Heat flow as a primary control factor on global earthquake magnitude distribution

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Abstract

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Overview

Earthquake magnitude distributions vary across space and time, with the *b*-value indicating the relative proportion of small to large events. While often linked to stress and fault properties, clear physical drivers of *b*-value variations remain elusive.

In this study, we show that crustal heat flow is a key factor controlling earthquake size distribution. Using a global dataset (Global CMT, 1980–2023) and a heat flow model, we find a robust positive correlation: higher *b*-values consistently occur in regions with elevated heat flow, regardless of tectonic setting or faulting style.

These results suggest that thermal conditions strongly influence seismogenic behavior and provide a new framework for interpreting *b*-value variations in seismic hazard assessments.

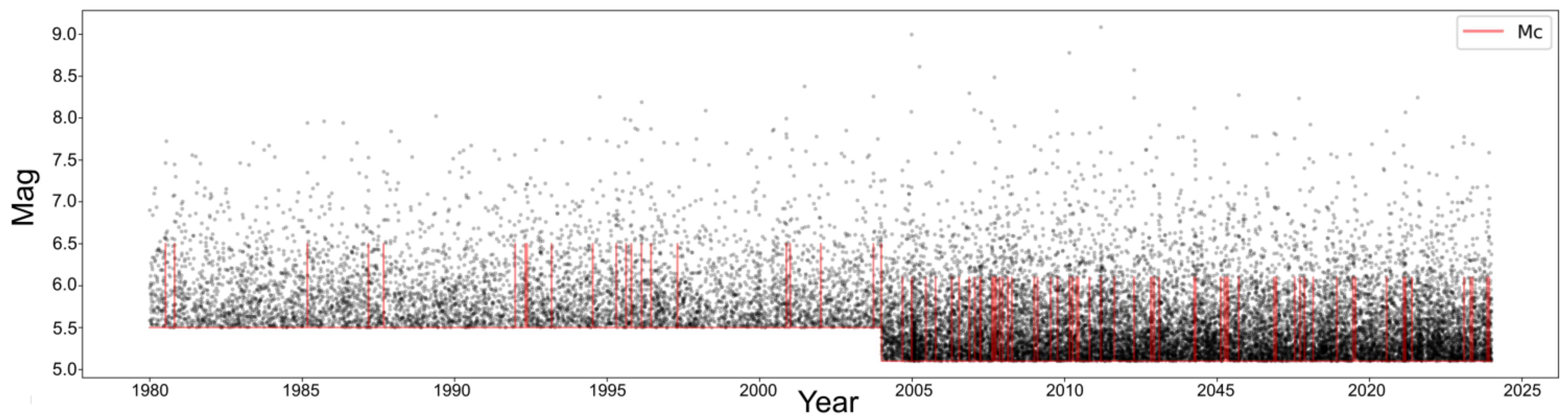

Fig. 1 Timeline of the events of the CMT catalog above the completeness magnitude (M_C; red line)

Methods

- Earthquake Catalog:
Global CMT catalog (1980–2023), events ≤50 km depth.

- Completeness Magnitude (M_c):
Estimated using Taroni (2023) method with Lilliefors test; adjusted for catalog changes over time and short-term incompleteness after large events (**Fig. 1**).

- Heat Flow Assignment:
Heat flow values interpolated from the global model by Davies (2013) to each earthquake location.

- *b*-value Estimation:
Maximum likelihood method accounting for time-varying M_c (Taroni, 2021);
also tested with the tapered Gutenberg-Richter distribution.

- Statistical Tests:

Pearson correlation (*b*-value vs. heat flow) (**Fig. 2**)

Utsu test (*b*-value difference significance) (**Fig. 4**)

Kolmogorov-Smirnov and Mann-Whitney tests (distribution comparisons) (**Fig. 4**)

Bonferroni correction for multiple testing

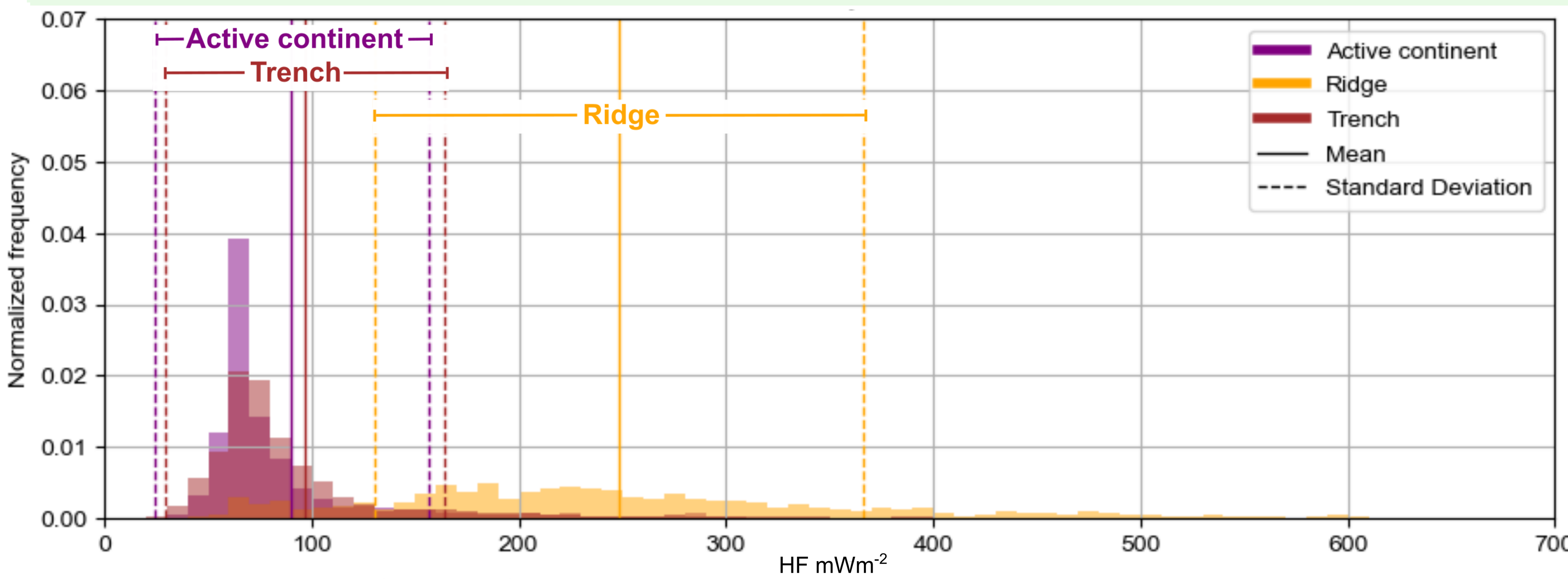

Fig. 3 Distribution of the heat flow in the three main tectonic zones considering only the events above the M_C

b-value vs Heat Flow

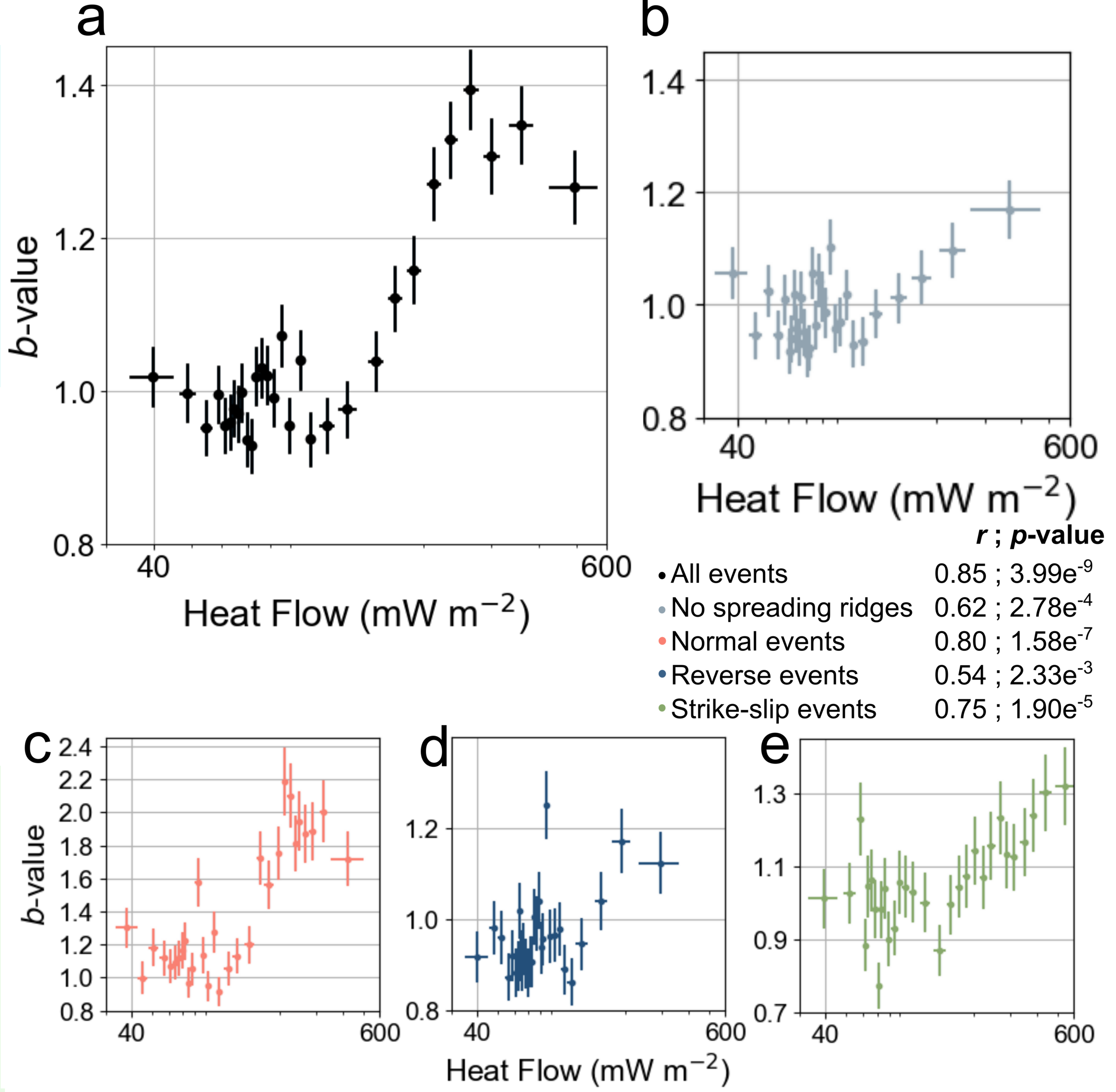

Fig. 2 Correlation between *b*-value and heat flow a) Considering all the events in the catalog above the completeness magnitude (M_c); b) Excluding events that occurred in spreading ridges; c-e) Considering all the events and grouping them according to the focal mechanism.

Magnitude distribution comparison

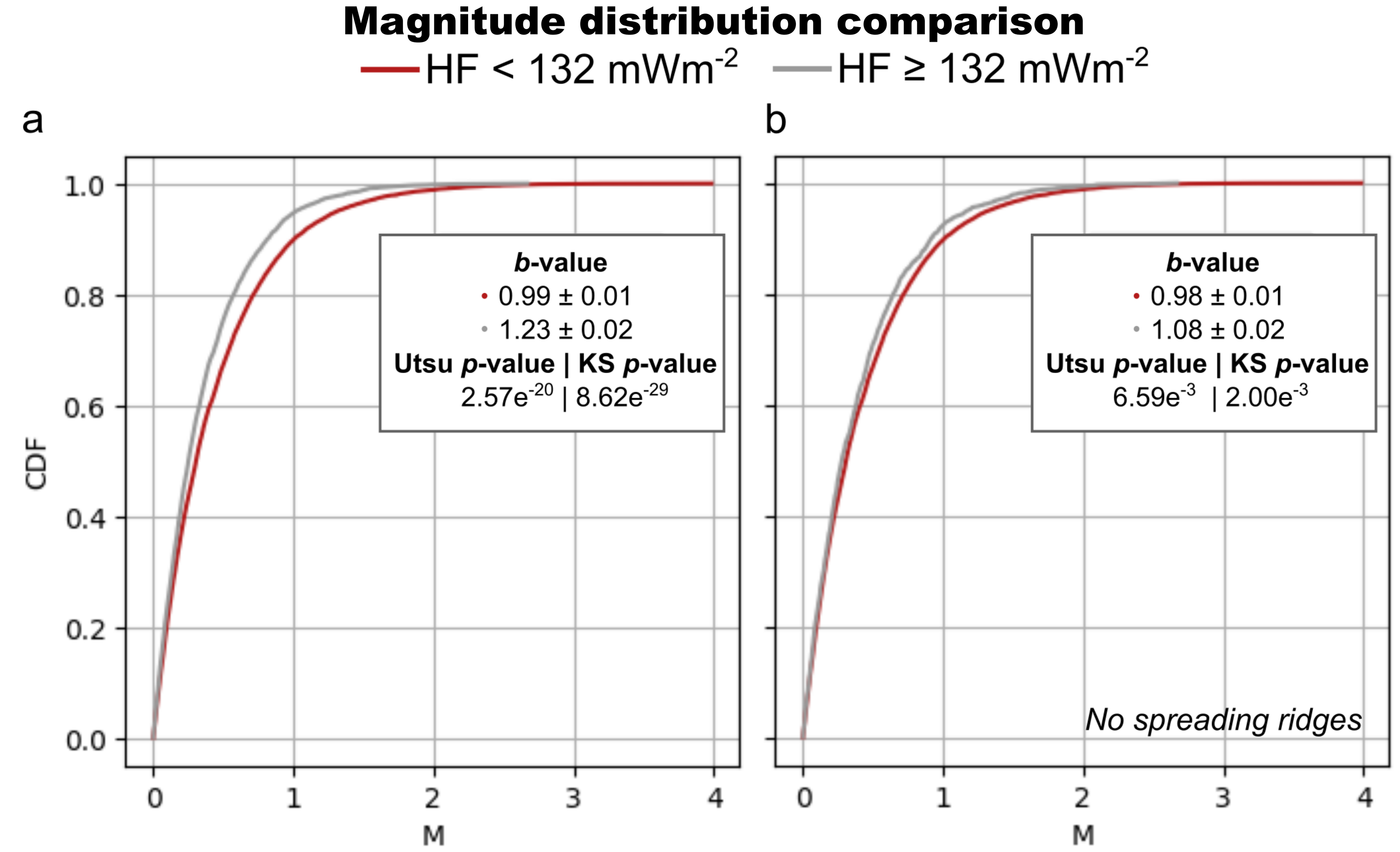

Fig. 4 Cumulative distributions of the magnitudes below 132 mWm-2 and above a) All the events; b) Excluding events occurred in spreading ridges.

MFD

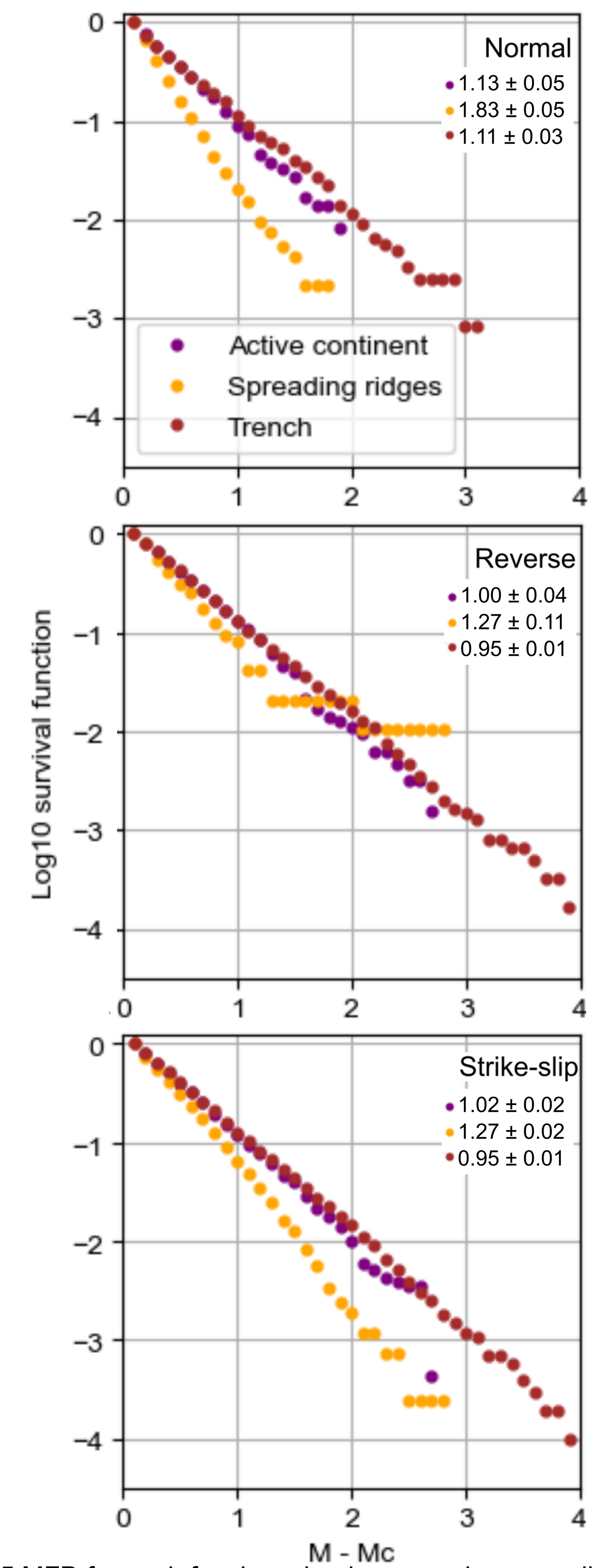

Fig. 5 MFD for each focal mechanism grouping according to the tectonic environment.

Conclusions and future work

Crustal heat flow plays a fundamental role in shaping the earthquake magnitude distribution. High heat flow correlates with elevated *b*-values, indicating fewer large events in these regions.

This relationship holds across tectonic environments and faulting mechanisms, highlighting heat flow as a unifying physical control on seismic behavior. Integrating thermal conditions into seismic hazard models could significantly improve our understanding of where and how large earthquakes are more likely to occur.

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