EGU24-10911, updated on 20 May 2024
https://doi.org/10.5194/egusphere-egu24-10911
EGU General Assembly 2024

Fluid flow in the Nevados de Chillán Geothermal System as an example of fractured reservoir, Southern Andes

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Understanding the controls on crustal fluid-flow in geothermal fractured reservoirs is critical to assessing their occurrence and storage capacity. The Nevados de Chillán Geothermal System (NChGS), located in Southern Chilean Andes, is hosted in volcanic-volcaniclastic rocks and fractured granitoids. In this work, we present evidence of how regional to local fault and fracture networks control the location and size of the NChGS.

Fractures in crystalline rocks were analyzed in three sites: 1) Shangri-La diorite, 2) Las Trancas granodiorite and 3) Valle Hermoso hornfels. Linear scanlines have a total cumulative length of 130 meters, in which >1000 fractures were measured. Results show preferential fracture orientations of N60E, N30E, and N45E for the three sites, respectively. Minor families of fractures in NNW and NW directions are also observed. The intensity of fractures (i.e. number of fractures/scanline length) is ~5m^{-1} at Shangri-La and exhibits minimum and maximum values between 6-13m^{-1} at Las Trancas, and between 8-13m^{-1} at Valle Hermoso. Variability in fracture intensity relates to profile orientation, presence of localized shear zones or distance from the geothermal system. These outcrop-scale structures are consistent with regional geometric arrangement and kinematics of major faults.

A fourth site was analyzed in the Las Termas-Olla de Mote area. Here, Miocene volcanic and volcaniclastic rocks present an intense argillic alteration in an area *ca*. 1 km^2. Numerous surface geothermal manifestations, such as fumaroles, hot springs, mud pools, mud volcanoes, and heated soils, can be observed. Using a Hanna HI 98509 thermocouple and Fluke TiS45 infrared camera, surface temperatures between 13°C and 95°C were measured. In this site, 85 fractures were measured in a 3-meter-long scanline in a localized cataclastic shear zone. The fracture alignment is essentially isotropic with an intensity of ~28m^{-1}. We noted a hydrothermal alteration pattern associated with centimetric to metric fault planes and fault zones. X-Ray Diffraction on clay minerals related to these fault-controlled alteration zones shows high-crystalline illite (Ku bler index as low as 0.096) and kaolinite (Aparicio-Galan-Ferrer index as high as 1.115).

Numerical modeling, considering structural, hydrothermal and temperature data, was performed with COMSOL Multiphysics, which allowed us to demonstrate the control of fractures in the development of a crystalline rock hosted geothermal reservoir. The simulated reservoir isothermal pattern can be reproduced consistently with our conceptual geological model after 15 ka.

These combined results evidence the first order structural control on the formation of the NChGS. Intersection of regional fault/fracture systems and local dilation areas are the main controls that permit the formation and growth of the active geothermal system. Moreover, the high crystallinity fault-related illite and kaolinite confirms that fluid-flow is mainly controlled by secondary structural permeability. Finally, the surface temperature data, coupled with thermal numerical modelling, allow us to establish a comprehensive theoretical model for the active NChGS relevant for sustainable exploitation.

This work is a contribution to the ANID-FONDECYT Project 1220729 and Andean Geothermal Center of Excellence (CEGA). Valentina Mura thanks to ANID -Beca Doctorado Nacional 21210890.