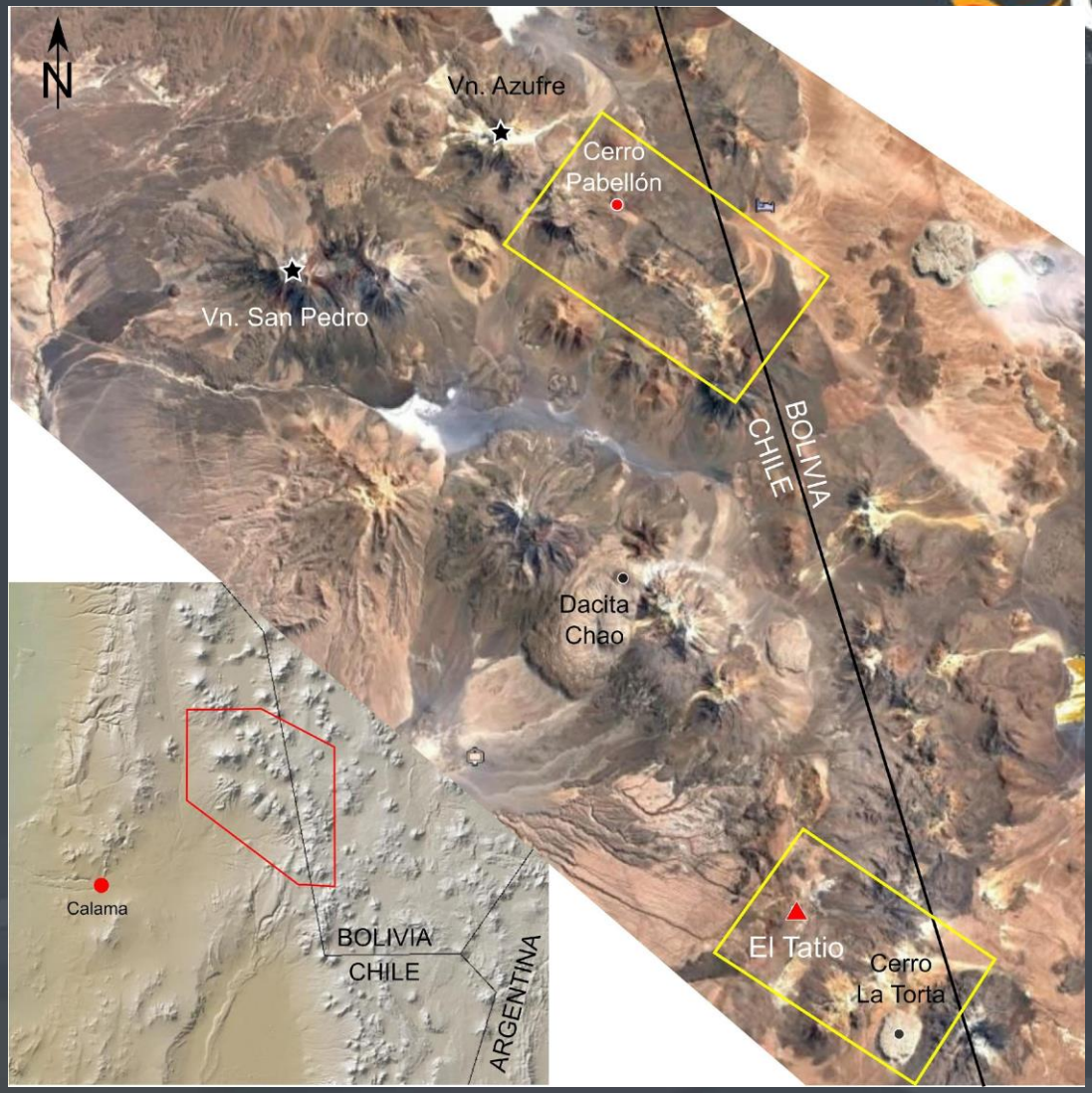
Active geothermal concessions	N
Exploration	75
Exploitation	8

New geothermal concessions pending	N
Exploration	56
Exploitation	20

Source: Ministery of Energy, Chile & ACHEGEO, May 2014

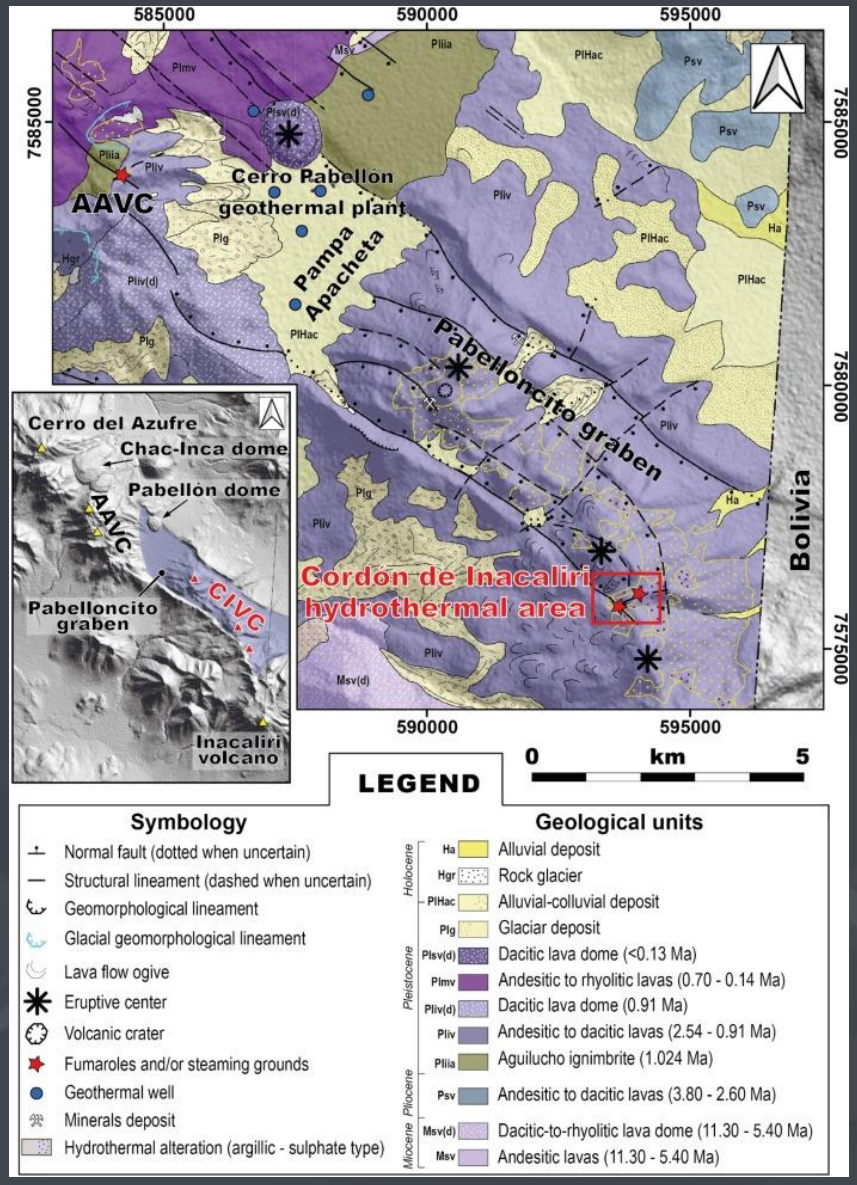
….but today….only three projects are really existing:

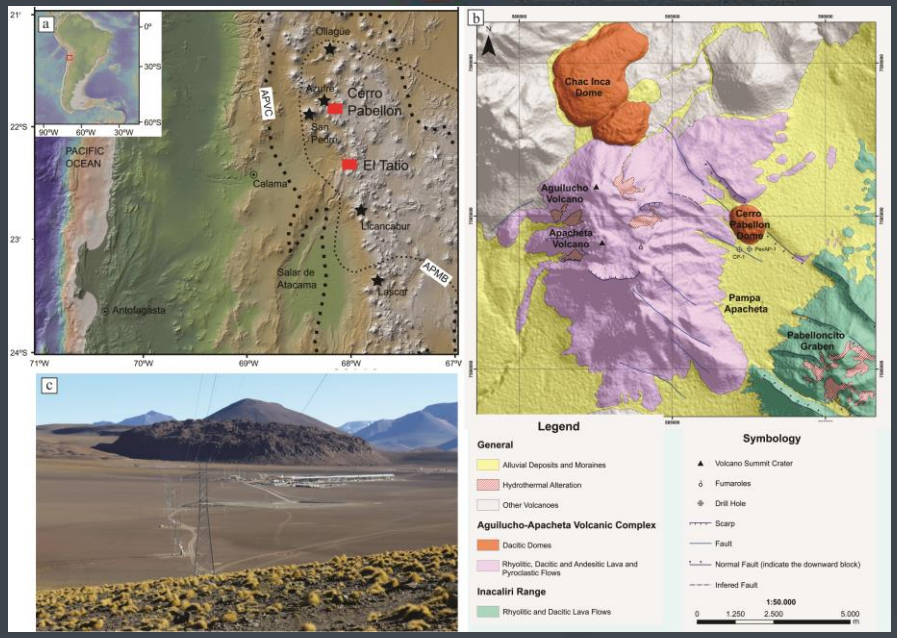
- Cerro Pabellón
- Mariposa
- Peumayén (ex- Tolhuaca)

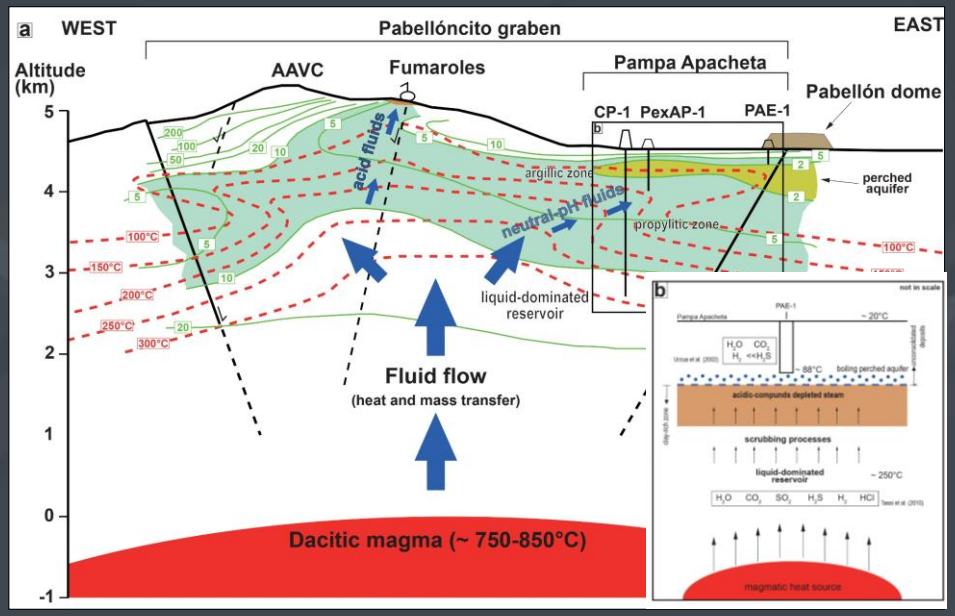


Google image of Northern Chile, showing the Cerro Pabellón geothermal site, the El Tatio geothermal area and the main NW to SE alignments of volcanoes and rhyodacitic domes present in the area

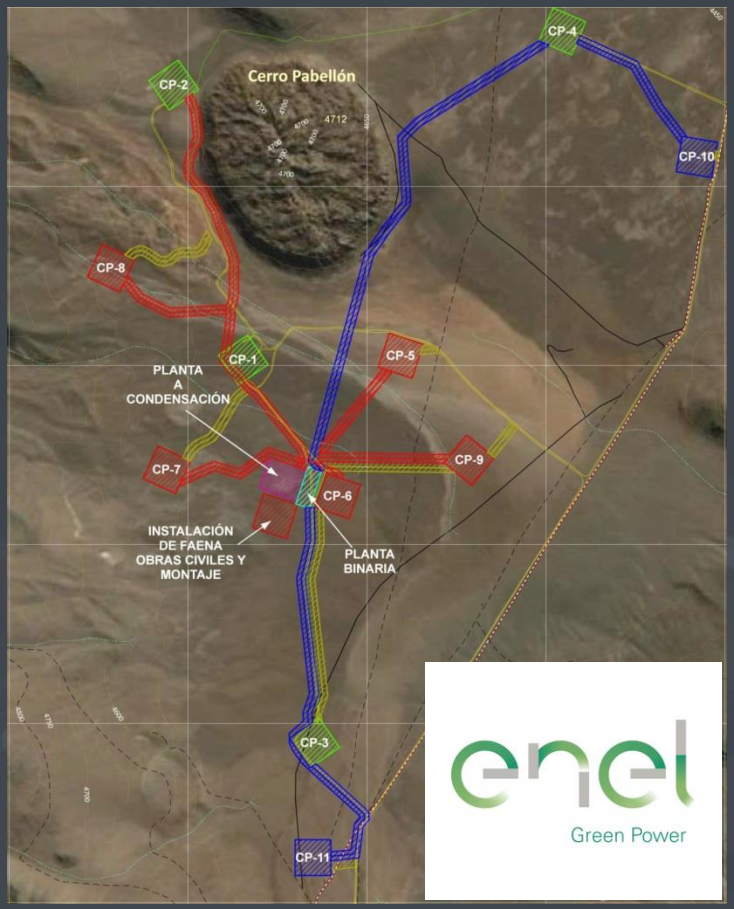
Cerro Pabellón







Maza et al (2018), Taussi et al (2019)

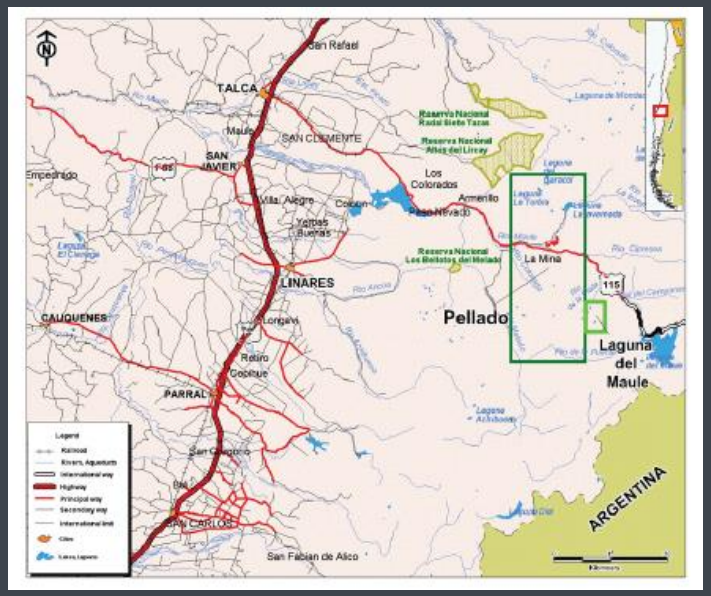


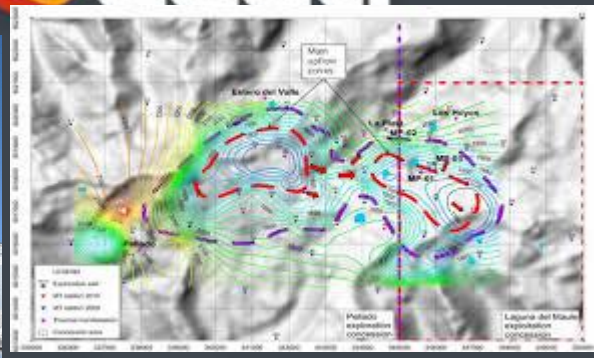
First geothermal power plant in South America.
Placed in the Ollagüe province, at c. 4500 m a.s.l.

Two binary units, from 2017 48 MWe installed.
Energy neccesary for supply anual electricity demand for more than 165.000 houses.
Reduction of more than CO_2 166.000 tons/year.
In expansión for additional 33 MWe during 2021.
Total capacity end 2021…81 MWe

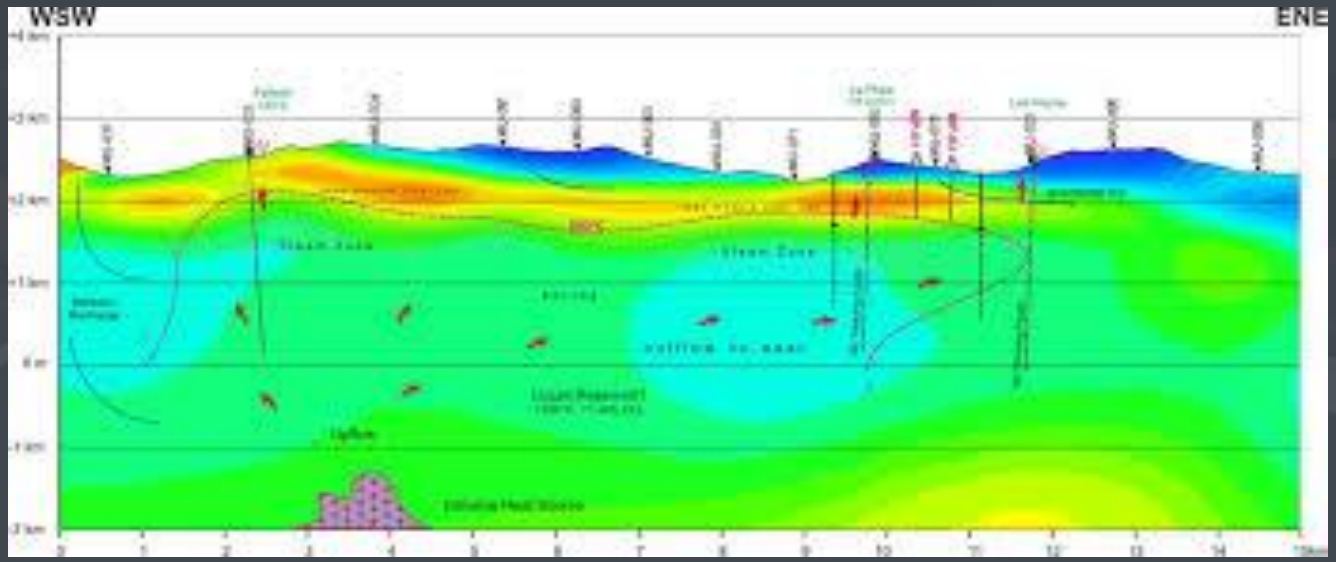
See Capetti et al (2020) this WGC 2020+1

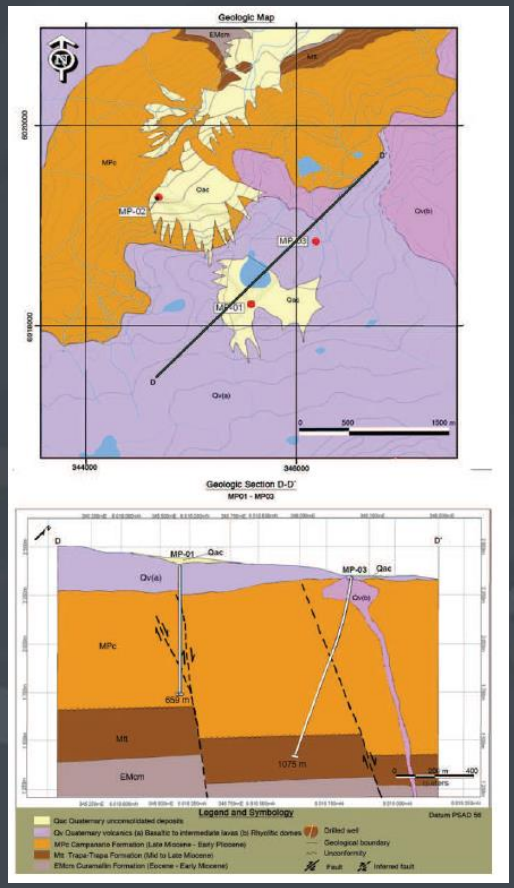
Mariposa



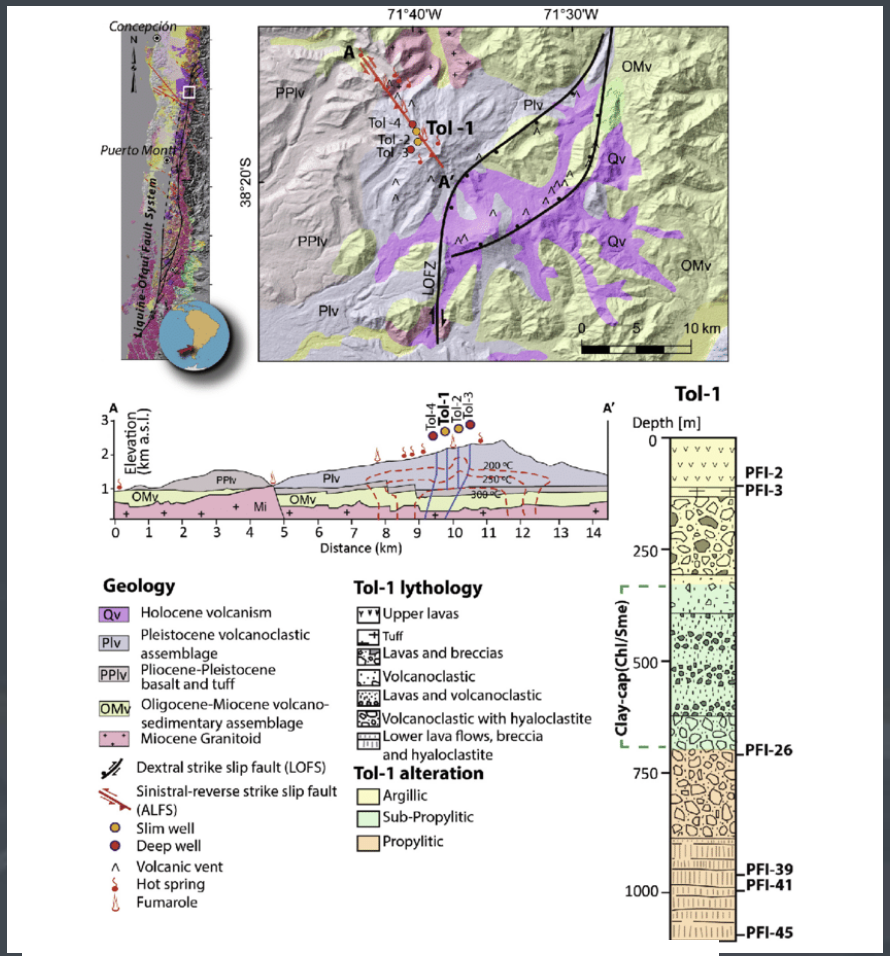


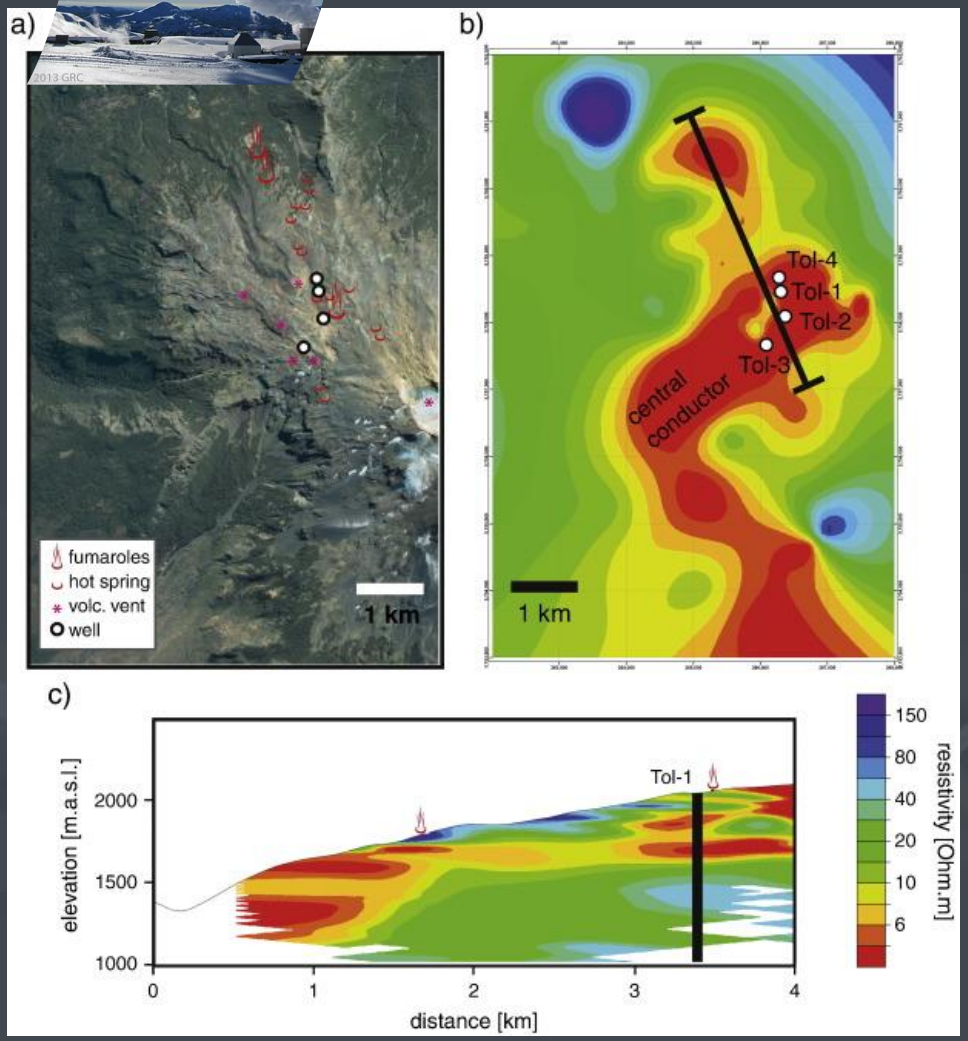
energy
DEVELOPMENT CORPORATION





Peumayén (ex Tolhuaca)





Resources estimations

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Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Assessment of high enthalpy geothermal resources and promising areas of Chile

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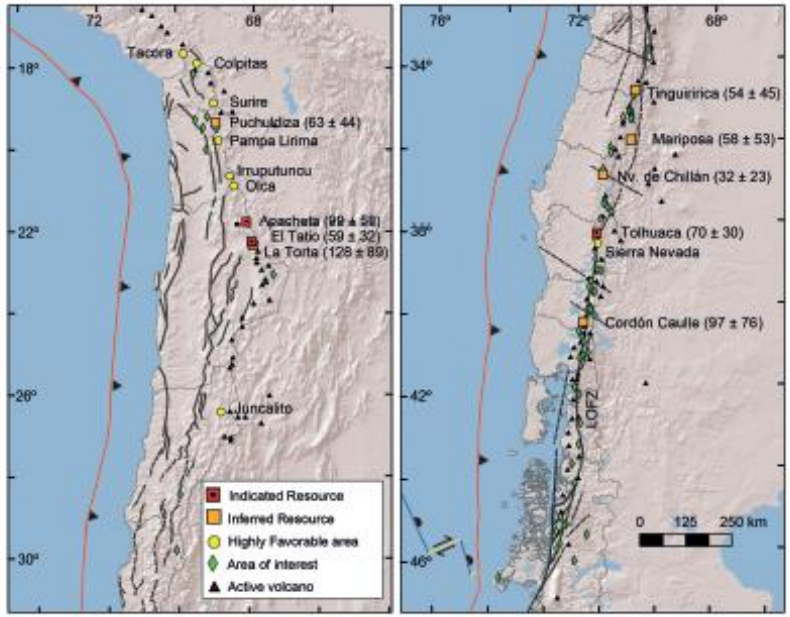
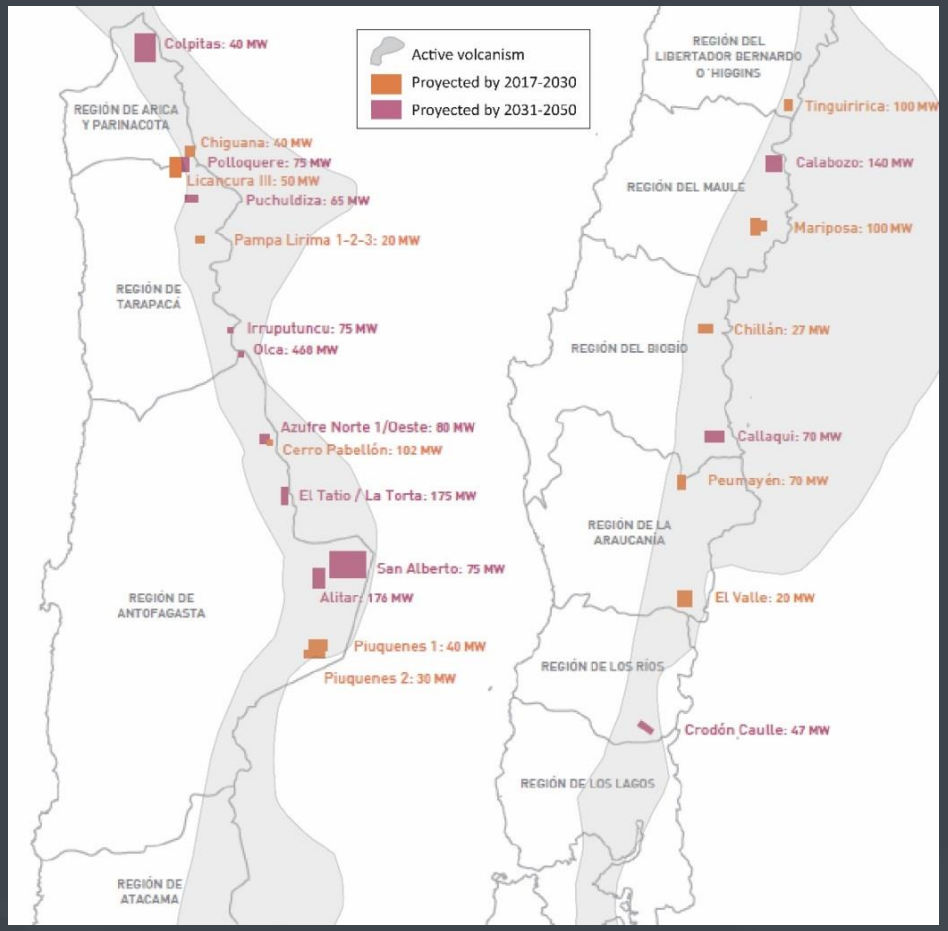
A B S T R A C T

This work aims to assess geothermal power potential in identified high enthalpy geothermal areas in the Chilean Andes, based on reservoir temperature and volume. In addition, we present a set of highly favorable geothermal areas, but without enough data in order to quantify the resource. Information regarding geothermal systems was gathered and ranked to assess Indicated or Inferred resources, depending on the degree of confidence that a resource may exist as indicated by the geoscientific information available to review. Resources were estimated through the USGS Heat in Place method. A Monte Carlo approach is used to quantify variability in boundary conditions. Estimates of total Indicated resource are confined to 3 geothermal systems; Apacheta, El Tatio and Tolhuaca, yielding a total value of 228 ± 154 MWe. The estimates of the total Inferred resources for Chile include 6 geothermal systems and yield a total value of 431 ± 321 MWe. Standard deviation reflects the high variability of reservoir specific parameters for each system. A set of 65 favorable geothermal areas are proposed as the most likely future development targets. Eight of them have initial exploration results that suggest they are highly favorable targets as potential geothermal resources.





Geothermal potential to be installed by 2030 & 2050.....

Source: Mesa de Geotermia 2017 (http://www.minenergia.cl/mesa-geotermia/

Period	Minimum Capacity (MW)	Maximum Capacity (MW)	Reference Capacity (MW)
2017-2030	471	599	599
2031-2050	827	3,243	1,487
Total 2017-2050	**1,298**	**3,842**	**2,086**

Chilean electricity market (future projects…)

Cuadro Resumen—Estado de Proyectos ERNC

Tecnología	Operación (1) [MW]	En Pruebas [MW]	Construcción [MW]	RCA Aprobada (2) [MW]	En Calificación [MW]
Biomasa (3)	*501*	*9*	*171*	*1.076*	*15*
Eólica	*1.798*	*345*	*1.711*	*10.620*	*3.592*
Geotermia	*40*	*0*	*33*	*155*	*0*
Mini Hidro (4)	*519*	*37*	*102*	*779*	*8*
Solar - PV	*2.817*	*177*	*3.063*	*18.194*	*11.016*
Solar - CSP	*0*	*0*	*0*	*2.032*	*0*
Total	*5.675*	*568*	*5.079*	*32.856*	*14.631*

Fuente: CNE, Ministerio de Energía, Coordinador Eléctrico Nacional.

Source: Comisión Nacional de Energía, June 2020

(1) Considera sólo proyectos entregados a explotación comercial.

(2) Considera todos los proyectos aprobados a la fecha.

(3) Considera los proyectos de biogás.

(4) Representa las centrales hidroeléctricas de pasada con capacidad instalada inferior a 20 MW.

Chilean electricity market

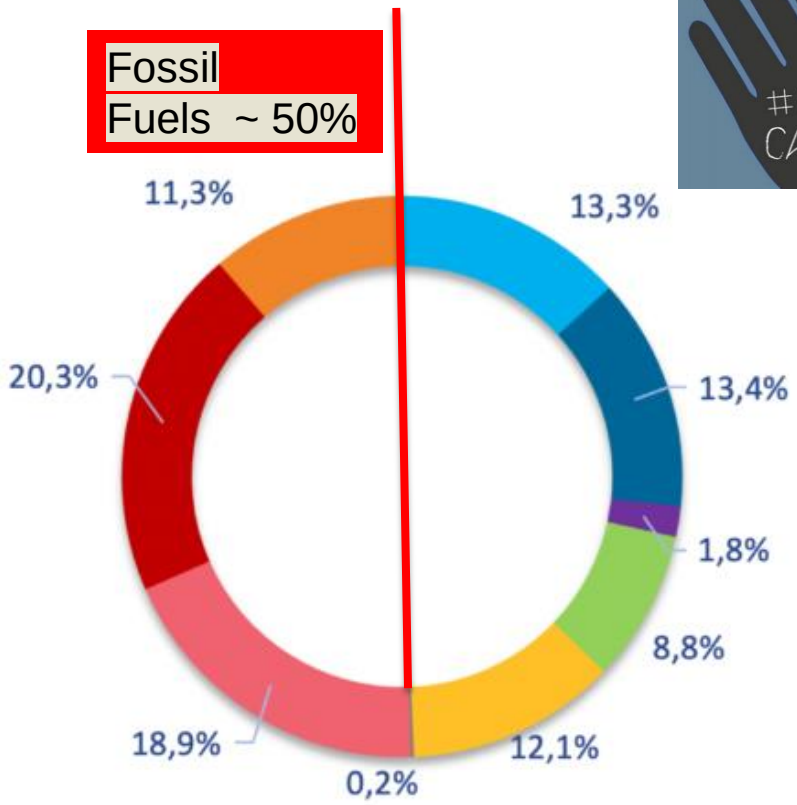
CAPACIDAD TOTAL SEN - MW

RENOVABLE	**12.681**
HIDRO EMBALSE	3.395
HIDRO PASADA	3.444
BIOMASA	451
EÓLICO	2.242
SOLAR	3.104
GEOTÉRMICA	45
NO RENOVABLE	**12.935**
GAS NATURAL	4.843
CARBÓN	5.192
DERIV. DEL PETRÓLEO	2.899
TOTAL	**25.616**

Renewable energies ~ 50%

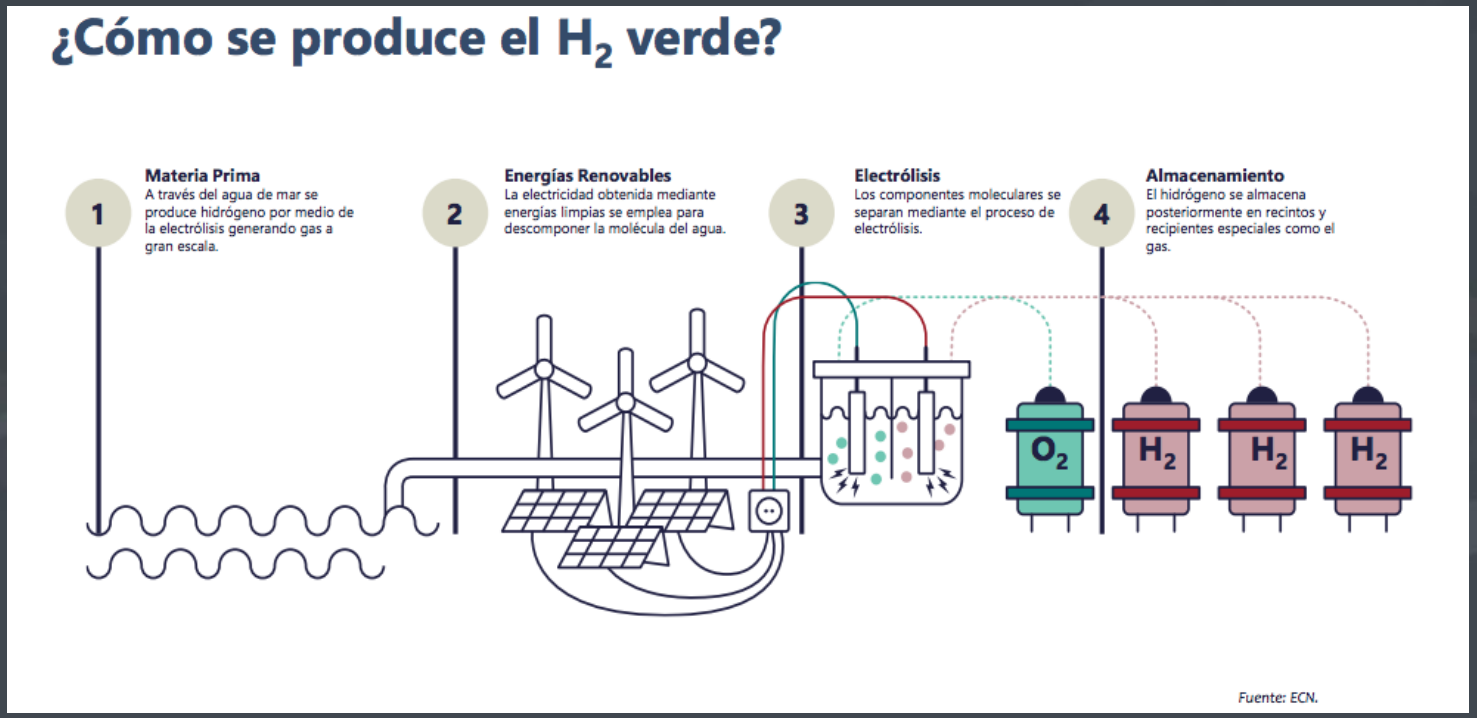
Fuente: Coordinador Eléctrico Nacional

Fossil Fuels ~ 50%



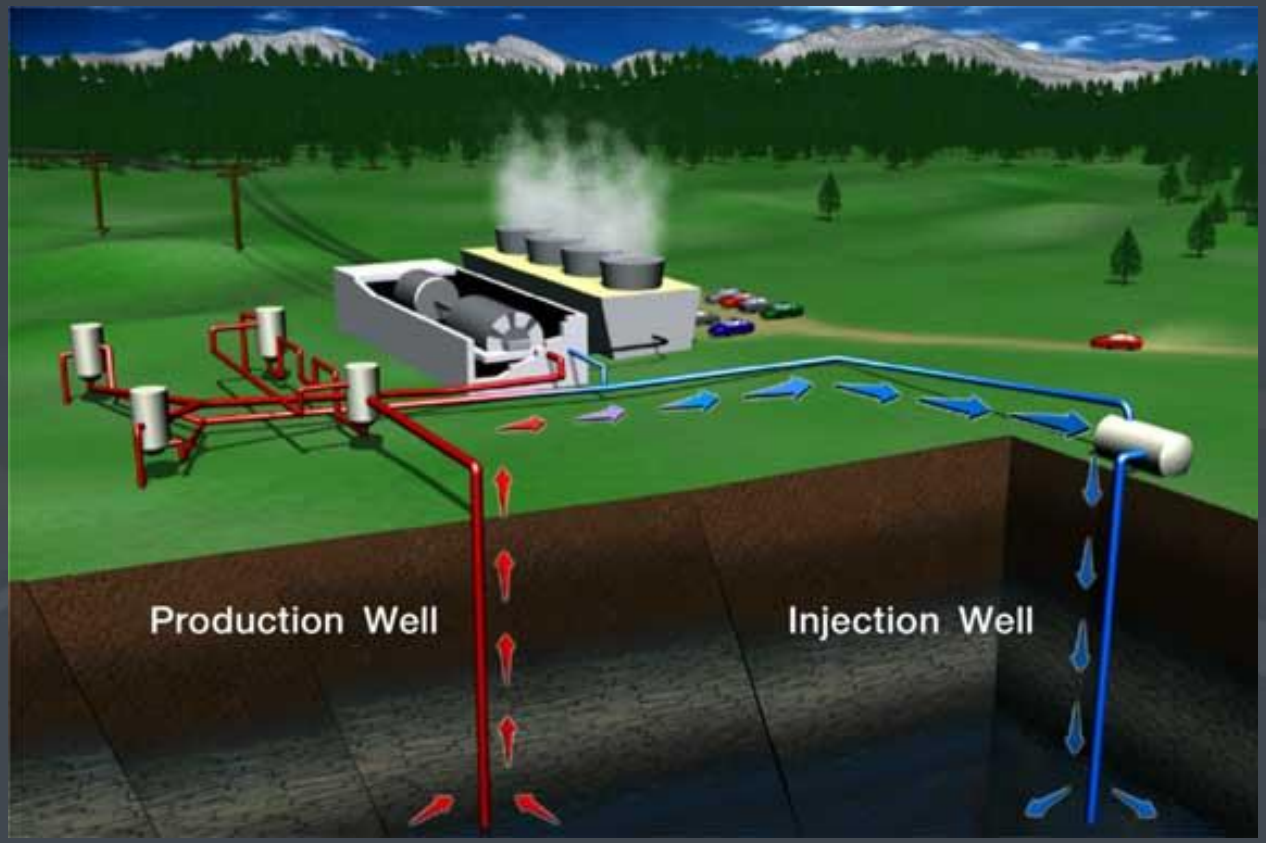
Source: Comisión Nacional de Energía, August 2020

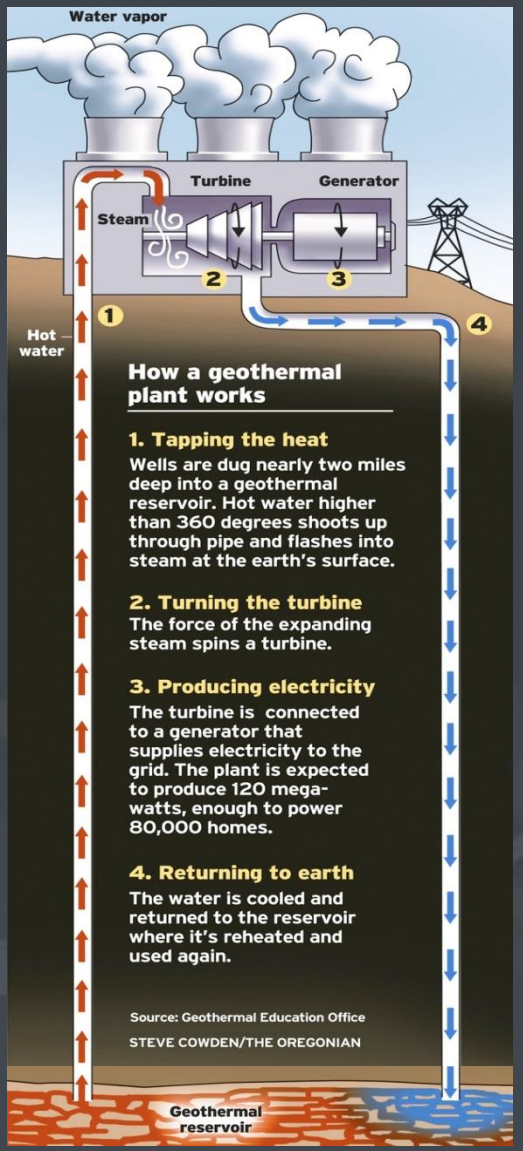
A new player for the future electricity team: the Green Hydrogen but…what don't also use geothermal energy



Circular economy with high-enthalpy geothermal systems:

- electricity production (and direct use)
- raw materials extraction
- green H_2





The future…

- High-enthalpy projects with (today) really very limited possibility to be developed becasuse electricity market limitations (but with > 2 GWe availables for 2050!)
- A real clean transition: the coal-base thermoelectricity (c. 4000 MWe capacity installed) **MUST** to be removed from the Chilean electricity grid before 2050: a great opportunity for geothermal energy
- A real interest from the State is mandatory
- The opportunity for medium-enthalpy systems (smaller systems but closer urban sites) and direct use
- The new oportunity given by Green H_2 and the possibility of added values to geothermal brines: Li and other metals recovering (and water production).

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