

General comments

The authors, Tsarsitalidou et al., present a case study of focal spot imaging for hardrock exploration in an interesting, geologically complex environment at an active mine. The manuscript builds on the focal spot imaging method the first author previously used for regional-scale seismology (USArray, AlpArray). Here, they present focal spot imaging as an exploration tool for near-surface features, highlighting its potential as a stand-alone prospecting method. This work builds on and is validated by previous work in the area using traveltimes tomography and various ambient noise studies. Overall, the manuscript makes an important scientific contribution to hardrock seismic exploration and is well written, meeting the highest standards of scientific writing. I congratulate the authors on this work, as I truly enjoyed reading it. However, a few points would benefit from further analysis and discussion, particularly concerning the lateral and depth resolution and the nature of the wavefield. Therefore, I suggest a minor revision and include my comments, which I hope will help further improve the quality and clarity of the authors' work.

Specific comments

Line 41: "... the method can resolve lateral structures that are smaller than the wavelength, and that it can provide better depth resolution than the more widely used ambient-noise tomography"

- What is the depth resolution of the method?
- What is the lateral resolution? Can it resolve structures smaller than the focal spot radius r used in this study?

Section 2.1 Geological setting

- I recommend introducing a table with the geological units/lithologies and their expected V_p and V_s ratios. This would help later in the text (results, discussion) link the results to the expected lithologies and give the reader clarity on the seismic medium.

Section 2.2 Data acquisition, array configuration, and ambient seismic wavefield conditions

- How would this channel spacing and geometry affect the wavenumber resolution? Which wavelengths can be resolved, and which cannot? Consider plotting the Array Response Function (ARF) if the concept of wavenumber resolution can be translated to focal-spot imaging.

Section 2.3 Preprocessing and noise correlations and

Section 3 Anatomy of the correlation field

- I recommend displaying the cross-correlograms either for all traces related to the interstation distance (as in Tsarsitalidou et al., 2024, Fig.1) or by extracting a single line from the dataset. It would be helpful to clarify the features discussed in Figure 2 and Section 3, particularly the P-wave, Rayleigh wave, and spurious arrivals in the wavefield.
- If possible, please consider doing some sort of beamforming on the cross-correlograms to further support their interpretation of the directionality and origin of noise sources. MUSIC beamforming has been shown to be useful for identifying wave velocities and

back-azimuth, also on cross-correlograms. There are available codes (see references). If not possible, perhaps a reference to a figure from some of the work of Chamarczuk et al. would be useful.

- Please also show the average amplitude spectrum for a range of 0.2-40 Hz and perhaps an inset to a 3-6 Hz range with the amplitude response of the narrow-band Gaussian filter $h(w)$ as an example. This would help readers understand the seismic wavefield and the filter's behaviour.
- I suggest summarising the processing steps in a table for more clarity

Section 4 Focal Spot Imaging

- I am missing a more thorough explanation of the lateral resolution/depth resolution trade-off that I would expect from a surface-wave-based and spatially averaging method. It is touched upon in places but would benefit from a theoretical foundation linked to the survey geometry and target wavelengths.
- I suggest moving the note on the image enhancement techniques by Kolehmainen et al. (2025) to the discussion (Line 168).
- Please clearly state your choice of the search radius r . Other papers used a radius of 1.5λ . It would help the reader to understand the reasoning behind the choice of r . If you have experimented with other radii, please state it briefly.
- Line 188: k_1 , k_2 , etc. are not explained in Eq. 2, to which they refer.
- It would help to see a table or a diagram showing a step-by-step methodology for obtaining the final result. It can be combined together with the preprocessing steps.
- Please provide (in this section or elsewhere) a more detailed discussion on the target frequency range. You mention (Line 197) that “The target frequency range is typically constrained by the shortest and longest wavelengths, which are estimated from the interstation distance and the array aperture, respectively”. Knowing your seismic velocities, array aperture and interstation distance, please state which wavelengths you are looking at here. Try to put a number on the wavenumber resolution (see also the previous comments).
- Line 199: “In this study, however, frequencies below 3 Hz are excluded because the anisotropic noise wavefield 200 at near-field distances leads to velocity estimates that are clearly biased by the mine activity. At frequencies above 6 Hz, the velocity maps no longer exhibit coherent features.” If possible, please give more details on this statement. Perhaps link it to the requested cross-correlograms or the amplitude spectra. Readers would benefit from knowing how the authors define what is usable and what is not. I leave it to the authors whether to include this in the main text.

Section 5.1 Focal spots

- Line 224: “... indicate the presence of body-wave energy”. Please explain how the residuals indicate the body-wave energy. Also, line 232. Would a high-velocity body wave interfere with the 0-lag spatial autocorrelation in the 1λ radius, and if so, can we decouple this effect? Considering that you are aware of the presence of body waves, I think it needs a comment in the discussion.

- Line 238: Just a comment that strengthens your filtering choice. Your filter is essentially a moving average over the inline on a length of 200 m, effectively limiting both your inline and crossline resolution to 200 m. This is acceptable considering the wavelengths you are using (min. 400 m?)
- Figure 3b. The points used to fit the Bessel function seem to have a bimodal distribution, and the fitting function either underestimates or overestimates the results. Is this related to the elliptical distribution, and if so, can we fit two independent curves? Could that indicate horizontal anisotropy? Please discuss.

Section 5.3 Dispersion curve clustering

- Considering that at each point the dispersion curve is averaging the information of 1 lambda radius, isn't it expected that the dispersion curves are also spatially clustered? Please comment on this if you find it interesting for the readers.
- Line 280: The edge points use only half of a focal spot, and the corner points use a quarter of a focal spot. Does this affect the standard error because of the lower number of data points?

Section 6 Discussion

- Lines 298 to 301: these values would read very well in a table, as suggested already in Section 2.1
- Line 309: relating to the lambda/3 rule of thumb, please state the expected depth sensitivity for the 3-6 Hz radius. Possibly somewhere around Section 3, together with the resolution discussion?
- Line 337: I suggest you emphasise that the emergence of spurious phases does not influence your result. I think this adds significance to your work.
- Line 340: Again, please validate the choice of this frequency range (see also previous comments).
- Line 353: "As the lateral resolution depends on the data range ...", please state how it depends on it.
- Line 365: You mention the theoretical depth resolution. Please state it in the method introduction.

Technical corrections

- Line 22: I suggest rephrasing "translated" to "inverted" or similar.
- Line 27: "... contains complementary information" – you do not comment further on how it complements the CC tomography. Would the two methods benefit from working together, or would they reach the same result? Consider rephrasing.
- Line 67: **P-wave** travel time tomography
- Lines 127- 128: Consider citing Wapenaar et al., 2010.
- Line 129: Consider citing Halliday and Curtis, 2009.
- Line 147: "We demonstrate..." – where? In this section, in this paper, or in a specific figure? Please clarify
- Line 149: Broadband refocusing pattern (shown in Figure 2?)
- Line 167: I suggest moving the image enhancement techniques to the discussion or providing slightly more details here.

- Line 263: K-means
- Line 267: If suitable, please provide a reference for the elbow method.
- Line 284: The first paragraph of the discussion seems similar to the conclusions. Consider rephrasing or merging the two.
- Line 375: hardrock environment → hardrock exploration

ARF literature:

- Wathelet, M., Jongmans, D., Ohrnberger, M. *et al.* Array performances for ambient vibrations on a shallow structure and consequences over V_s inversion. *J Seismol* **12**, 1–19 (2008). <https://doi.org/10.1007/s10950-007-9067-x>
- Mordret, A., & Grushin, A. G. (2025). Beating the aliasing limit with aperiodic monotile arrays. *Physical Review Applied*, 23(3). <https://doi.org/10.1103/physrevapplied.23.034021>
- Löer, K., & Finger, C. (2024). B3AM: A beamforming toolbox for three-component ambient seismic noise analysis. *Seismica*, 3(2). <https://doi.org/10.26443/seismica.v3i2.1343>

MUSIC beamforming

- van den Ende, M. P. A., & Ampuero, J.-P. (2021). Evaluating seismic beamforming capabilities of distributed acoustic sensing arrays. *Solid Earth*, 12(4), 915–934. <https://doi.org/10.5194/se-12-915-2021>
- Wilczynski, Z., Kaslilar, A., Malehmir, A., Manzi, M., Vivin, L., Lepine, J., Valishin, O., & Högdahl, K. (2024). Ambient noise surface-wave imaging in a hardrock environment: implications for mineral exploration. *Geophysical Journal International*, 240(1), 571–590. <https://doi.org/10.1093/gji/ggae392>

Spurious arrivals:

- Wapenaar, K., Slob, E., Snieder, R., & Curtis, A. (2010). Tutorial on seismic interferometry: Part 2 — Underlying theory and new advances. *Geophysics*, 75(5), 75A211–75A227. <https://doi.org/10.1190/1.3463440>
- Halliday, D., & Curtis, A. (2009). Seismic interferometry of scattered surface waves in attenuative media. *Geophysical Journal International*, 178(1), 419–446. <https://doi.org/10.1111/j.1365-246x.2009.04153.x>