GFZ
Helmholtz Centre
Potsdam
EGU2020-373698

Local earthquake tomography at Los Humeros geothermal field (Mexico)

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Motivation and objectives

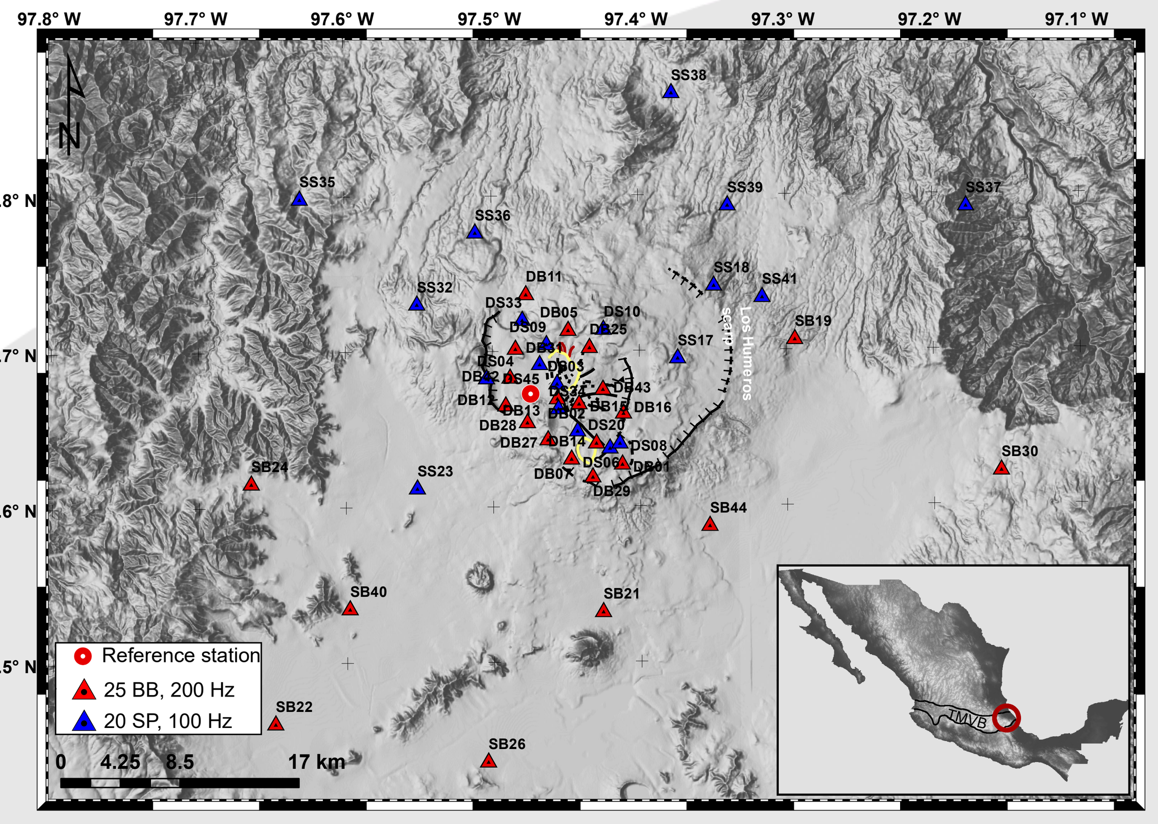

Fig. 1. Temporary seismic network at Los Humeros geothermal field in Mexico. Known fault scarps are delineated in black.

Los Humeros geothermal field is located in the eastern part of the Trans Mexican Volcanic Belt (TMVB). It is one of the largest geothermal fields in Mexico with around 40 wells operated by the Federal Electric Comission (CFE, by its Spanish acronym). From a geological point of view it is divided into **4 units**: basement (mainly limestones and shales), pre-caldera (andesites hosting the geothermal reservoir), caldera (ignimbrites), and post-caldera units (ignimbrites and basalt).

Between September 2017 and September 2018, a seismic network consisting of **45 seismic stations** was deployed to monitor the geothermal field. This experiment, in addition to several geophysical, geological, and geochemical surveys, has been conducted in the framework of the European H2020 project GEMex for a better understanding of the structures and behavior of the geothermal reservoir under current exploitation, and for investigating future development areas.

We analized the continuous records to **detect local microseismicity**. The retrieved catalog was used to derive a **minimum 1D velocity model**. We then performed a joint inversion to **obtain the 3D Vp and Vp/Vs structures** of the geothermal field. Our main objective was the **identification of underground structures, and possible variations due to changes in fluid content, temperature, and rock porosity for future development of the geothermal field. [11]**

Local seismicity

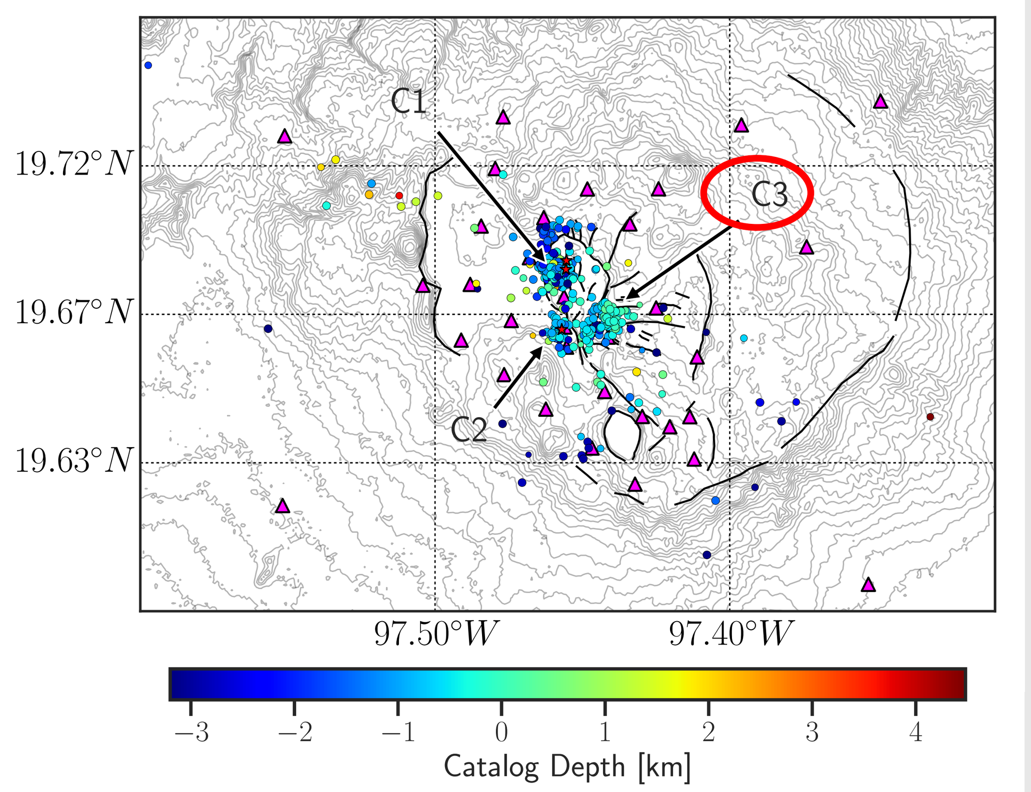

Fig. 2. Distribution of all detected local earthquakes after nonlinear localization over a homogeneous 3D volume of 3.5 km/s P-wave velocity and 1.73 Vp/Vs ratio. Dark solid lines indicate structures inferred at surface. Red stars mark the position of three injection wells

The retrieved **local seismicity** is mainly grouped in **three clusters**. Cluster C1 is located at the main production area, where 2 of 3 injection wells are located. C2 is located west to Los Humeros fault also in the vicinity of a third injection well. C3 is a deeper cluster located to the east. C3 could indicate a **potential fluid pathway at depth**, given the proximity to C2. **C3 has not been identified in previous studies.**

Minimum 1D Velocity model

To obtain a **minimum 1D velocity model**, simultaneous inversions of hypocentral parameters, velocities and station corrections were performed by using the VELEST software [7].
We inverted for a set of around 10000 initial velocity models with varying top velocities and gradients. We compared the results and selected the model with lowest resulting RMS as an initial reference models for the seismic tomography.

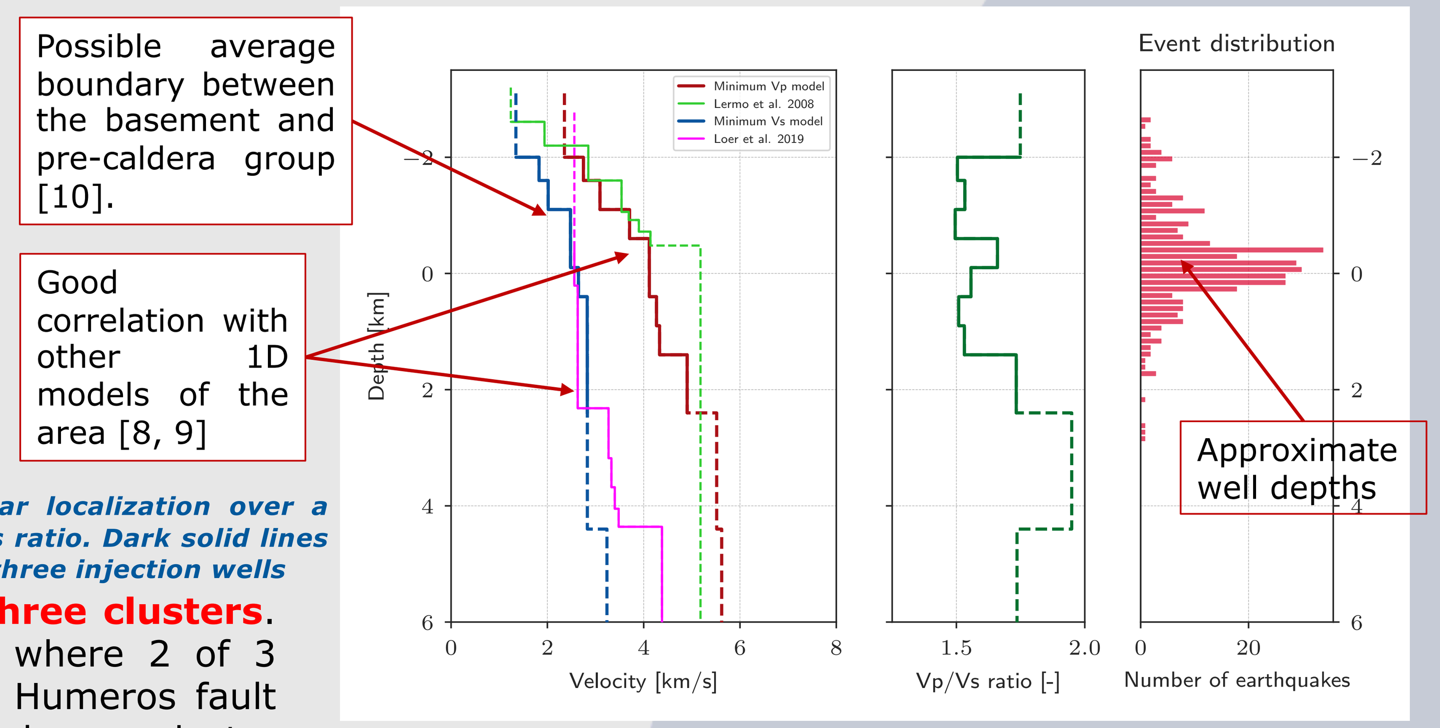

Fig. 3. Minimum 1D model showing: left) the selected Vp and Vs models along with 2 available models (Lermo et al 2008, Löer et al 2020), center) the resulting Vp/Vs ratio, and right) the earthquake distribution after the 1D inversion. Solid lines indicate the depth intervals with best sensitivity for each model.

3D Velocity model

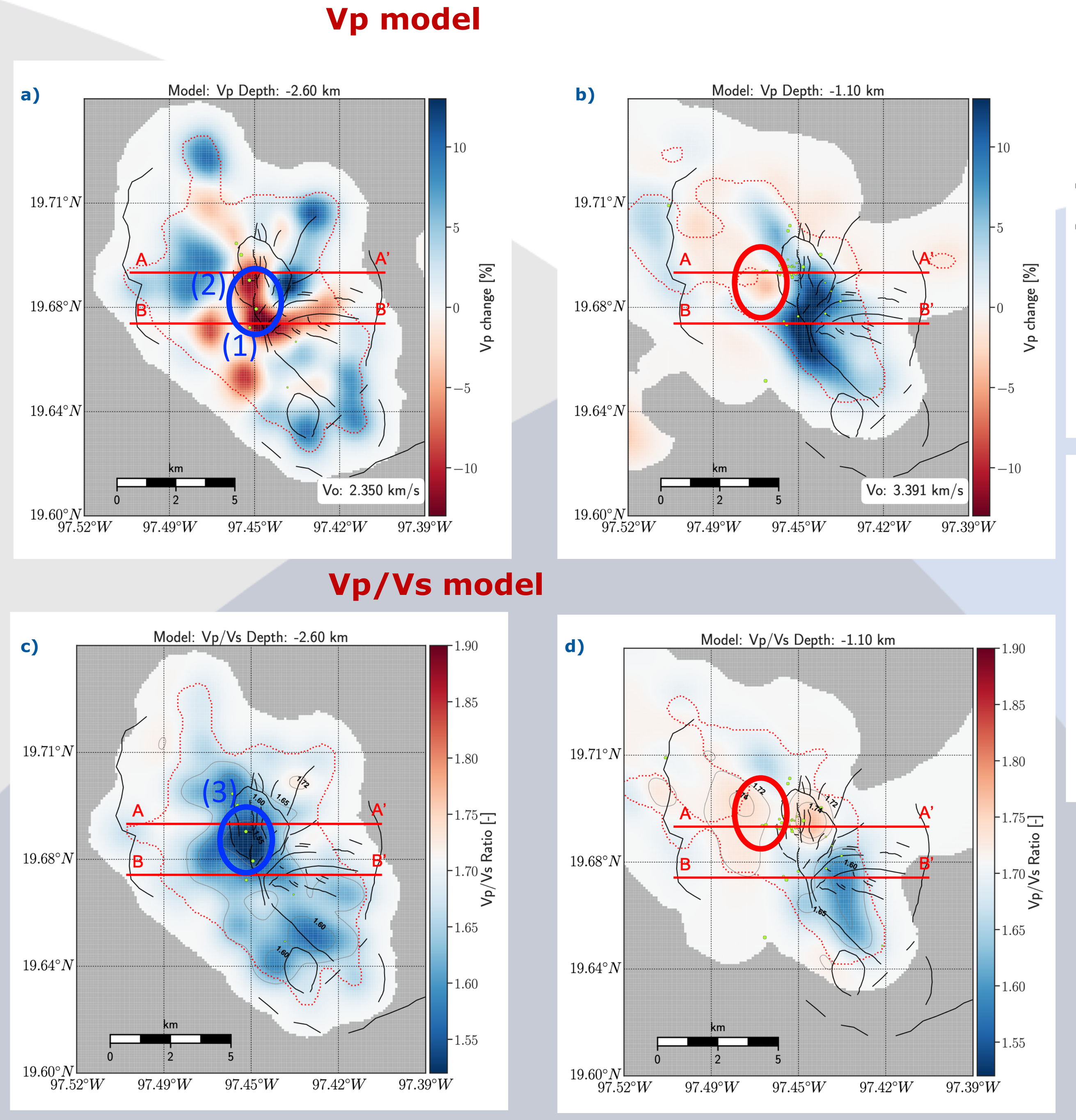

Fig. 4. Tomographic results at different depth levels. Panels a) and b) show depth slices for the resulting Vp model variations with respect to the minimum 1D velocity model. Panels c) and d) show depth slices for the Vp/Vs model. Green circles mark the location of earthquakes +/- 150 m away from slice. Dashed red line indicate the boundary at which spread values are less or equal than 1.5 (best resolution). Gray areas mark the boundaries where the DWS (ray density) is less or equal than 5. Known fault scarps are delineated in black.

We performed the simultaneous inversion for the **3D tomographic velocity structure and earthquake hypocenters** using the SIMUL2000 code [5]. We extended the classical tomographic method by inverting for several different initial grids and averaging the results.

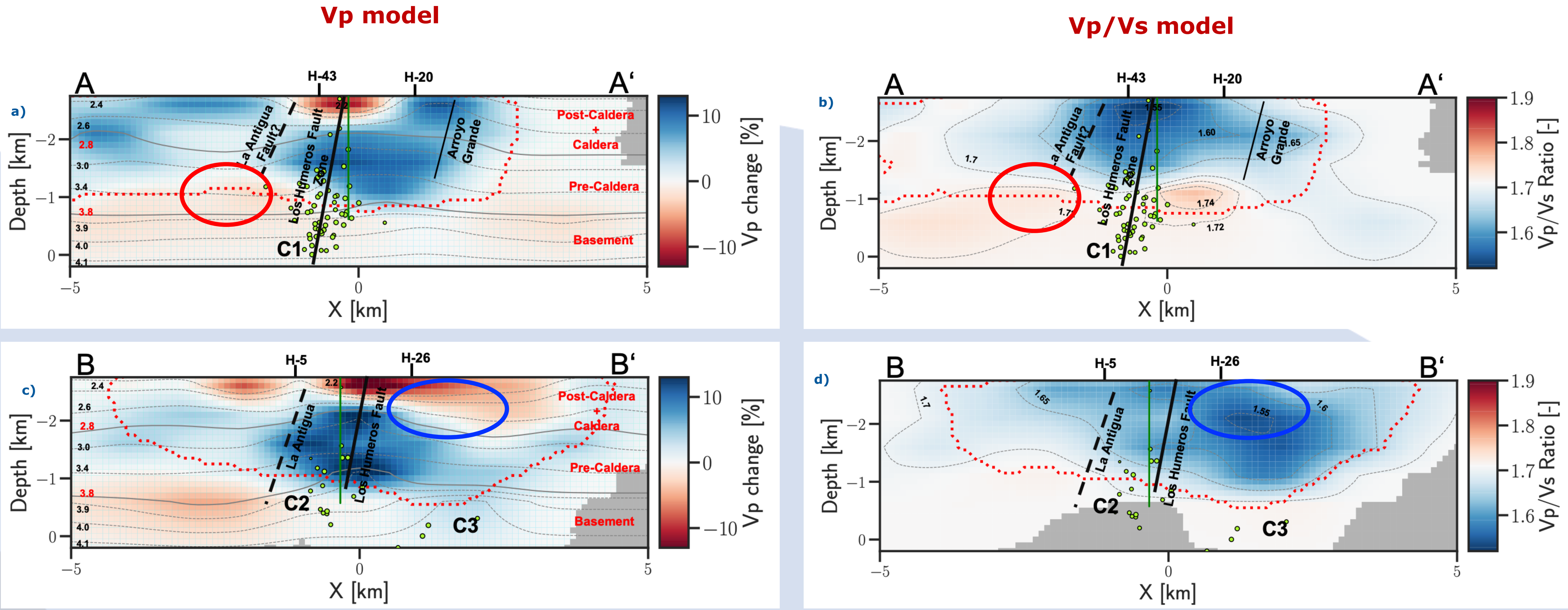

Fig. 5. Cross-sections of the tomography. Panels a) and c) show depth slices for the resulting Vp model variations with respect to the minimum 1D velocity model. Panels b) and d) show depth slices for the Vp/Vs model. Green circles mark the location of earthquakes +/- 200 m away from slice. Main structures are indicated in black. Vertical green lines indicate the location of neighboring injection wells. Dashed red line indicate the boundary at which spread values are less or equal than 1.5 (best resolution). Gray areas mark the boundaries where the DWS (ray density) is less or equal than 5.

P-wave velocities range between 2 and 4.1 km/s, Vp/Vs ratios range between 1.50 and 1.77 (Fig. 4 and Fig. 5). We used newly acquired laboratory measurements [1] and well data interpretations [4] to **identify the approximate limits of the main geological units and underground structures** in Fig.5.

At shallow depth (Fig.4a) the Vp model follow the surface geology. Lower velocities (1) are located over a very faulted zone with undefined pyroclastics. A higher velocity anomaly (2) coincides with a region of basalt. Fig. 4c (3) shows a low Vp/Vs region (≤ 1.6) which coincides in shape and position with a very conductive anomaly (≤10Ωm) [2]. This anomaly may indicate the cap rock location (ignimbrite from the caldera unit). This region of low velocity (most likely very porous) in combination with low Vp/Vs values (blue ellipses) may indicate gas filled zones in shallower layers.

At depth, a high velocity anomaly is located to the west of the main production zone (Fig. 4b,d and Fig. 5). This region coincides with a high Vp/Vs ratio anomaly (red ellipses). This area could indicate a fluid bearing zone [6].

Observing the Vp/Vs A-A' cross-sections, two high Vp/Vs anomalies appear on each side of the Los Humeros Fault Zone (Fig. 5b). A heat source could be assumed as located at greater depths transporting heat along permeable faults especially in the region close to Los Humeros Fault Zone. However, due to the limited imaging capabilities of the dataset used, this hypothesis would need to be tested with different techniques such as ambient noise tomography.

Conclusions and outlook

Results of this study reveal several new insights of the geothermal field. First, a **new seismogenic zone** has been identified towards the east of the main production area (cluster C3). In addition we have **identified several known and inferred structures** with our tomographic results.
The retrieved seismic properties, in combination with alternative geophysical and laboratory measurements have allowed the understanding of the **geometry of the underground units** and the **rheology of the system**. Although at the moment interpretation is performed in a qualitative manner, the next step would be a quantitave analysis of the gathered data from the different techniques via cluster analysis for better discrimination of different units.

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Acknowledgements

We thank Prof. Michael Weber, Dr. Christian Haberland, and Msc. Anna Jentsch for the fruitful contributions to this work. Data loggers, broadband and short period stations were provided by the Geophysical Instrumental Pool of Potsdam (GIPP). This work is presented within the framework of the GEMex project, which has received funding from the ***European Union's Horizon 2020 research and innovation program under grant agreement No. 727550 and the Mexican Energy Sustainability Fund CONACYT-SENER, project 2015-04-68074.***

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