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

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This study investigates the Alaşehir Geothermal Basin using microtremor array measurements.

INTRODUCTION

Ambient noise–based microtremor methods provide a rapid and non-invasive approach for geothermal exploration and subsurface characterization. In this study, single-station HVSR and microtremor array measurements were conducted across the Alaşehir Geothermal Basin to estimate shear-wave velocity (Vs) structures and basin geometry. SPAC and 3C f-k analyses were applied to obtain dispersion curves, followed by dispersion-only and joint inversion approaches. Results demonstrate that joint inversion significantly improves basement depth estimation and produces models consistent with drilling and reflection seismic data. Geothermal alteration processes were also found to influence empirical HVSR-based sediment thickness relationships.

STUDY AREA

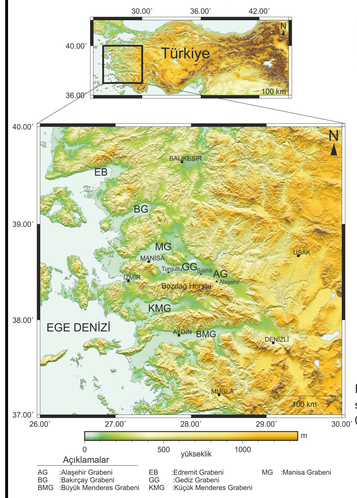

Figure 1. Location map of the grabens developed under the influence of the extensional regime in Western Anatolia and the Alaşehir Graben (modified from Çiftçi, 2007).

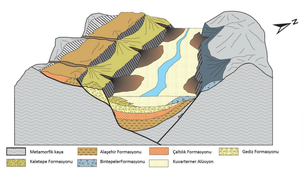

Figure 2. 3D block diagram showing the stratigraphy of the Alaşehir sub-graben (modified from Çiftçi, 2007).

The Alaşehir Geothermal Basin is located within the Büyük Menderes Graben system in western Türkiye, one of the most active extensional tectonic regions in the Aegean domain. The basin is characterized by high heat flow, active faulting, thick Neogene–Quaternary sedimentary deposits, and intensive geothermal activity associated with the Menderes Massif metamorphic basement.

PREVIOUS STUDIES

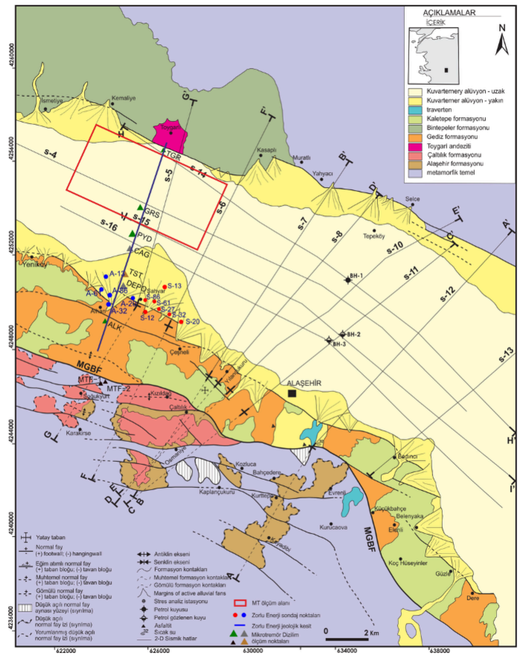

Figure 3. Geological map of the Alaşehir Graben showing the locations of previous geophysical investigations conducted in the study area (modified from Çiftçi, 2007). Colored triangles represent nine different microtremor array measurement locations with varying array apertures used for SPAC analyses. Blue and red circles indicate single-station HVSR measurement points located at production and reinjection wells, respectively. The blue solid line represents the south–north oriented geological/geophysical profile used for section interpretation. The red rectangle indicates the area where Magnetotelluric (MT) surveys were conducted. BH-1, BH-2, and BH-3 represent previously drilled boreholes within the geothermal field. The map also includes major geological units, active fault systems, geothermal wells, and previously acquired 2D seismic reflection lines used for integrated subsurface interpretation.

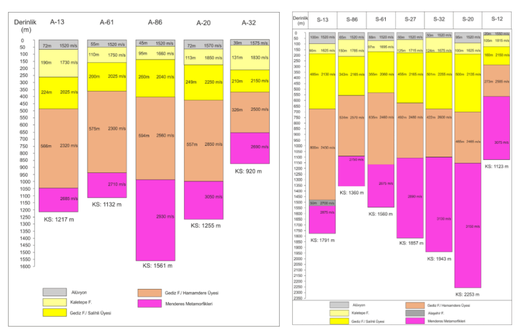

Figure 4. Well logs from the Alhan and Şahyar geothermal wells operated by Zorlu Enerji. Blue circles represent production wells, while red circles indicate reinjection wells. Formation thicknesses and P-wave (Vp) velocities derived from seismic reflection data are presented together on the logs for integrated geological and geophysical interpretation.

HVSR RESULTS

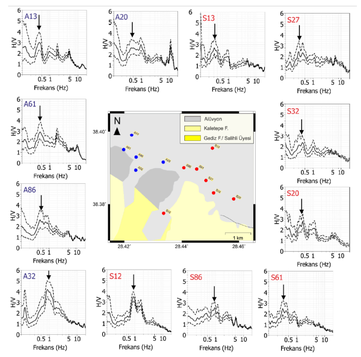

Fig 5. The borehole locations used in the regression analysis are shown on the geological map with red and blue circles. HVSR curves corresponding to these locations are presented around the geological map for each measurement point. In the HVSR graphs, the solid line represents the average H/V curve, while the dashed lines indicate the standard deviations.

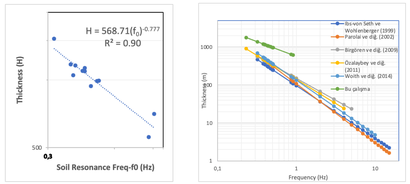

Fig 6. Regression analysis performed using bedrock depths obtained from boreholes and corresponding HVSR results. Comparison of the Alaşehir Graben regression analysis results with empirical relationships reported in previous studies.

- Empirical HVSR-based depth relationships showed significant deviations in the Alaşehir geothermal field due to elevated Vs values associated with silicification and hydrothermal alteration.
- Geothermal alteration processes modify subsurface seismic velocities and reduce the reliability of conventional empirical sediment-thickness relationships.
- Joint inversion of dispersion curves and HVSR data provided more reliable basement depth estimations consistent with drilling and seismic reflection data.

SPAC INVERSION

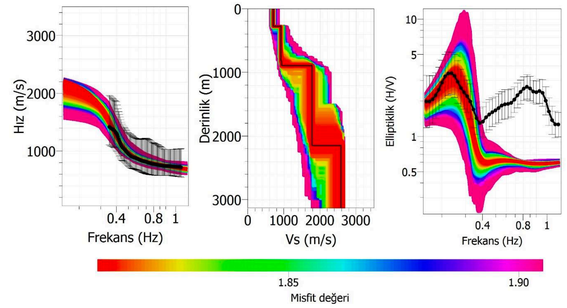

Figure 8. Joint inversion results for the PYD station. (a) Modeled dispersion curve of the fundamental mode Rayleigh wave; black dotted points represent the observed dispersion curve, while vertical bars indicate standard deviations. (b) Vs-depth profile obtained from the joint inversion; the best-fit model is shown by the solid black line. (c) Ellipticity model curve corresponding to the inverted subsurface model; the black dotted line represents the observed H/V curve, while vertical bars indicate the standard deviations.

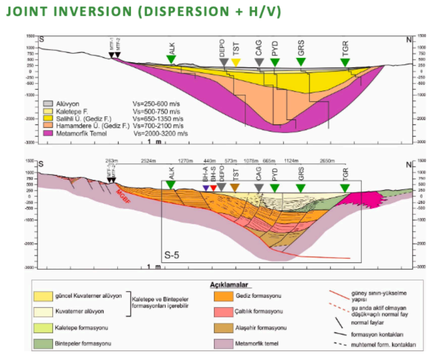

Figure 9: Improved vertical subsurface profile obtained from the joint inversion results.

SPAC analyses were applied to ambient noise array recordings to obtain Rayleigh-wave dispersion curves at different investigation depths. Dispersion curves and HVSR data were jointly inverted to estimate 1D Vs-depth profiles and improve basement depth characterization. Joint inversion results produced more stable and geologically consistent subsurface models compared to dispersion-only inversion.

CONCLUSION

1. Microtremor array measurements successfully resolved the basin geometry of the Alaşehir Graben along a south–north profile.
2. Joint inversion of dispersion curves and H/V spectral ratios significantly improved basement depth estimation compared to dispersion-only inversion.
3. Results are consistent with available drilling data and reflection seismic cross-sections, validating the applied methodology.
4. Elevated Vs values within geothermal sedimentary units, associated with silicification and carbonation, cause empirical relationships to underestimate basin depth.
5. Passive seismic methods provide rapid, cost-effective, and non-invasive subsurface characterization for geothermal, hydrocarbon, and mineral exploration studies.

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