Widespread complex surface rupture associated with the Mw 7.0 16 April 2016 Kumamoto, Japan, earthquake

- Complex near-fault zone features
- Large restraining bend & Slip partitioning
- Remote triggered slip

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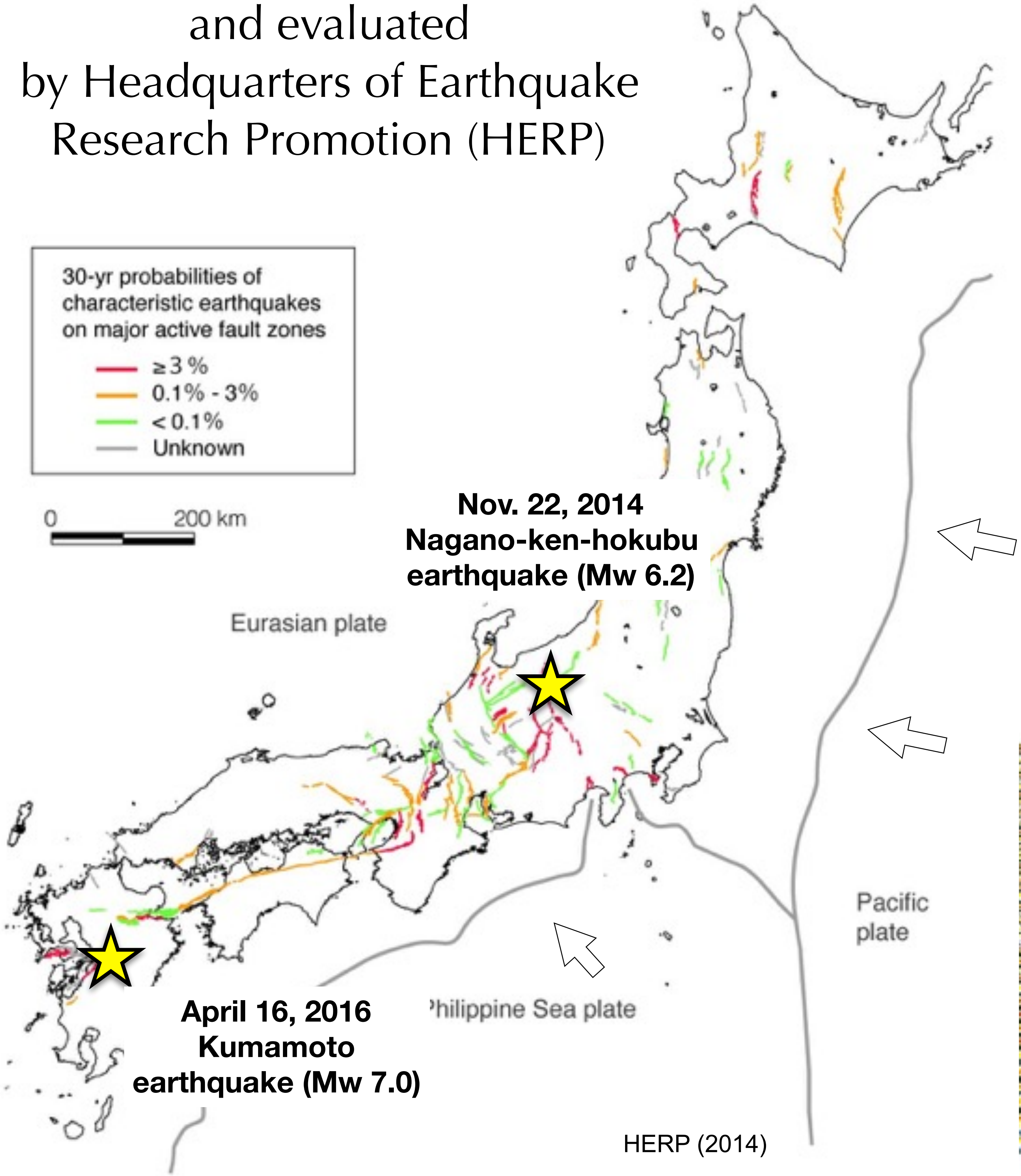
and Research Group for Surface Rupture of the Kumamoto Earthquake

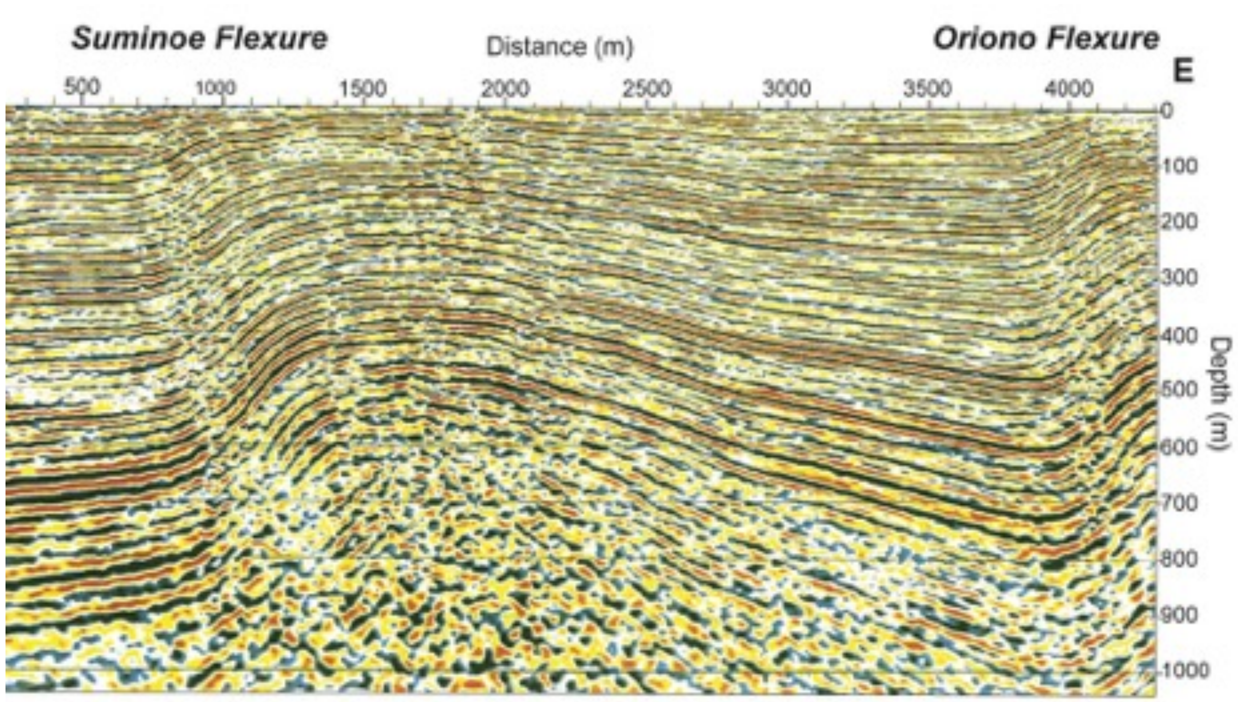
Since 1995 Kobe earthquake, ~100 major active faults have been intensively surveyed and evaluated by Headquarters of Earthquake Research Promotion (HERP)



HERP (2014)

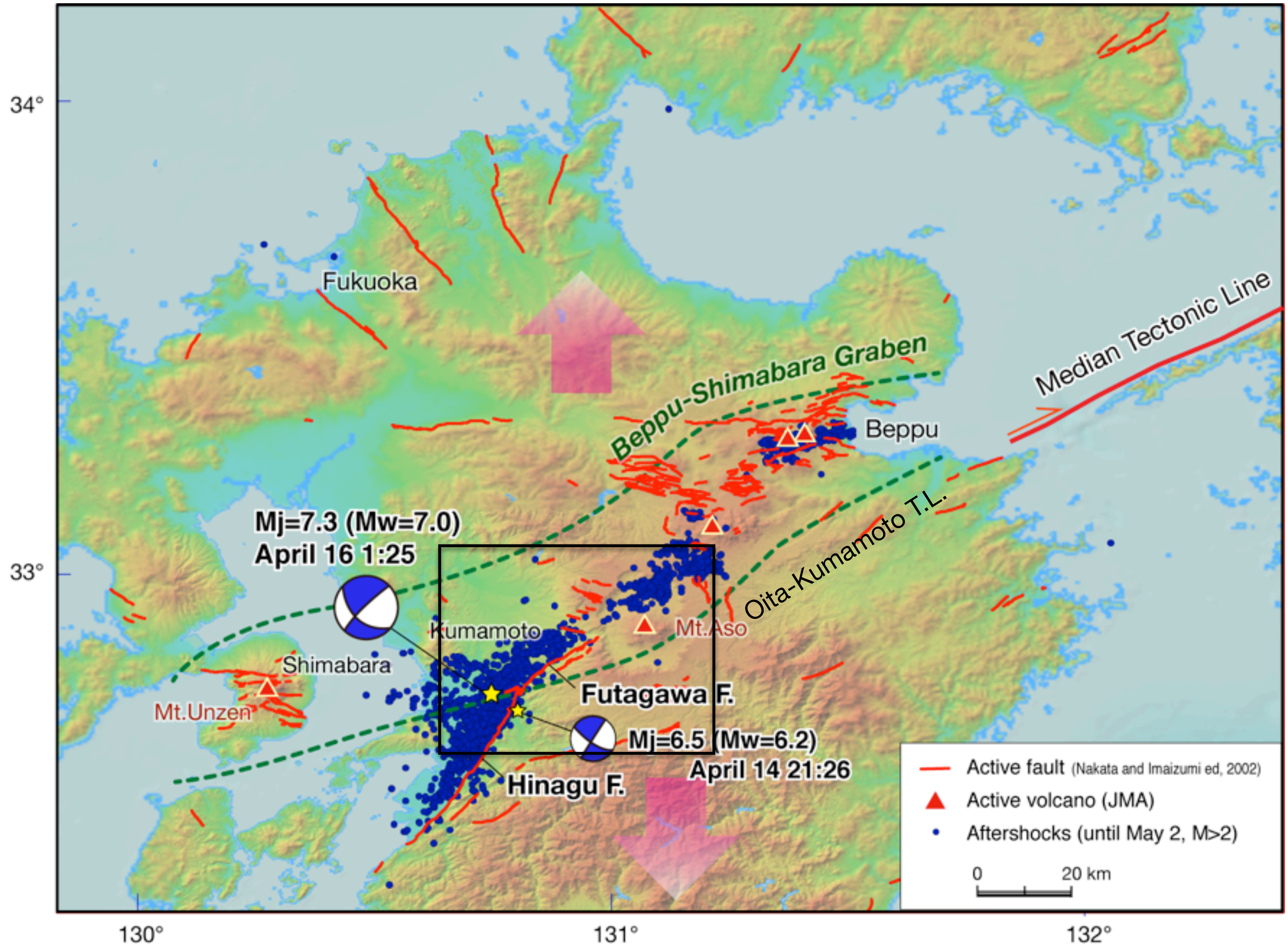
Paleoseismic trench

Seismic reflection survey

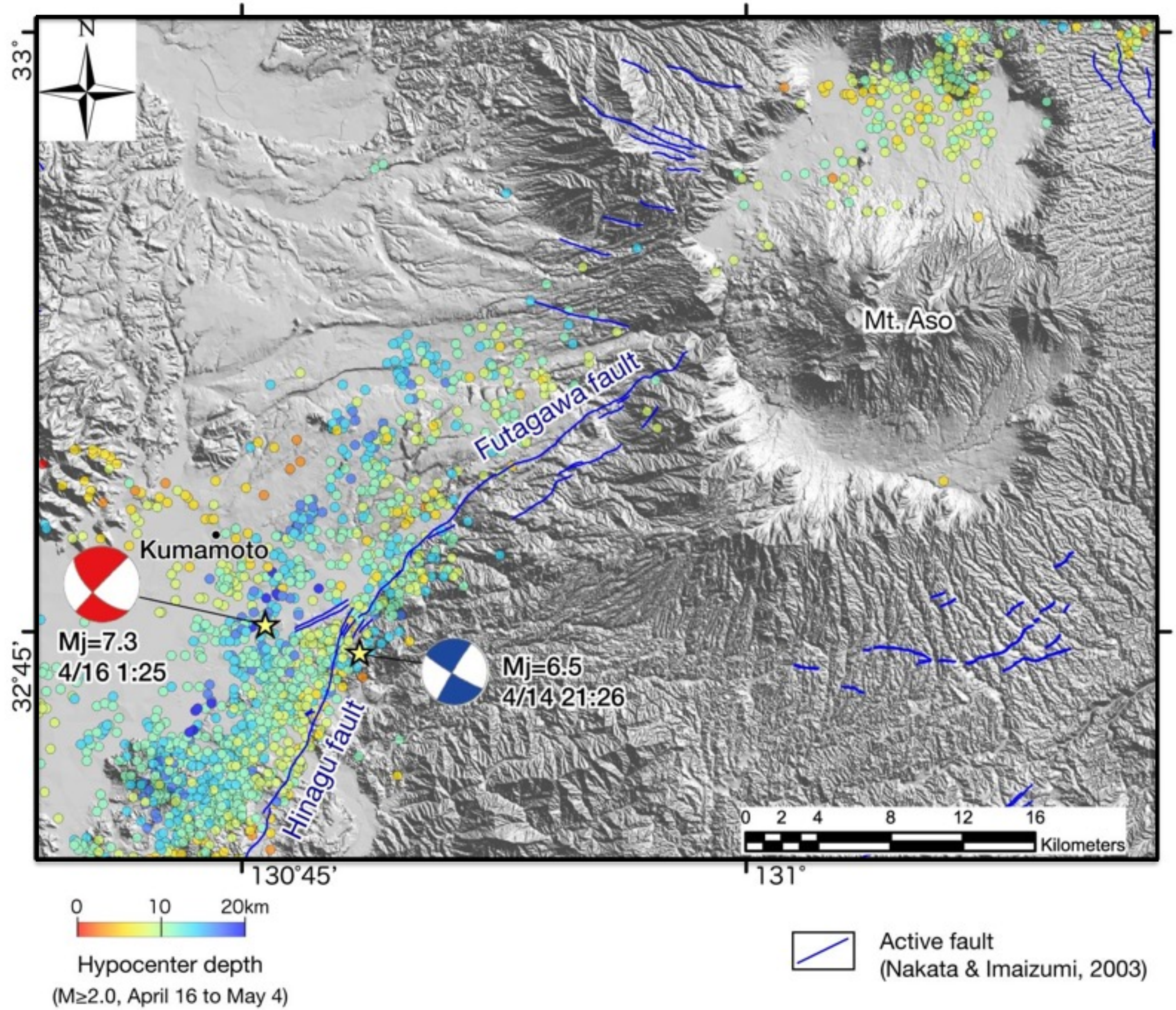


The Uemachi fault beneath the city of Osaka (Sugiyama et al., 2003)

The Kumamoto earthquakes occurred on the southern margin of the Beppu-Shimabara Graben



Surface rupture associated with the Mw 7.0 April 16, 2016 Kumamoto earthquake



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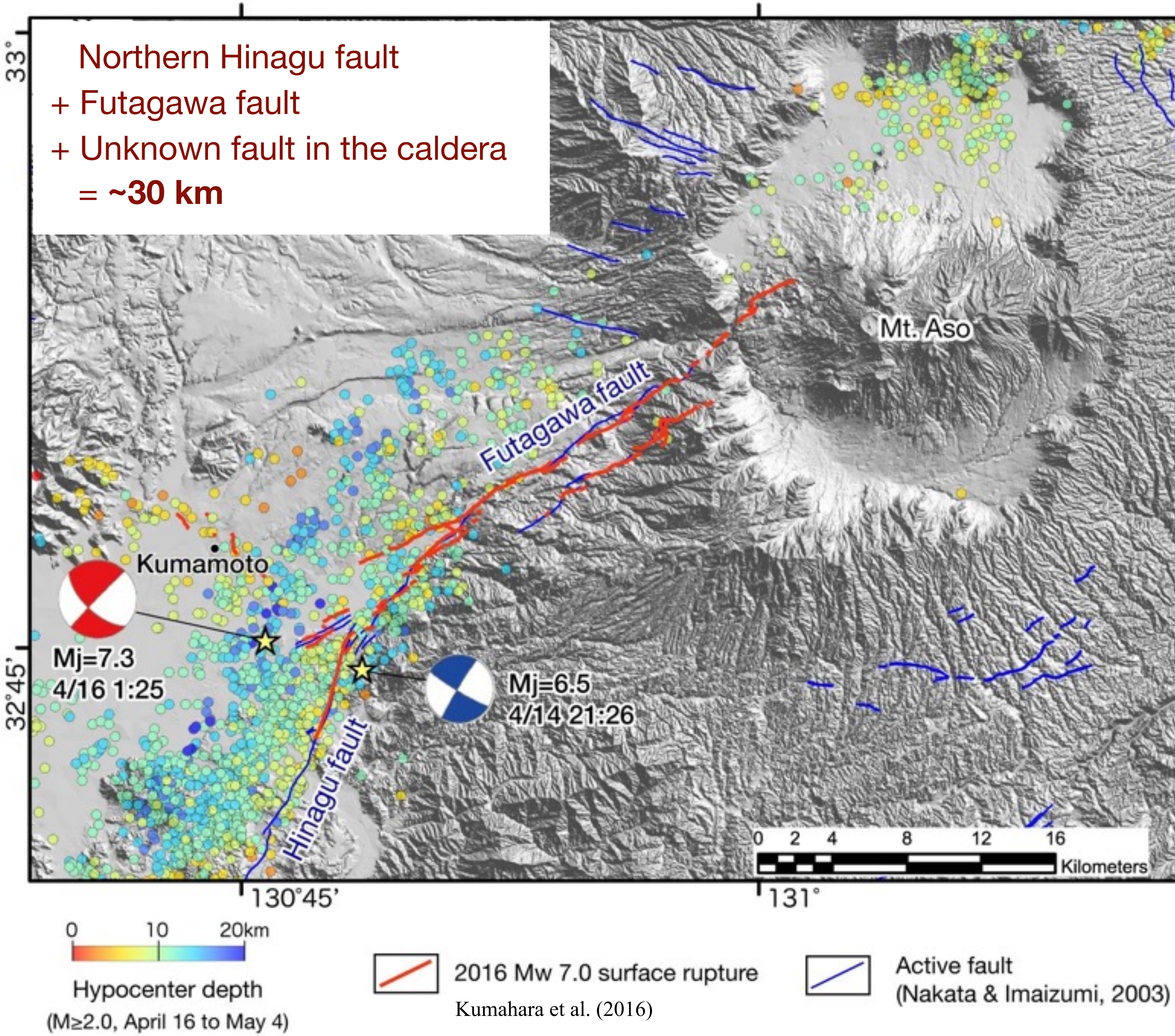

Kumahara et al. (2016)

Structural damage due to surface rupture

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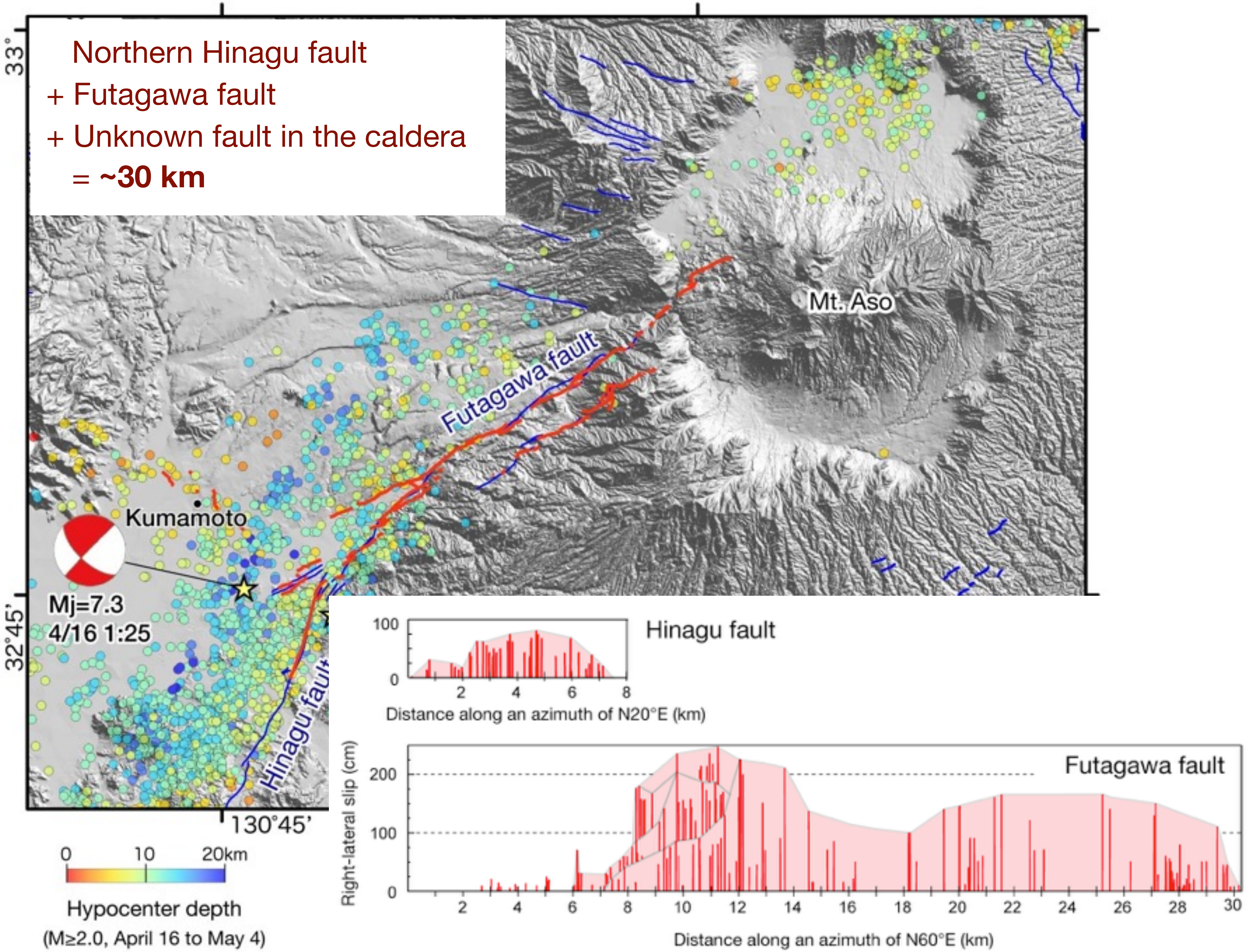
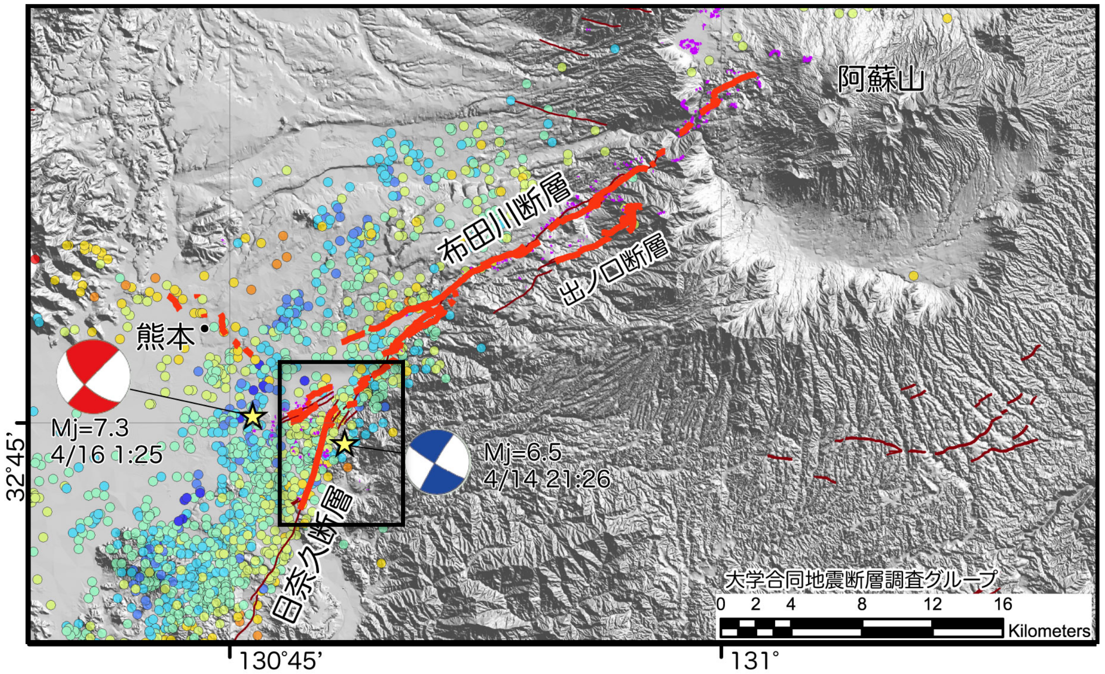
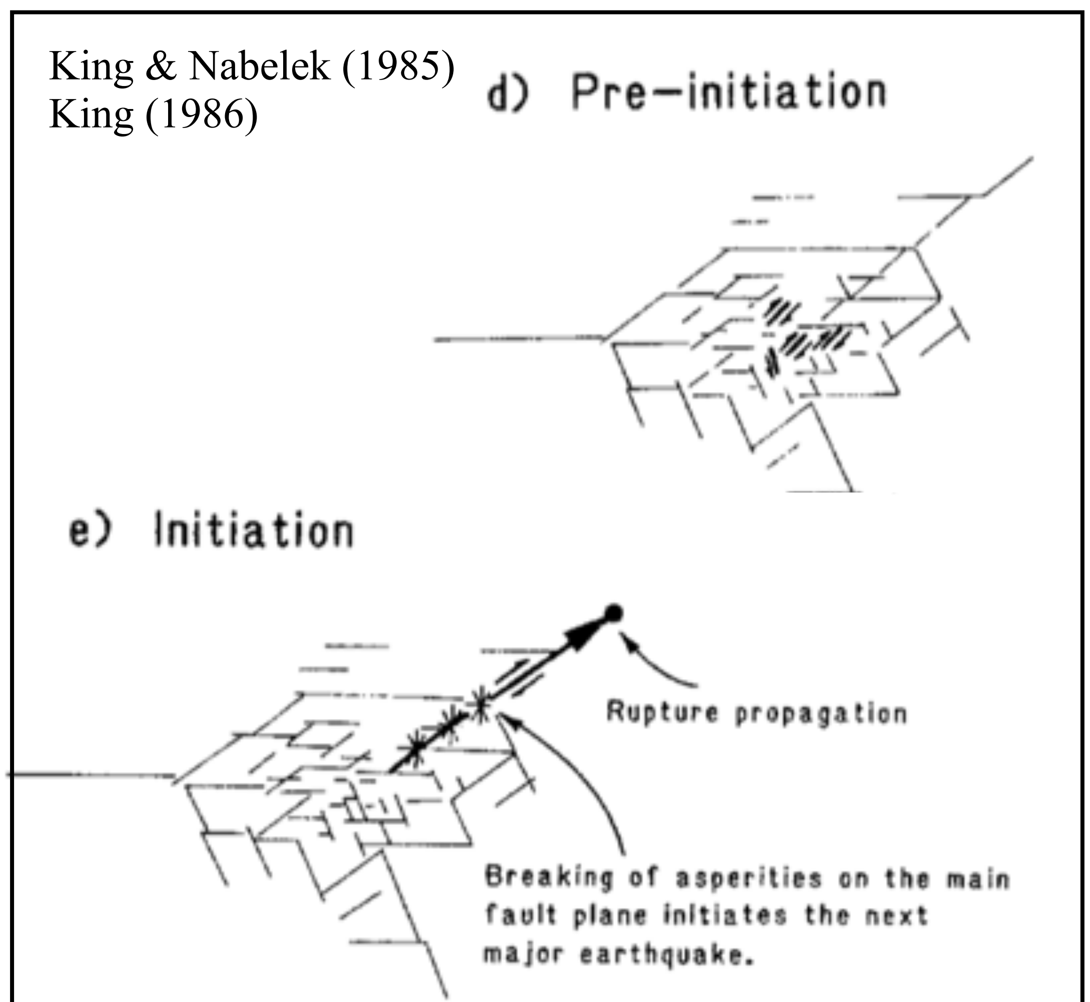
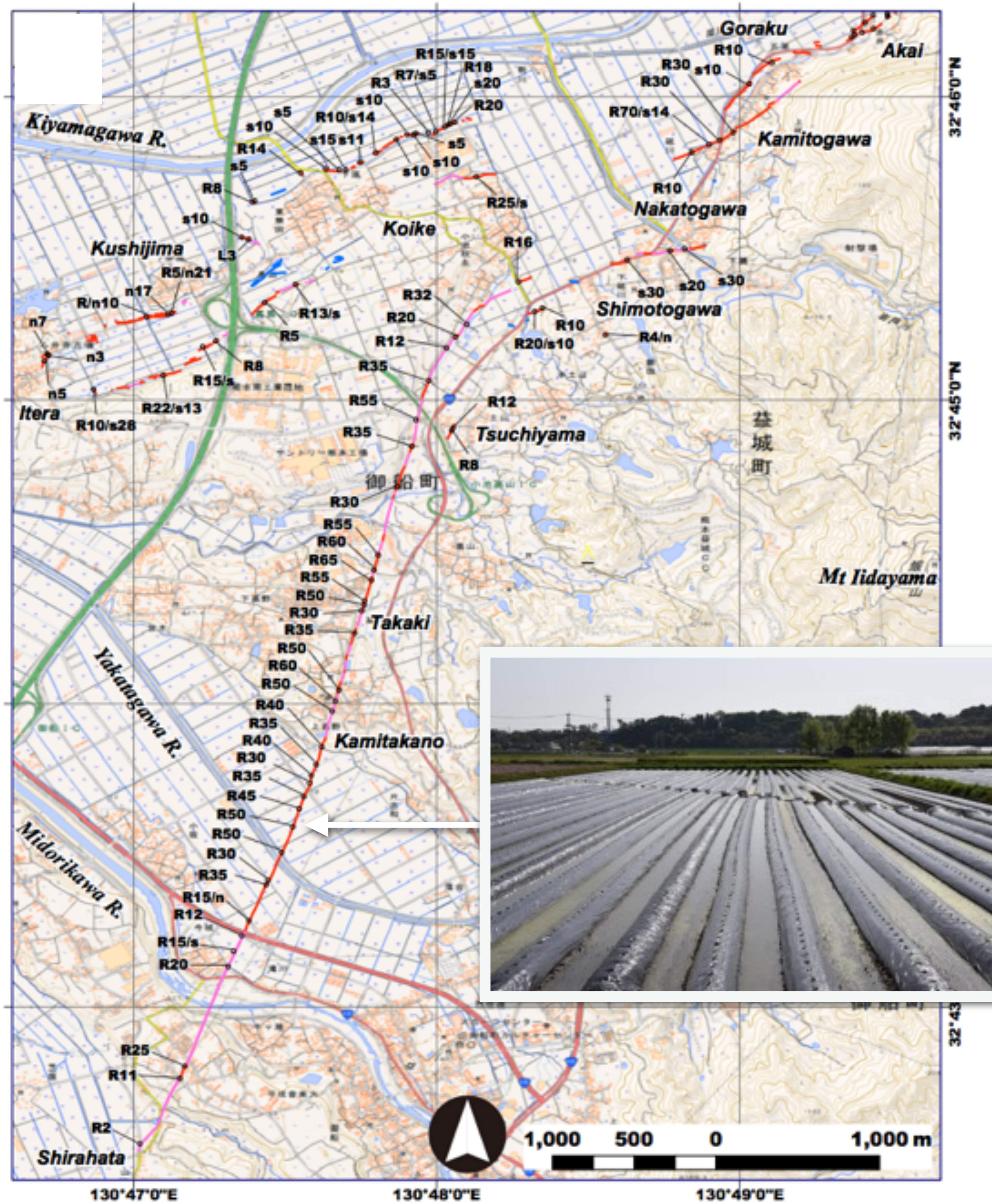
Surface rupture associated with the Mw 7.0 2016 Kumamoto earthquake



Restraining bend at the junction of the Hinagu & Futagawa fault zones



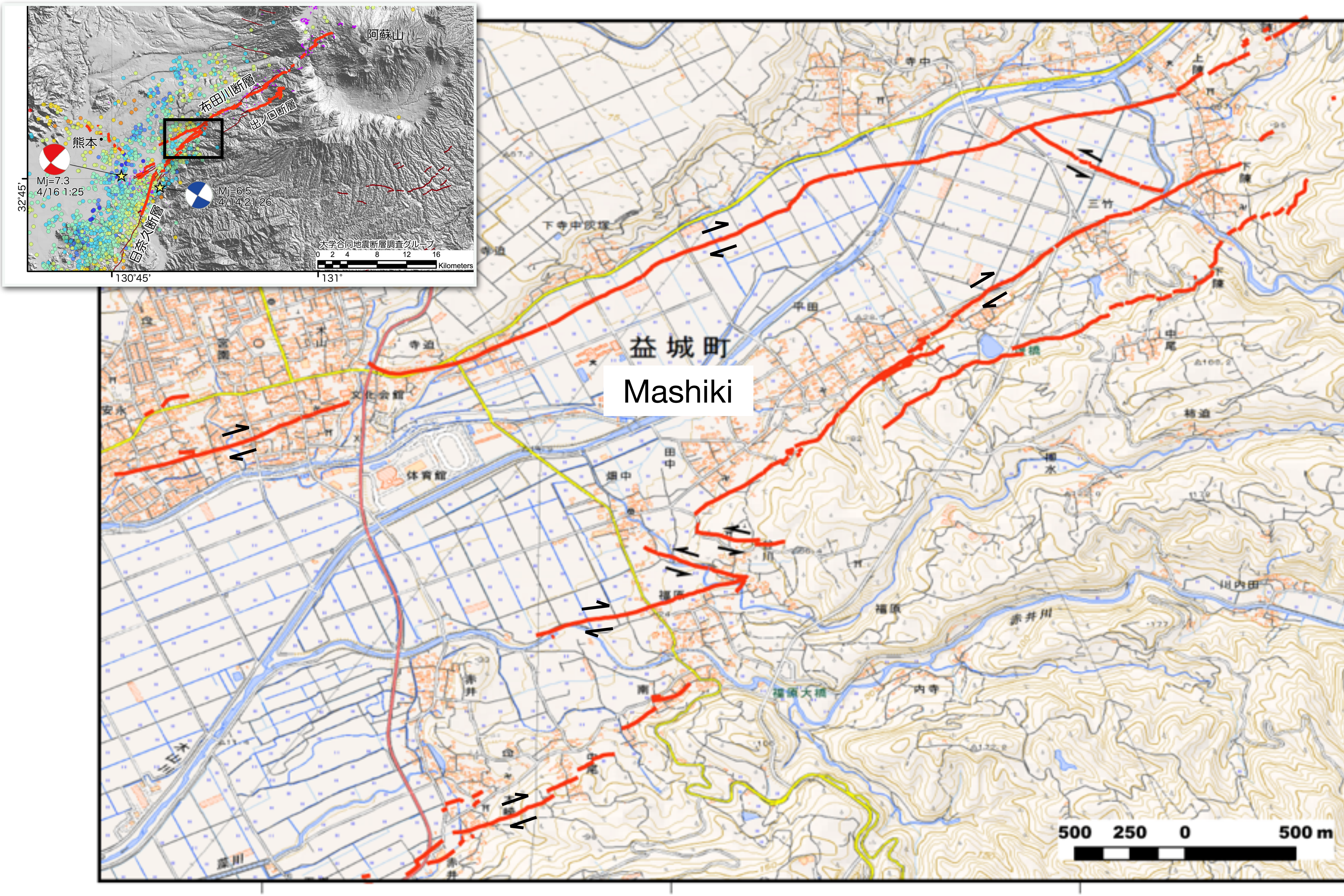




Right-lateral slip on the Futagawa fault

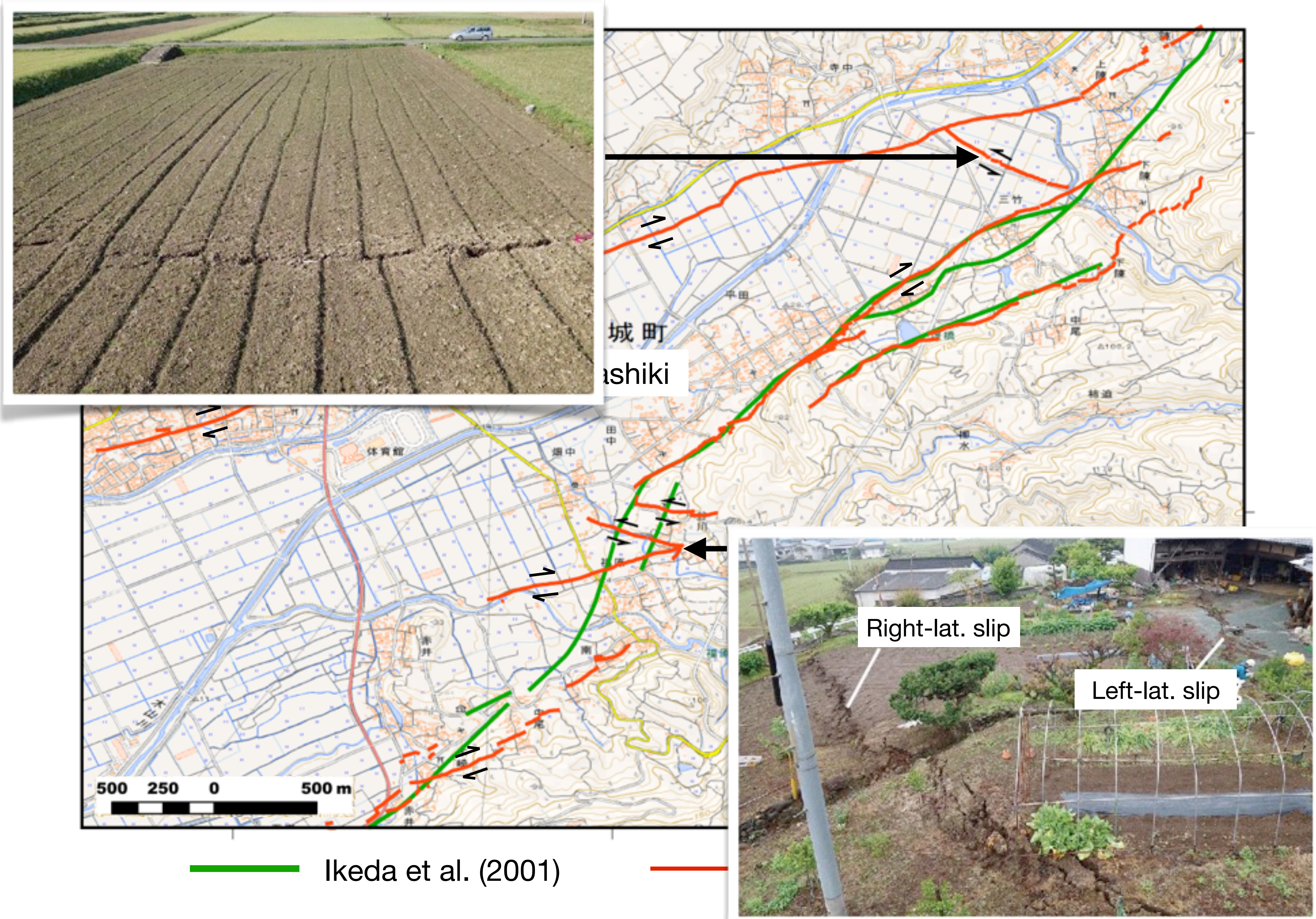
Left-stepping en echelon step-overs at various scales, like fractal

Left-stepping en echelon step-overs at various scales and left-lateral conjugate ruptures (unpredictable)



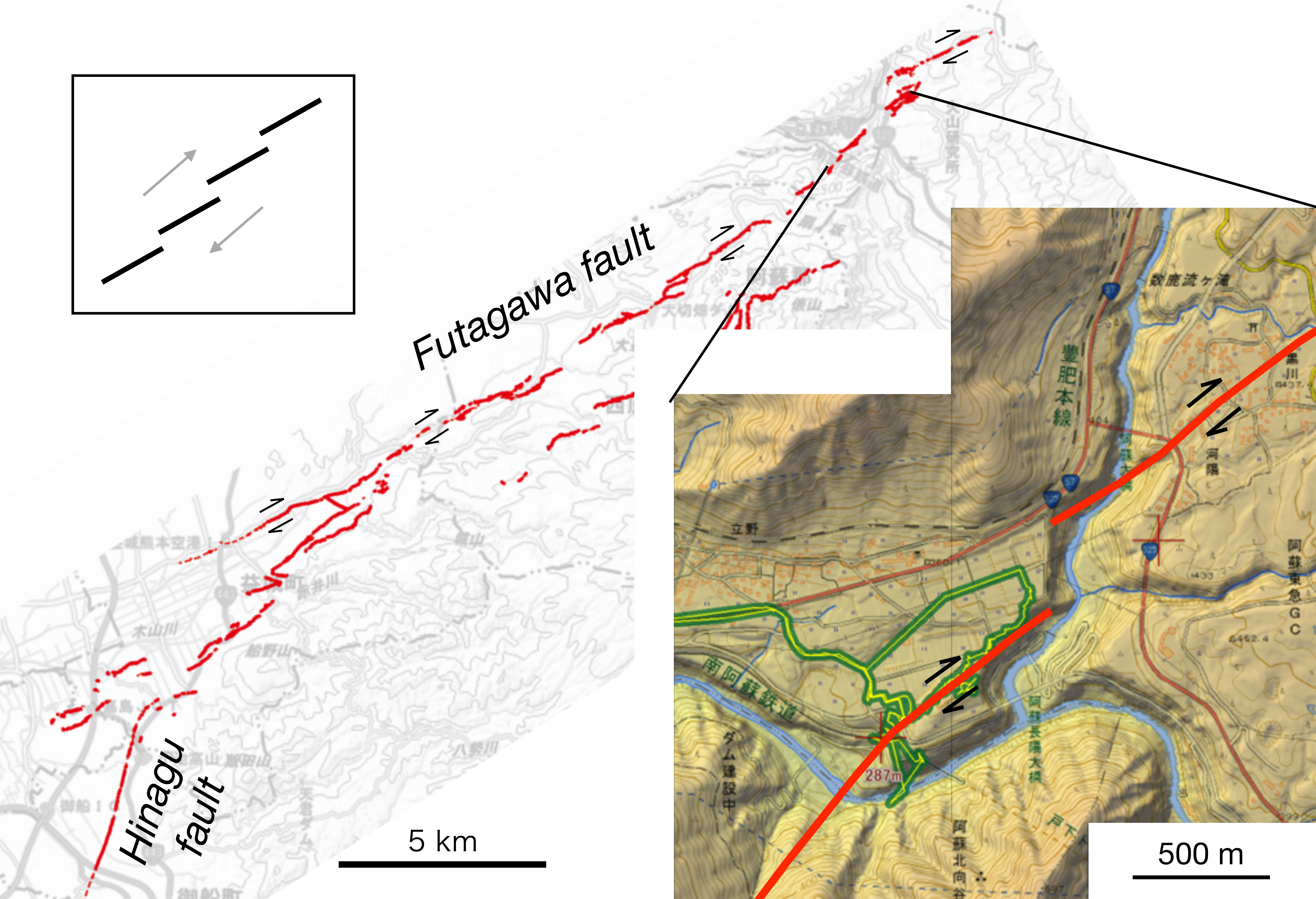
2016 surface rupture

Left-stepping en echelon step-overs at various scales and left-lateral conjugate ruptures (unpredictable)

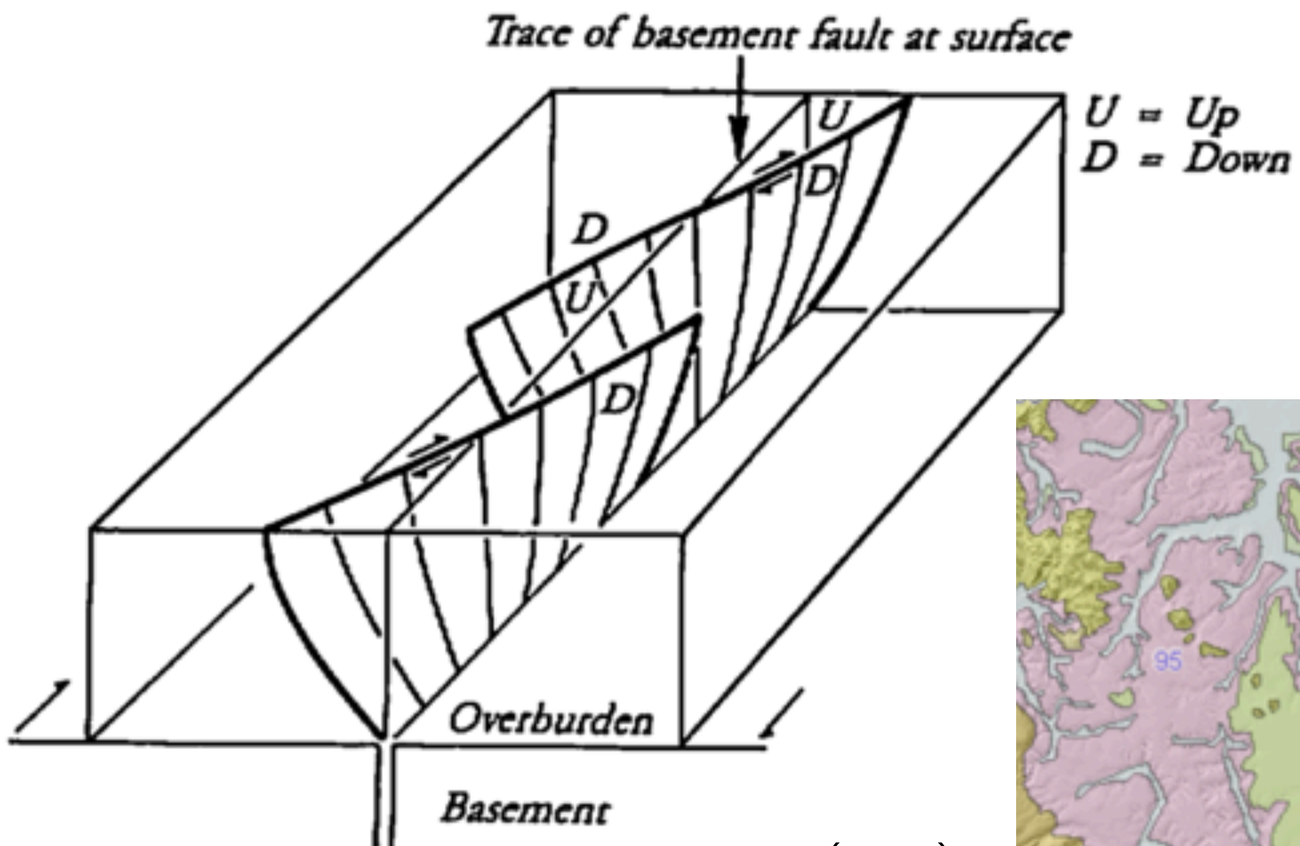


Ikeda et al. (2001)

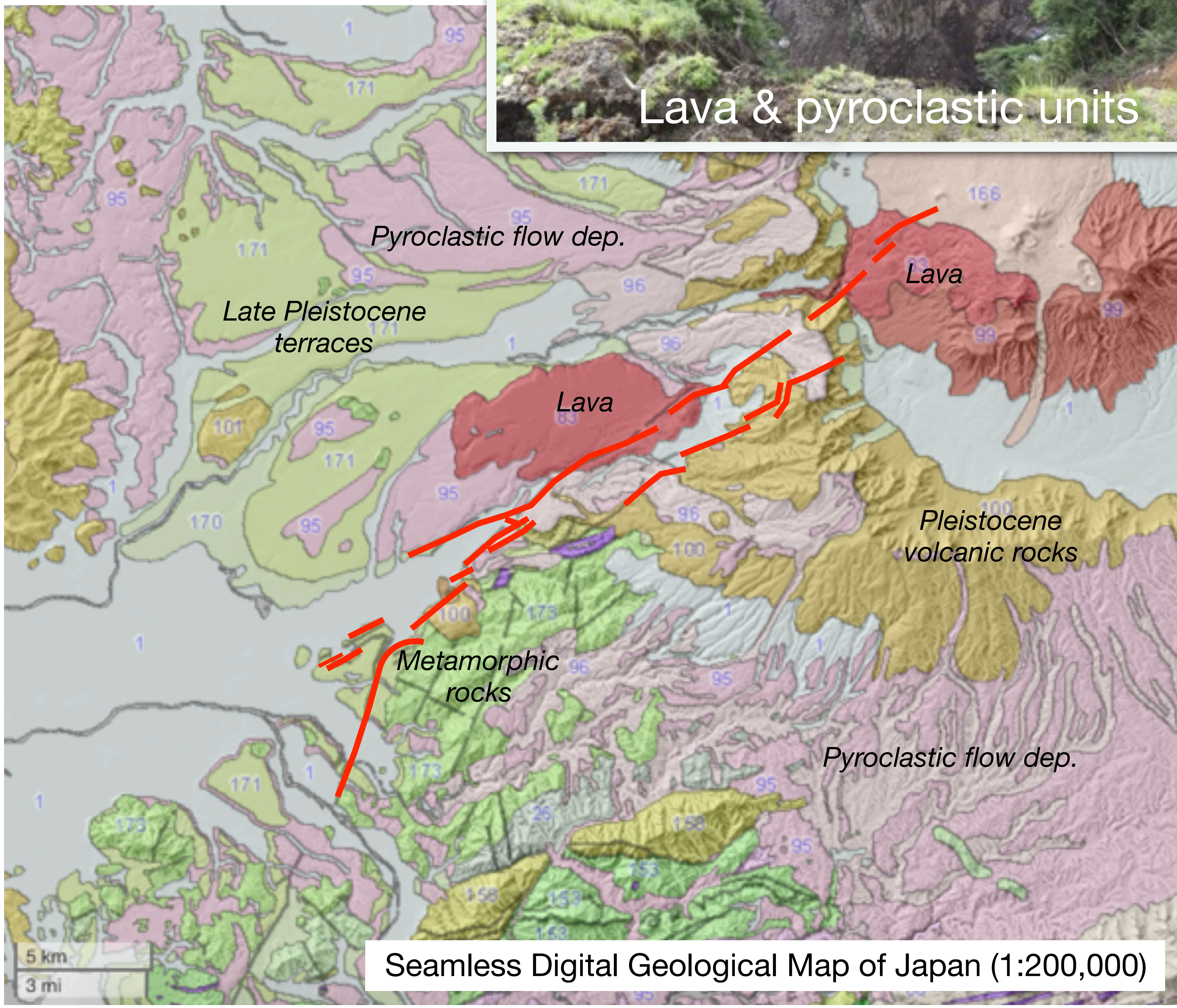
Left-stepping en echelon step-overs at various scales



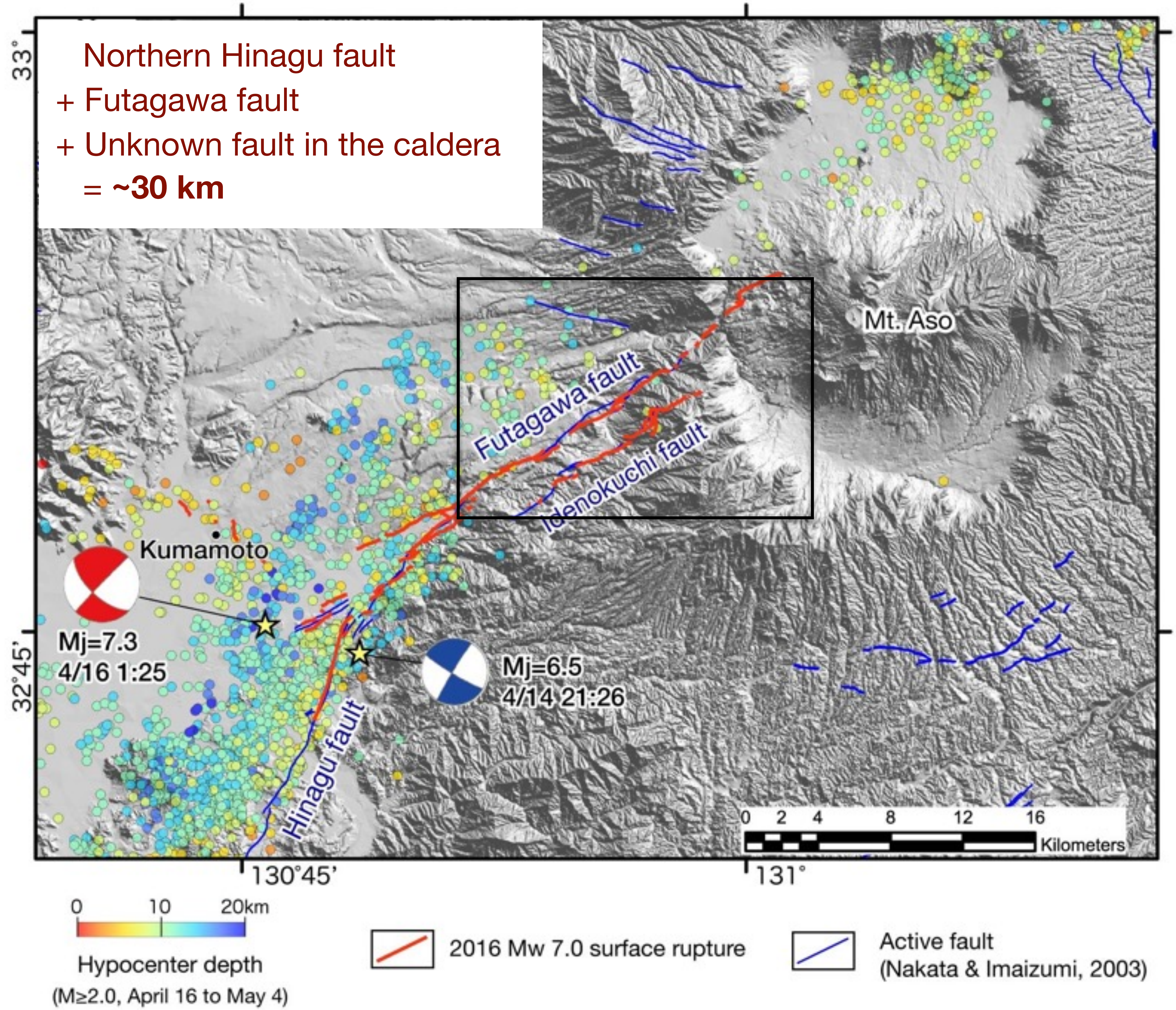
Several scales of overburden might be associated with the fractal-like en echelon step-overs



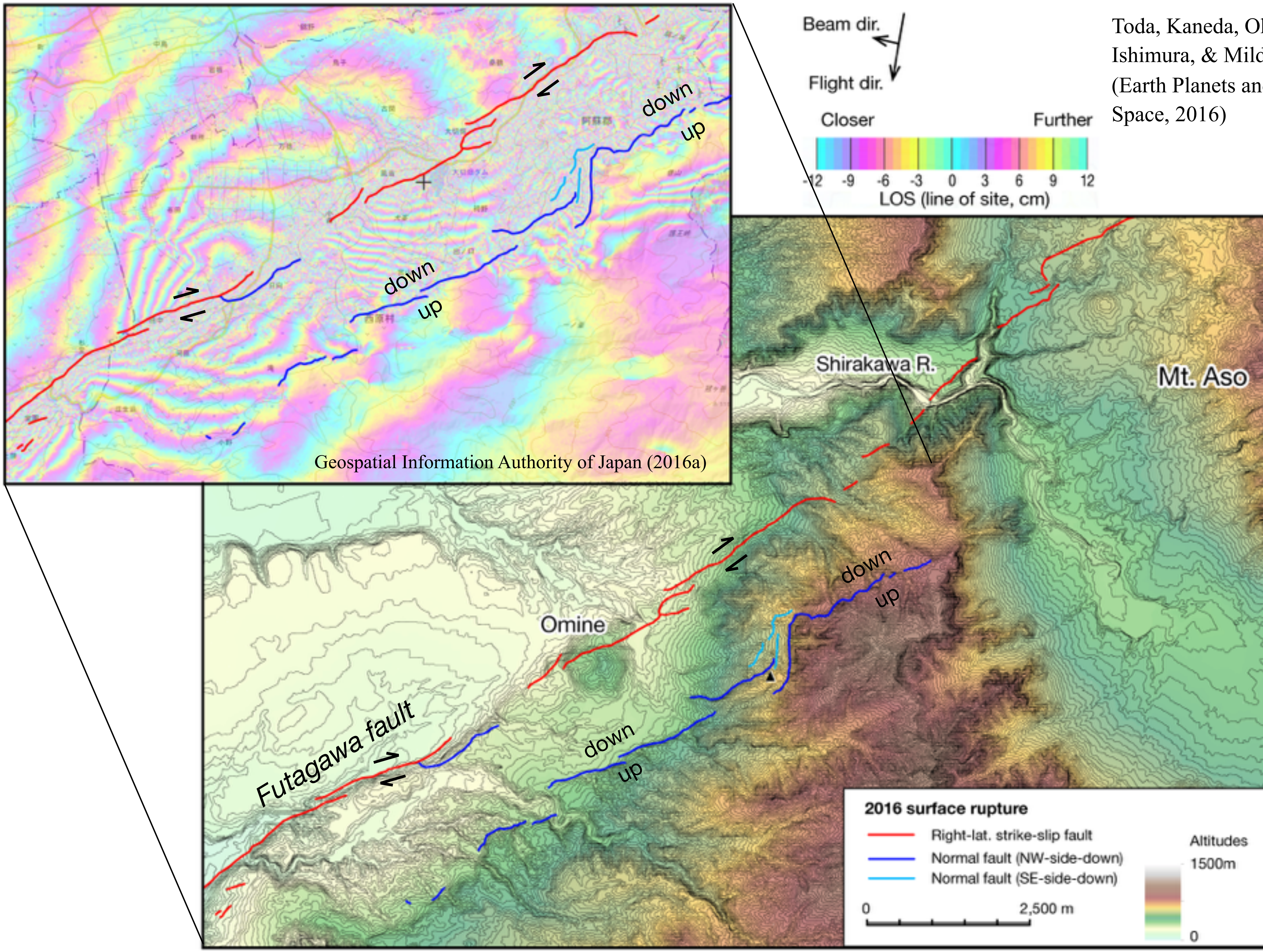
Mandl (1988)



Previously mapped Idenokuchi fault (normal fault) also ruptured together



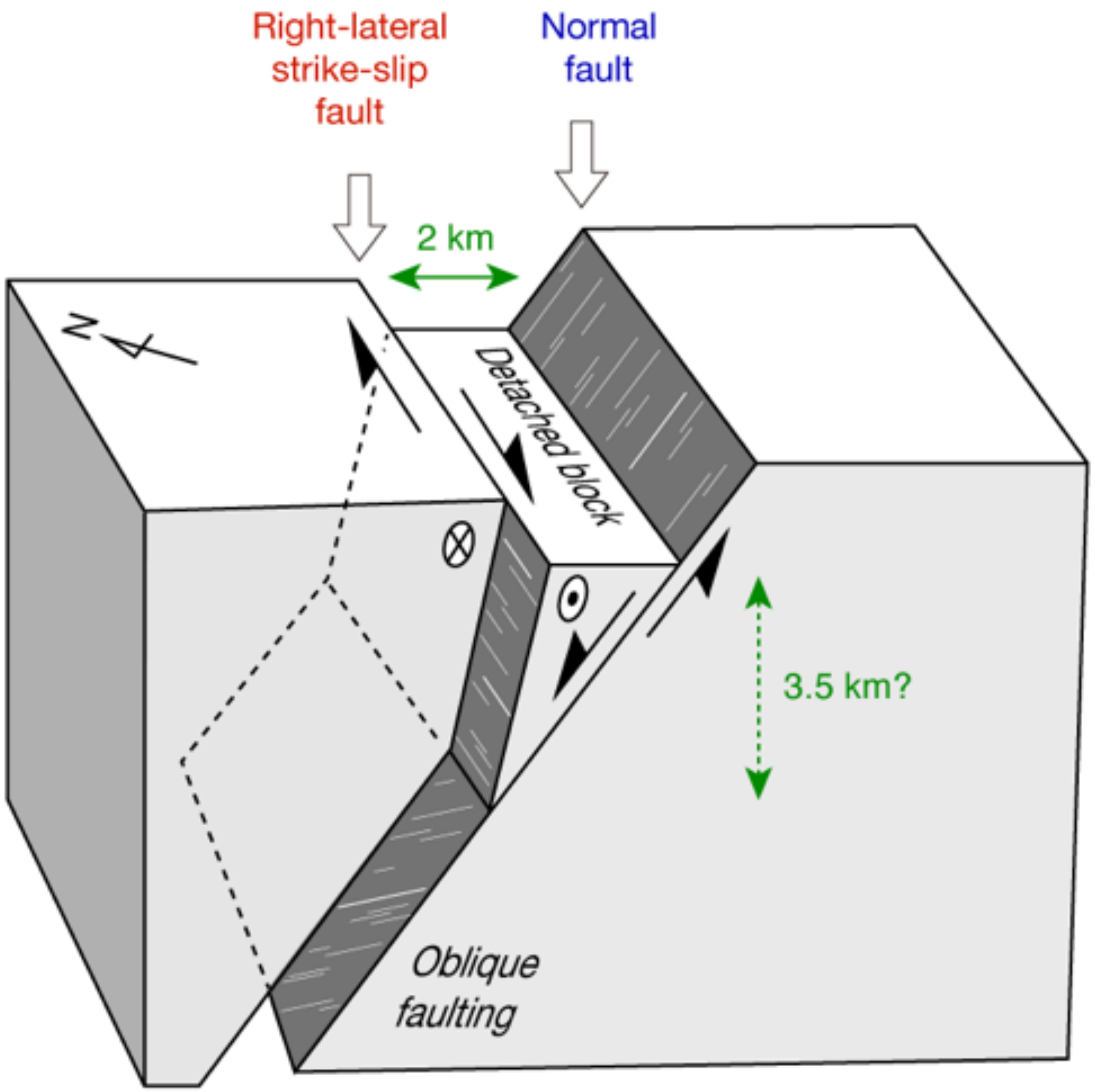
~10-km-long normal faulting scarps parallel to the Futagawa fault emerged



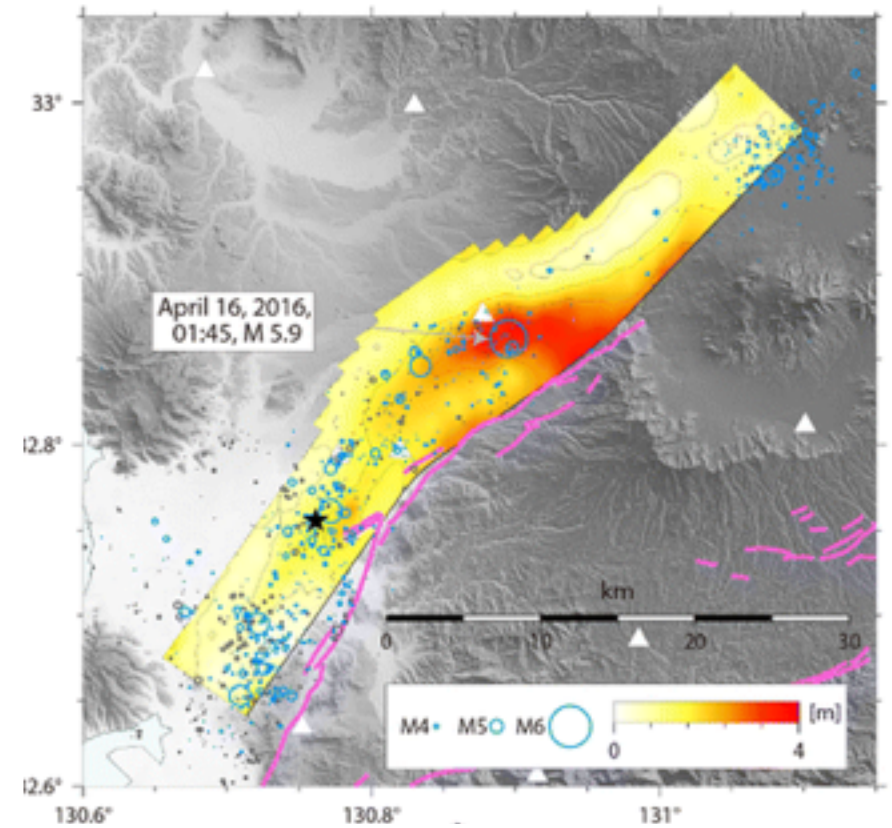
Toda, Kaneda, Okada, Ishimura, & Mildon, (Earth Planets and Space, 2016)

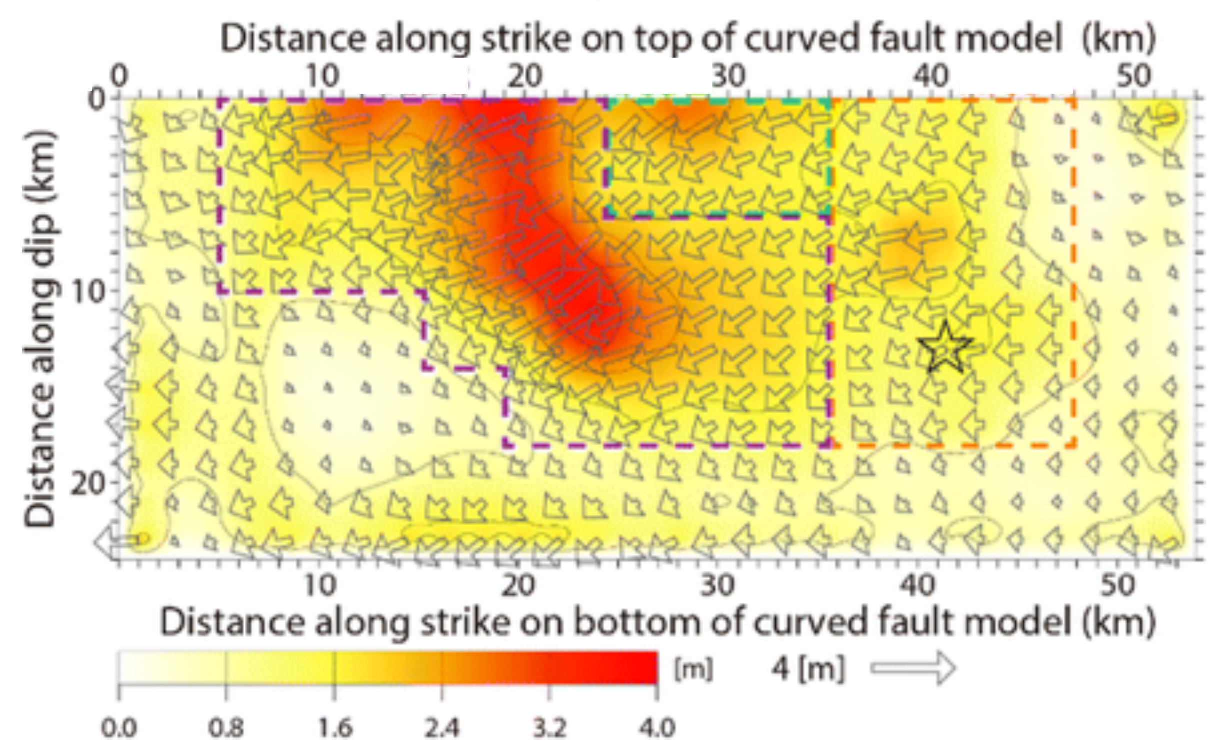
Cumulative vertical slip and antithetic fault rupture prove that it is not massive landslide

"Coseismic slip" partitioning occurred from a NW-dipping oblique seismogenic slip



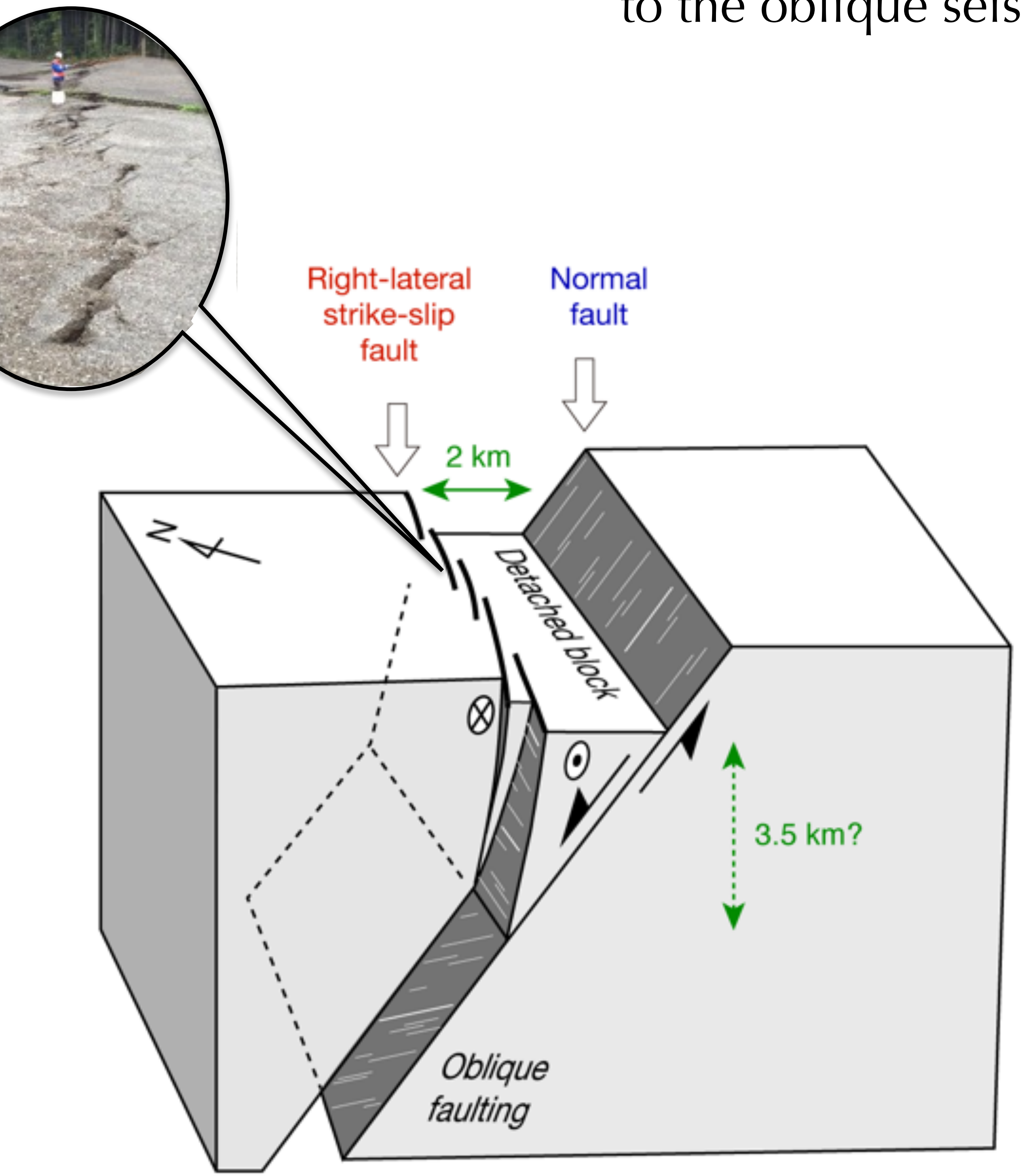
Similar example: Slip-partitioned surface breaks for the Mw 7.8 2001 Kokoxili earthquake, China, King et al., BSSA, 2005

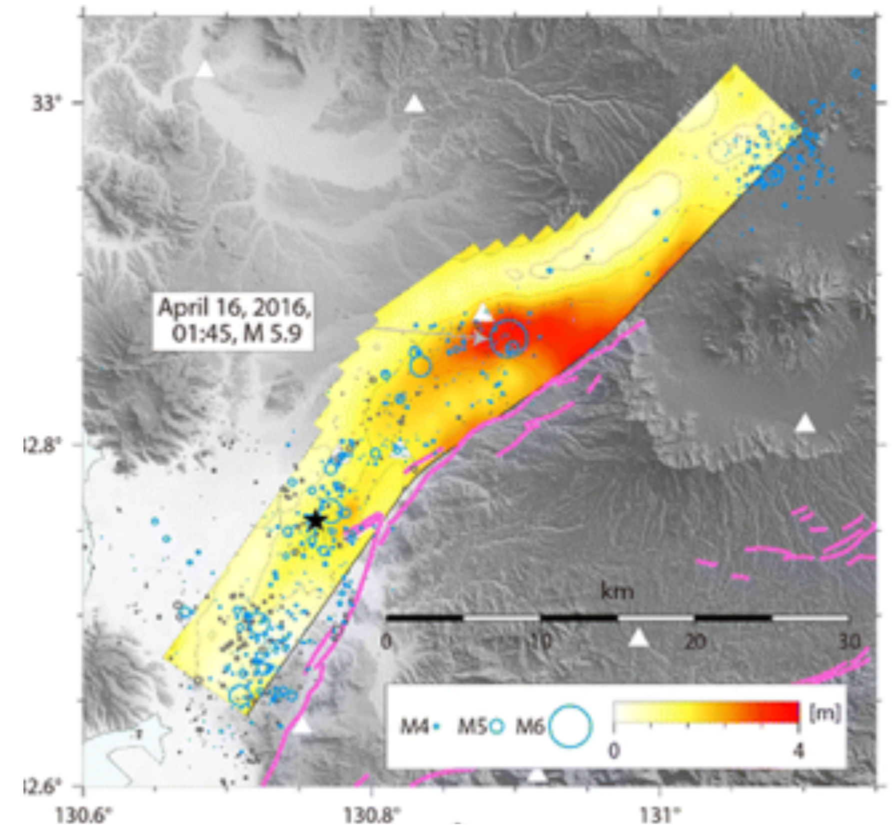


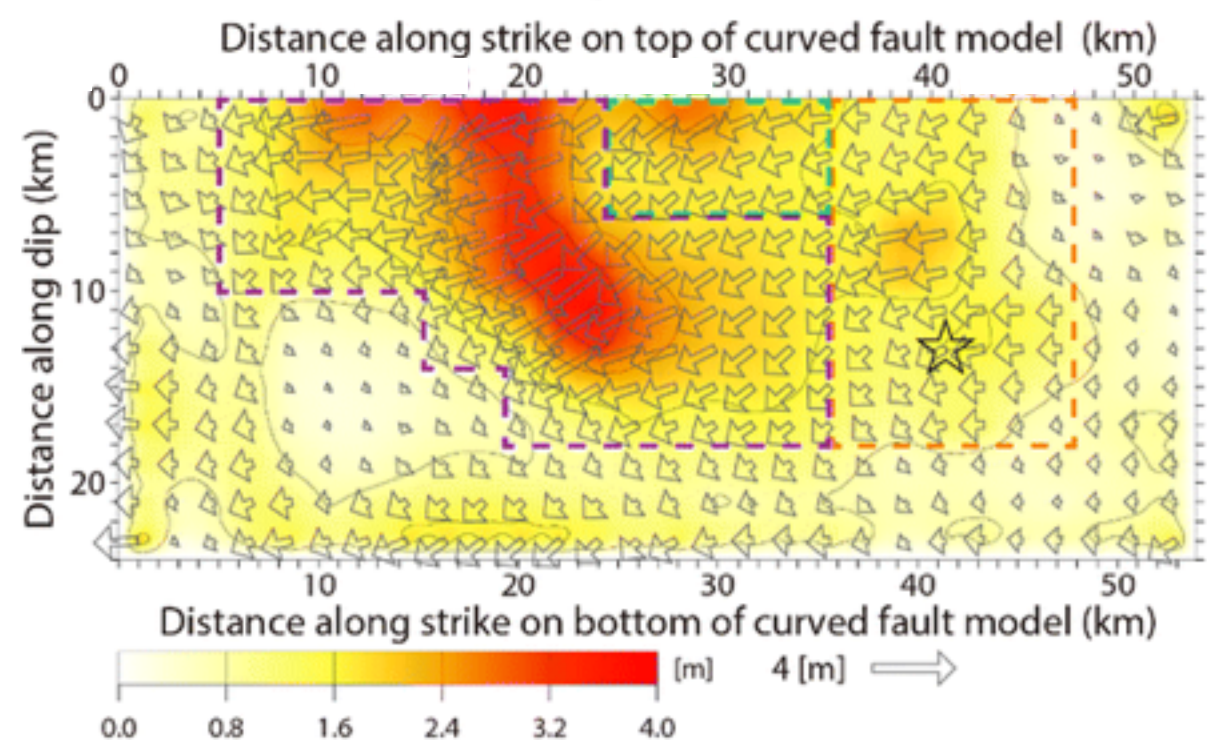


Kubo et al., EPS, 2016

Fractal-like en echelon features are limited at surface and may not be continuous to the oblique seismogenic fault



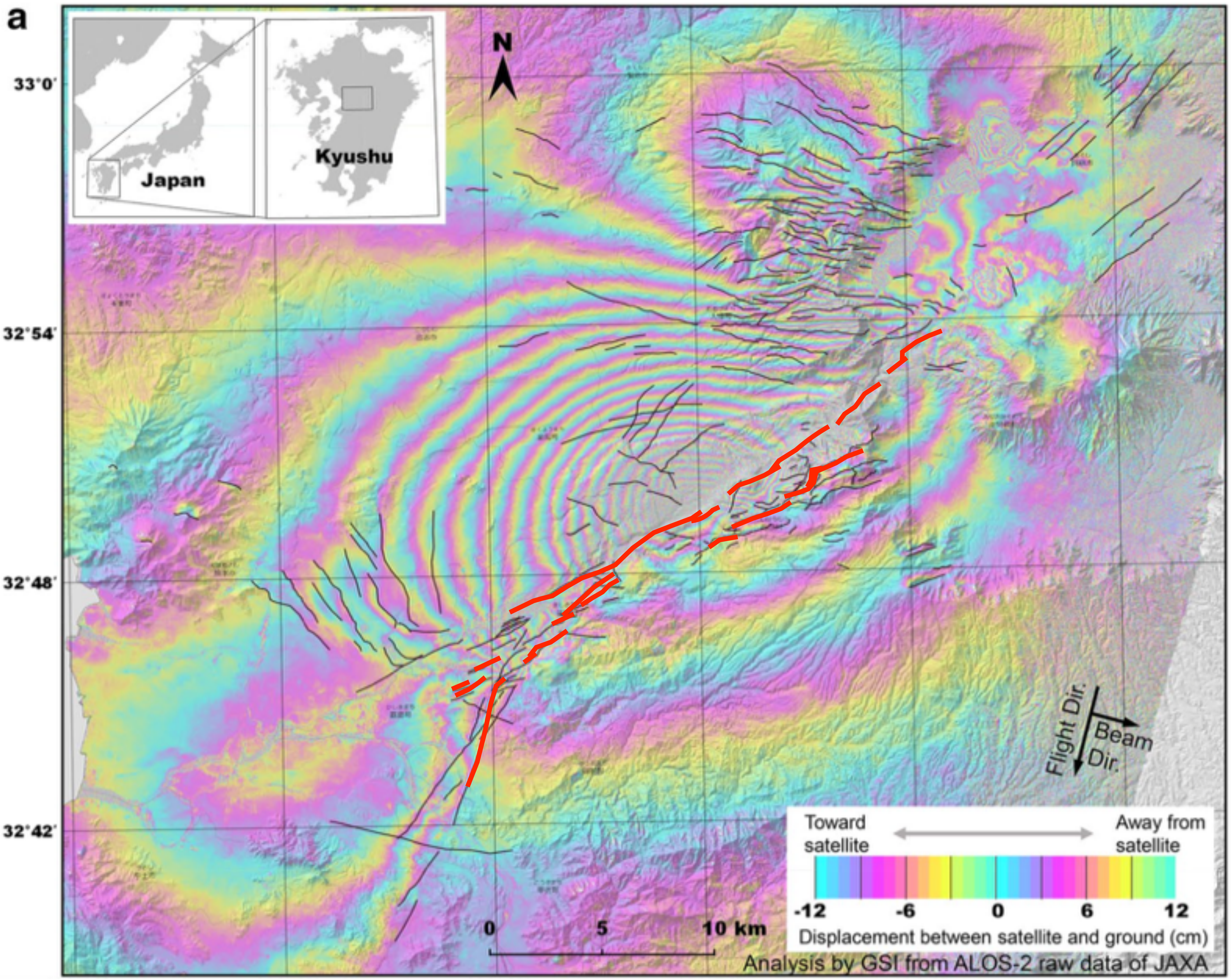




Similar example: Slip-partitioned surface breaks for the Mw 7.8 2001 Kokoxili earthquake, China, King et al., BSSA, 2005

Kubo et al., EPS, 2016

Remotely triggered slip on previously mapped and unmapped active faults



Fujiwara et al. (2016) *Small-displacement linear surface ruptures of the 2016 Kumamoto earthquake sequence detected by ALOS-2 SAR interferometry, Earth, Planets and Space, 68:160, doi:10.1186/s40623-016-0534-x*

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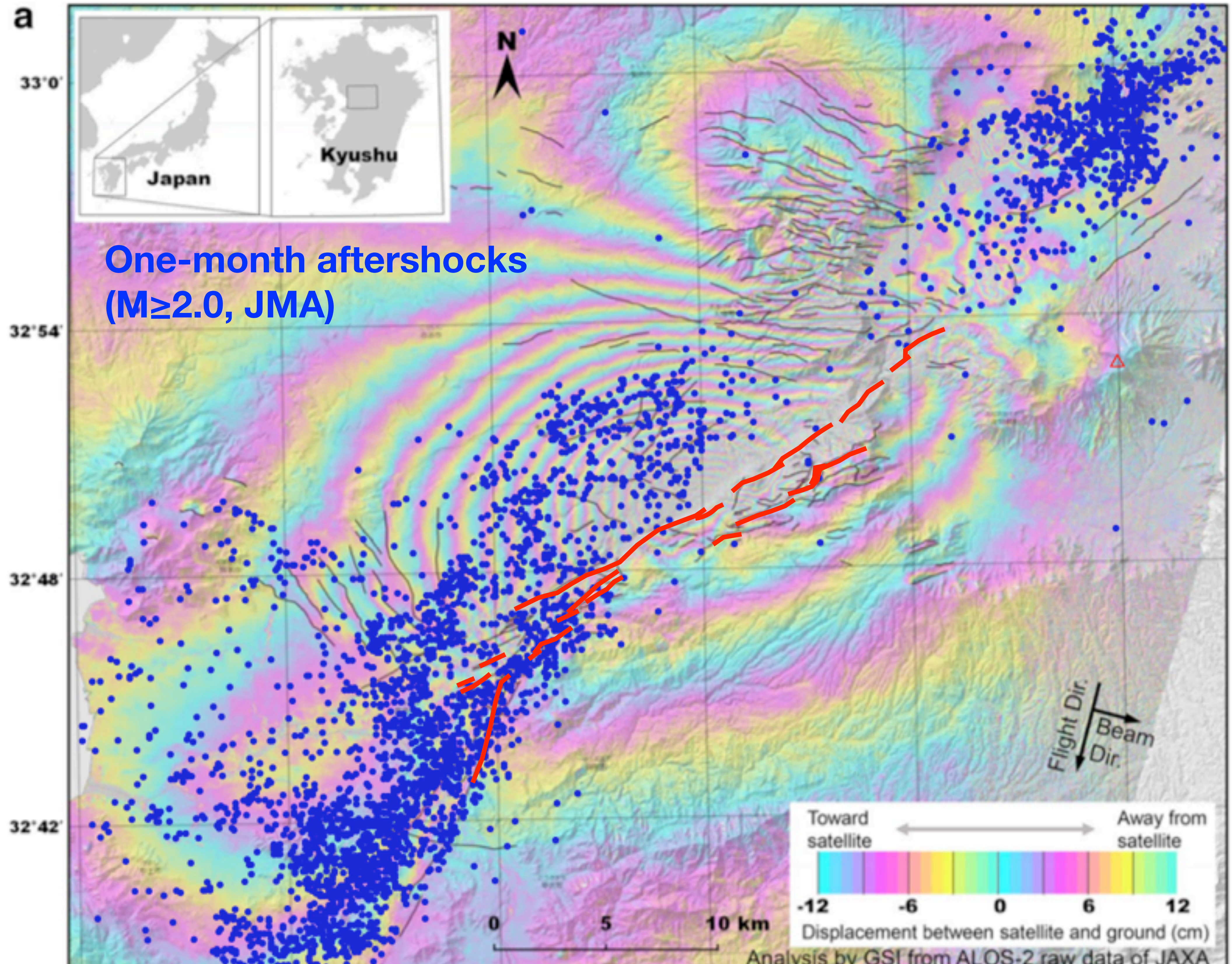

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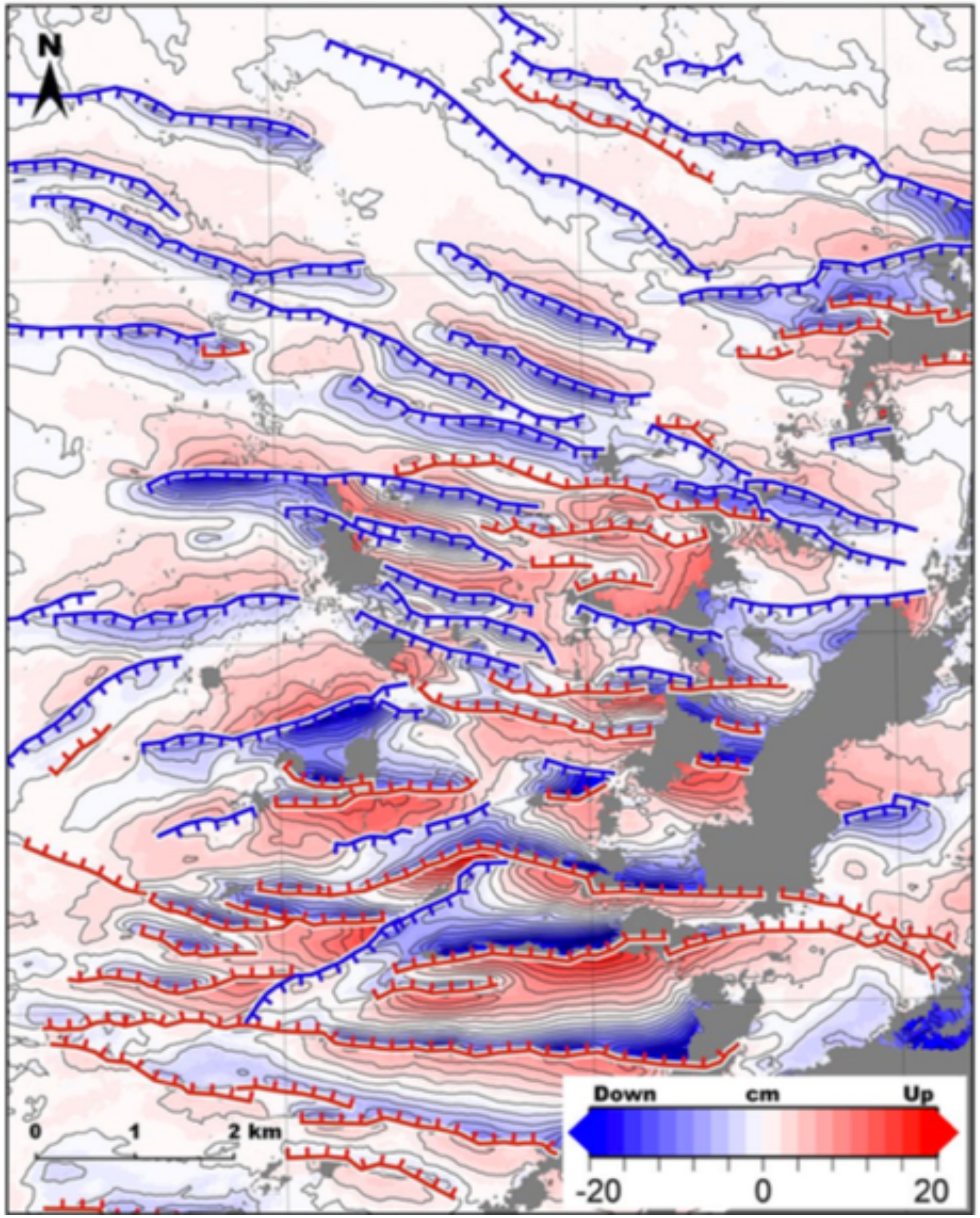
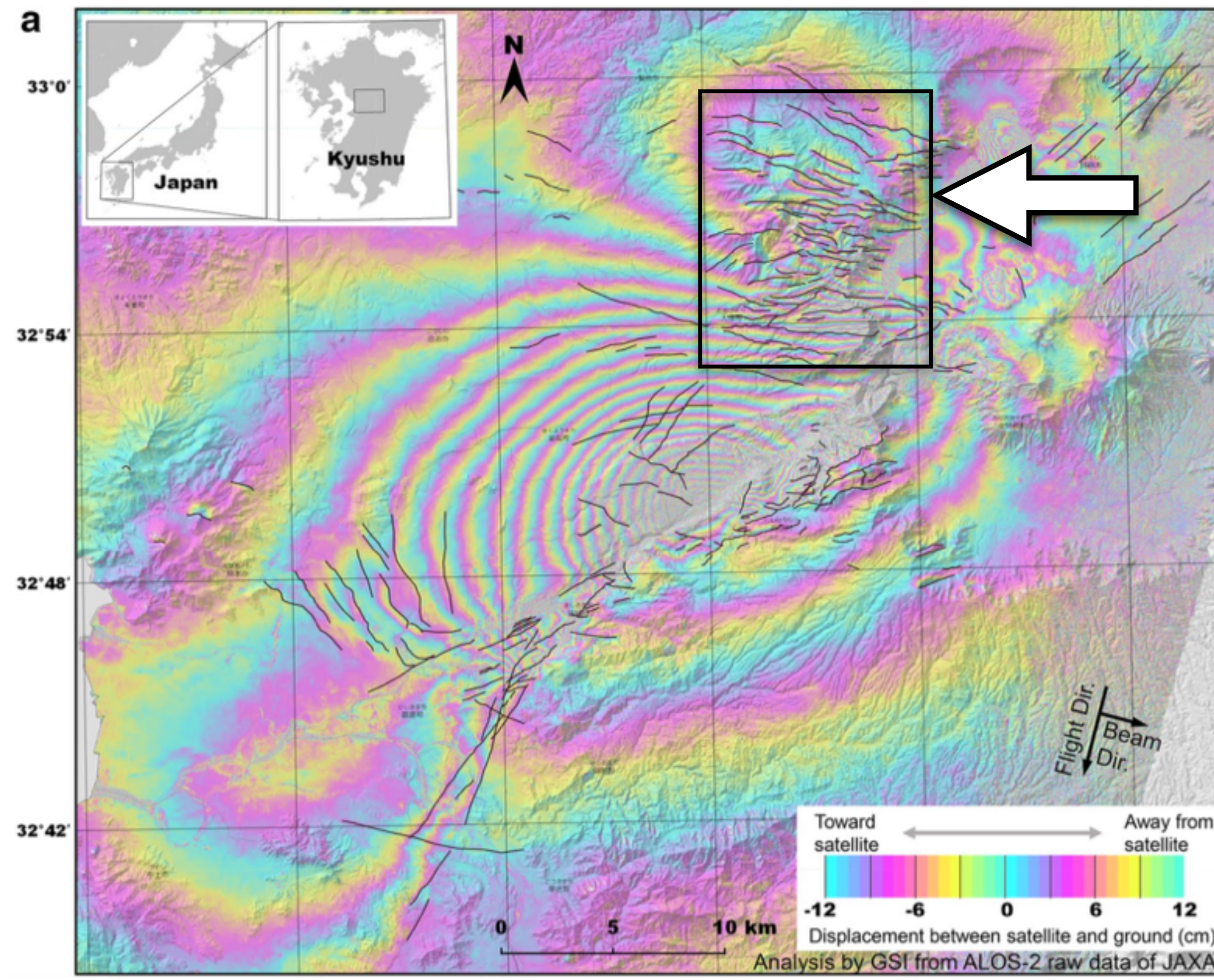


South-dipping normal fault

North-dipping normal fault



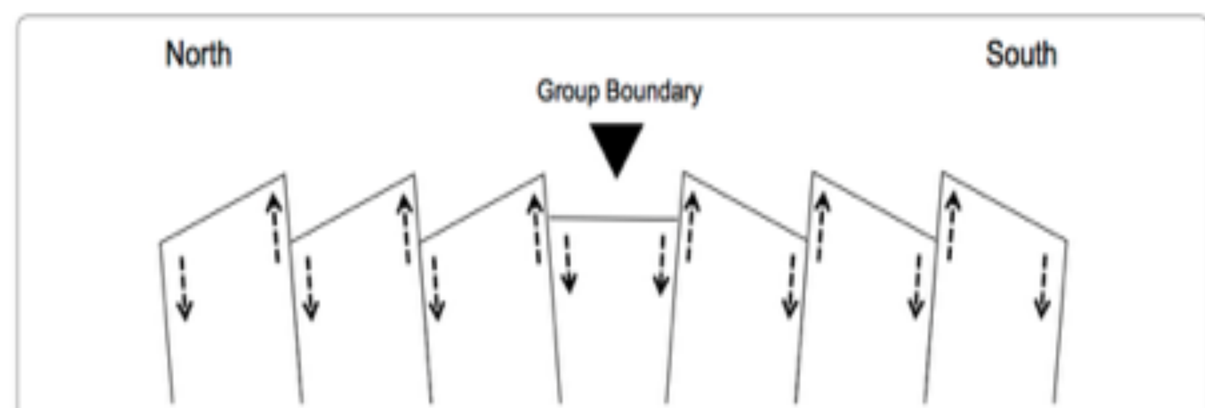


Fig. 6 Schematic explanation of "sawtooth" displacement. Schematic profile of surface displacement from north to south in the northwest area of the outer rim of Aso caldera. *Dashed arrows show displacement of each block divided by linear surface ruptures*

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Courtesy of Dr. Hiroshi Une (GSI)

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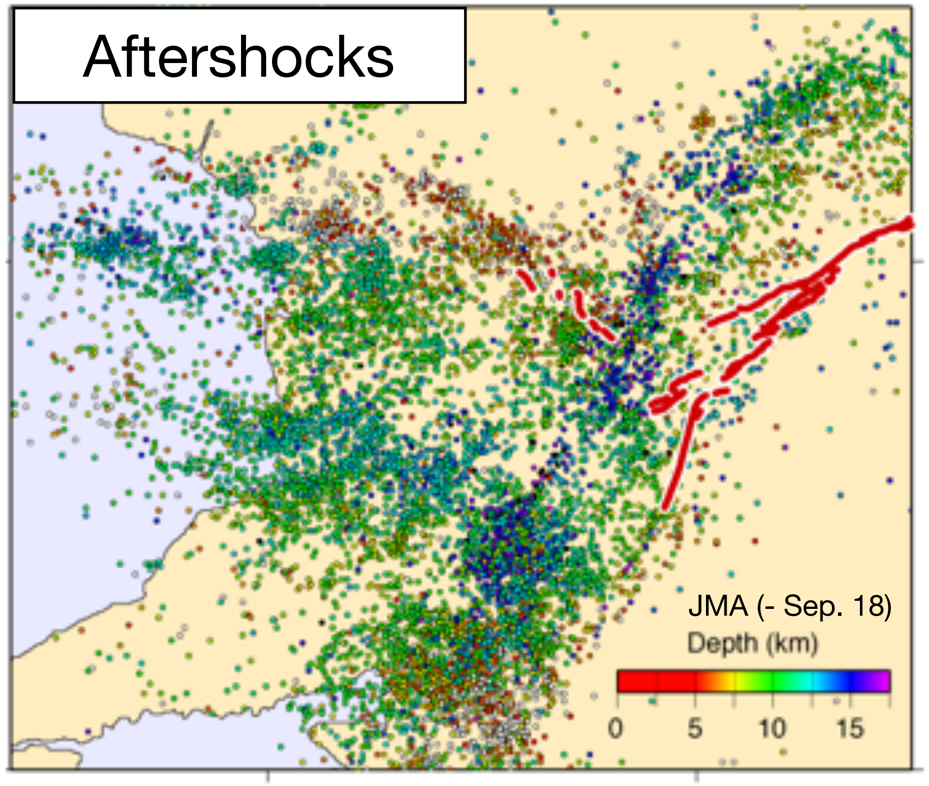

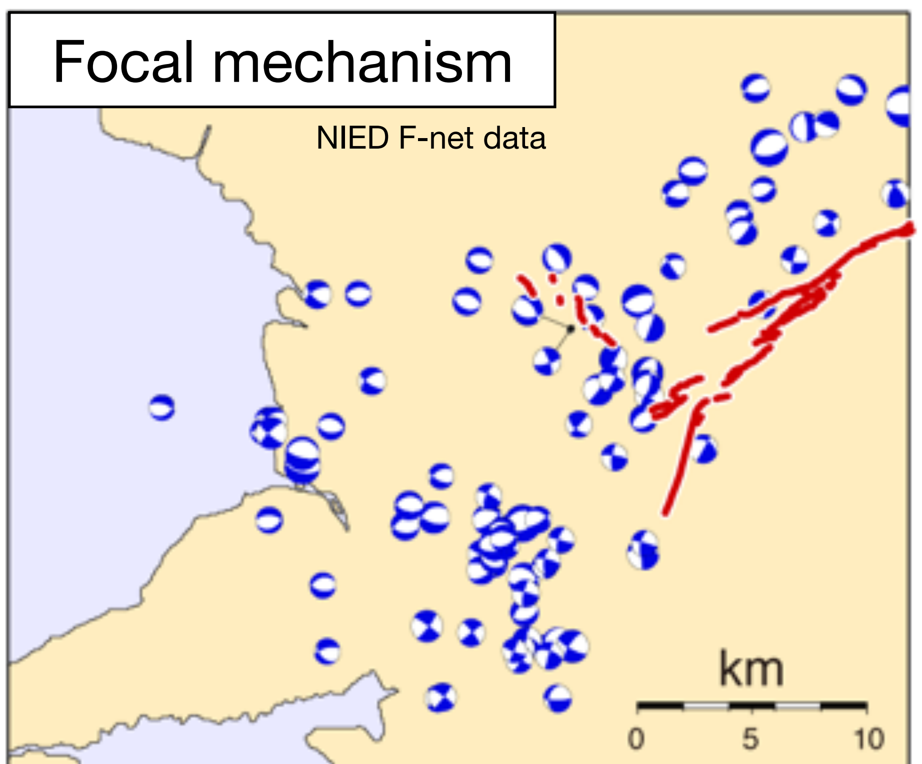

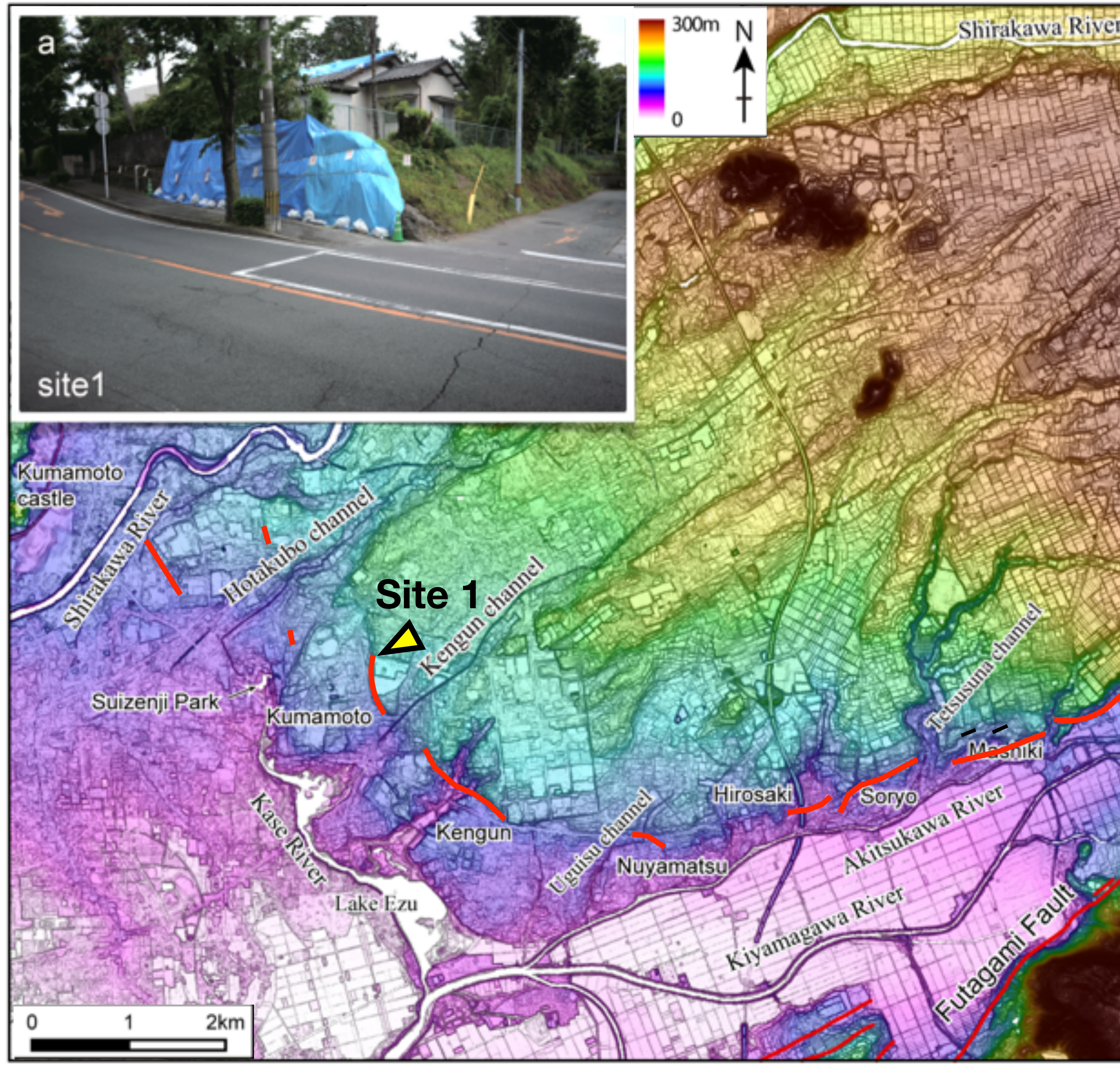

Goto, Tsutsumi, Toda, & Kumahara, submitted to Earth, Planets and Space (EPS)

2016 Mw=7.0 Kumamoto, Japan, earthquake faulting:

The ruptures are much more complex than fault maps, thus unpredictable

This would have made Alquist-Priolo zones very inadequate guidelines

- **Left-stepping en echelon step-overs are seen on various scales** from meters to km, and left-lateral conjugate slip probably due to thick Quaternary volcanic sediments
- **Seismogenic oblique slip partitioned** into pure right-lateral slip and normal faulting scarps at the surface along a 10-km-stretch
- **Scores of short triggered slips (up to 40 cm) as far as 15 km** from the main rupture zone revealed by InSAR images and surveys