

Layer-specific Q estimation for deep geothermal potential beneath Malargüe, Argentina, using seismic interferometry and ghost reflections

Nishitsuji, Y.; Draganov, D.

DOI

[10.3997/2214-4609.202521039](https://doi.org/10.3997/2214-4609.202521039)

Publication date

2025

Document Version

Final published version

Citation (APA)

Nishitsuji, Y., & Draganov, D. (2025). *Layer-specific Q estimation for deep geothermal potential beneath Malargüe, Argentina, using seismic interferometry and ghost reflections*. Paper presented at 6th EAGE Global Energy Transition Conference and Exhibition, Rotterdam, Netherlands. <https://doi.org/10.3997/2214-4609.202521039>

Important note

To cite this publication, please use the final published version (if applicable). Please check the document version above.

Copyright

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy

Please contact us and provide details if you believe this document breaches copyrights. We will remove access to the work immediately and investigate your claim.

**Green Open Access added to [TU Delft Institutional Repository](#)
as part of the Taverne amendment.**

More information about this copyright law amendment
can be found at <https://www.openaccess.nl>.

Otherwise as indicated in the copyright section:
the publisher is the copyright holder of this work and the
author uses the Dutch legislation to make this work public.

Layer-specific Q estimation for deep geothermal potential beneath Malargüe, Argentina, using seismic interferometry and ghost reflections

Y. Nishitsuji^{1,2}, D. Draganov²

¹ Sumitomo Corporation; ² Delft University of Technology

Summary

We examine the deep geothermal potential beneath Malargüe, Argentina, using global-phase seismic interferometry (GloPSI) and ghost reflections, retrieved from it, to analyze the intrinsic attenuation in the crust and upper mantle. By processing data from the MalARRgüe seismic array and distant earthquakes, we identify distinct patterns of seismic-wave attenuation: the crust displays moderate attenuation, while the upper mantle near the Moho discontinuity shows much higher attenuation. This sharp contrast suggests the presence of elevated temperatures or partial melt, possibly linked to a magma chamber, which could enhance geothermal potential in the region. The method provides higher spatial resolution and depth-specific information than traditional models, allowing non-invasive identification of zones with increased heat flow—potential geothermal “sweet spots.” This approach also avoids the need for expensive drilling, making it valuable for large-scale geothermal assessment.

Layer-specific Q estimation for deep geothermal potential beneath Malargüe, Argentina, using seismic interferometry and ghost reflections

Introduction

Geothermal energy has emerged as a promising renewable resource for sustainable power generation and direct-use applications. As global energy demands rise, there is increasing interest in exploring deep geothermal resources to tap into the Earth's vast heat reserves (IEA 2024). However, accurately characterizing deep geothermal reservoirs remains challenging due to subsurface complexities at great depths (Medici et al. 2023).

Seismic interferometry has proven powerful for imaging and monitoring subsurface structures relevant to geothermal exploration (Chang and Nakata 2022). This method allows researchers to study upper mantle properties, crucial for understanding deep geothermal potential (Lehuteur et al. 2015; Nishitsuji and Masaya 2021). The quality factor Q , which quantifies seismic wave attenuation, provides valuable insights into the Earth's interior thermal and compositional state.

Estimating Q in the upper mantle and near the Moho discontinuity is vital for advancing our understanding of deep geothermal resources (Zhu et al. 2022). It elucidates the crust-mantle transition and its implications for heat transfer, fundamental to assessing geothermal potential. Non-physical arrivals or "ghosts" in seismic-interferometric results could be used to extract valuable information about specific subsurface-layers' seismic properties (Draganov et al. 2013).

This study applies global-phase seismic interferometry (GloPSI; Ruigrok et al. 2008) to estimate Q at greater depths using ghost reflections, focusing on the crust and the upper mantle in Argentina's Malargüe region, part of the Neuquén basin known for its deep geothermal potential (Vieira and Hamza 2019) (Figure 1). Using distant-earthquake arrivals, we create high-resolution images around the upper mantle, Moho, and crust. This approach offers enhanced spatial resolution, more uniform sampling of the Earth's deep interior, and the ability to probe deeper structures using body waves.

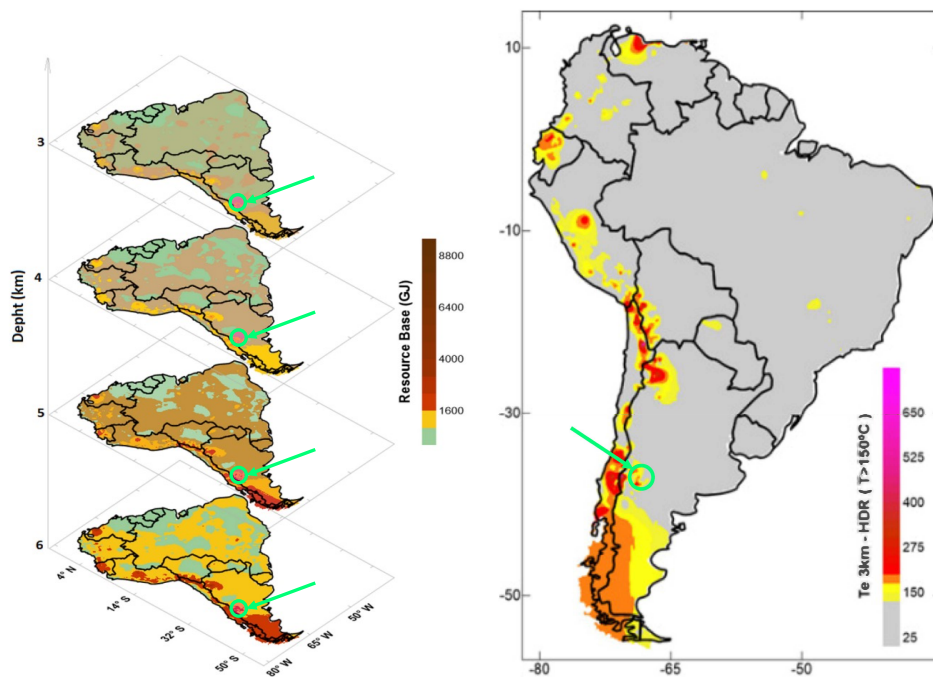


Figure 1 (left) Thermal resource base per unit area (GJ) for South America at depth of 3 km, 4 km, 5 km, and 6 km. The green circles correspond to our study region. (right) Distribution of deep geothermal systems at depth of 3 km. The figures are modified after Vieira and Hamza (2019).

Method

The Malargüe region in Argentina offers an intriguing setting for studying Q , with its complex geological structure including its deep geothermal potential in the Neuquén basin. The MalARRgüe seismic array, deployed in 2012, provides an excellent opportunity to investigate Q with its T-shaped configuration consisting of two linear arrays spanning approximately 60 km (Ruigrok et al. 2012).

Our study utilized data from 72 distant earthquakes with magnitude $M_w \geq 5.5$ and epicentral distances $\geq 120^\circ$ recorded at the TN-array (19 stations in the north-south direction of MalARRgüe). After quality control, we select four events for further analysis based on the clarity of their *PKIKP* phases.

The overall processing workflow to estimate Q consists of two main steps (Figure 2):

1. Using GloPSI, retrieval of a ghost reflection between two reflectors
2. Using the retrieved ghost reflections, estimate the effective Q for the overburden above the top of the two reflectors

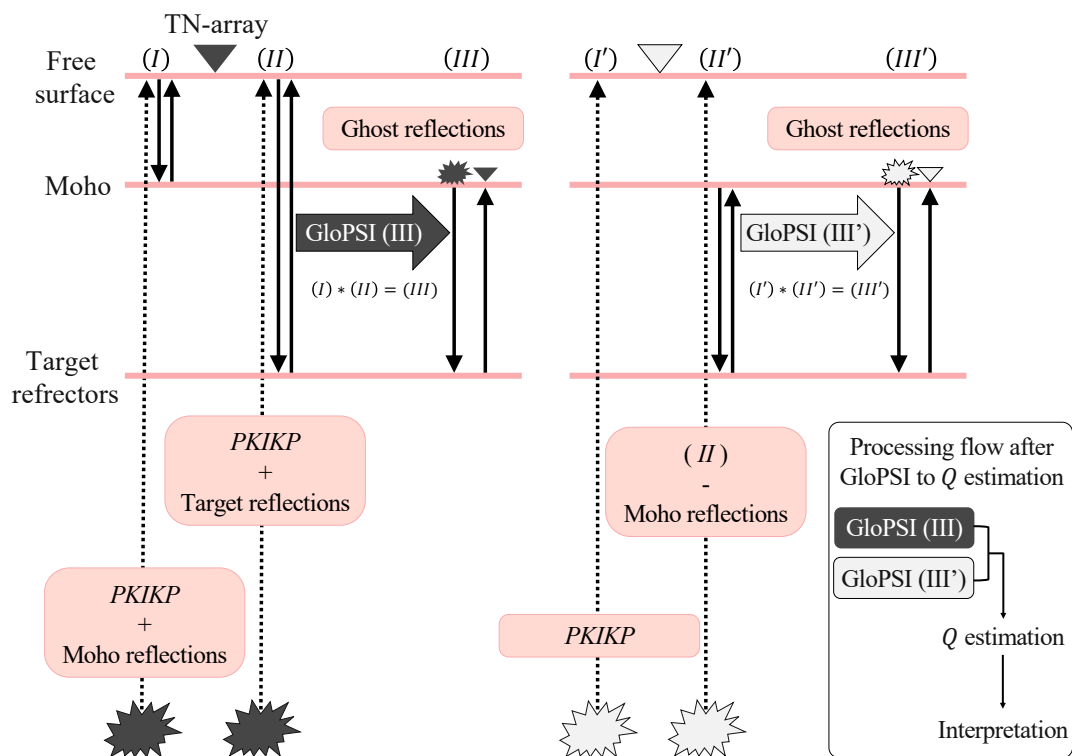


Figure 2 Overall processing flow of this study. Q estimation is carried out using two parts of a ghost reflection using GloPSI, following Draganov et al. (2013).

Key processing steps for effective ghost-reflection retrieval include:

- Careful preprocessing of the data, including deconvolution and muting of undesired events;
- Modal separation to isolate specific arrivals (wave types);
- Identification of key seismic phases: *PKIKP*, Moho, and a target reflector.

We use *PKIKP* and Moho data from Nishitsuji et al. (2016), while identifying a suitable target reflector deeper than the Moho. To retrieve the ghost reflection, we extract the arrivals around the Moho and the target reflector using a 14-s time window; we use the extracted arrivals for cross-correlation in GloPSI. Adopting the procedure of Draganov et al. (2013), we use the GloPSI retrieved ghost reflection to estimate the effective Q of the overburden above the top of a layer that causes a ghost reflection to appear. We apply Q compensation to the retrieved ghost reflections by multiplying the four individual arrivals in Figure 2 with an amplitude damping-compensation parameter containing a trial Q .

We investigate Q values ≤ 200 , based on recent global Q models for the region. To determine the optimal Q above the target layer, we carry out seismic interpretation focusing on traces whose polarity becomes reversed as a function of trial Q values. This technique allows us to achieve higher spatial resolution, depth-specific information, and layer-specific Q values compared to global Q models, providing a more nuanced picture of attenuation variations with depth in the upper mantle beneath the Malargüe region.

Discussion

Using the green-highlighted ghost reflection in Figure 3, whose overburden corresponds to the crust, we estimate $Q_{crust} = 104.5 \pm 13.9$. On the other hand, using the magenta-highlighted ghost reflection in Figure 3, whose overburden corresponds to the crust and the bifurcated Moho, as expected to exist (Gilbert et al. 2006), we estimate $Q_{crust+bifurcatedMoho} = 28.6 \pm 5.2$. The observed trend of low Q values below the crust, suggests a complex upper mantle structure relevant to geothermal potential such as magma or partial melting (Figure 3). Note that the estimated Q values should be increased to compensate for using only four arrivals for the ghost-reflection retrieval (Figure 2) instead of all multiple-scattered arrivals that would contribute to the ghost-reflection retrieval. In our case, using impedance models (Brocher 2005; Farias et al. 2010), we estimate these corrections to be $< 0.1\%$.

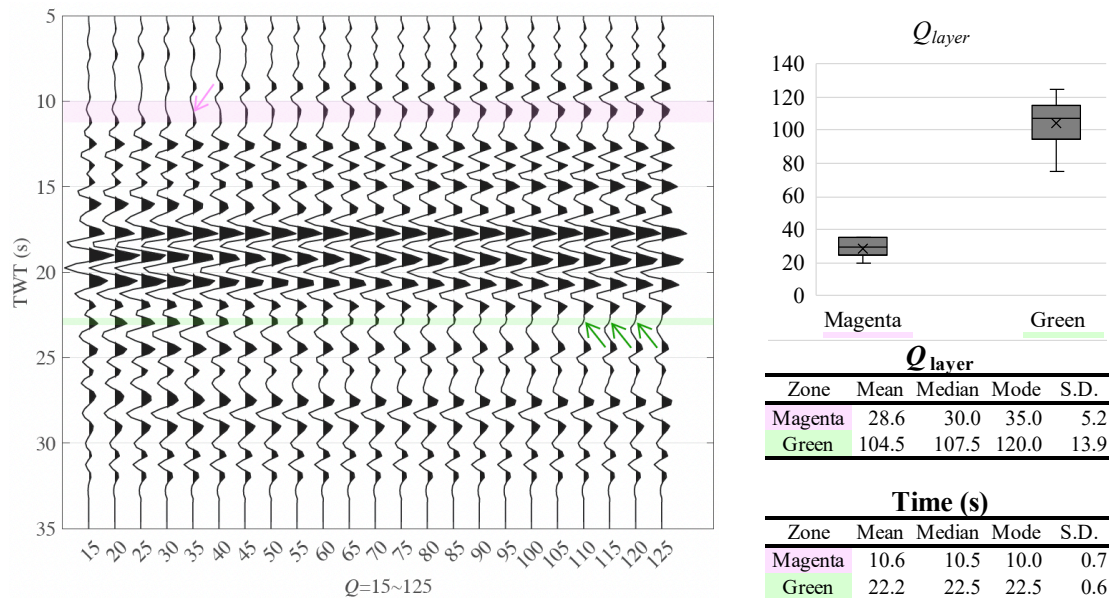


Figure 3 Results of estimated Q . (left) Rectangular in magenta and green indicate where polarity changes are evidently seen. Arrows point out locations where seismic phase begin to reverse or get closest to amplitude of zero, which is an indication of Q . (right) Summary of Q_{layer} for four events we evaluated.

Lower Q values near the Moho could be associated with higher temperatures or partial melt presence, aligning with Gilbert et al. (2006)'s suggestion of a magma chamber between a bifurcated Moho in this region. Such a feature could be a significant heat source for deep geothermal systems, enhancing the area's geothermal potential.

The detailed Q structure revealed by our study could serve as a valuable tool for identifying and characterizing deep geothermal reservoirs in the Neuquén basin. Areas with lower Q values may correspond to zones of elevated temperature or fluid content, key factors in geothermal resource assessment. The higher resolution and depth-specific information provided by our method allows for a more nuanced understanding of the upper mantle structure, helping to (i) identify potential geothermal "sweet spots" with highest heat flow, (ii) characterize depth and extent of potential geothermal reservoirs, and (iii) understand heat transfer mechanisms from mantle to crust.

Our approach offers several advantages over traditional geothermal exploration methods: non-invasive deep imaging without expensive drilling operations; large-scale assessment to focus detailed exploration efforts; integration with other geophysical and geological data for comprehensive modelling. While our study demonstrates the potential for deep geothermal exploration using GloPSI with Q estimates, further research, such as correlation with temperature data, is needed to fully leverage this method in geothermal resource assessment and development.

Conclusions

We applied global-phase seismic interferometry to estimate Q values in the crust and upper mantle beneath the Malargüe region, Argentina. We extracted ghost reflections and provided layer-specific Q estimates, revealing values of 104.5 ± 13.9 in the crust and below 28 at the bifurcated Moho, indicating increasing attenuation at the Moho depth. Our approach offers higher spatial resolution and depth-specific information compared to global Q models. These insights have implications for understanding the Neuquén basin's deep geothermal potential, as Q variations can indicate changes in temperature, composition, or partial melt content. This method opens new avenues for investigating deep Earth structures and understanding upper mantle dynamics.

References

- Brocher, T. M. [2005]. Empirical relations between elastic wavespeeds and density in the Earth's crust. *Bulletin of the Seismological Society of America*, **95**, 2081–2092.
- Chang, H. and Nakata, N. [2022]. Investigation of time-lapse changes with DAS borehole data at the Brady geothermal field using deconvolution interferometry. *Remote Sensing*, **14**, 185.
- Draganov, D., Ghose, R., Heller, K., and Ruigrok, E. [2013]. Monitoring changes in velocity and Q using non-physical arrivals in seismic interferometry. *Geophysical Journal International*, **192**, 699–709.
- Farias, M., Comte, D., Charrier, R., Martinod, J., David, C., Tassara, A., Tapia, F. and Fock, A. [2010]. Crustal-scale structural architecture in central Chile based on seismicity and surface geology: Implications for Andean mountain building. *Tectonics*, **29**, TC3006.
- Gilbert, H., Beck, S. and Zandt, G. [2006]. Lithospheric and upper mantle structure of central Chile and Argentina. *Geophysical Journal International*, **165**, 383–398.
- IEA [2024], *The Future of Geothermal Energy*, IEA, Paris <https://www.iea.org/reports/the-future-of-geothermal-energy>.
- Lehujeur, M., Vergne, J., Schmittbuhl, J. and Maggi, A. [2015]. Characterization of ambient seismic noise near a deep geothermal reservoir and implications for interferometric methods: a case study in northern Alsace, France. *Geothermal Energy*, **3**, 1-17.
- Medici, G., Ling, F. and Shang, J. [2023]. Review of discrete fracture network characterization for geothermal energy extraction. *Frontiers in Earth Science*, **11**, 11:1328397.
- Nishitsuji, Y., Ruigrok, E., Gomez, M., Wapenaar, K. and Draganov, D. [2016]. Reflection imaging of aseismic zones of the Nazca slab by global-phase seismic interferometry. *Interpretation*, **4**, SJ1-SJ16.
- Nishitsuji, Y. and Masaya, S. [2021]. Energy exploration for low-carbon resources: a case study of deep geothermal and lithium extraction by passive seismic interferometry with curvelet denoising. *Proceedings of the 14th SEGJ International Symposium*, 214-217.
- Ruigrok, E., Wapenaar, K. and Draganov, D. [2008]. Global-scale seismic interferometry: theory and numerical examples. *Geophysical Prospecting*, **56**, 395-417.
- Ruigrok, E., Draganov, D., Gomez, M., Ruzzante, J., Torres, D., Lopes Pumarega, I., Barbero, N., Ramires, A., Castano Ganan, A. R., van Wijk, K., & Wapenaar, K. (2012), Malargüe seismic array: Design and deployment for the temporary array. *The European Physical Journal Plus*, **127**, 126.
- Vieira, F. P. and Hamza, V. M. [2019]. Assessment of geothermal resources of south America – a new look. *International Journal of Terrestrial Heat Flow and Applications*, **2**, 46-57.
- Zhu, M., Sun, S., Zhou, Y. and Wu, Q. [2022]. Mantle Q structure from S, SS, SSS and SSSS amplitude measurements. *Geophysical Journal International*, **231**, 703–716.