Geomorphology 159-160 (2012) 73–83

Contents lists available at SciVerse ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

The river it goes right on: Post-glacial landscape evolution in the upper Waipaoa River basin, eastern North Island, New Zealand

Basil Gomez [a,*], David M. Livingston [b]

[a] Department of Geography, University of Hawai'i at Mānoa, Honolulu, HI 96822, USA
[b] Department of Water and Power, City of Los Angeles, Bishop, CA 93514, USA

ARTICLE INFO

Article history:
Received 13 December 2011
Received in revised form 8 March 2012
Accepted 12 March 2012
Available online 17 March 2012

Keywords:
Waipaoa River basin
New Zealand
River terraces
Landscape evolution
Incision
Post-glacial

ABSTRACT

Post-glacial incision created 50 to 120 m of relief in the headwaters of the Waipaoa River basin, but it is not known how the signal of incision propagated along the trunk streams. We addressed this issue by imposing previously determined long-term rates of rock uplift, that vary between 0.6 and 4 mm year^{-1}, on the preaggradation longitudinal profile. Acting over the past 27.1 ± 2 cal. ka BP, these rates are sufficient to passively elevate the Waipaoa-1 terrace to its present level. But during the Last Glacial Maximum, rates of vertical incision failed to match those of the uplifting rocks. Thus, by the time favorable conditions for incision were reestablished after the Antarctic Cold/New Zealand Late Glacial reversal we estimate that the channel would have been elevated ≤55 m above the datum the river should otherwise have maintained. The channel incised rapidly after the transition from glacial to interglacial conditions and reacquired its steady-state form in the mid-Holocene (5.5 ± 2 cal. ka BP). Thereafter, we suggest rates of incision matched rates of uplift. No knickpoints are found on the upper Waipaoa and Mangatu Rivers because incision commenced simultaneously along the entire length of the trunk streams, and the pattern of incision is consistent with the downstream decline in the rate of rock uplift. We also used hypsometric analysis to show how post-glacial incision affected the surface morphology of low order (0.1–4.3 km^2) drainages in the headwaters of the Waipaoa River basin. Values of the hypsometric integral are higher for proximal basins, which the incision signal did not permeate, than for low-order basins bordering the upper Waipaoa River and the lower reaches of tributaries that possessed enough erosive capacity to keep pace with incision along the mainstem. Hillslope adjustments were focused on the lower and mid-sections of these basins so that the most pronounced changes to the hypsometric curve occur in the vicinity of the toe, whereas the entire form of the hypsometric curve changes once mass wasting processes encroach onto hillslopes in the middle and upper sections of a basin.

1. Introduction

In regions where rates of tectonic rock uplift are high there is potential for rivers to incise as they are elevated above base level (Gilbert, 1877). However, the way incision is accomplished is, in large part, dependent on the manner in which the fluvial system responds to changes in climate, which determines the availability of sediment and the river's ability to mobilize and transport it downstream (Bull and Knuepfer, 1987). Moreover, as the legacy of incision that river terraces preserve attests, because rates of rock uplift are unsteady and climate is susceptible to change, rates of river incision and rock uplift are not always closely balanced over millennial timescales (Hancock and Anderson, 2002; Wegmann and Pazzaglia, 2009).

The major, unglaciated river basins draining the actively uplifting subduction margin on the east coast of New Zealand's North Island contain a suite of four intercorrelated fill terraces, the youngest and most widespread of which is interpreted to have formed during the Last Glacial Maximum (Marine Isotope Stage 2) when it is inferred that drier conditions favored aggradation (Litchfield and Berryman, 2005). In the Waipaoa River basin, where the aggradation gravels form the Waipaoa-1 terrace (Berryman et al., 2000; Marden et al., 2008), knickpoint retreat may have been responsible for transmitting the pulse of incision throughout the drainage network. However, the history of incision in one locale may not be representative of the history at other points in the drainage network. Thus, the knickpoints present in tributaries may not be characteristic of the adjustment that occurred along the trunk stream (Crosby, 2006; Crosby and Whipple, 2006). Understanding the nature of the adjustment in the Waipaoa River basin is crucial to comprehending the broader landscape response to fluvial incision and to interpreting the post-glacial record of fluvial processes preserved on the adjacent continental shelf (Carter et al., 2010).

In this paper, with reference to the accepted elevation and age of the Waipaoa-1 terraces bordering the upper Waipaoa and Mangatu

* Corresponding author. Tel.: +1 808 956 8465; fax: +1 808 956 3512.
E-mail address: basilg@hawaii.edu (B. Gomez).

0169-555X/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.geomorph.2012.03.006

Rivers and regional pattern of late Quaternary uplift (Berryman et al., 2000; Litchfield and Berryman, 2006; Marden et al., 2008), we place age constraints on and reevaluate the mechanism for rapid post-glacial incision in these two neighboring and deeply incised headwater basins (Fig. 1). Then, using high resolution (2 m) digital elevation data, we show how hypsometric analysis can be used to quantify the response that low order channels in the upper Waipaoa River basin had to the post-glacial drop in base level.

2. Tectonics, climate and morphology

The Waipaoa River basin lies within the active forearc of the Hikurangi subduction margin. In the basin headwaters, the pattern of uplift is determined by an anticlinal uplift zone in the basement-cored axial ranges; and uplift rates are thought to be enhanced by the subduction of seamounts, sediment underplating, and tectonic erosion of the subduction margin (Litchfield et al., 2007). Late Quaternary uplift rates derived from pairs of fill terraces in locations where tephra coverbeds provide age control decrease rapidly on the eastern flanks of the uplift zone, from ~4 mm year^{-1} at the crest of the axial Raukumara Range to between 0.5 and 0.9 mm year^{-1} in the middle reaches of the Waipaoa River basin (Berryman et al., 2000; Litchfield and Berryman, 2006). Pollen in marine cores from the Bay of Plenty (core S803) and the Wairarapa coast (core P69) provide a record of changes to the climate of the eastern North Island during the late Quaternary (Wright et al., 1995; McGlone, 2001; Figs. 1 and 2). These marine-derived terrestrial records indicate that the transition from dry, cold conditions to milder climates began ~18.5 cal. ka BP, which is in broad agreement with terrestrial records derived from speleothems (Williams et al., 2010). Warmer, wetter conditions were reinstated after the termination of the cool (Antarctic Cold/New Zealand Late Glacial) reversal, from ~12.5 cal. ka BP (Wright et al., 1995; McGlone, 2001; Hadjas et al., 2006; Williams et al., 2010); and the transition to a more variable climate occurred at ~6.5 cal. ka BP.

Genesis of the Waipaoa-1 terrace in the upper Waipaoa River valley, and the equivalent fill terrace elsewhere on the East Coast of the North Island, is interpreted as being a response to the transition to an interglacial climate (Berryman et al., 2000; Formento-Trigilio et al., 2002; Litchfield and Berryman, 2005; Marden et al., 2008). The drier, colder glacial climate is thought to have favored physical weathering and enhanced rates of sediment production on hillslopes in the headwaters of the Waipaoa River basin (Gage and Black, 1979). Aggradation commenced within the time span bracketed by the ~31 cal. ka BP Omataroa and 27.097 ± 0.957 cal. ka BP Kawakawa tephras (Litchfield and Berryman, 2005). Material eroded from the hillslopes filled the river valley to a depth of between 10 and 30 m, and the aggradational surface continues (as the Matokitoki gravel) beneath the Poverty Bay Flats (Gage and Black, 1979; Brown, 1995; Berryman et al., 2000). A point ~50 km upstream (~33 km upvalley) where the terrace emerges above the modern floodplain in the vicinity of Te Karaka (Figs. 1 and 3) delimits the post-glacial upstream limit of base level control. Here the Waipaoa-1 terrace is preserved on three levels, separated vertically by between 2 and 15 m (Berryman et al., 2000; Marden et al., 2008), and it has been traced for a further ~30 km upvalley along the upper Waipaoa and Mangatu Rivers (Figs. 3 and 4). In the upper reaches of these rivers, the Waipaoa-1 terrace attains a maximum elevation of between

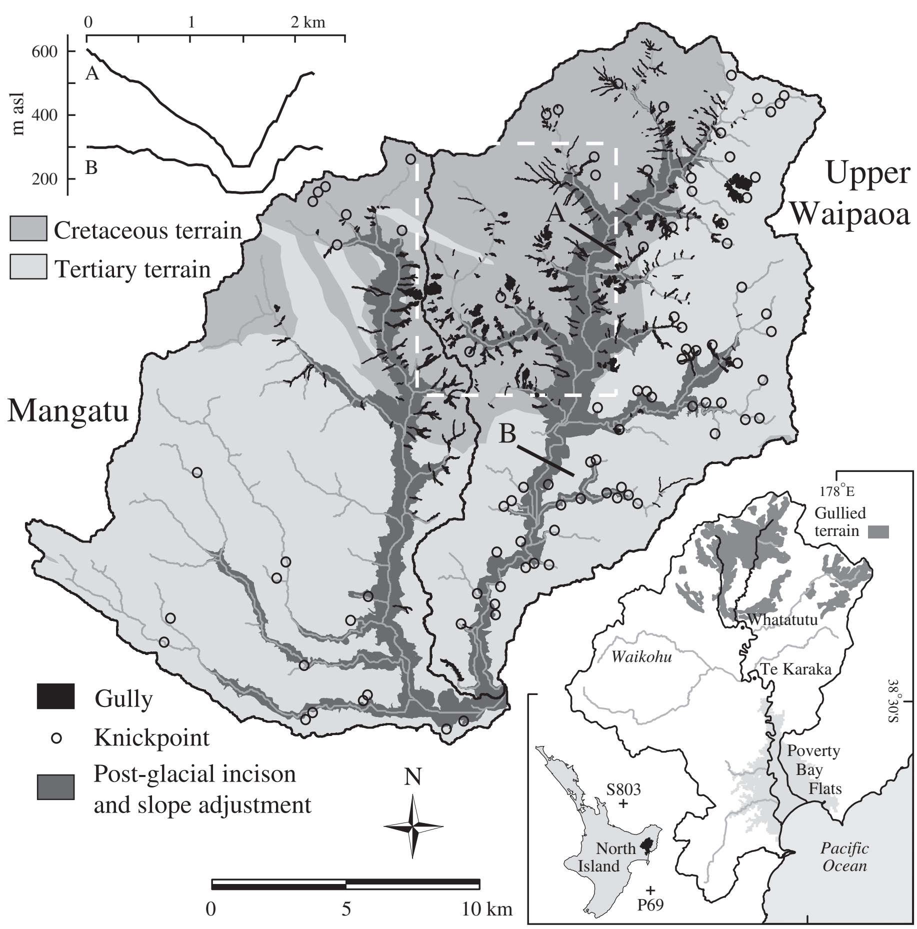

Fig. 1. Generalized bedrock geology, location of knickpoints and gullies (after Marden et al., 2005; Crosby and Whipple, 2006), and portions of the landscape that have responded to post-glacial incision in the upper Waipaoa and Mangatu River basins. Solid lines labeled 'A' and 'B' indicate the locations of the valley cross sections shown in the inset, and the dashed rectangle (white) delimits the area depicted in Fig. 6. Location maps show the extent of the gullied terrain in the Waipaoa River basin as a whole and locations and core sites referred to in the text.