

HIGH-RESOLUTION BATHYMETRIC MAPPING
OF ISKENDERUN BAY, TÜRKİYE:
INSIGHTS INTO MORPHOLOGICAL
AND TECTONIC FEATURES

Yeliz İşcan Alp^{1✉}, Hakan Alp²

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Abstract

Iskenderun Bay, situated at the tectonically dynamic triple junction of the African, Arabian, and Anatolian plates in the northeastern Mediterranean, exhibits complex deformation driven by ongoing plate interactions. The region's structural complexity arises from the westward convergence of the African-Anatolian plates and the collision of the Arabian-Anatolian blocks. Post-Middle Miocene escape tectonics along the Dead Sea Fault Zone (DSFZ) generated the North Anatolian and East Anatolian Fault Zones (EAFZ). The EAFZ segment southeast of the Maraş Triple Junction remains enigmatic due to its subdued surface expression and sparse geophysical constraints. Here, we present the first high-resolution digital bathymetric model (DBM) of Iskenderun Bay, derived from multibeam bathymetric surveys. Our dataset reveals previously unresolved seafloor morpho-structures, including fault-controlled slopes and submarine ridges, providing critical evidence for the submerged continuation of the EAFZ. The bay's predominantly flat morphology contrasts with localized deformation along its eastern and southwestern margins, reflecting active tectonic partitioning. These findings gain urgency following the 6 February 2023,

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Mw 7.8 and Mw 7.6 earthquakes, underscoring the seismic hazard posed by unresolved fault geometries in this densely populated region.

Key words: multibeam echosounder (MBES), digital bathymetric model (DBM), seafloor morphology, Iskenderun Bay, East Anatolian Fault Zone (EAFZ)

Introduction. The left-lateral strike-slip East Anatolian Fault Zone (EAFZ), a major active tectonic boundary in the Eastern Mediterranean, represents the convergence between the Anatolian and Arabian plates. Together with the right-lateral North Anatolian Fault Zone (NAFZ), it facilitates the westward escape of the Anatolian Block (Fig. 1a) [1–9]. While the ~ 430 km segment of the EAFZ between Karhova and Türkoğlu (Kahramanmaraş) is well-constrained, its southwestern continuation beyond Türkoğlu and its linkage to the Dead Sea Fault Zone (DSFZ) remain contentious. A prevailing hypothesis posits that the EAFZ merges with the DSFZ near Türkoğlu, extending through the Amanos Mountains into Iskenderun Bay and ultimately connecting to the Cyprus Arc [7, 10–13]. However, recent geological and geomorphological studies challenge this interpretation, arguing that the EAFZ and DSFZ do not intersect in the Amik Plain. Instead, slip along the DSFZ is transferred to the EAFZ via the Karasu Fault [13]. Geodetic data further highlight significant fault displacement near Iskenderun Bay, supporting the presence of active structures in this region [14]. Paleoseismological fieldwork has refined the EAFZ’s southwestern trajectory, identifying Türkoğlu as its junction with the DSFZ and proposing active faults between Türkoğlu and the Mediterranean coast [15]. Critical among these are the Yumurtalık and Toprakkale faults along the northwestern margin of Iskenderun Bay, which exhibit Quaternary activity and may accommodate slip transfer from the EAFZ through the Amanos Mountains (Fig. 1b).

This study examines the seabed morphostructures of Iskenderun Bay, with a focus on the morphological processes that control its extensive shallow plain. A key objective is to identify potential submarine fault systems within the Bay that may represent the offshore continuation of the left-lateral strike-slip East Anatolian Fault Zone (EAFZ), offering critical insights into regional tectonic controls and seismic hazard assessment.

Materials and methods. Multibeam bathymetry data for Iskenderun Bay were sourced from the Turkish Navy’s Navigation, Hydrography, and Oceanography Directorate (SHODB). The dataset was acquired during 2016 and 2018 surveys conducted by SHODB aboard the TCG Çubuklu and TCG Çeşme research vessels. Data were recorded in ASCII format (*.xyz files) with three columns corresponding to UTM Zone 35 coordinates: easting (m), northing (m), and depth (m). The bathymetric data are georeferenced to the WGS84 datum and comply with International Hydrographic Organization (IHO) S-44 standards for hydrographic surveys.

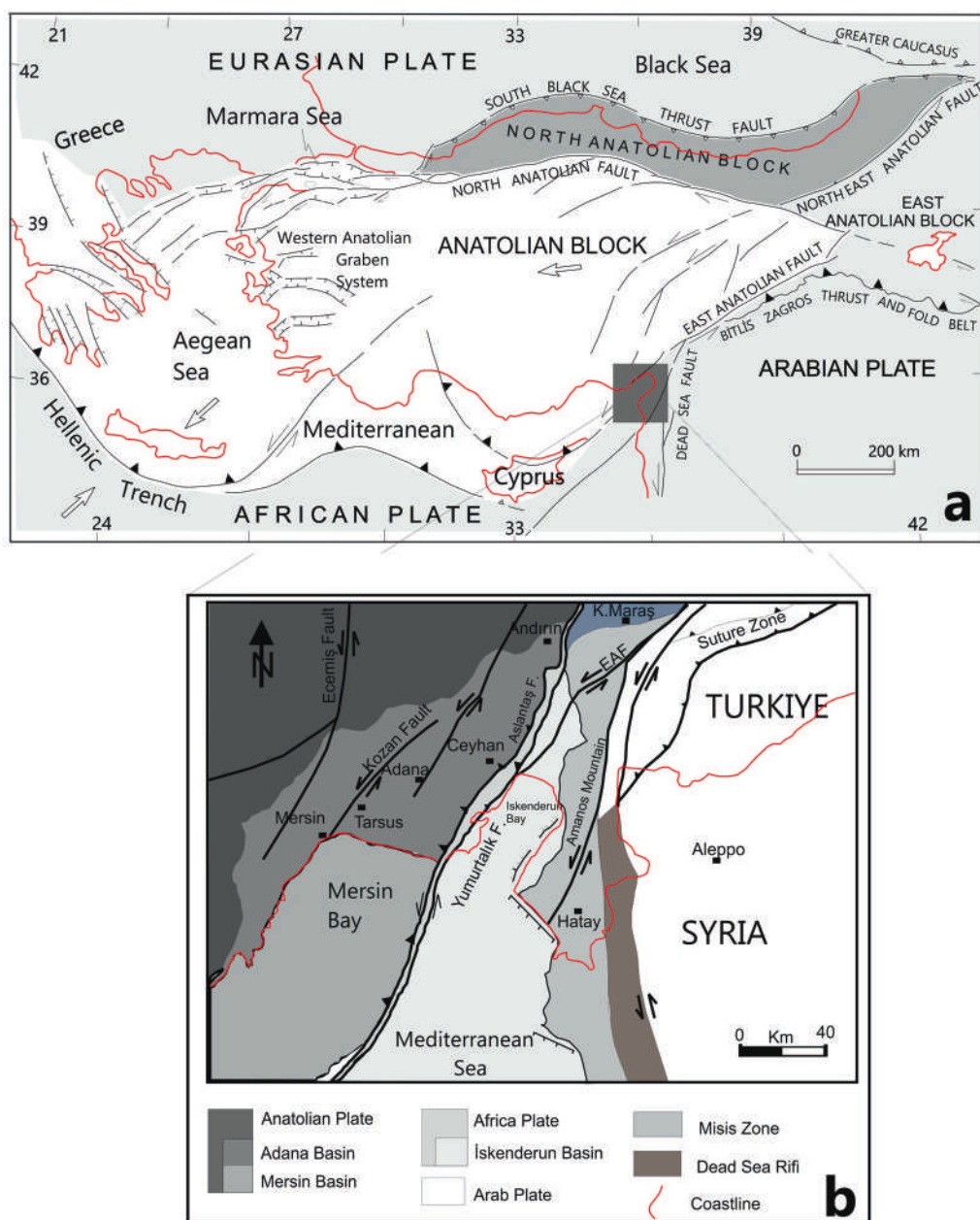


Fig. 1. a) General tectonic elements and broader plate tectonic context (modified from [1]), b) the regional structural framework of the Cilicia Region and Iskenderun Bay (modified from [16])

Data acquisition was performed using the Elac-Nautic 1050D multibeam sonar system, which comprises the following components: acoustic system, ship motion sensor, Sea-Bird conductivity-temperature-depth (CTD) profiler, differen-

tial GPS, and data processing system. The acoustic system operates at 180 kHz, enabling rapid and continuous depth measurements at water depths of up to 700 m. The system employs two transmitter-receiver arrays to generate and detect acoustic signals: transmitted signals are emitted simultaneously, while reflected signals from the seabed are recorded separately by the arrays.

The Elac-Nautic 1050D arrays are mounted on the vessel's hull at a horizontal angular offset of 30° relative to each other. On the TCG Çubuklu vessel, the transmitter generates 56 beams arranged in a 120° fan-shaped swath. This configuration results in a seabed coverage area approximately seven times the water depth. In shallow waters, the acoustic energy emitted by multibeam sonar systems is transmitted as beam lobes spanning 1°–5° along the vessel's heading and 100°–180° perpendicular to the heading. The receiver detects reflected beams returning at angles of 1.5°–3° forward and 3.3°–30° aft of the vessel. Intersecting beams form narrow-angle rays (0.9°–2.5°) to optimize resolution.

In multibeam bathymetry – unlike single-beam systems – a fan-shaped array of beams is transmitted at short intervals, both parallel and perpendicular to the vessel's trajectory, enabling rapid scanning of a wide seabed area. Each beam reflected from the seabed at varying angles is recorded by the receiver arrays, with water depth calculated using the formula:

$$\text{Water depth} = (\text{speed of sound} \times \text{travel time})/2.$$

The speed of sound in water is influenced by parameters such as temperature, salinity, conductivity, and pressure. Depth-dependent sound velocity profiles were measured in situ using the Sea-Bird CTD profiler to ensure accurate depth corrections.

Coverage area of multibeam bathymetry data. The multibeam bathymetry data covers an area of approximately 3135 km² in Iskenderun Bay. The spatial distribution of the dataset, represented as a point-based coverage analysis using ESRI's ArcGIS platform (version 11), is presented in Fig. 2a.

The solid black regions in Fig. 2a indicate that the survey lines for bathymetric data collection were densely spaced, with significant overlap, and exhibited a high sampling frequency along the lines. Moreover, even in the zoomed-in image of a small region from this area, it is observed that the measurement points are positioned very close to each other. The distance between adjacent sampling points ranged from 1 to 4 meters, confirming comprehensive coverage of the study area.

Data Processing Workflow in ArcGIS. The multibeam bathymetry data were processed in ArcGIS using the following steps:

a) Data acquisition and preprocessing. Raw multibeam bathymetry data in ASCII format were obtained from SHODB. SHODB performed preprocessing and calibration of the data as detailed in the previous section.

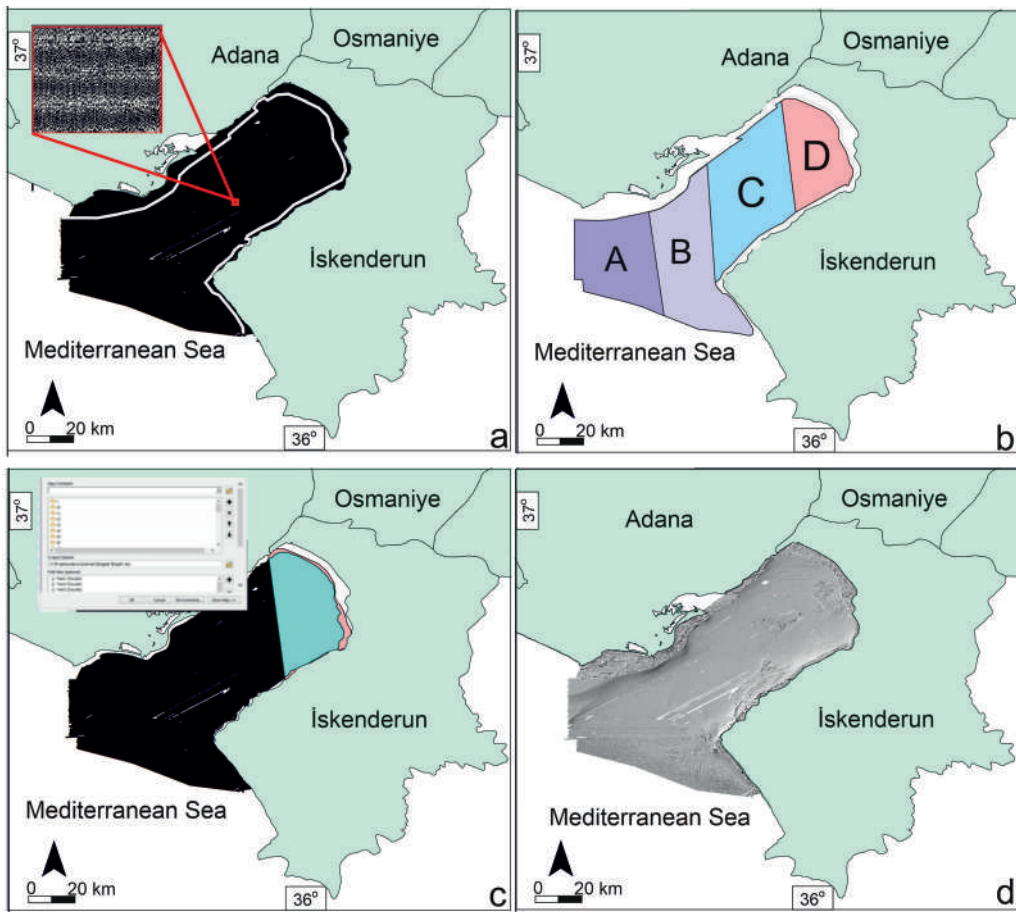


Fig. 2. a) Multibeam bathymetry data field sampling area. The black coverage area shows all bathymetry sample points collected in the field. Areas beyond the white line are supplemented with satellite-derived data, while the inset demonstrates data density; b) Segmentation process applied to the data; c) Separate storage of data divided into sections; d) A shaded relief map of the region was generated by illuminating the topographic surface from the northeast (NE) direction

b) Data integration and management. The ASCII files were merged with coordinate and depth metadata. To optimize file handling, datasets were automatically segmented into subsets not exceeding 150 MB.

c) Spatial subdivision for processing efficiency. The transformed dataset was visually inspected, and the study area was divided into four overlapping subregions (Fig. 2b). This subdivision aimed to balance computational load during data processing. Polygons delineating these subregions were exported as separate vector files (Fig. 2c).

d) Integration of separately prepared files and error elimination. These models are in raster (GRID) format, where data are represented as pixels

and may contain errors or gaps. To consolidate the data, all files were merged into a single model. Two error-control methods were applied to address inaccuracies in the model and its regional intersection points: (1) Single-pixel errors (e.g., anomalous peaks or valleys) were removed, and the DBM was subsequently regenerated. (2) A shaded relief (hillshade) map of the model was generated to visually identify potential artifacts (Fig. 2d). Regions of interest, particularly intersections, were manually inspected. The correction process was iteratively repeated for erroneous areas.

e) Shaded relief generation with various values. The generated shaded relief was systematically evaluated under multiple illumination azimuths to identify the optimal direction for highlighting regional morphological features. Comparative analysis revealed that illumination from the northeast (NE; 45° azimuth) most effectively represented the terrain's structural elements (Fig. 2d). Vertical exaggeration (Z-factor) was rigorously tested during shaded relief generation, with values spanning 1 m (minimal) to 100 m (extreme). Empirical results demonstrated a trade-off: higher Z-factors (> 40 m) introduced significant noise, while values ≤ 1 m failed to resolve critical elevation variations. Based on this sensitivity analysis, a Z-factor of 20 m was selected to balance feature visibility and noise suppression.

f) Integration of satellite-derived bathymetry (SDB) in shallow coastal areas. Multibeam bathymetric data were unavailable in shallow coastal zones (depths < 10 m), where rapid bathymetric transitions occur, as delineated by the white boundary line in Fig. 2a. To address this gap, satellite-derived bathymetry (SDB) was employed. The SDB dataset also exhibited no coverage in nearshore regions with depths < 5 m. For these areas, satellite-based methods were applied to estimate bathymetry. Two distinct SDB models were implemented, both grounded in the spectral matching principle:

Data-driven experimental model. This empirical approach applies regression analysis between in situ depth measurements and satellite-derived pixel reflectance values. The resulting regression relationship is extrapolated across the entire satellite image to estimate depths.

Physics-based radiative transfer model (RTM). This method leverages the radiative transfer equation to simulate light interaction with the water column, seafloor, and atmosphere.

In this study, the physics-based algorithm described in [17] was adopted. This method utilizes logarithmic ratios of blue and green band reflectances from Sentinel-2 multispectral imagery (15 July 2024) to derive bathymetry. The algorithm was applied to shallow waters (0–20 m depth) in Iskenderun Bay, achieving a maximum vertical error of 15% relative to ground-truth measurements.

g) Colour visualization for DBM. DBM was augmented with hillshade data optimized to accentuate morphological features. Subsequently, the bathymetric model was (1) colour-mapped using a perceptually uniform colourmap, (2)

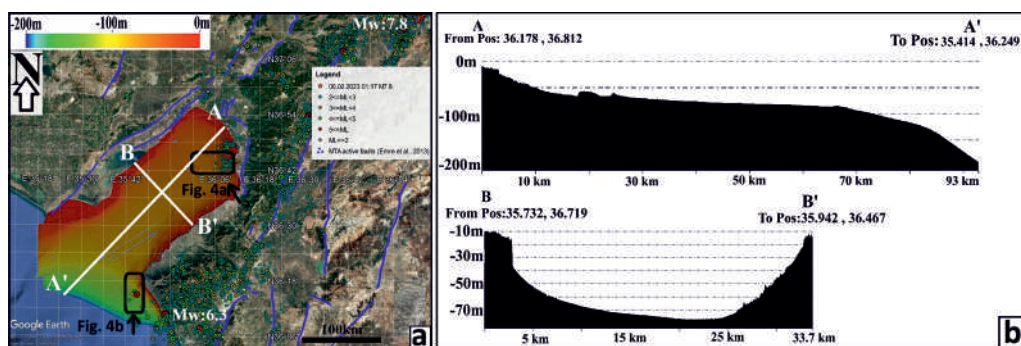


Fig. 3. a) Digital bathymetric model of Iskenderun Bay, showing main tectonic features derived from the MTA fault map (blue lines; [18]) and refined epicentre locations of earthquakes (6 February 2023 – 30 October 2023), colour-coded by magnitude (yellow, green, red circles; [19]). Small black arrows indicate the direction of view of the figure. b) Cross-sectional and longitudinal bathymetric profiles of Iskenderun Bay extracted from the digital bathymetric model

rendered with 30% transparency, and (3) contrast-enhanced to improve feature discrimination (Fig. 3a).

Results and discussion. Following the data processing steps outlined above, the Digital Bathymetric Model of Iskenderun Bay (Fig. 3a) was developed, and the key findings derived from the results are presented and discussed in this study.

The Iskenderun Basin, located in the tectonically active convergence zone of the African-Arabian and Anatolian plates in the northeastern Mediterranean, is a small NE-SW-oriented submarine depositional basin bounded by the southern flank of the Misis Mountains and the Aslantaş Fault Zone. Its northern and western faulted margins adjoin the Kızıldağ-Hatay ophiolite complex within the Amanos Mountains [12]. The bathymetric map of Iskenderun Bay (Fig. 3a, b) reveals an asymmetric morphology, characterized by a steepening and deepening continental shelf, slope, and floor seaward.

The bay floor lies within the 0–200 m continental shelf. Bathymetric data reveal that the floor exhibits a relatively uniform morphology with a gentle slope (≤ 100 m water depth), transitioning abruptly to steeper gradients (100–110 m) that deepen toward the open Mediterranean. Across the basin, small hills with 10–20 m elevation variations, gentle relief plains, and bowl-shaped depressions are prominent. Regional variations are evident: the northern bay floor is dominated by inclined plains, while the southern sector displays valley-like morphostructures. Steep subaerial coastal slopes along the eastern and northern parts of western coasts (Fig. 3a) correlate with underwater slope breaks that extend across the bay floor, reflecting tectonic controls on basin morphology [20].

The NW-SE-oriented bathymetric profile (A–A') across the bay reveals a rapid depth increase from -10 m to -60 m within the first 10 km, followed by a

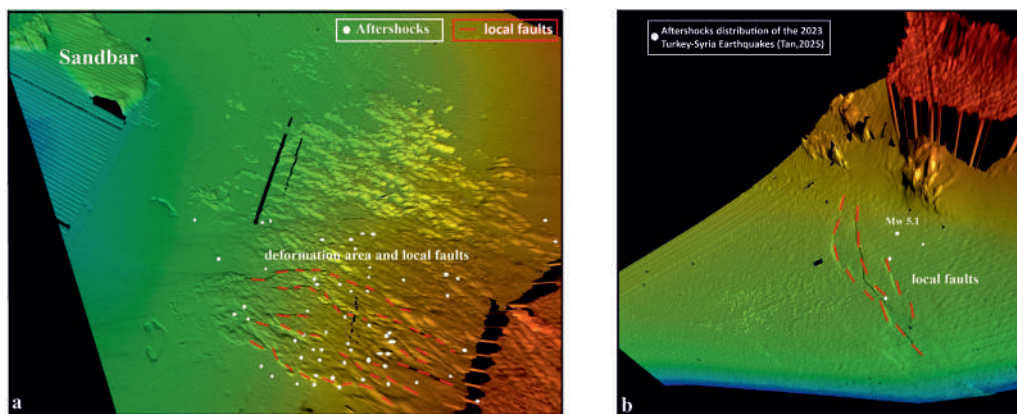


Fig. 4. a) Morphological structures in the northwestern Iskenderun Bay, showing the aftershock clustering from the February 2023 earthquakes; b) Local faults (red lines) and aftershock epicentres (white circles) identified near the southeastern exit of the Bay

gradual descent to -80 m. Beyond 68 km, the slope steepens markedly, reaching -200 m at the bay mouth by 85 km (Fig. 3b). A prominent morphological feature along this profile is a sandbar-like ridge (likely formed by longshore drift) in the northern part of the central bay, characterized by a steep 10 m elevation rise along the NW–SE axis. This structure extends approximately 3 km in width, terminating with a gentle slope, and occupies an area of ~ 47 km² within the gulf (Fig. 4a).

The spatial distribution of aftershocks from the 6 February 2023 earthquakes (6 February – 30 October 2023) [19] reveals a pronounced clustering (106 events, clustered within a 12 km radius) in the northwestern sector of the gulf (Fig. 3a, 4a). Bathymetric data from this seismically active zone indicate that the aftershocks align with local faults, suggesting active deformation along these structures. A secondary cluster (24 events, including $M_w = 5.1$ within the bathymetric model), likely associated with a $M_w 6.3$ earthquake on 20 February 2023, is observed near the southeastern gulf exit. High-resolution bathymetry further identifies previously unmapped local faults within this region, which correlate spatially with the aftershock sequences (Fig. 4b).

Conclusion. In this study, we present the first high-resolution digital bathymetric model of the tectonically complex Iskenderun Bay, southeastern Türkiye, derived from multibeam sonar data. This model reveals unprecedented details of seabed morphology, including fault-controlled slopes, submarine ridges, and basin structures. Furthermore, we analyze the spatial distribution of aftershocks following the 6 February 2023 earthquakes, demonstrating their clustering along previously unmapped local faults within the bay. Our results highlight a strong correlation between aftershock activity and bathymetric features, suggesting that active tectonic deformation influences both seismic events and seafloor morphology in this region.

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¹*Istanbul University-Cerrahpaşa, Vocational School of Technical Sciences, Underwater Technology Program, 34500 Büyükçekmece, Istanbul, Türkiye*
e-mail: yeliziscanalp@iuc.edu.tr

²*Istanbul University-Cerrahpaşa, Engineering Faculty, Department of Geophysical Engineering, 34500 Büyükçekmece, Istanbul, Türkiye*
e-mail: hakanalp@iuc.edu.tr