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Research Paper

Erosion rates in an active orogen (NE-Taiwan): A confrontation of cosmogenic measurements with river suspended loads

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ABSTRACT

The direct and feedback relationships between tectonics, climate and denudation are a matter of debate. A better understanding of these relationships requires quantifying rates of denudation in a wide range of climate and tectonic settings, as well as at various time and space scales. Because of an ongoing active collision implying high uplift rates and a climate prone to extreme rainfall events and frequent tropical typhoons facilitating strong erosion dominated by mass movements and high degree of fluvial transport, the Taiwan environment is highly dynamic. In this work, spatially-averaged denudation rates determined along the network of one of the major rivers in Taiwan (Lanyang River) from in situ-produced cosmogenic nuclides (^{10}Be) measured in river-borne quartz minerals are compared to the erosion rates determined from the statistical analysis of modern sediment load data. Integrated over the last several hundreds of years, the denudation rate derived from in situ-produced ^{10}Be concentrations averages 2 ± 1 mm/yr within the Lanyang watershed. Integrated over the last 50 years, the erosion rate given by modern sediment load data is 5–7 mm/yr within the same catchment area. The studied catchment being characterized by a relatively low-level of human activity, the discrepancy between the two rates is most probably due different sensibilities to high-frequency, stochastic erosional events (typhoons and earthquakes). The cosmogenic-derived denudation rates can thus be regarded as more representatives for quantifying erosion processes on the short-time scale, and be strictly compared to the long-term exhumation rates derived from low-temperature chronological data.

1. Introduction

Earth's surface evolution and morphogenesis mainly result from the combined actions of internal (*i.e.*, volcanic activity and tectonics) and external (*i.e.*, weathering and erosion) processes. Tectonic processes set the initial conditions forcing surface uplift and, in regions of continuous tectonic activity, renewing topography as it is eroded. Climatic processes sculpt the Earth's surface through geomorphic processes acting on hillslopes or riverbeds for example. Numerous studies underlined the importance and the complexity of interactions and coupling relationships between tectonics, erosion and climatic processes (e.g., Beaumont et al., 2000; Willett, 1999; Whipple and Meade, 2004). However, the debate is still open and several coupling mechanisms very likely act together on the control of topographic evolution (Molnar and England, 1990; Molnar, 2003). Such actions and reactions have been modeled (Willett, 1999; Willett et al., 2001; Whipple et al., 1999; Koons, 1989; Beaumont et al., 1992; Montgomery and Brandon, 2002) but not often been documented in the field. Within this general context, quantifying pattern and magnitude of denudation processes on various time and space scales is essential, for example, to validate and calibrate the parameters to be supplied to landscape evolution models or to evaluate the isostatic response to erosional unloading in connection with tectonic modeling.

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In this article, we investigate at the drainage basin scale the rates at which the topography of an active orogen is being eroded. To achieve this goal, we compare spatially-averaged denudation rates determined from cosmogenic nuclides (^{10}Be) measured in river-borne quartz minerals with the statistical analysis of modern sediment load data along the same river network. To apply this approach, we focused on the Taiwan Island (Fig. 1A), where the obliquity of the convergence between the Philippine Sea Plate and Eurasia involves the progressive subduction of the continental margin of China, and induces the fast growth of the Taiwan Mountains. Indeed, because of the high rate of plate convergence (~9 cm/yr), deformation and erosion rates are extreme. Today, the orogen culminates at about 4000 m, and rose from the sea level only a few million years ago. Within such a context, the impacts of climate and surface processes are particularly well-expressed, allowing studying their interaction with tectonic processes. Taiwan is thus a natural laboratory, where a complete sequence of mountain building processes can be studied from oceanic subduction (South Taiwan) to mature continental subduction (Central Taiwan), and orogenic wedge collapse in a back-arc context (North Taiwan).

In this paper, we focused on the Lanyang River watershed, which drains the Backbone and the Hsüehshan mountains in Northeastern Taiwan (Fig. 1B). Since it is located in the part of the orogenic wedge where collapse is ongoing, this area might be characterized by relatively low erosion rates compared to the central part of the mountain belt. Indeed, using suspended sediment observations smoothed at catchment scale, Dadson et al. (2003) have shown that northern Taiwan is experiencing modern rates lower than 10 mm/yr whereas they can reach values higher than 15 mm/yr in the eastern Central Range.

The Lanyang watershed has thus been selected as a test site for the quantification of the denudation rates using measurements of cosmogenic ^{10}Be in river-borne sediments in such a dynamic environment. Moreover, the Lanyang River is also well-instrumented with hydrological stations allowing the comparison of ^{10}Be-derived erosion rates with the analysis of river suspended loads.

Hereafter, we first present a review of the published erosion and denudation rates in Taiwan. We then consider the geomorphic context of the Lanyang River, where we explore the denudation rates based on in situ-produced cosmogenic ^{10}Be in river-borne quartz minerals, and modern erosion rates derived from suspended load data. Finally, we discuss the results independently obtained through these different approaches, trying to highlight the most critical observations for unraveling the erosional conditions that prevail in this area of the Taiwan mountain belt.

2. Review of published erosion rates in Taiwan

The present-day erosional context of the Taiwan Island is controlled by high uplift rates and a strong sub-tropical climate. On average, three typhoons hit the island during the wet season (May to October). These typhoons commonly follow preferential westward pathways, which are mainly controlled by air currents and relief distribution. In Taiwan, most of the erosion is achieved by runoff on hillslopes and transport by rivers with a predominance of suspended and bed loads (Lee, 1976; Li et al., 2005). Moreover, the erosional role of landslides that break away the rock masses and promote rapid outgoing sedimentary fluxes by rivers is particularly important (Hovius et al., 2000; Chen et al., 2005). In turn, the high rates of erosion affecting the island of Taiwan are thought to have a major positive feedback on the tectonic processes by involving high exhumation and uplift rates to compensate for the loss of mass. This feedback is believed to produce a balance between the processes of tectonic accretion and outgoing eroding flows, leading to steady-state topography (Fuller et al., 2006).

For the last thirty years, the erosion rates have been studied in Taiwan by methodological approaches spanning two very different time scales: the short-term (a few decades) from the analysis of the river suspended loads, and the long-term (several hundred of thousands to a few millions of years), using data from low-temperature thermo-chronology and associated thermo-mechanical models. The pioneering study by Lee (1976) involved a calibration

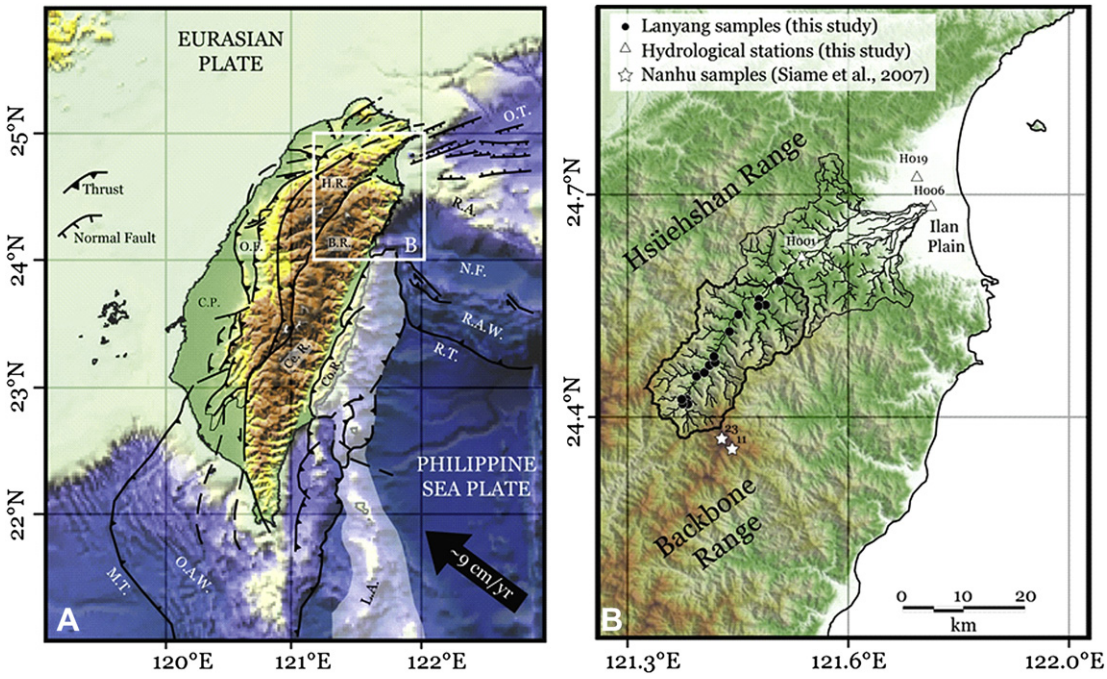

Fig. 1. A: General geodynamic map of Taiwan. Keys: M.T., Manilla Trench; O.A.W., Oceanic Accretionary Wedge; L.A., Luzon Arc; R.T., Ryukyu Trench; R.A.W., Ryukyu Accretionary Wedge; N.F., Nanao Forearc; R.A., Ryukyu Arc; O.T., Okinawa Trench, Co.R., Coastal Range; Ce.R., Central Range; B.R., Backbone Range; H.R., Hsüehshan Range; I.F., Inner Foothills; O.F., Outer Foothills; C.P., Coastal Plain. B: Map of North-eastern Taiwan localizing the studied Lanyang River watershed, the sampled sites for cosmogenic ^{10}Be measurements and hydrological stations used in this article.