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Landform development of mountains and rivers in Japan

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ABSTRACT

The geomorphic development of Japanese mountains and rivers during the Quaternary is the result of tectonic effects, sea-level change and climate change. The majority of the Japanese archipelago is being uplifted, with its mountains rising at rates ranging from 0.1 to 7 mm/y, as calculated by the mean altitudes of mountains under the assumption that they are in equilibrium between uplift and erosion. Filltop terraces built by climate-controlled accumulation of gravel are distributed throughout central and northern Japan. These terrace surfaces formed during glacial periods, and their surface ages are progressively younger upstream. This phenomenon was caused by sea-level lowering. These fluvial terraces are keys to reconstruction of geomorphic and topographic changes in Japanese mountain.

Yonekura et al. classified the 61 mountainous areas of Japan into seven types, from the steepest type I to the gentlest type VII, on the basis of a steepness metric incorporating mountain heights, a steepness along the longitudinal and transverse profiles of ridges, and the heights of ridges relative to the valley floors. Half of Japanese mountains (types I to III) are in a state of equilibrium between uplift and erosion. Slowly rising or young mountains (types V to VII) have preserved uplifted peneplains on their tops and are not in the state of equilibrium.

A proposed classification of river morphology into upper, middle and lower reaches, combined with the seven types classification of mountain morphology offers insight into the Quaternary development of Japanese landforms. The lower reaches of rivers in Japan are defined as lower area in elevation than the aggradation limit of sea level change. Terraces here are controlled by sea-level change. The middle reaches are defined as the part between point AL and the upstream limit of river terraces. Several terraces of older to younger ages are formed in middle reaches, indicating that the middle reaches are also uplifting. Sea level acts as the base level of erosion in the lower and middle reaches. River terraces are not formed in the upper reaches. Down-cutting for terrace emergence ceased at the LR, suggesting that the LR is stable. The upper reaches are defined by the LR point, which acts as a local base level of erosion.

1. Introduction

Fluvial terraces are well developed and abundant in Japan. The occurrence of several fluvial terraces in a river basin reflects a relatively long history concerning to elevation changes of the river bed, and careful studies can supply significant information on the history of regional geomorphology, including the development of the mountains of Japan.

The Japanese island arc, part of an active subduction zone, has a rainy climate in the temperate zone. The mountainous relief of Japan thus is the result of tectonic uplift and vigorous erosion by rivers. The present Japanese mountains are inferred to have formed mainly in Quaternary time, after slow uplift starting around 5 Ma and an acceleration of uplift from 2 to 1 Ma (Ota et al., 2010). Fluvial, lacustrine, and shallow marine successions of Plio-Pleistocene age are widely distributed in Japan and are considered to have formed on a subsiding lowland. Uplift rates in most mountain areas of Japan increased greatly in the Quaternary (eg. Huzita and Ota, 1977).

Rivers are actively eroding mountains in Japan, and the existence of several knickpoints suggests that uplift may be exceeding erosion. Whereas sea level usually acts as the base level of erosion, in the mountains of Japan, major rivers and basins act as local base levels such that landform development in the mountains is largely influenced by river erosion and deposition. Climatic control of terrace formation was proposed by Bauling (1935) in the Rhone River valley, where a valley-floor plain was formed by an outpouring of glacially derived gravel during the last glacial stage, then incised during postglacial time to form terraces. Similar

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features are observed in the rivers of central and northern Japan, but glacial landforms are limited. Kaizuka (1977) and Takagi (1990) demonstrated climate-controlled terrace formation in the Tama River valley of central Japan.

This paper reviews significant developments in research on river terraces in Japan over the last 30 years, most of them published in the Japanese literature and summarized by Yanagida (2009). This paper also discusses the effects of climate and sea-level change on terrace formation. Fig. 1 shows Japanese rivers with terraces, including those mentioned in this paper, and Table 1 lists information about these terraces.

uplift rates. However, this method relies on the assumption that all mountains are in equilibrium between uplift and erosion. Yoshiyama and Yanagida (1995) proposed three methods to obtain more accurate uplift rates. Their TT method relies on the relative heights of different terraces (Fig. 2). The elevations of river beds and river profiles are controlled by sea-level change and climate change. Terraces form repeatedly in glacial–interglacial cycles, such that glaciation related terraces from MIS 6 (about 140 ka) and MIS 2 (about 20 ka) would have similar profiles. Therefore, the elevation difference between terraces dating from MIS 6 and MIS 2 (TT in this paper) indicates the uplift during a period of about 120 ky. Similarly, their buried-valley method relies on the value of BV and BB, the elevation difference between the buried valley floor of MIS 5 age and the modern river bed (BV in this paper), the elevation difference between the buried valley floor of MIS 7 and MIS 5 (BB in this paper, Fig. 2). The values of TT and BV are most similar in the middle reaches of Japanese rivers. Fujiwara et al. (2005) adapted these methods to prepare a bedrock uplift map of Japan from the elevations of marine terraces and river terraces, which shows average uplift rates of 0.2–0.6 mm/y and maximum rates of 2 mm/y, but uplift rates were not estimated in the center of

Table 1
Correlation of the Late Quaternary fluvial terraces in Japan.

River name	Catchment area (km^2)	MIS 1	MIS 2	MIS 3	MIS 4	MIS 5.1–5.4	MIS 5.5 (coastal terrace)	MIS 6	Older than MIS 6	References
Yubetu River	1493		2		3		5	(4)		Koaze et al. (2003)
Tokachi River	8780	KoIV	KoIII	KoII	KoI		OIV	KsIII	KsII, Ks I	Hirakawa (1974)
Saru	1350									
Atsubetu	292		MwII	MwI	Ms	Ks	Mn5	Ty		Yanagida (1991)
Monbetu Rivers	107									
Hidaka-horobetu	338		Mw		Ms		Ac	To	Hh	Iwasaki et al. (1991)
Motoura Rivers	240									
Kitakami River	10,720		L1		M2			M1	H2.H1	Matsu'ura et al. (2007a)
Naruse River	1133		Ajigahukuro	Dainohara				(Yakurai)	Urushizawa	Toyoshima (1986)
Natori River	967		Lf3	Lf2	Lf1			Mf	Hf	Hataya et al. (2005)
Agano River	7340			Nozawa	Tokusawa			Shibasaki	Nishidaira	Yanagida (1979), Yoshiyama and Yanagida (1995), Yanagida (1979), Yoshiyama and Yanagida (1995)
Uono River	1551	Lf4	Lf3	Lf2	Lf1			Mf	Hf3, Hf2, Hf1	Hataya et al., 2006
Tsunan (Nakatsu River)	346	Oowarino2	Oowarino1	Shoumen	Kaizaka			Hounokizaka	MaibaraI, MaibaraII, Tanigami	Hayatsu and Arai (1981), Hataya et al. (2006), Hayatsu and Arai (1981), Hataya et al. (2006)
Kurobe River	682			LL1	LH1			M1	H4, H3, H2. H1	Matsu'ura et al. (2007b)
Matsumoto Basin (Azusa River)	1226		Kamikaido	Moriguchi	Hata			Osakada	Nashinoki	Matsumoto Basin Collaborative Research Group (1977)
Ina Basin (Tenryu River)	5094			Nakagoshi and Hongo	Toriihara			Rokudoubara		Matsushima and Teradaira (1999)
Nakagawa River	3269		Lf3	Lf2	Lf1			Mf	Hf	Hataya (2006)
Ara River	2940		Onohara	Kagemori	Oyahana			Hitsujiyama	Odamaki	Yoshinaga and Miyadera (1986)
Usui River	291		IVs	IVf	III			IIf	Is,If, H	Sugai (1993)
Tama River	1235	Aoyagi	Tc3	Tc2, Tc1	M3	M2, M1	S	(Tokorozawa)	T-a, T-b, T-c, T-d, T-e	Kaizuka et al. (1977)
Sagami River	1804		Minahara	Tanahara	Nakatsuhara	Sagamihara	Koza	Oosawa		Kubo, 1997
Eastern foot of the Suzuka Range	–		L2	L1	M2	M1	M1	H2	H1	Ota and Sangawa (1984)
Miya River	850			Tanahashi				Kamise		Nogami et al. (1979)
Yoshino river	3650			Ichiba				Nagamine	Higher terraces	Okada (1970)
Northern foot of the Ishiduchi Range	–			Lower				Middle	Higher terraces	Okada (1973)

2. Estimation of Quaternary uplift of mountains and river valleys in Japan

Marine terraces have been intensively studied to estimate uplift rates in Japan. Elevations of marine terraces correlated with marine isotope stage MIS 5.5 are important indicators for this purpose. However, it has been difficult to evaluate the uplift rates of the central mountain ranges because of their distance from marine terraces. Ohmori (1987) calculated uplift rates on the basis of the mean height of mountains, such that high mountains have high