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A mass-wasting dominated Quaternary mountain range, the Coastal Range in eastern Taiwan

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ABSTRACT

Fluvial bedrock incision, which creates topographic relief and controls hillslope development, has been considered the key medium linking denudation and tectonic uplift of unglaciated mountains. This article, however, shows a different scenario from the Coastal Range in eastern Taiwan. This range, with the steepness inherited from pre-orogenic volcanoes, has been subject to mass wasting even before its emergence above sea level no earlier than Middle Pleistocene. Numerous terraced alluvial fans/fan deltas record the ancient mass movements of the range, including rock avalanches. Multiple radiocarbon dates <16 ka cal BP reveal the recurrence intervals of these movements of over several thousand years. The largest event is dated ~15 ka cal BP, and the two second largest, 9–8 ka cal BP. These mass movements were sourced from ridges with minimum heights of 350–400 m, have sequences not clearly related to the known climate-change events, and are believed to have been triggered mainly by severe rainfall events, large earthquakes, or their combinations. The resulting fluctuation of sediment yield has episodically changed river behavior, forming river terraces in catchments >1 km^2. Alluvial terraces are typically exhibited close to the source ridges of mass movements, and strath terraces along the downstream parts of rivers. Both were created when enormous sediment supply had exceeded or matched the prevailing river transport capacity. This process, along with the protection by giant boulders from mass movement, disturbed the long-term incision trend of rivers in response to tectonic uplift. As a result, the observed Holocene bedrock incision at most sites has not kept pace with the tectonic uplift. The spatial contrast in mass-wasting histories further accounts for the great diversity of the terrace sequences, even in areas with similar tectonic and base-level conditions.

1. Introduction

River networks incise downward in response to tectonic uplift. This incision then enlarges and steepens hillslopes, setting the threshold for mass wasting. The combination of these two aspects has led to a notion that river bedrock incision plays a primary role in linking denudation and tectonic uplift of non-glaciated mountain ranges (e.g., Howard et al., 1994; Whipple and Tucker, 1999; Whipple, 2004). An appealing implication here is that where tectonic uplift of mountains has been balanced by denudation, the rate of river bedrock incision would be representative of the rate of the uplift, and vice versa (e.g., Lavé and Avouac, 2001; Pazzaglia and Brandon, 2001; Yanites et al., 2010).

On the other hand, more and more studies have emphasized the role of mass wasting in the evolution of mountain ranges (Korup et al., 2010). Catastrophic deep-seated landslides are the most efficient agents lowering landscapes (Strasser and Schlunegger, 2005; Meng et al., 2006; Hewitt et al., 2008), and are often triggered by seismic or meteorological events (see examples in Evans and DeGraff, 2002), not directly by river cutting (Korup et al., 2007). Such landslides also are capable of damming rivers and altering river gradients (Korup, 2006; Ouimet et al., 2007; Korup et al., 2006). Additionally, mass wasting determines the yield/caliber of bedload sediment, which exerts strong controls on the incision of bedrock rivers (Sklar and Dietrich, 2001, 2004; Cowie et al., 2008; Turowski et al., 2008). For example, enormous sediment supplied from landslides can protect riverbeds, hindering

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bedrock incision or even causing river aggradation in rapidly uplifting mountains (e.g., Ouimet et al., 2008; Ray and Srivastava, 2010; Hsieh et al., 2014). Fewer landslides render low sediment yield, which limits bedrock incision due to a lack of tools for abrasion. This scenario suitably explains the reason why bedrock rivers in ancient, tectonically inactive mountains can maintain relatively high gradients for more than ten millions of years (Egholm et al., 2013).

In this article, we use the Coastal Range in eastern Taiwan (Fig. 1), which started growing no earlier than Middle Pleistocene,

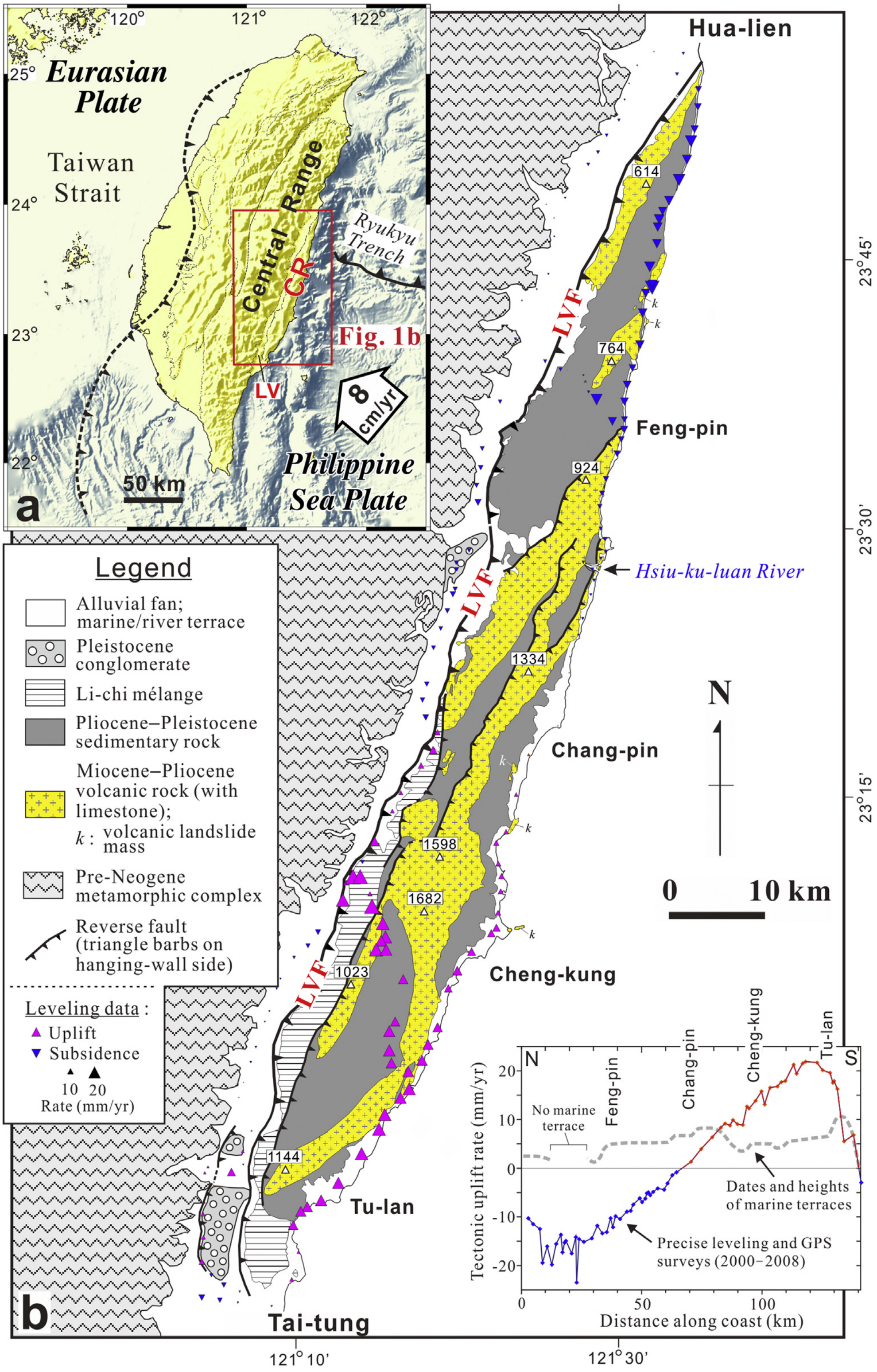

Fig. 1. Study area. (a) Tectonic setting of Taiwan and the locations of the Coastal Range (CR) and the Longitudinal Valley (LV). Open arrow with rate shows the current movement of the Philippine Sea plate relative to the Taiwan Strait of the Eurasian plate based on GPS data (Yu et al., 1997). (b) Geological map of the Coastal Range. Summarized from Wang et al. (1992), Lo et al. (1993), and Chen and Wang (1997). LVF: Longitudinal Valley fault. Also shown are current tectonic uplift/subsidence rates derived from precise leveling and GPS surveys (Ching et al., 2011). Those along the coast, together with the Holocene uplift pattern (dotted lines) deduced from the dates and heights of marine terraces (Hsieh and Rau, 2009; Hsieh and Liew, 2010a), are plotted in the lower right.