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FLUVIAL LANDSCAPE RESPONSE TIME: HOW PLAUSIBLE IS STEADY-STATE DENUDATION?

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ABSTRACT. Whether or not steady-state topography and denudation are probable states depends on the timescale of system response to tectonic and climatic perturbations relative to the frequency of those perturbations. This paper presents analytical derivations of algebraic relations for the response time of detachment-limited fluvial bedrock channel systems both to tectonic and climatic perturbations. Detachment-limited fluvial erosion is described by the stream-power incision model, and the derivations are limited to the applicability of that model. All factors likely to influence system response time that are not adequately captured by the stream-power incision model will tend to increase the response time. The calculations presented thus provide minimum estimates of landscape response time and therefore over-predict the probability of attaining and sustaining steady-state topography and denudation. The Central Range of Taiwan is used as a case study to estimate response times in a landscape often argued to be in steady state. Model parameters are fit to modern stream profiles by assuming that the topography represents a quasi-steady-state form. Estimated response times generally range from 0.25 to 2.5 Ma, depending on the non-linearity of the incision rule and the magnitude and type of perturbation. Thus it may be reasonably argued that steady-state topography and denudation are likely to prevail during periods of climatic stability (response time is sufficiently short compared with plate tectonic timescales). However, rapid climatic fluctuation in the Quaternary appears to preclude the attainment of steady-state conditions in modern orogens.

MOTIVATION

Steady-state landforms and denudation rates are the natural attractor state under conditions of invariant rock uplift rates (defined relative to a fixed baselevel), climate, and lithology (Adams, 1985; Hovius, Stark, and Allen, 1997; Howard, 1994; Moglen and Bras, 1995; Ohmori, 2000; Willgoose, Bras, and Rodriguez-Iturbe, 1991). Topographic and denudational steady-state is defined as a delicate balance of erosion and (constant) rock uplift such that a statistically invariant topography and constant denudation rate are maintained. As indicated above, for topographic and denudational steady-state to hold, the distribution of rock types exposed at the surface must remain unchanged (that is, there must be no progressive exhumation of more or less resistant rock types). Thus, the topographic and denudational steady-state discussed in this paper implicitly assumes that the orogen has achieved exhumational steady state (see Willett, Slingerland, and Hovius, this issue, p 455). The competing forces of uplift and erosion naturally tend toward attainment of this balance. For example, as initially low-relief landscapes are uplifted, erosion rates steadily increase over time in response to steepening of river profiles and adjacent hillslopes, further enhanced by orographic precipitation. Eventually erosion rates increase sufficiently to counterbalance the rock uplift rate, and a steady-state landscape is achieved (for example, Adams, 1985). An important exception occurs where erosion is so inefficient or rock uplift rate so rapid that the growth of topography reaches limits imposed by crustal strength (Beaumont