INVERTING MARINE TERRACE MORPHOLOGY TO CONSTRAIN PALEO SEA-LEVEL

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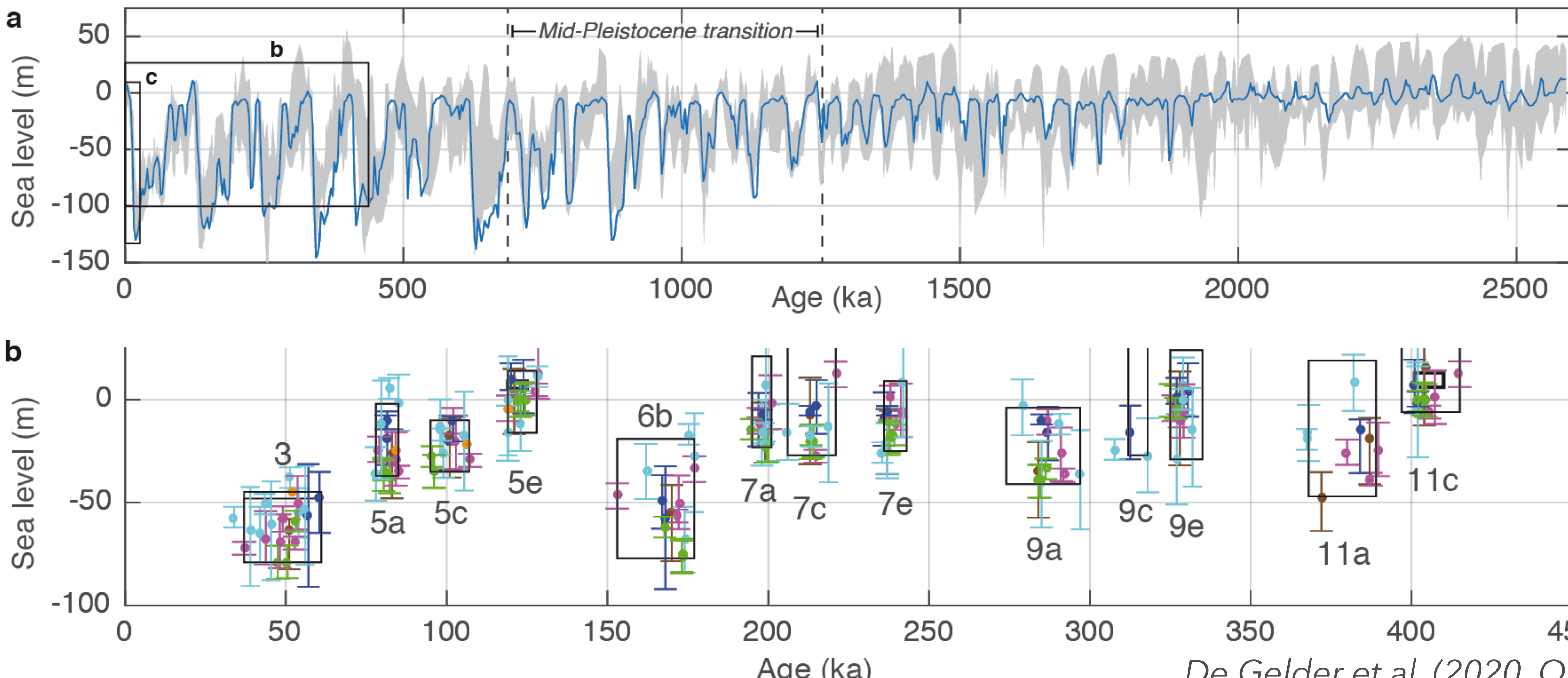
Paleo sea-level: important for paleo-climate, -ice-sheets and geodynamics

Problem: There are currently large uncertainties in Quaternary sea-level curves



De Gelder et al. (2020, QSR)

Why? Typically based on oxygen isotope ratios ($\delta 18O$):

- sea-level curves are very variable depending on methodology to convert $\delta 18O$

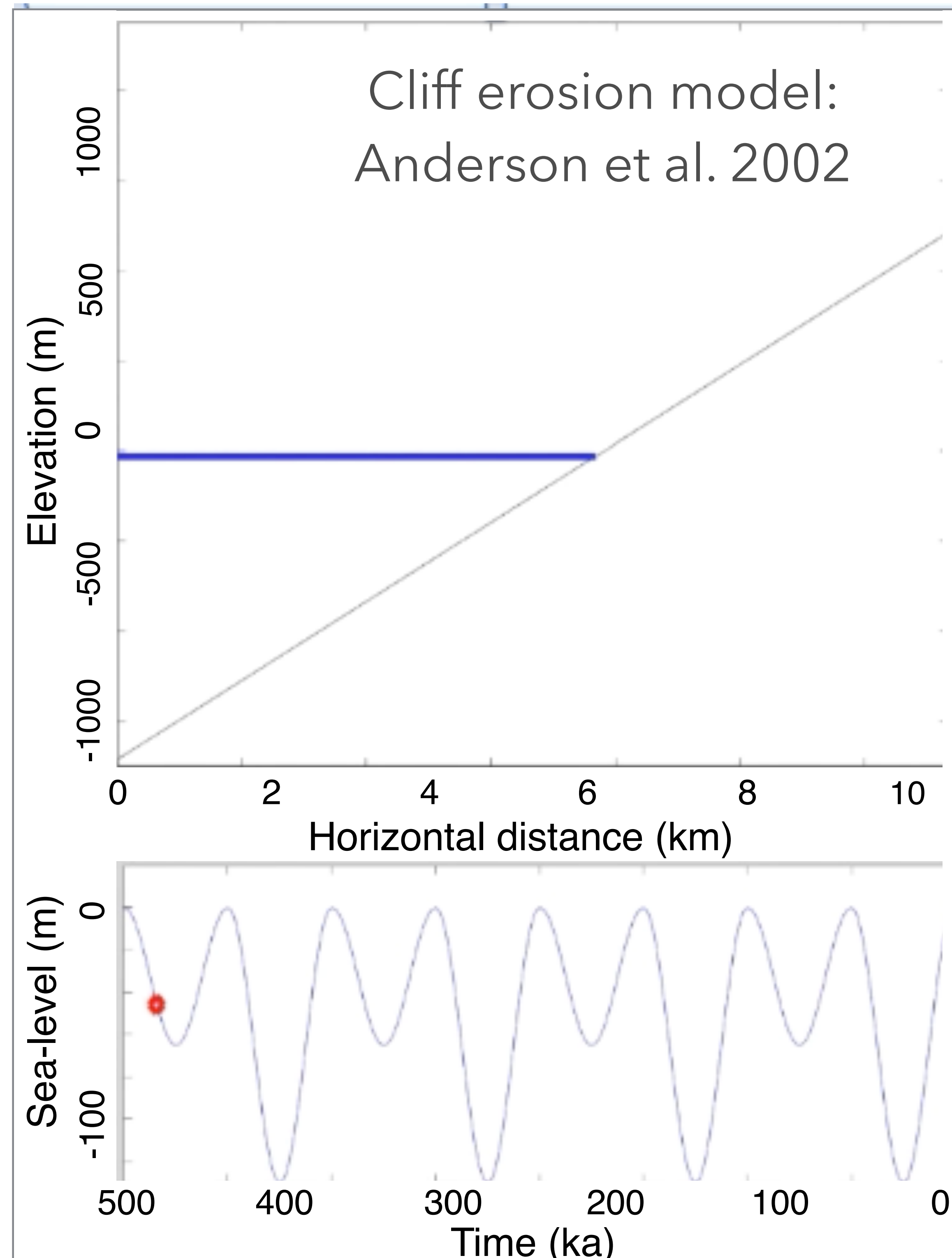
Alternative: Looking at the coastlines for relative sea-level indicators -> **marine terraces**

Marine terraces are flat or gently sloping surfaces of marine origin, bounded by (fossil) sea-cliffs land- and seawards

Forward modelling studies
Varying input parameters (existing sea-level curves) to compare models and observations

e.g. Jara-Muñoz et al., 2016, 2019; Melnick, 2016; Leclerc & Feuillet, 2019; Pastier et al., 2019; De Gelder et al., 2020

Next step: inversion?
We aim to develop a method to find range of parameters (sea-level histories) that could reproduce observed morphology

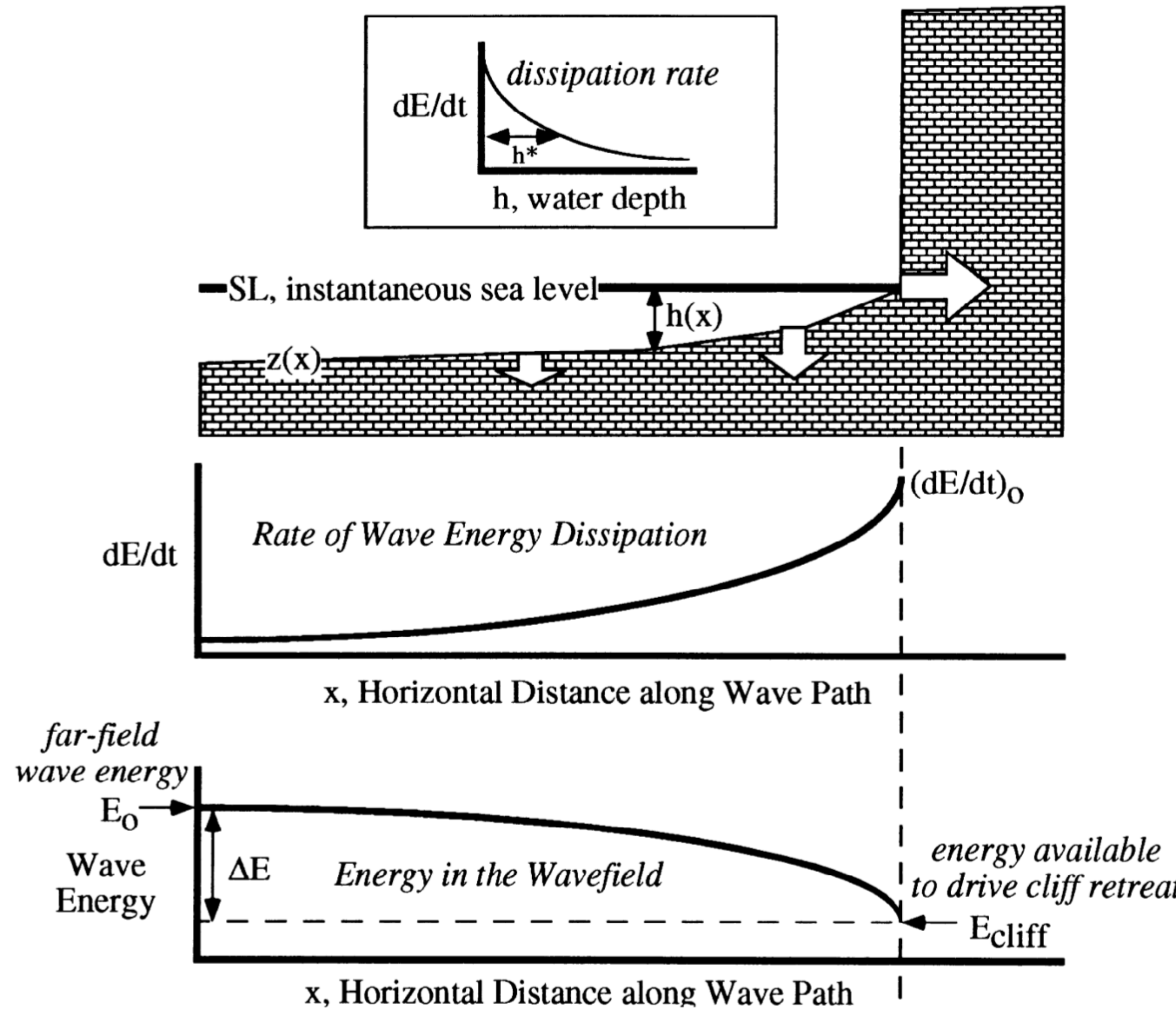


CLIFF EROSION MODEL

- Uplift Rate (-3 to 3 mm/yr)
- Initial Slope (1-20%)
- Erosion Rate (0.1-1 m/yr)
- WaveBase Depth (3-25 m)
- Sea-Level Curve

INVERSION PARAMETERS

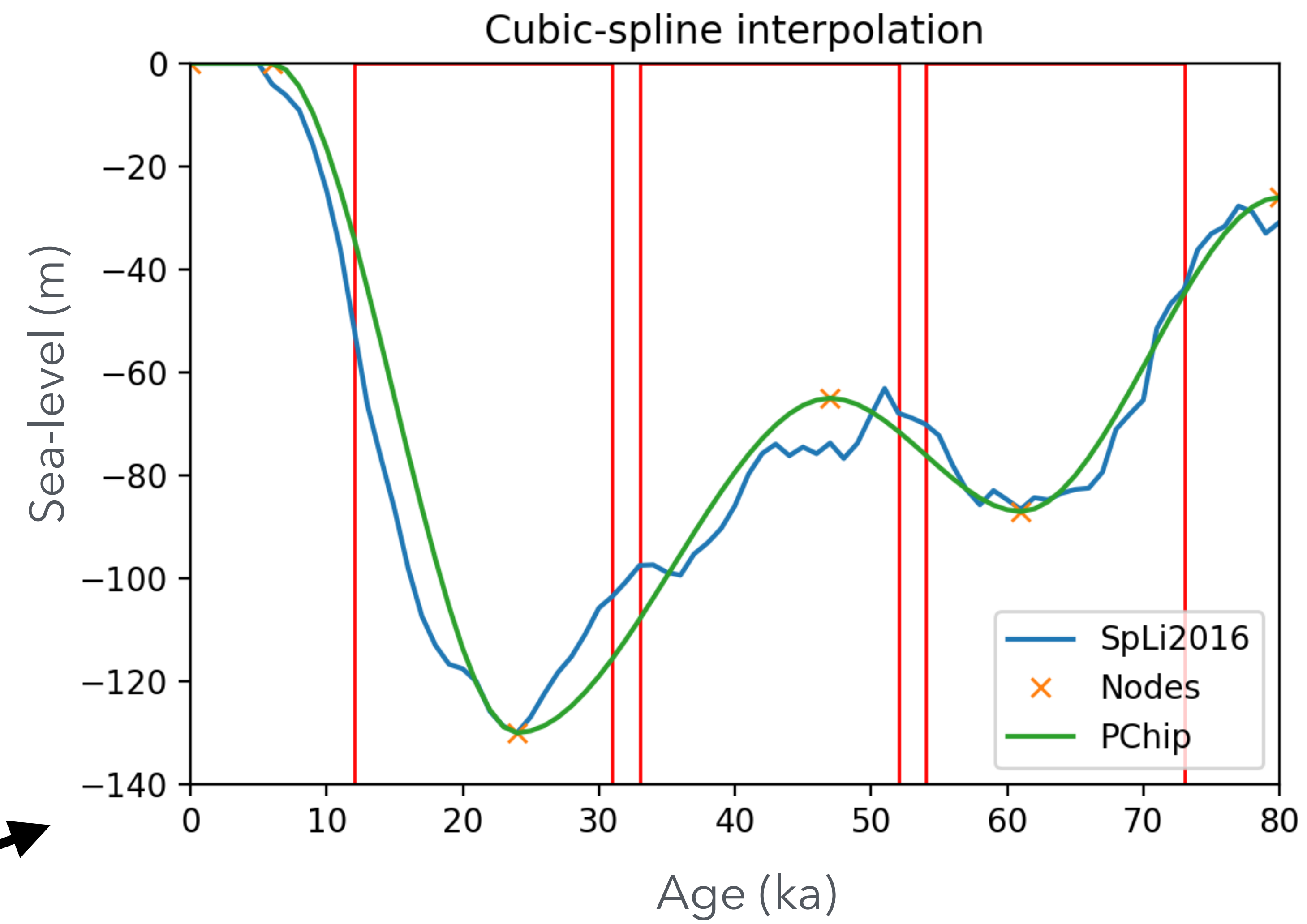
- n_samples
- prop_S (size of step within the box)
- sigma (noise standard deviation)
- corr_l (correlation length of noise)
- IP (interpolation stepwise in m)

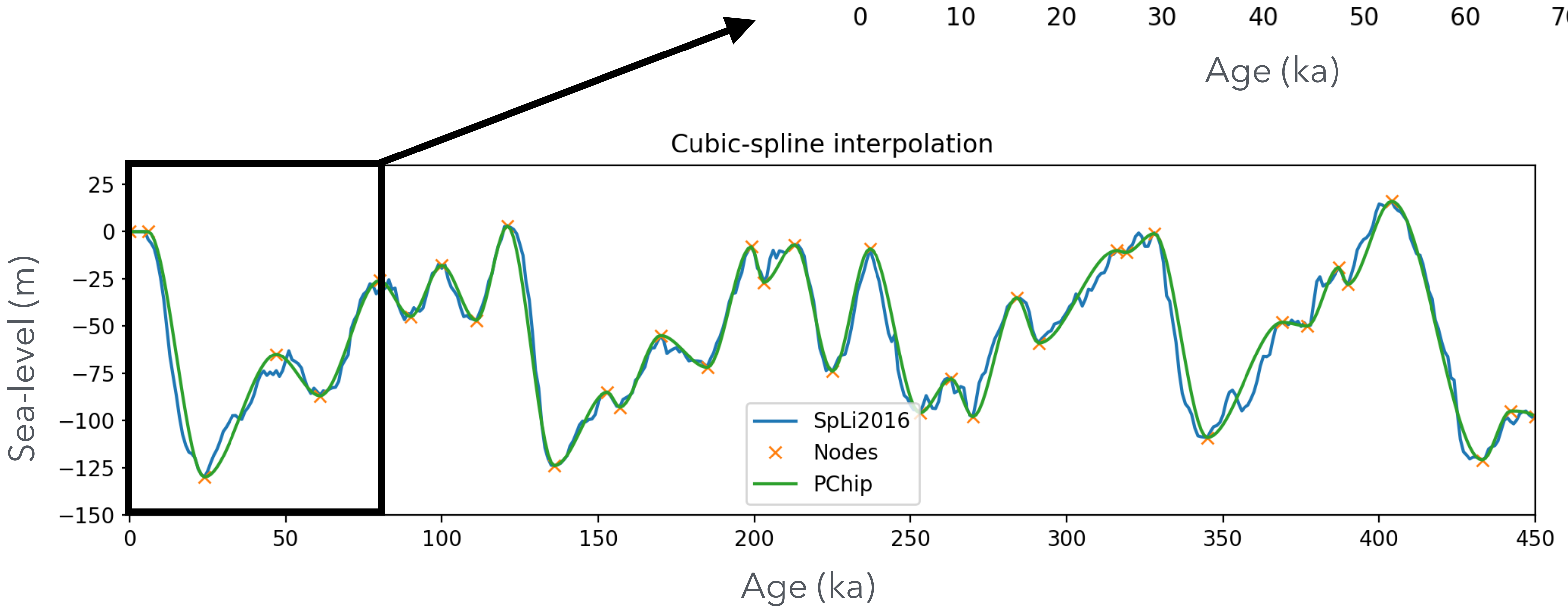


Anderson et al., 1999

SEA-LEVEL CURVES

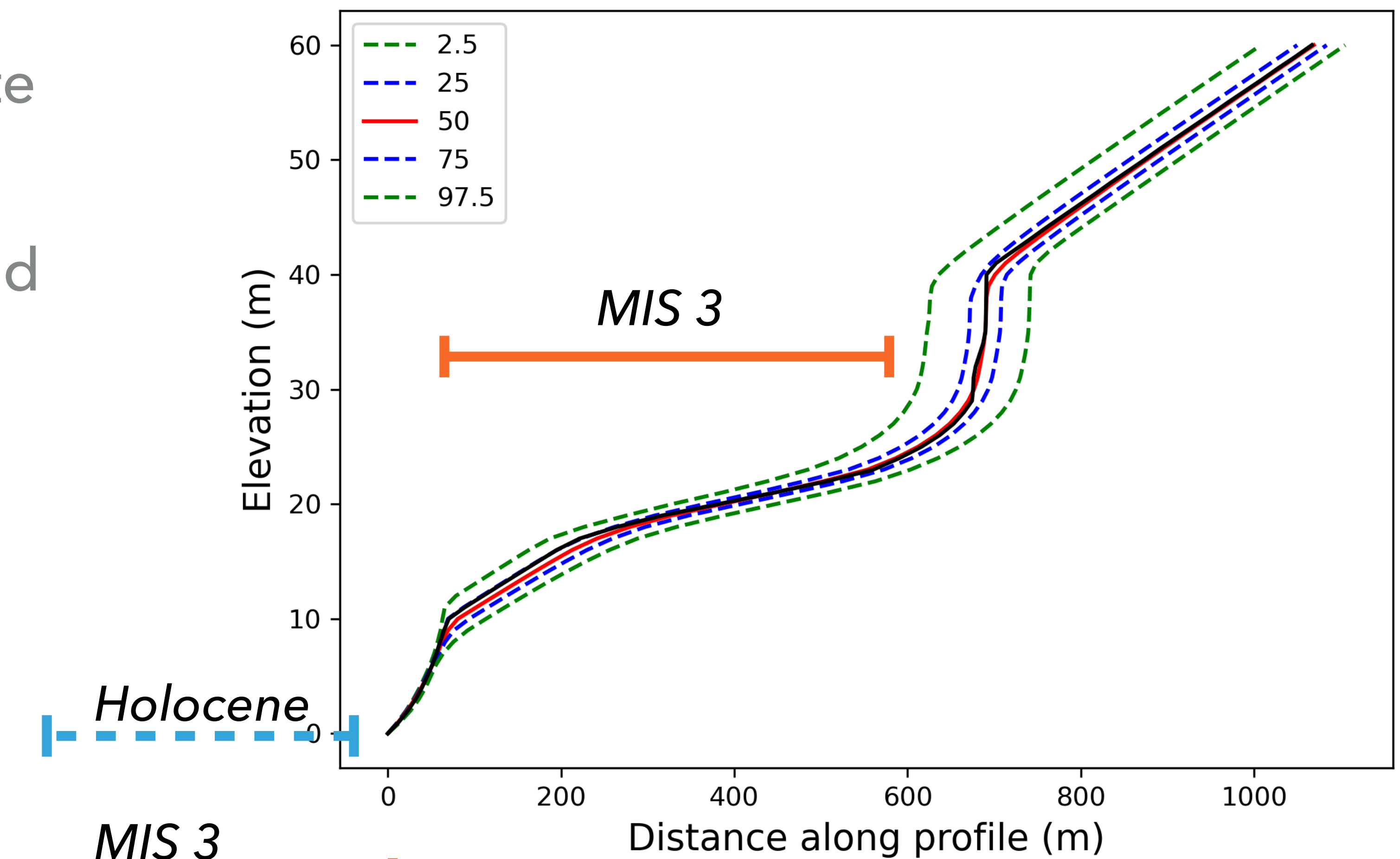
- Using nodes and cubic-spline interpolation as approximation
- Allow nodes to vary within specific boxes



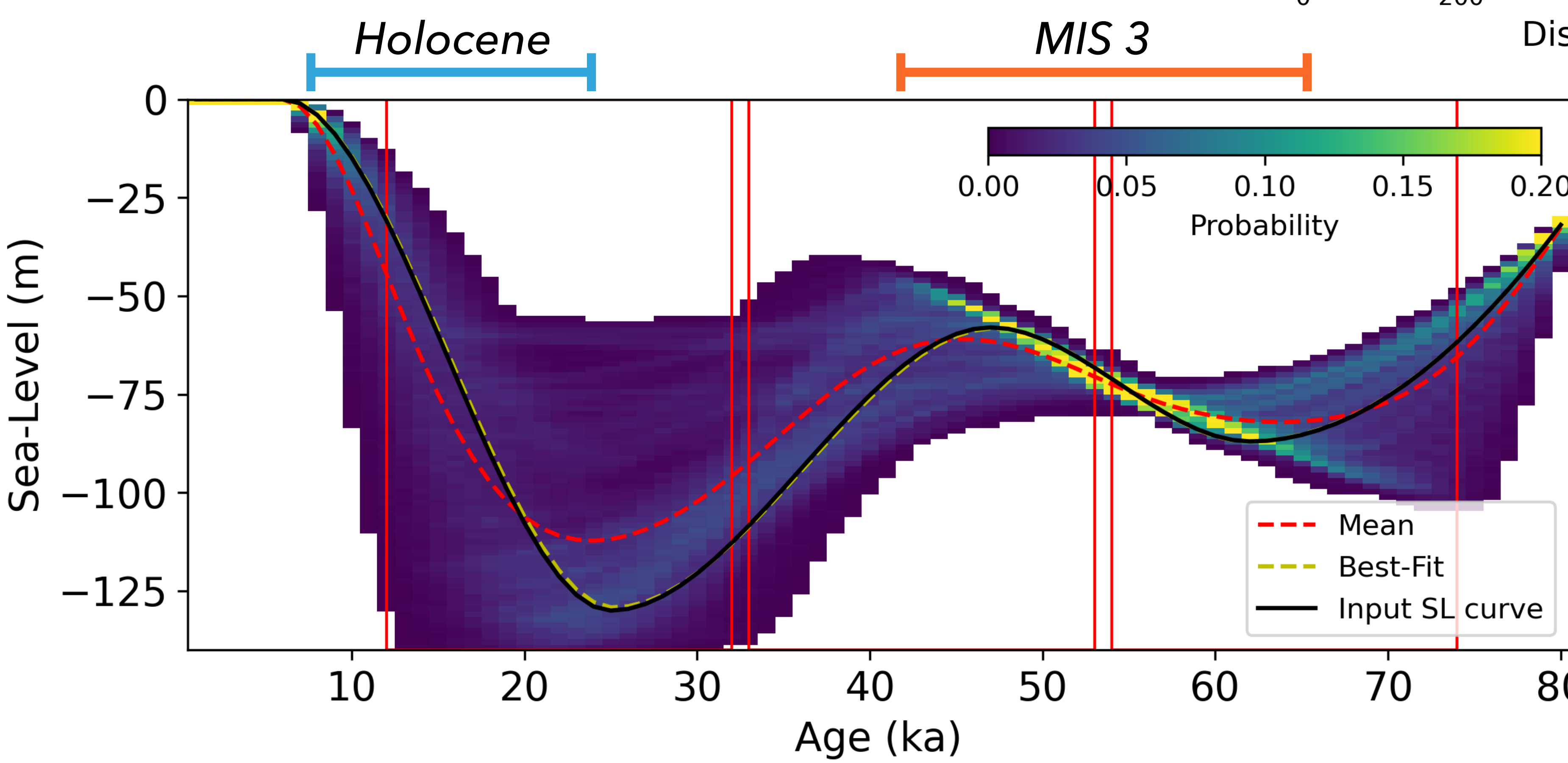


SYNTHETIC TESTS: 3 NODE INVERSION

- Use known parameters to create an "observed topography"
- Vary the nodes in the box to find back the correct values that could have created the topography



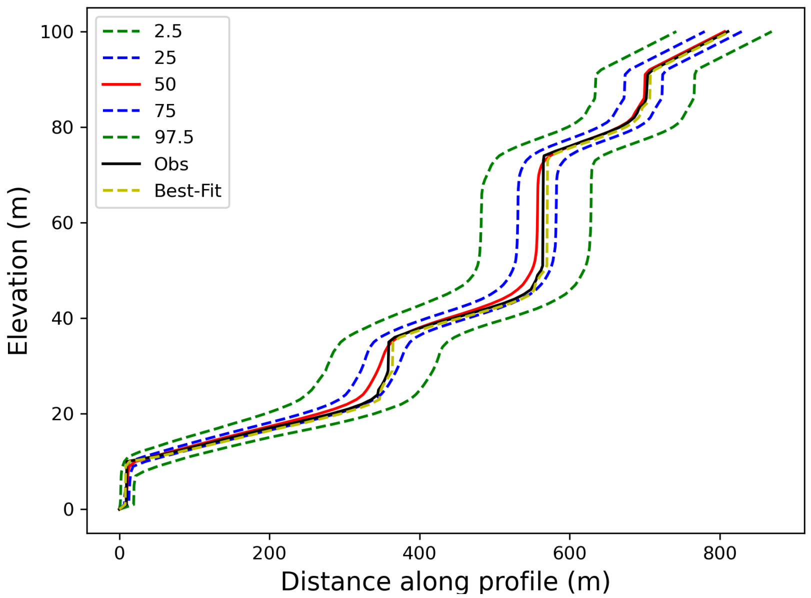
Holocene terrace mostly below sea-level: poorly constrained sea-level curve



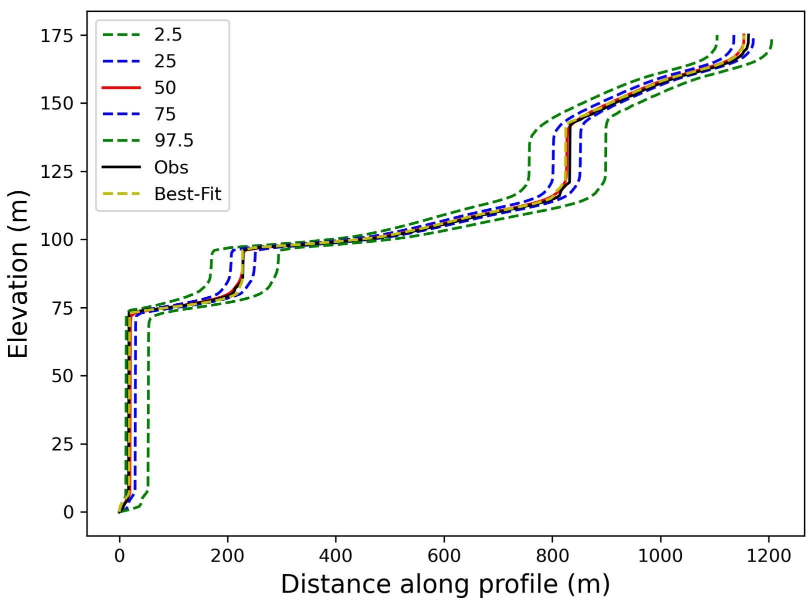
Younger (older), higher (lower) sea-level peaks can create terrace at same elevation, hence "slope" of yellow portion, proportional to UR (2 mm/yr)

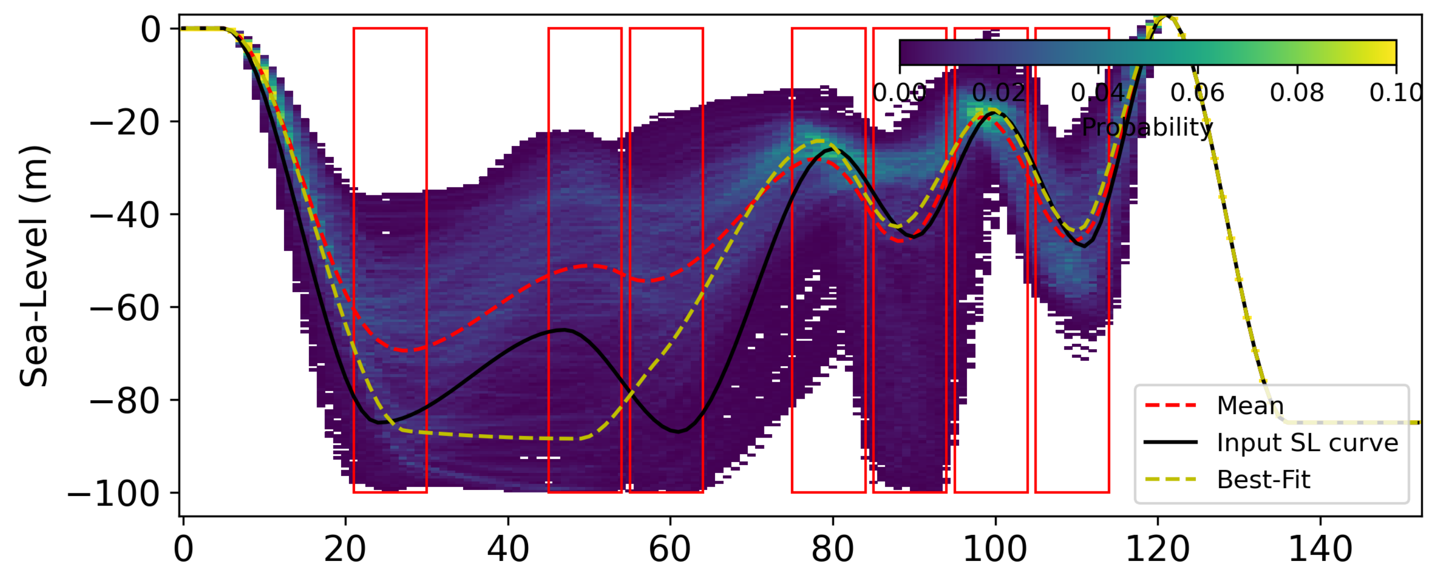
SYNTHETIC TESTS: 7 NODES, 2 PROFILES

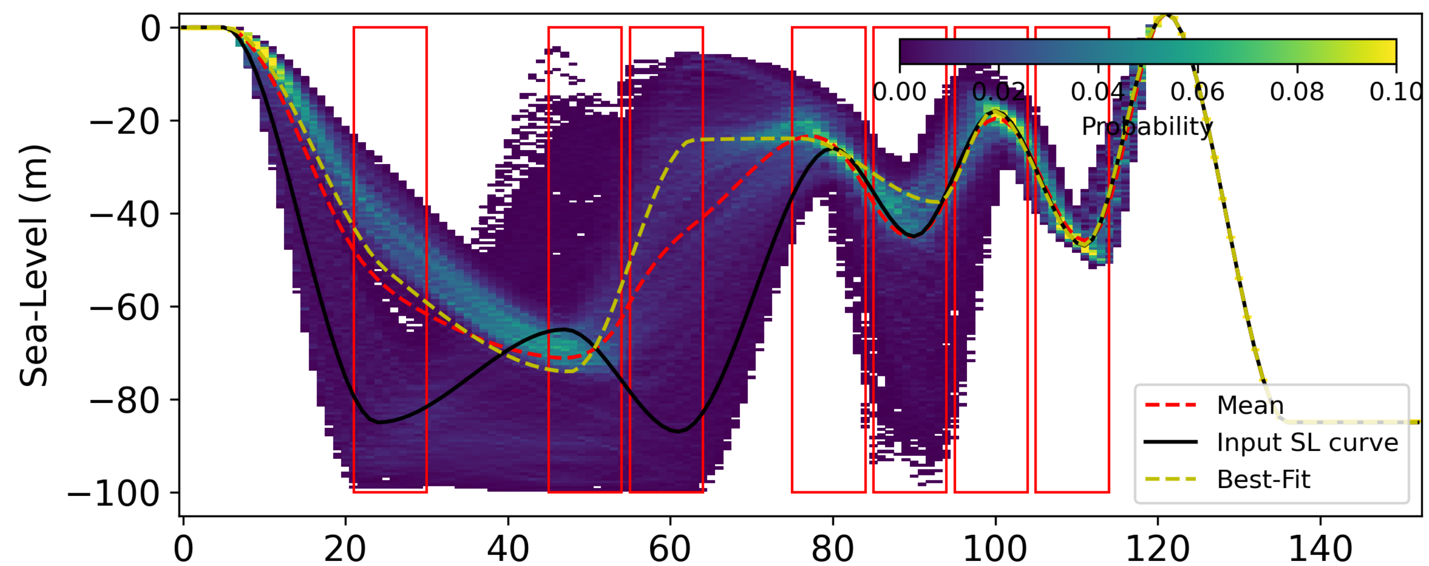
Uplift Rate 0.7 mm/yr



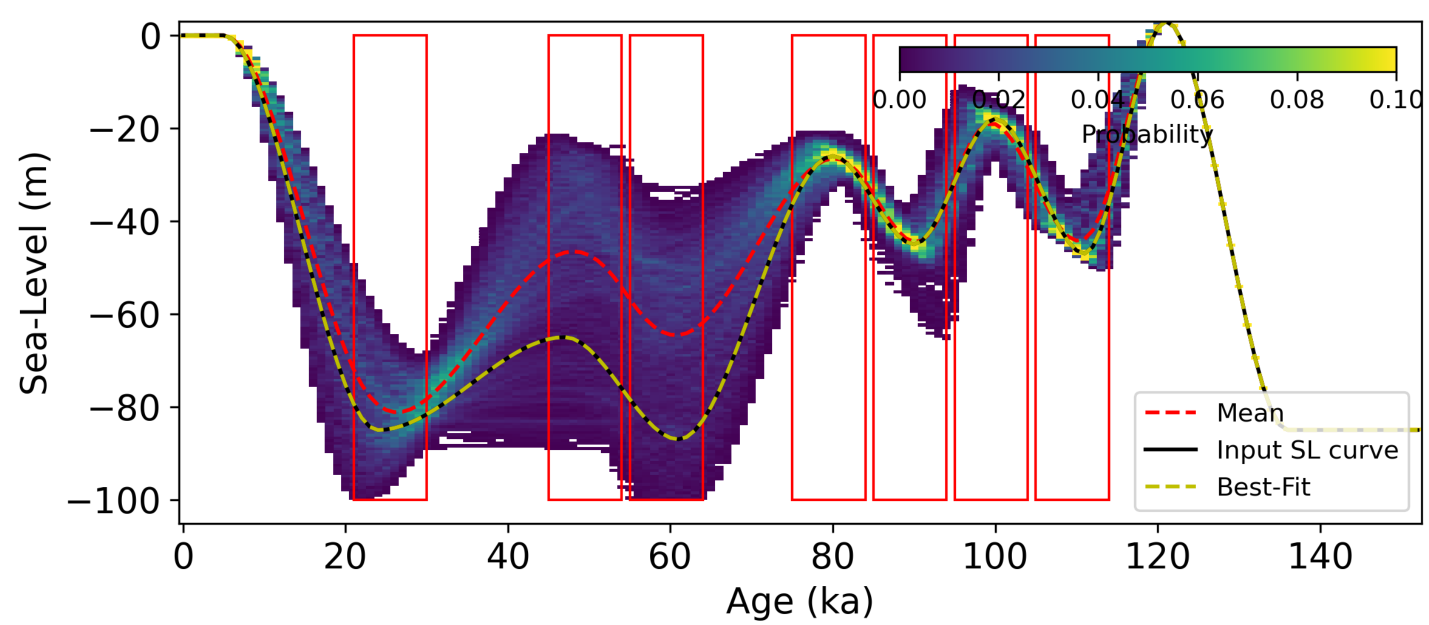
Uplift Rate 1.4 mm/yr







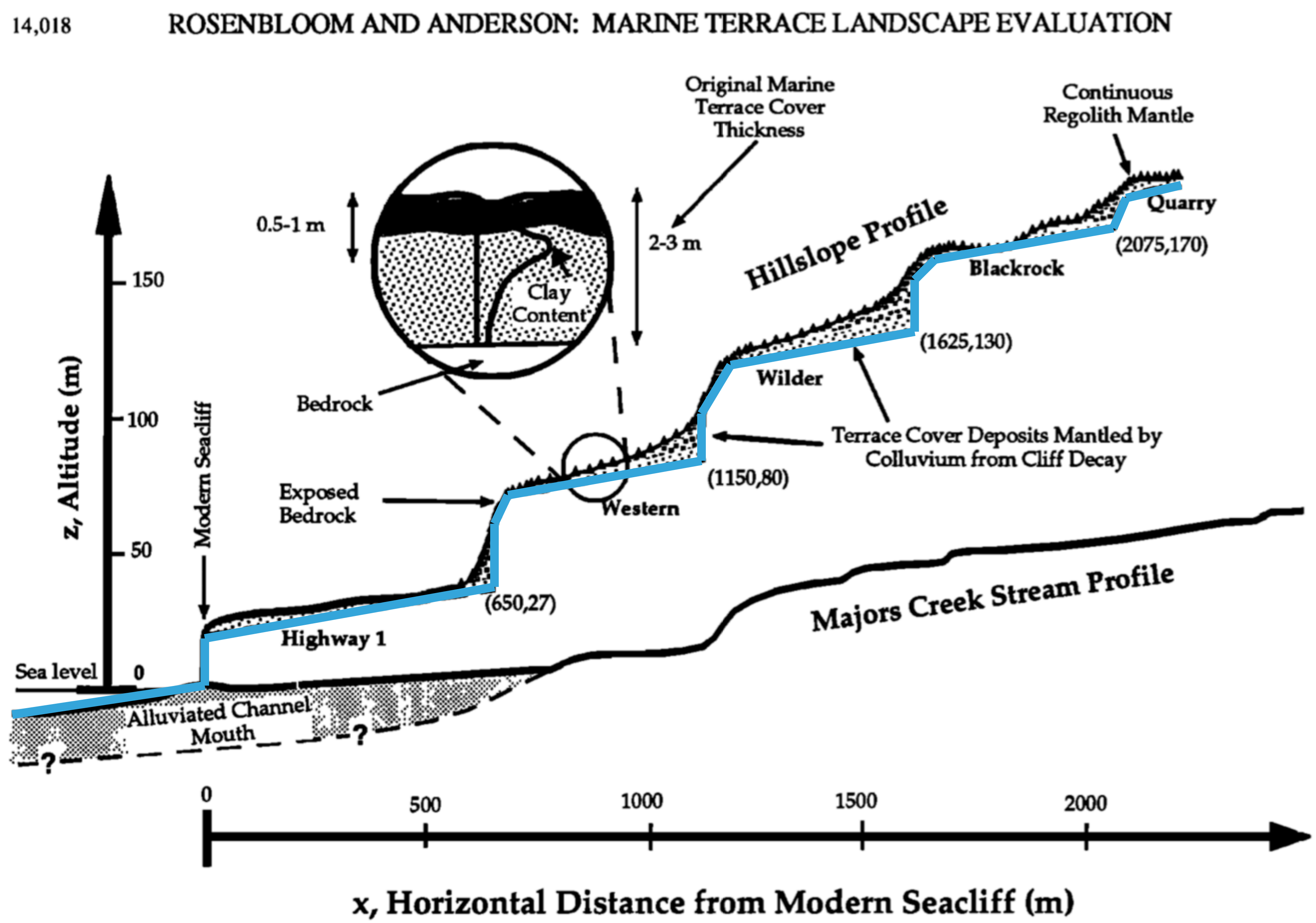
Inverting both profiles at the same time



- Gives a much better constrained inversion result

SANTA CRUZ

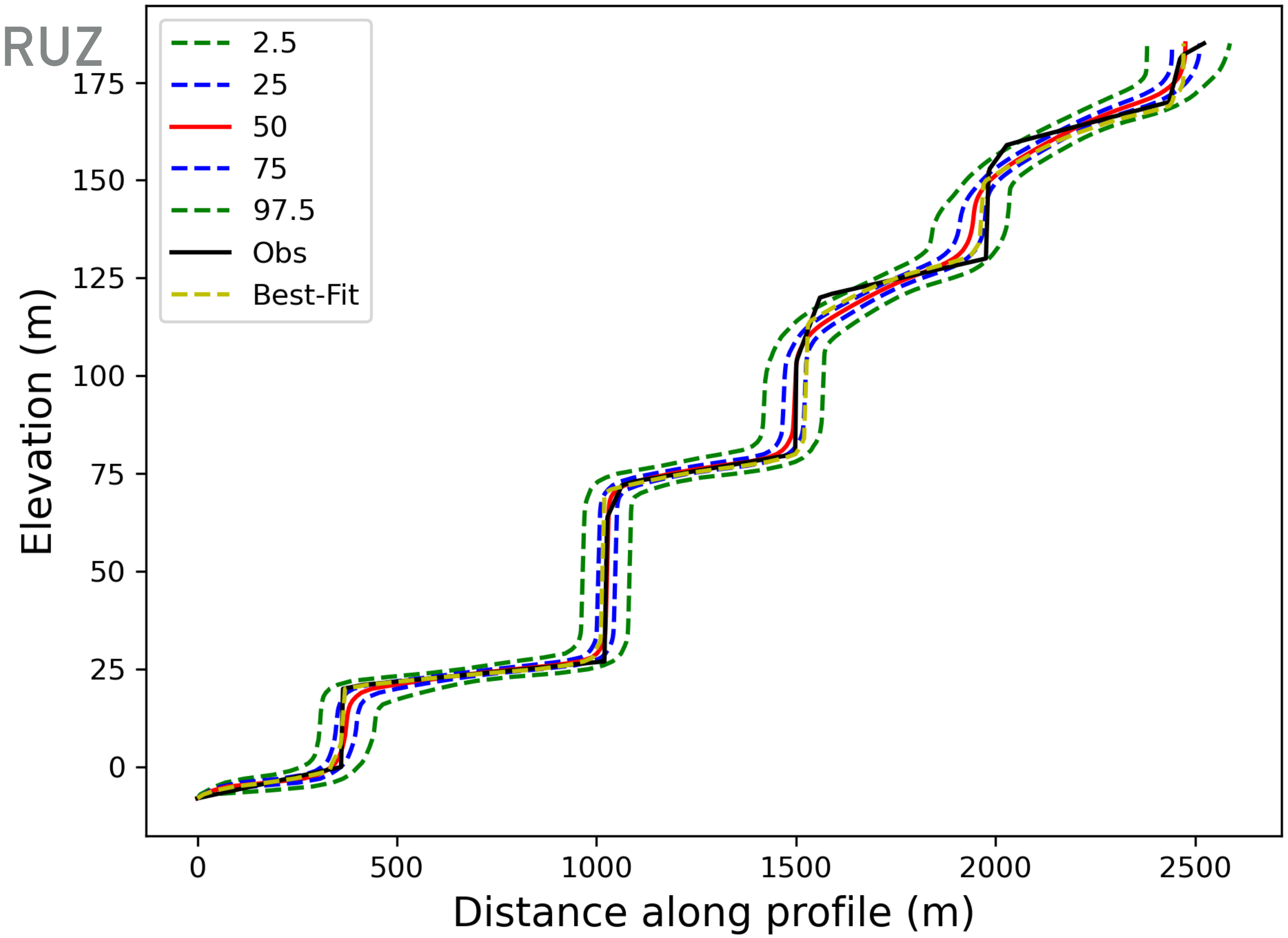
- Simple profile - 5 terraces, all dated (though under discussion)

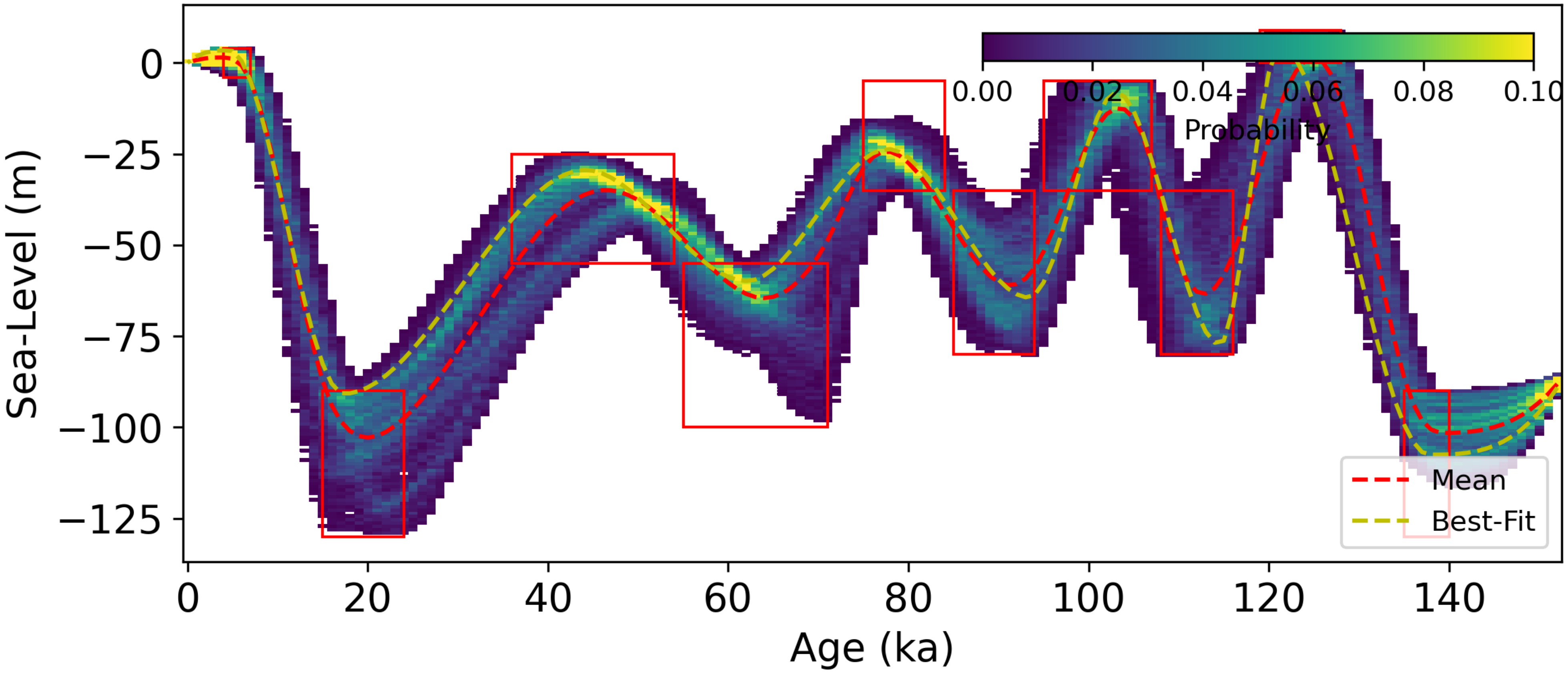


REAL TERRACE EXAMPLES: SANTA CRUZ

SANTA CRUZ

- Good fit with realistic results
- Highstands better constrained than lowstands
- Non-unique solutions: younger, higher sea-level peaks similar effect as older, lower sea-level peaks





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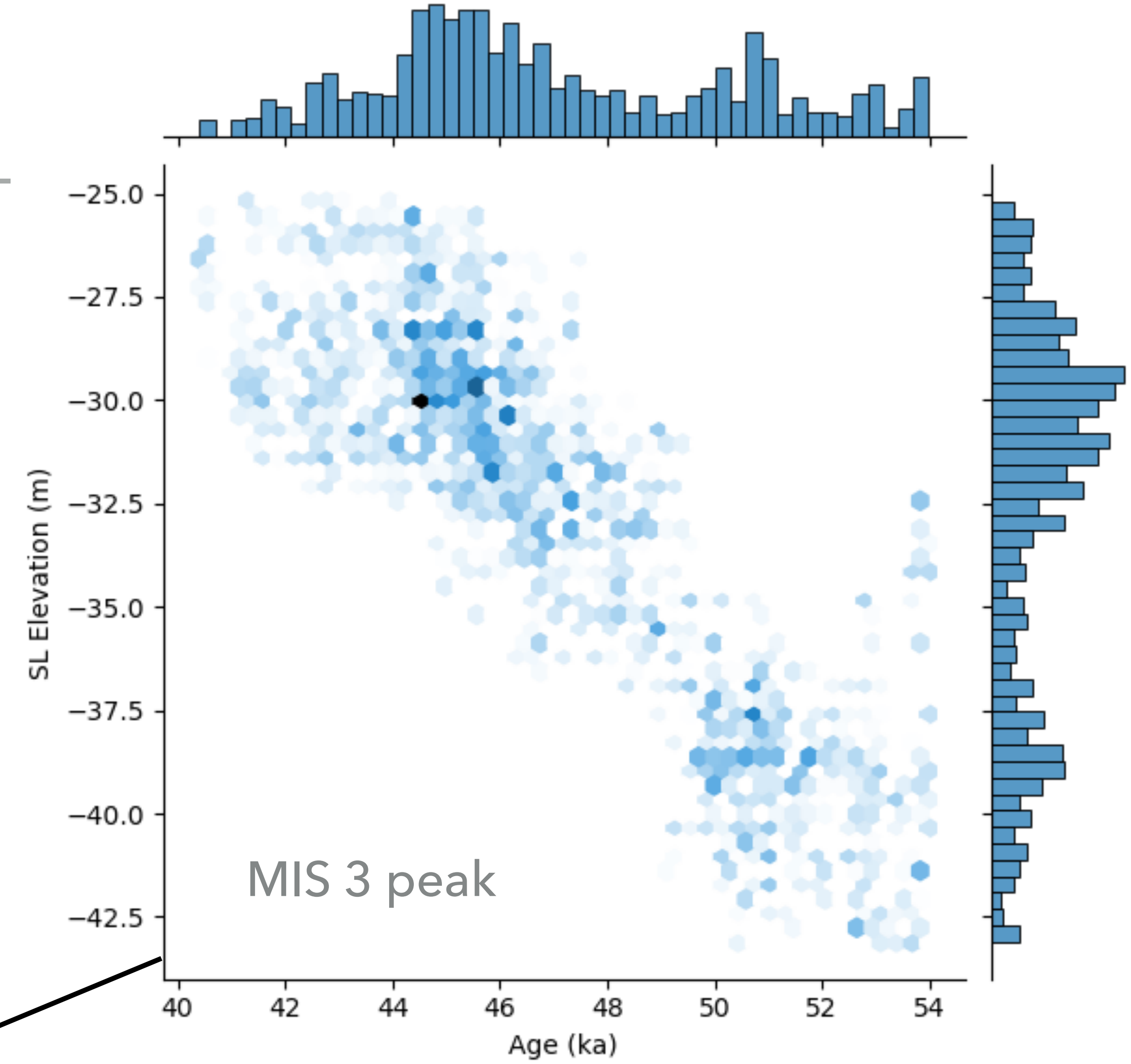
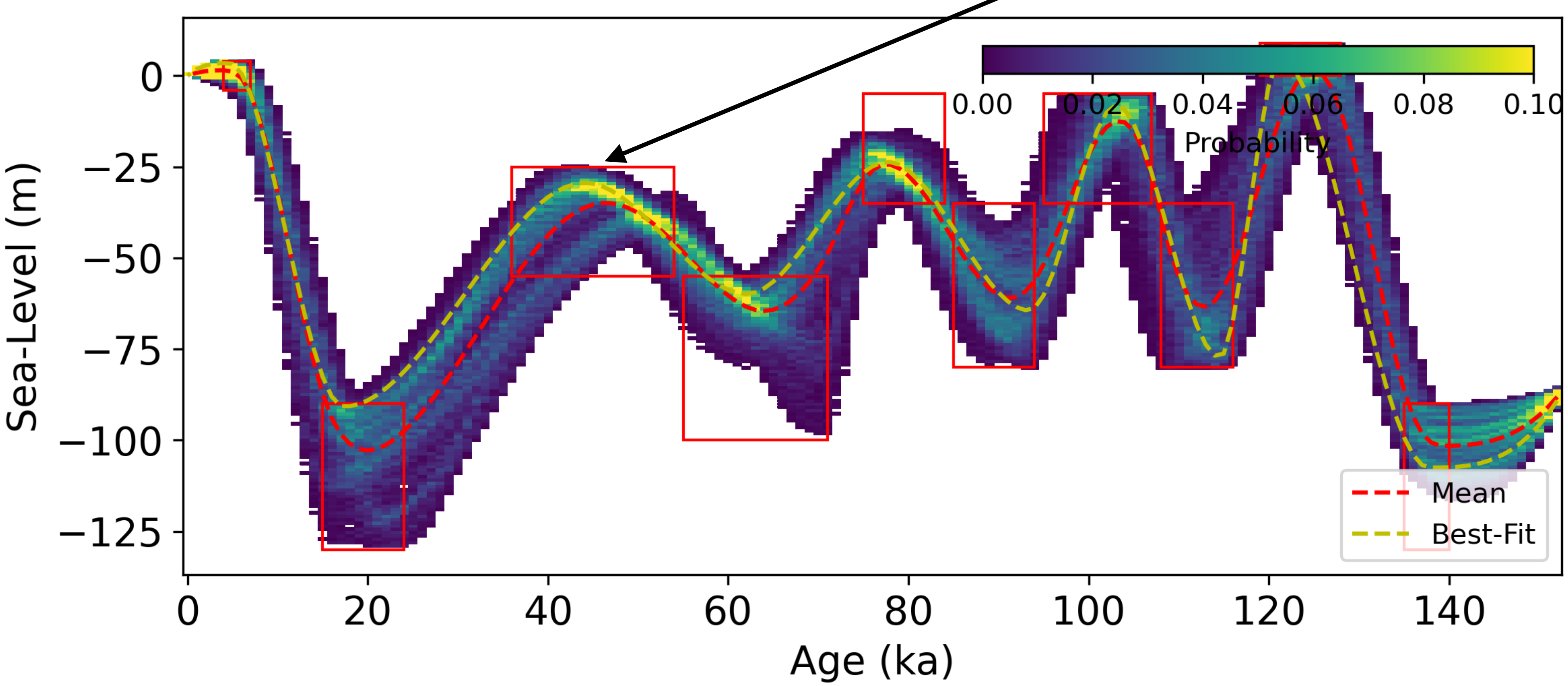
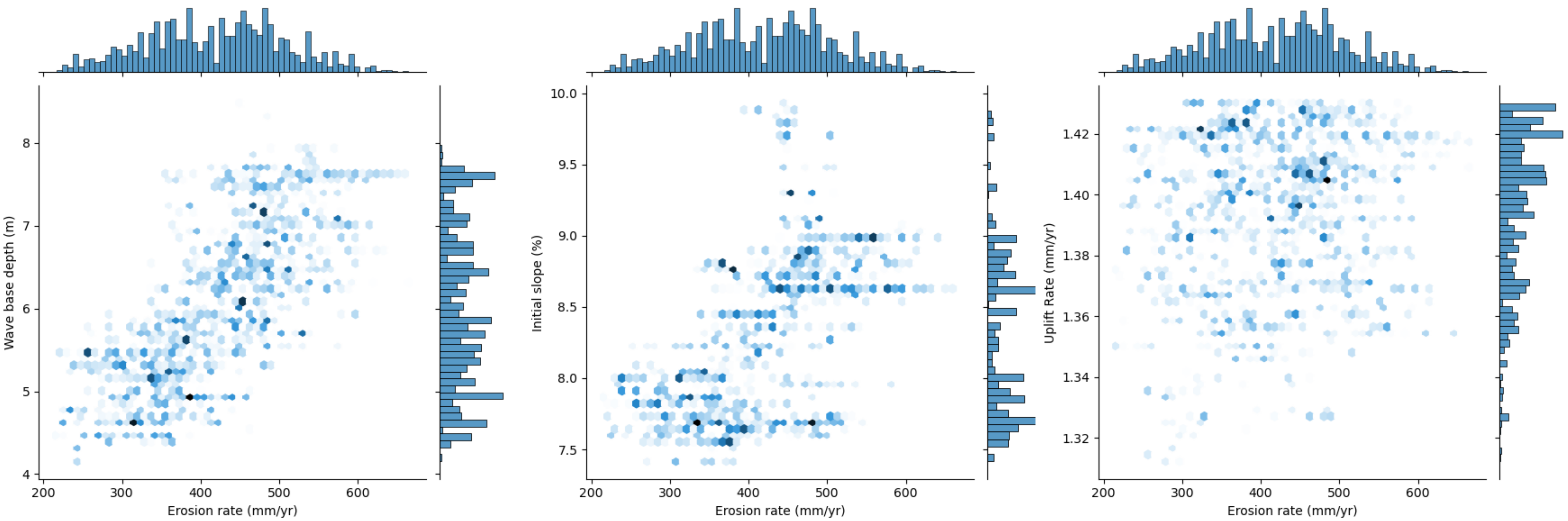




OTHER PARAMETERS

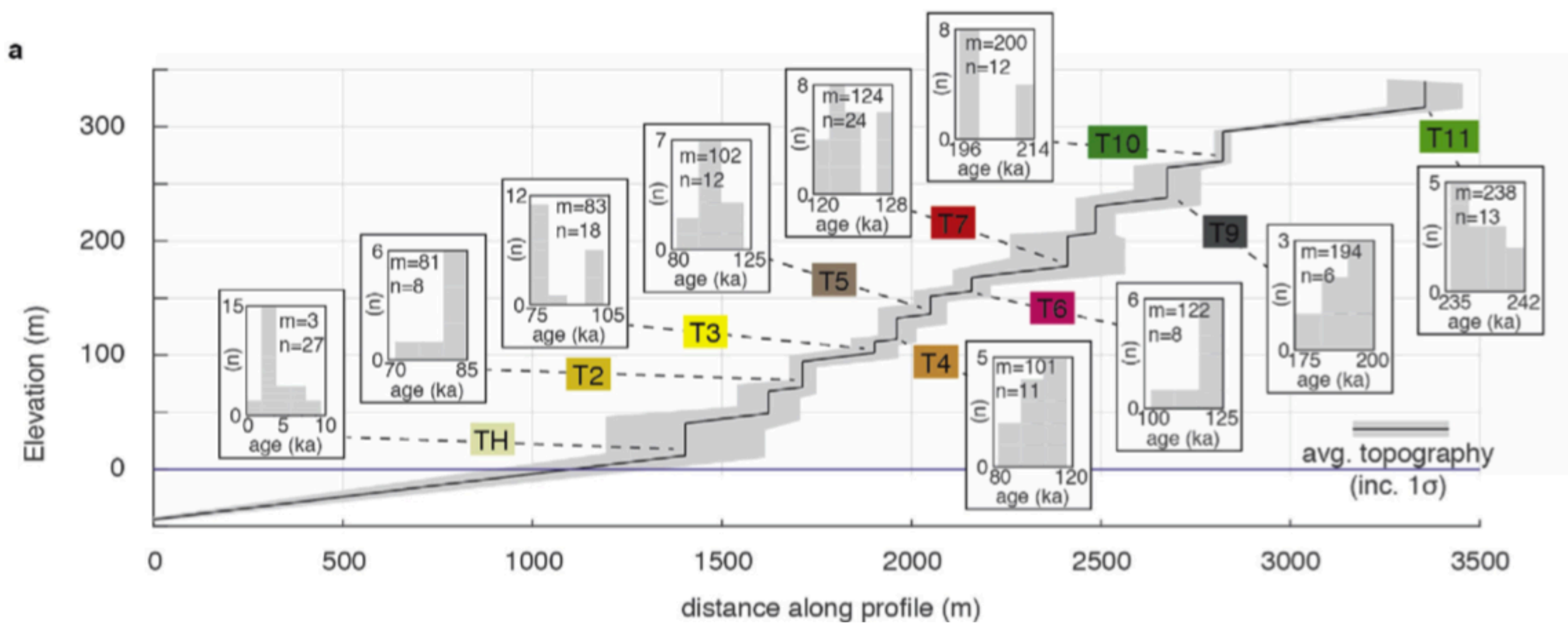
- Apart from sea-level, also constraining other parameters



CORINTH

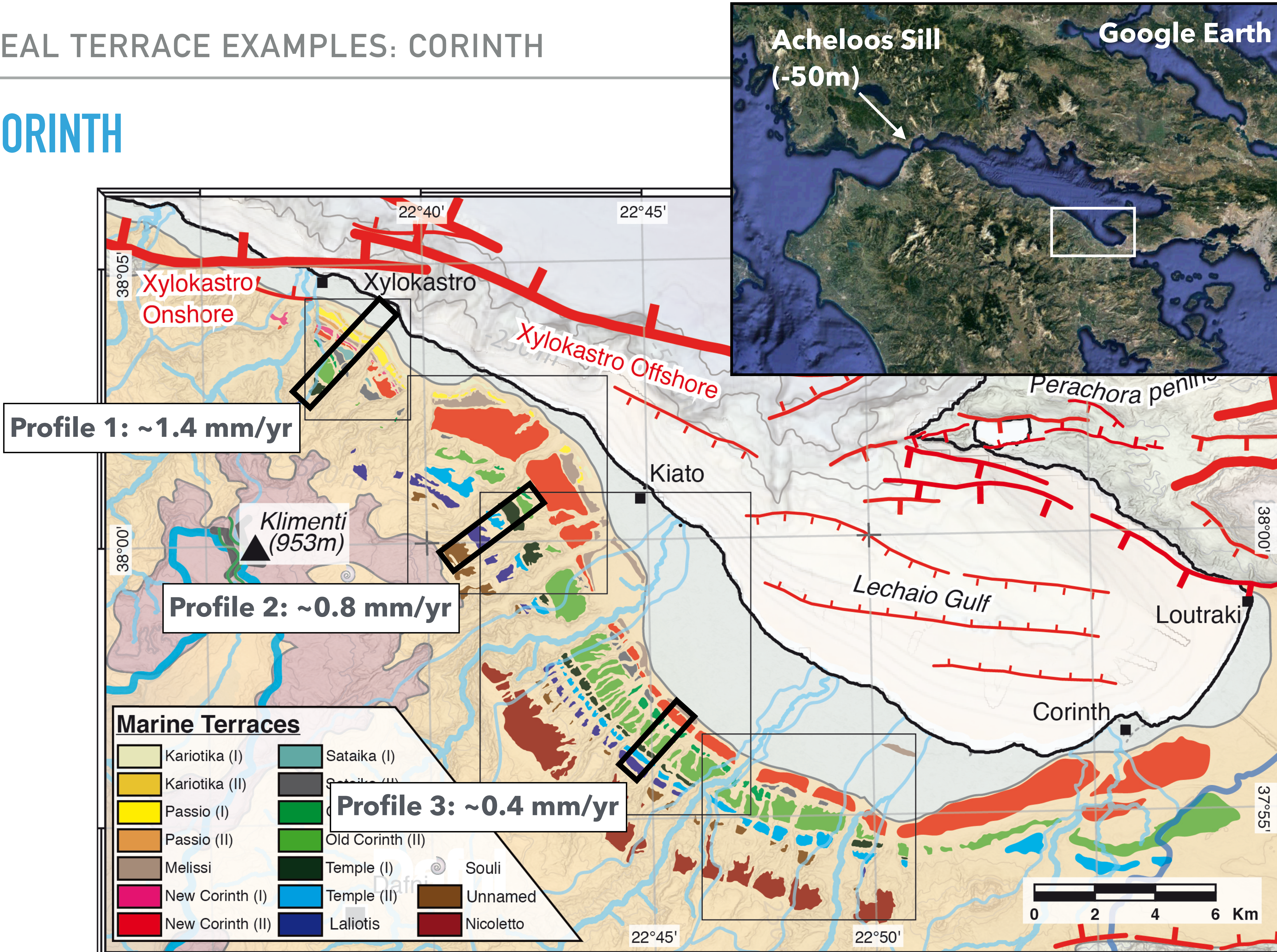
- More terraces (more complicated), poorly dated
- Possible to invert multiple profiles, down to ~400 ka

G. de Gelder et al. / Quaternary Science Reviews 229 (2020) 106132



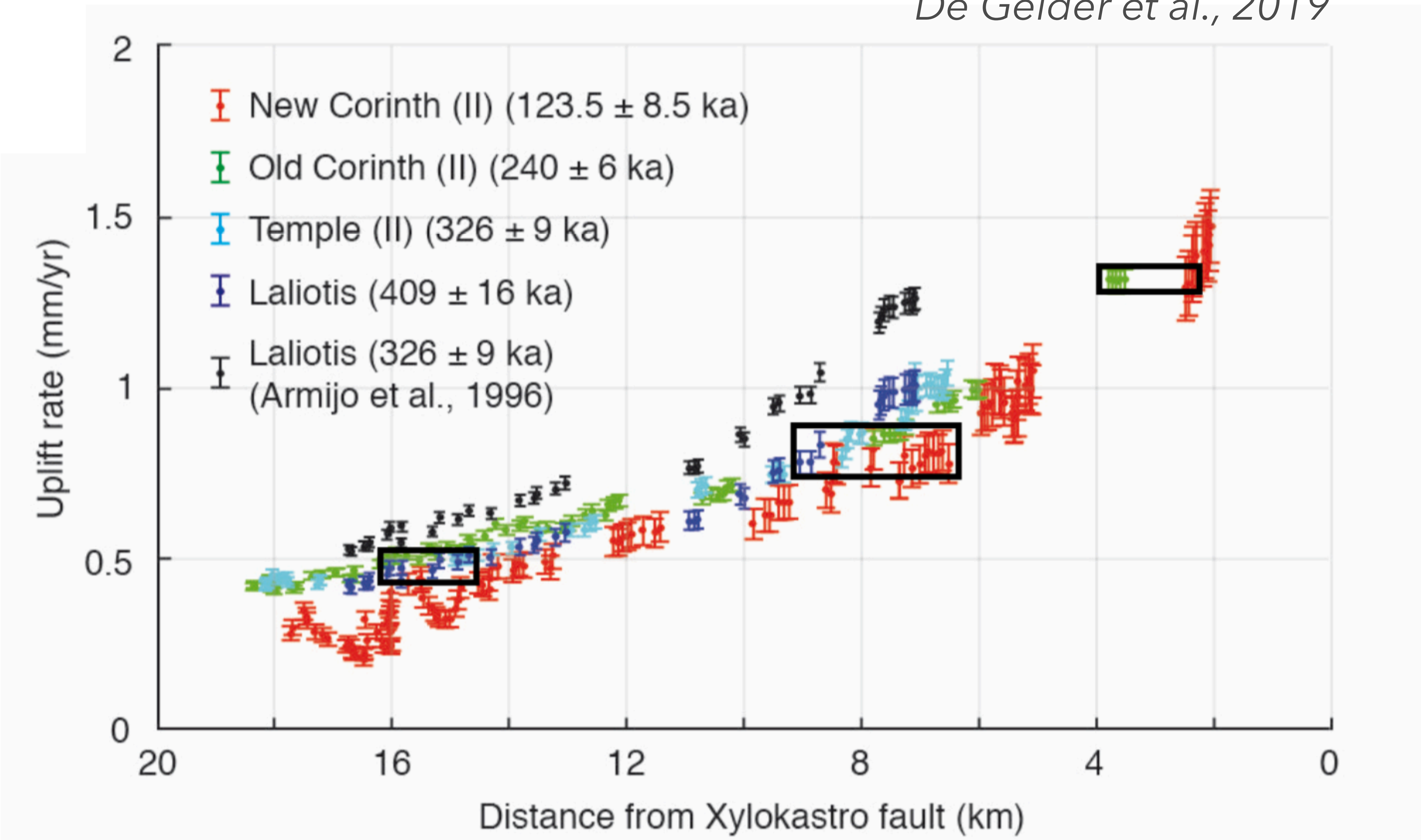
REAL TERRACE EXAMPLES: CORINTH

CORINTH



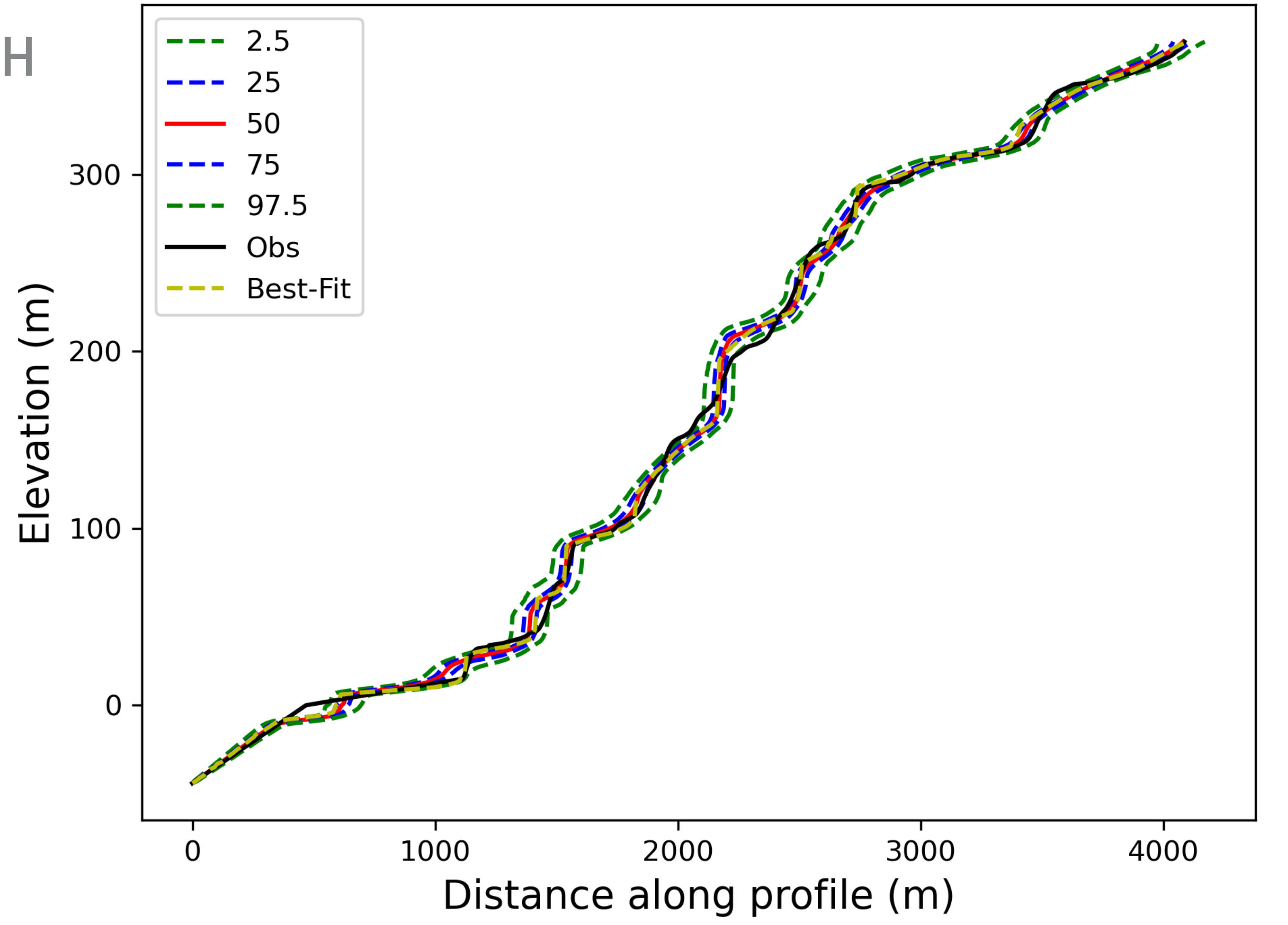
CORINTH

De Gelder et al., 2019

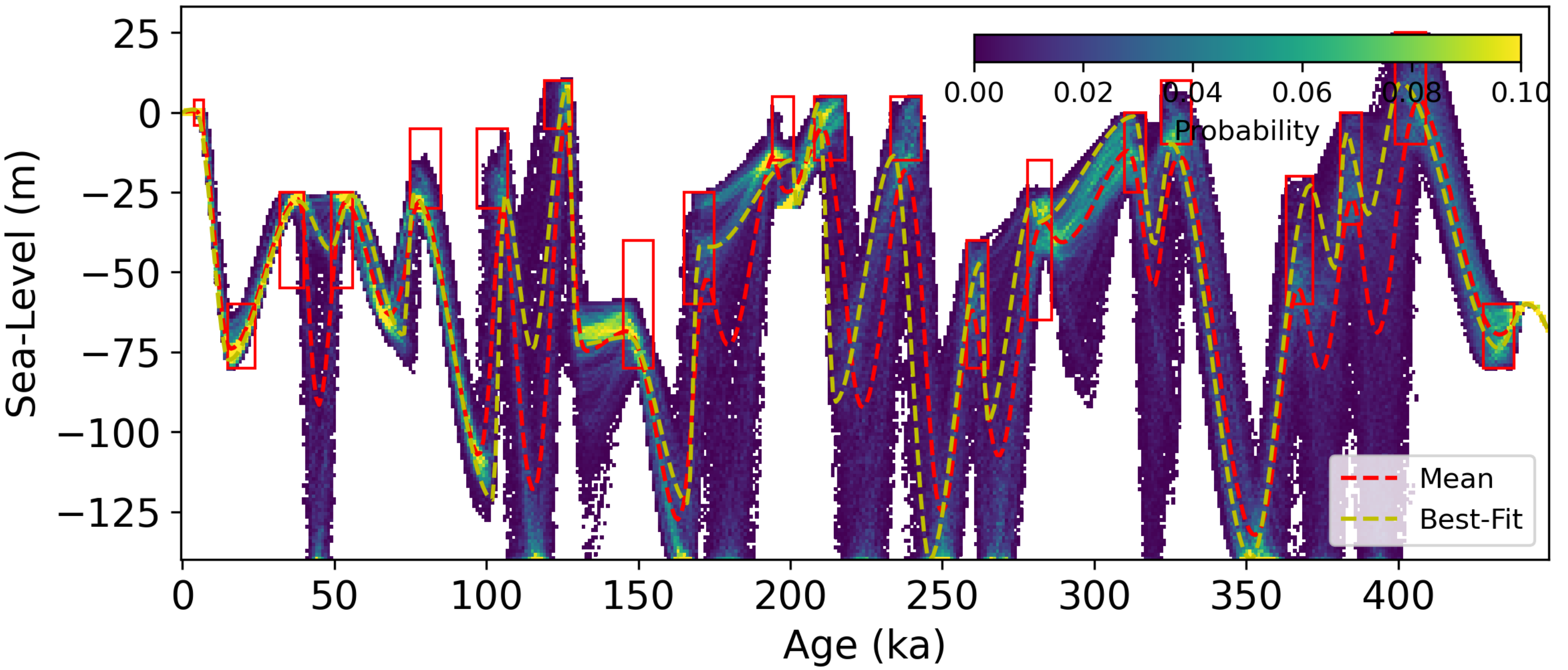


- Constant uplift rates for the three profile

CORINTH – PROFILE 1

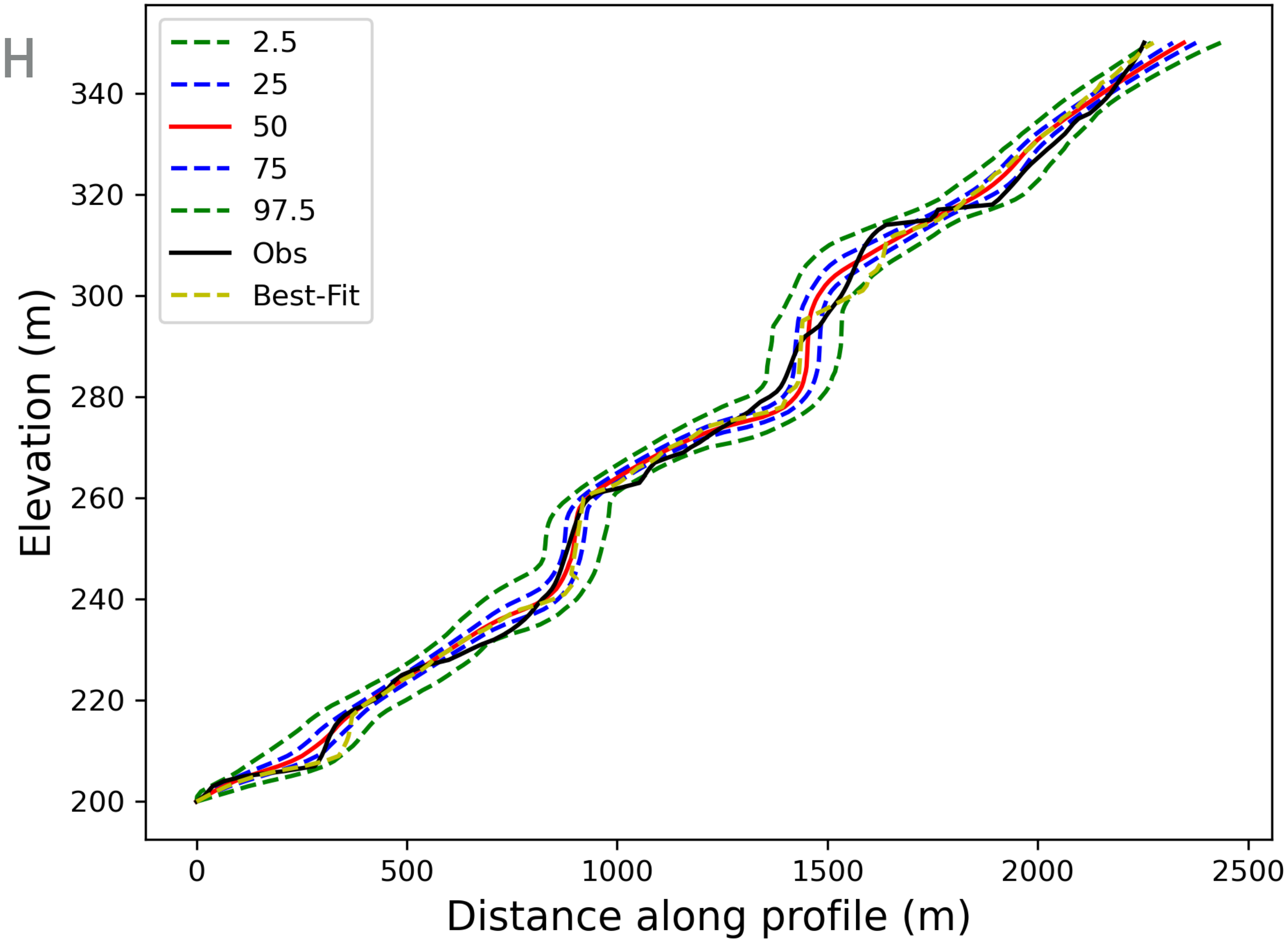


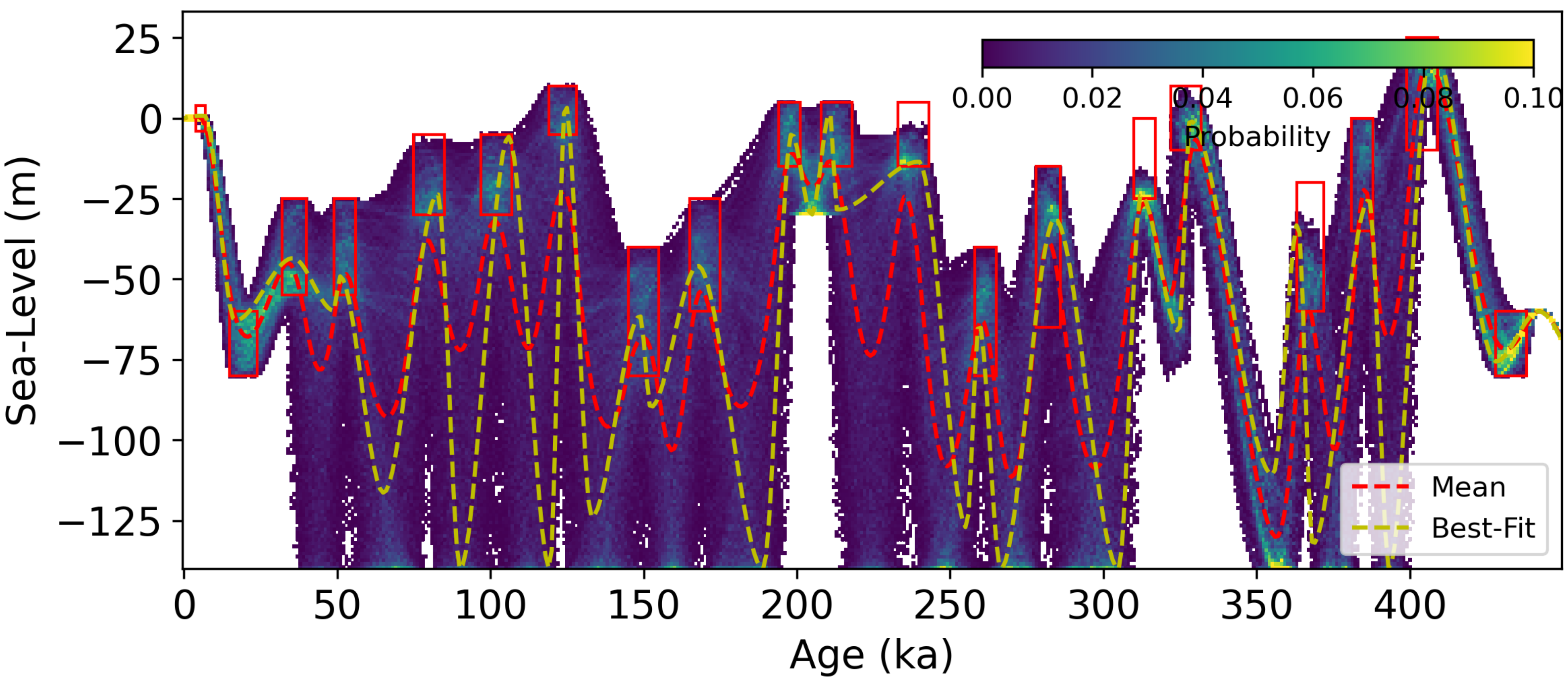
- Only fixed the highstands, low stands percentage between peaks, max. rate of sl-change
- Narrower constraints for younger terraces



CORINTH – PROFILE 2

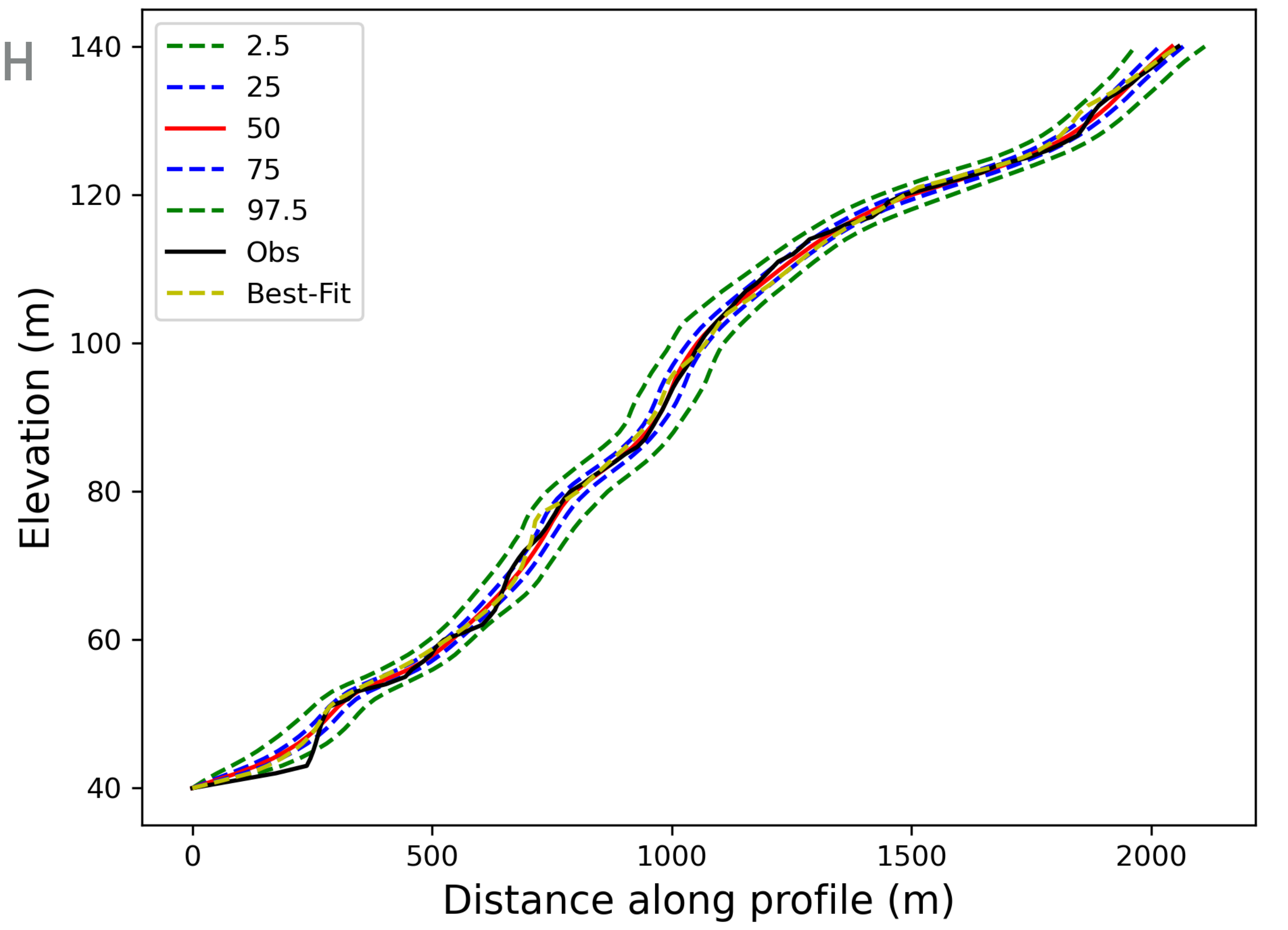
- Relatively broad range of possible sl-histories
- Better constrained for older ages

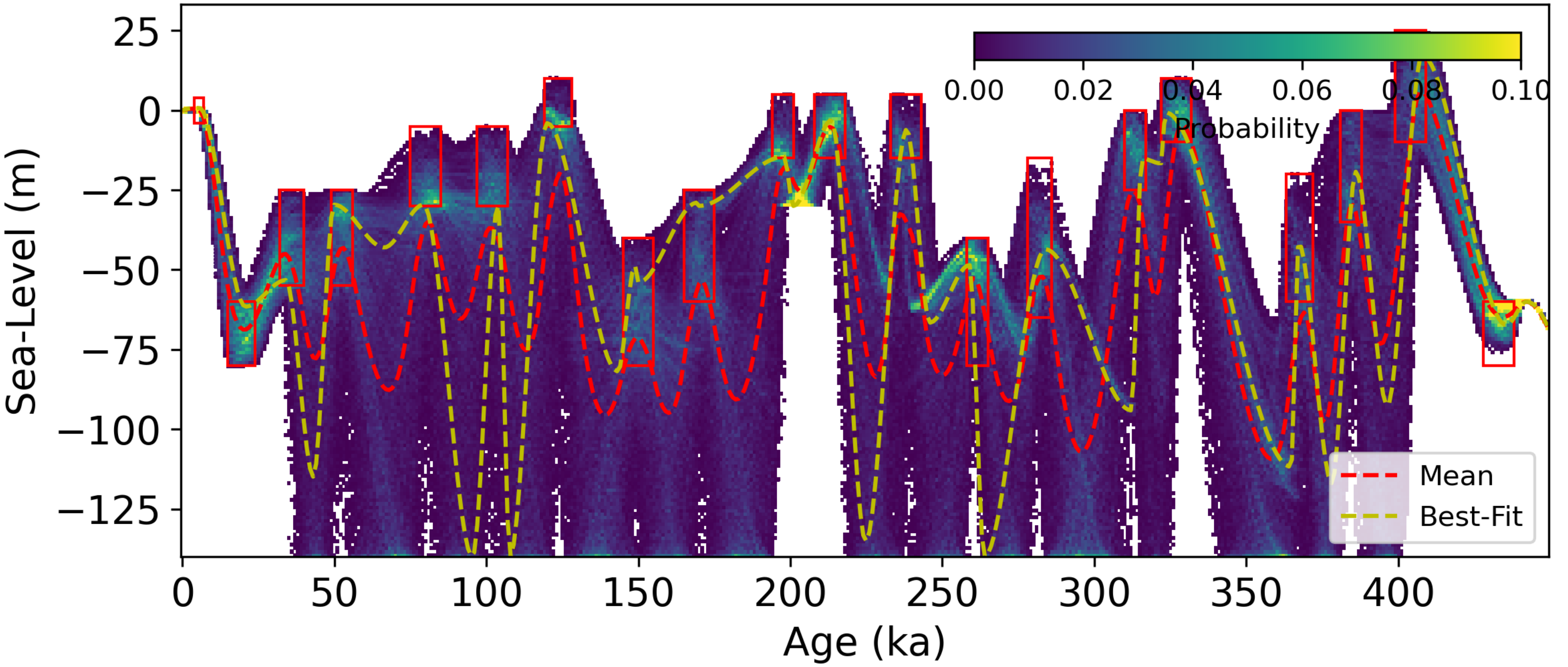




CORINTH – PROFILE 3

- Relatively broad range of possible sl-histories

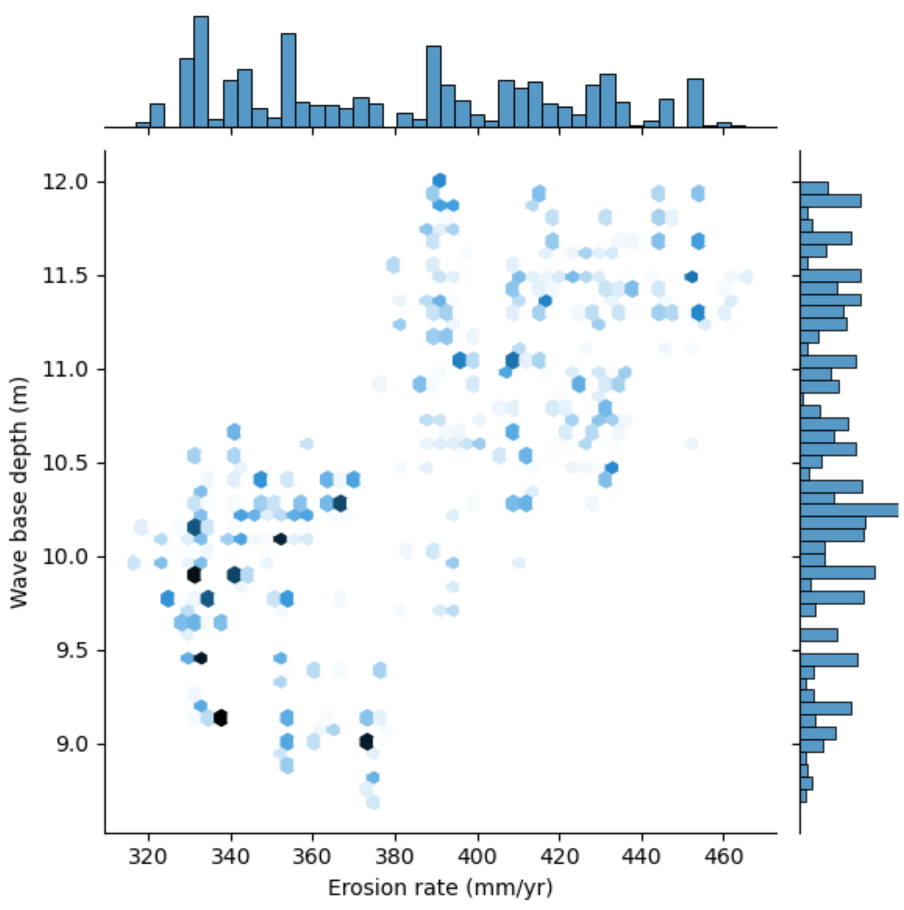




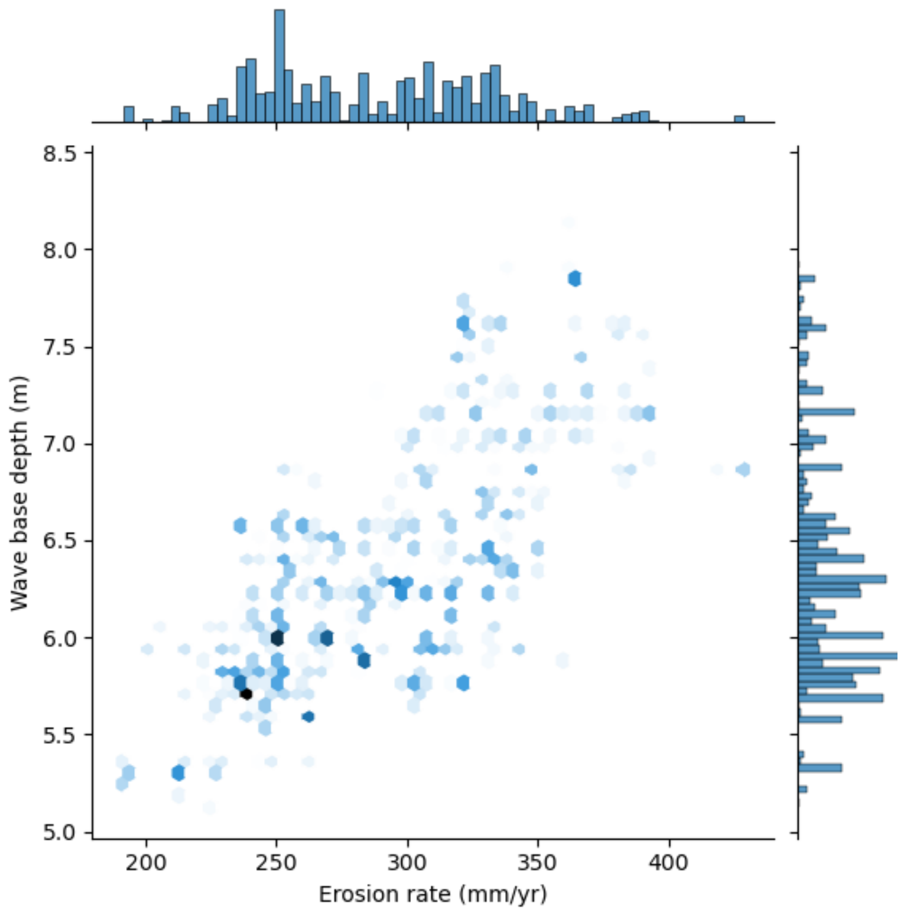
CORINTH – WAVE BASE AND EROSION RATE?

- Trade-off between wave base and erosion rate
- Slightly deeper wave base in Profile 1
- Slightly lower erosion rate in Profile 3

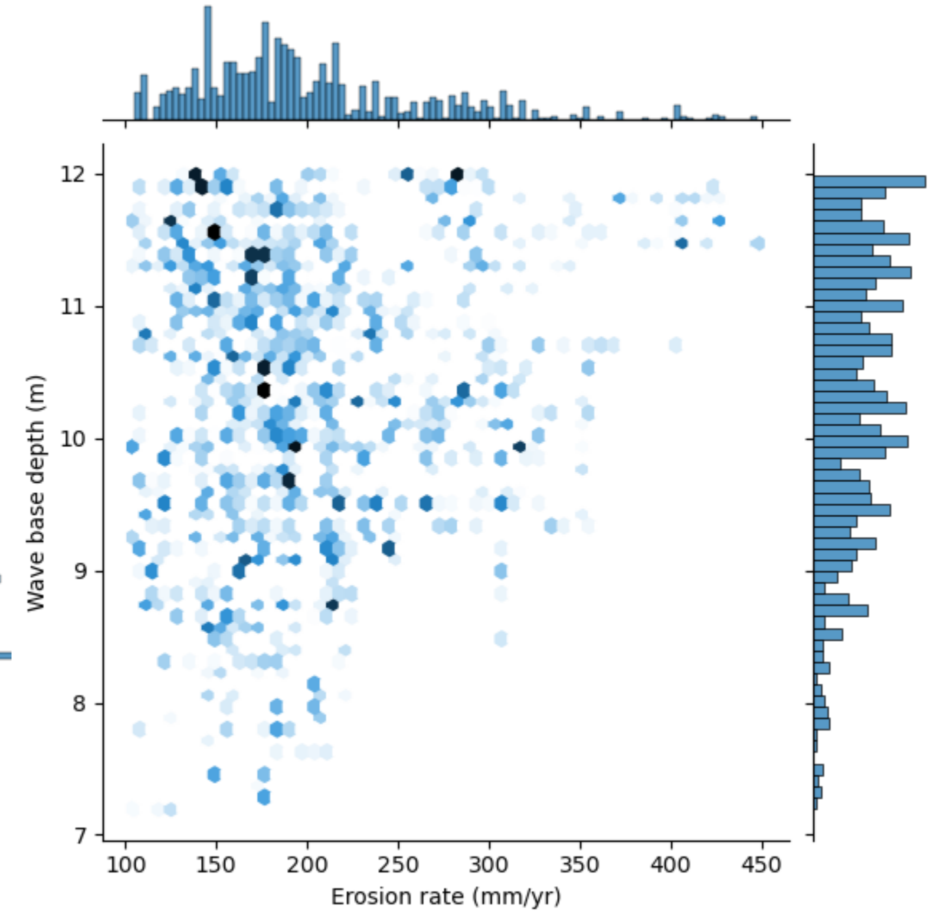
Profile 1



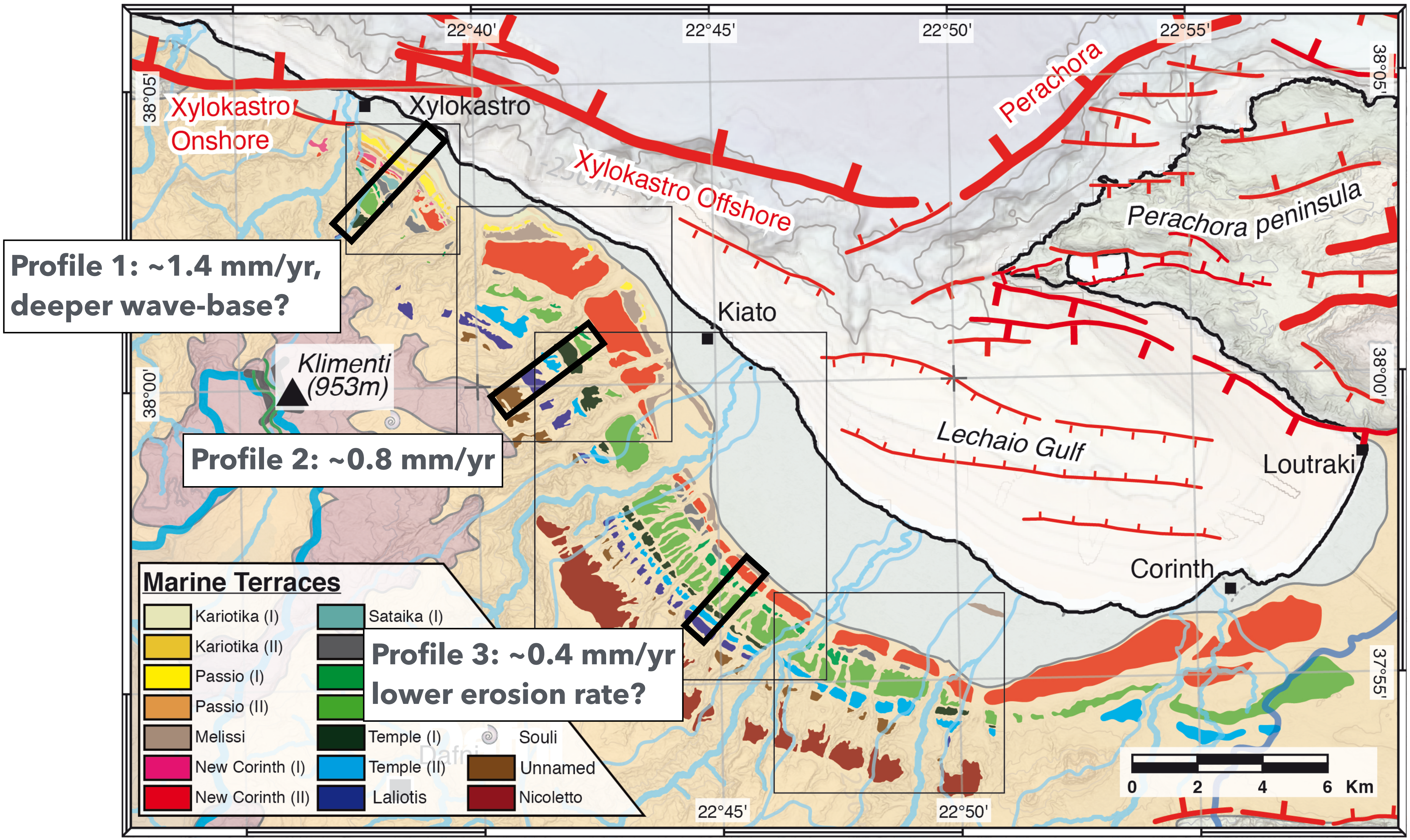
Profile 2



Profile 3



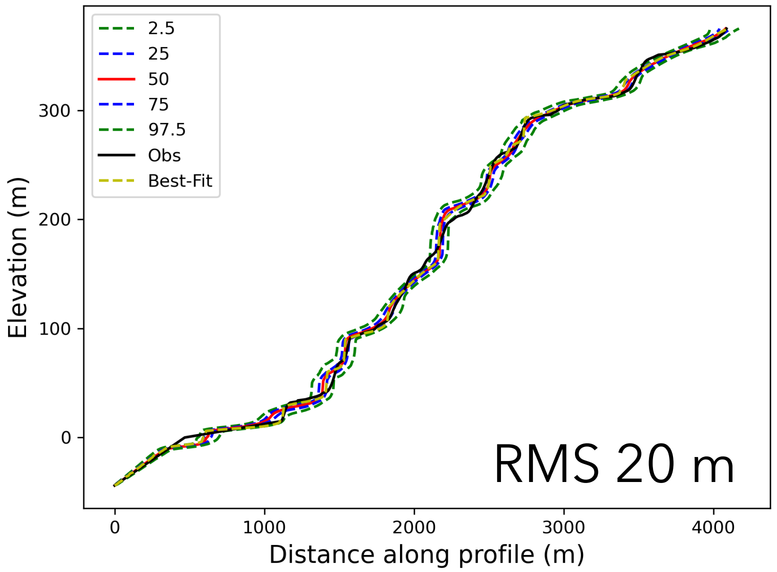
CORINTH – WAVE BASE AND EROSION RATE?

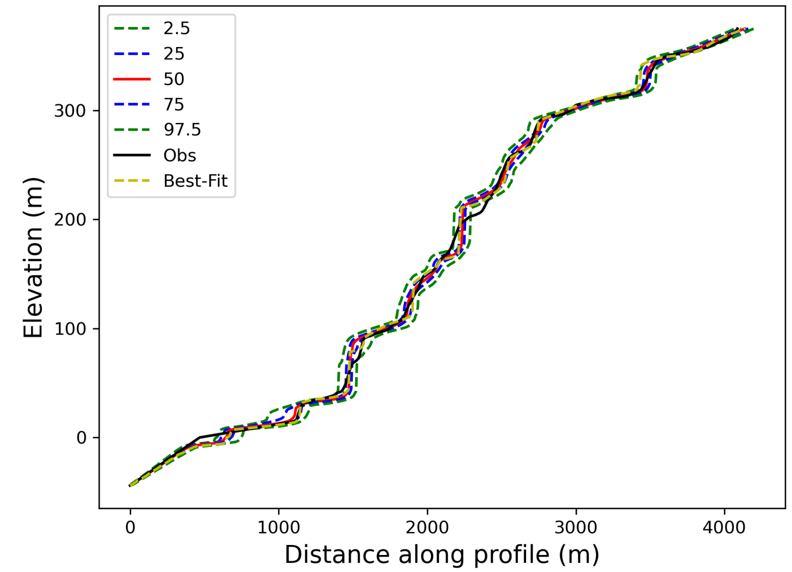


REAL TERRACE EXAMPLES: CORINTH

Profile 1

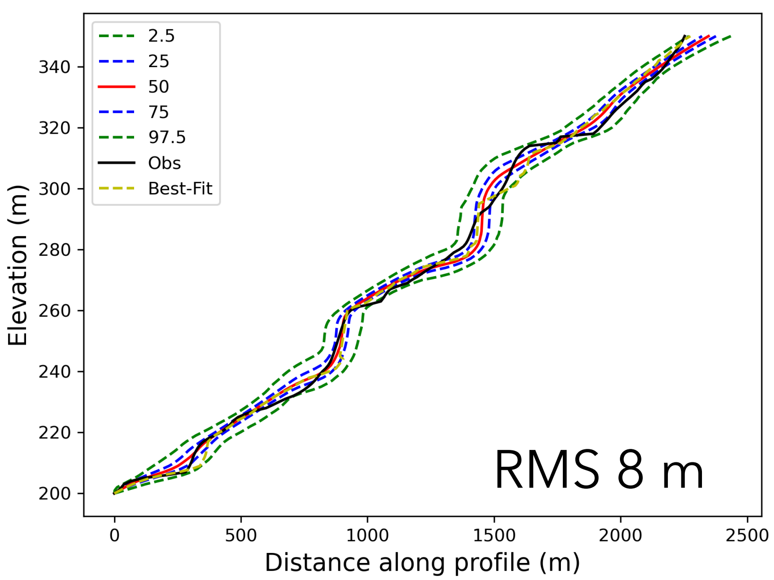
Uplift Rate ~1.4 mm/yr





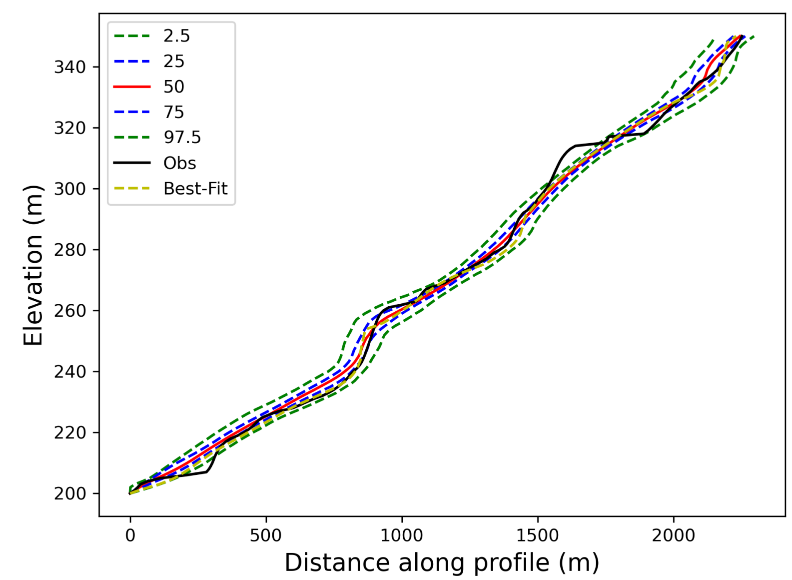
Profile 2

Uplift Rate ~0.8 mm/yr



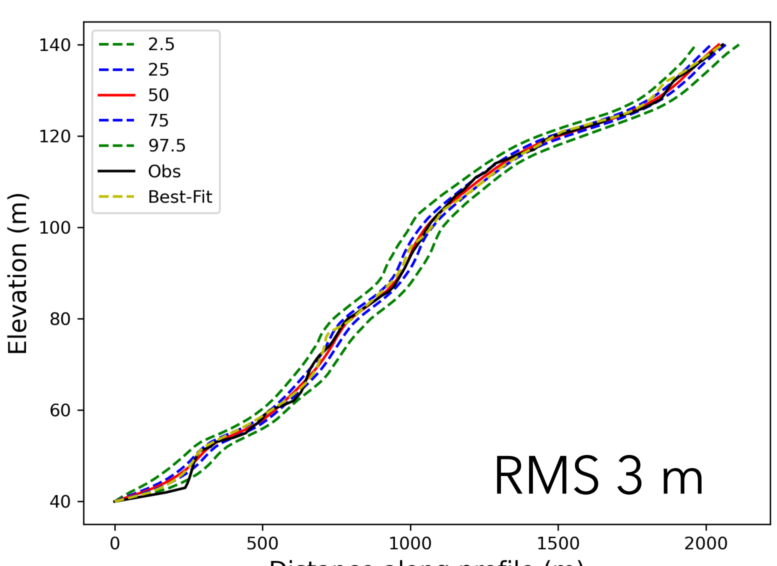
3-profile inversion

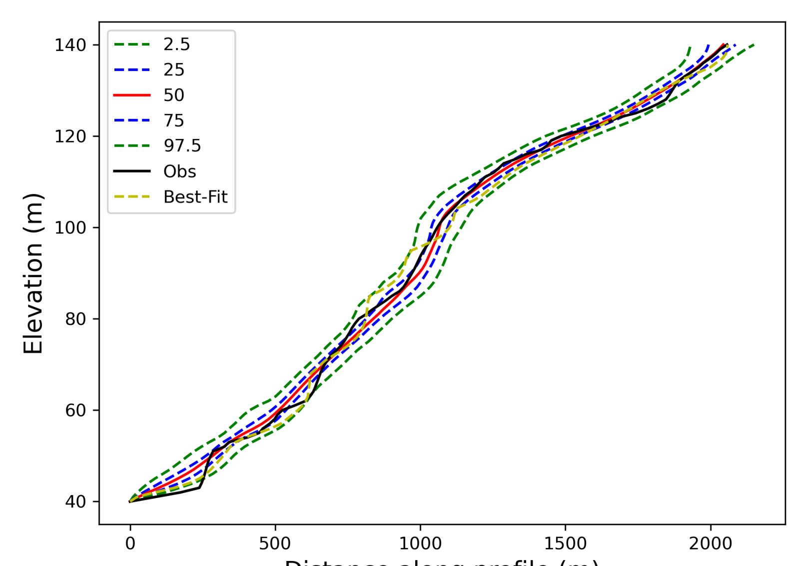
RMS 41 m



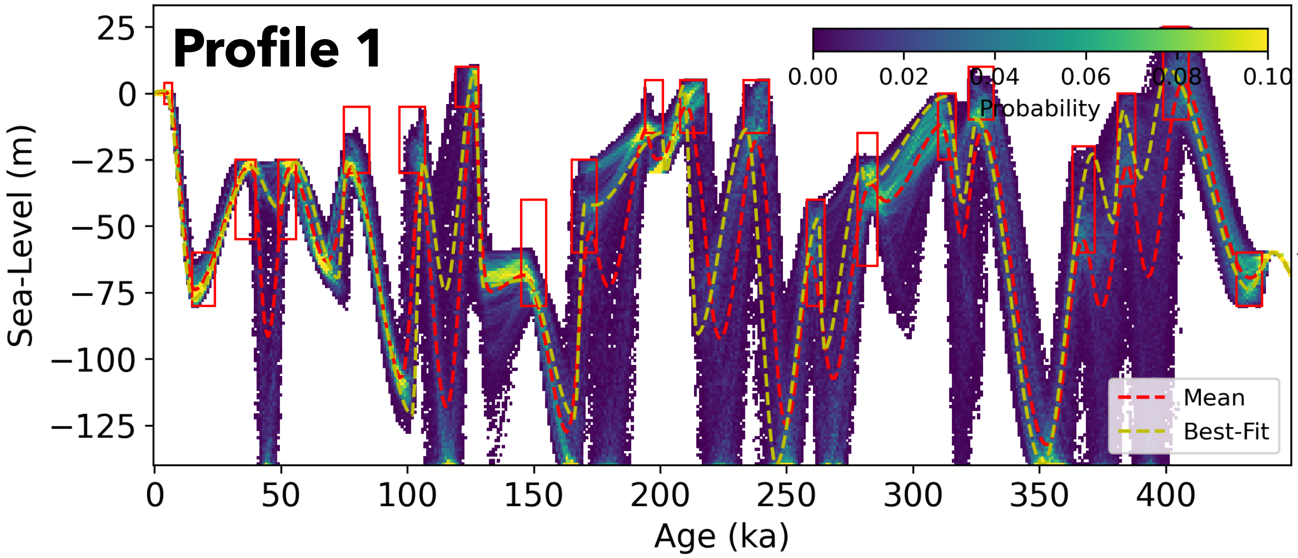
Profile 3

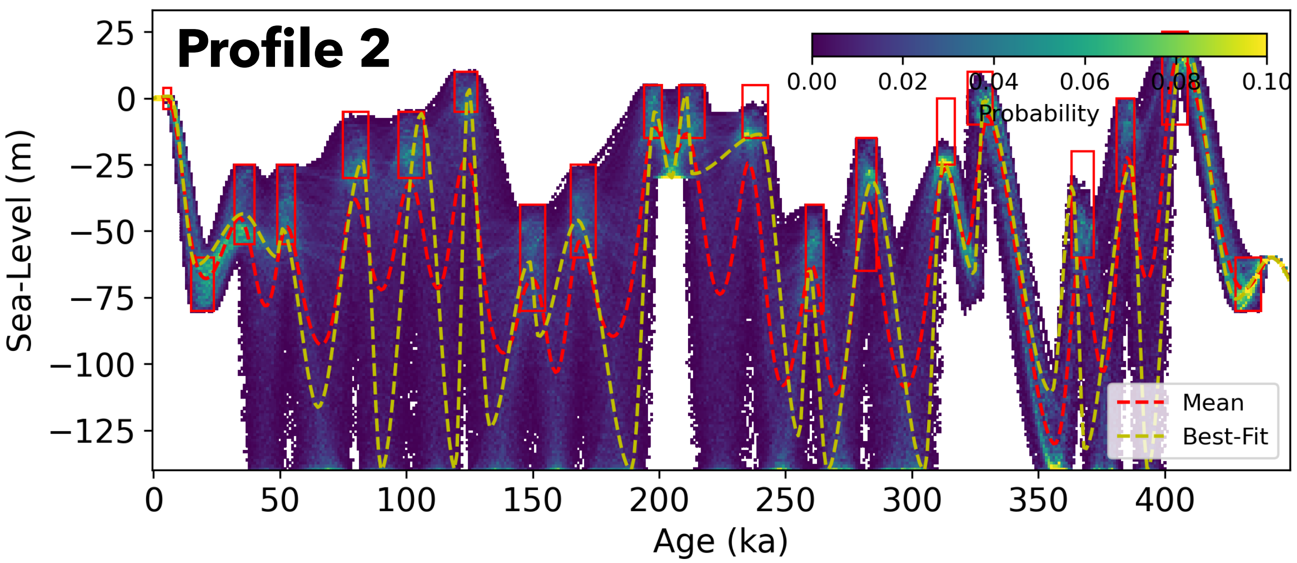
Uplift Rate ~0.4 mm/yr

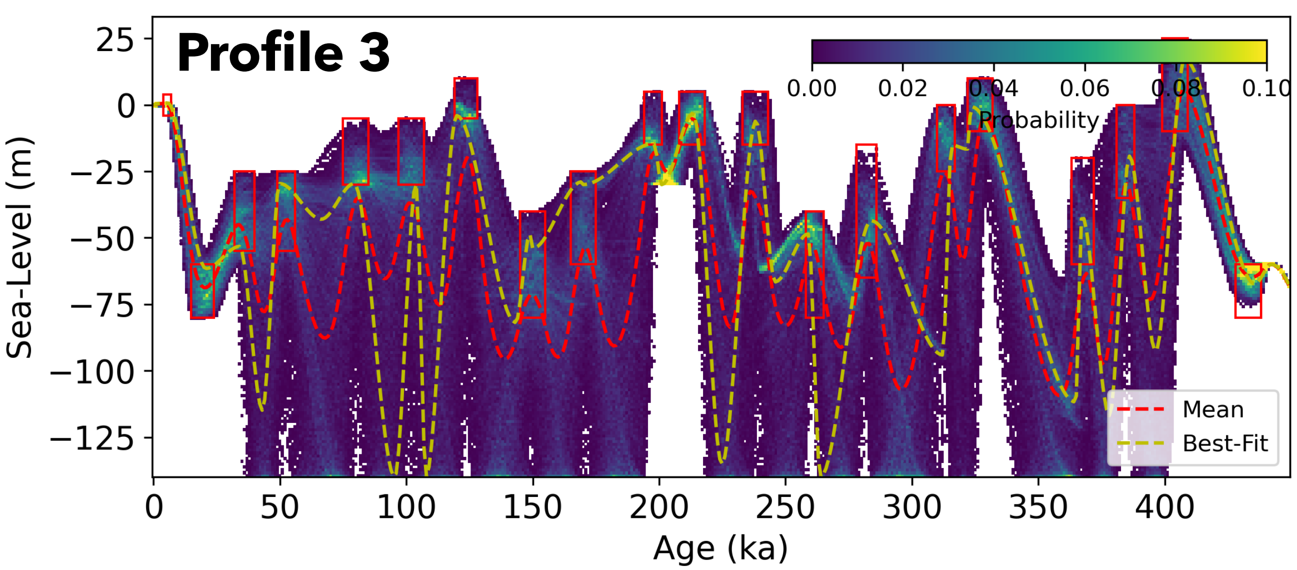




REAL TERRACE EXAMPLES: CORINTH

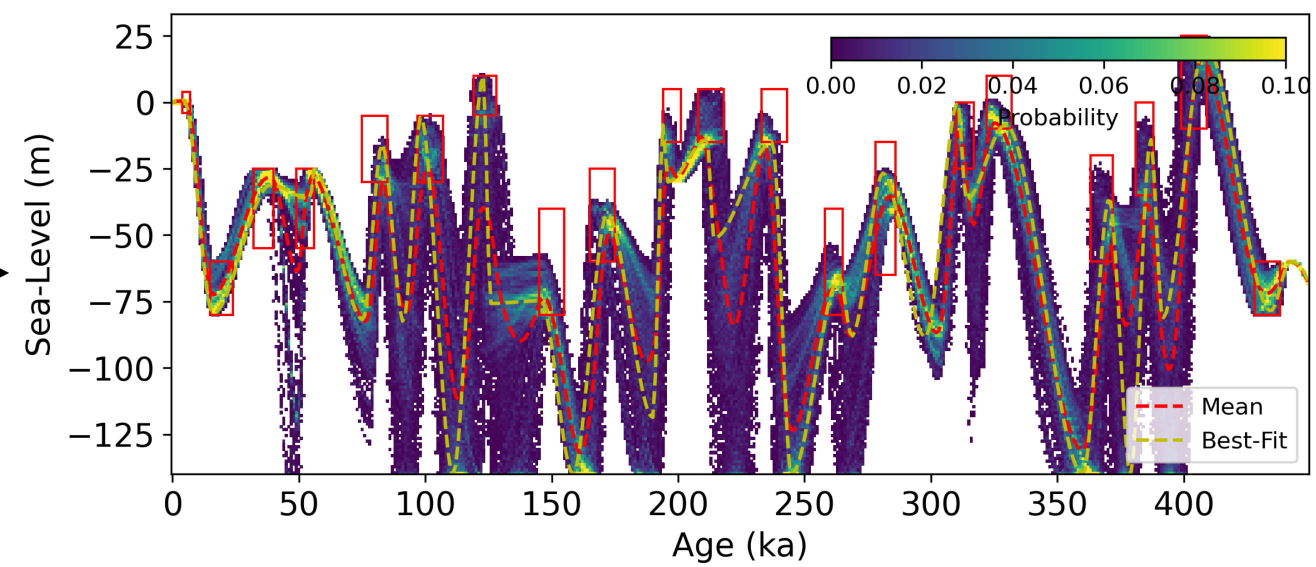




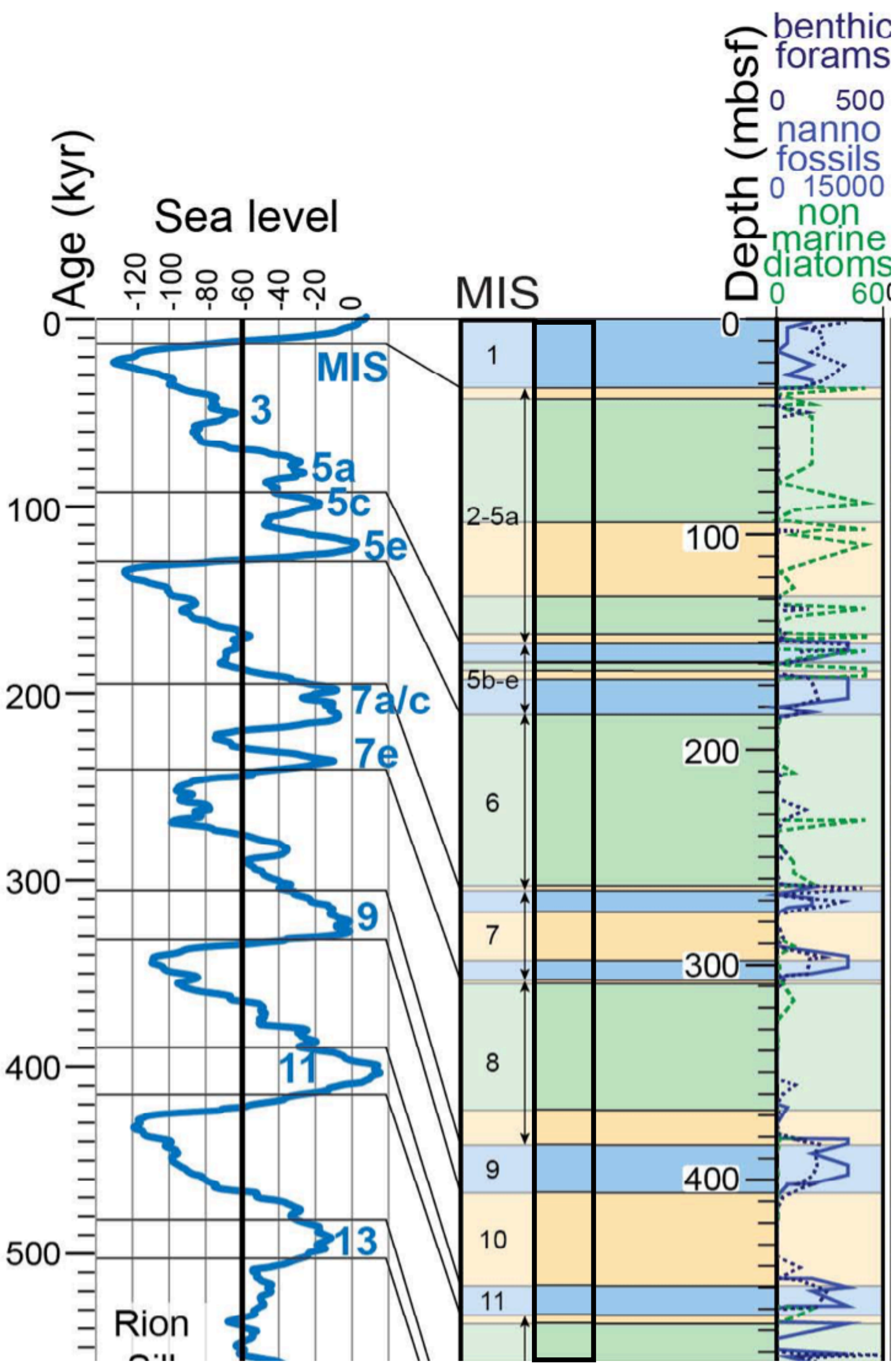


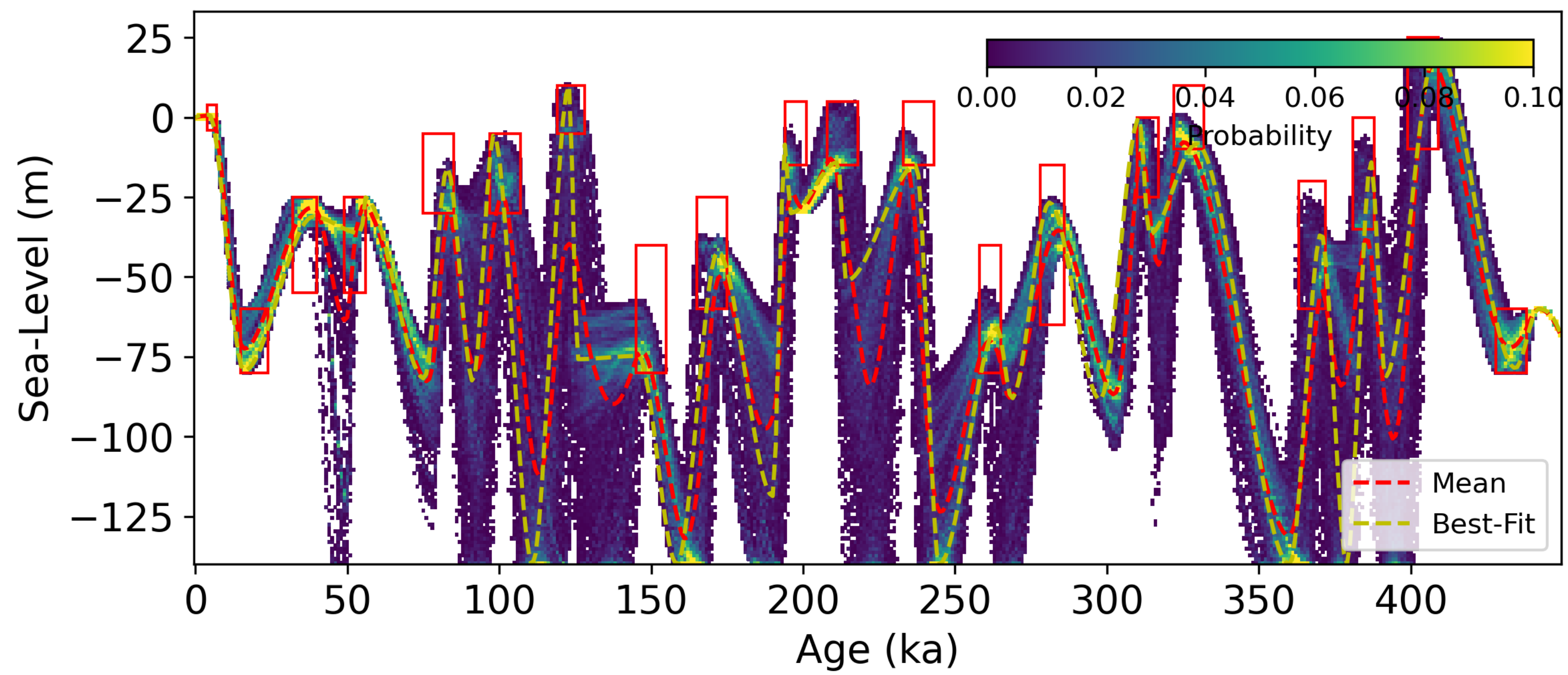
- Joint inversion gives narrower range of sea-(or lake-)level histories

3-profile inversion



DISCUSSION: SEDIMENTOLOGY

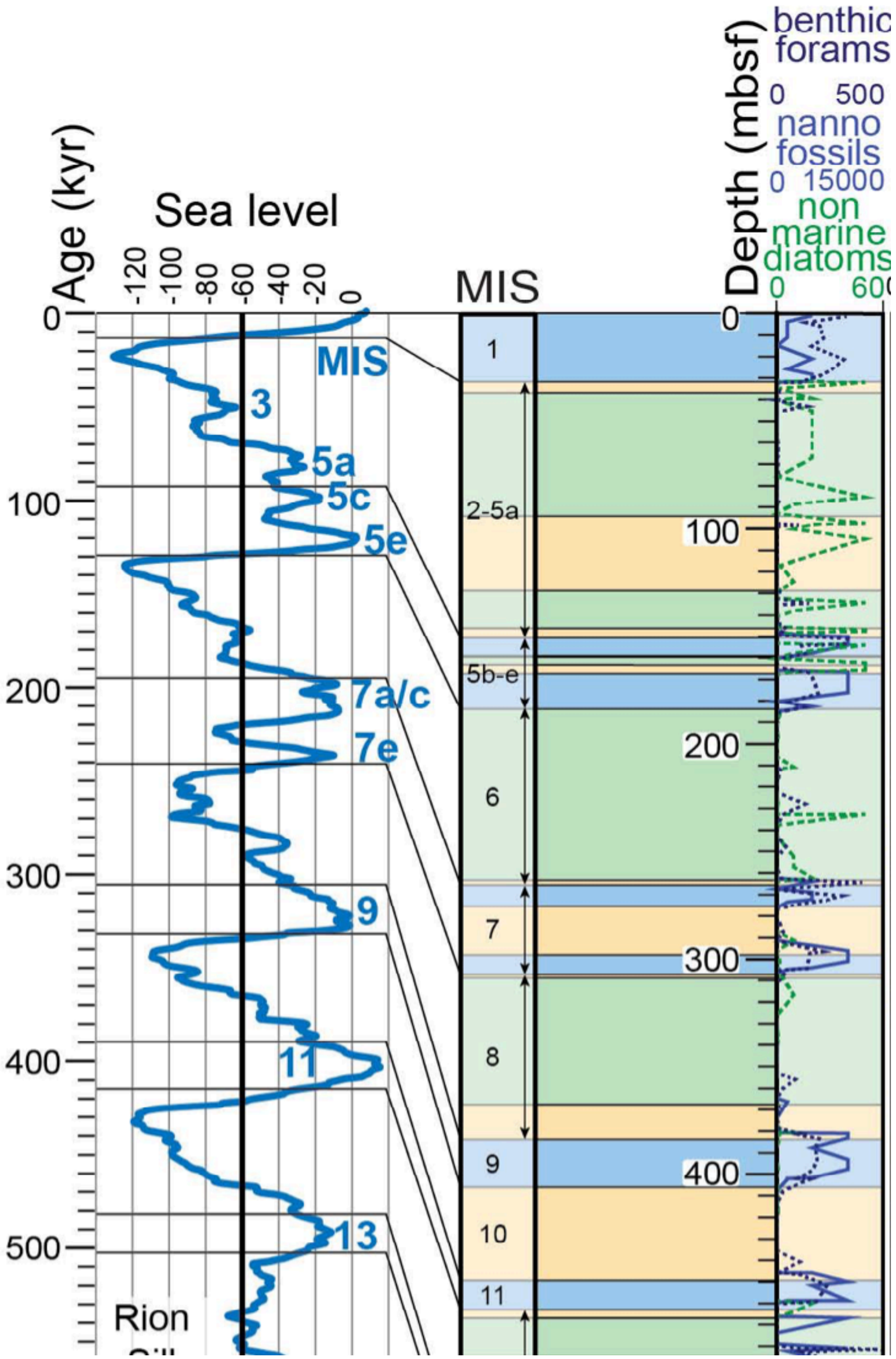




- Sedimentology and palaeontology suggests short marine intervals, largely lake history

Gawthorpe et al., 2022.

DISCUSSION: SEDIMENTOLOGY



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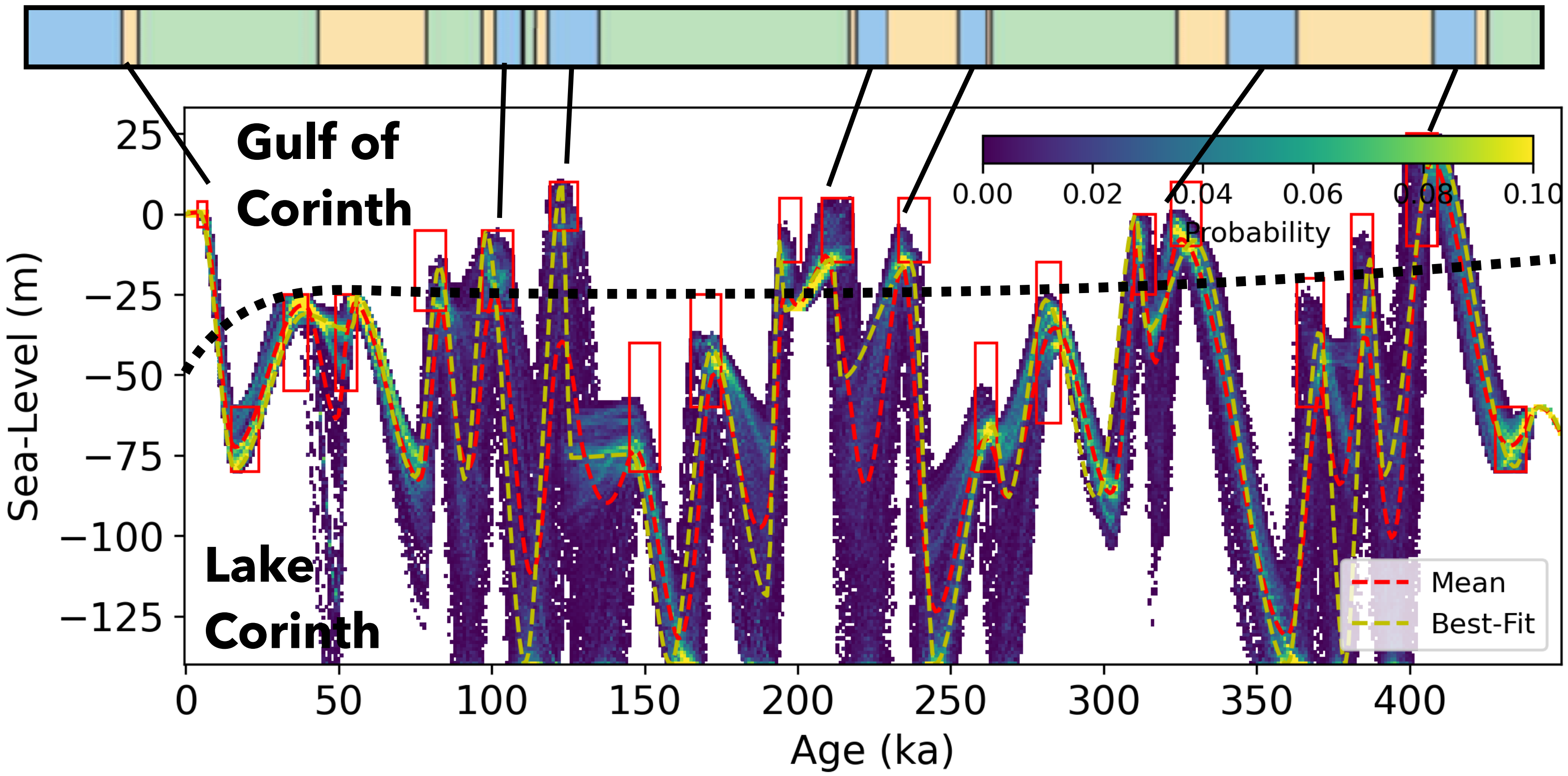

- Sedimentology and palaeontology suggests short marine intervals, largely lake history
- Compatible with our results, sill depth shallower in the past?
- Lake level probably fluctuated significantly

CONCLUSIONS

- Inversion useful tool in marine terrace analysis, more comprehensive perspective
- Multiple terraces much better constrained inversion, and/or reducing bias
- Applicable to marine terrace sequences that are poorly dated and/or have a complicated sea/lake level history

OUTLOOK

- Applying model to wave-cut marine terraces worldwide
- Apply for coral reef terraces