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Spatiotemporal variability of earthquake surface rupture behavior and its implications for seismic hazard assessment: insights from paleoseismology of recently appeared surface ruptures in northeast Japan

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The 14 June 2008 Mw 6.9 Iwate-Miyagi Nairiku earthquake struck the mountainous region in northeast Japan and was accompanied by 20-km-long thrust-faulting surface rupture with generally ~50 cm vertical offset. Since these breaks occurred where no active fault trace had been mapped, we have been pursuing its predictability retrospectively for improving seismic hazard assessment. Here we argue the spatiotemporal variability of surface breaks of the past events in and around the Iwate-Miyagi seismic source. Diversity of rupture patterns for intra-plate thrust fault is particularly less understood than the ones for subduction megathrust, inland strike-slip and normal faults. To recover paleoseismic evidence from the 2008 rupture zone, we performed detailed tectonic-geomorphic mapping, paleoseismic trenching, radiocarbon dating and tephrochronologic age determination. We first focused on a site (Hanokidachi) on the central part of the rupture zone, which is characterized by a ~1 km long and ~0.2 km wide pop-up structure wedged between the west-dipping main thrust and an east-dipping back-thrust which also faintly ruptured at the 2008 event. A high-resolution geomorphic image mapped by the post-earthquake airborne-LiDAR clearly displays a-few-meter-high fault scarps on the late Pleistocene to Holocene fluvial terraces, which is suggestive of past surface-rupturing earthquake(s). We excavated two trenches across the back-thrust scarp on the terraces that is inferred to have formed at ca 10-20 ka. The trench walls exposed evidence for at least three surface-rupturing events including the 2008 one since ca 20 ka. Retrodeformation analyses also enabled us to measure the amount of surficial slip due to each event, which is substantially larger than that of the 2008 event. The other intensive study site (Okayama) ~2 km north of Hanokidachi also showed the similar irregular rupture behavior. A flight of fluvial terraces at Okayama is developed across the 2008 rupture trace. Our survey revealed that the older terrace formed at ca 80-50 ka is warped to form the distinct 2- to 3-m-high east-facing scarp, whereas the younger terrace of ca 20-10 ka shows no identifiable scarp except the 10-30-cm throw of the 2008 event. This is inconsistent with that the multiple events occurred during the past 20,000 years at Hanokidachi. A trench across the scarp on the older terrace exposed 2 to 2.5 m of vertical separation of fluvial sediments by a single thrust event, which is consistent with the 2- to 3-m-high topographic throw. Our comprehensive interpretation from these two sites is that the terraces formed at nearly the same age do not share the same paleoseismic events and each exposed variable slip per event. We thus conclude that simple characteristic earthquake model does not fit the complex thrust fault system of the Iwate-Miyagi source region. It implies that limited number of excavations underestimates the frequency of surface-breaking earthquakes and cannot predict size of earthquakes from paleo-displacements.