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Research Article

Keywords: seismic ambient noise, HVSr, directionality, shear wave velocity, Rayleigh wave ellipticity, Mitidja Basin

Posted Date: September 28th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10437753/v1>

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Resonance, Directionality, and the Limits of Depth: Basin-Wide Ambient-Noise Characterization of the Mitidja Basin (Northern Algeria)

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Abstract

The Mitidja Basin, Northern Algeria, is a structurally complex, densely urbanized coastal basin filled with Neogene and Quaternary sediments, extending ENE–WSW over approximately 90 km in length and 20 km in width. Despite its high seismic risk, sedimentary thickness and basement geometry remain unconstrained basin-wide, as previous ambient-noise studies focused on individual cities. This study presents the first systematic, basin-wide characterization of seismic ambient noise in the basin, based on 132 broadband measurement points on a regular grid. The Horizontal-to-Vertical Spectral Ratio (HVSr) technique was used to estimate the fundamental resonance frequency (f_0), and Rayleigh-wave ellipticity inversion (successful at 72 sites) to derive 1D shear-wave velocity (V_s) profiles and basin-wide directionality.

Results show f_0 below 1 Hz across most of the basin, with localized high-frequency zones associated with shallow bedrock. Azimuth-dependent site response occurs basin-wide, oriented mainly N–S along the margins and E–W centrally, reflecting structural heterogeneity. The inversion resolves a two-layer sedimentary model, a Quaternary layer over a merged Neogene unit, overlying a mechanically stiff interface at depths of up to 950 m. Cross-validation against independent gravimetric modeling shows that this interface coincides with the true crystalline basement at only a minority of sites; elsewhere it marks an intermediate stiff horizon, reflecting the resolving-depth limit of the acquisition design.

These results provide a basin-wide velocity and resonance model and a directionality dataset, directly usable for strong-motion simulation, site-amplification studies, and seismic hazard assessment in one of Algeria's most exposed and rapidly urbanizing regions.

Keyword: seismic ambient noise; HVSR; directionality; shear wave velocity; Rayleigh wave ellipticity; Mitidja Basin

1. Introduction

Soft sediments significantly influence seismic ground motion, amplifying the wavefield as waves pass through them. Among the many examples of the role of soft soil in amplifying ground motion, the 1906 San Francisco (USA) (Borcherdt & Gibbs, 1976) and the 1985 Mexico City (Mexico) (Singh et al., 1988) are classic cases. Additionally, the damage caused by the 1755 Lisbon earthquake in the city of Lisbon is another example of the role of surface geology in ground motion (Borges et al., 2015).

The horizontal-to-vertical spectral ratio (HVSR) is a non-invasive technique that exploits ambient seismic noise, using the spectral ratio between the horizontal and vertical components to provide insight into the frequency peaks and amplitudes associated with contrasting velocity layers (Nogoshi and Igarashi, 1970; Nakamura, 1989; Panzera et al., 2011; Ozalaybey et al., 2011; Layadi et al., 2023). The method became widely used after Nakamura (1989), mainly to locate site effects in seismic hazard assessment, and is a popular, cost-effective tool for microzonation, determining the thickness of sedimentary layers, and obtaining reliable estimates of resonance frequencies. The theoretical basis for the method's ability to estimate the site amplification factor, however, remains unclear: Nakamura (1989, 2000) argues that body waves control the HVSR peak, whereas Lachet & Bard (1994) and Bonnefoy-Claudet et al. (2006, 2008) attribute control to surface waves. Given the dominant role of surface waves, several studies indicate that the amplitude of the HVSR peak is not correlated with the site amplification factor (Arai et al., 2004; Malischewsky & Scherbaum, 2004; Bonnefoy-Claudet et al., 2006; Rosa-Cintas et al., 2012). Malischewsky & Scherbaum (2004) further showed that simulated HVSR frequency peaks agree with the soil fundamental frequency, f_0 , only when the

velocity contrast between bedrock and sediment exceeds 3.5, for basin-edge and flat-layer models.

Seismic noise can be used for near-surface geophysical surveys to characterize the mechanical properties of the subsurface by inverting the H/V spectral ratio. HVSR inversion can handle complex 2D or 3D geometries and detect a preferred amplification direction by estimating the polarization azimuth of the horizontal components (Woolery & Street, 2002; Bonnefoy-Claudet et al., 2008; Uebayashi et al., 2012; Hartzell et al., 2014; Baena-Rivera et al., 2024; Layadi et al., 2023; Boudjenana et al., 2025). The polarization (or directionality) can reveal 2D/3D subsurface geometry (Matsushima et al., 2014, 2017; Vantassel et al., 2018; Cheng et al., 2020), identify wavefield polarization such as cultural noise, which is often polarized in specific directions (Cheng et al., 2020; Sánchez-Sesma et al., 2025), and aid fault and fracture characterization because they tend to produce amplification perpendicular to their strike (Di Giulio et al., 2009; Pischiutta et al., 2015, 2024; Panzera et al., 2014).

Often, HVSR is interpreted as the ellipticity of Rayleigh waves because of their similar shapes in the frequency domain (Fäh et al., 2003; García-Jerez et al., 2007; Barnaba et al., 2010; Milana et al., 2014; Nakamura, 2019). However, this remains an approximation, as the HVSR and Rayleigh-wave ellipticity curves coincide only when the microtremor wavefield consists exclusively of Rayleigh waves (Hobiger et al., 2013).

The Mitidja Basin is a densely urbanized coastal basin south of Algiers, repeatedly affected by destructive earthquakes throughout its history. Regarding site effects, research has focused on northern Algeria, where seismic risk is high due to the proximity of seismic sources to cities located on sedimentary basins (Boutaraa et al., 2018; Boutaraa, 2024), such as the Chelif Basin (Layadi et al., 2016, 2018; Issaadi et al., 2020, 2021), Mleta Plain (Saadi et al., 2023, 2025), and Mitidja Basin (Hellel et al., 2010; Bouchelouh et al., 2017; Tebbouche et al., 2017; Benkaci et al., 2021; Chibane et al., 2025). Numerous studies on site effects in the Mitidja Basin focus on the largest and most densely populated cities, Algiers, Boumerdès, and Blida. Several damaging earthquakes have occurred along the active faults surrounding the basin. Site effects in the Mitidja Basin were first observed during the 2003 Boumerdès earthquake (Laouami et al., 2006; Meslem et al., 2010), particularly in the eastern part. Layadi et al. (2026) showed that the observed V/H ratios of PGV at stations installed in this part of the basin (~ 0.4) differ from those at stations installed in the Bouzaréah Massif (~ 0.6).

The present study presents the first systematic, basin-wide characterization of seismic ambient noise in the Mitidja Basin, targeting the depth of the crystalline basement rather than the shallower engineering horizons addressed by previous city-scale studies. It encompasses the fundamental resonance frequency, peak spectral amplitude, and wave-field polarization, derived from 132 broadband measurement points distributed across the full basin surface on a regular grid. The spatial maps of fundamental frequency f_0 enable identification of zones with thick and thin sedimentary fill within the 0.1–20 Hz frequency range of engineering interest, while the corresponding peak amplitude A_0 serves as a first-order indicator of the impedance contrast between the sedimentary fill and the underlying bedrock. In addition, 1D Vs profiles are derived through Rayleigh wave ellipticity inversion using the DINVER module of the GEOPSY (Wathelet, 2020), constrained by borehole logs documenting four stratigraphic units and the geo-electrical cross-sections from the CGG project (1967). These profiles capture the dominant impedance contrasts detectable by this approach and are presented as a first-order seismic velocity model, acknowledging the inherent resolving power limitations of ellipticity inversion. The results provide a useful basis for future seismic risk mitigation strategies, particularly given the continuous urban expansion across the region.

2. Background:

2.1. Geological Framework

The Mitidja Basin is a narrow coastal strip south of Algiers, characterized by a depression that extends southward. It lies between longitudes 2.00° and 3.80° and latitudes 36.20° and 37.00°, with an elongated shape oriented ENE-WSW, spanning approximately 90 km in length and 20 km in width. Structurally, it is bounded to the north by the Sahel anticline and the Mediterranean Sea, and to the south by the Blida Atlas. The earliest geological studies of the basin were those of Glangeaud (1932), who conducted a detailed study of the coastal region within the Province of Algiers; Muraour (1950) studied the micropaleontology of Piacenzian marls from the Algiers region; and Aymé (1956) contributed to the stratigraphy and geological studies of the Mitidja plain.

The basin formed after nappe emplacement in the early Burdigalian and is characterized by Miocene-Quaternary sedimentary deposits (Glangeaud et al., 1952; Wildi, 1983). In the south, the boundary with the Blida Atlas Mountains is marked by the overthrusting of Cretaceous units

onto post-nappe Miocene strata (Figure 1a). The basin has a complex, poorly known internal structure, and some faults remain unidentified (Maouche et al., 2011).

Miocene deposits comprise marl, clay, conglomerate, and sandstone; Pliocene sediments consist of sandstone, limestone, molasse, sandy clay, and blue clay of Piacenzian stage. Quaternary sediments are mainly alluvium, sandy clay, and gravel (Table 1). The basement of the Mitidja Basin exhibits a dual lithostratigraphic composition and outcrops along its northern and southern NE–SW boundaries (CGG, 1967). The first basement unit, dating to the Upper Cretaceous, consists of marl interbedded with marly limestone and limestone nodules, characteristic of the Blida Atlas and visible in cross-sections AA' and BB' (Figure 1b). The second basement unit, outcropping in the Bouzaréah Massif, consists of crystalline rocks (Figure 1a; Glangeaud et al., 1952; Saadallah, 1981).

Table 1: Geological properties of the main units of the Algiers region, including the Mitidja Basin, extracted from JICA (2006).

Geological Unit	Deposits	Vs [m/s]	Density [g/cm ³]
Quaternary	Sand ; Clay ; Marine terrace	240-330	1.80-1.90
Upper-Pliocene	Weathered and fresh marl ; Weathered calcareous	310-770	1.92-2.10
Lower-Pliocene	Weathered and fresh blue marl	310-630	2.00-2.09
Miocene	Weathered and fresh schist	490-1030	1.89-2.55

2.2. Seismicity in the Mitidja Basin

The north-central region of Algeria is characterized by weak to moderate seismic activity. Between 2006 and 2020, seismicity in central Algeria was primarily concentrated along the borders of the Mitidja basin and other intermountain basins (Yelles-Chaouche et al., 2022). The major faults surrounding the basin, such as the Sahel fault to the north and the Mitidja fault to

the south, constitute some of the most important seismogenic sources in the region (Figure 1a; Maouche and Harbi, 2018).

Figure 1a shows historical seismicity in the Mitidja basin. The most damaging was the earthquake that struck Algiers in 1365, causing extensive material damage and many casualties, with a maximum intensity of X (Harbi et al., 2007; Ayadi and Bezzeghoud, 2015). In February 1716, another damaging earthquake destroyed large parts of Algiers and Blida, resulting in many casualties (Harbi et al., 2007). Other significant earthquakes occurred in the surrounding region, affecting several localities: Blida in 1825, 1842, and 1847, with intensities X–XI, VIII, and VII, respectively; Mouzaïa in 1867 with intensity VIII; Gouraya in 1891 with intensity X; and Blida in 1903 and 1908 with intensities VII and VIII, respectively (Ayadi and Bezzeghoud, 2015; Harbi et al., 2017).

More recent seismic events in the vicinity of the basin have occurred offshore, in the Blida Atlas, the Tablat Atlas to the south, and the Chenoua Mountain to the west, and have significantly affected cities within and surrounding the Mitidja Basin. Notable examples include the Chenoua earthquake in 1989 (Ml 6.0; Bounif et al., 2003), the Zemmouri earthquake in 2003 (Mw 6.8; Ayadi et al., 2003; Harbi et al., 2007), the Algiers earthquake in 2014 (Mw 5.5; Yelles-Chaouche et al., 2019), and the Mihoub earthquake in 2016 (Mw 5.4; Khelif et al., 2018; Figure 1a).

2.3. Previous Geophysical Investigations

The first geophysical investigation of the Mitidja Basin was an electrical survey conducted by the *Compagnie Générale de Géophysique* (CGG, 1967) to identify aquifers and determine their geometry. Several geoelectrical profiles were carried out across the basin, and the resulting cross-sections indicate that sediment thickness exceeds 300 m. Five boreholes from this project document the sedimentary succession across the central and western parts of the basin (Figures 2 and 3), revealing a superposition of three main geological units: Quaternary, Pliocene, and Miocene, with variable thicknesses. Comparison of boreholes in the western and central parts shows significant lateral variation: near the northern boundary, the Miocene unit is reached after more than 250 m of Quaternary and Pliocene sediments, whereas in the central sector it is absent beyond 600 m depth. This lateral heterogeneity reflects the complex sedimentary filling of the basin. Despite the numerous boreholes drilled within the Mitidja Basin, the bedrock formation remained unreachable. Additional drilling studies by Binnie et Atkins (1983), in

conjunction with the study undertaken by Mutin (1977), further advanced understanding of the basin geology.

Following the 2003 Boumerdès earthquake, a seismic microzonation project was launched in cooperation with the Japan International Cooperation Agency (JICA, 2006) to produce seismic microzonation maps of Algiers province, including loss scenarios for future earthquakes. The project also included recommendations for seismic hazard management. Six active faults near the study area were selected to assess seismic hazard: the Sahel, Chenoua, Blida, Khair-al-Din, Zemmouri, and Thenia faults. Fifty new boreholes were drilled to investigate the mechanical properties of the subsurface, including shear-wave velocity (V_s), density, and Atterberg limits, among other geotechnical properties, with the aim of classifying the different sedimentary units at depth. Based on these parameters, the amplification potential in terms of peak ground acceleration and seismic intensity was analyzed for the subsurface materials (JICA, 2006). These properties were further explored by Gherboudj et al. (2024a, 2024b) to estimate probabilistic seismic hazard maps, uniform hazard spectra, and spectral amplification functions for Algiers.

Gravity surveys have provided additional constraints on the basin structure. Ouyed et al. (2011) determined the variation of the Bouguer anomaly in the Mitidja Basin, and Hamai (2011) carried out a gravimetric survey at the center of the basin to determine the density distribution of the sediments. More recently, Yalaoui et al. (2025) performed gravity modeling, revealing a complex 3D structure of the crystalline basement, characterized by significant depth variations. The crystalline basement reaches maximum depths of 3 km in the west and 2.8 km in the east, while the conductive basement (Piacenzian layer) follows a correlated morphology with shallower maximum depths of 0.5 km and 0.4 km in those respective areas.

Despite results from various geophysical approaches, sediment thickness remains unknown, a gap the present study aims to address.

3. Methodology

Acquisition of ambient seismic noise was carried out in the Mitidja Basin within the framework of the bilateral project “A Seismic Hazard Overview of the Mitidja Basin (Northern Algeria)” between Portugal and Algeria, aiming to develop a detailed 3D model of the basin’s structure. The ambient noise field campaign was scheduled for July 2017 to mitigate the impact of adverse

weather conditions, such as wind and rain, on the recorded wavefield. To acquire seismic noise across the entire basin, a discrete grid was established with 19 profiles separated by 5 km and an interstation distance of 2.5 km within each profile, totaling 132 points (Figure 2). We collected seismic noise using five broadband seismic stations with a natural frequency of 30 s at a sampling rate of 100 Hz. Each site was occupied for 60 to 90 minutes.

The analysis of seismic ambient noise relied on GEOPSY (Wathelet, 2020) for its graphical user interface, ease of data processing and management, extensibility through plugins and scripting, and open- source nature. To ensure the quality of HVSR curves, we followed SESAME's guidelines (SESAME, 2004). For processing, we discarded the first 10 minutes of the raw signal to remove transient noise from operator handling of the equipment and to allow the seismic station to stabilize. The spectrum was calculated using a 45- second time window over the signal, with a minimum of 15 valid windows required per site; sites not meeting this threshold were excluded from further analysis. To remove the non-stationary signal, we used STA = 1 s, LTA = 30 s, with min and max of 0.2 and 2.5 for the anti-trigger STA/LTA, respectively. Each time window for the horizontal and vertical components was tapered with a 5% cosine window. The spectral amplitudes were processed using Konno and Ohmachi smoothing, with a smoothing constant of 40 and a cosine- taper width of 5%. Horizontal components were combined using a squared average. The signal was converted from the time domain to the frequency domain using a Fast Fourier Transform, producing an amplitude spectrum from which the dominant frequency was identified. The HVSR curve was calculated in the frequency range of 0.2 - 20 Hz. GEOPSY takes the highest peak of HVSR curves as the main f_0 and A_0 . Finally, the automatically picked peaks were visually inspected across the sites (Figure 4), particularly in zones where boreholes indicate complex multi-layer stratigraphy.

Two additional exclusion criteria were applied prior to f_0 mapping. First, HVSR curves exhibiting a non- flat spectral response without a discernible frequency peak were discarded from the f_0 variation map (Figure 5a) , regardless of inversion outcome. Second, several measurement points exhibited multiple HVSR peaks (single, double,

and multi- peak curves; examples in Figure 4), reflecting the structural complexity of the basin; all peak shapes were retained for mapping except where criterion one applied.

Narrow-band peaks near 1.5 Hz were screened for anthropogenic origin using SESAME (2004) criteria: the characteristic "eye-shape" amplitude pattern relative to the vertical component (Molnar et al., 2022) and corroborating damping analysis to distinguish site response from non-site-effect contamination. Points meeting these criteria were excluded from the f_0 variation map, as were those showing unstable amplitude spectral density across the three components (Figure 5b).

For the directionality analysis, only measurement points with a clear, unambiguous f_0 peak were retained, using the HVSR-rotate module in GEOPSY (Wathelet, 2020).

Rayleigh wave ellipticity inversion is a nonlinear, nonunique problem: multiple subsurface configurations can reproduce a given observed ellipticity curve (Tarantola & Valette, 1982). Scherbaum et al. (2003) emphasize the need for independent constraints, such as layer thickness or velocities (V_p , V_s), from other geological data to restrict the search space to geologically plausible models. The inversion is performed using a stochastic, iterative search, in this case the neighborhood algorithm implemented by Wathelet (2008) in DINVER (Wathelet, 2020), which minimizes the misfit between the observed and forward-modeled ellipticity curves. Table 2 lists the constraint variables (V_s , density, and thickness) used in the Rayleigh wave ellipticity inversion. To further constrain the inversion, we used 39 vertical electrical soundings (VES) from the CGG (1967) survey, selected for their proximity to the HVSR measurement points (Figure 2). These soundings provided independent information on the number and thickness of subsurface layers, which was used to bound the layer geometry in the velocity model.

Table 2: Input parameters used on the Rayleigh Wave Ellipticity (sources CGG, 1967; JICA, 2006; Layadi et al., 2018; Issaadi et al., 2020; Saadi et al., 2023).

Period	Geology	V _s (m/s)		H (m)		ρ (Kg/m ³)	
		Min	Max	Min	Max	Min	Max
Quaternary	Sand; clay; marine terrace	300	500	300	500	1500	2000
Neogene	Fresh and weathered marl, blue marl, and schist; weathered calcareous	500	1050	500	1050	2000	2500
Bedrock		1050	2600	> 1050		2500	3000

Although JICA (2006) data indicate a measurable V_s contrast between Pliocene and Miocene units (comparable in magnitude to the Quaternary-Pliocene contrast), this deeper interface falls beyond the depth range over which Rayleigh wave ellipticity retains adequate resolving power. This deeper interface falls beyond the depth range over which Rayleigh wave ellipticity retains adequate resolving power and was therefore merged into a single inversion layer (Layer 2), hereafter referred to as the Neogene layer, as distinct from the overlying Quaternary (Layer 1). Upper- and Lower-Pliocene sub-units, in contrast, show near-total V_s overlap and were merged independently of depth considerations.

For each layer, admissible ranges of V_s, density, and thickness were defined to bound the model space explored during inversion. For each candidate model, DINVER computes a theoretical Rayleigh wave ellipticity curve (forward modeling), which is compared to the observed HVSr curve. The misfit between the observed and modeled

HVSR curves is calculated. Models are iteratively refined until misfit values stabilize below the defined acceptance threshold. If the recorded wavefield at a site is dominated by Love waves or body waves rather than Rayleigh waves, the theoretical Rayleigh ellipticity curves would systematically fail to fit the observed HVSR. The misfit would remain stubbornly high regardless of how many models the neighborhood algorithm tested. The fact that the inversion converges (a family of models with acceptably low misfit exists) is itself indirect evidence that Rayleigh waves dominate the wavefield at that measurement point. The acceptable models are filtered not only by misfit but also by geological plausibility. For the bedrock layer, where constraints were derived independently from analogue Algerian basins rather than from Mitidja-specific data, the geological coherence of the inverted V_s values provides genuine corroborating evidence of Rayleigh wave dominance. For the sediment layers, plausibility checks against CGG and JICA data are, by construction, less independent of the input constraints, and the convergence argument above remains the primary evidence. Of the 132 measurement points, 72 yielded acceptable inversion results. The remaining 60 points were excluded because forward modeling failed to reproduce the observed HVSR curves within the defined misfit threshold, regardless of the subsurface model tested. This systematic failure indicates either significant wavefield complexity inconsistent with the 1D assumption or insufficient Rayleigh wave dominance at those sites, both constituting physically principled grounds for exclusion.

4. Results and Discussions

The results of the HVSR analysis, with some sites plotted in Figure 4, show that the variation maps of the fundamental frequencies f_0 (Figure 6) reflect the lithological heterogeneity of the basin. The f_0 values range between 0.2 and 10 Hz. This wide range can be attributed to several geological and geophysical factors. The most significant factor is the strong variation in sedimentary cover thickness throughout the basin, with low frequencies generally associated with areas of thick sediment accumulation and high frequencies corresponding to locations where the bedrock lies closer to the surface.

This variability may be further enhanced by lateral changes in shear-wave velocity (V_s) resulting from lithological heterogeneity within the sedimentary cover. A comparable lateral facies change within the Neogene (Layer 2) and Quaternary (Layer 1) sediments has been observed in the Chelif Basin further west (Issaadi et al., 2021; Saadi et al., 2023). The complex basin geometry can also significantly influence the resonance frequency: the resistivity cross-sections from CGG (1967) show that the sedimentary cover is affected by faults, basement highs, and variable thickness. Basin-edge effects may also occur near the margins, where sediment thinning modifies the seismic response. Some frequencies are controlled by impedance contrasts within the sediment succession rather than by the sediment–bedrock interface itself.

The f_0 values are consistent with those reported for Algiers (Chabane et al., 2017; Chibane et al., 2025) and Blida (Bouchelouh et al., 2017). Corresponding amplitudes range from 1.7 to 7.5. Across most of the basin, predominant f_0 values range from 0.2 to 1 Hz, reflecting thick sedimentary cover. Locally higher frequencies occur at a few sites in the western and northeastern parts of the basin, near Algiers. At some sites (e.g., MT37, MT91, MT108), both f_0 and A_0 are high, consistent with very shallow bedrock, where Plio-Quaternary alluvium lies directly on bedrock, producing a high impedance contrast.

A directionality analysis was performed using the HVSR-rotate module of GEOPSY (Wathelet, 2020), following the site-selection criterion described in Section 3. Azimuth-dependent site responses were identified at several locations across the basin (Figure 7a), likely related to the basin's complex geometry, lateral variations in sediment thickness, irregular basement topography, and major tectonic structures (Woolery and Street, 2002; Bonnefoy-Claudet et al., 2008; Uebayashi et al., 2012; Burjáněk et al., 2012). Basin-edge effects, buried-fault impedance contrasts, and local lithologic heterogeneity within the sedimentary sequence may all contribute to anisotropic site response; anthropogenic noise near the basin's main cities cannot be excluded as a contributing factor. The predominant orientations are N–S (0°) along the eastern and western margins and E–W (80 – 100°) in the central basin, with NW–SE and NE–SW

orientations at scattered sites reflecting local subsurface variation. Figure 7b shows examples of directionality distributed along the basin.

The inverted Vs profiles (Figure 8) reflect the two-layer sedimentary model used in the inversion (Section 3): Layer 1: sand, clay, and marine terrace deposits (Quaternary); and Layer 2: the merged Neogene unit (weathered and fresh marl, weathered calcareous beds, weathered and fresh blue marl, weathered and fresh schist). The topmost layer (Layer 1) reaches a maximum thickness of 200 m, with Vs ranging from 390 to 500 m/s. Layer 2 is the most extensive in the basin, with thickness ranging from 200 to 800 m and Vs from 780 to 1100 m/s. Bedrock Vs ranges from 1500 to 2500 m/s. Unlike the a priori bounds in Table 2, these ranges represent the resolved per-site model output.

The bedrock reaches a maximum depth of 950 m, exceeding the minimum sediment thickness of 300 m reported by CGG (1967). This is consistent with CGG's figure being a lower bound from limited boreholes, not a basin-wide maximum. At most sites, however, the deepest seismically resolved interface ($V_s \geq 1500$ m/s) does not correspond to the crystalline basement defined by gravimetric modeling (Yalaoui et al., 2025), but to an intermediate, mechanically stiff horizon above it. This is consistent with the $V_s \geq 1500$ m/s threshold marking a methodological cutoff for this study's third layer, not a claim of lithologic crystalline basement. This is attributable, at least in part, to the acquisition design: ambient noise was recorded for 60–90 minutes per site (60 minutes at most points), with HVSR computed using 45-second time windows. Per SESAME (2004), reliable resolution of a given frequency requires a window length of at least ten times its period; a 45 s window therefore reliably constrains frequencies down to ~ 0.22 Hz, independent of total recording duration. Using the Layer 2 Vs range resolved in this study (780–1100 m/s) in the classical quarter-wavelength approximation, this floor corresponds to a maximum reliably resolvable depth of roughly 880–1240 m, bracketing both the basin-wide maximum depth above (950 m) and the depths at which an independently cross-checked subset of sites bottoms out (870–950 m). This is consistent with the deepest interface at most sites representing this acquisition-imposed ceiling rather than true crystalline basement.

Among a 22-site subset cross-checked against Yalaoui et al. (2025)'s gravimetric basement model, MT101 and MT139 show the smallest residuals relative to depth (16–20%). MT131 shows a similar absolute offset (0.19 km) but, because its depth is shallow (0.25 km seismic vs. 0.44 km gravimetric), this represents a far larger relative difference (>40%). MT139 and MT131 share the same sign (gravimetric deeper than seismic) despite differing in depth by nearly a factor of four, consistent with a depth-independent stiffness–density offset between methods, of the kind attributed by Yáñez et al. (2015) to compaction-driven Vs increase preceding the full density contrast resolved by gravity, rather than to any resolution limitation of the seismic method. MT101, by contrast, shows the opposite sign at a depth comparable to MT139, with the seismic interface reading deeper than the gravimetric basement, a reversal not explained by either mechanism above and resting on the least certain of the three gravimetric estimates.

Notably, the lowest fundamental frequency observed across the full basin-wide dataset sits at the edge of this same resolution floor, providing independent, basin-wide corroboration that the deepest sites in this study are operating at the limit of what the acquisition design can reliably constrain, rather than indicating a true absence of deeper structure.

To further characterize the basin's sedimentary thickness and bedrock geometry, three 2D Vs cross-sections were constructed (Figure 9): Profile 1 along the basin axis and Profiles 2 and 3 perpendicular to it. All three reveal a highly irregular sedimentary infill, with pronounced lateral thickness variations and complex bedrock morphology, consistent with strong control by bedrock paleotopography. The cross-sections show the bedrock locally rising to shallow depths even within the central basin, forming basement highs that interrupt the continuity of the sedimentary cover — a likely contributor to the strong spatial variability in f_0 and further evidence of the basin's structural complexity.

The Mitidja Basin shares several characteristics with the Chelif Basin: both are Neogene–Quaternary basins with a comparable E–W to ENE–WSW orientation, and both reach a maximum bedrock depth of approximately 1000 m (Layadi et al., 2018; Issaadi et al., 2021; Saadi et al., 2023). Both also show basement highs in their central

parts, producing lateral variation in sediment thickness and irregular bedrock morphology, and both are dominated by thick Neogene deposits. These similarities suggest comparable tectono-sedimentary evolution and shared structural controls, and are drawn here explicitly as a cross-basin analog, given that three of the five sources constraining this study's Vs model (Layadi 2018, Issaadi 2020, Saadi 2023) are from outside the Mitidja Basin.

5. Conclusion

This study addresses a long-standing gap in the seismic characterization of the Mitidja Basin: despite earlier geoelectric, microzonation, and gravimetric investigations (CGG, 1967; JICA, 2006; Yalaoui et al., 2025), sediment thickness and basement geometry across the basin as a whole remained unconstrained, and previous ambient-noise studies in the region were confined to individual cities (Blida, Algiers) rather than the basin's full extent. By deploying 132 broadband measurement points across a regular 19-profile grid, this work provides the first systematic, basin-wide characterization of fundamental resonance frequency and wave-field polarization for the Mitidja Basin, explicitly targeting the depth to the basin's stiff/crystalline interface rather than the shallower engineering horizons addressed by prior city-scale work.

The f_0 (0.2–10 Hz) variation maps reveal a basin whose resonant behavior is governed not by a simple, uniform sediment wedge but by structural complexity inherited from faulting, basement highs, and lateral facies changes, consistent with and extending the basin-wide geo-electrical heterogeneity previously documented only at the borehole scale by CGG (1967). Of the 132 measurement points, Rayleigh wave ellipticity inversion (DINVER/GEOPSY) yielded acceptable 1D Vs profiles at 72 sites, resolving a two-layer sedimentary model, Quaternary (Layer 1, Vs 390–500 m/s) over a merged Neogene unit (Layer 2, Vs 780–1100 m/s) — overlying a stiff interface ($V_s \geq 1500$ m/s) and reaching a maximum resolved depth of 950 m.

Cross-validating a subset of these profiles against an independent gravimetric basement model (Yalaoui et al., 2025) shows that this stiff interface coincides with the true crystalline basement at only a minority of sites; at most locations, it represents an intermediate, mechanically stiff horizon lying above the crystalline basement. This is attributable to both an acquisition-imposed resolution ceiling (the 45 s HVSR window length constrains reliable resolution to frequencies no lower than ~ 0.22 Hz, capping resolvable depth at roughly 1.2 km given this basin's Vs structure) and, independently of depth, to a stiffness-density offset between gravimetric and seismic basement estimates consistent with mechanisms reported in other basins. Rather than a limitation to be set aside, this result is itself a methodological contribution: it demonstrates, with a quantified and cross-validated mechanism, the conditions under which single-station ambient-noise ellipticity inversion can and cannot resolve true crystalline basement depth in a basin of this scale, a distinction not previously established for the Mitidja Basin, and directly informs how its 60 unresolved sites and any future deployments should be interpreted.

The basin-wide directionality analysis further identifies systematic azimuth-dependent site response, predominantly N–S along the basin margins and E–W centrally, providing a polarization dataset not previously available for the Mitidja Basin and directly usable as an input parameter in seismic hazard assessment.

Together, these results constitute a basin-wide first-order velocity and resonance model suitable as direct input for 2D/3D strong-motion simulations and site-amplification studies. Given the continuous urban expansion across the Mitidja Basin and its demonstrated exposure to destructive earthquakes, this basin-wide constraint on subsurface structure is a necessary foundation for future seismic risk mitigation in one of Algeria's most densely populated regions.

Acknowledgements:

This research used data obtained within the framework of the MITMOTION project (Project code: PT-DZ/0003/2015), funded by the Fundação para a Ciência e a

Tecnologia, I.P. (FCT) under the Concurso de Projetos Bilaterais Portugal–Argélia (PT-DZ 2015). This work is partially supported by FCT, I.P./MCTES through national funds (PIDDAC): LA/P/0068/2020 (<https://doi.org/10.54499/LA/P/0068/2020>), UID/50019/2025 (<https://doi.org/10.54499/UID/50019/2025>), UID/PRR/50019/2025 (<https://doi.org/10.54499/UID/PRR/50019/2025>), and UID/PRR2/50019/2025 (<https://doi.org/10.54499/UID/PRR2/50019/2025>). The authors acknowledge the project’s principal investigators, José Borges (Portugal) and Merzouk Ouyed (Algeria), for granting access to the data and coordinating the original research activities. Some images were created with GMT (Wessel et al., 2019). Amel Khelil is grateful to the CRAAG team, especially Semmane Fethi, Issaadi Abdelouahab, Tizeraoui Abderrezak, and Saadi Ahmed for their valuable assistance during this work. The data were made available to PhD student Amel Khelil for academic research with the appropriate authorization.

Data availability:

The data are available from the corresponding author upon reasonable request.

Conflict of interest:

All authors declare that they have no conflicts of interest.

Author Contributions:

Amel Khelil: Data curation, Methodology, Formal Analysis, Validation, Visualization, Writing - original draft; **João Fontiela:** Conceptualization, Data Acquisition, Data curation, Methodology, Formal Analysis, Validation, Visualization, Writing - original draft, review and editing; Supervision, Scientific Coordination; **Walidi Farhi:** Validation, Writing - original draft Supervision; **Redoune Chimouni:** Data Acquisition, Formal Analysis, Validation, Visualization, Writing - original draft; **Khalissa Layadi:** Formal Analysis, Validation, Writing - original draft

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CAPTIONS

Figure 1: a) Geological and seismotectonic map of the Mitidja basin and its surroundings (modified from Mohammadi et al., 2020); the red lines represent geoelectrical cross-sections from CGG (1967) illustrated in b).

Figure 2: Geographical distribution of measuring points on the Mitidja basin. Red circles are the location of seismic ambient noise measurements; the blue hexagons are the vertical electrical soundings, and yellow triangles are boreholes, while letters refer to the logs shown in Figure 3

Figure 3: Thickness (in meters) of the main geological units available from five boreholes of the CGG project (CGG, 1967). For the logs location, consult Figure 2. Further details of the geology are in Table 1.

Figure 4: Examples of HVSR curves with a clear f_0 peak. The shadow area is ± 1 standard deviation. F_0 is indicated at the top of each peak.

Figure 5: A) Some examples of HVSR that fail the quality control; B) Excluded site MT103 due to instability on amplitude disturbance. At left, HVSR without meaningful information, and at right, amplitude spectral density for each component. The shadow area is ± 1 standard deviation.

Figure 6: Map of the distribution of the 72 fundamental ground resonance frequencies (f_0 Hz) after quality control

Figure 7: A) Map showing the distribution of the directionality obtained in 34 sites within the basin. B) shows the directionality of 12 sites distributed along the basin.

Figure 8: Some S-wave profiles obtained by Dinver. The red line is the model with the smallest misfit, and light grey lines are the iterations. The spread of misfit values shown indicates that the inversion remains stable even at comparatively high misfit.

Figure 9: Interpretation of cross-section from shear wave velocity inversion. The inset shows the cross-sections' locations.

FIGURES AND CAPTIONS:

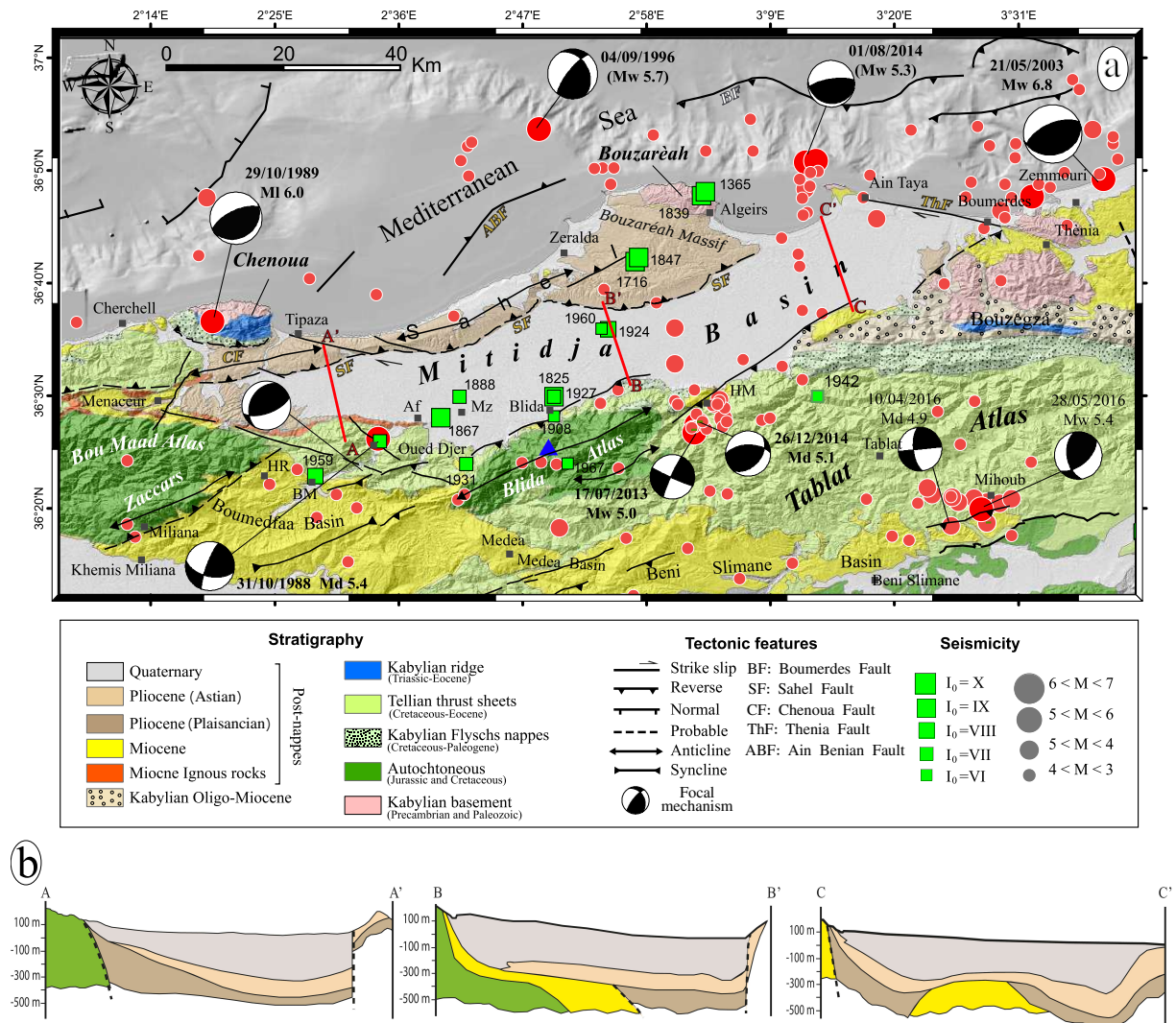


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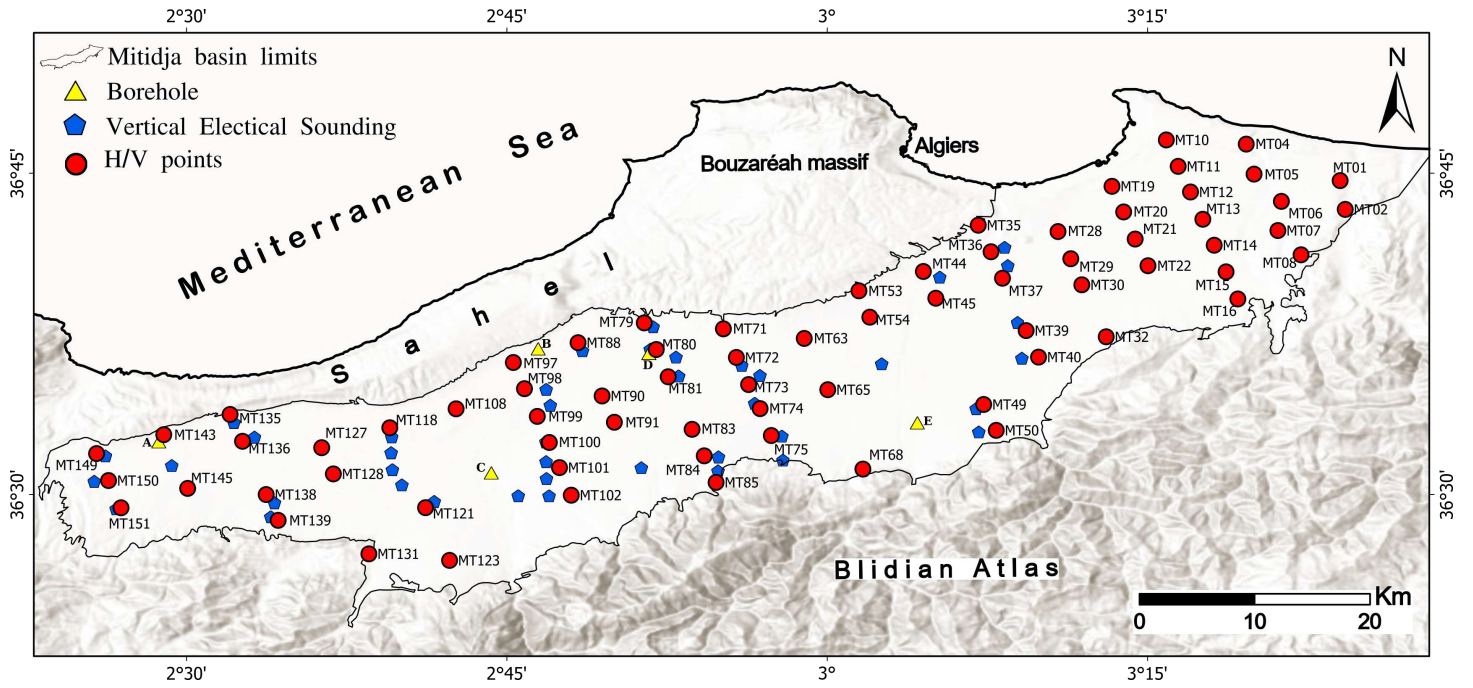


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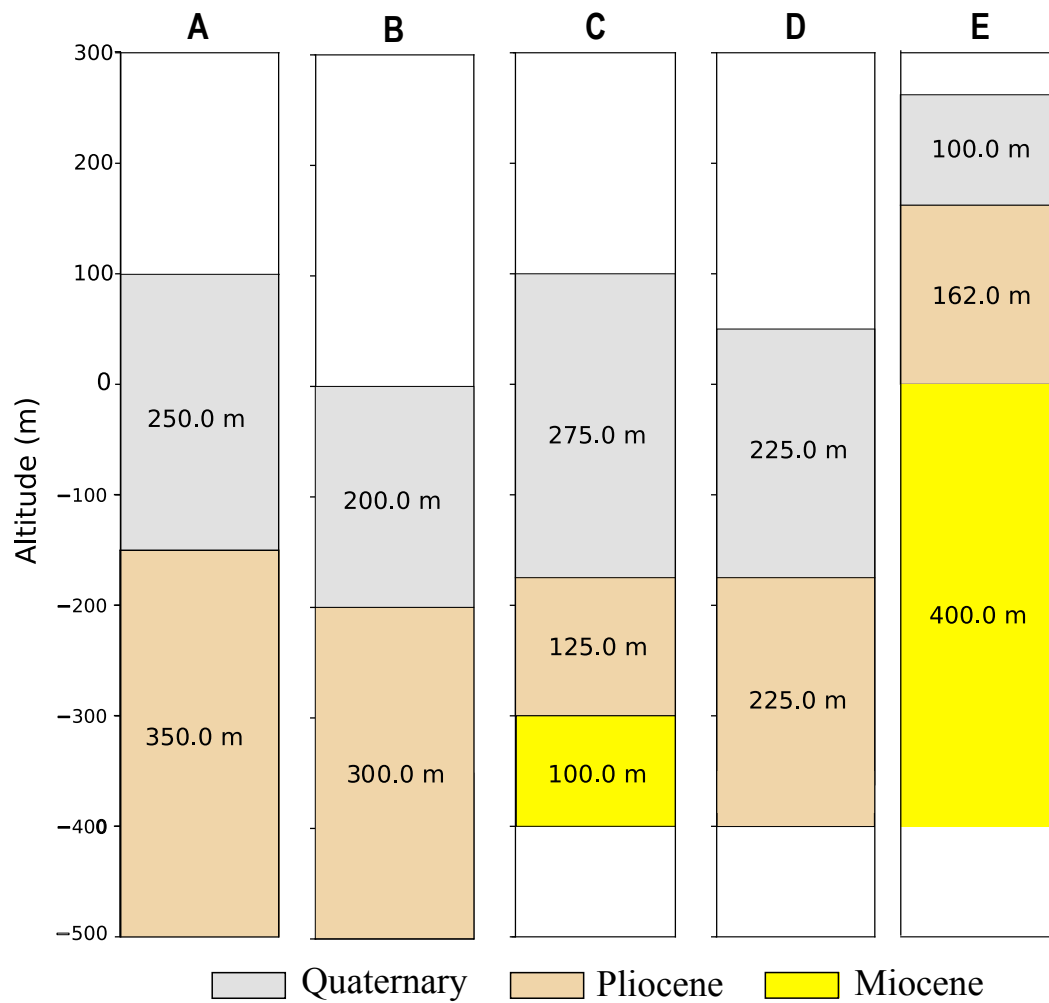


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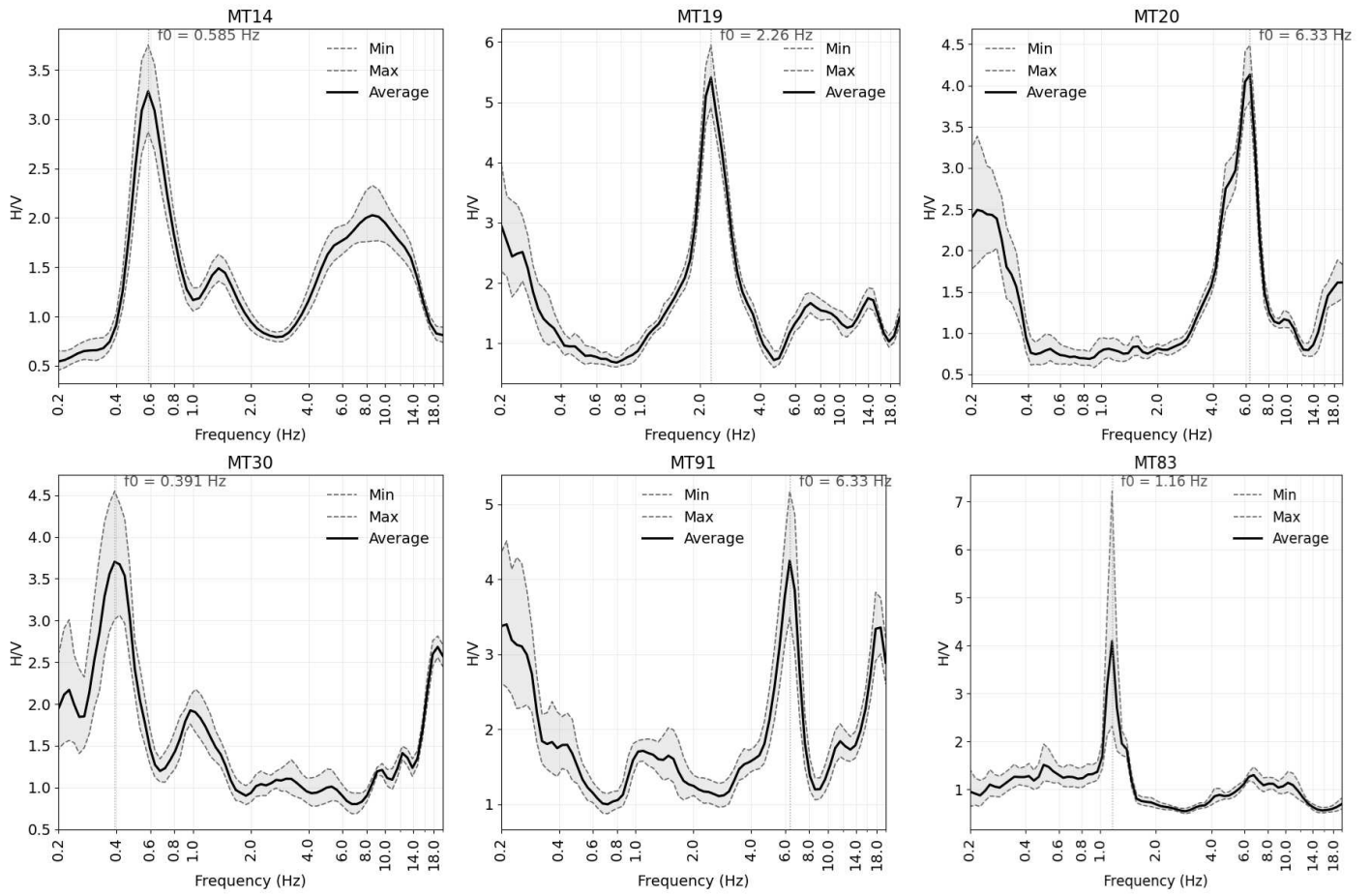


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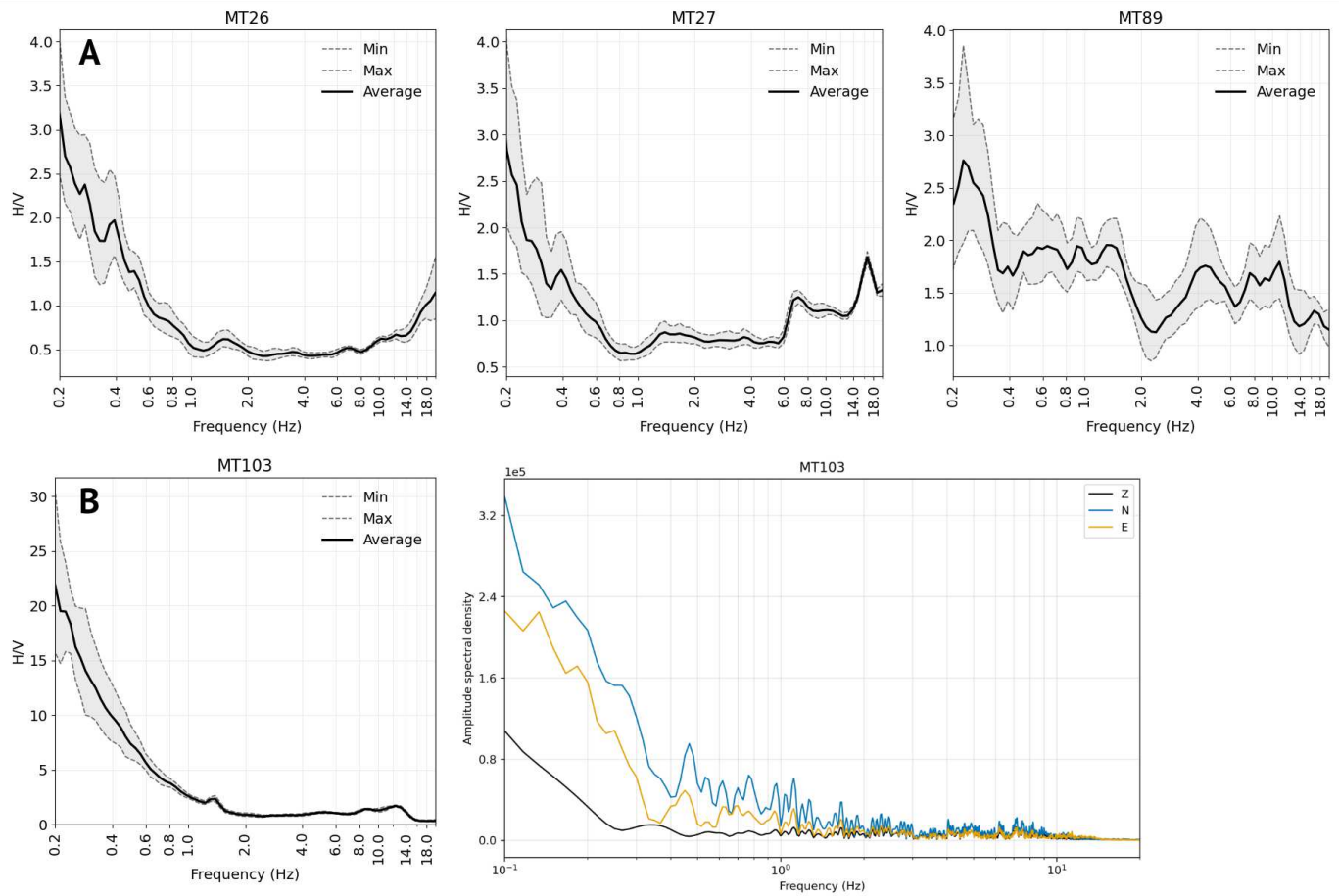


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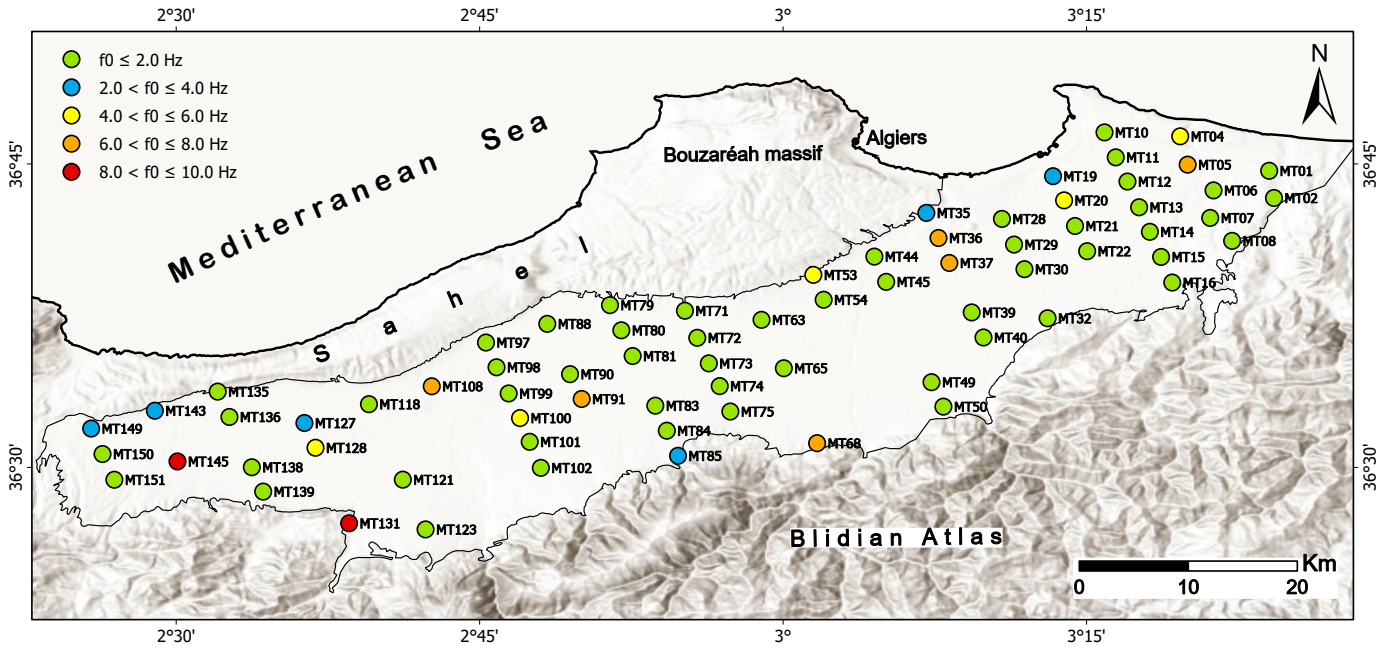


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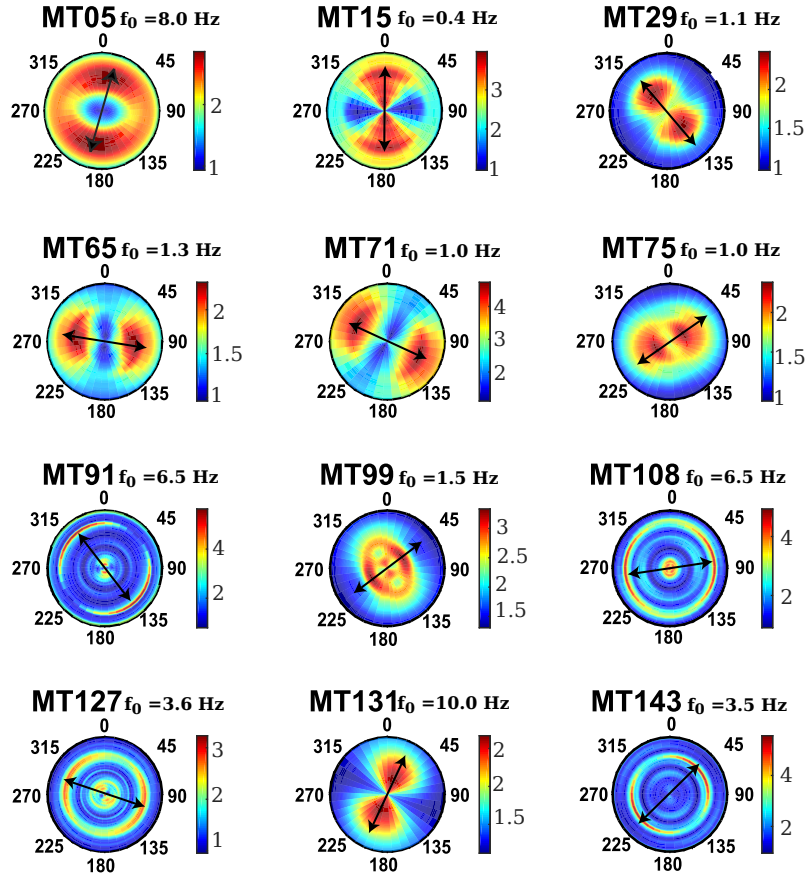
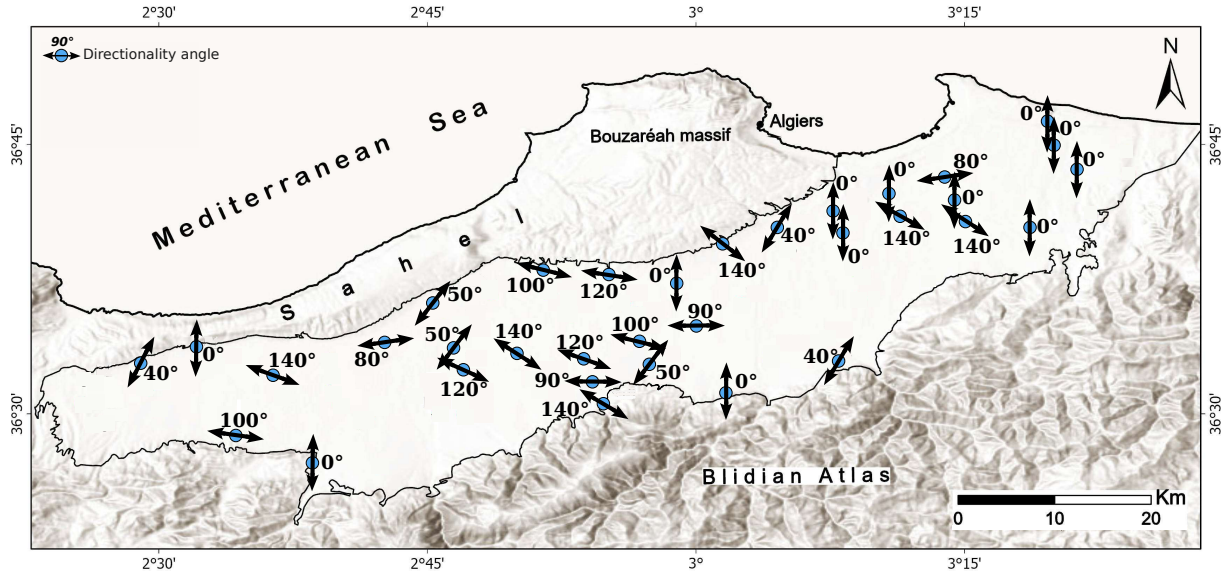


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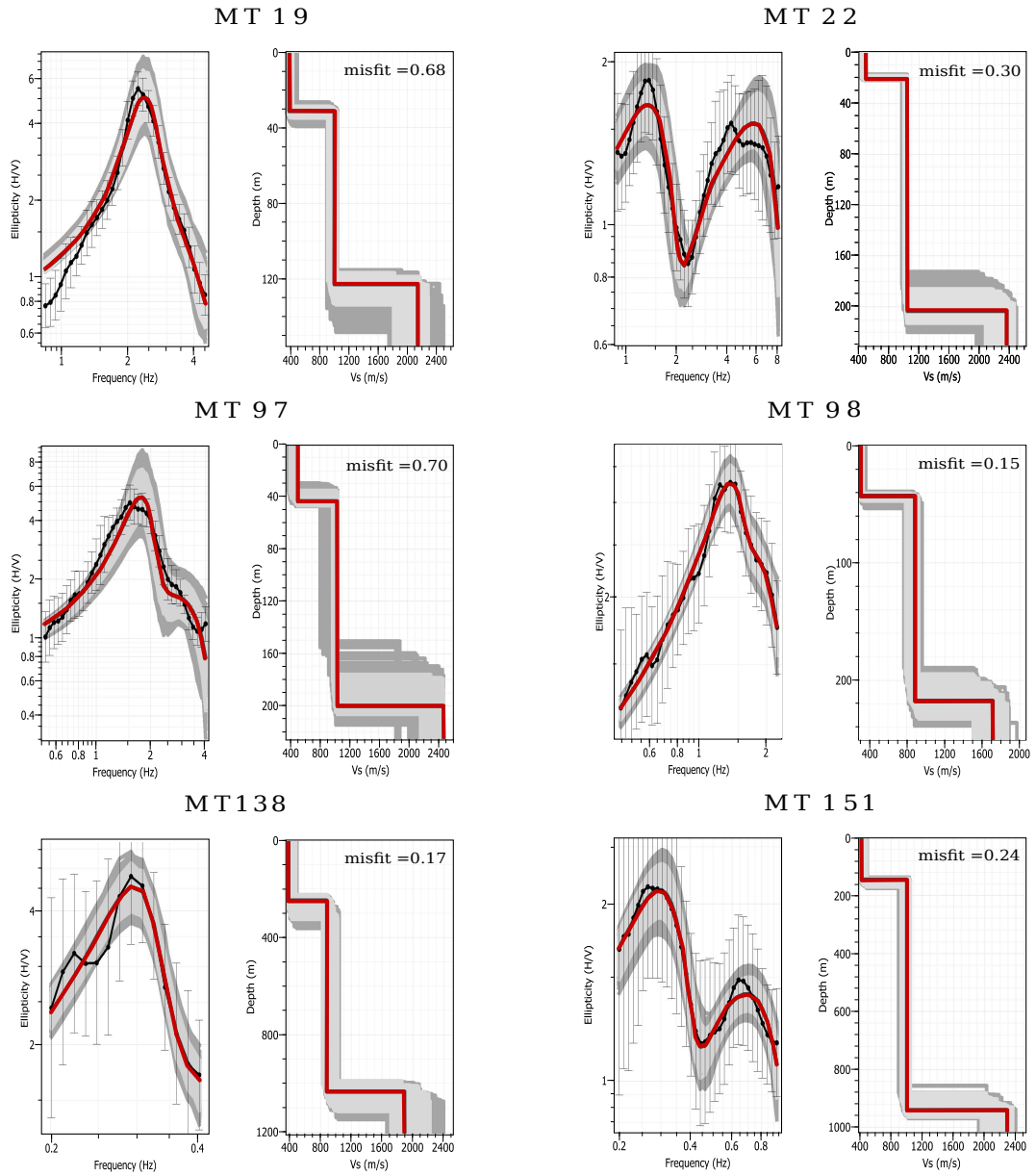


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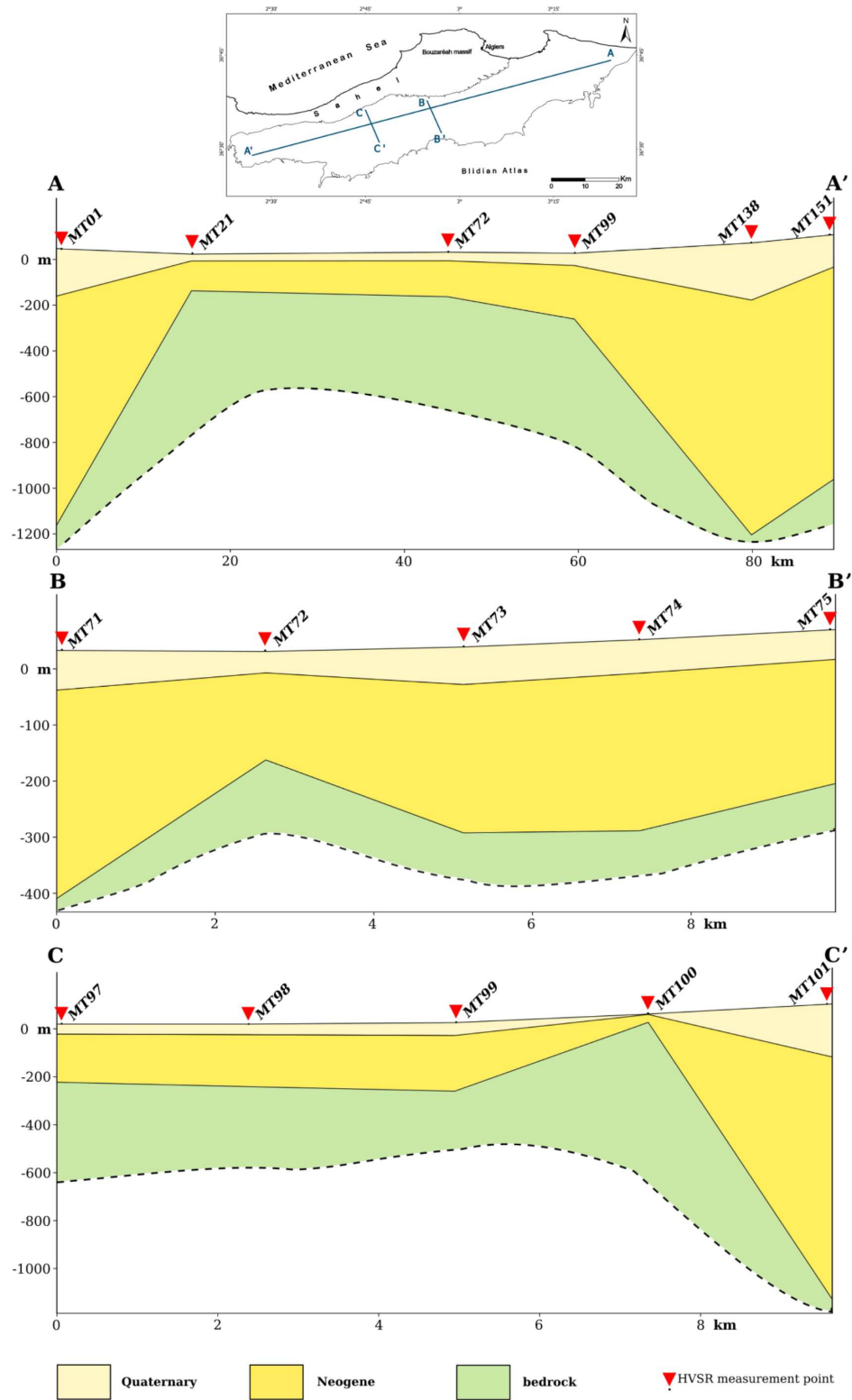


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