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A recursion model to calculate the original widths of narrow terraces and their backwearing rates in a coastal area subjected to regular uplift during the late Holocene

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ABSTRACT

This paper presents a new and simple recursion model to calculate the erosion rates of flights of narrow, late Holocene terraces under conditions of regular uplift. The general equations developed are: $\Delta x_n = \Delta x'_n + \Delta x_{n-1} - \Delta z_{n-1} / \tan\theta_{n-1}$, and $\varepsilon_n = \Delta x_n / (t_n - t_{n+1})$, where n is the number of narrow terraces, Δx_n is the original width of narrow terrace n, $\Delta x'_n$ is the observed width of narrow terrace n, Δx_{n-1} is the original width of narrow terrace $n-1$ (one step below terrace n), Δz is the height of the narrow terrace, θ is the gradient of the slope, and ε is the backwearing (i.e., horizontal erosion) rate. The model can be used to calculate the backwearing rate if the widths of the present shore platform and of the emerged narrow terraces can be obtained, and where chronological control is available. Backwearing rates on the Ashizuri, Boso and Kii peninsulas in Japan were calculated using the model to be approximately 0.001, 0.2–1.0, and 0.009 m/yr, respectively. These calculated values are in agreement with the rates of backwearing directly measured in previous studies.

1. Introduction

To understand the development processes of rocky coast landforms, it is important to understand how rocky coasts erode. Shore platforms provide evidence of coastal erosion (by waves) in the form of shoreline profile data (Trenhaile, 1980, 1987, 2011, 2014; Sunamura, 1992; Stephenson, 2000; Naylor et al., 2010; Stephenson et al., 2013). Numerical modeling of the erosion of rocky coasts has contributed to our understanding of the evolution of shore platforms (Sunamura, 1978; Trenhaile, 2000, 2001a; Walkden and Hall, 2005). Estimations of erosion rates based on direct measurements and maps have suggested that relationships between wave power and rock strength exist and that erosion can be caused by weathering processes, such as the physical (wetting and drying), chemical and biological weakening of coastal rock strength (e.g., Tsujimoto, 1987; Stephenson and Kirk, 2000; Naylor et al., 2012). Erosion rates on rocky coasts measured over short durations (10^0–10^1 years) can differ from those obtained over longer intervals (>10^2 years), as cliff retreat may occur episodically (Trenhaile, 1987; Sunamura, 1992; Castedo et al., 2013). In addition, long-term coastal erosion rates may change progressively over time in response to subsidence, uplift or global sea-level change (Uesawa and Yamaguchi, 2014). Therefore, it is important to obtain erosion rates over various timescales and in different environmental settings.

Island arcs located near subduction zones, such as those in the Japanese arc, are often characterized by extremely high rates of Holocene uplift. These coastlines in such areas commonly exhibit successive flights of narrow marine terraces (Fig. 1) that were created by the coseismic uplift of shoreline platforms during interplate seismic events (e.g., Ota and Odagiri, 1994; Shishikura, 2003; Maouche et al., 2011). As coseismic uplift occurs quickly, the initiation of development of a new shore platform and the timing of uplift of marine terraces are well constrained. However, estimations of the average backwearing (i.e., horizontal erosion) rates of these narrow terraces, based on estimated changes in terrace width and ages of the terraces, may result in underestimates or overestimates of actual erosion rates. For example, the width of an emergent narrow terrace may be less than its original width because of erosion at the back of an actively forming terrace immediately below, which causes the backslope of the actively forming terrace to recede, thereby reducing the width of the emergent terrace above. Thus, determining the correct value for the erosion rate requires a modified approach that takes into account the nature of the erosion system associated with such flights of narrow terraces.

In this study, a simple recursion model is proposed for calculating the backwearing rates of flights of narrow terraces. Although some assumptions and specific circumstances (e.g., regular uplift during the late Holocene) are required, this model estimates the original widths of narrow terraces, and their mean backwearing rates can be calculated

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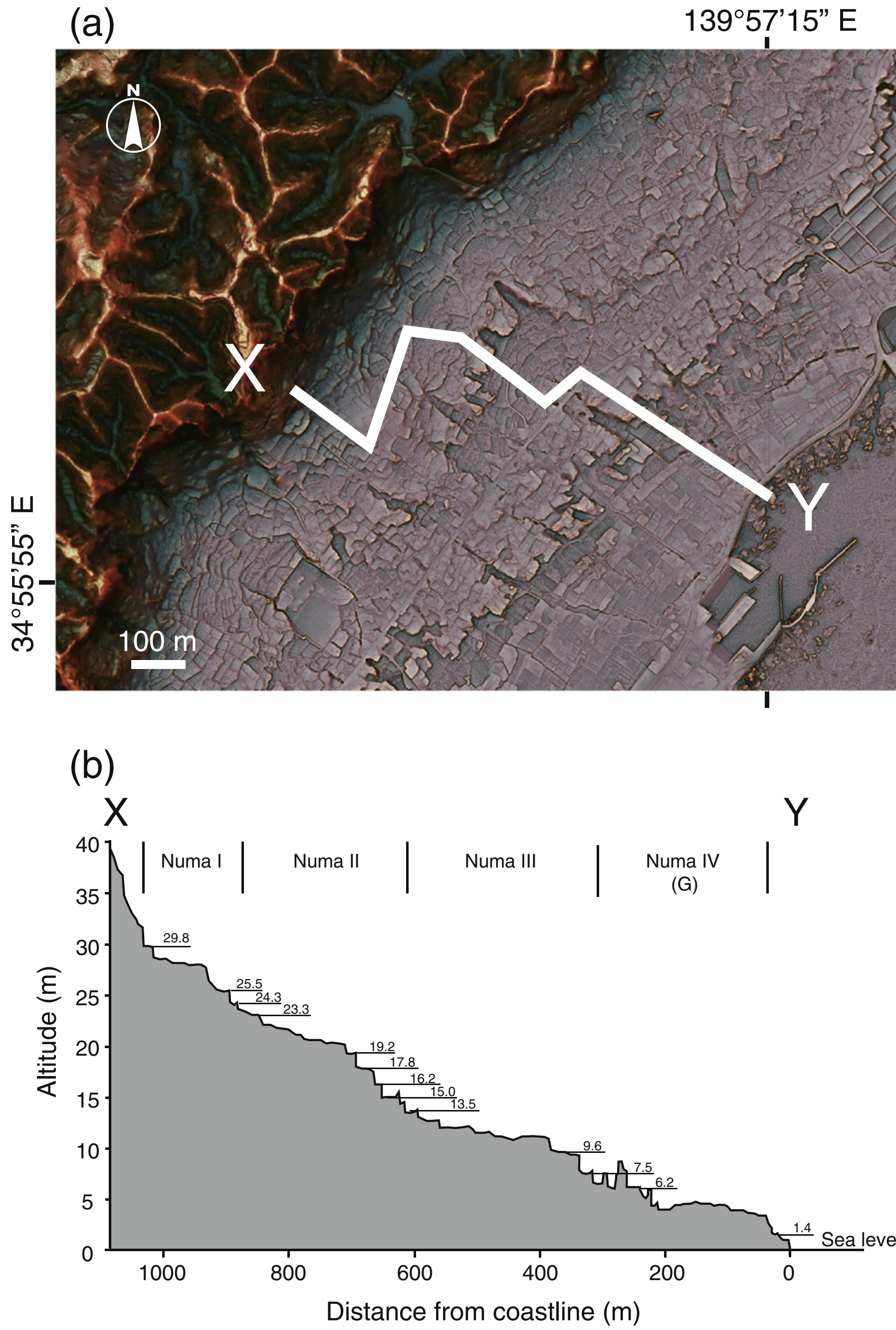

Fig. 1. Red-relief image map (a) and a geomorphic profile (b) of the Holocene lowlands on the southernmost Boso Peninsula. The red-relief image map was produced by Asia Air Survey Co. Ltd. The 0.5 m mesh DEM data were provided by M. Shishikura (AIST). The X–Y profile is modified after Kawakami and Shishikura (2006). Numa I–IV are the names of the narrow terraces. G: narrow terrace that emerged during the Genroku earthquake (1703 AD).

using the observed present width, the amount of uplift, and the timing of the initial uplift of each terrace.

2. Recursion model for calculating backwearing rates of narrow terraces

The recursion model we propose here is based on a simplified version of the erosion processes acting on flights of narrow terraces. Consequently, the model is based on several assumptions. First, we assume that the recession of the seaward margin is negligible as compared with the rate of landward erosion. This first assumption is based on previous studies of the evolution of such shore platforms, from which two theories have been proposed regarding their development: an equilibrium model and a static model (de Lange and Moon, 2005). The equilibrium model states that the entire shore platform migrates landward at a rate controlled by the recession of the associated coastal cliffs, whereas the static model states that the seaward margin of the shore platform is relatively fixed, so that the platform width increases over time as the cliffs retreat (e.g., de Lange and Moon, 2005). However, the static model was criticized by Stephenson (2008) because the data presented by Stephenson and Kirk (1996) should not be interpreted as an indication of the “stability” of the seaward edge of a shore platform. In contrast, although Stephenson (2001) examined the erosion of the front edges of shore platforms using aerial photographs taken 52 years apart, no backwearing of the seaward edge was detectable. On the other hand, Trenhaile (2008) showed that erosion of the seaward