Numerical simulation for topographic evolution with a stream erosion model: Relation between asymmetric topography and uplift rate

Yosuke Shikakura[1]; Yukitoshi Fukahata[2]; Mitsuhiro Matsu'ura[1]

[1] Dept. of Earth & Planetary Science, Univ. of Tokyo; [2] DPRI, Kyoto Univ.

There are lots of asymmetric mountain ranges in the world, such as the Himalayas, the Taiwan Central Range, and the New Zealand Southern Alps. The asymmetric feature of the mountain ranges may be caused by horizontal rock movement or asymmetric distribution of precipitation or lithology. However, the asymmetric rock uplift must be one of the most important causes of the asymmetry of the mountain ranges. In this study we investigated the topographic evolution of mountain ranges due to asymmetric rock uplift based on numerical simulations with a stream erosion model (e.g., Tucker & Slingerland, 1996, Basin Res.).

In general, the landform evolves toward a dynamic stable state, in which the two opposite processes are balancing with each other: one is endogenic processes, such as rock uplift and subsidence due to plate subduction or collision, and the other is exogenic processes, such as surface erosion and sedimentation, mainly constrained by climate and lithology. On this basic concept, we have developed a numerical simulation code of topographic evolution, where we give uplift rates beforehand and calculate erosion rates with a stream erosion model. In the stream erosion model, the erosion rate is expressed by the product of power functions of the drainage area and the channel gradient. The exponent of drainage area m is commonly bigger than the exponent of channel gradient n. In this situation the erosion rate is faster in the steeper side if the other conditions, such as the lithology and precipitation, are the same. The asymmetry of erosion rates must be compensated by asymmetric rock uplift rates to maintain the topography. As a result, we can expect a significant offset between the distribution of rock uplift rate and topography.

Based on the numerical simulation with the topographic evolution model, we quantitatively verified this prediction (Shikakura et al., 2004, JEPS Joint Meeting). We showed that the offset between the axis of rock uplift and that of topography was related with a logarithm function. However, we investigated this relation for only one pair of the exponents m=0.5, n=1.0. It is known that these exponents are different for mountain ranges. Therefore, in this study we investigated the generality of the logarithm relation for various pairs of exponents. As a result, we found that 1) the logarithm relation was still valid for various pairs of the exponents in usual parameter ranges. In addition to this, based on the analytical solution and numerical simulation of the topographic evolution model, we found that 2) the offset between the axis of rock uplift and that of topography was larger for smaller ratio of m (exponent of drainage area) to n (exponent of the channel gradient), 3) the location of the topographic axis did not depend on the rock uplift rate in the dynamic steady state, and that 4) the height of the topographic axis was proportional to the n-th power root of the maximum rock uplift rate.

Taking numerical results, geological studies, and topographic characteristics into account, we discussed the evolution process of the Hida mountain range for the last 3 Myr. In the Hida mountain range the topographic axis is located in the eastern region. Based on the present result, we can expect that the distribution of rock uplift rate is further asymmetric than the topography. This expectation is consistent with thermo-chronological data (Ito & Tanaka, 1999, Jour. Geol. Soc. Japan). According to their report, the cooling rates of the rocks are more rapid in the eastern side of the Kurobe-Takase Fracture Zone, which runs from north to south in the east of the Hida mountain range.