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Holocene crustal movement along the coast of western Kobe, and the 1995 Hyogoken-Nanbu Earthquake, Japan

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The 1995 Hyogoken-Nanbu Earthquake in Japan, which has been attributed to the Nojima fault of the Rokko-Awaji fault system, resulted in vertical uplifts of 0.19 m at Tarumi and 0.07 m at Akashi, relative to Takasago. Here we evaluate these uplifts in the context of Holocene local tectonics derived from relative sea-level (RSL) records. The RSLs during the mid to late Holocene are considered to reflect the sum of glacio-hydro-isostasy and local tectonics, of which the hydro-isostatic contribution has been quantitatively modelled for the Japanese coast. For the purpose of this study, we estimate the Holocene relative uplift via a comparison study of observed and predicted sea-level variations along the traverse from Takasago to Tarumi and Akashi. These estimates are then applied to evaluate the uplift associated with the fault system responsible for the 1995 earthquake.

The sea-level variations for each site are evaluated by using the depositional environment of the sediment derived from the diatom and sulfur content, and its derived age. The age of the sediment is based on 14C dates and Kikai-Akahoya tephra (K-Ah), which is a widespread marker tephra in Japan. Radiocarbon ages are calibrated to calendar year (cal BP). In this study, we adopt about 7300 cal BP as the caribrated age for K-Ah.

In most coastal regions of the Japanese Islands, the 'Jomon transgression' culminated during the mid-Holocene. A subsequent regression led to a transition in sedimentary facies from marine to freshwater. Diatom floras also changed during the transition. Thus the altitude of the upper limit of marine facies, which provides direct evidence for the marine limit, is recognized by the horizon where diatom assemblages in the sediments change from marine or brackish-water diatoms to freshwater ones. The upper limit of Holocene marine facies is referred to here as the 'Holocene marine limit (HML)'.

In our study the HML provides a RSL index point, and reasonable index points are also indicated by intertidal sedimentary situations. The RSL identified by intertidal diatoms and/or shells is an approximate index for the PMSL. Taking account of situations that selected species of diatom live over, the present spring tidal range (Takasago:0.40 m, Tarumi:0.40 m, Akashi:0.30 m) is given for probable vertical range of the RSL index point in which the PMSL occurs, as there is no information on paleo- tidal range. For surveying errors and uncertainties associated with sampling procedures, an estimate of 0.10 m is also incorporated into the overall error figure.

A rate of tectonic uplift of between 0.1 mm and 0.3 mm per year, corrected for the prediction, fits well with RSL index points of Akashi at 6415-5320 cal BP. Depending on the altitude of the RSL index point of +2.20 m at about 5700 cal BP, the best estimate of the rate of tectonic uplift for Akashi is calculated as 0.11-0.25 mm/yr over the period concerned. A rate of tectonic uplift between 0.3 mm and 0.5 mm per year is derived for Tarumi at the altitude of +1.90 m with an age of about 7300 cal BP and +2.06 m with an age of 3835-3365 cal BP. Depending on the altitude of the RSL index point of +0.60 m at the interception age of 6790 cal BP, the best estimate of the rate of tectonic subsidence for Takasago is calculated as 0.08-0.23 mm/yr over the period concerned. This value permitted us to evaluate rates of uplift at Tarumi and Akashi relative to Takasago.

Uplift rates of 0.38-0.73 mm/yr and 0.19-0.48 mm/yr are thus derived for Tarumi and Akashi, respectively, relative to Takasago. This suggests that the cumulated vertical uplift due to the Nojima fault activity, with a recurrence interval of approximately 2000 yr, may contribute at most 25% of the Holocene uplift proposed for the tectonically active coast of western Kobe.