Microtremor Array-Based Estimation of Shear-Wave Velocity Structure in the Alaşehir Geothermal Basin, Western Turkey

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Summary

Microtremor measurements were carried out to investigate the subsurface structure of the Manisa–Alaşehir geothermal field using passive seismic techniques. Both single-station and microtremor array measurements were applied to investigate the shear-wave velocity structure of the study area. Microtremor array measurements were conducted at nine locations along a south–north oriented profile crossing the Alaşehir Graben, while single-station measurements were performed at twelve active geothermal well locations. Field surveys were completed in two separate phases in August and November 2017.

Microtremor array recordings were analysed using three-component frequency–wavenumber (f–k) and spatial autocorrelation (SPAC) methods to extract Rayleigh and Love wave dispersion curves. These dispersion curves were inverted to obtain one-dimensional shear-wave velocity profiles beneath each array location. Horizontal-to-vertical spectral ratio (H/V) analyses were applied to both single-station measurements and to all individual sensors forming the microtremor arrays. All measurements were acquired using three-component Güralp CMG-6TD seismometers.

The derived shear-wave velocity profiles were evaluated together with available geological information, borehole data, and previous seismic reflection studies conducted in the Alaşehir Graben. The results indicate that the combined use of microtremor array analyses and H/V spectral ratio techniques provides consistent subsurface velocity models for the geothermal field.

Theory / Method / Workflow

Field measurements were conducted in the Manisa–Alaşehir geothermal field using a combination of single-station and microtremor array measurements. Single-station microtremor measurements, shown as blue and red circles in Fig. 1, were carried out at active geothermal production and reinjection well locations, predominantly situated along the margins of the Alaşehir Graben. These sites were selected where borehole information is available, allowing direct comparison between H/V-derived resonance frequencies and sediment thickness values inferred from well logs, considering the relationship $f_0 = V_S / 4H$ between sediment thickness, shear-wave velocity, and fundamental resonance frequency. At the well locations, three-component seismometers were deployed during evening hours and recorded ambient seismic noise continuously throughout the night for approximately 12–15 hours. In addition, previously drilled exploratory boreholes (BH-1, BH-2, and BH-3), which are independent of geothermal production activities and constrain the deepest part of the basin and maximum sediment thickness, are shown in Fig. 1 for reference.

Microtremor array measurements, indicated by colored triangles in Fig. 1, were deployed at selected locations along a south–north oriented profile crossing the Alaşehir Graben. Array configurations were designed according to the target investigation depth and local geological conditions. In areas where the metamorphic basement outcrops, small-aperture arrays with radii of approximately 5–10 m were deployed over stiff rock to characterize the shear-wave velocity properties of the basement using ambient vibration data.

Within the central and deeper parts of the graben, array apertures were increased, with radii typically ranging from about 50 m up to 300 m, to enable investigation of deeper subsurface structure. Microtremor array recordings were generally acquired for durations of approximately 1–2 hours, providing sufficient data quality for surface-wave dispersion analyses.

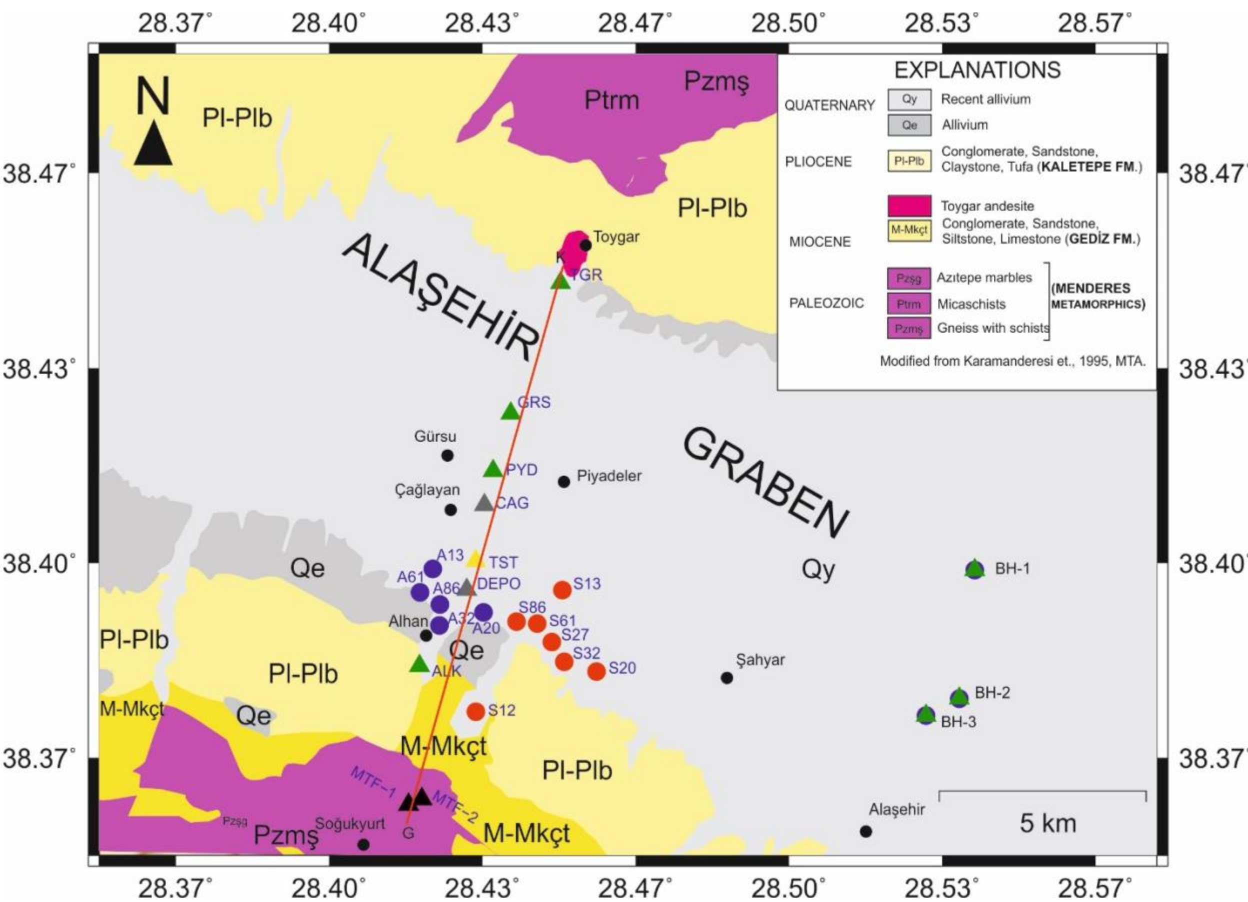

Figure 1: Geological map of the Manisa–Alaşehir geothermal field showing the distribution of microtremor measurement sites used in this study. Single-station microtremor measurements are indicated by blue and red circles, while microtremor array measurement locations are represented by colored triangles. Each triangle color corresponds to a different array site. The red line denotes the south–north profile along which subsurface cross-sections were constructed. Previously drilled boreholes (BH-1, BH-2, and BH-3) are also shown for reference. Major lithological units of the Alaşehir Graben and surrounding geological formations are displayed.

Results, Observations, Conclusions

Inversions performed using only the dispersion curves derived from microtremor array data demonstrate a limited investigation depth, with bedrock resolved only at the BH-A and BH-S array locations. In contrast, joint inversion incorporating both dispersion curves and H/V spectral ratio results yields subsurface models that show good agreement with geological cross-sections previously derived from drilling and seismic reflection studies.

Based on these joint inversion results, shear-wave velocity (V_S) ranges were estimated as 250–600 m/s for alluvial deposits, 500–750 m/s for the Kaletepe Formation, 650–1350 m/s for the Salihli Member, 700–2100 m/s for the Hamamdere Member, and 2000–3200 m/s for the metamorphic basement of the Menderes Massif (Fig. 2).

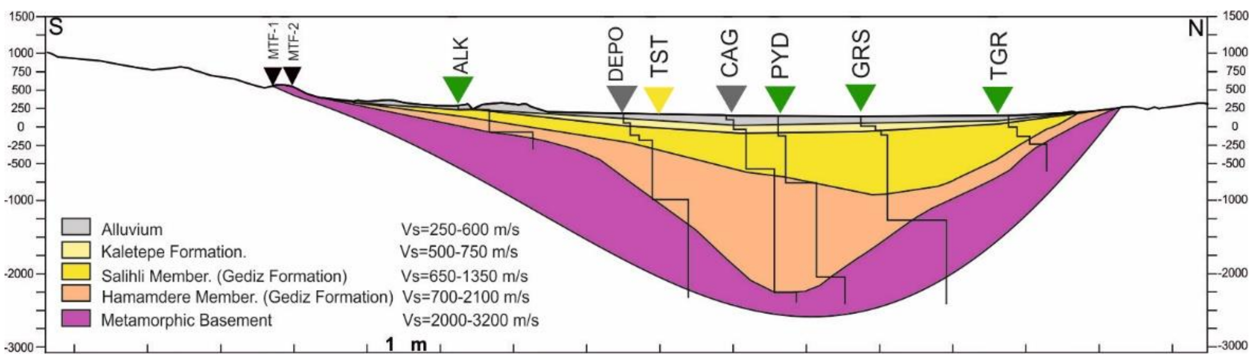

Figure 2: South–north oriented subsurface cross-section of the Alaşehir Graben along the red profile shown in Figure 1, derived from joint inversion of microtremor array dispersion curves and H/V spectral ratio analyses. The section illustrates the basin geometry and shear-wave velocity (V_S) structure beneath the measurement profile. Individual V_S–depth profiles obtained from joint inversion at each array site are shown as black curves beneath their respective locations, and the continuous cross-section is constructed by interpolating between these profiles.

The results demonstrate that the basin geometry of the Alaşehir Graben, as inferred from shear-wave velocity variations, can be effectively estimated using microtremor array measurements. However, sediment thickness estimates calculated from H/V-derived resonance frequencies using empirical relationships proposed in the literature are inconsistent with borehole data.

This discrepancy could be explained by locally increased shear-wave velocities within the sedimentary units, likely resulting from silicification associated with hydrothermal fluid–rock interaction and secondary cementation due to carbonation processes. This finding represents an important consideration for microtremor analyses in geothermal fields, indicating that higher-than-expected shear-wave velocities may be associated with the presence of geothermal fluids and should therefore be interpreted with caution.

Novel/Additive Information

Reducing subsurface uncertainty prior to drilling is of critical importance. From this perspective, microtremor-based methods offer significant added value as a rapid, cost-effective, and noninvasive approach for subsurface characterization when compared to conventional seismic reflection surveys and drilling campaigns.

The results of this study demonstrate that microtremor measurements, when combined with joint inversion of dispersion and H/V data, can yield reliable subsurface velocity models consistent with the geological structure of the site. This capability highlights the potential of microtremor techniques as an efficient preliminary exploration tool, supporting drilling site selection and reducing exploration risk in geothermal exploration, as well as in other subsurface investigations such as hydrocarbon and mineral exploration.

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