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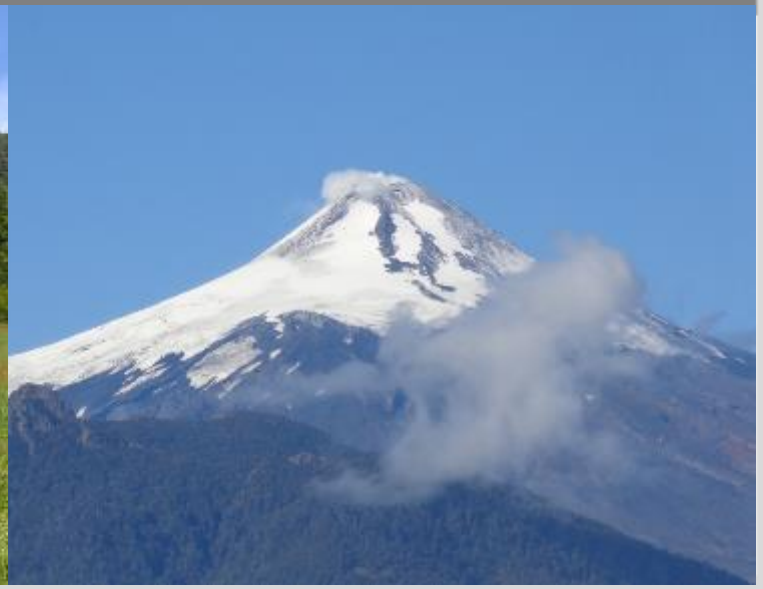
Geothermal exploration in the Pucón area, southern Chile

Collaboration AGW/Geothermics – CEGA

Thomas Kohl, Sebastian Held, Ingrid Stober

INSTITUTE OF APPLIED GEOSCIENCES, GEOTHERMAL RESEARCH



Figures

Employees

8,500

Students

24,700

374

Professors

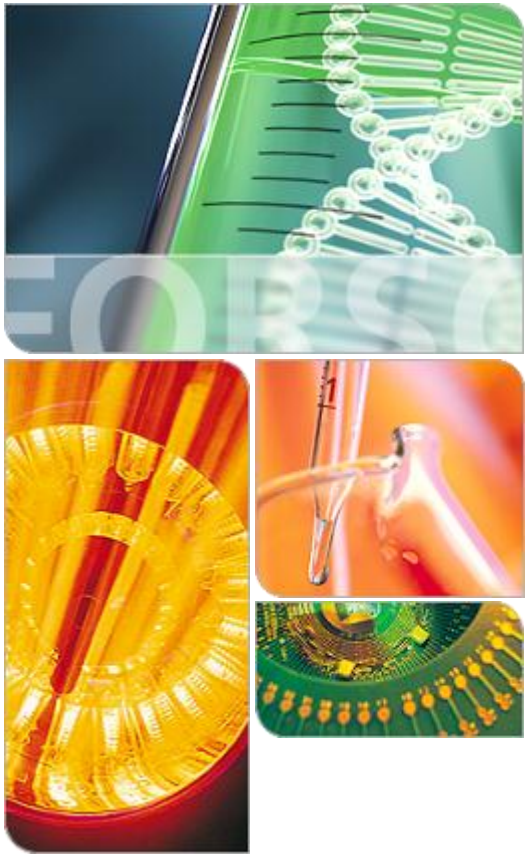
750

Annual Budget in Million Euros

Centers and Focuses

- Concentration on Topics, Strategic Research Planning

- KIT Centers:
  - Energy
  - Nano & Micro Science and Technology
  - Elementary Particle and Astroparticle Physics
  - Climate and Environment
  - Mobility Systems
- KIT Focuses:
  - COMMputation
  - Optics and Photonics
  - Humans and Technology
  - Anthropomatics and Robotics



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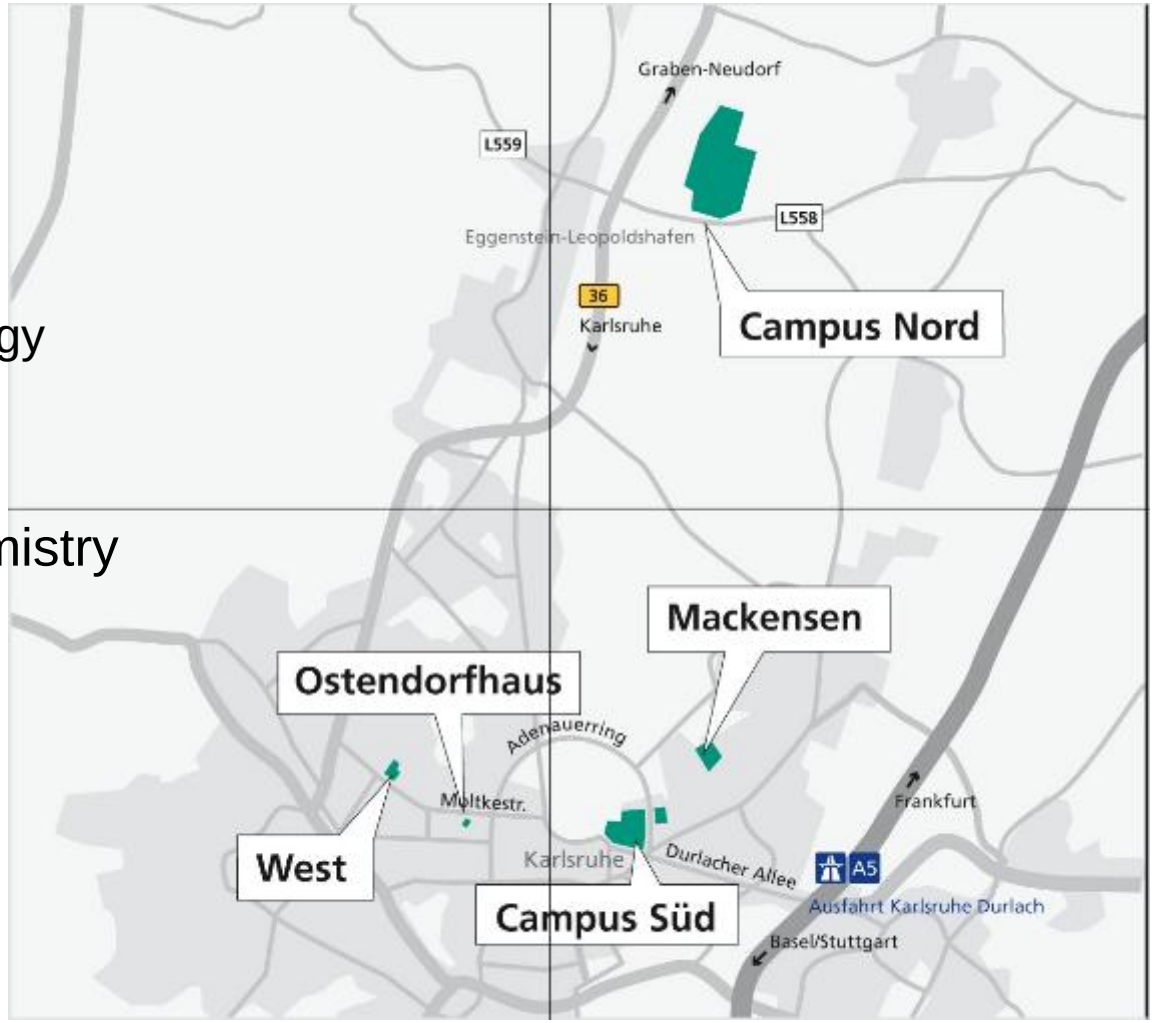
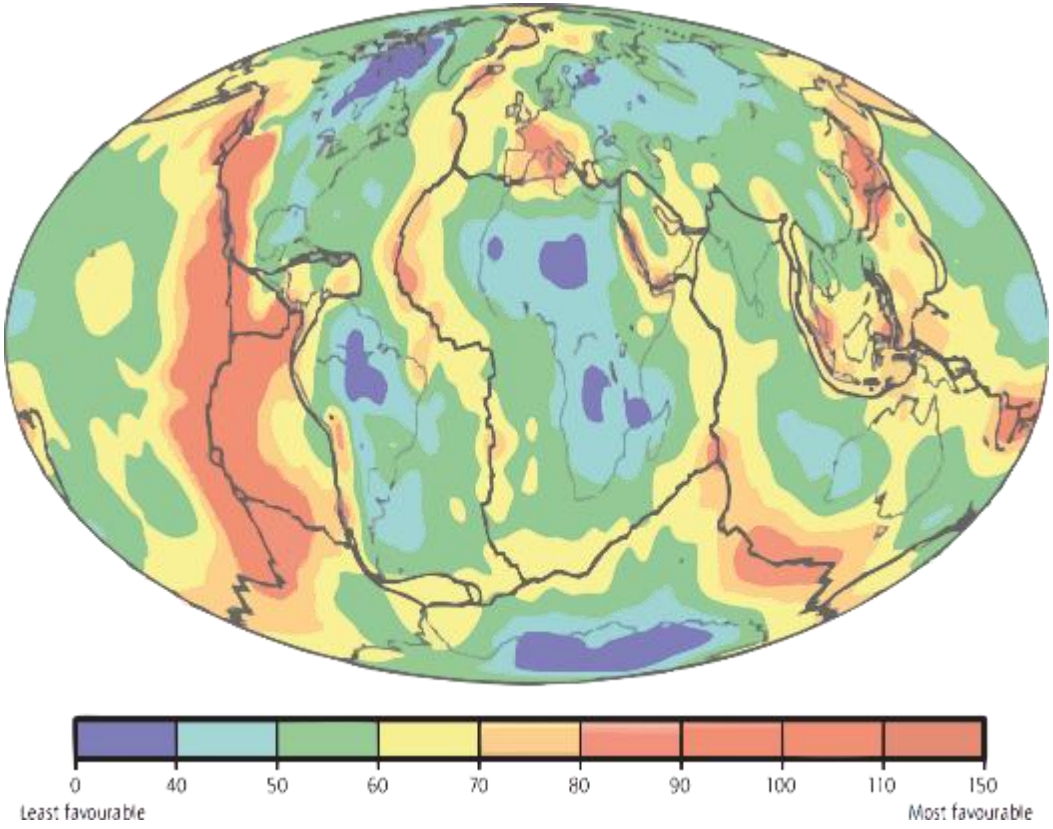
Structure of KIT: Geothermal relevant Institutions

- Campus South
  (former University)
  - Applied Geoscience
    - Geothermics
    - Engineering Geology
    - Petrophysics
    - …
  - Mineralogy/Geochemistry
  - Geophysics, …
- Campus Nord
  (former Helmholtz Centre)
  - IKET,
  - INE, …



Worldwide Resources and Power Production

World resource map of convective hydrothermal reservoirs



Source : International Energy Agency : Technology Roadmap

Country	Geothermal Power Capacity (MW)	Geothermal Electricity Generation (MKWh)
United States	2,923.5	15,883
Philippines	1,969.7	12,596
Indonesia	1,226.0	6,344
Mexico	953.0	6,094
Italy	810.5	5,183
Japan	535.2	3,422
New Zealand	471.6	3,016
Iceland	421.2	2,693
El Salvador	204.2	1,306
Costa Rica	162.5	1,039

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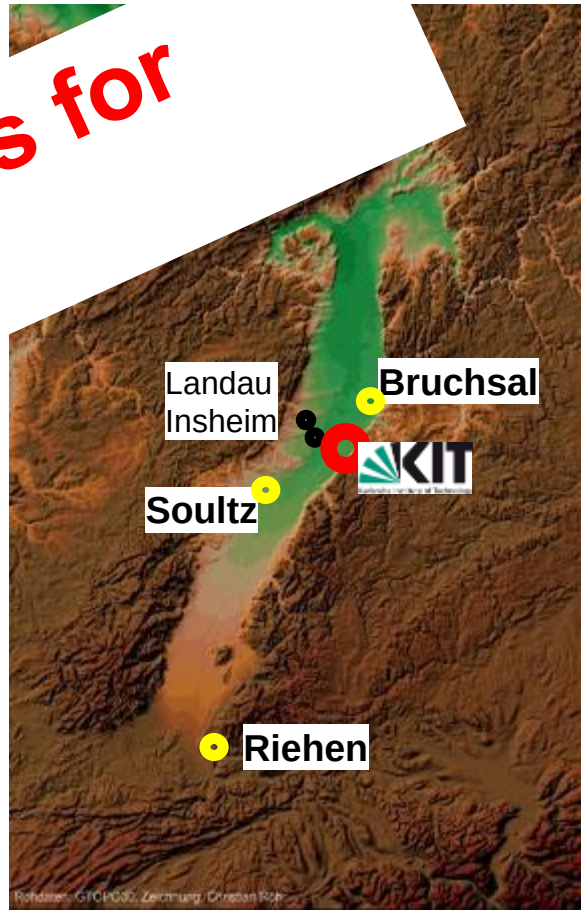
Geothermal Projects in Rhine Graben

- European geothermal project at **Soltz-sous-Forêts** (EGS)
- **Bruchsal** research power p… geothermal
- **Landa**… …rmal power p… …uro-geothermal
- **K**… …geothermal district heating system

Favorable stress conditions for Geothermal utilization



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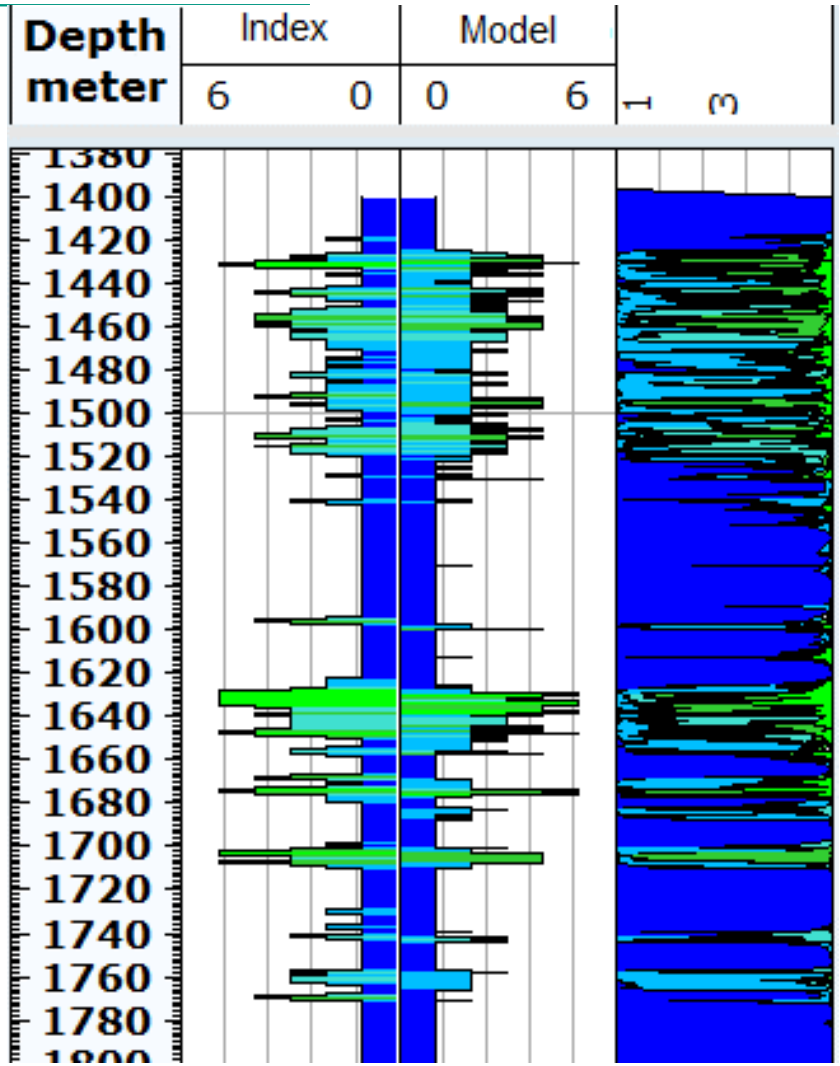
Synthetic logs of clay-bearing zones

Carola Meller

- Forcasting clay content based on standard gamma logs
  - Neural network analysis of spectral gamma logs
  - Training on index-log derived from core



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BMBF Project in Chile "Geothermal utilization for Mining"

- Mining in Chile
  - Huge Energy demand in North Chile
  - Currently mostly covered by Carbon Power Plants
  - No local energy resource
- Geothermal Resources
  - Chile has highest number of volcanoes
- Example: Ladolam (Lihir, Papua New Guinea)
  - Epithermal gold mine (44 Mio. ounces) / geothermal since 2003
  - Installed capacity 56 MWel
  - Exploration was most important for the discovery of both, gold and geothermal
    - Mostly MT, focusing on hydrothermal alteration products

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Chile Project

- BMBF Project:

  "Exploration and Characterization of High Enthalpy Resources for geothermal electricity production in Chile"

- Demo Project at Pucón with CEGA
  - Fault controlled reservoirs
- Three Phases:
  - Oct. 12 – Mar. 13
    - Start up Phase
  - Apr. 13 – June 14
    - Measurement Phase of PhD
  - Jul. 14 – May 16
    - Identifying Mining Cooperation (with Conicyt / CEGA)
    - Initiating new partnerships

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Collaboration KIT - CEGA

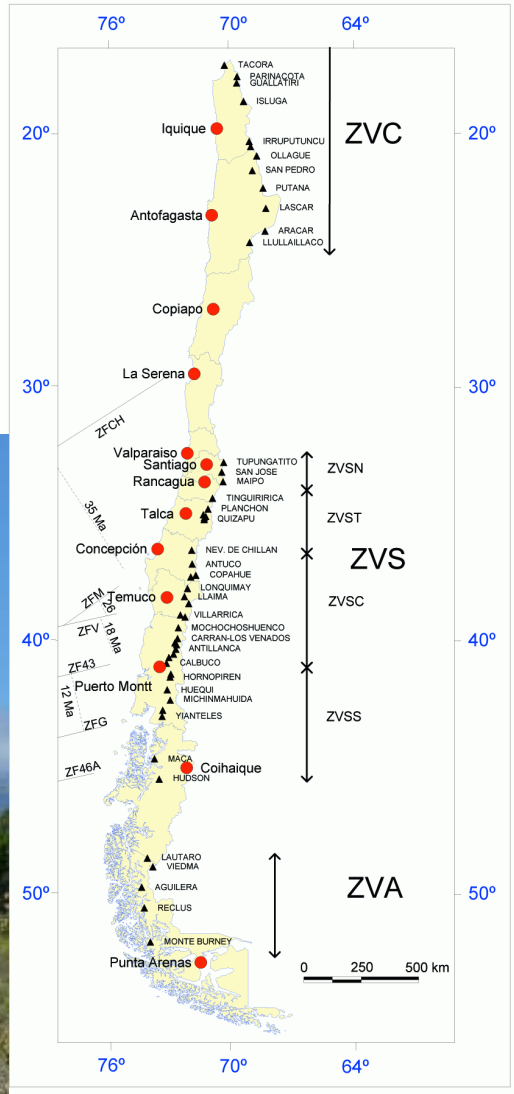
- Participating institutions:
  - KIT - AGW - Prof. T. Kohl
  - CEGA (Andean geothermal center of Excellence) – Prof. D. Morata

- Further researchers included in the Project:
  - Dr. D. Diaz, CEGA
  - Prof. T. Neumann, KIT - IMG
  - Dr. E. Schill, KIT - INE
  - Dr. K. Emmerich, KIT - IFG
  - GTN LA, geothermal company, Santiago de Chile
  - Hydrosion – Dr. J. Schneider

- Further important contacts in Chile:
  - SERNAGEOMIN, Chilean geological survey, Dr. J. Rojas
  - University of Antofagasta, Rector J. Tabilo

Geothermal Potential Chile

- Part of the “Pacific ring of fire”
- Estimated potential at least of 16 GW_{el} (Lahsen 2010)
- High-enthalpy geothermal fields located in the High Andes
- Currently NO geothermal production



Ref.: southernchileproperties.com

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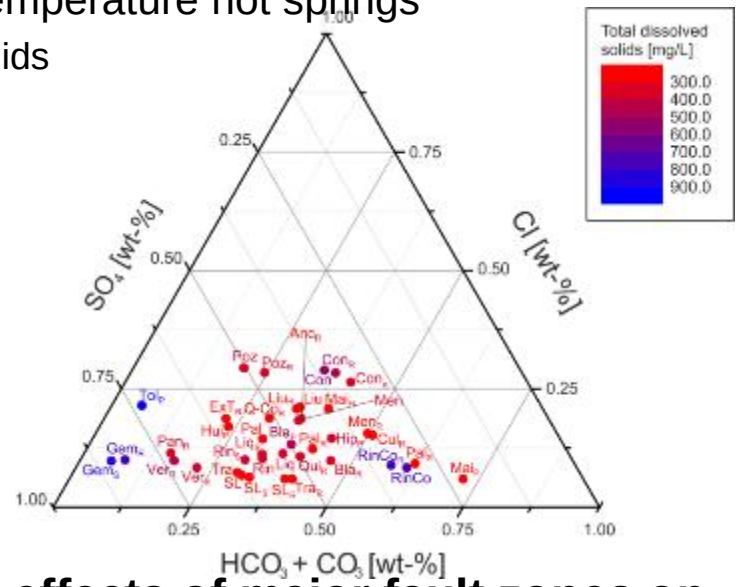
Motivation "Characterization of fault controlled geothermal systems"

- Villarrica Location:
  - active volcano (large eruption in 1984)
  - No high-enthalpy manifestations
    - no secondary clay minerals
    - no fumaroles in surrounding area
  - Abundant medium temperature hot springs
    - low mineralized fluids
  - Major fault zones



- **Goal: Investigate the effects of major fault zones on geothermal reservoir**

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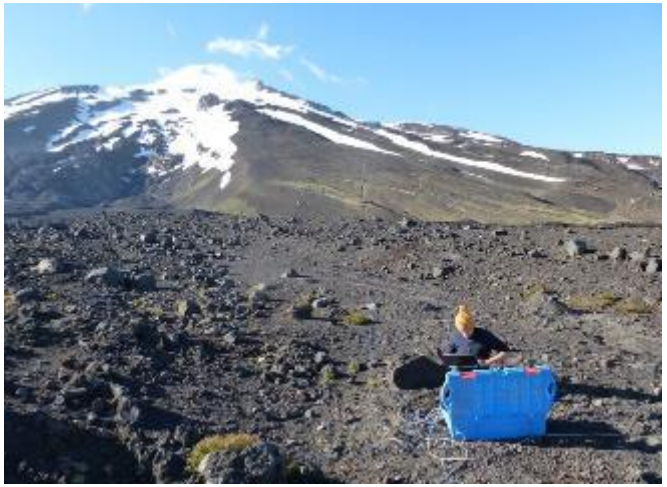
Project "Multidisciplinary geothermal exploration in the southern volcanic zone of Chile "

- Joint project:
  - Title: AGW - Prof. T. Kohl
  - CEGA - Prof. D. Morata
- Partners: KIT-INE, KIT-IMG, GTN
- Campaigns in Chile:
  - Fluid sampling at hot springs:
    Mar ’13 / Nov ‘13 / Mar ‘14
  - Magnetotelluric survey:
    Oct. - Dec. ‘13
  - Gravimetry:
    planned in 2015
- Lab at KIT:
  - Interpretation and Combination of data
  - Fluid-Rock analysis: Mar-May ‘14



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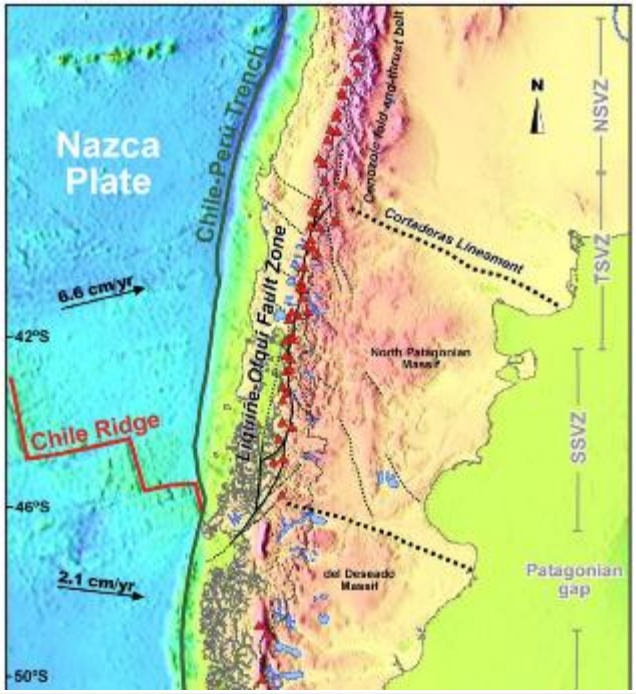
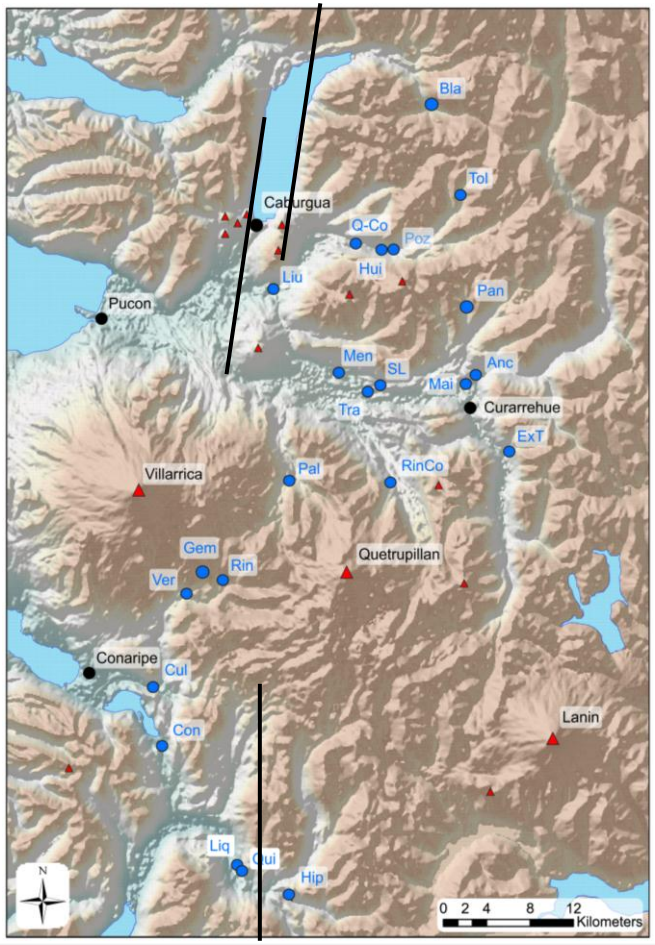
Liquine Ofqui Fault Zone LOFZ at Villarrica area

- Impact of volcanic heat source
  - Effect on geothermal reservoirs unknown
- Active tectonics at LOFZ
  - Detailed structure remains unclear
  - Effect on geothermal reservoirs unknown

The LOFZ



Locations of hot springs



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Research location
Impressions

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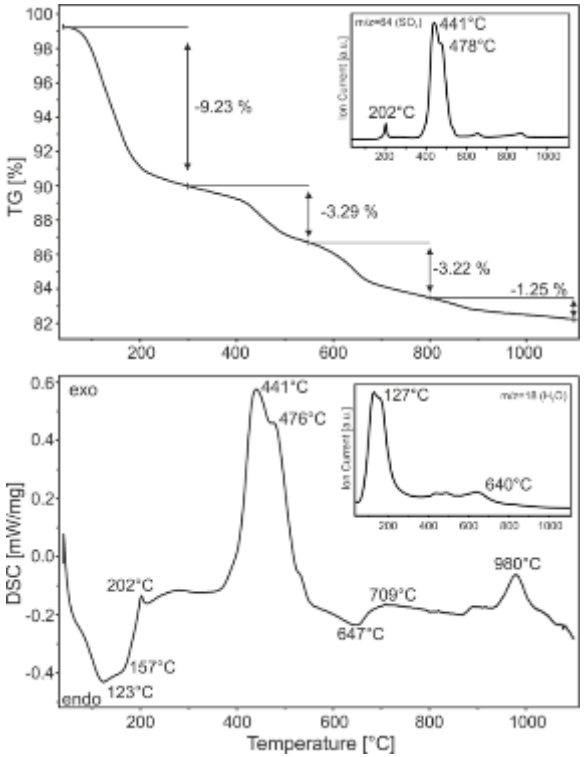
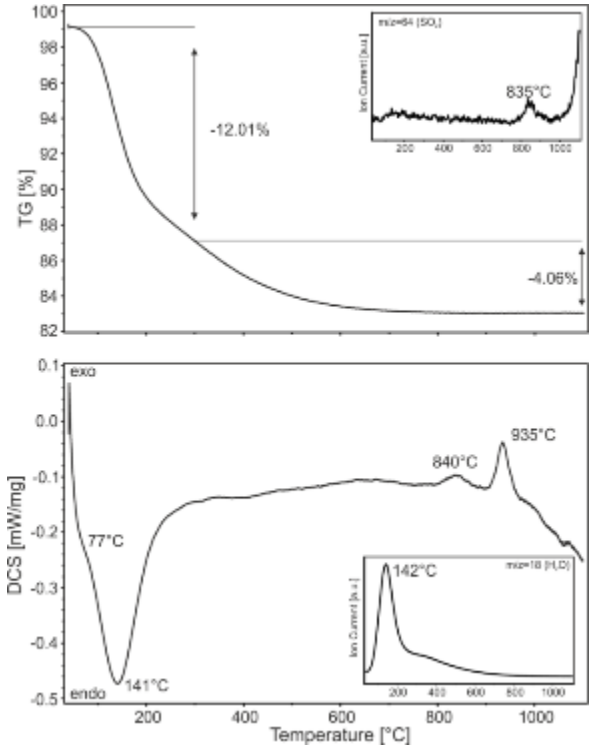
Analysis of Clay Mineralogy

- Comparison of hydrothermal alteration products between Villarrica area with high-enthalpy “El Toro” side
- Result: No hints on secondary hydrothermal clay minerals at Villarrica side



STA from El Toro



STA from Villarrica

Published in: Held et al. (2015)

Analysis Fluid Sampling: Advanced geothermometry

- General geothermometry
  - Silicium and standard cation (Na-K, K-Mg, Na-K-Ca) give no convincing result
- Sulfate (isotope) geothermometry
  - temperature depended fractionation of ^{18}O in sulfate or water $\delta^{18}O(H_2O)$ vs. $\delta^{18}O(SO_4)$

Sample	$\delta^{18}O$ (SO_4) [‰]	$\delta^{18}O$ (H_2O) [‰]	Temp. after Halas & Pluta (2000)[I]
Rincon	0.33	-9.74	116 °C
Liquiñe	3.78	-9.41	83 °C
Coñaripe	0.63	-8.09	134 °C
Trancura	0.14	-9.24	125 °C
San Luis	0.04	-9.28	126 °C
Palguin	0.74	-9.83	110 °C
Los Pozones	0.68	-10.2	123 °C
Liucura	2.55	-9.07	99 °C
Rinconanda	0.56	-11.1	98 °C
Menetue	1.55	-9.04	110 °C

[I] Formulae after Halas and Pluta (2000): $10^3 \ln \alpha(SO_4^{2-} - H_2O)_{empirical} = 2.41 \cdot 10^6/T^2 - 5.77$

- **Result: No signature of high enthalpy**

Held et al. (2015)

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Campaign:
Magnetotellurics, MT

- MT
  - Electromagnetic method
  - used for identification of ρ(z)
  - sensitive for secondary alteration products and fluids
- Goal: Faults zone detection and characterization of location and orientation
- High resolution Magnetotelluric:
  - Duration campaign: 6 weeks
  - # Stations: 31
  - Duration measurements: 1-2 days
  - # Students: 6
  - Master thesis included: M. Pavez

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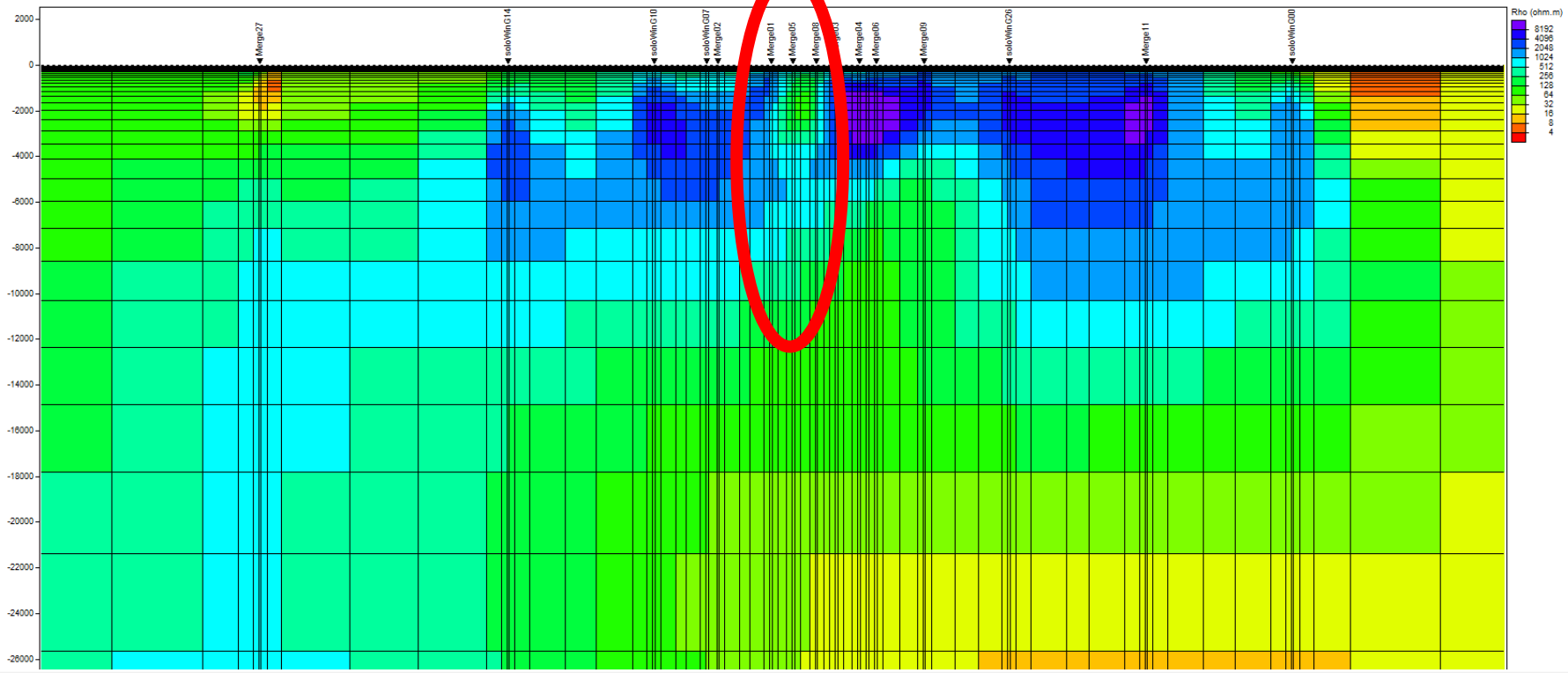
Results
Magnetotelluric Interpretation (Preliminary)

- 2D inversion using Winglink
  - Tomography rho(z)
  - Clear identification of LOFZ
  - Distinct width of approximately 1km can be determined



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Conclusions

- Clear evidence on
  - Maximum temperature of fluids under reservoir conditions → medium-enthalpy reservoir
  - Location of hidden LOFZ

- New Questions:
  - How can active volcano be isolated from fluid reservoir?

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Our Geothermal Team

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Thanks for your attention and to ..

- BMBD for sponsoring (# CHL-13WTZ-24)
- EnBW for support and funding

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Collaboration KIT - CEGA

- Timeline:
  - Oct. 2012: Official project start (only German funding)
  - Nov. 2012: Kick off meeting with German delegation in Chile
  - March 2013: Geochemical survey in the Villarrica area with German an Chilean researchers
  - April 2013: Start of project phase II
  - Oct. – Dec. 2013: Geophysical survey (MT) in the Villarrica area with German an Chilean researchers
  - March 2014: 2nd Geochemical campaign + project meeting to plan next steps with German researchers in Chile
  - Oct. 2014 2nd project started with binational funding

- Student exchange program
  - PhD thesis of Sebastian Held funded by collaborative research project; Title: Multidisciplinary geothermal exploration in the southern volcanic zone of Chile, 2013 – 2015, including several research stays in Chile
  - Bachelor thesis: E. Hoffmann & J. Bodman , finished June 2014
  - Master thesis: M. Pavez & I. Villalon with research stay at KIT, running