Stream power incision model and the stage of topographic equilibrium, using physical experiments

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Bedrock rivers develop their landforms very slowly, compared with alluvial river, thus bedrock rivers and their surrounding topographies are expected to record long-term environmental changes such as tectonics and climate. The stream power incision model (SPIM) is an empirical model that expresses the erosion rate due to rivers by the product of two power functions of the contributing area and river bed slope. Using this equation with an uplift term, the differential equation of the temporal change in the altitude of riverbed is constituted. When applying the model to a natural drainage basin, the equilibrium state between erosion and uplift is often assumed, partially because the uplift rate is usually unknown. Under the assumption of equilibrium state, SPIM is reduced to the relationship in which the riverbed slope is a power function of the contributing area, known as Flint's law, which is the basis of "slope-area analysis" to determine the concavity (equivalent to the ratio of two power exponents in SPIM). Usually the two power exponents in SPIM are presumed to be constant if lithology, climate, and other factors are the same. This postulation, however, is difficult to verify for natural landforms, because of heterogeneity of various kind of property within a single drainage basin and difficulty in evaluation of the incision rate.

This study investigates the relation between the incision rate and topographic properties in river basins, through the observation of small-sized physical experiments under well-controlled conditions. A flume used was 90×180 cm, and the substrate to be dissected composed of the uniform mixture of sand and clay was installed. Rainfall was simulated by supplying mist from 10 nozzles. Uplift was realized by lowering a weir that was installed at the downstream end of the flume and determined the base level. The landform was measured by photogrammetry using several hundred photos taken during intermission from rainfall for photographing.

We compared the results of (1) this and (2) the previous studies (Imamura and Endo, 2018) realizing different kinds of uplift: (1) sudden base level lowering from a stable state of basin, to observe the response processes of the landforms until the basin became stable again (about 5 hours); (2) Sudden change in the uplift rate, to observe the change from a stable state under constant uplift of 4.5 mm/h to a new stable state under faster uplift rate of 6.0 mm/h (about 6 hours).

The results of Experiment (1) showed that the incision rate decreased with time (presumably asymptotic to zero), while Experiment (2) always displayed a certain finite value of the incision rate. The power exponents in SPIM, m (for the contributing area) and n (for the slope) did not seem to be constant in both experiments. The ratio m/n also changed, but seemed to converge to a certain value in each experiment.

We evaluated the correlation of the incision rate with the fitted function for each measurement time. In Experiment (1), although the denudation rate decreased with time, the first half of the run time showed good correlations but the latter half showed the worse. By contrast, Experiment (2) exhibited increasing correlations in the latter half of the run. These results suggests that SPIM holds for dynamic equilibrium (tectonic steady state (Montgomery, 2001)) or the early stage of static quasi-equilibrium (erosional stead state (Montgomery, 2001)), but fails for mature or later stages in which a landform proceeds to a peneplane.

Imamura and Endo, 2018. Incision rate, riverbed slope and contributing area of an experimental drainage basin. JPGU 2018 Abstract.

Montgomery, 2001, Slope distributions, threshold hillslopes, and steady-state topography. American Journal of Science, 301, 432–454.

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