Relationship between the coseismic uplift during the 2024 Noto Peninsula earthquake and Holocene marine terraces

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The 2024 Noto Peninsula earthquake (M7.6) caused a large uplift due to the activity of submarine active faults surrounding the northern Noto Peninsula (Fig. 1b). It was accompanied by coastal emergence, which produced some emerged features. The littoral sessile organisms attached to reefs and harbor dike walls were dried up, and wave-cut benches formed around the mean sea level raised and created marine terraces (Fig. 1c). These heights are consistent with the amount of uplift revealed by geodetic observations by the GSI. Although a little subsidence due to post-seismic relaxation may occur, most of the uplift will likely be permanent displacement. Therefore, emerged features such as sessile organisms and marine terraces will be preserved in the future if they are spared from erosion.

Older emerged features were also observed along the Noto Peninsula as traces of past uplifts even before the 2024 Noto Peninsula earthquake. This suggests that similar earthquakes have occurred, and uplift has been repeated. For example, the M6.9 earthquake of 25 March 2007 in the north-west of the Noto Peninsula caused an uplift of up to 50 cm, and the emerged sessile organisms were found (Awata et al., 2008), while the same amount of uplift was also found in the same area approximately 1000 years ago (Shishikura et al., 2009). In addition, an M6.5 earthquake on 5 May 2023 in the north-eastern Noto Peninsula caused an uplift of up to 24 cm (Shishikura et al., 2024). The northeastern Noto Peninsula may have also been uplifted by a historical earthquake (inferred M6.6-7.0) with a damage record in 1729. Emerged sessile organisms have been found on the coast of the area, dating more than several hundred years ago, and less than 80 cm uplift has been estimated (Hamada et al., 2016). Thus, earthquakes of less than M7 with an uplift of less than 1 m have occurred in various parts of the peninsula. Still the uplift is relatively small compared to the 2024 Noto Peninsula earthquake and their effects are spatially limited. The active faults around the northern Noto Peninsula can be roughly divided into four segments (Inoue and Okamura, 2010), and these relatively small earthquakes occurred in each segment, though the 2024 Noto Peninsula earthquake is considered to be of larger magnitude due to the multi-segment rupture.

Holocene marine terraces divided into three levels (called L1–L3 in descending order), which are estimated to have been formed within the last 6000 years are identified along the northern coast of the Noto Peninsula (Fig. 1a; Shishikura et al., 2020). The distribution of terraces is intermittently but almost the same as the area uplifted by the 2024 Noto Peninsula earthquake, indicating that the entire area was uplifted in the past. The highest L1 elevation is distributed in the western part of the Noto Peninsula, coinciding with the location where the largest uplift was recorded during the 2024 Noto Peninsula earthquake. This indicates that large uplift earthquakes with a magnitude of over M7.5, similar to the 2024 Noto Peninsula

earthquake, may have occurred at least three times in the past 6000 years and that the 2024 Noto Peninsula earthquake newly formed the L4 surface. The age of each terrace surface is not yet clear at present, but on average they occur with recurrence intervals of a thousand to several thousand years.

As described above, earthquakes that occur on the Noto Peninsula have a hierarchical nature: earthquakes of less than M7 that occur in single segments uplift less than 1 m, while earthquakes of a magnitude of over M7.5 that occur in multi-segment rupture with a frequency of a thousand to several thousand years are considered to uplift significantly and form marine terraces. However, because the distribution of marine terraces is intermittent, the timing of uplift may vary from place to place, even for terraces of the same level identified by topographic succession. To discuss this in detail, it is necessary to determine the emergence age of terraces in each segment.

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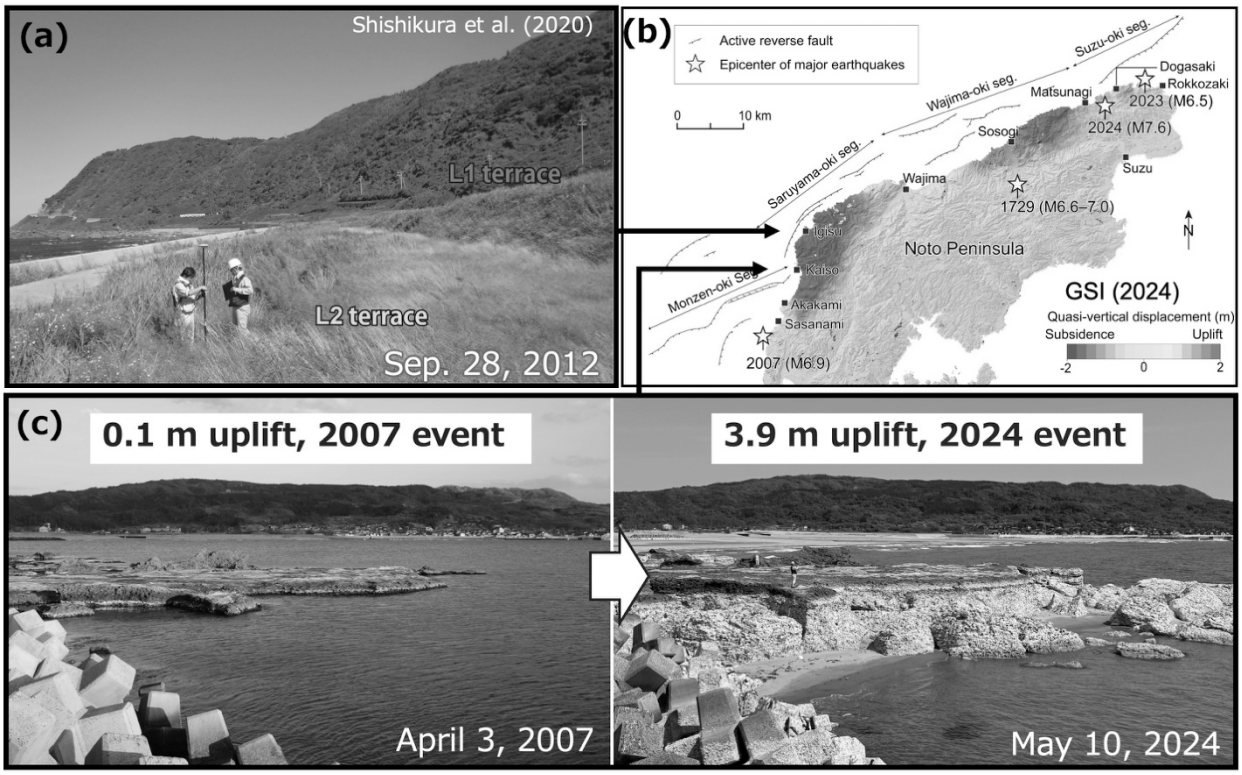

Fig.1 (a) Holocene marine terraces in Igisu. (b) Vertical crustal deformation caused by the 2024 Noto Peninsula Earthquakes (GSI, 2024), the location of submarine active faults and epicenters of major earthquakes. (c) Geomorphic change of the Kaiso coast due to the 2024 Noto Peninsula Earthquake.