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Pursuing the Unknown

Segmented Structure of the Kinneret Basin: Insights from a DST Locked-Creeping Transition Zone

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Introduction

Continental transforms like the Dead Sea Transform (DST) are primary sites for strain partitioning. The Sea of Galilee (SoG) marks a critical transition from creeping to locked behavior. Within this zone, the Kinneret Western Border Fault (KWBF) and Diagonal Fault (DF) accommodate localized tectonic stresses. We evaluate whether the 2018 swarm follows a continuous plane or a segmented network. Crucially, we test the role of static stress transfer versus fluid-driven pore-pressure diffusion in the sequence's evolution.

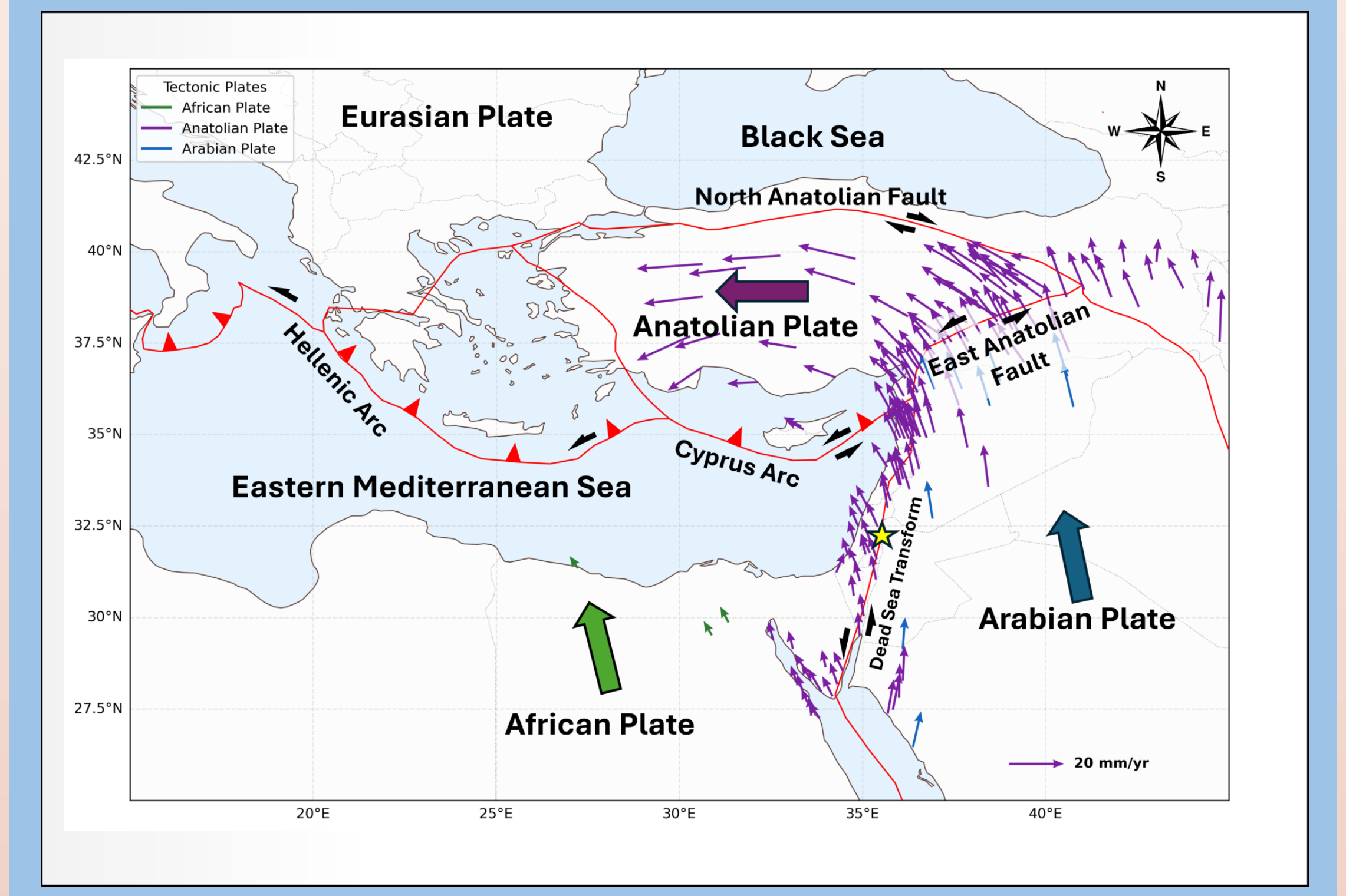

Fig. 1. Small colored arrows represent GPS velocity vectors in a Eurasia-fixed reference frame, synthesized from Reilinger & McClusky (2011) and Nocquet (2012). Red lines represent major plate boundaries and fault systems (after Bird, 2003; Özden et al., 2015; Heckenbach et al., 2024). Triangles on the red lines indicate subduction zones (Hellenic and Cyprus arcs); black half-arrows indicate the sense of strike-slip motion along the North Anatolian, East Anatolian, and Dead Sea Transform (DST) faults. Large colored arrows represent generalized plate motion. The yellow star indicates the Sea of Galilee (SoG) study area, situated at a major regional transition in fault behavior.

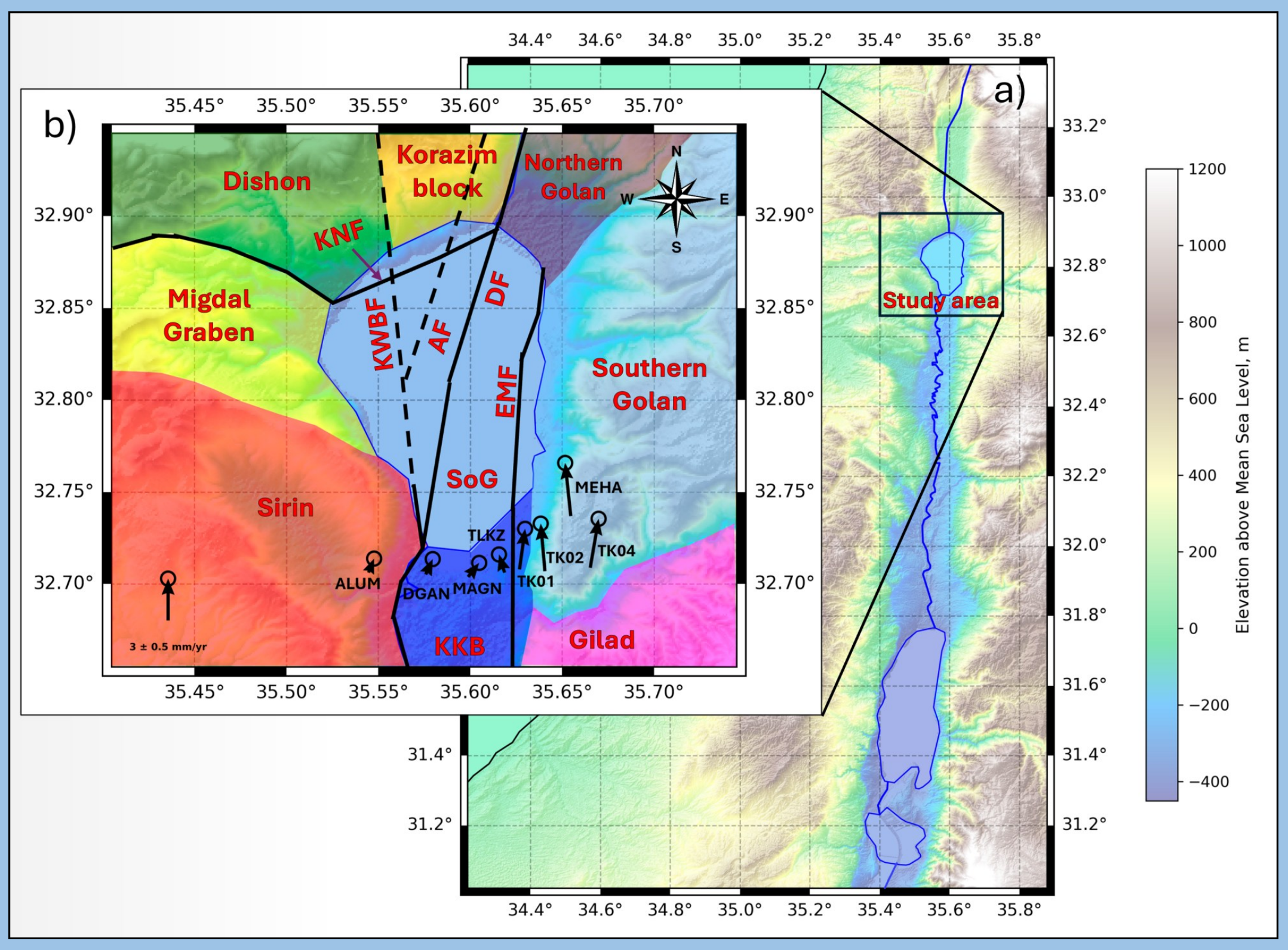

Fig. 2. (a) Regional setting along the DST plate boundary. (b) Detailed map of the study area highlighting KWBF and DF as the primary structures facilitating the transition between locked and creeping segments (black lines, adapted after Segev and Schattner, 2023). Black arrows and 95% confidence ellipses represent GNSS velocity vectors (2018–2021) relative to a stable Sinai reference frame. Scale vector (bottom left) represents 3±0.5 mm/yr. Regional plate motion is ~4 mm/yr, with a shallow creep rate of 2.6±0.3 mm/yr observed along the northern Jordan Valley segment, temporally coincident with the resumption of localized seismic activity (geodetic data adapted from Hamiel and Piatibratova, 2023).

Data and Methods

We analyzed 1,244 earthquakes (2018–2025) relocated with high precision (mean RMS ~0.166 s) using the Ben-Dor et al. (2025) 3D velocity model. To resolve active fault geometries, we performed 3D full-waveform moment tensor inversions for 94 events, retaining 65 high-fidelity solutions for kinematic ensemble analysis. Triggering mechanisms were evaluated by calculating effective hydraulic diffusivity (D) via $L \approx \sqrt{Dt}$ and modeling static Coulomb stress changes (ΔCFS) for the Mw 4.5 mainshock. Modeling assumed a vertical strike-slip rupture to assess elastic interactions between active fault branches.

Results

- 3D relocation resolves a sharp lateral depth contrast at 35.58 °E.
- Deep background seismicity (to 15 km) defines the master Diagonal Fault (DF) trace.
- The 2018 swarm represents shallow structural reorganization (< 6 km) along the western fault system.
- Kinematic ensemble analysis resolves a dominant strike-slip regime (75.5° dip) with a 130° (±5°) conjugate angle.
- A 4–6 day delayed southern cluster activation was initiated within a significant static stress shadow (ΔCFS ≈ -1 MPa).
- Estimated hydraulic diffusivity (D = 14.2–21.3 m^2/s) identifies pore-pressure diffusion as the dominant trigger for southern cluster activation.

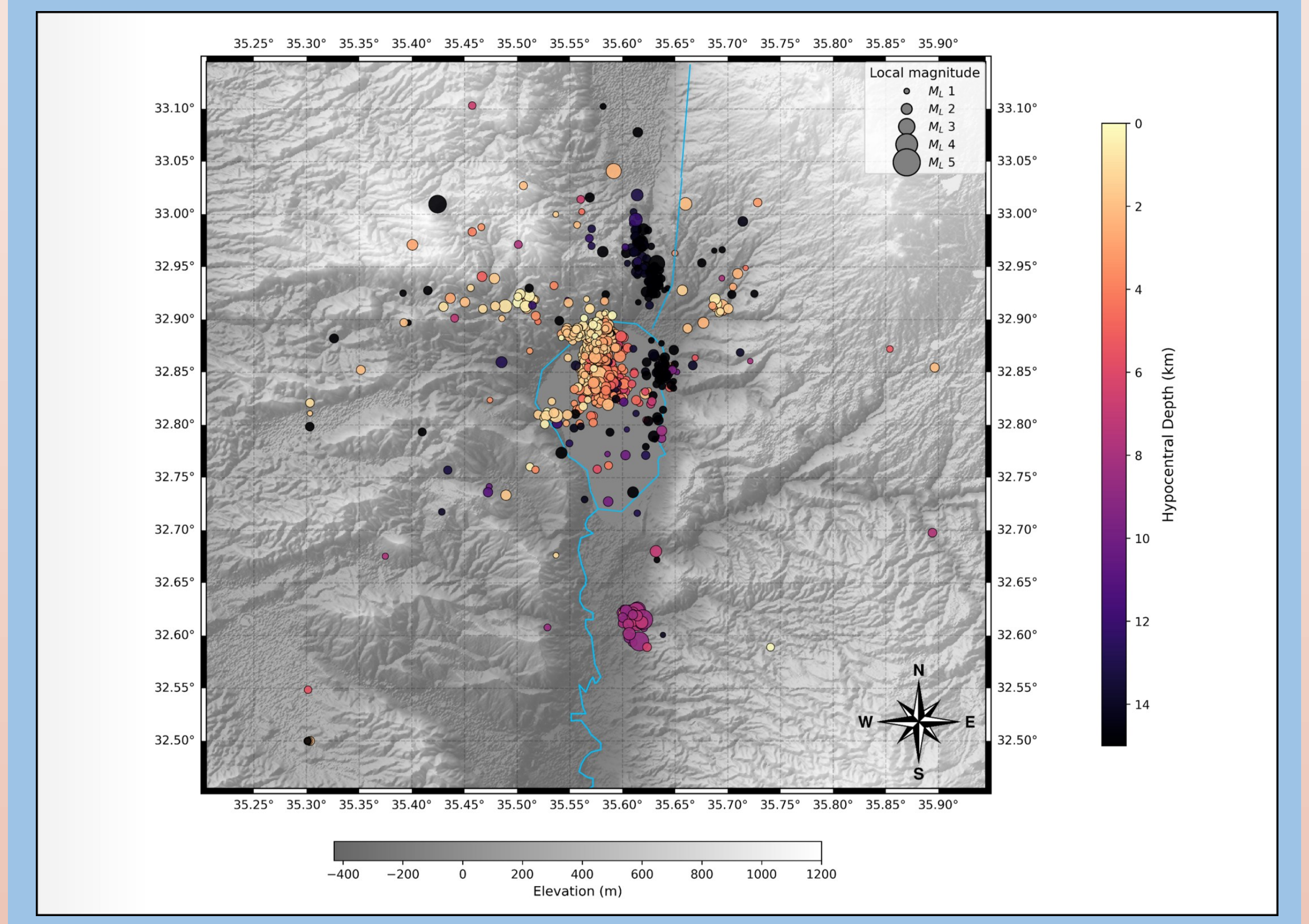

Fig. 3. Map of the 3D manually relocated catalog (N=1,244). Hypocenters are color-coded by depth (0-15 km) and scaled by magnitude, overlaid on high-resolution grayscale shaded relief. Shallow clusters (< 6 km) in the central-west of the northern basin correspond to the 2018 swarm.

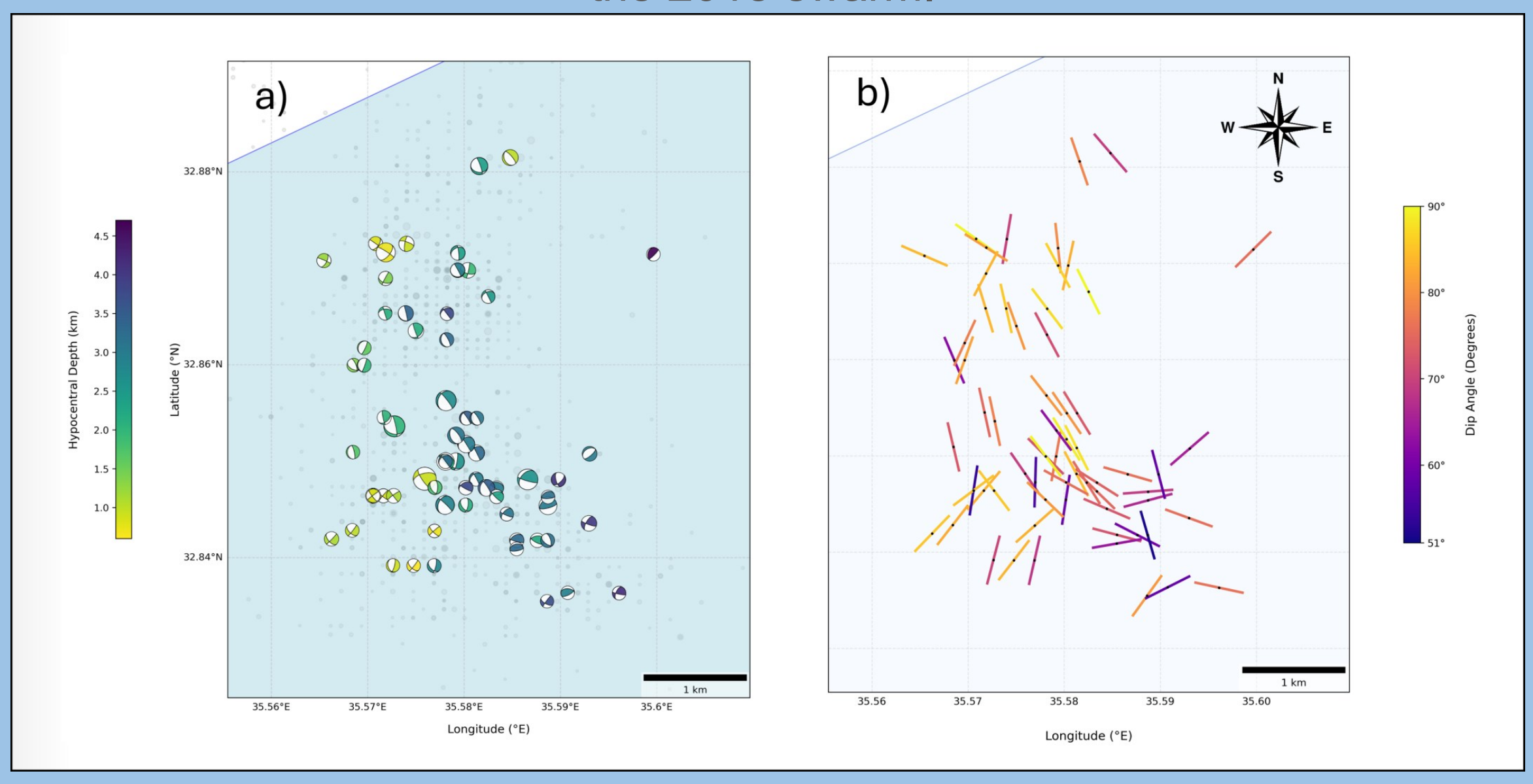

Fig. 4. Kinematics of the July-August 2018 SoG swarm. (a) Relocated microseismicity (gray circles, scaled by magnitude) and focal mechanisms (sized by magnitude, colored by hypocentral depth). (b) Ensemble analysis showing strike orientations of steep nodal planes (50°-90°) extracted from (a), centered on epicenters and colored by dip to highlight active fault architectures. The light blue line denotes the western shoreline.

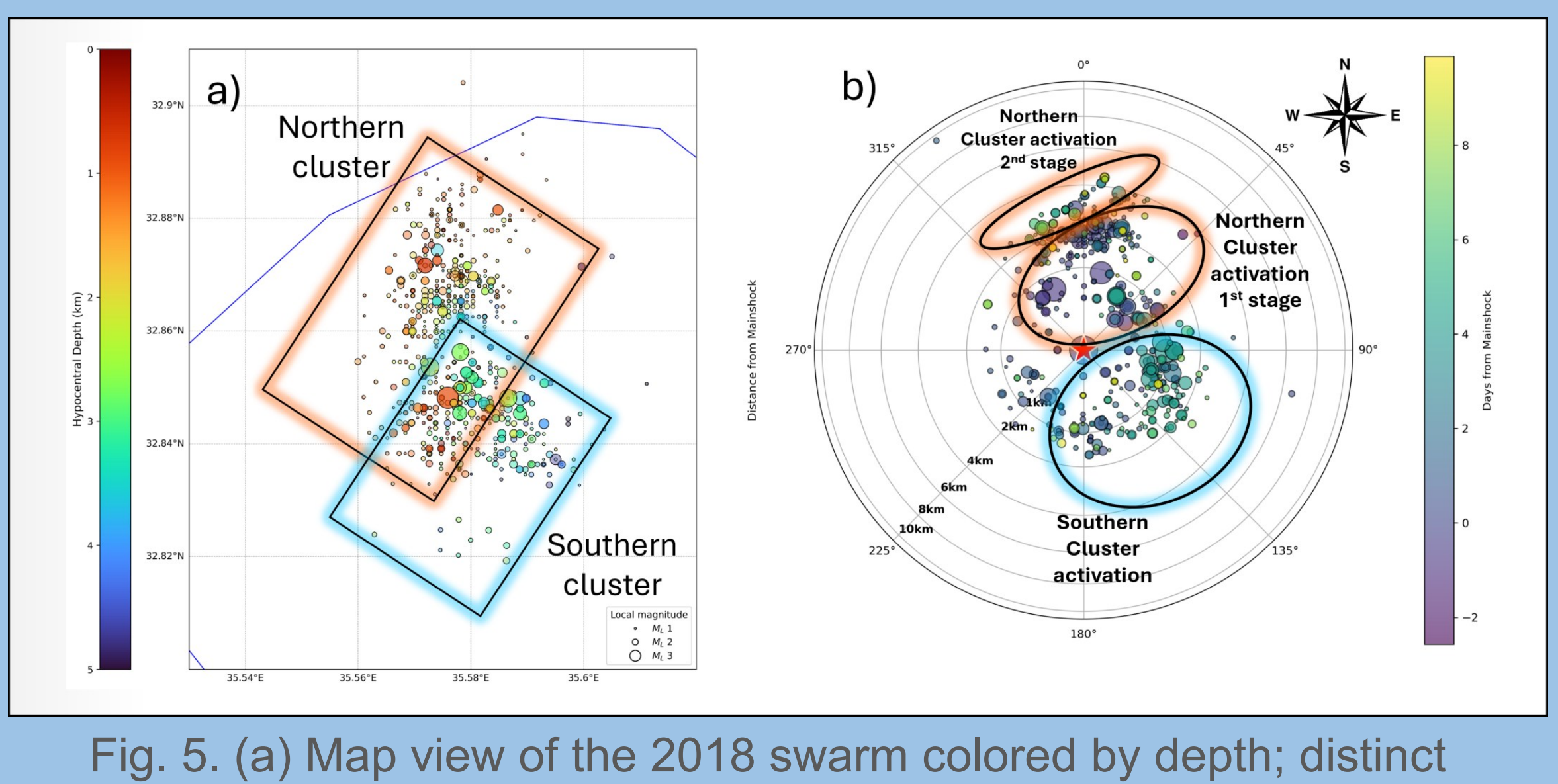

Fig. 5. (a) Map view of the 2018 swarm colored by depth; distinct northern and southern clusters suggest activity on multiple fault segments rather than a single plane. (b) Polar plot showing event distance and azimuth relative to the mainshock (star), with color indicating time (days). The delayed activation of the southern cluster relative to the northern one indicates that the swarm migrated across distinct fault branches rather than propagating linearly along a simple plane.

Discussion

Findings link the 2018 sequence to geodetic creep (2.6 ± 0.3 mm/yr) observed by Hamiel and Piatibratova (2023). Rather than a single plane (Wetzler et al., 2019), we resolve two intersecting segments at a 130 ± 5° conjugate angle between active fault branches.

This optimally oriented "corner" geometry accommodates strain differently than proposed "horsetail" splays. A 4–6 day delayed southern activation within a static stress shadow (ΔCFS ≈ -1 MPa) provides a mechanical "smoking gun" for pore-pressure diffusion. Estimated diffusivity (D = 14.2-21.3 m^2/s) demonstrates that fluid pulses bypass elastic inhibition to activate conjugate fault segments. This multi-branched framework mirrors the split-system geometry of the Hula Basin to the north, suggesting conjugate fault architectures may characterize maturing Dead Sea Transform sub-basins.

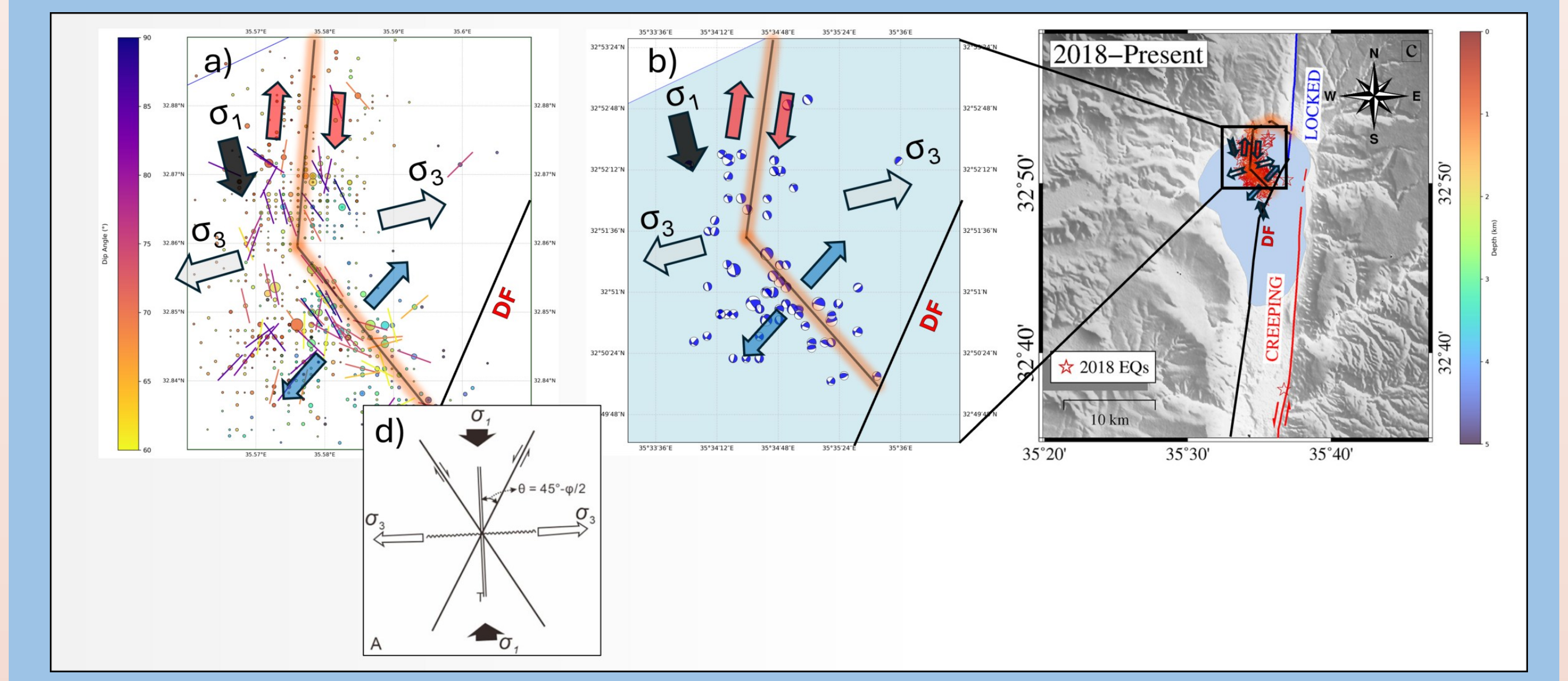

Fig. 6. Seismotectonic analysis of the 2018 Kinneret earthquake swarm. (a-b) Earthquake distribution, focal mechanisms, and principal stress orientations (σ_1,σ_3) indicating transpressive slip. (c) Regional context of the swarm at the transition between locked and creeping segments of DF, within DST. (d) Schematic model of the 130° conjugate geometry based on an Andersonian pure shear model (after Aydin and Page, 1984; Sylvester, 1988). The angle θ=25° defines the relationship between the maximum compressive stress and the active fault planes.

Conclusions

- Findings challenge structural models depicting the KWBF as a singular, continuous plane.
- Deep background seismicity (~15 km) along the eastern margin defines the master Diagonal Fault (DF) trace and its link to regional DST seismicity.
- The 2018 swarm reveals intersecting fault segments (130° ± 5° conjugate angle) rather than a unified rupture surface.
- Delayed southern activation within a static stress shadow (ΔCFS ≈ -1 MPa) is inconsistent with static triggering alone and requires fluid-driven pore-pressure diffusion.
- Results demonstrate that fluid-rich fault systems can trigger failure even where static stress changes are inhibitory.
- Seismic hazard models for maturing pull-apart basins must incorporate multi-segment rupture scenarios and active conjugate geometries.

Importance of the Research

We resolve the mechanical link between localized swarms and master faults, addressing a critical structural blind spot. Our findings demonstrate that pore-pressure diffusion bypasses static stress inhibition, establishing a new framework for assessing seismic hazards and multi-segment architectures worldwide.

Acknowledgements

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