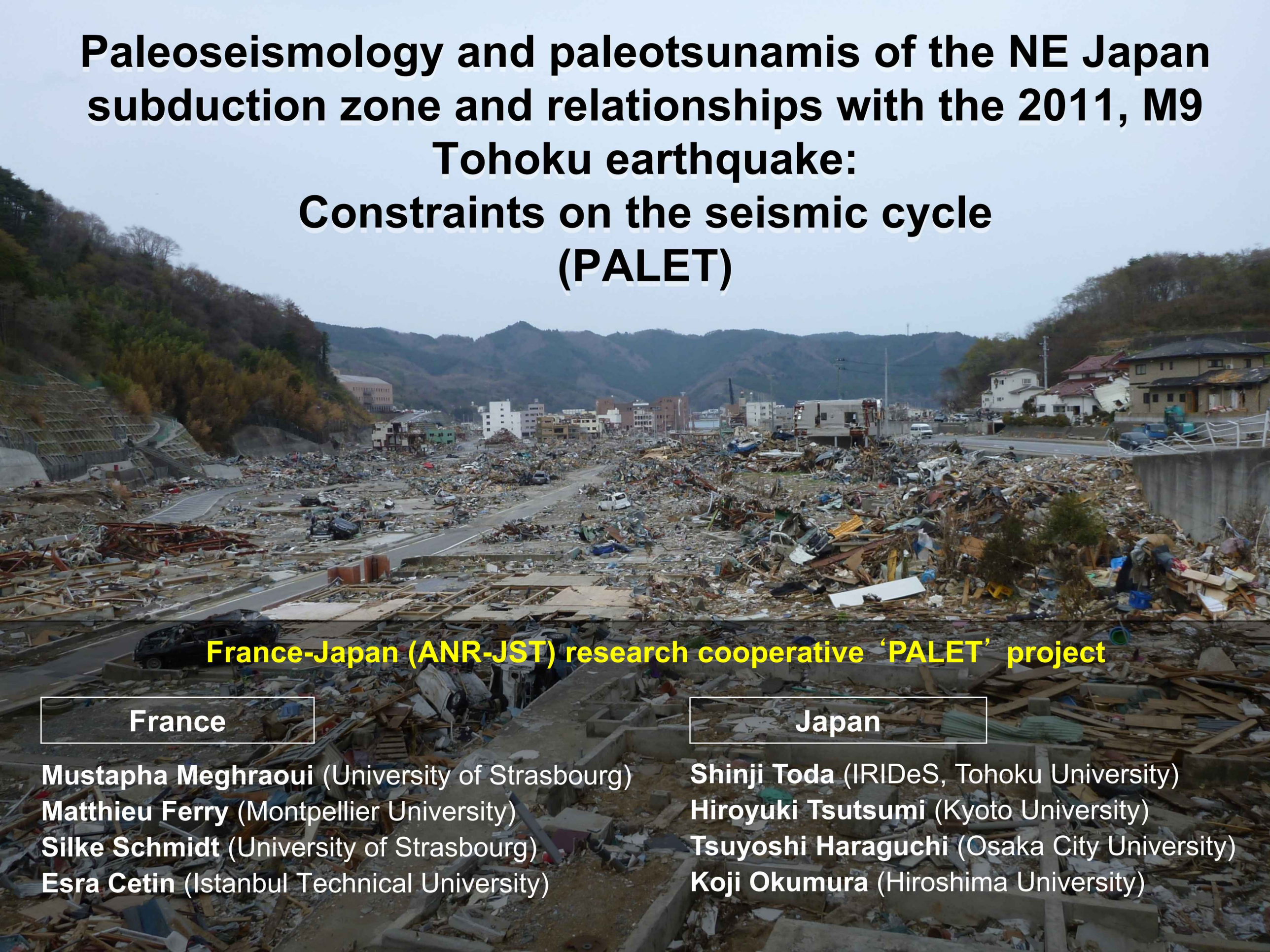
Paleoseismology and paleotsunamis of the NE Japan subduction zone and relationships with the 2011, M9 Tohoku earthquake: Constraints on the seismic cycle (PALET)



France-Japan (ANR-JST) research cooperative 'PALET' project

France

Mustapha Meghraoui (University of Strasbourg)
Matthieu Ferry (Montpellier University)
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Japan

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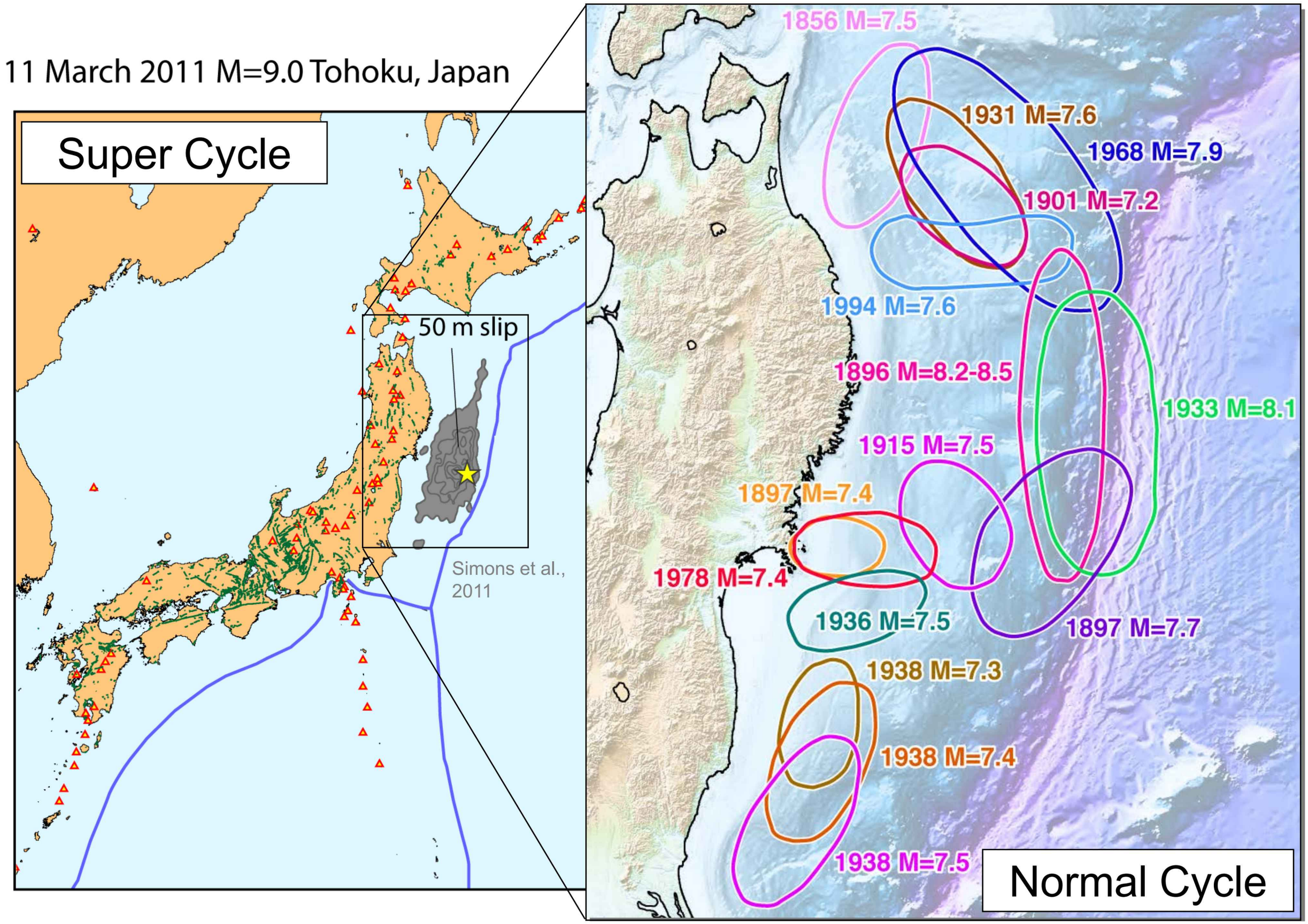
Tsuyoshi Haraguchi (Osaka City University)
Koji Okumura (Hiroshima University)

2011 Tohoku rupture may be a “super cycle” earthquake



To reveal the seismic cycle of M9 events

1. **Paleo-tsunami** record in Holocene deposits

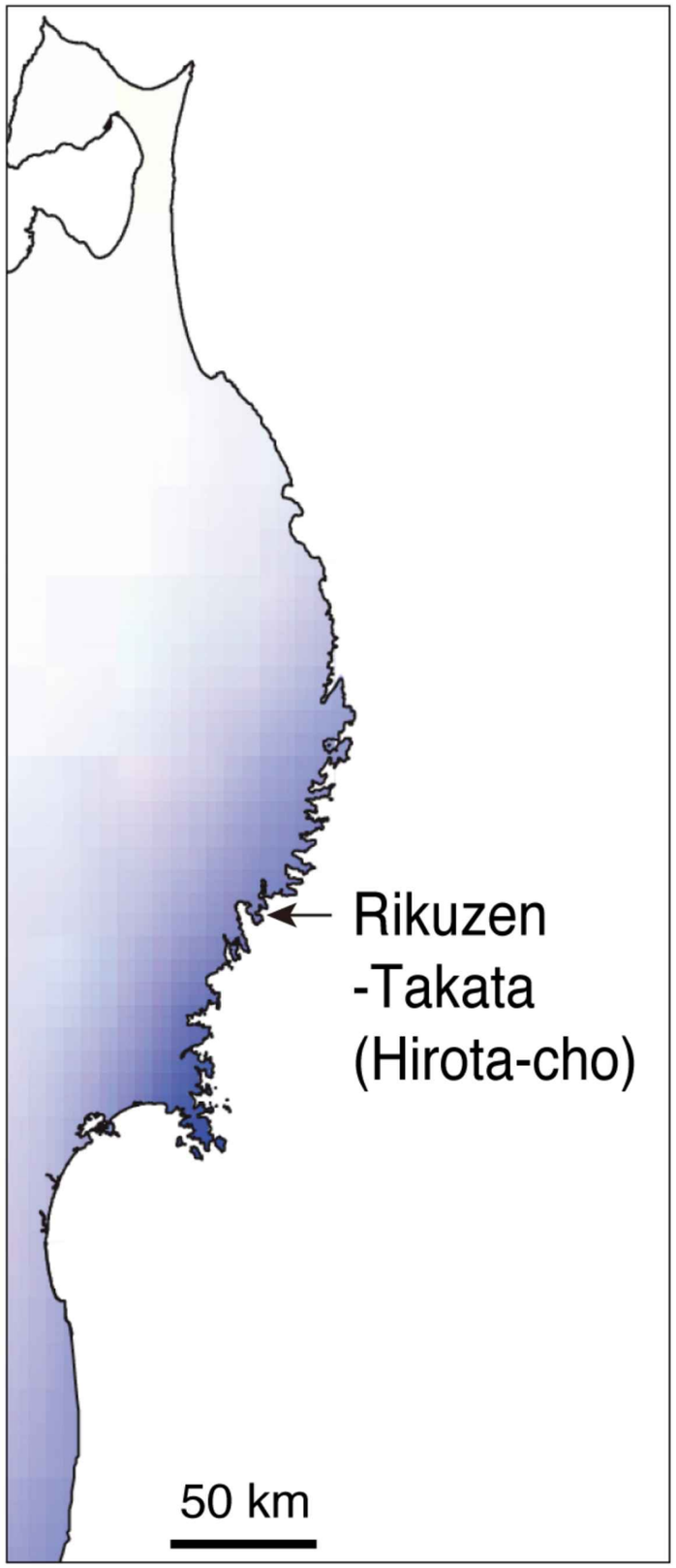
2. Long-term behavior of directly **triggered inland normal faults**

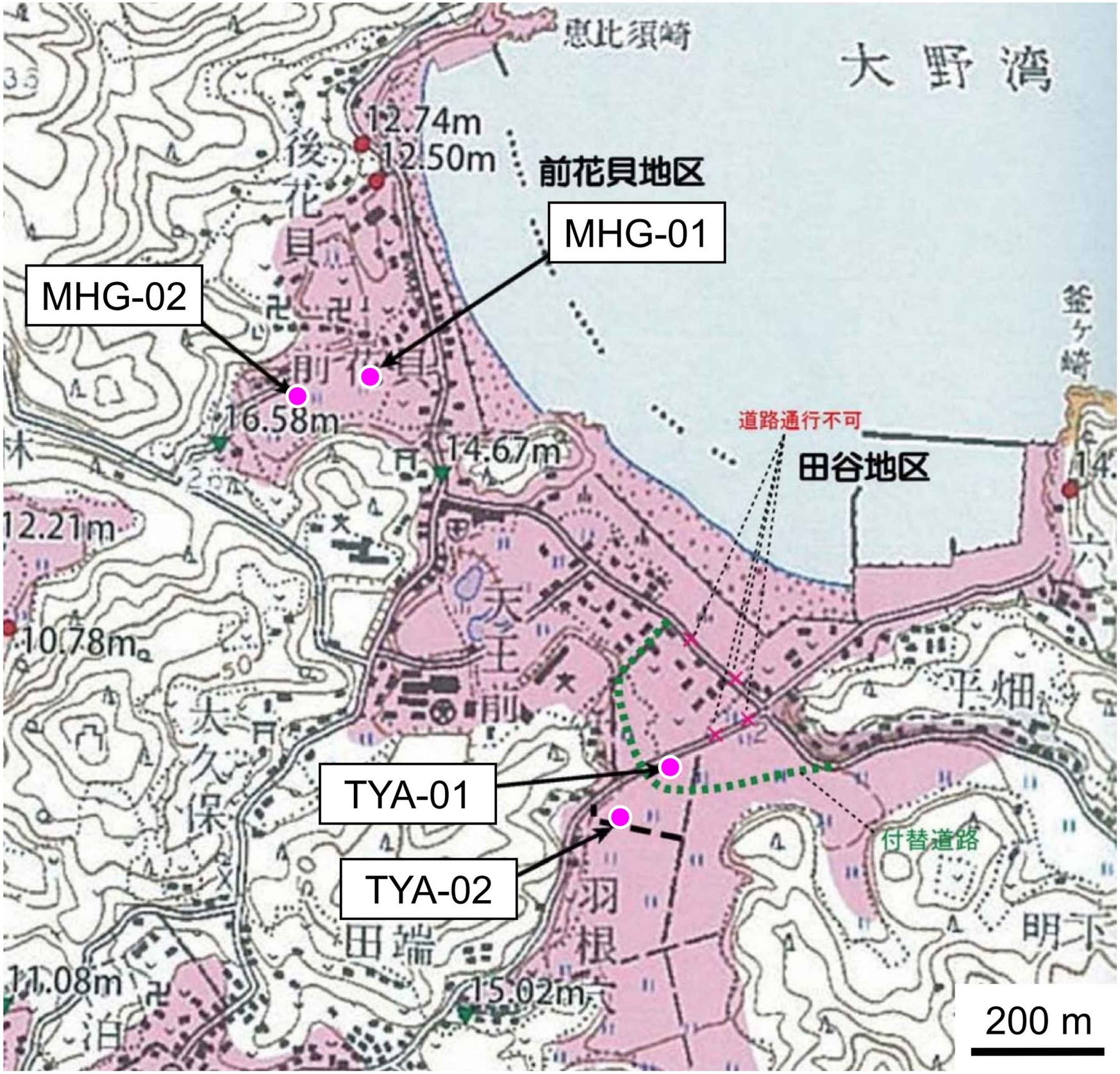
- Long-term deformation using **marine terraces** and comparison with the 2011 coseismic movements

Back marsh inundated by the 2011 tsunami may preserve older events

「東日本大震災大船渡市・陸前高田市記録写真集　気仙の惨状」村田プリントサービス（2011）による

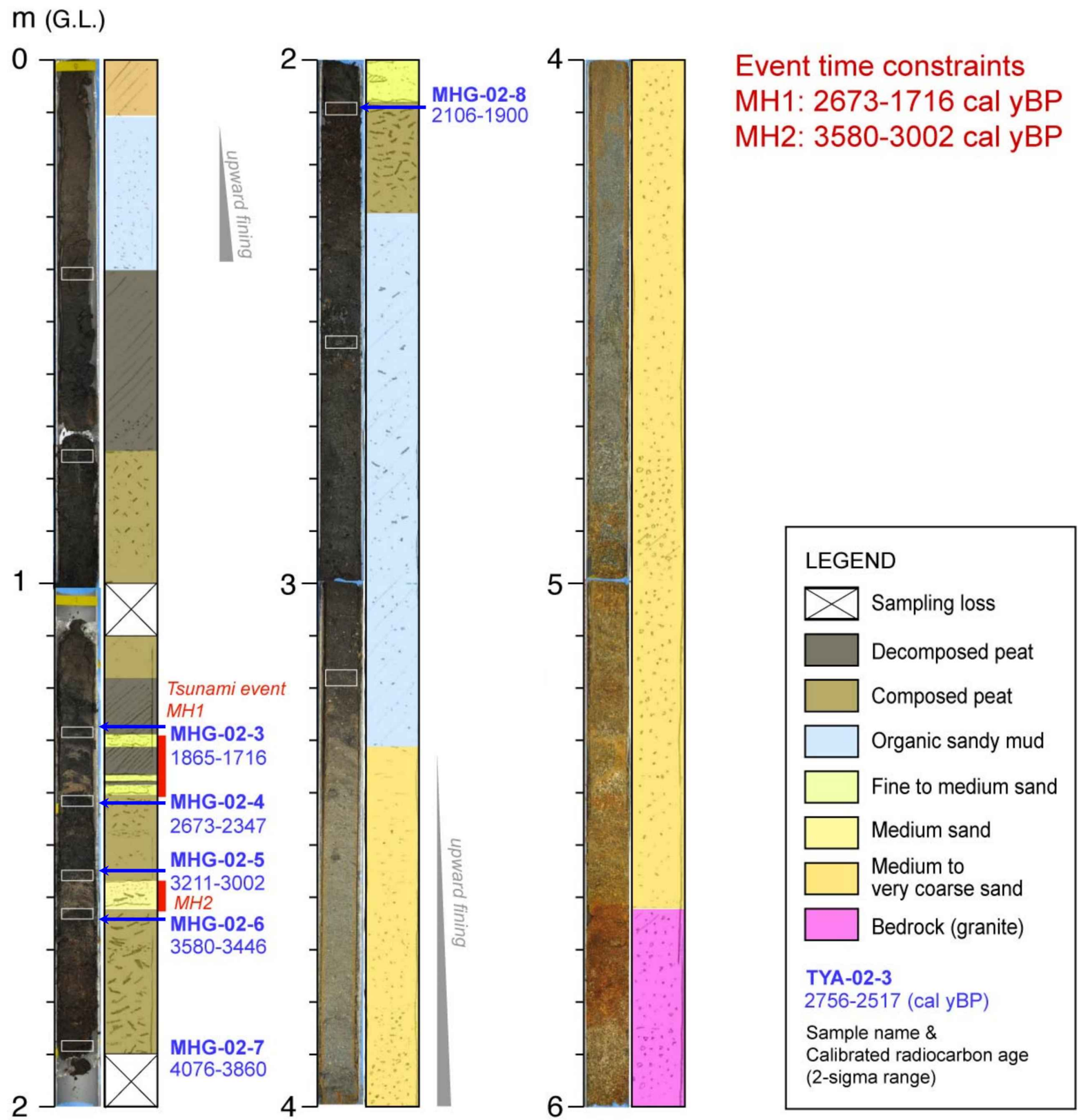
Back marsh inundated by the 2011 tsunami may preserve older events





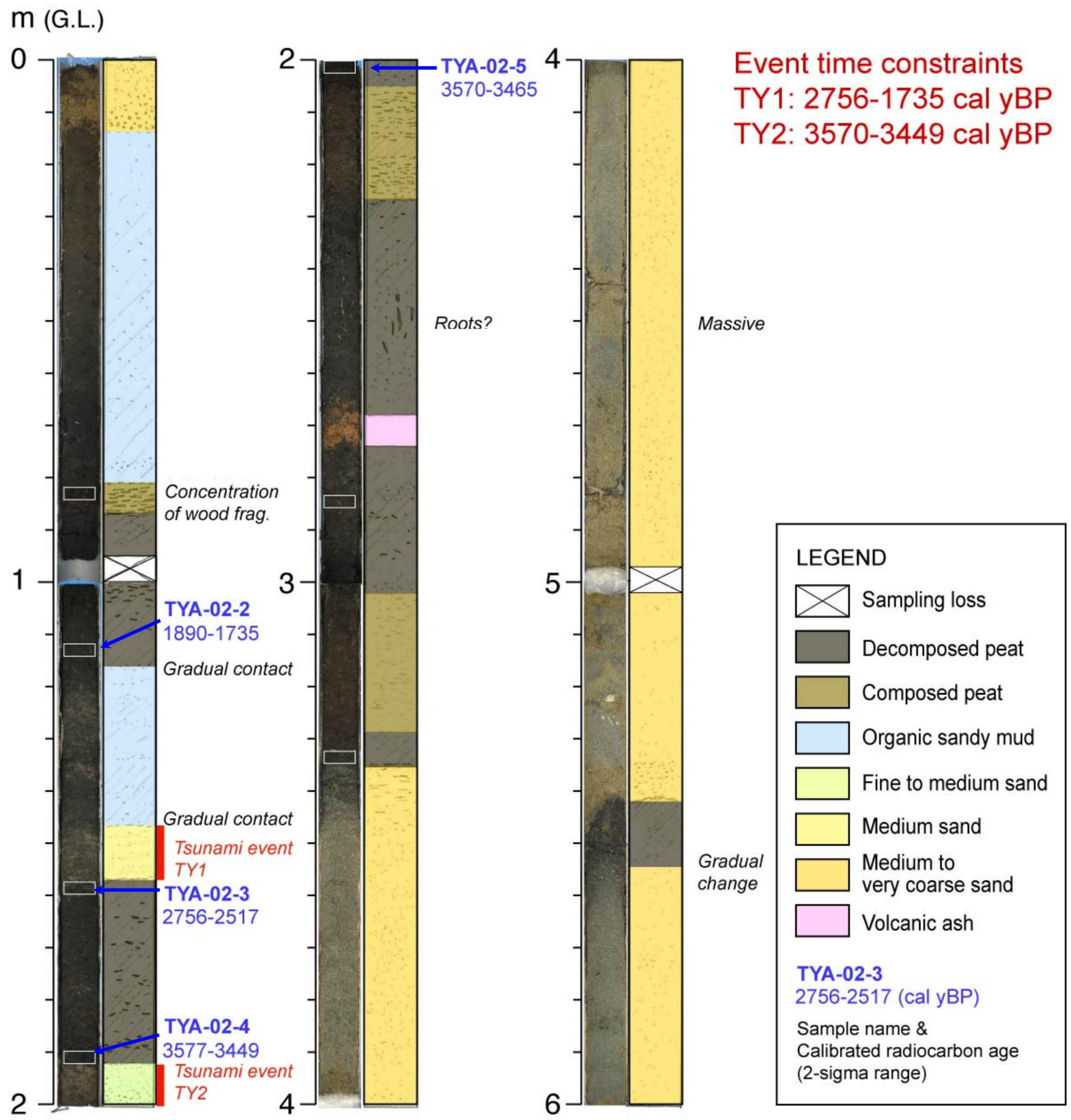
Back marsh inundated by the 2011 tsunami may preserve older events

800-m-apart two cores share the same Tsunami event horizons in Rikuzen-Takata



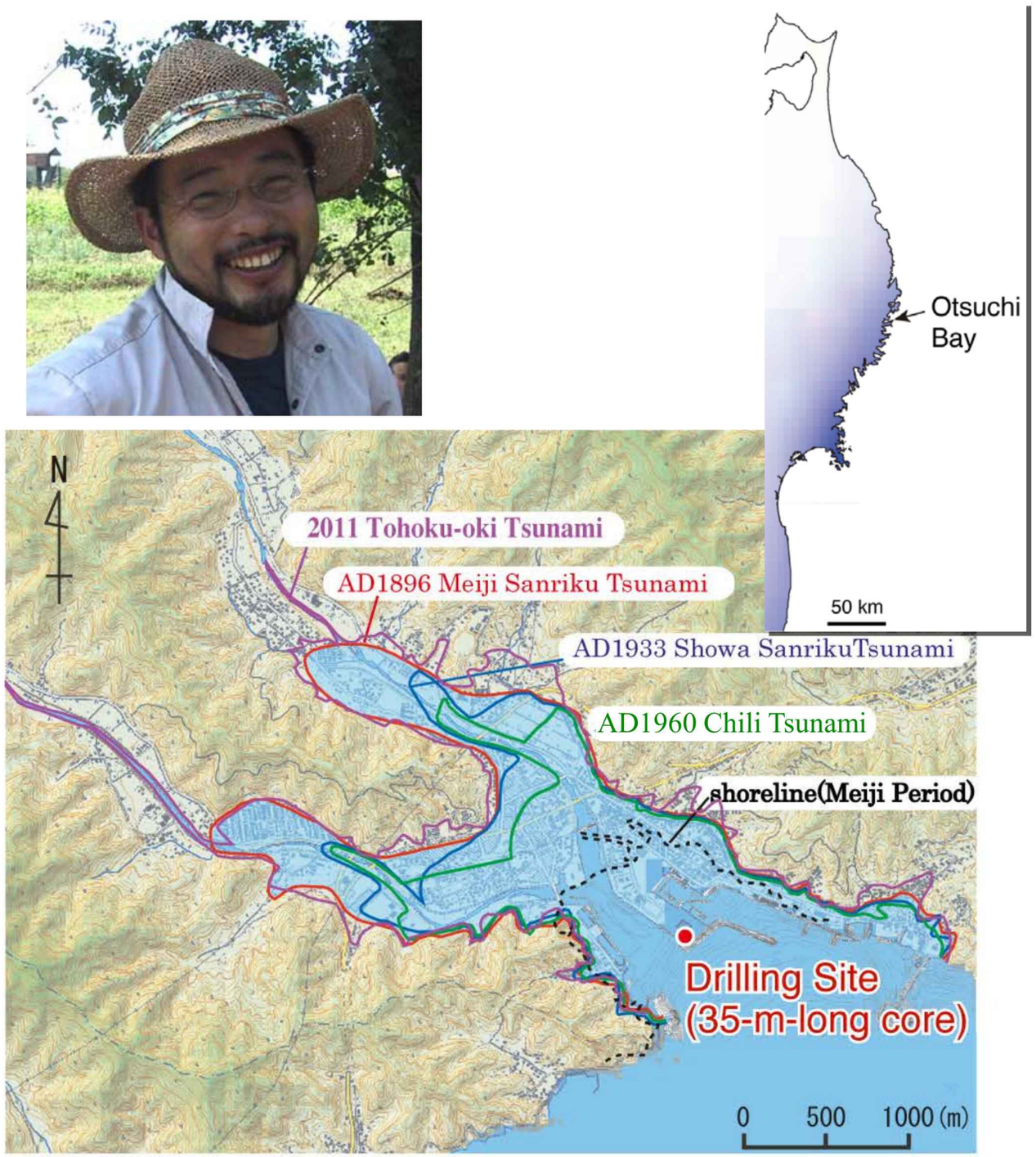
Event MH2

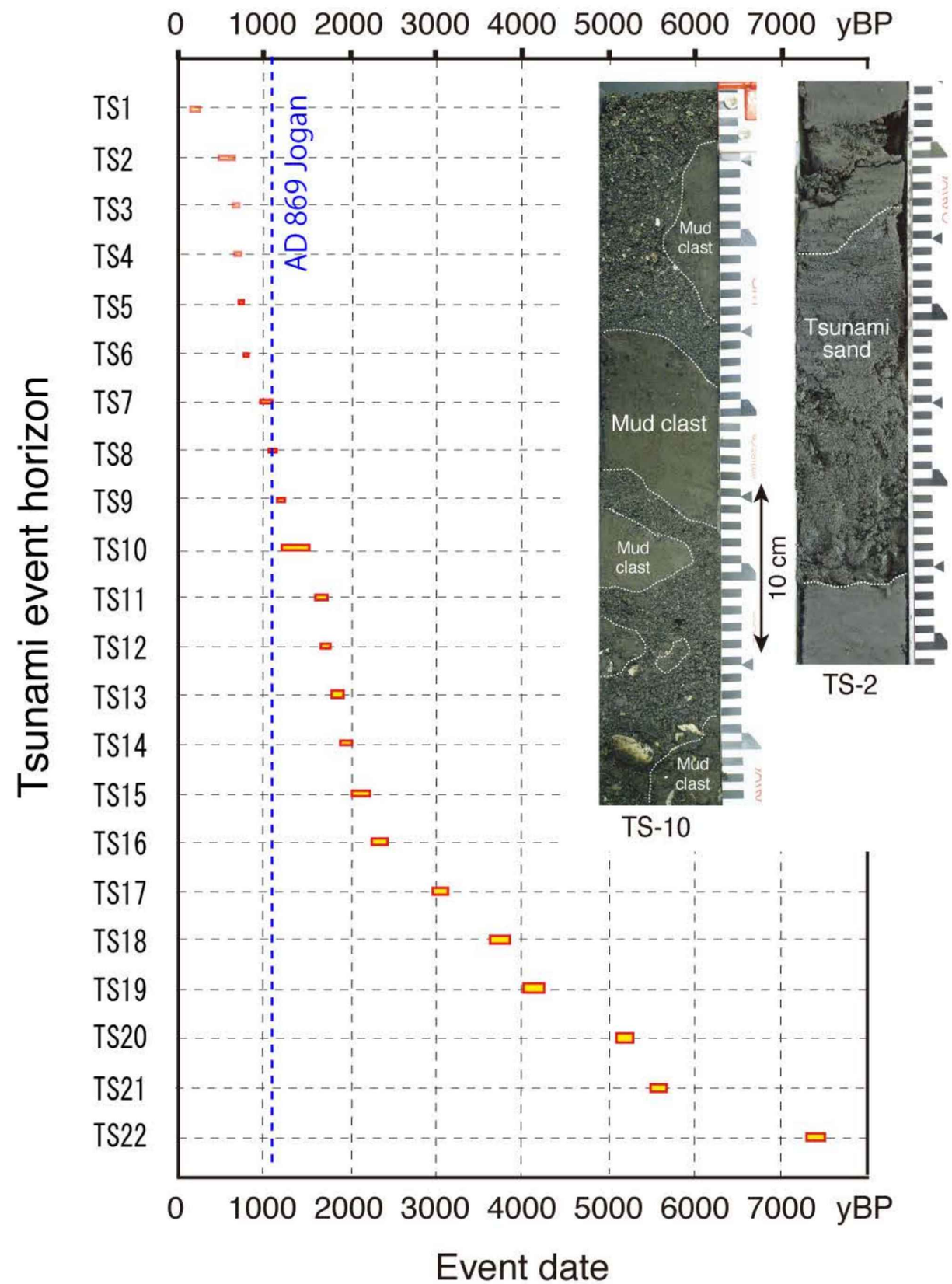
800-m-apart two cores share the same Tsunami event horizons in Rikuzen-Takata



Event TY2

Offshore tsunami deposits from Otsuchi reveal major tsunamis, possibly every hundreds of years, rather than every 1,000 yr





Haraguchi et al. (2006), Haraguchi & Ishibe (2009), Haraguchi et al. (2012, AGU poster)

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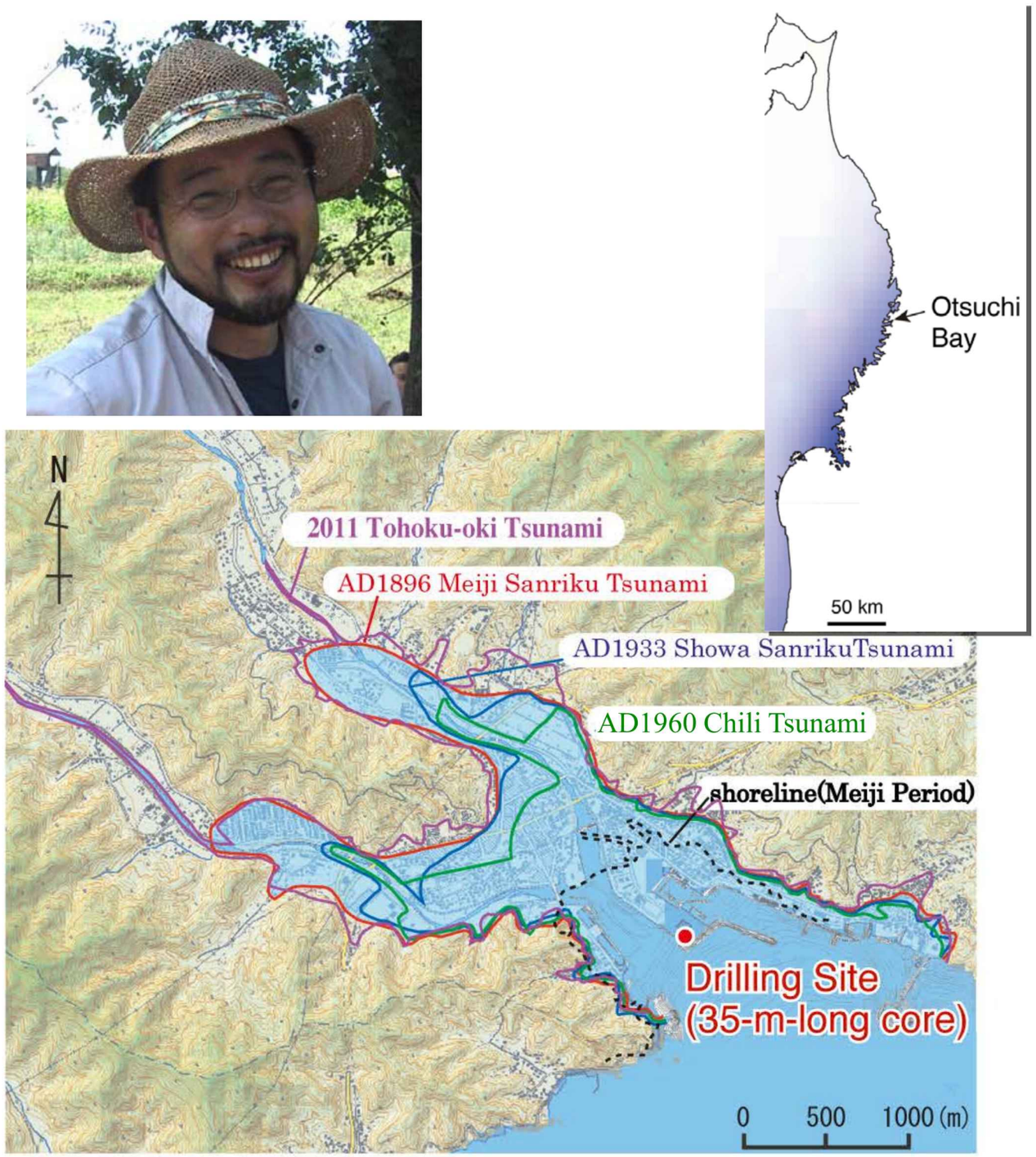

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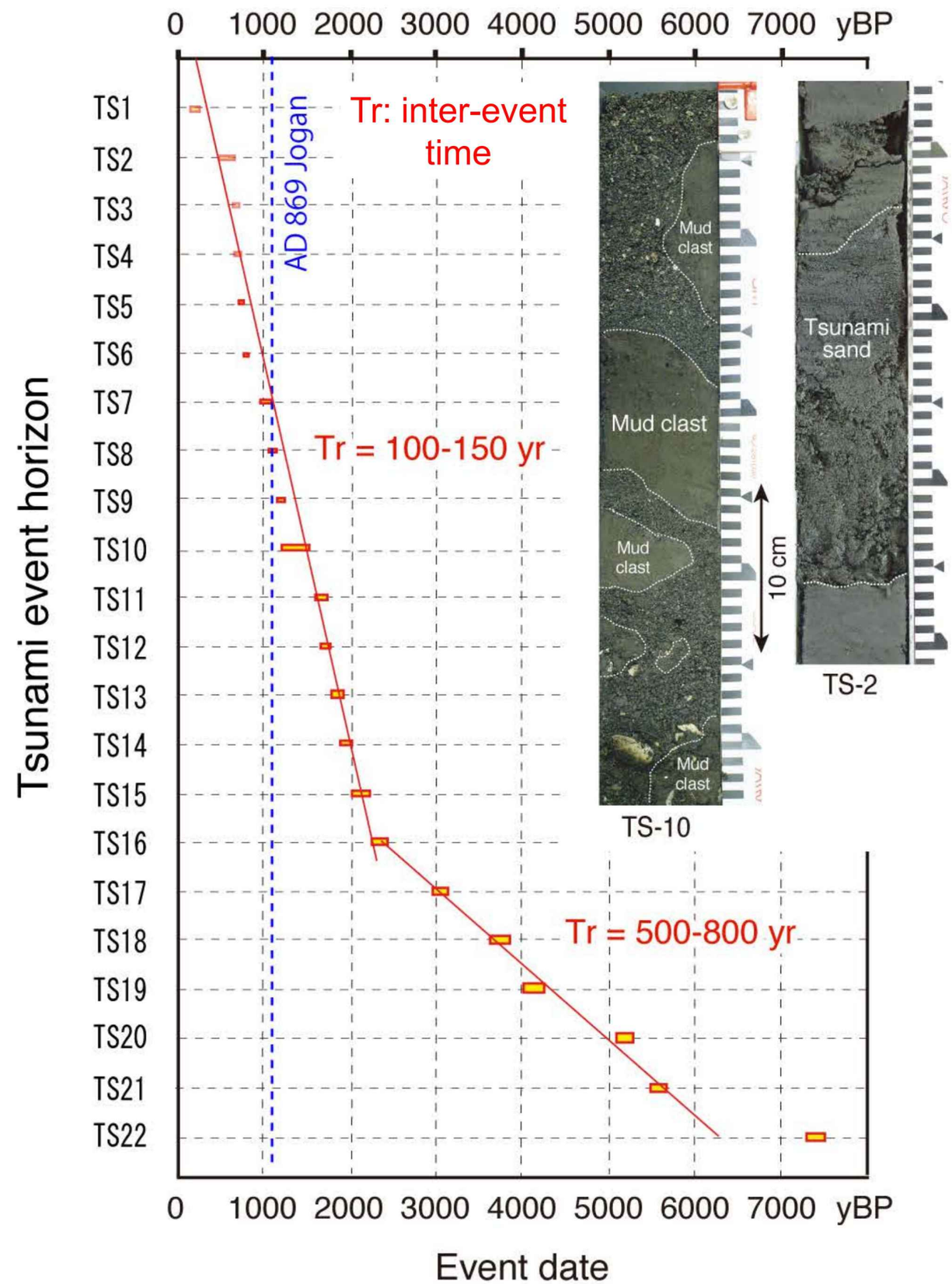
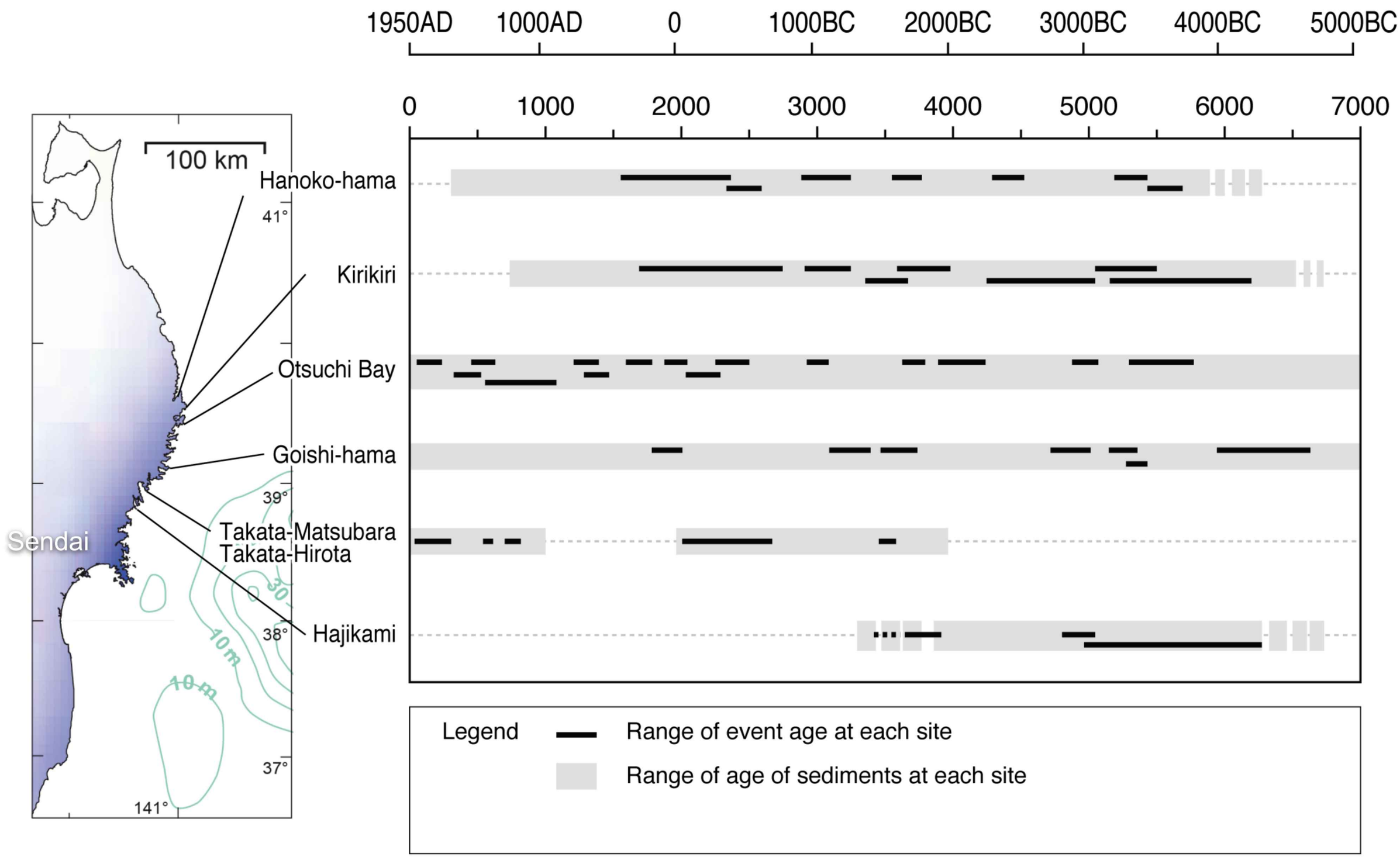
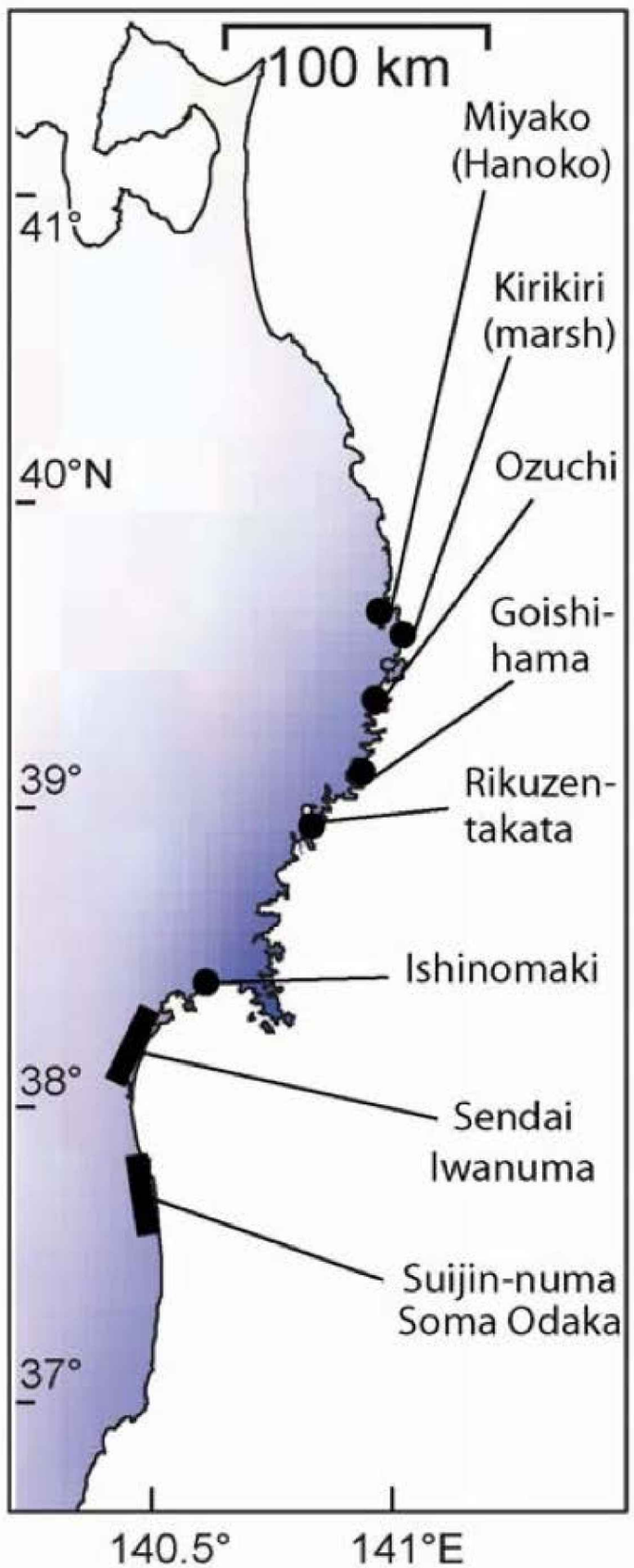
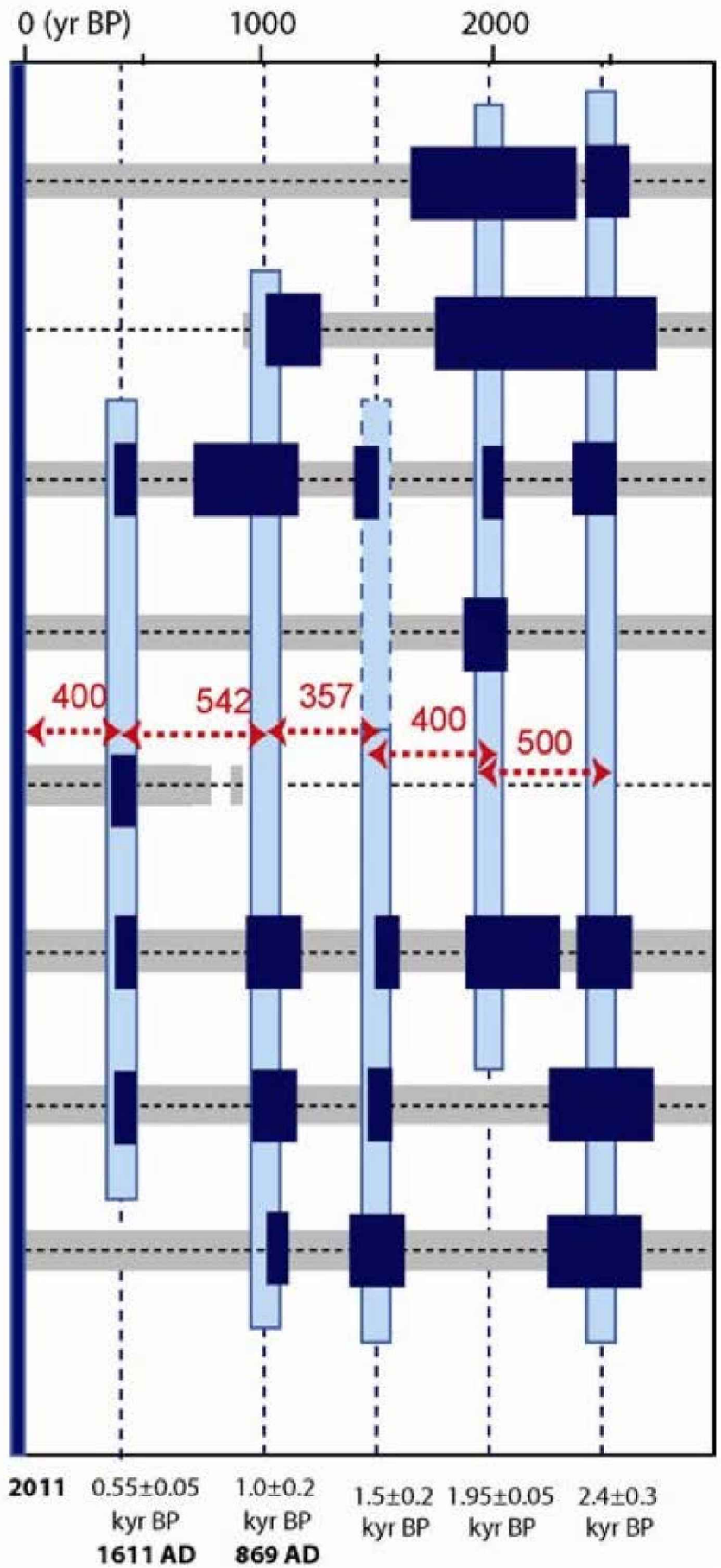


Onshore evidence for paleo-tsunamis along Sanriku coast suggests about 500-yr recurrence of huge tsunamis



Haraguchi et al. (2006), Haraguchi & Ishibe (2009), Haraguchi et al. (2012, AGU poster)

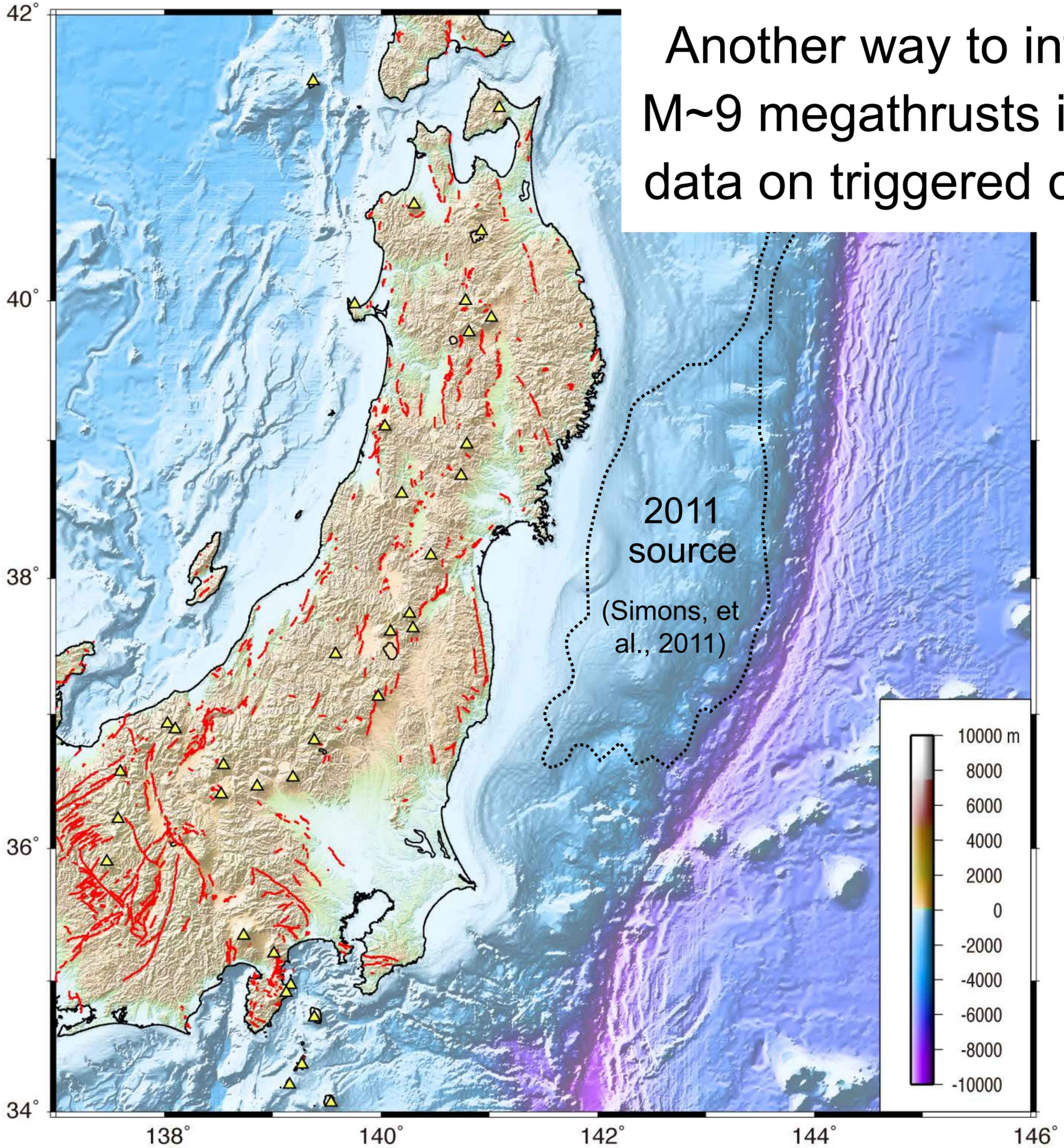




Together with the Sendai and Fukushima data, large tsunamis might have occurred every 350-550 years

Sawai et al. (2007)

Another way to infer seismic cycle of M~9 megathrusts is from paleoseismic data on triggered coastal normal faults



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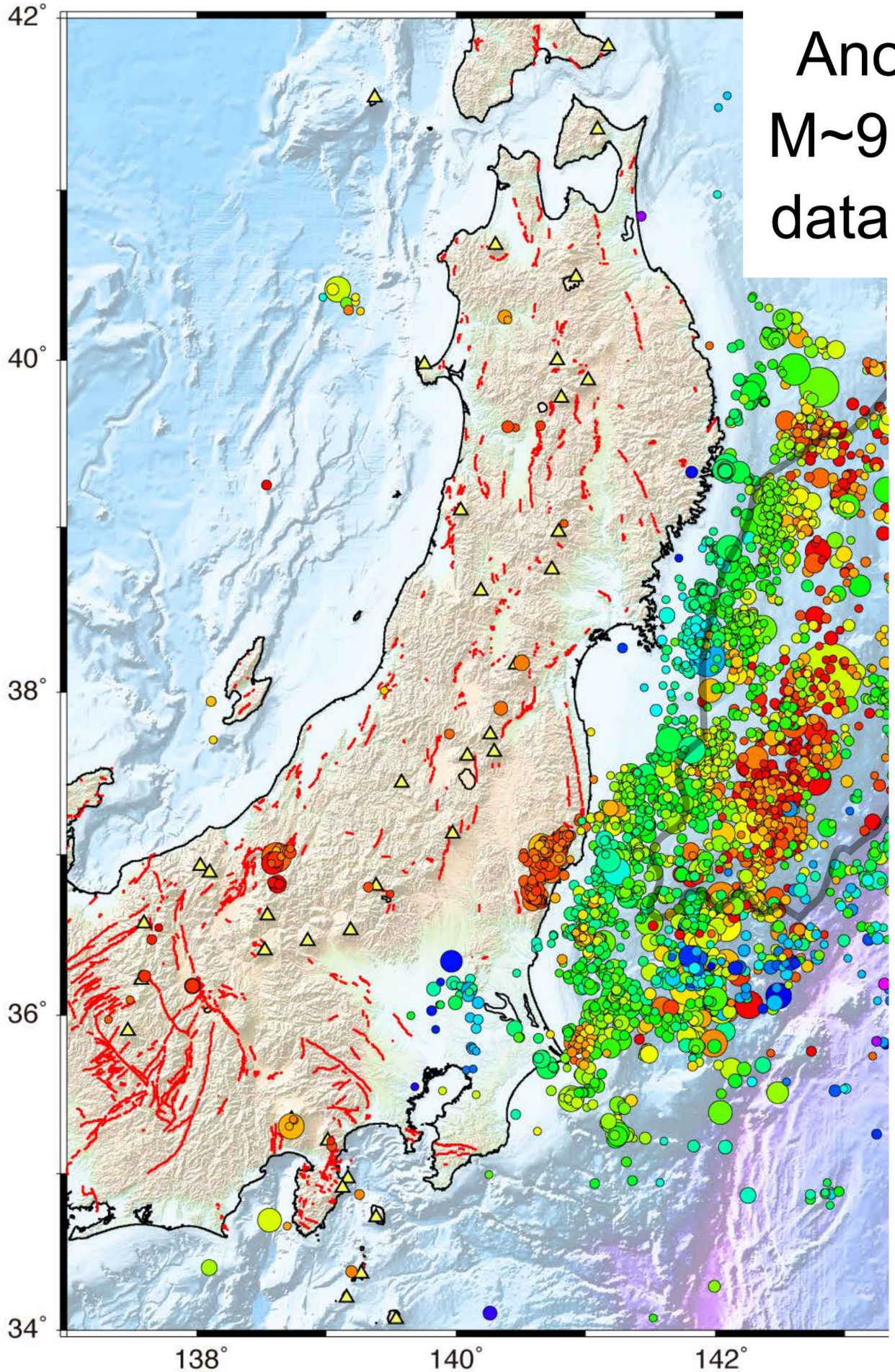
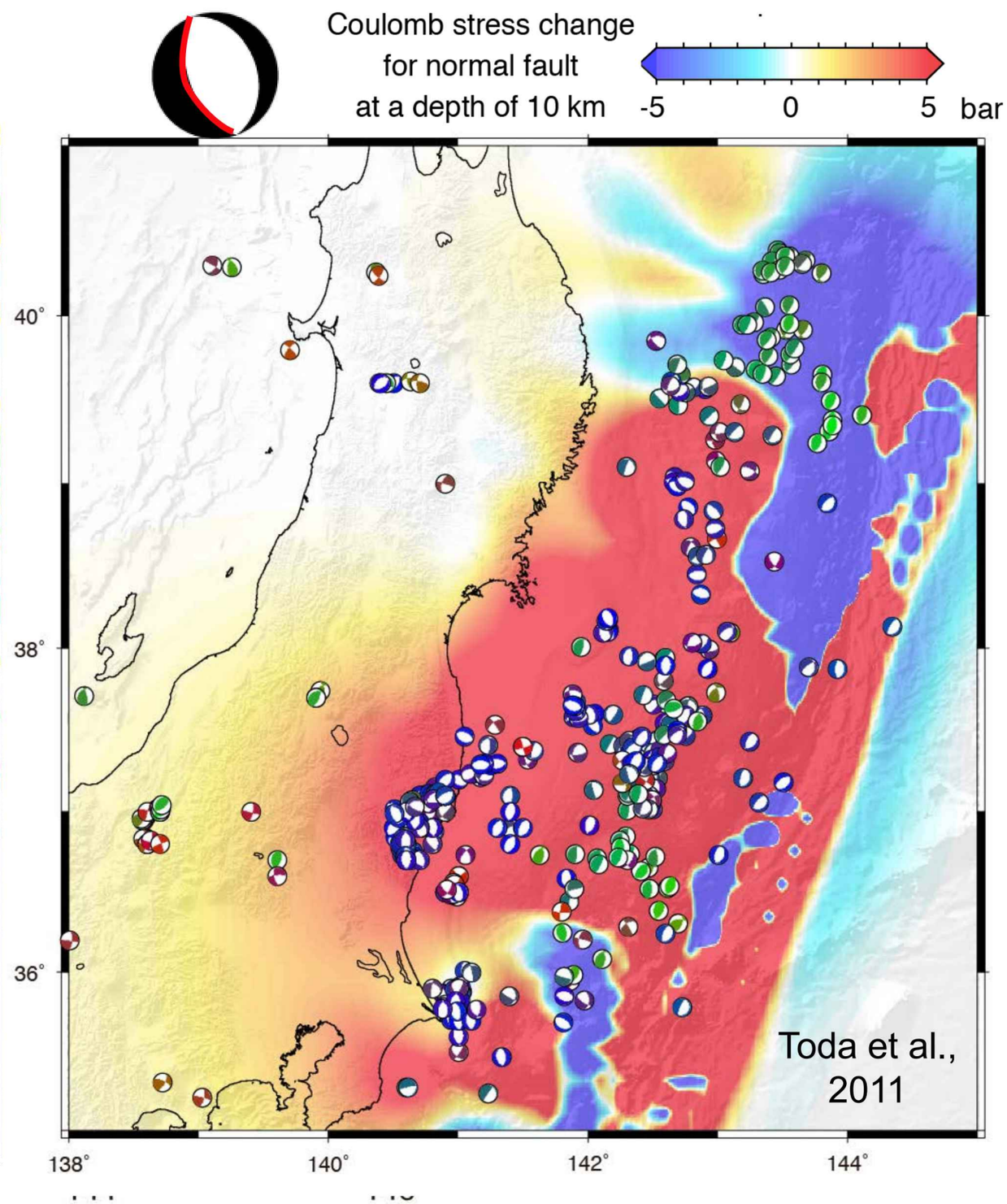
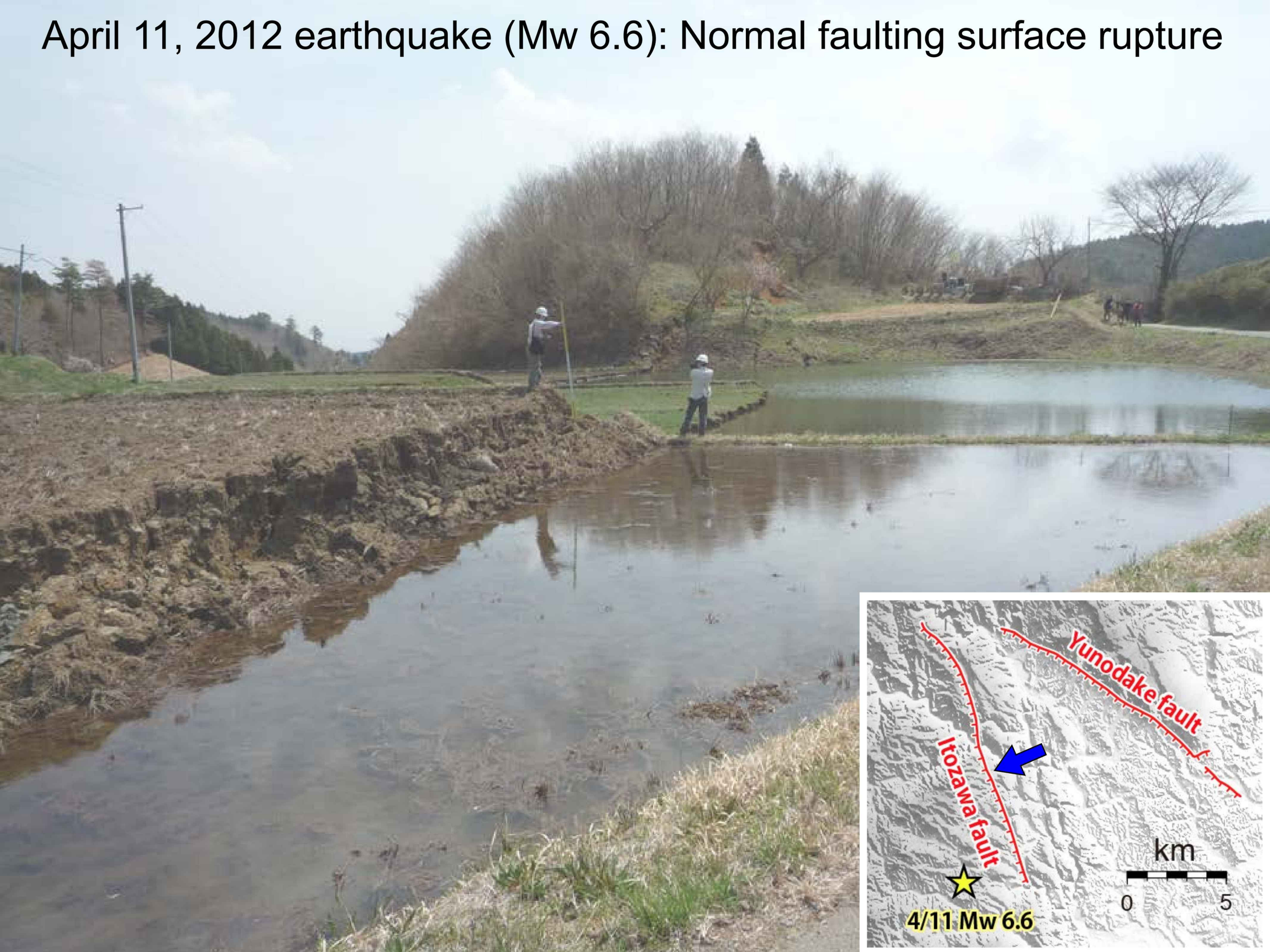




April 11, 2012 earthquake (Mw 6.6): Normal faulting surface rupture



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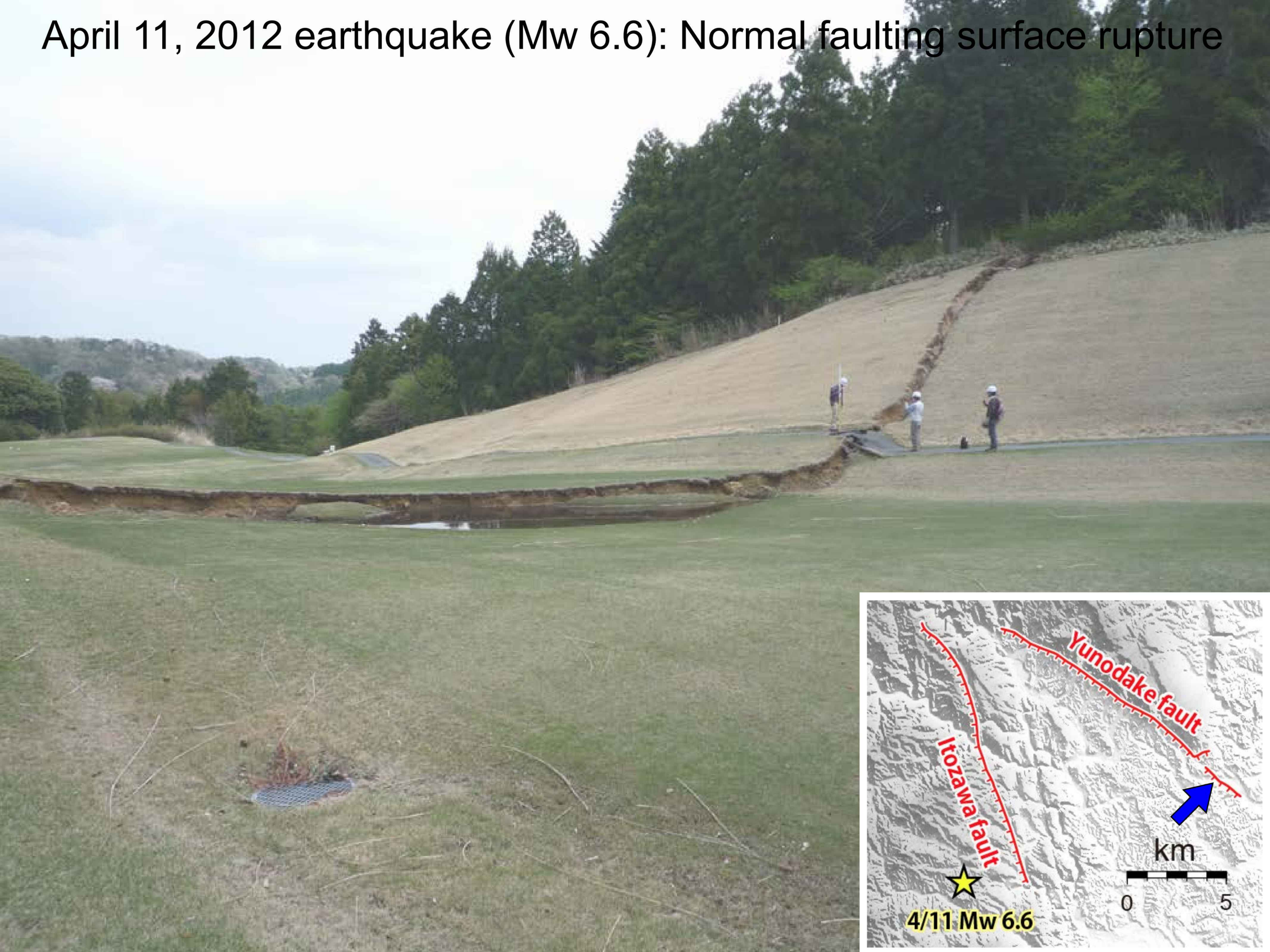
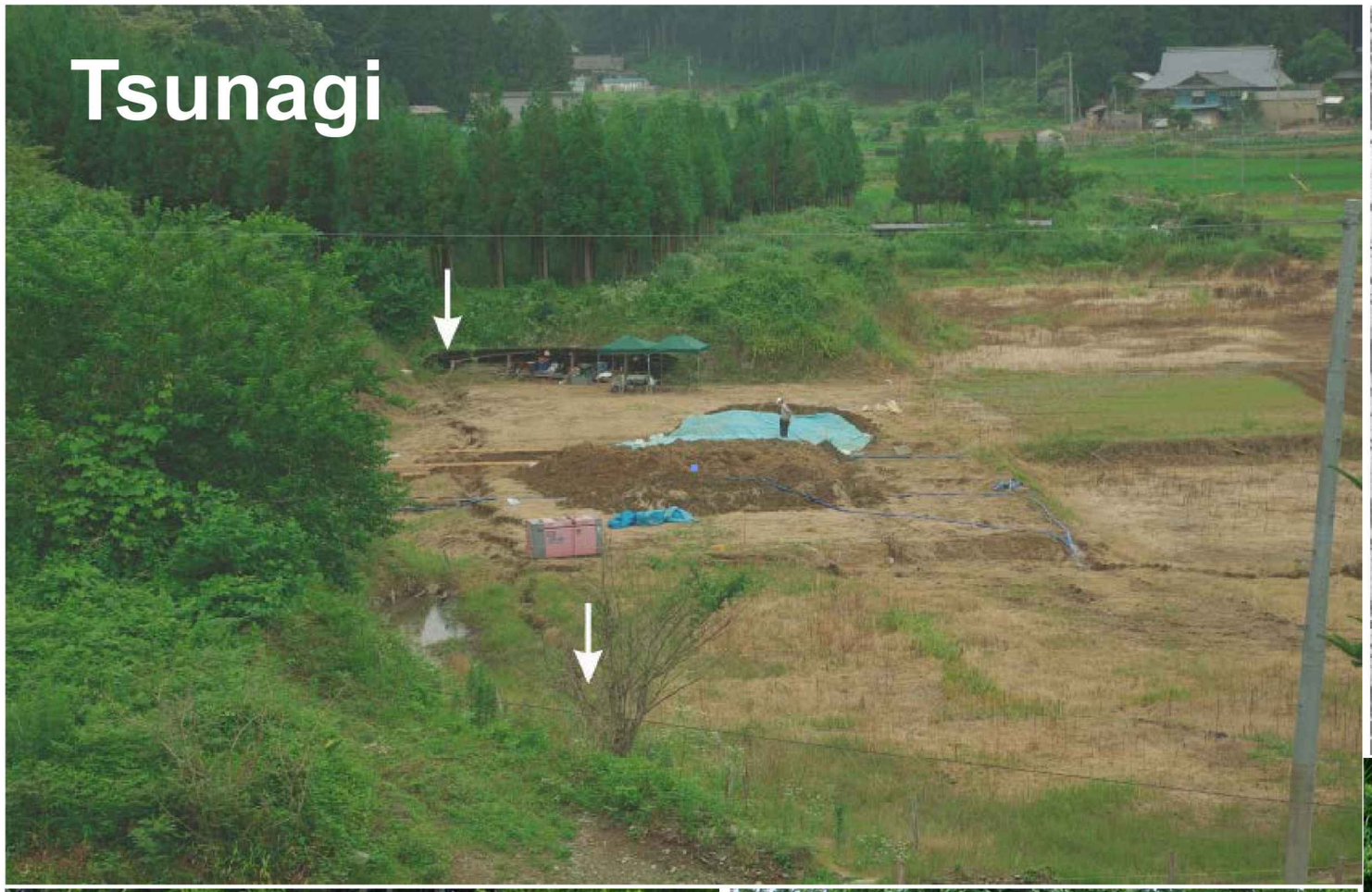
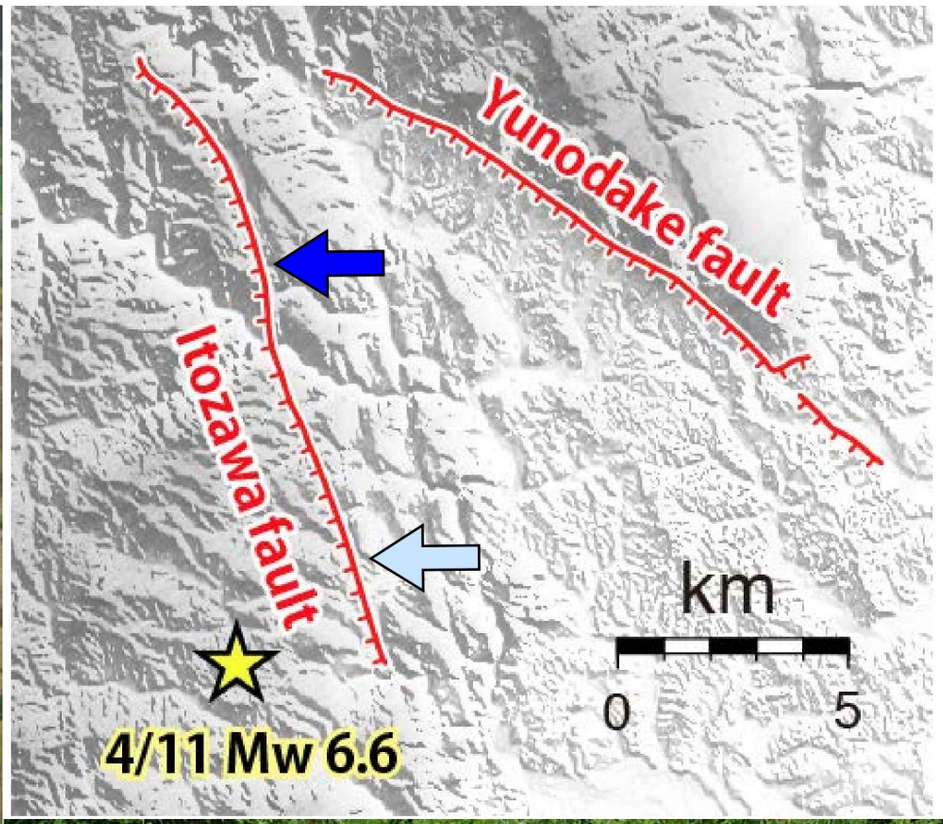
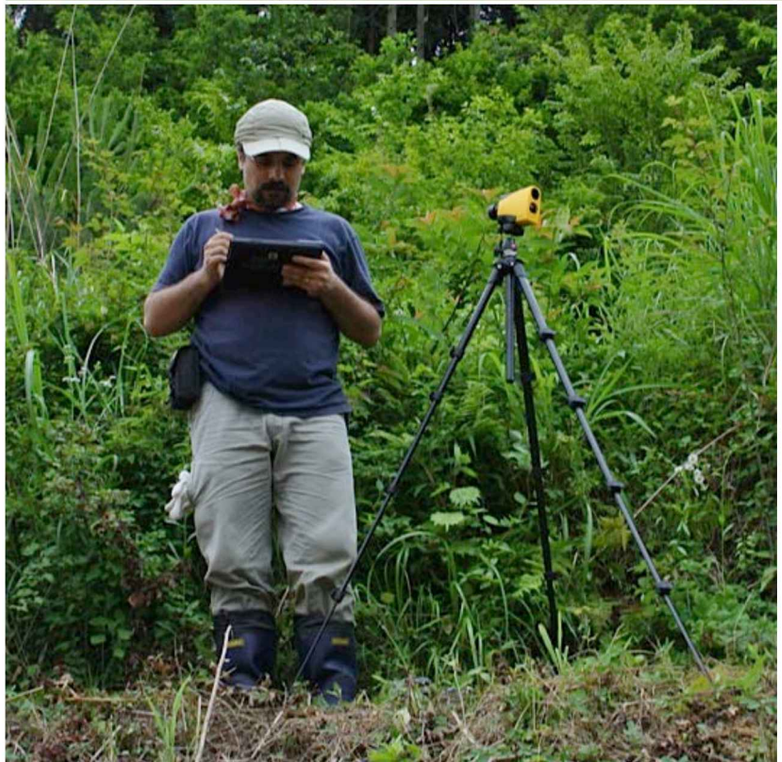


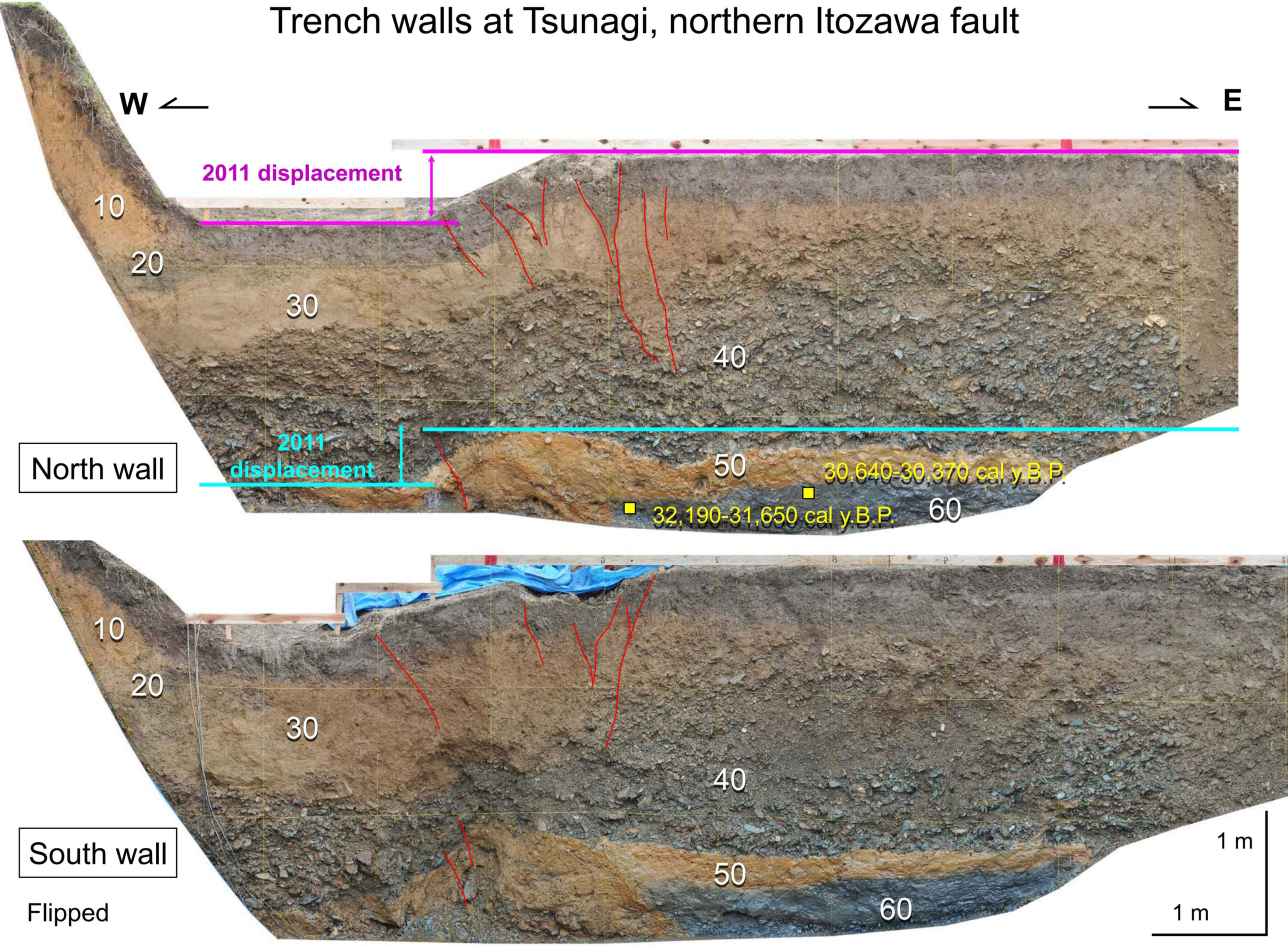
Trenches across the Itozawa fault exposed evidence for the past events



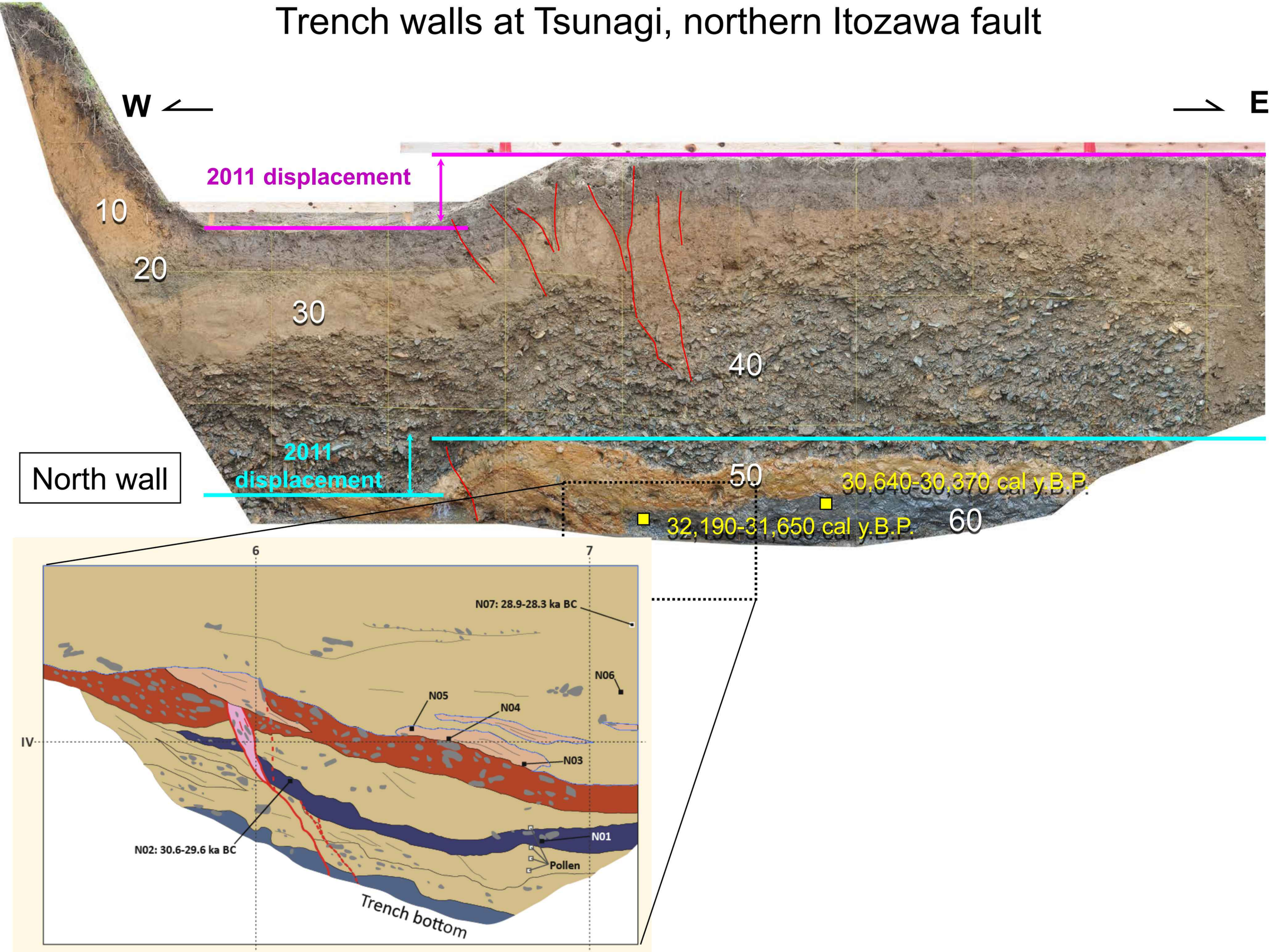




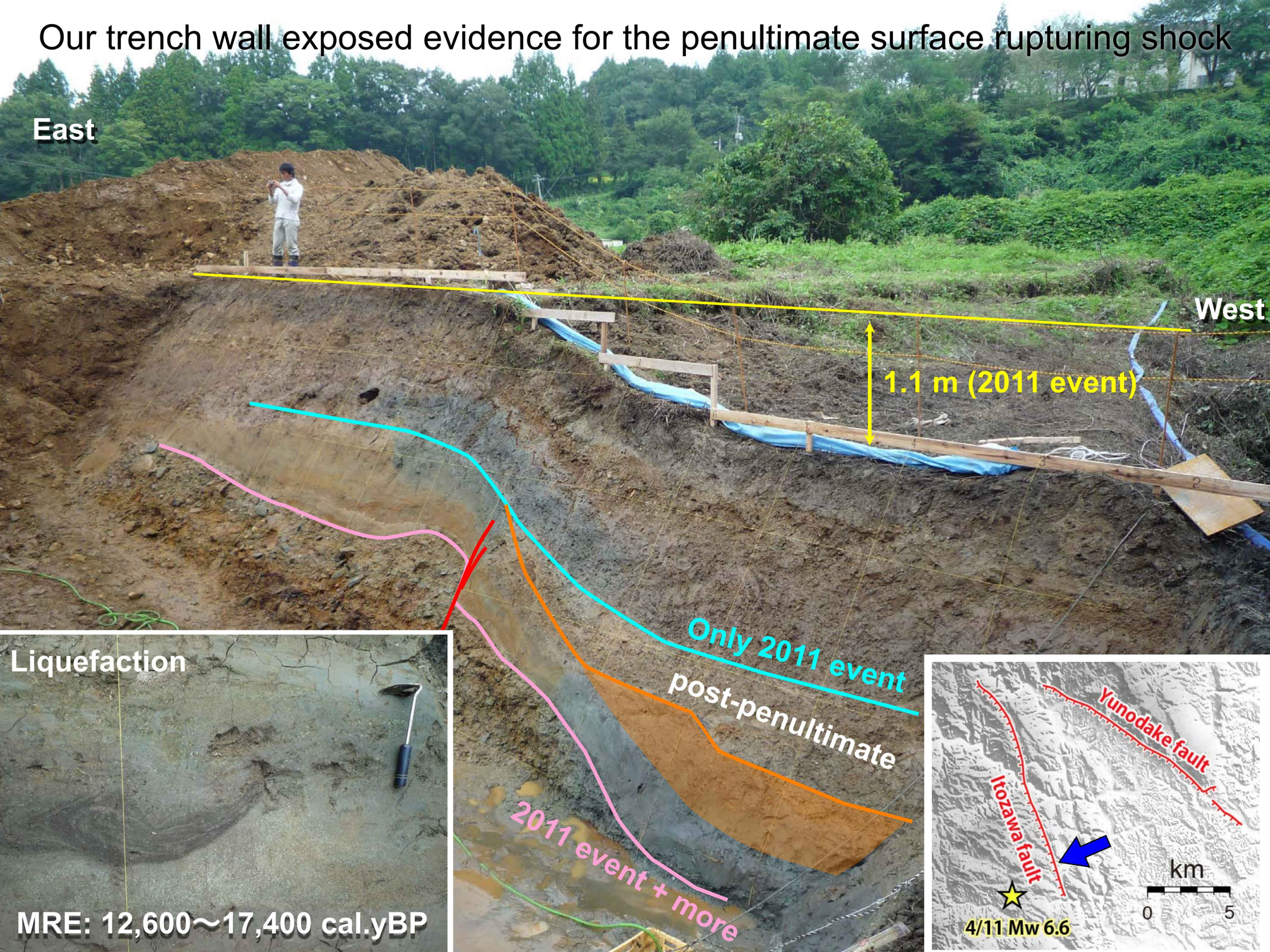
Trench walls at Tsunagi, northern Itozawa fault



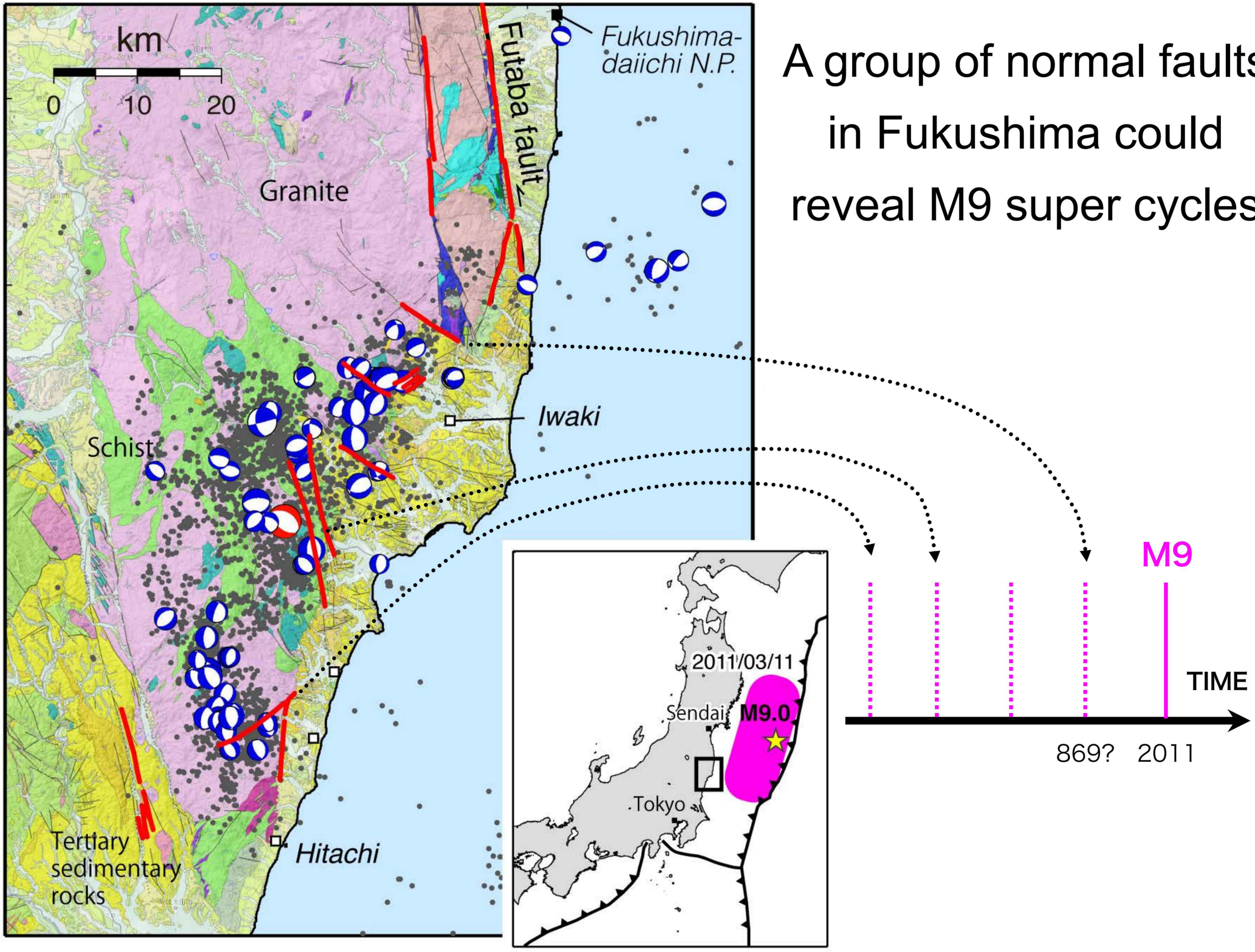
Trench walls at Tsunagi, northern Itozawa fault



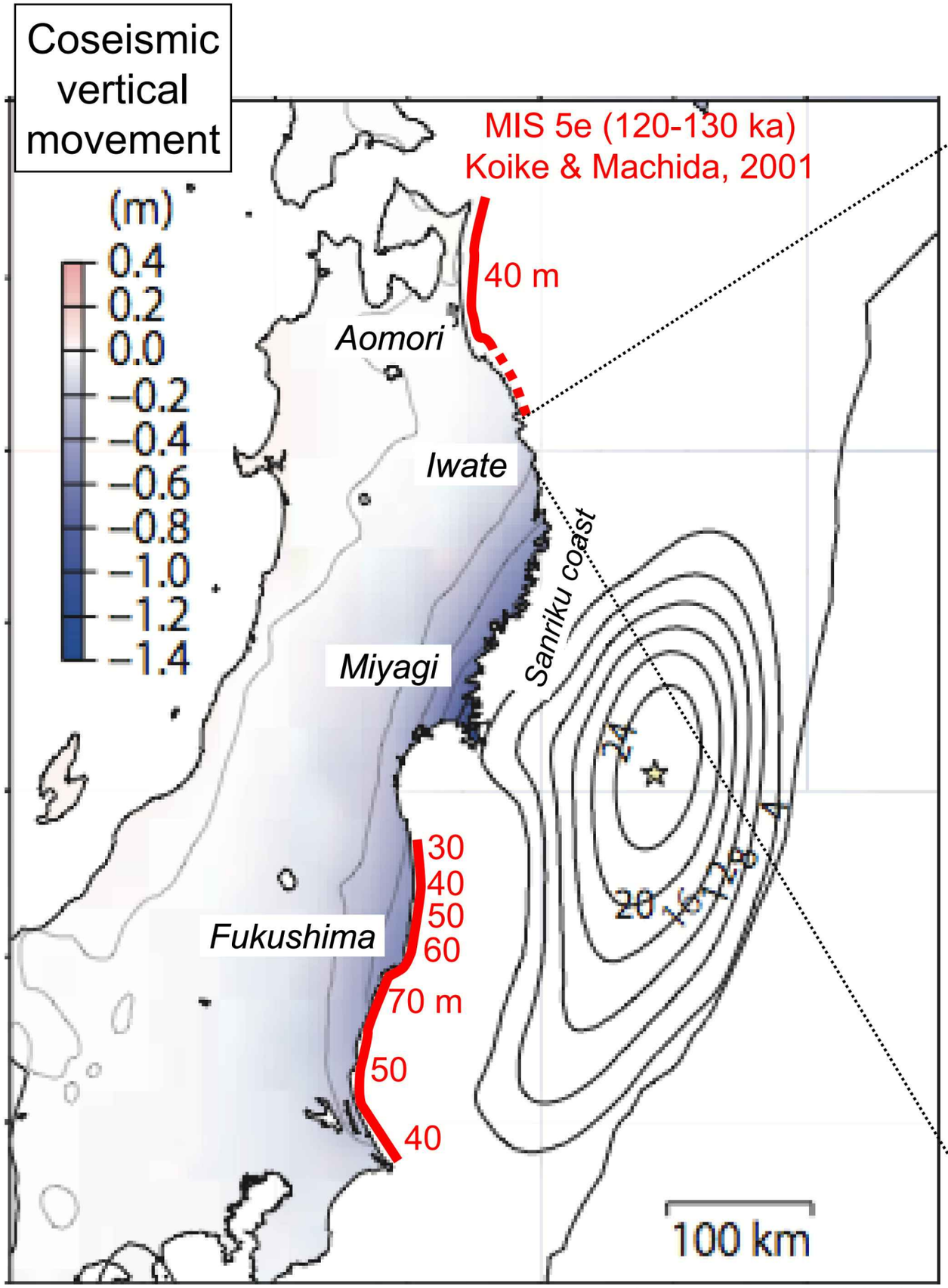
Our trench wall exposed evidence for the penultimate surface rupturing shock



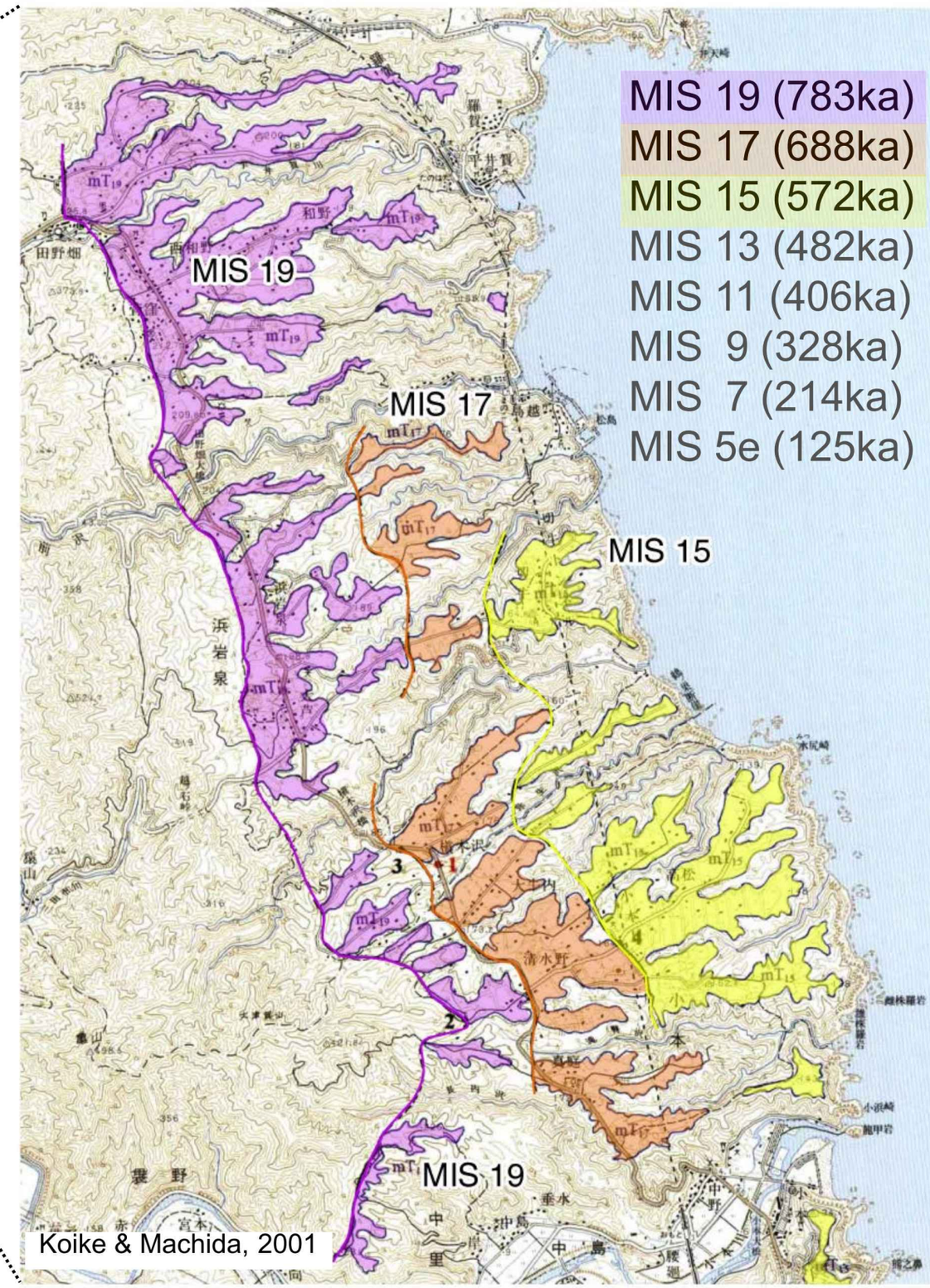
A group of normal faults in Fukushima could reveal M9 super cycles



Contradiction between 2011 coseismic subsidence and long-term coastal uplift

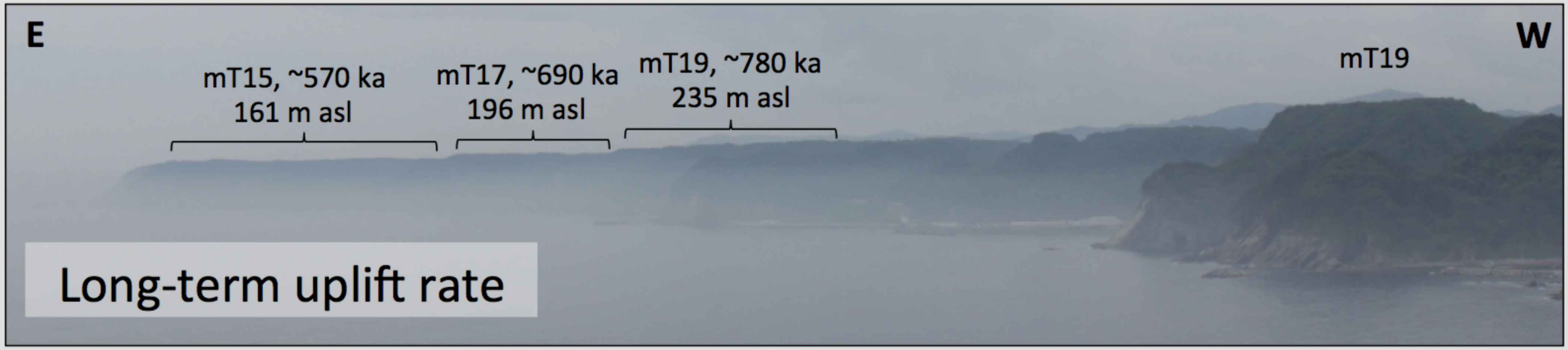


Ozawa et al., 2011

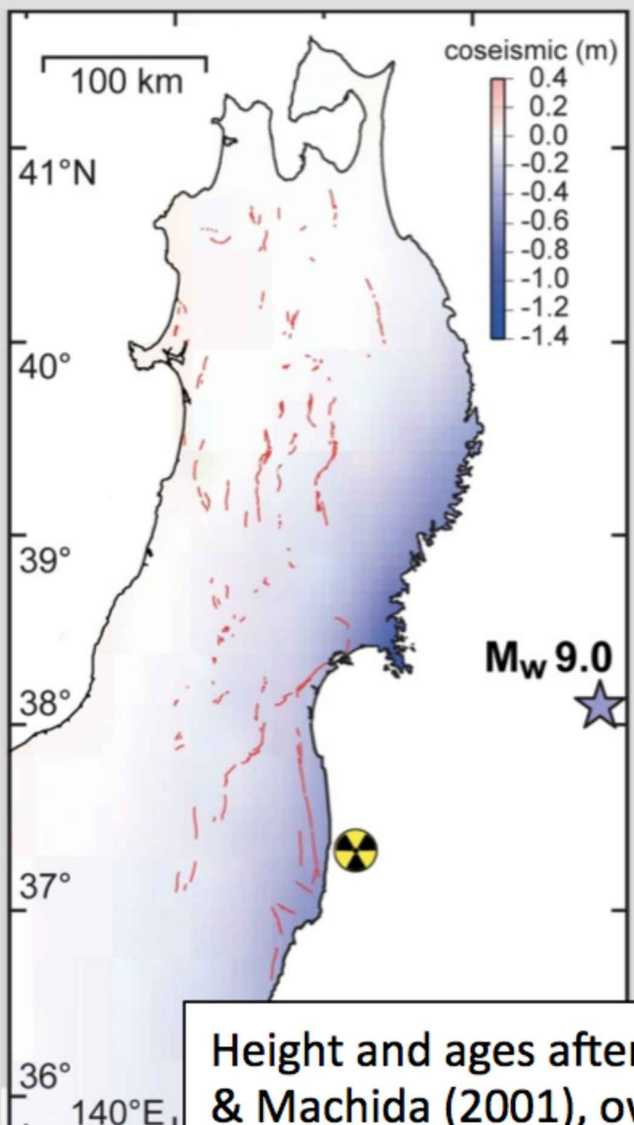


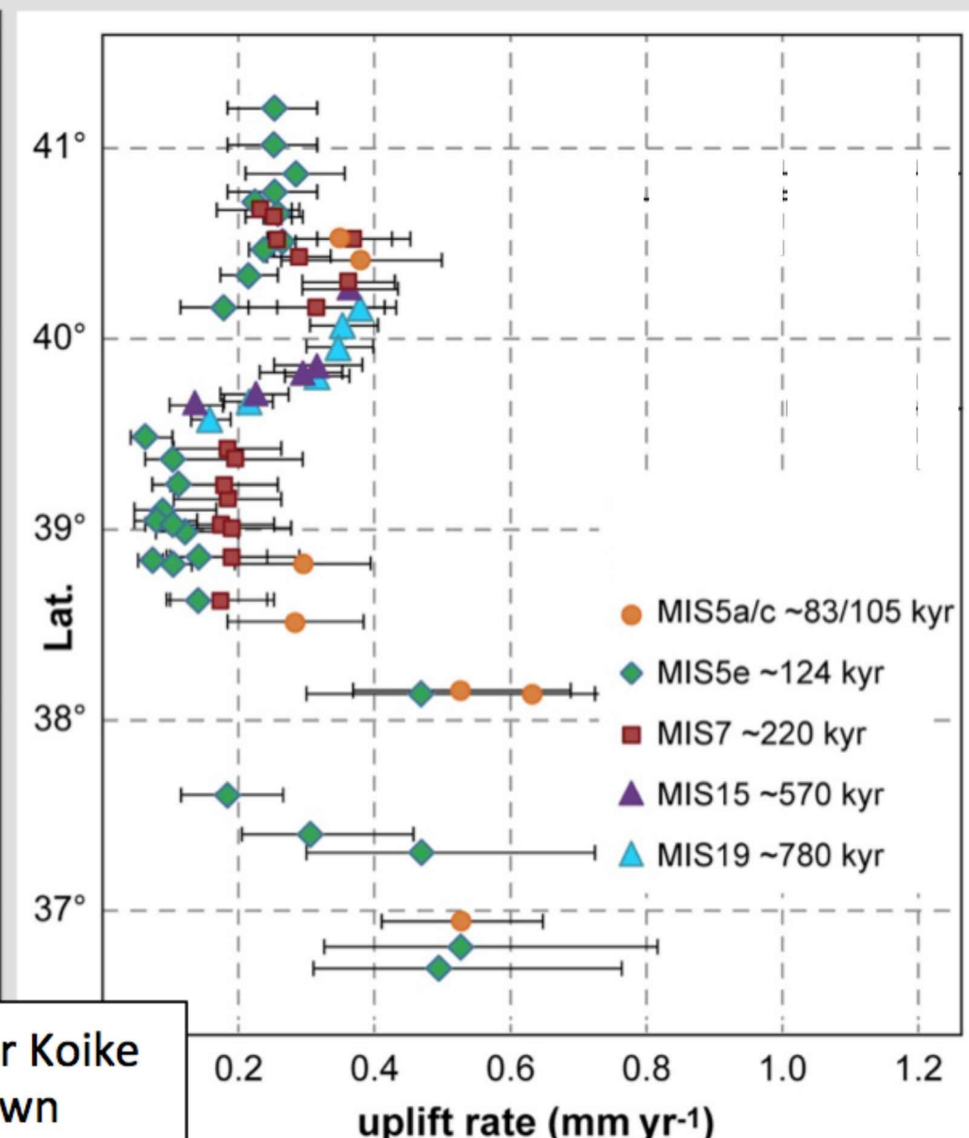
Koike & Machida, 2001

Older marine terraces (680-850 ka) are at altitudes of 150-250 m on the northern Sanriku coast: *Longterm uplift*



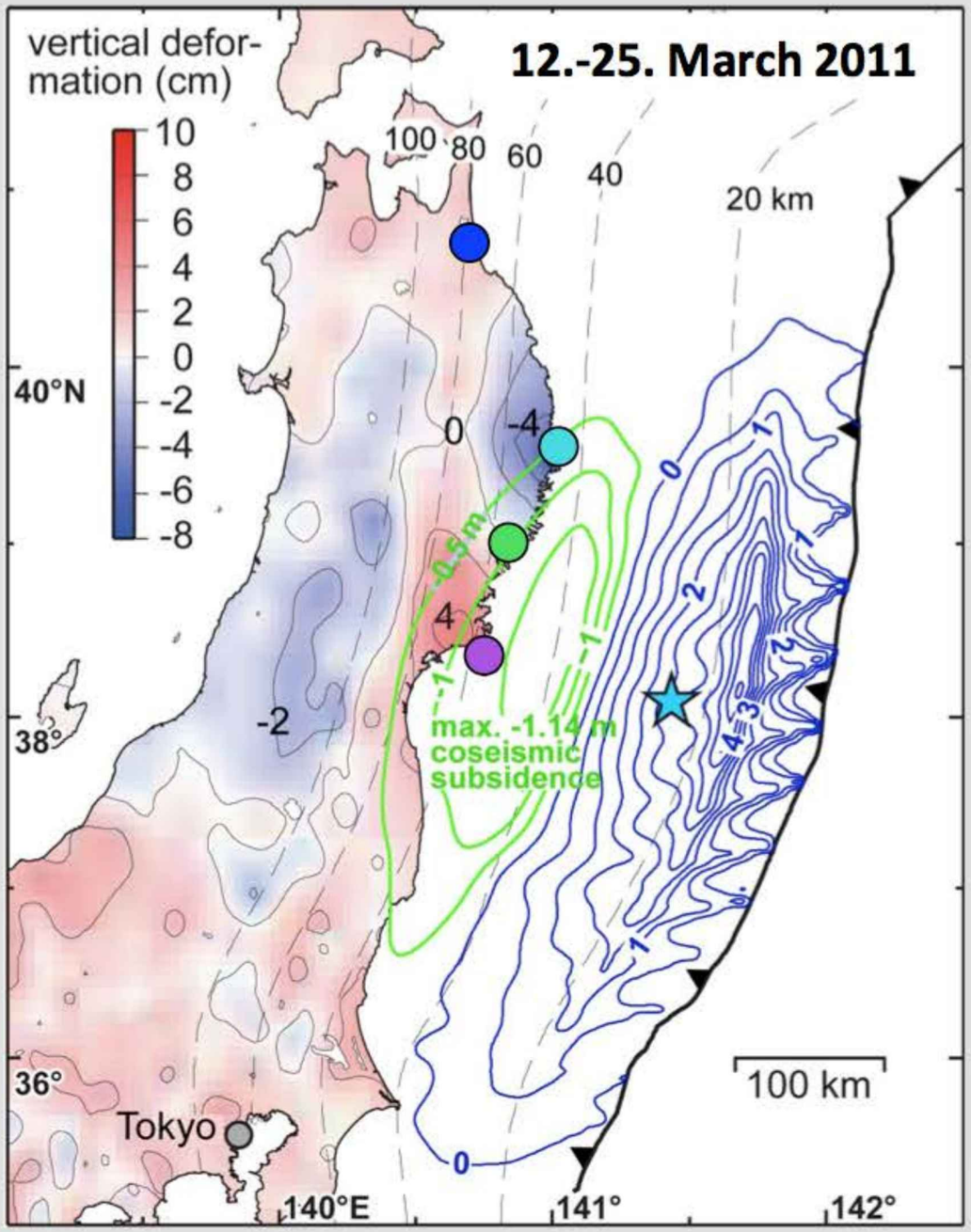
Long-term uplift rate

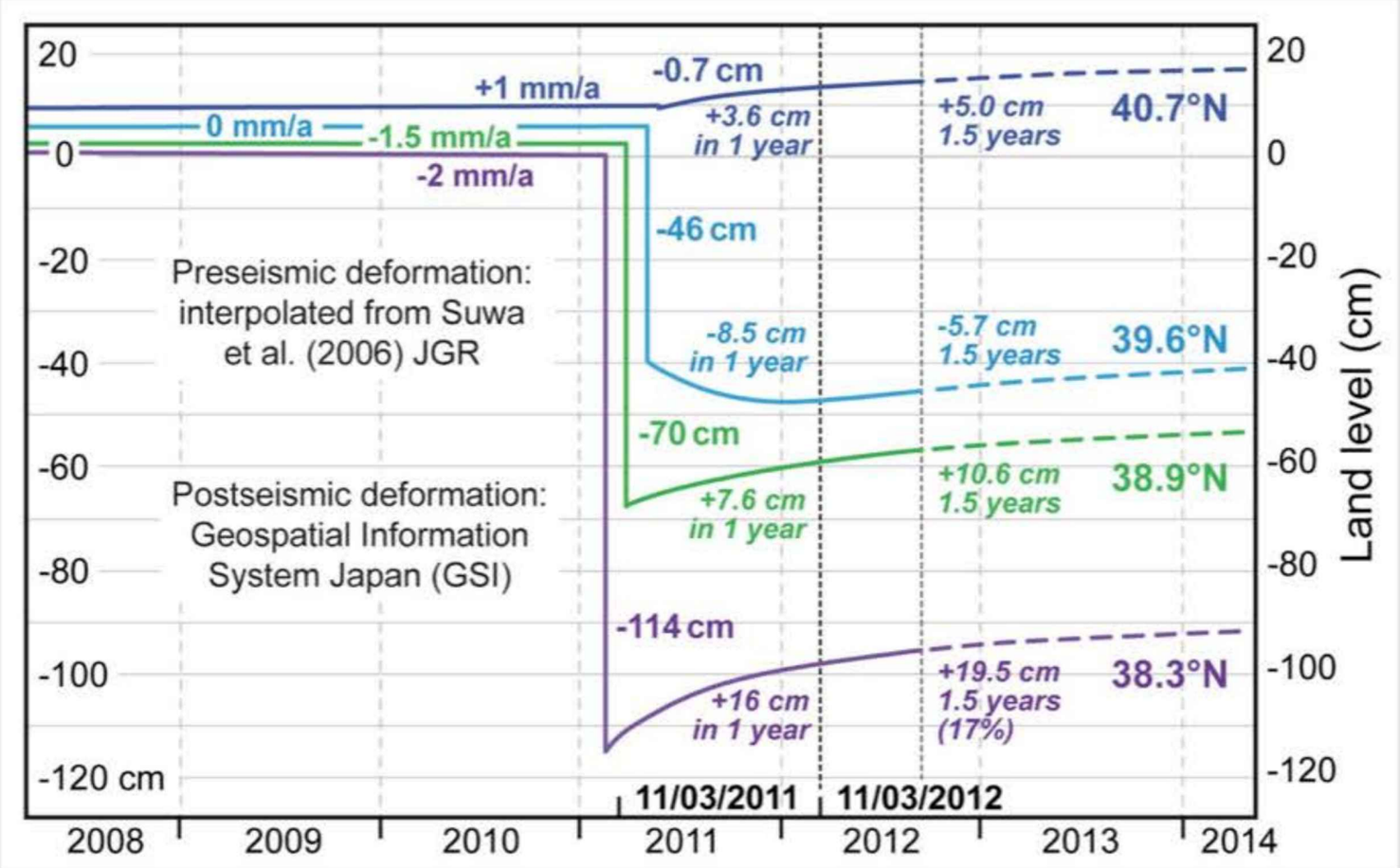




Height and ages after Koike & Machida (2001), own uplift rate determination

Co- and postseismic vertical deformation





Postseismic after Ozawa et al. (2011) Nature

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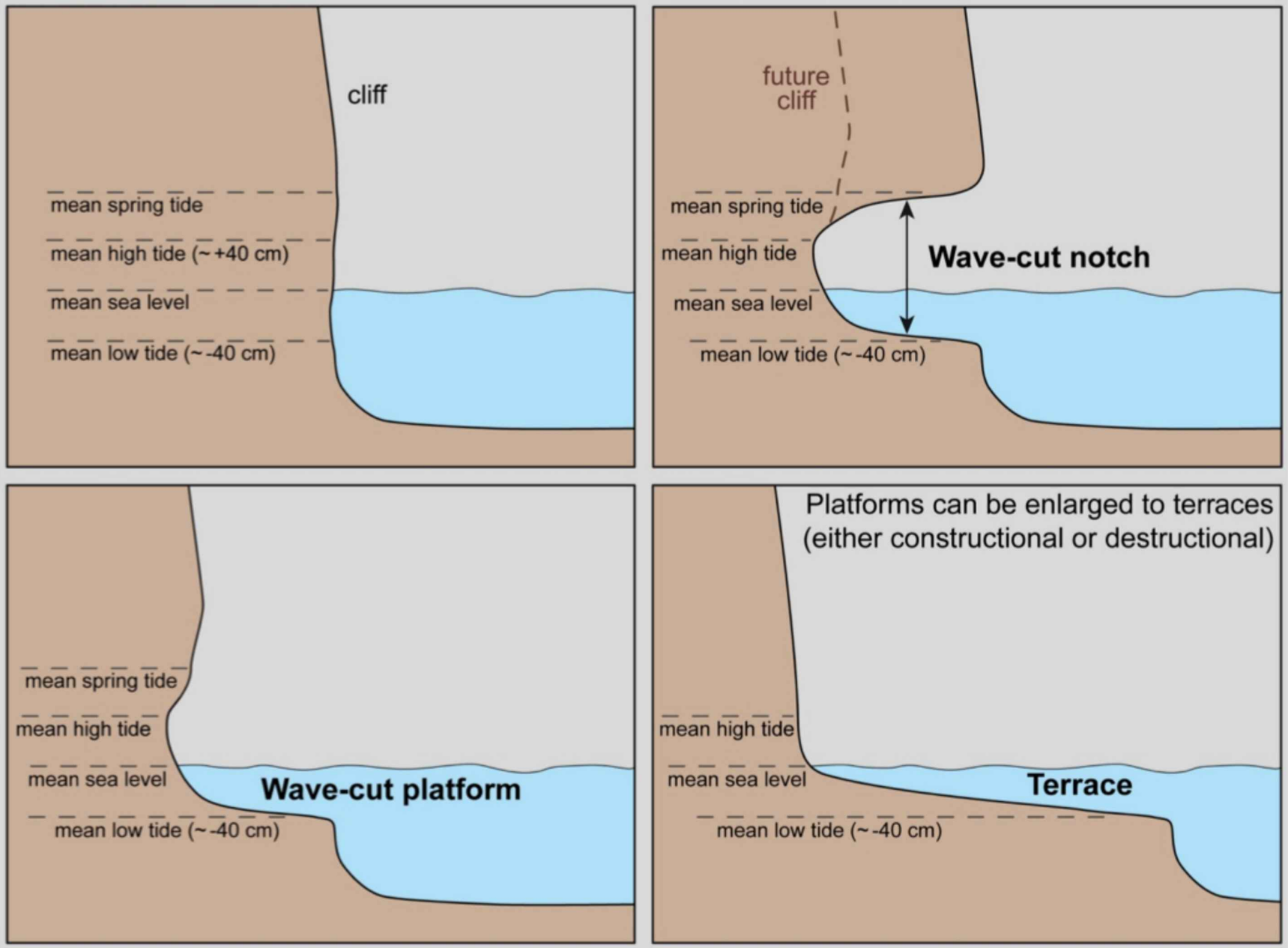
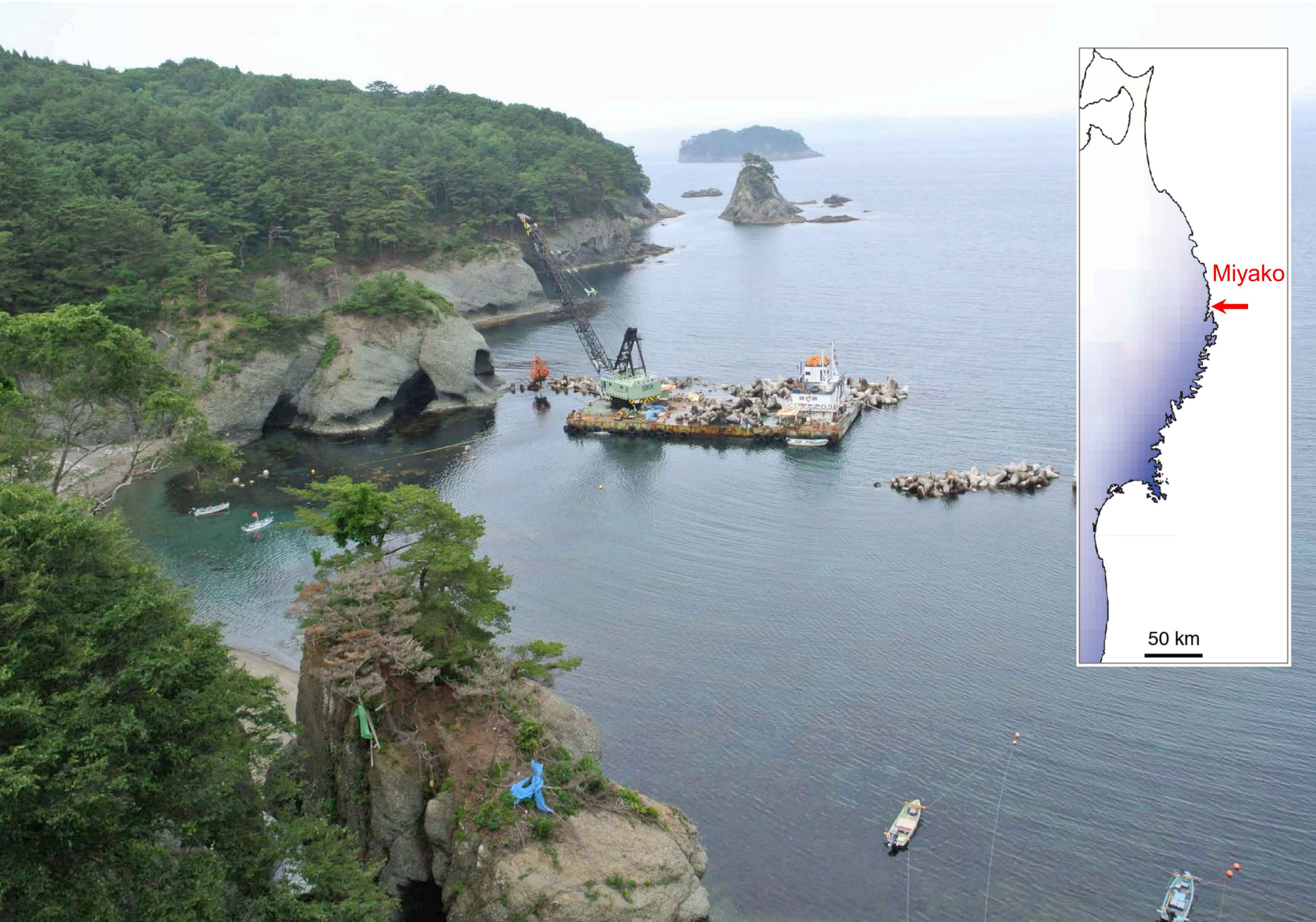
Long-term vertical deformation

- Marine benchmarks most useful
- Their formation requires a long period of stable relative sea level (e.g. sea level stability and tectonic quiescence)



After Scheffers et al. (2012) Holocene

Wave-cut notches



Wave-cut platforms

Height values are given as pre-2011 level (corrected for tide and co- and postseismic deformation)

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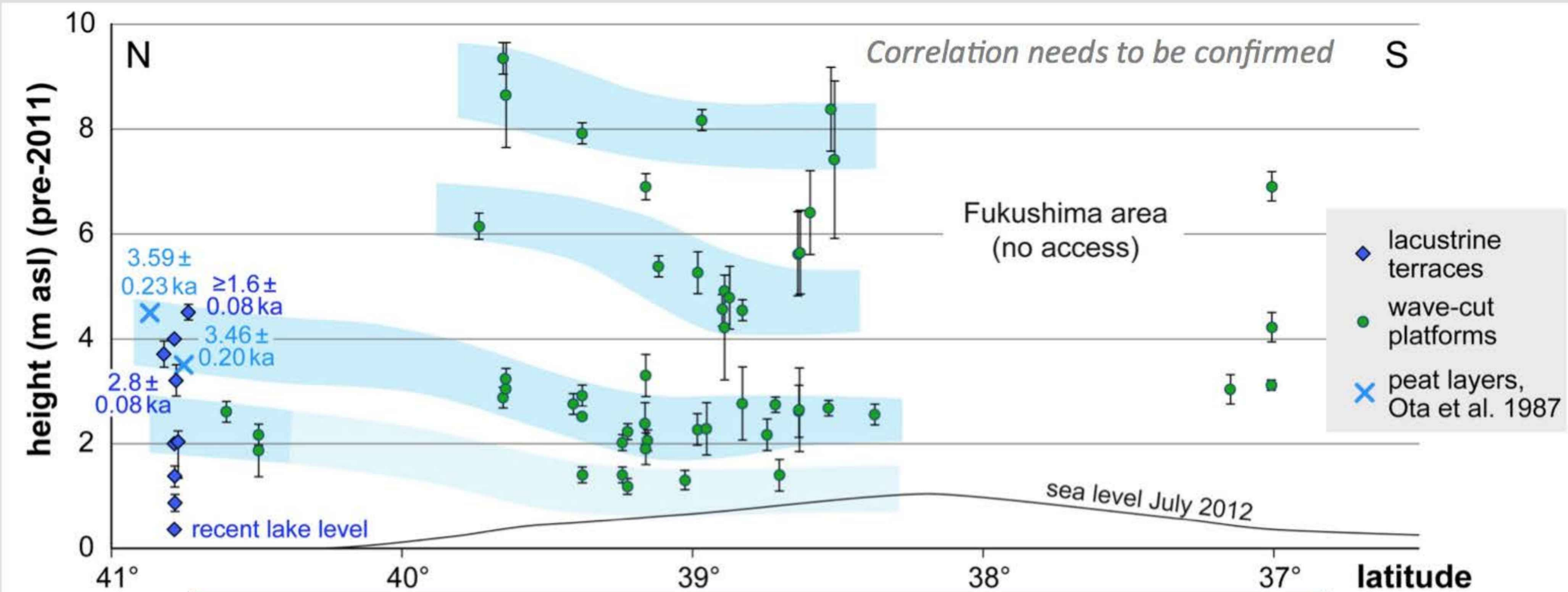
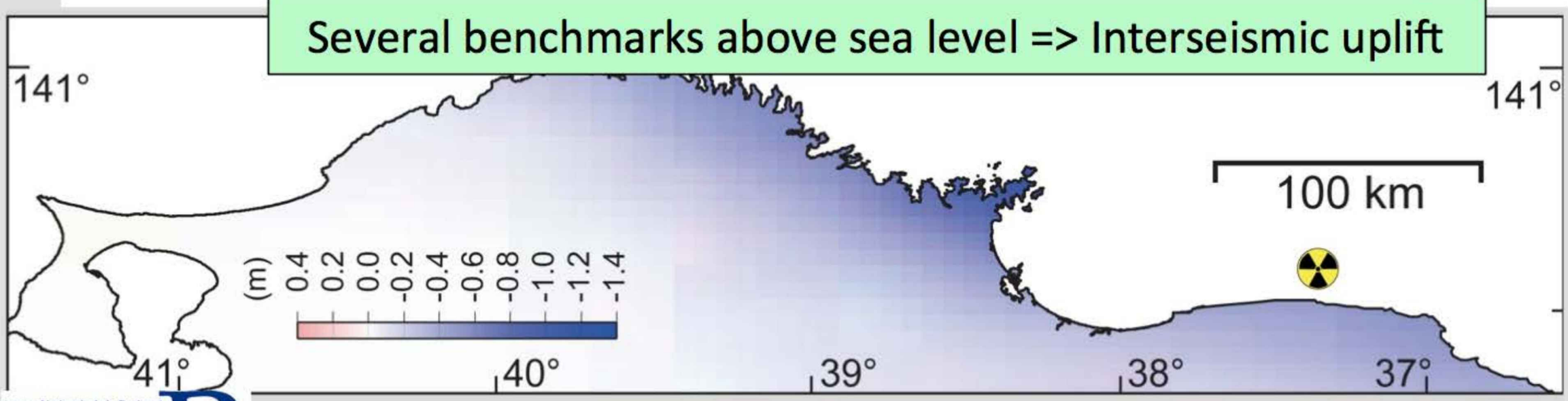
Distribution and height of lower wave-cut platforms and terraces



Several benchmarks above sea level => Interseismic uplift



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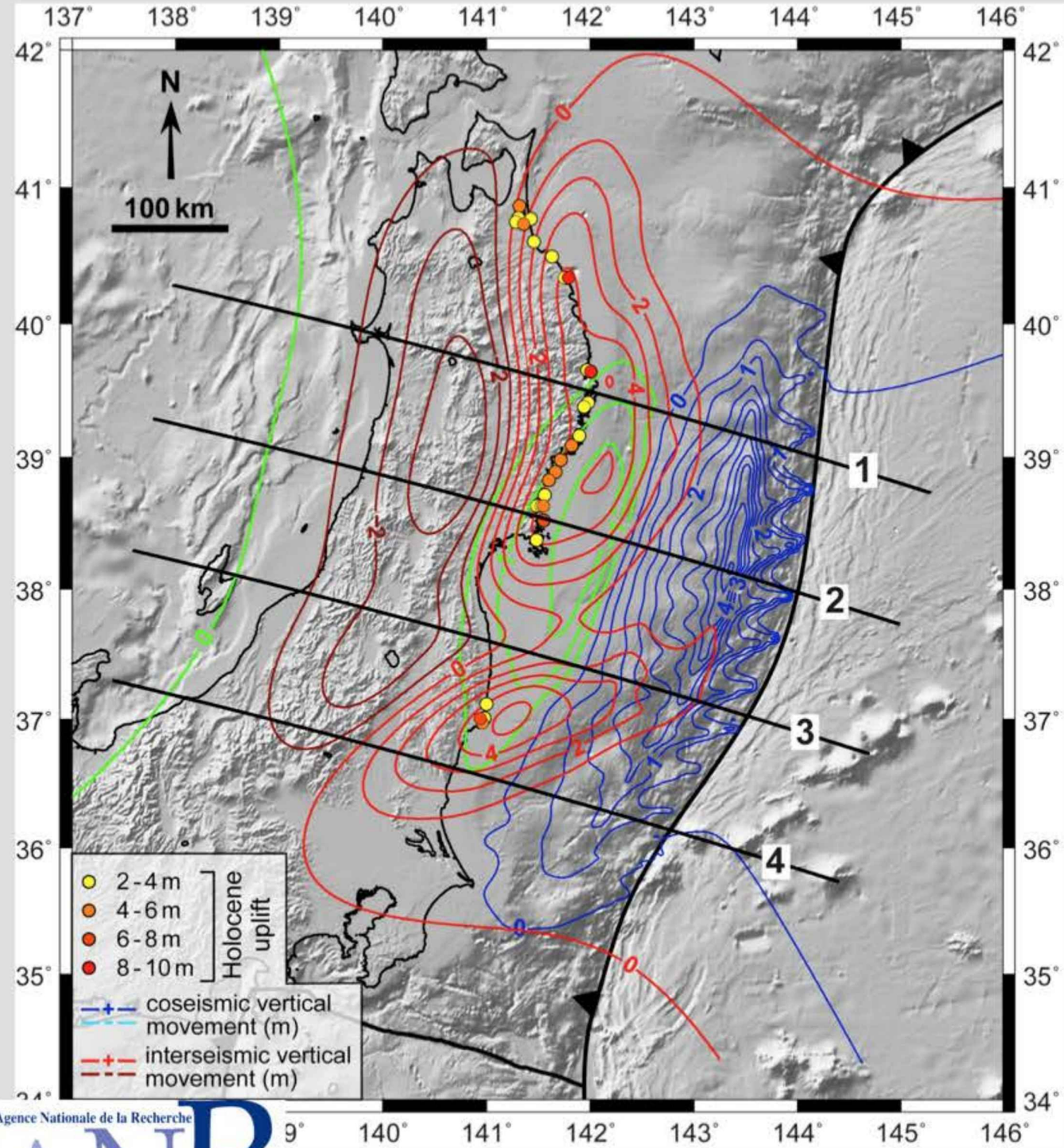
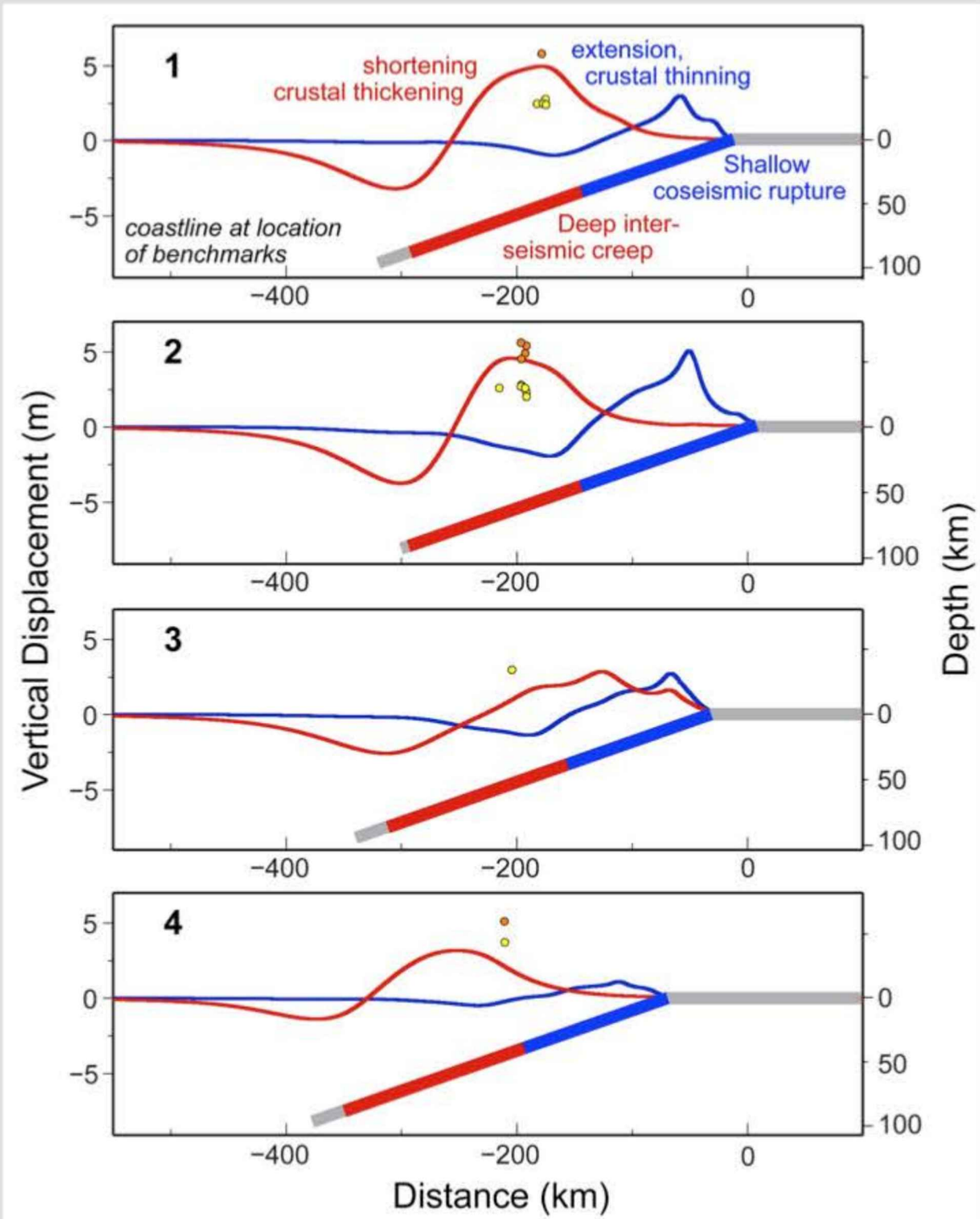
Coseismic & Interseismic deformation

Area of highest coseismic subsidence coincides with area of highest interseismic uplift





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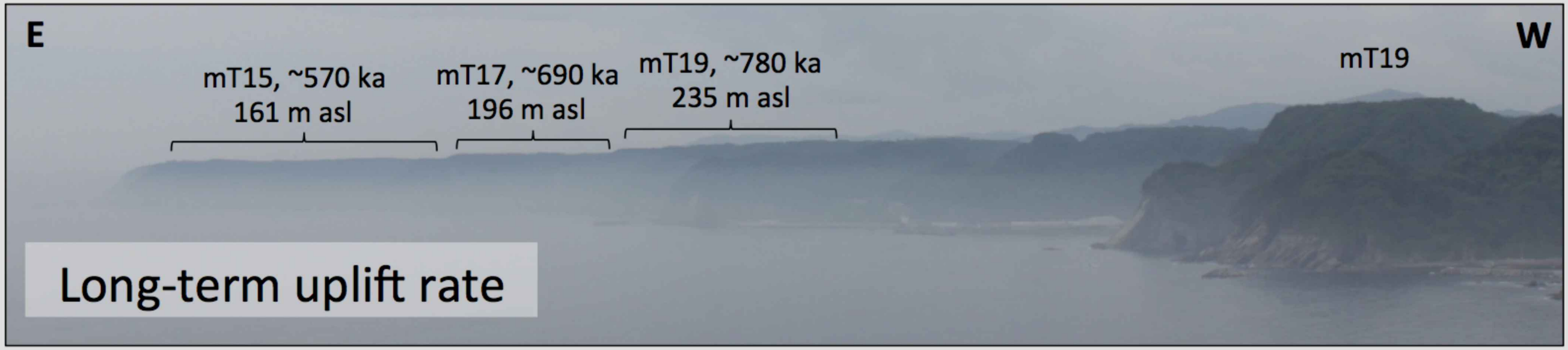
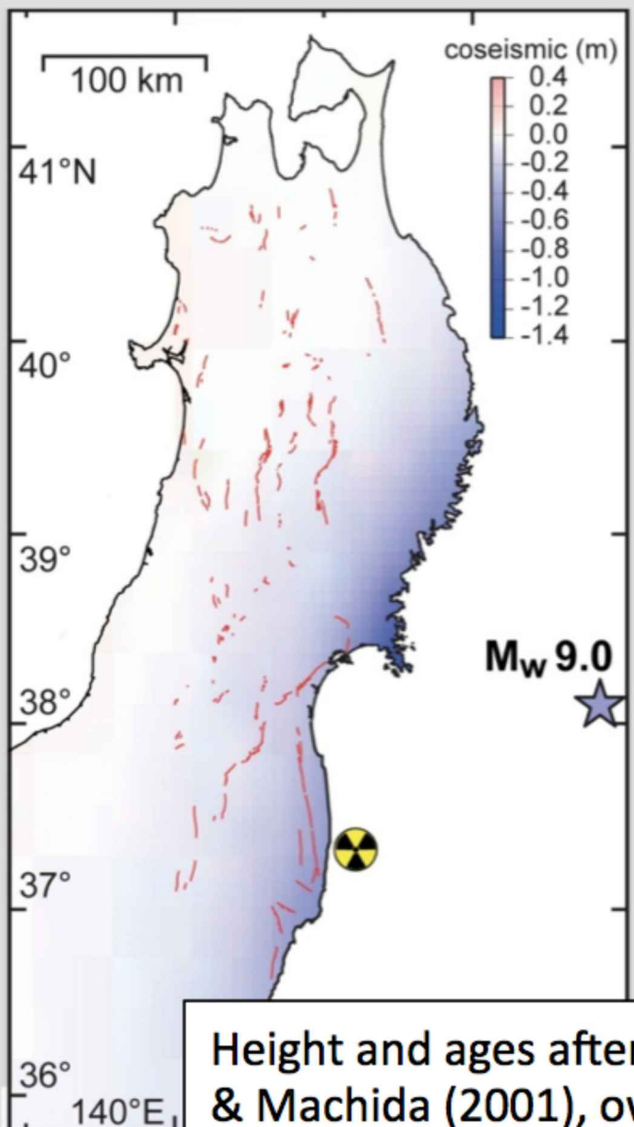
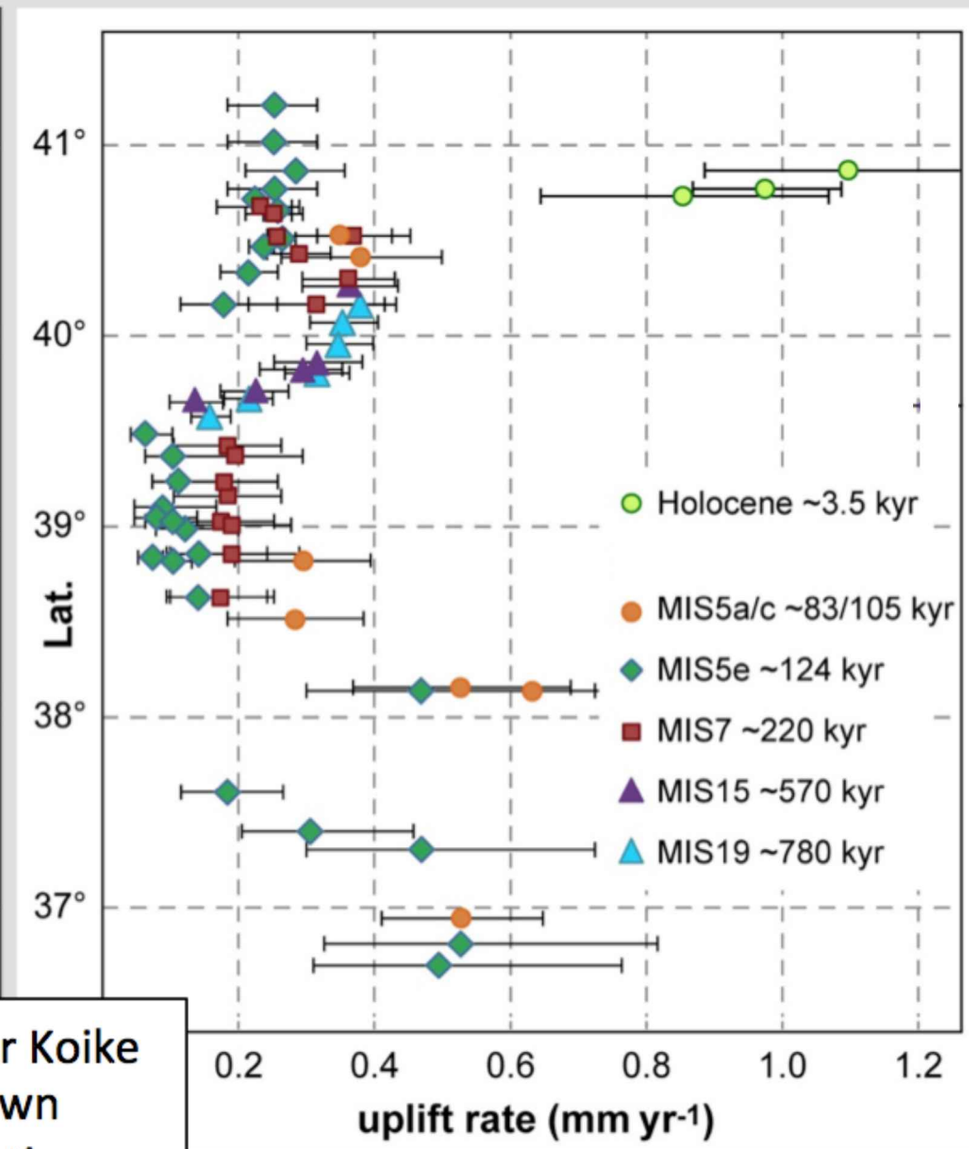


Long-term uplift rate





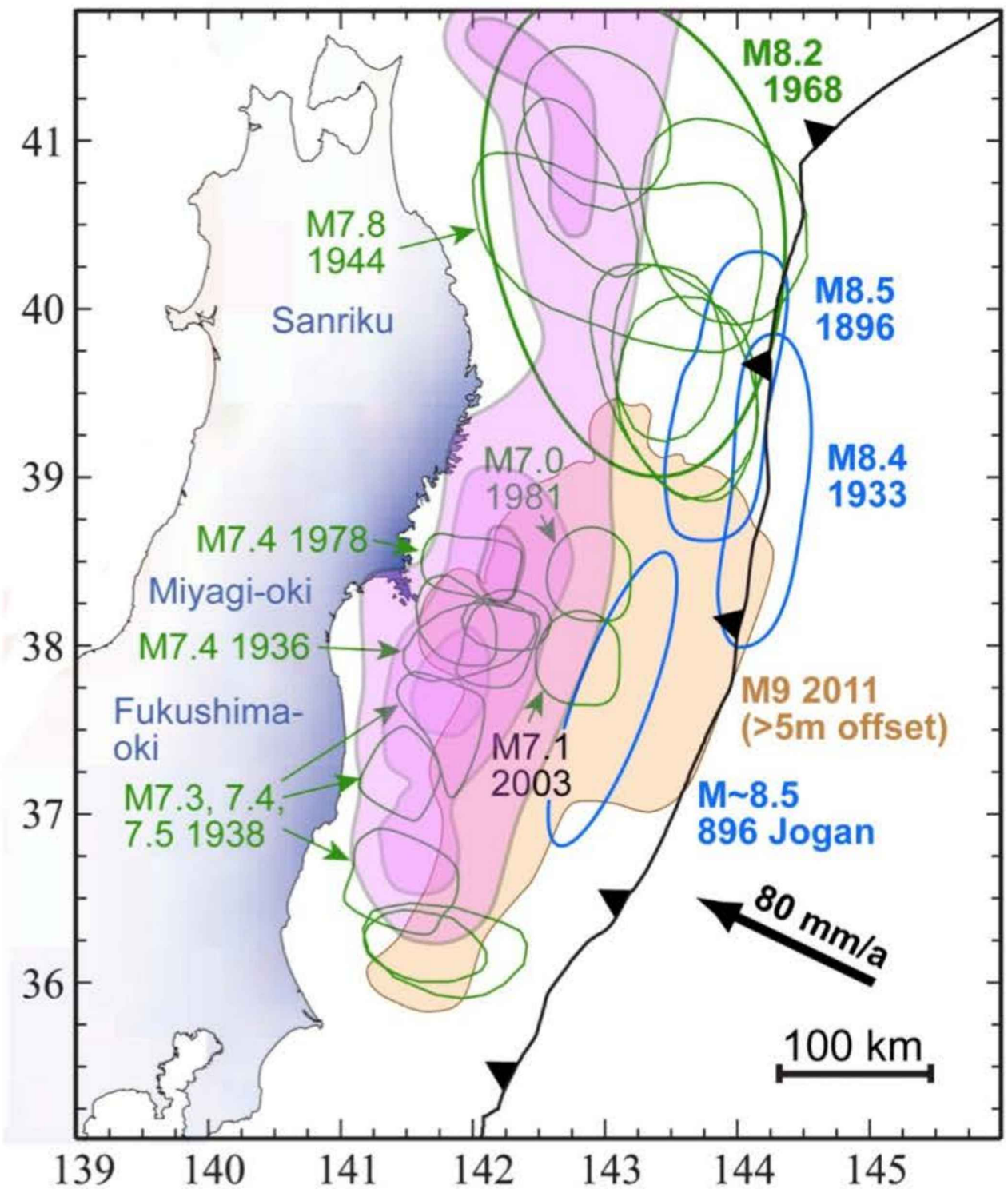
Height and ages after Koike & Machida (2001), own uplift rate determination

- Pleistocene uplift rates are significantly lower than Holocene uplift rates.
- Tendency that MIS5e has lowest rates (slip rate variability with time).
- 3 areas:
  - north: 0.2-0.4 mm/a,
  - south: 0.1-0.2 mm/a,
  - fault influenced: high and variable uplift

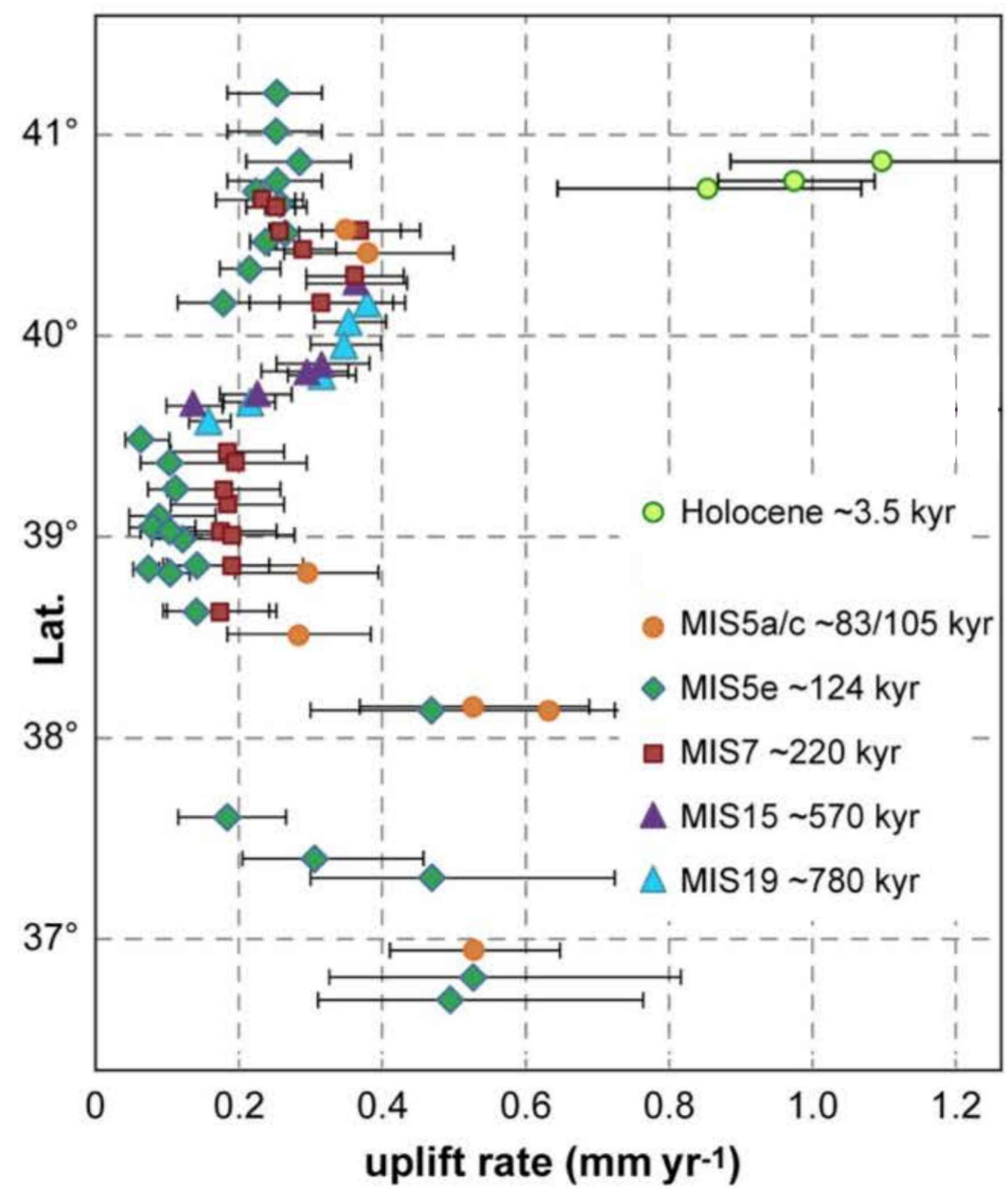
High coseismic subsidence in same area as lower long-term rates. Different rates due to the seismic cycle?

Correlation of datasets

Seismicity, Coupling & Coseismic deformation



Millennial uplift rates



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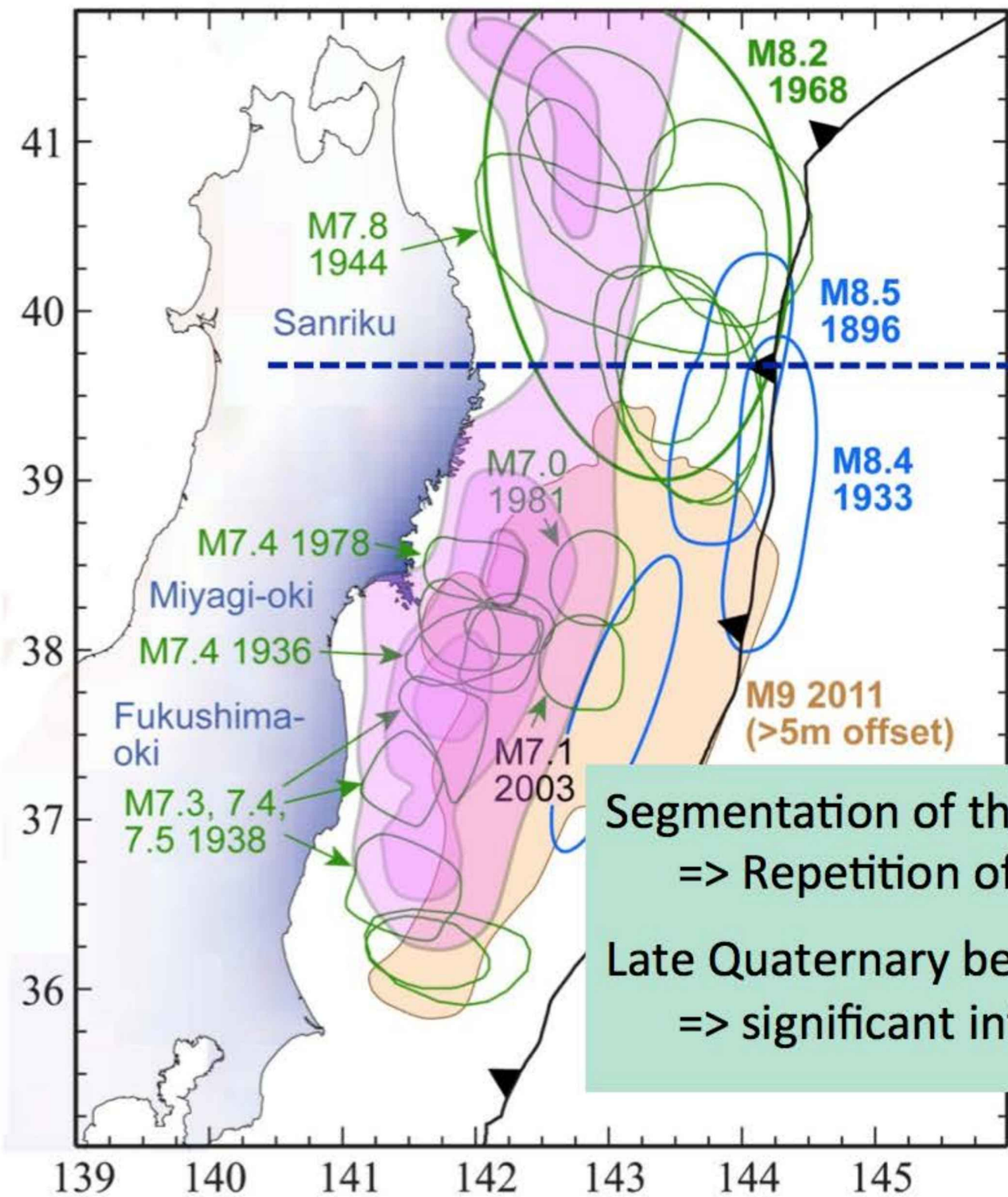

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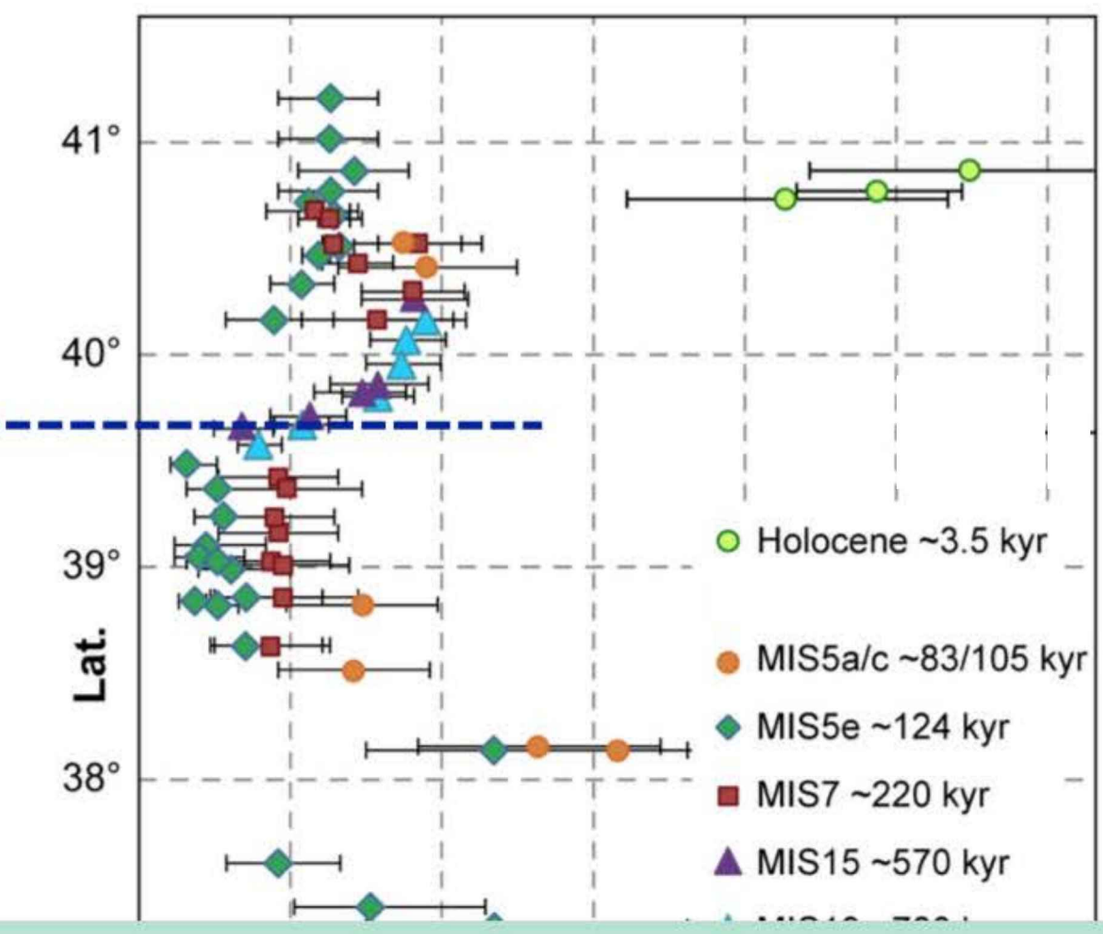


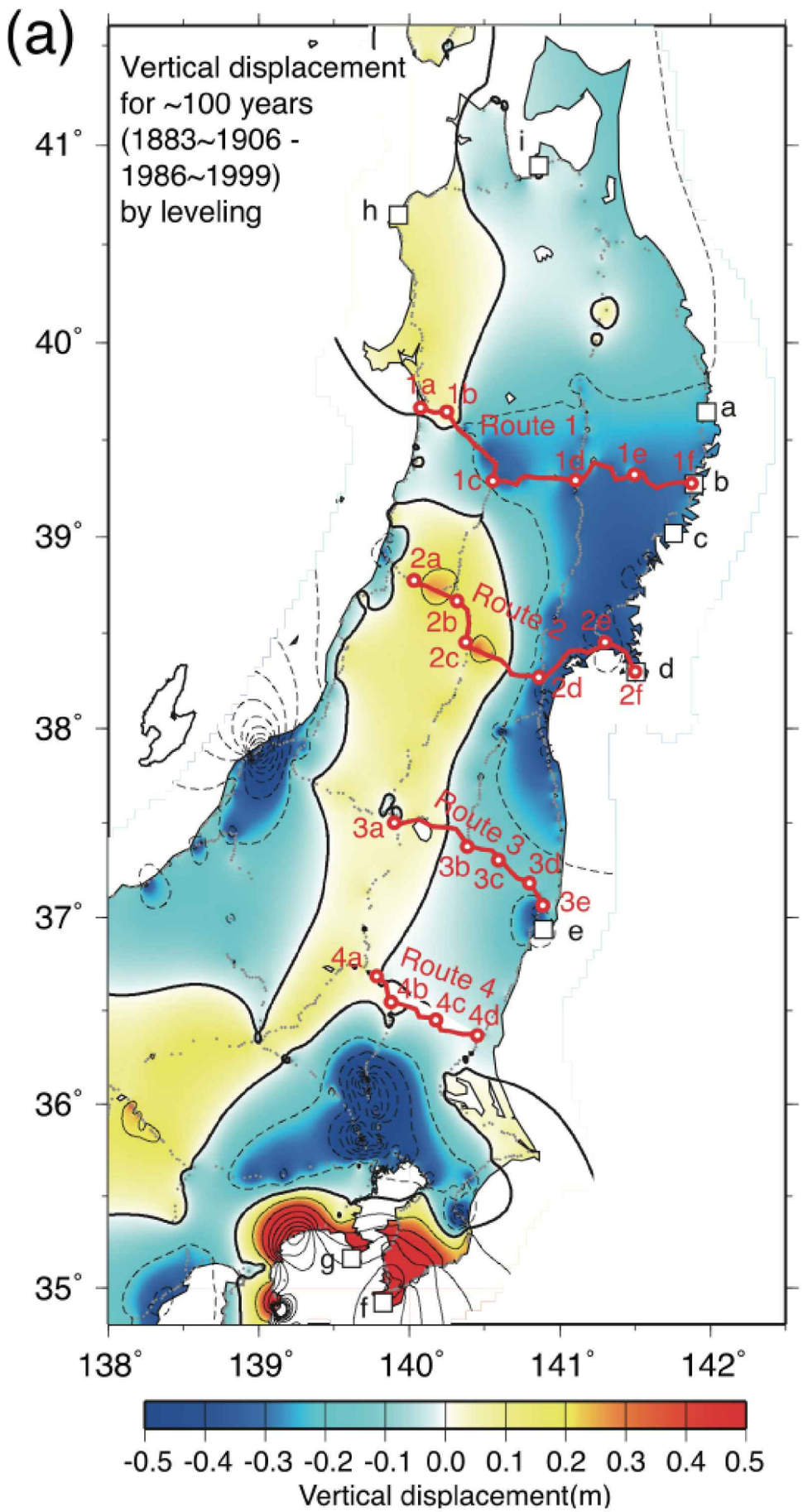
Segmentation of the Japan trench:

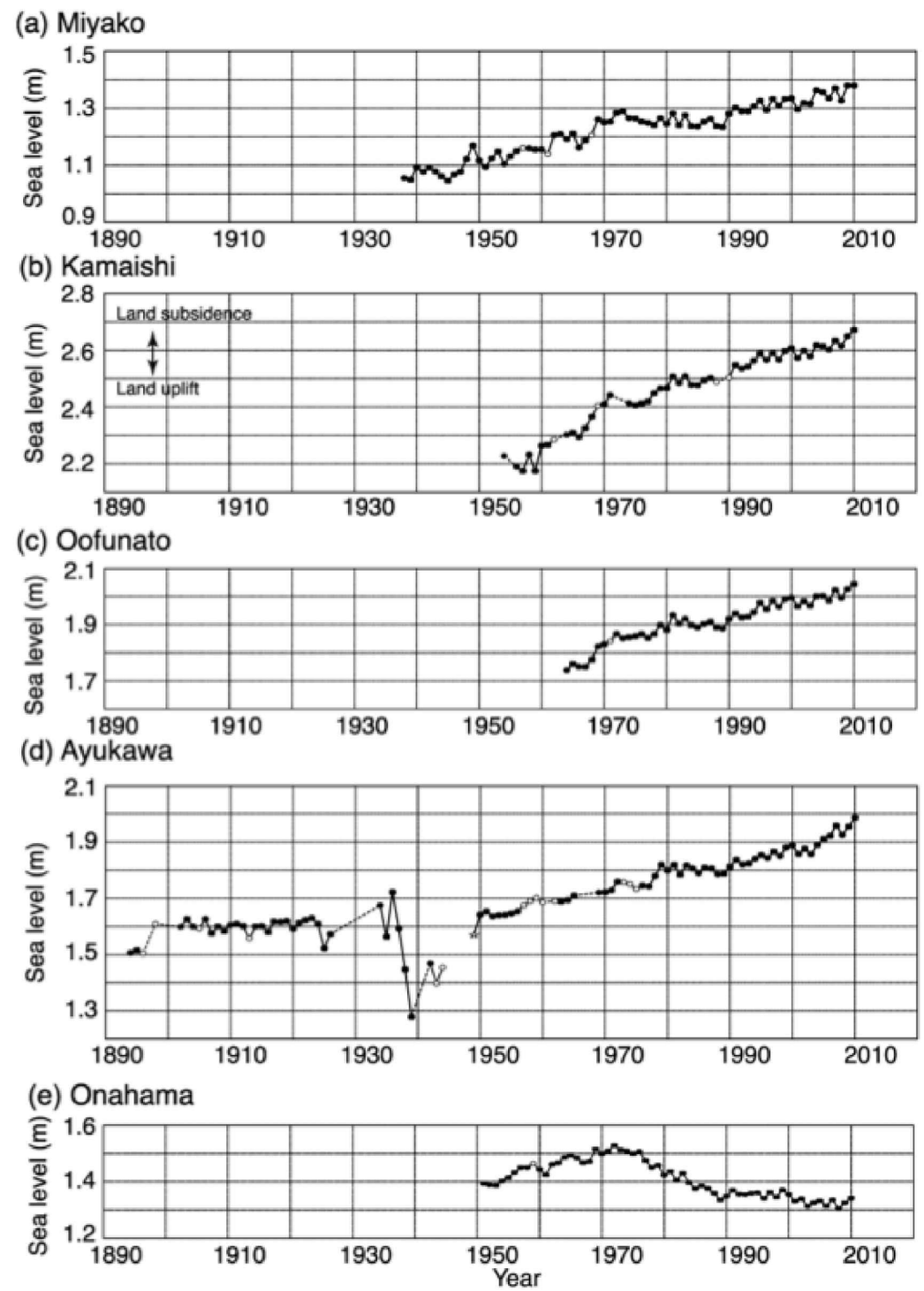
=> Repetition of the 2011 Tohoku earthquake was & is likely.

Late Quaternary benchmarks indicate strong uplift:

=> significant interseismic deformation.

Centennial geodetic data shows continuous (interseismic?) subsidence





Nishimura (2012)

To explain the Sanriku coastal data, either:

1) Gradual but episodic uplift occurs between earthquakes

2) 2011 M9 event typical, with long-term subsidence

3) A hidden huge event is still needed to uplift the coast

Major Outcomes

- 350-550 years of recurrence interval of extreme large tsunamis hit the Sanriku coast

- Presumed active faults in Fukushima Hamadori region, triggered by the 2011 earthquake, are confirmed active and recurrence interval of surface rupturing earthquakes on each fault is in the order of 10,000 years.

- Marine terraces along the Tohoku pacific coast have been uplifted at 0.2-0.4 mm/yr and 0.1-0.2 mm/yr in Aomori-northern Iwate, and Iwate-Fukushima respectively during late Quaternary period. The latter region corresponds to the 2011 earthquake.

- Together with these findings, we model crustal deformation and estimate the maximum 550-year recurrence intervals of M9 class earthquakes.