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Slope control on the aspect ratio of river basins

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River networks and their drainage basins have attracted a large attention due to their remarkable statistical properties (1-5). For example, although fluvial networks patterns seem to be influenced by diverse geological and climatic processes, the river basins that enclose them appear to mirror each other faithfully. Basin area A and length L of rivers from around the world consistently scale following L=cAexp(h) (2) with h often close to 0.5 (and c a constant) suggesting that river basins are self-similar (1, 6). Likewise, the main river basins that drain linear mountain ranges consistently manifest similar length-width aspect ratios between 1 and 5 (7). These observations question how the interplay between climate and tectonics is reflected in landscapes, and they highlight the challenge of inverting modern landscape records to reveal previous climates and tectonics.

The invariance of river basins aspect-ratio is puzzling when compared against observations at smaller spatial scales (<10 km). In analogue experiments, numerical simulations and outcrops, the form of stream networks is influenced by surface slope (8-11). Steep surfaces develop narrow elongate basins with near-parallel rills, whereas flatter surfaces produce wider basins. Initial surface geometry is also important in setting rivers paths and certain landscape properties such as the slope-area relationship (12).

Here we thus investigate the form of river basins developed on surfaces longer than 10 kilometres showing limited dissection such that the initial surface slopes can be measured. We find that, as for small scale basins, the form of large scale river basins is controlled by surface slope, with steep slopes developing narrower basins.

This observation is interpreted to originate from the nature of water flow over rough surfaces, with steeper slopes causing less flow convergence and longer-narrower basins. We derive an empirical relationship that can be used to infer the slope of a surface on which a river basin acquired its geometry based solely on a measure of its basin form. This relation provides a unique means of inferring the relative chronology of river basin development with respect to surface tilting and therefore provides a direct link between river basin morphology and tectonics.

Instead of viewing river basins as largely invariant, this work highlights the differences between basins that bear important information about tectonics and climate.

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