Timescale dependence of rates of landscape evolution

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Introduction

• Determining the rates of landscape evolution is vital for quantifying the response of landscapes to changes in climatic and tectonic conditions, and also for understanding the coupling between climate and tectonics.

• Sediment accumulation rates are time-dependent, showing an apparent increase towards present day. Thus, the reliability of the sedimentary record to infer the nature and pace of landscape evolution has come under question (Fig. 1).

• The leading hypotheses for explaining the observed dramatic increase in measured sedimentation rates take diametrically opposite views :

Hypothesis I) Since the Late Cenozoic, increase in climatic variability resulted in increased erosion of mountain ranges, which resulted in increased sedimentation rates in the associated sedimentary basins.

Hypothesis II) The sedimentary record is incomplete and the probabilistic structure of the hiatuses can result in an apparent time-dependence of measured sedimentation rates.

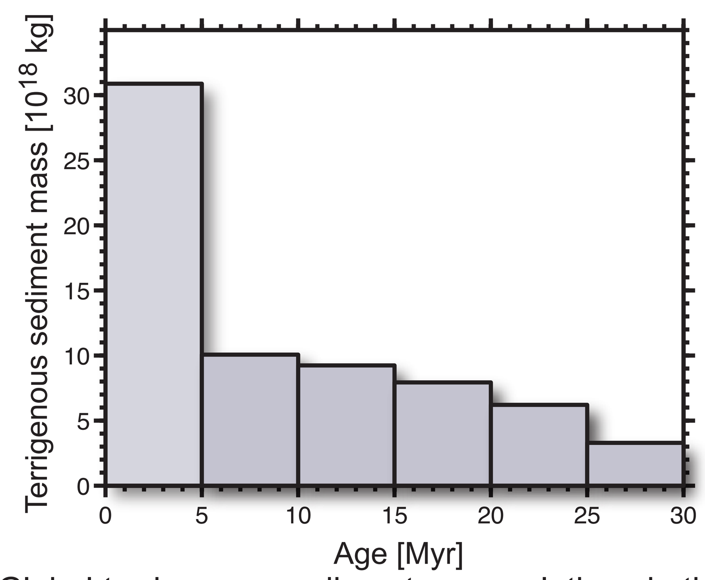


Fig. 1: Global terrigenous sediment accumulations in the oceans in the last 30 Myrs, binned into 5 Myr intervals (after Hay et al., 1988). Note the dramatic increase in sediment accumulation in the last 5 Myrs.

Can we quantitatively unravel the signatures of internally generated landscape dynamics (stochastic surface processes) from those forced by external conditions (climate & tectonics) in the sedimentary record?

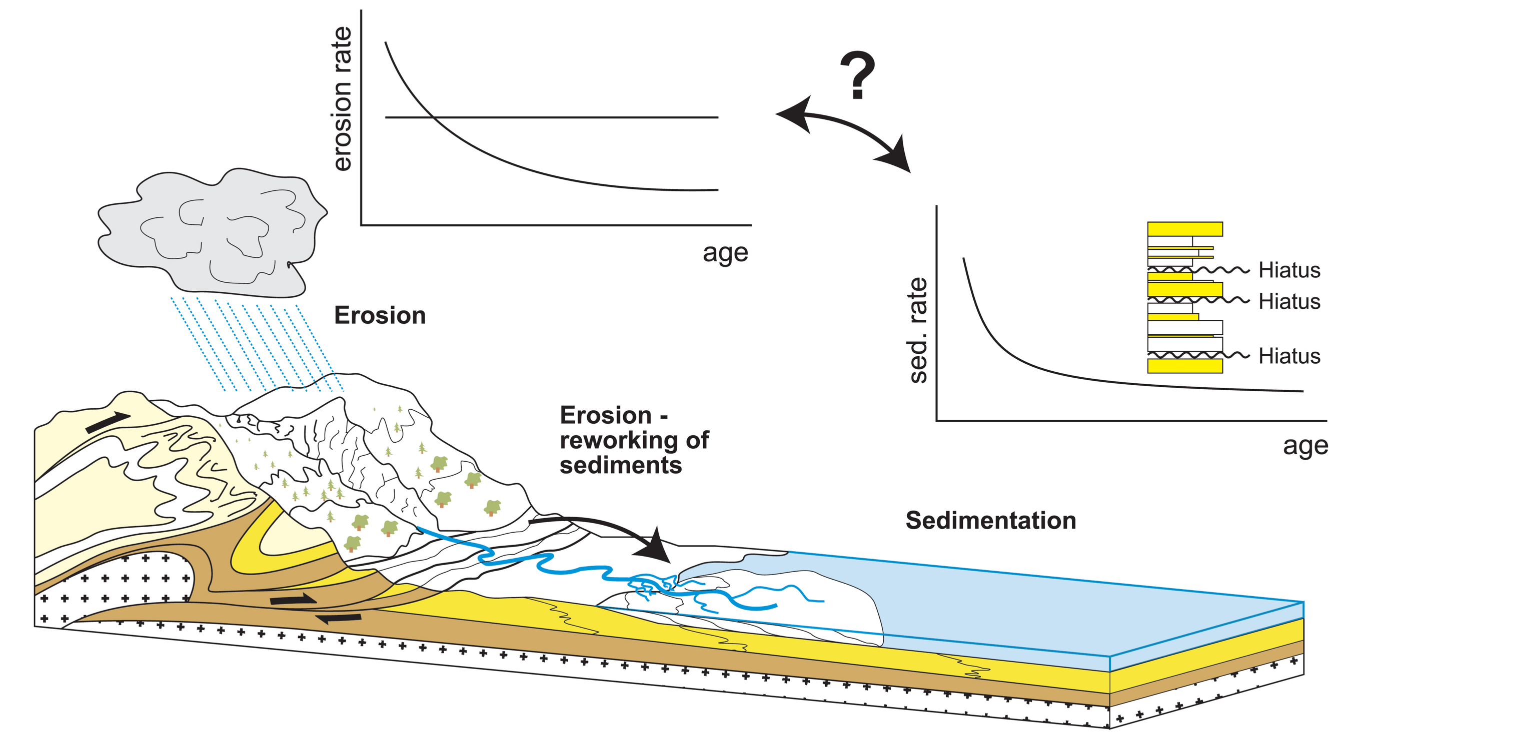


Fig 2 : Schematic illustrating our general approach. The multi-scale estimates of erosion rates are devoid of observational bias (at least on timescales larger than several kyrs), which the sedimentation rates suffer from. Comparing the timescale dependence of erosion rates with the associated sediment accumulation rates in the sedimentary basins will not only provide a means for assessing if the observed increase in sedimentation rates is real, but also for quantifying the degree to which the sedimentary record is influenced by the so-called Sadler effect.

Comparison of erosion and sedimentation rates for different landscapes

St. Elias Range

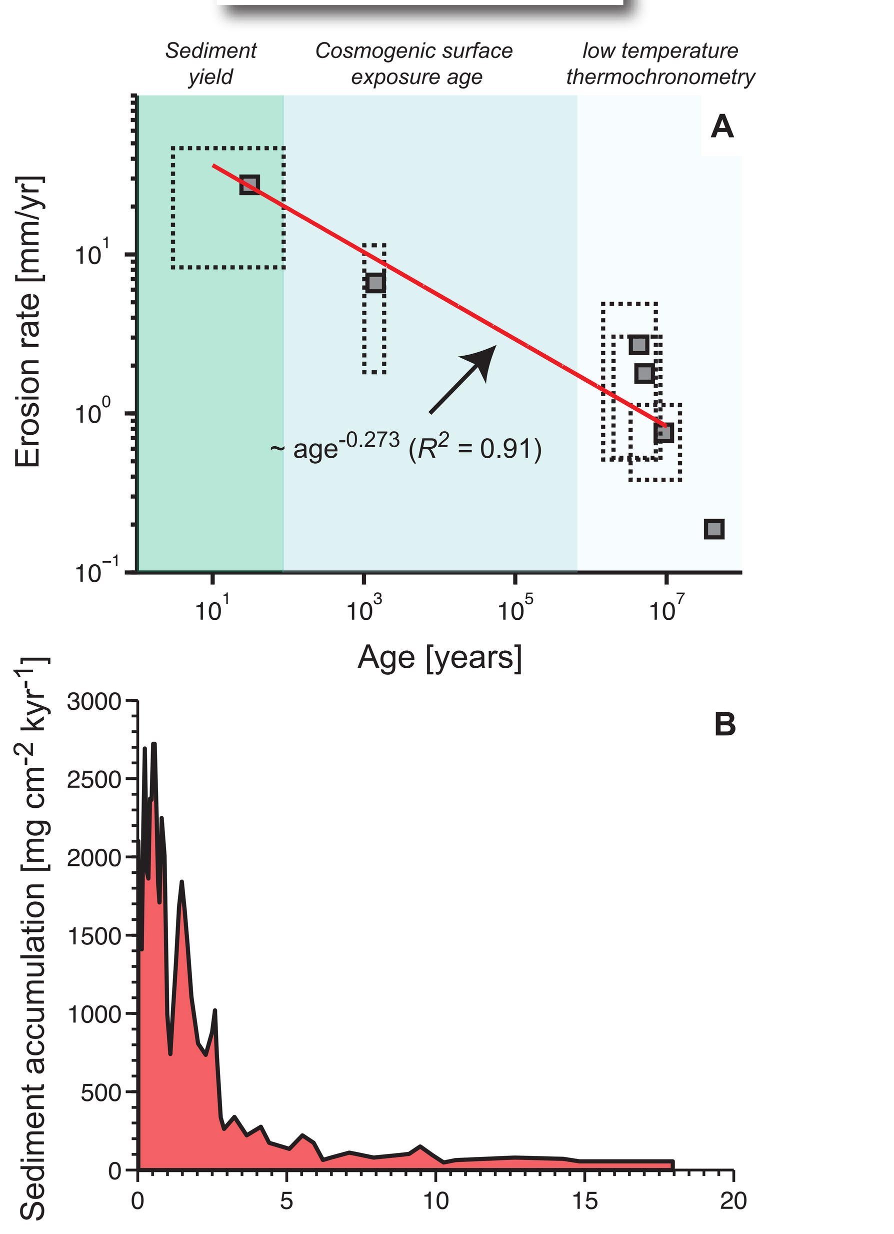


Fig. 3: (A) Compilation of multi-scale estimates of erosion rates for the St. Elias Range, Alaska. The estimates show a dramatic increase towards present day, which may be a result of increased rates of retreat of glaciers. (B) Sediment accumulation rates from the associated sedimentary basin, which shows a similar trend. **This indicates that the increase in sedimentation rates is a climatic signal**.

Western Alps

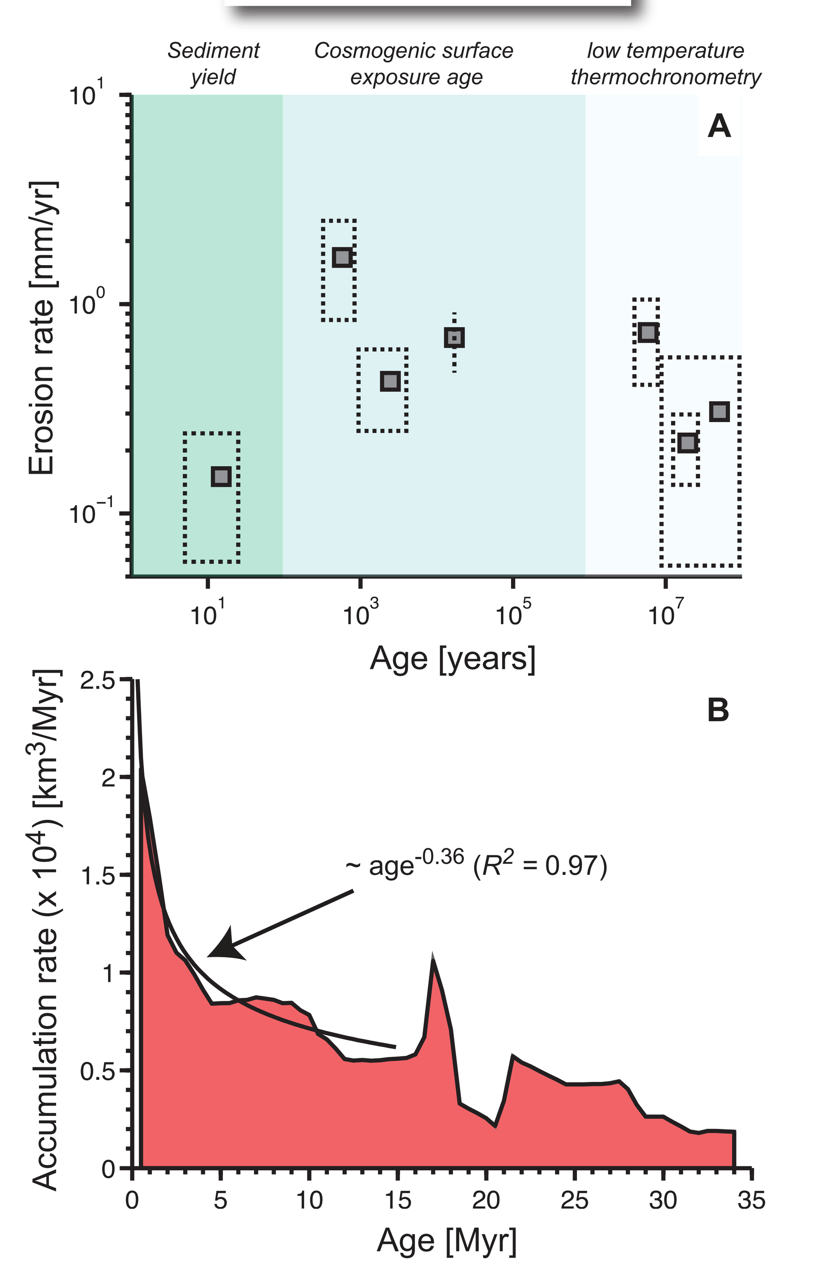


Fig. 4: Comparison of the estimated erosion and sedimentation rates over a wide range of timescales. The erosion rates do not show any discernible trend over the last 35 Myrs. Comparison with the sedimentary record reveals that the **apparent increase in the sediment accumulation rates may purely be a result of stochastic surface processes.**

Western Himalayas

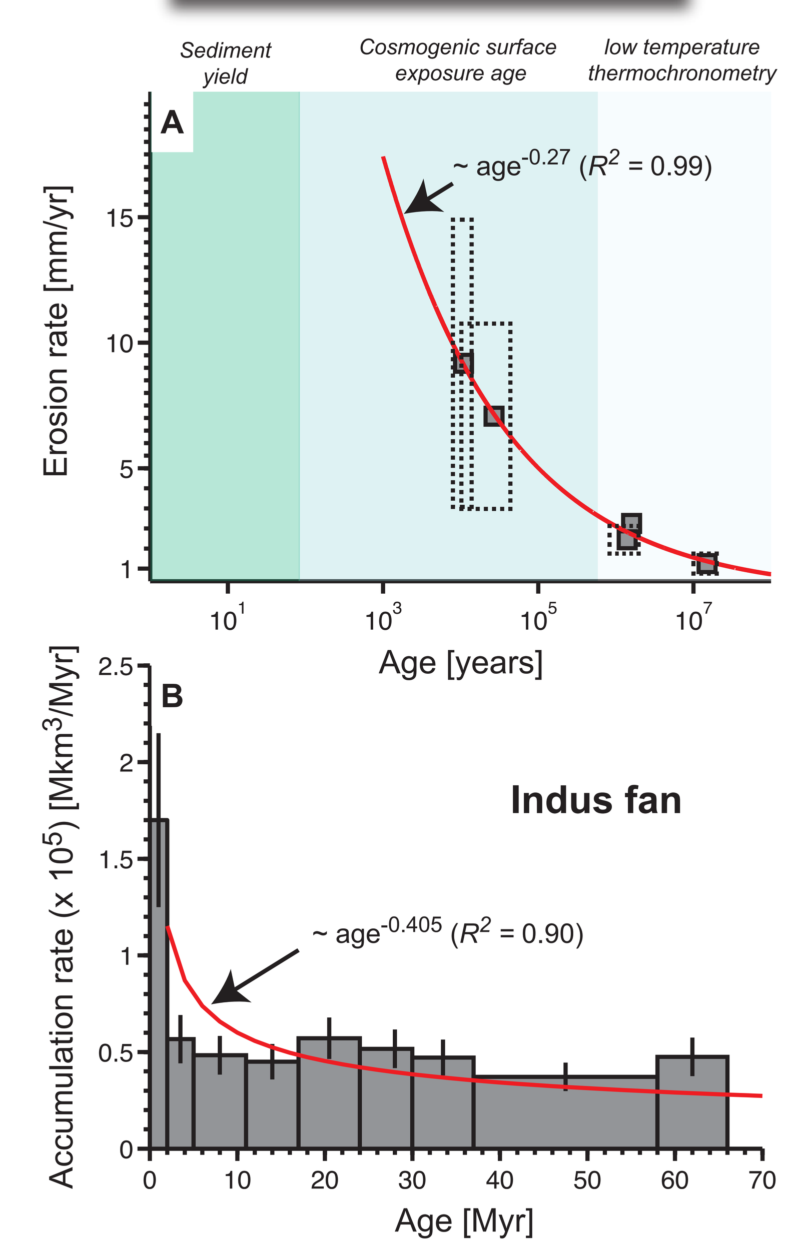


Fig. 5: The increase in estimated erosion rates for the Western Himalayas may be a result of increased climatic variability and the resulting coupling between climate and tectonics. However, comparison with sedimentation rates in the Indus fan reveals that **only a part of the increase in sedimentation accumulation rates may reflect the increase in erosion rates** in the Himalayan catchments.

Eastern Himalayas

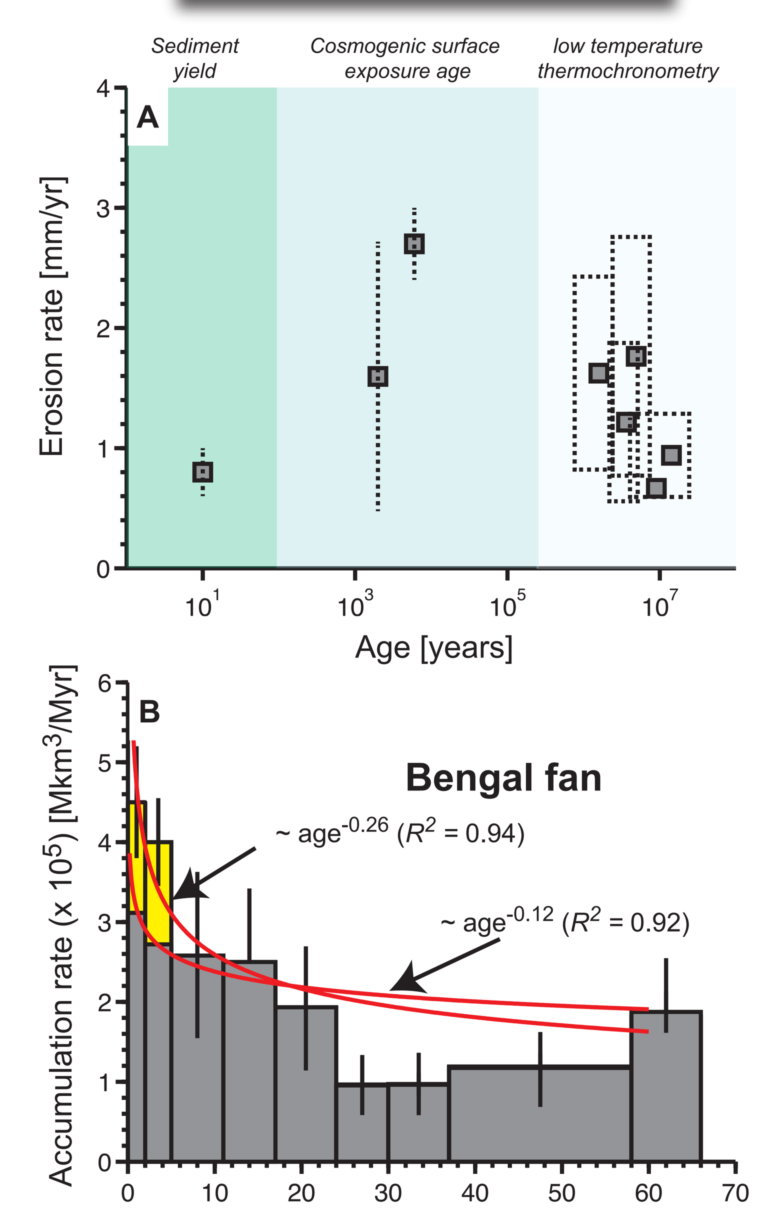
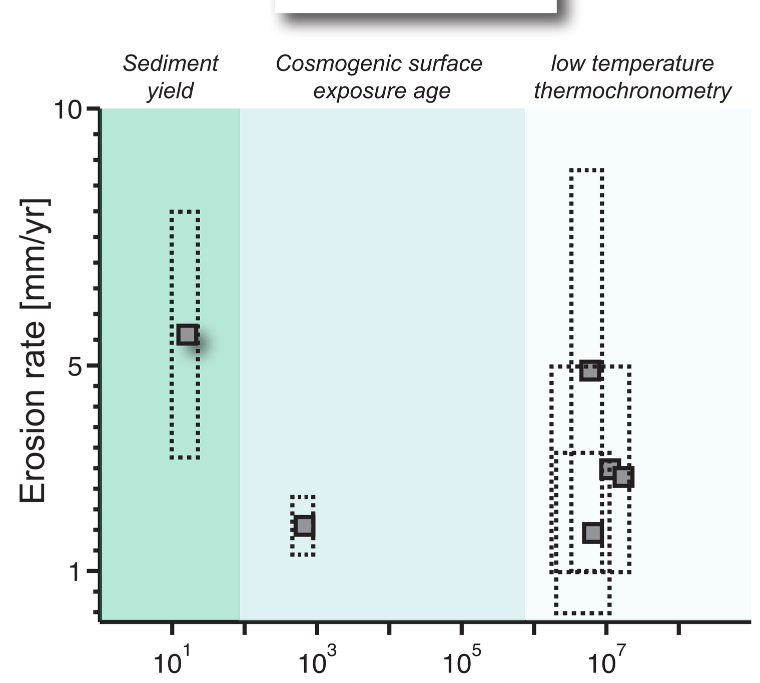


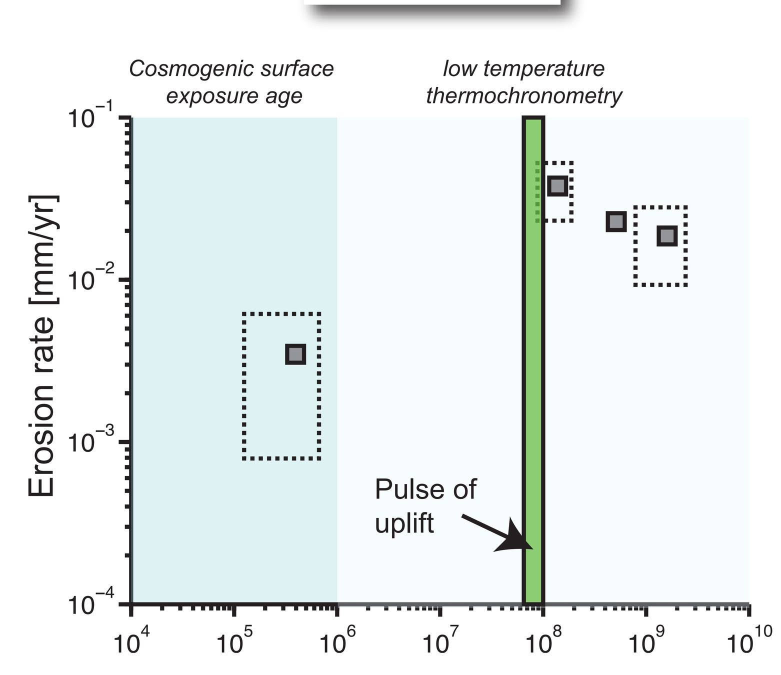
Fig. 6: Sedimentation rates in Bengal fan show a continuous increase towards present day. Accounting for the recycling of sediment (yellow bars) reduces this increase considerably. **The trend in the corrected sedimentation rates comes closer to the observed timescale dependence of erosion rates.** However, there is still a mild increase in the sedimentation rates through time, which may be a result of the Sadler effect.

Application to steady-state and slowly relaxing landscapes

Taiwan



Namibia



Idaho Batholith

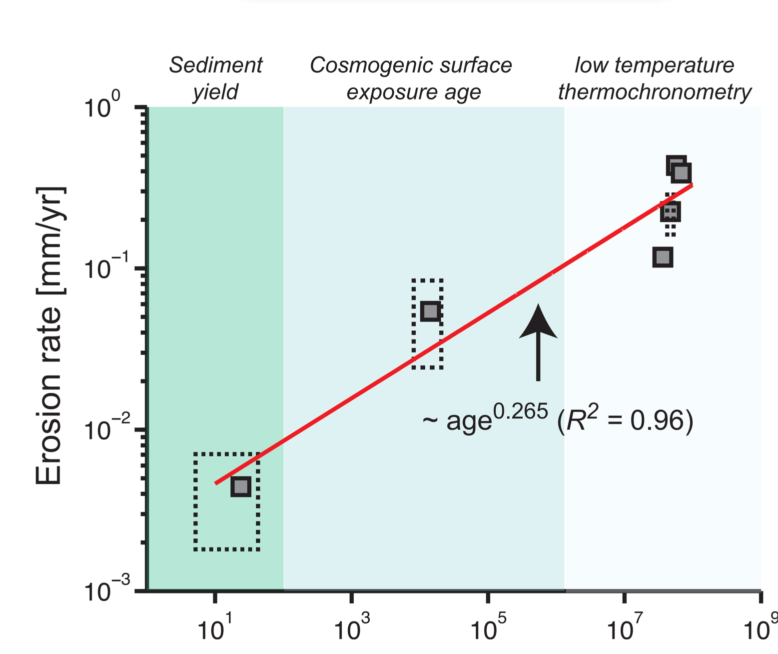


Fig. 7: Applications to steady-state and slowly relaxing landscapes indicates that, unlike the sedimentation rates, **the timescale dependence of erosion rates reveals a real signature** in changes in nature and pace of landscape evolution. For example, the estimated erosion rates in Taiwan show no trend over the last 10 Myrs, indicating that the erosion rate balanced the tectonic uplift rate through time and that the orogen is in steady-state. Similarly, estimated erosion rates from Namibia indicate that the landscape is relaxing from a tectonic perturbation. This prediction is in good agreement with previous work, suggesting that Namibia experienced an exhumation pulse between 65 Ma to 100 Ma (green column). The decay of the erosion rates through time for the Idaho Batholith is consistent with the hypothesis that this region is relaxing from an exhumation pulse, which occured ~ 50 Ma ago. Another important implication of our analysis is that **landscapes may adjust to tectonic perturbations very slowly, characterized by a power-law decay, and time to steady-state may be much larger than previously suggested**.

Conclusions

• We propose that combining the multi-scale estimates of erosion rate with the sediment accumulation rates in the associated sedimentary basins provides a means of quantitatively unraveling the signatures of internally generated landscape dynamics from those forced by external conditions.

• Our analysis reveals that while all of the sedimentary record is affected by the probabilistic structure of the hiatuses, the degree to which the sediment accumulation rates are corrupted by these stochastic processes varies.

• In the Western Himalayas and the St. Elias range, our analysis reveals that the increase in sedimentation rates may be recording a real increase in erosion rates.

• In extreme cases like the Eastern Himalayas and the Western Alps, the apparent increase in the sedimentation rates may be a result of stochastic surface processes and the estimated erosion rates do not show any discernible trend.

• Application of our methods to steady-state and slowly relaxing landscapes reveals that the time dependence of estimated erosion rates records changes in climatic and tectonic settings.

• Finally, we conclude that combining erosion rates and depositional rates may provide a robust framework under which we can quantitatively revisit the coupling between climate, tectonics, and landscape evolution.