Quaternary Science Reviews 91 (2014) 42–61

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Vertical tectonic crustal movements along the Japanese coastlines inferred from late Quaternary and recent relative sea-level changes

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ARTICLE INFO

Article history:
Received 10 December 2013
Received in revised form
7 March 2014
Accepted 14 March 2014
Available online

Keywords:
Glacio-hydro isostatic adjustment
Relative sea-level
Last Interglacial
Mid-Holocene
Tide gauge
Thermosteric sea-level change
Vertical crustal movement

ABSTRACT

Observed relative sea-level (RSL) changes during the past ~130 kyr make it possible to evaluate the vertical crustal movement due to several tectonic processes such as the subduction of oceanic plates. Here we infer average rates of tectonic crustal movement along the Japanese coastlines on three typical timescales of ~50 yr, ~6 kyr and ~125 kyr based on tide gauge and Holocene RSL observations and the altitudes of marine terraces formed at the Last Interglacial (LIG) phase at ~125 ka. The rates on a timescale of ~50 yr are derived from tide gauge data, thermosteric sea-level changes due to thermal expansion of the oceans and predictions due to the glacio-hydro isostatic adjustment (GIA) for the last deglaciation and also recent melting of the mountain glaciers and Greenland and Antarctic ice sheets. Those for ~6 kyr and ~125 kyr are based on the RSL observations and the predictions by GIA modelling, considering uncertainties for temporal changes in eustatic sea-level for the mid- to late-Holocene and LIG phase. The inferred rates for ~50 yr are significantly different from those for ~125 kyr in most sites, particularly for sites along the coastline from eastern Hokkaido to northeastern Japan, Shikoku and south Kyushu facing the Pacific Ocean. In these regions, the rates for ~125 kyr and ~50 yr are positive (uplift) and negative (subsidence), respectively. Also, the observed RSL changes at ~6 ka are consistent with the inferred RSL changes using the rates for ~125 kyr and GIA-predictions in many sites, but inconsistent with those for ~50 yr in most sites except for a few sites. These results suggest that the rates on a timescale of ~50 yr are not representative of the tectonic crustal movements for timescales longer than ~6 kyr in most sites along the Japanese coastlines. However, the inferred rates on these timescales may be useful in discussing the recurrence of megathrust earthquake with its interval of ~1 kyr such as the 2011 earthquake off the Pacific coast of Tohoku.

1. Introduction

Observed relative sea-level (RSL) changes, changes in sea-level relative to the present sea-level, during the late Quaternary are mainly caused by change of ocean volume, tectonic crustal movement and glacio-hydro isostatic adjustment (GIA) of the Earth in response to the redistribution of ice and water loads. In this paper, we define tectonic movement as vertical crustal movement that does not include the component of crustal response due to the late Quaternary glacial cycles and recent melting of mountain glaciers and the Antarctic and Greenland ice sheets. That is, RSL changes by tectonic crustal movement reflect the crustal responses associated with the tectonic processes such as plate subduction and seismic activity. The RSL changes for tectonically stable areas such as the Australian continental margins mainly reflect the eustatic and GIA process (Nakada and Lambeck, 1989), but those for tectonically active areas such as Japanese Islands are strongly influenced by spatially and temporally non-uniform crustal movements associated with the subduction of oceanic plates (e.g., Yonekura, 1989). Therefore, it is very important to separate the tectonic and GIA components in examining the tectonic processes and rheological structure from observed RSL changes at tectonically unstable areas (e.g., Nakada et al., 1991). For example, the separation makes it possible to estimate the vertical displacement induced by regional tectonic activity pertaining to long-term earthquake recurrence related to

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http://dx.doi.org/10.1016/j.quascirev.2014.03.010
0277-3791/

plate subduction (e.g., Lambeck et al., 2004). In this study, we examine the tectonic crustal movements of the Japanese Islands based on the observed RSL changes for the past ~130 kyr (kilo-year) available now, which may be a societal demand after the 2011 earthquake off the Pacific coast of Tohoku (e.g., Miyazaki et al., 2011).

For sites far away from both polar ice sheets (far-field), the observed RSL changes from the Last Glacial Maximum (LGM) to approximately 6–7 ka are dominated by the eustatic component due to the melting of both polar ice sheets (Nakada and Lambeck, 1988). The observed RSL changes for the past 6–7 kyr in nearly the post-glacial phase are, however, mainly controlled by mechanisms such as the GIA, together with local and regional tectonics (Clark et al., 1978). Mid- to late-Holocene RSL changes in tectonically stable areas such as the Australian continent primarily reflect the GIA contribution and observations for such areas are important in examining the rheological structure of the mantle and for inferring the minor mid- to late-Holocene melting of the Antarctic ice sheet (Nakada and Lambeck, 1988, 1989). The RSL changes at most sites for the tectonically active Japanese Islands are, however, generally affected by local and/or regional tectonics. For postglacial RSL changes in Japanese Islands, it should be possible to extract the GIA component by examining the crustal tilting derived from systematic RSL observations (Nakada et al., 1991; Maeda et al., 1992). This method was first adopted by Nakada and Lambeck (1989) and applied to the RSL changes for the Great Barrier Reef with systematic and reliable observed RSL changes in estimating the crustal tilting (Lambeck and Nakada, 1990). Such a method is, however, available for a few limited areas in Japanese Islands (e.g., Nakada et al., 1991).

Lambeck et al. (2004) examined the RSL changes for the past 12 kyr in Italy using the elevation of the Last Interglacial (LIG) marker (~125 ka), corresponding to marine isotope stage 5e, as a benchmark to assess tectonic stability at sites along the Italian coastlines. In the Japanese Islands, we have many Holocene sea-level observations and the data for many marine terraces formed at the LIG shown in Fig. 1, in which the data for the LIG were compiled by Koike and Machida (2001) [see also Ota and Omura (1991) and Pedoja et al. (2011)]. These data have been used to

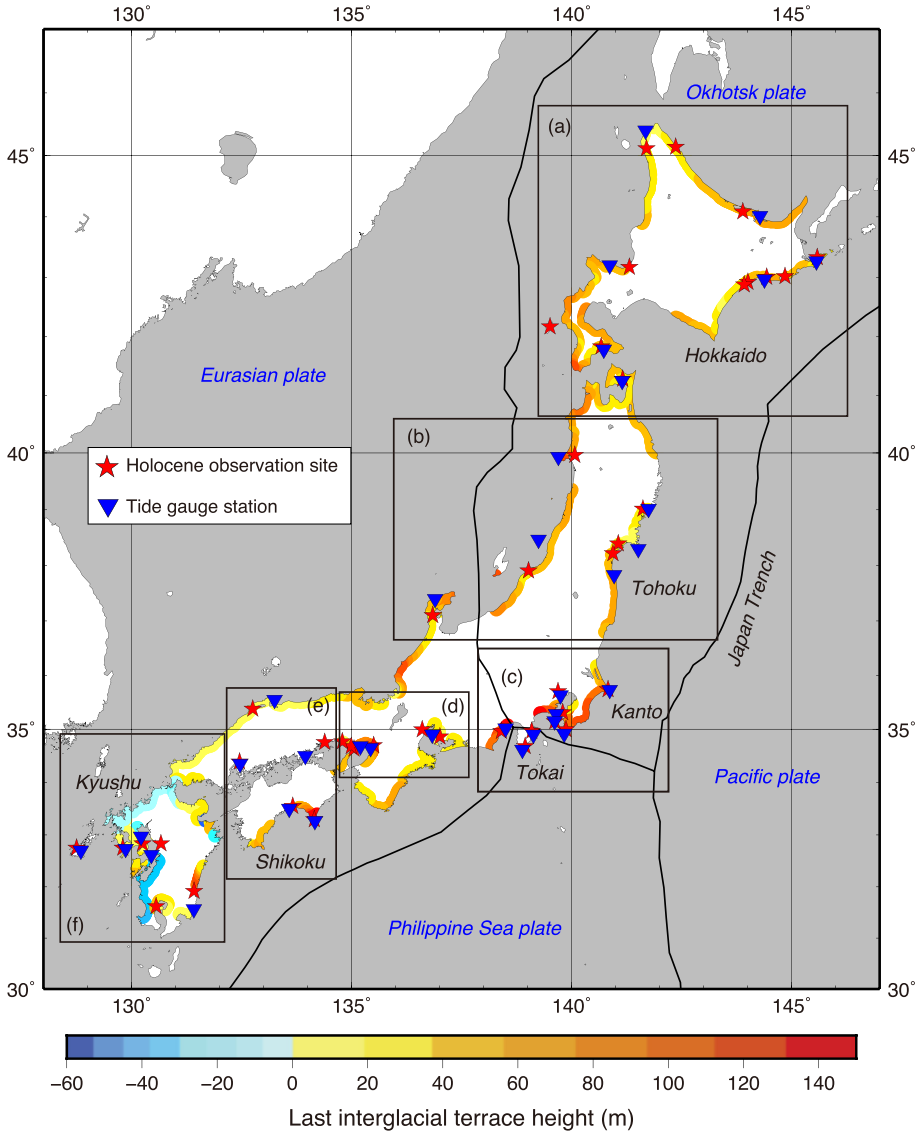

Fig. 1. Locations map used in this study and the plate boundaries around the Japanese Islands. The symbols of red star and inverted-triangle indicate the sites of Holocene RSL observations and tide gauge stations (see Tables 1 and 2 for more detailed information), respectively, and the distribution of LIG terrace elevations compiled by Koike and Machida (2001) [see also Ota and Omura (1991) and Pedoja et al. (2011)] are also shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)