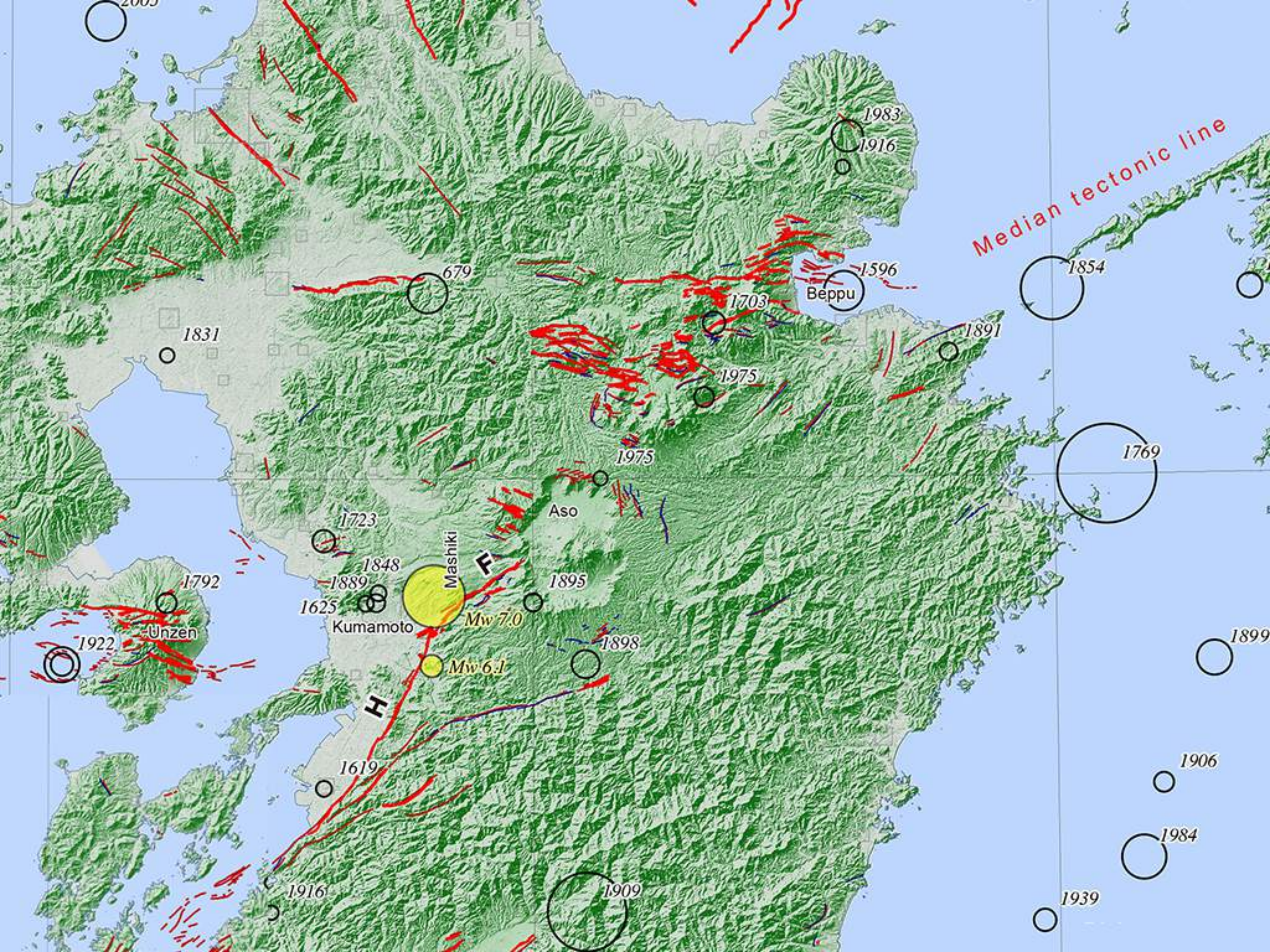


Median tectonic line
1983
1916
1596
Beppu
1854
679
1703
1831
1891
1975
1975
1769
1723
Aso
Mashiki
F
1848
1889
1895
1625
1792
Kumamoto
Mw 7.0
Unzen
1898
1922
Mw 6.1
1899
H
1619
1906
1984
1916
1909
1939

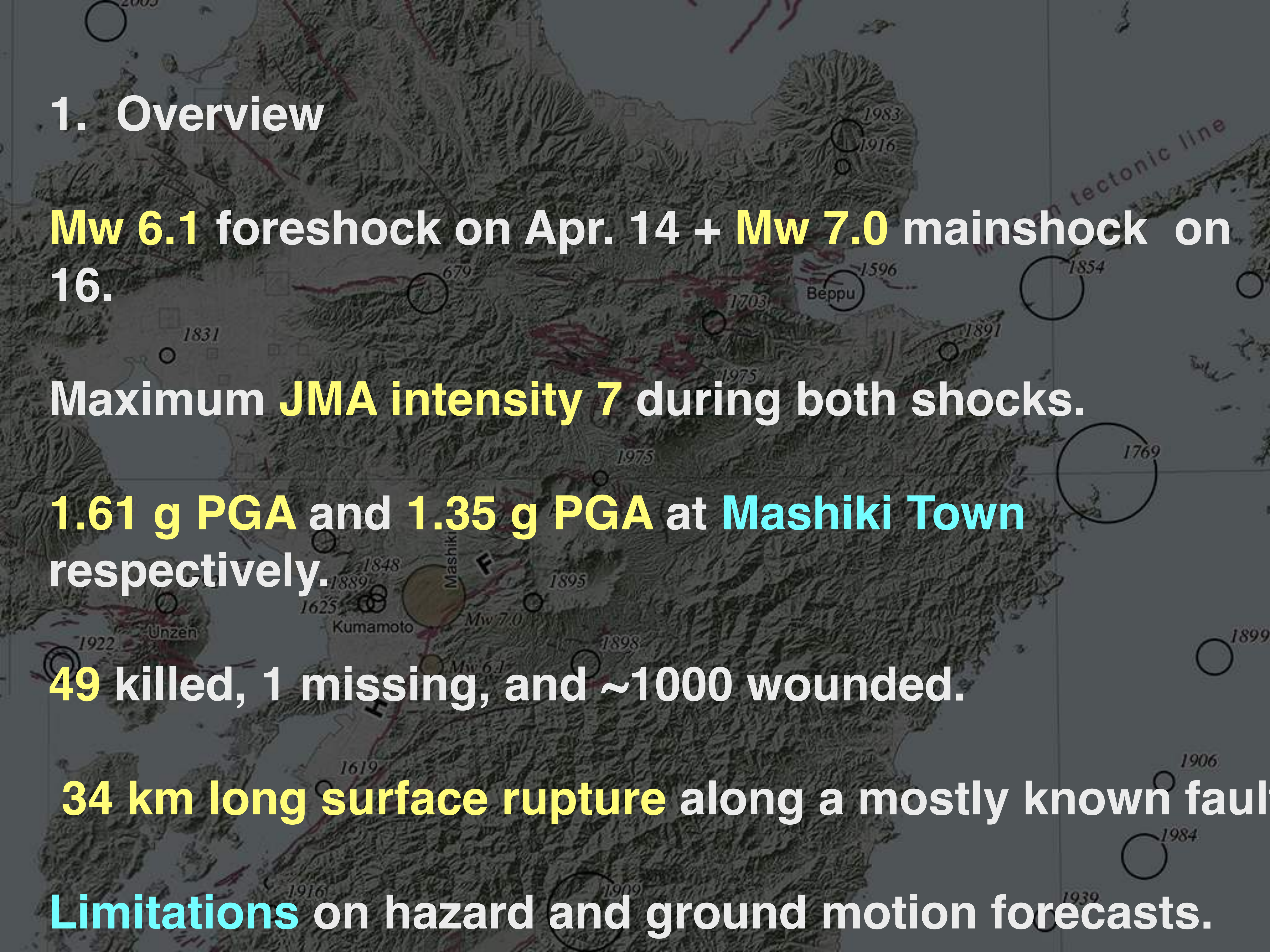
Kumamoto earthquake:
a complex earthquake sequence with large strike-slip ruptures

Koji Okumura (Hiroshima University)
kojiok@hiroshima-u.ac.jp

http://home.hiroshima-u.ac.jp/kojiok/kumamoto2016KOreport2.pdf


Median tectonic line
Beppu
Aso
Unzen
Mashiki
Mw 6.1
1983
1916
1596
1854
1703
1891
1831
1975
1769
1723
1848
1792
1889
1895
1625
1922
1899
1619
1906
1984
1916
1909
1939

Contents



1. Overview

Mw 6.1 foreshock on Apr. 14 + Mw 7.0 mainshock on 16.

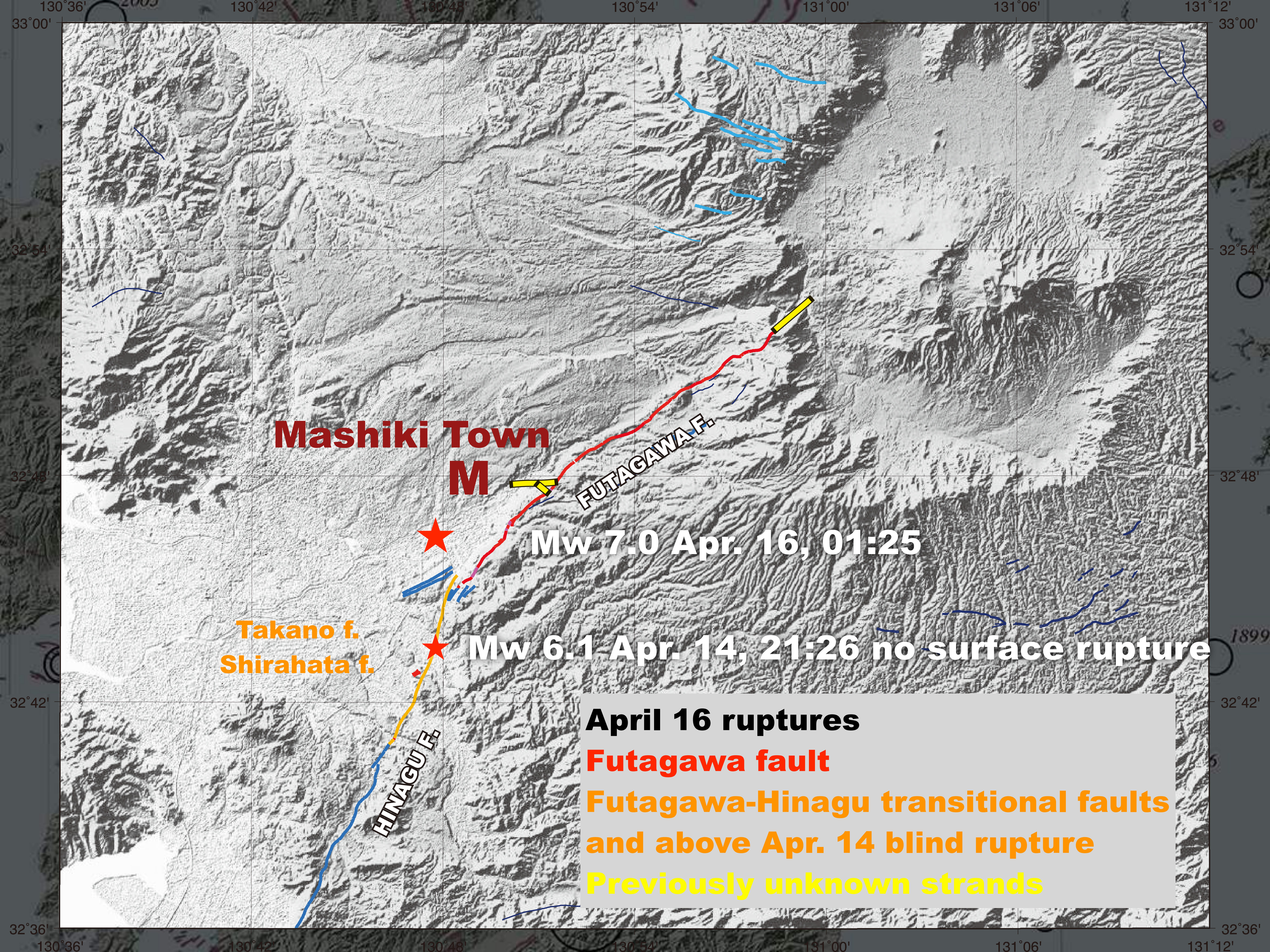
Maximum JMA intensity 7 during both shocks.

1.61 g PGA and 1.35 g PGA at Mashiki Town respectively.

49 killed, 1 missing, and ~1000 wounded.

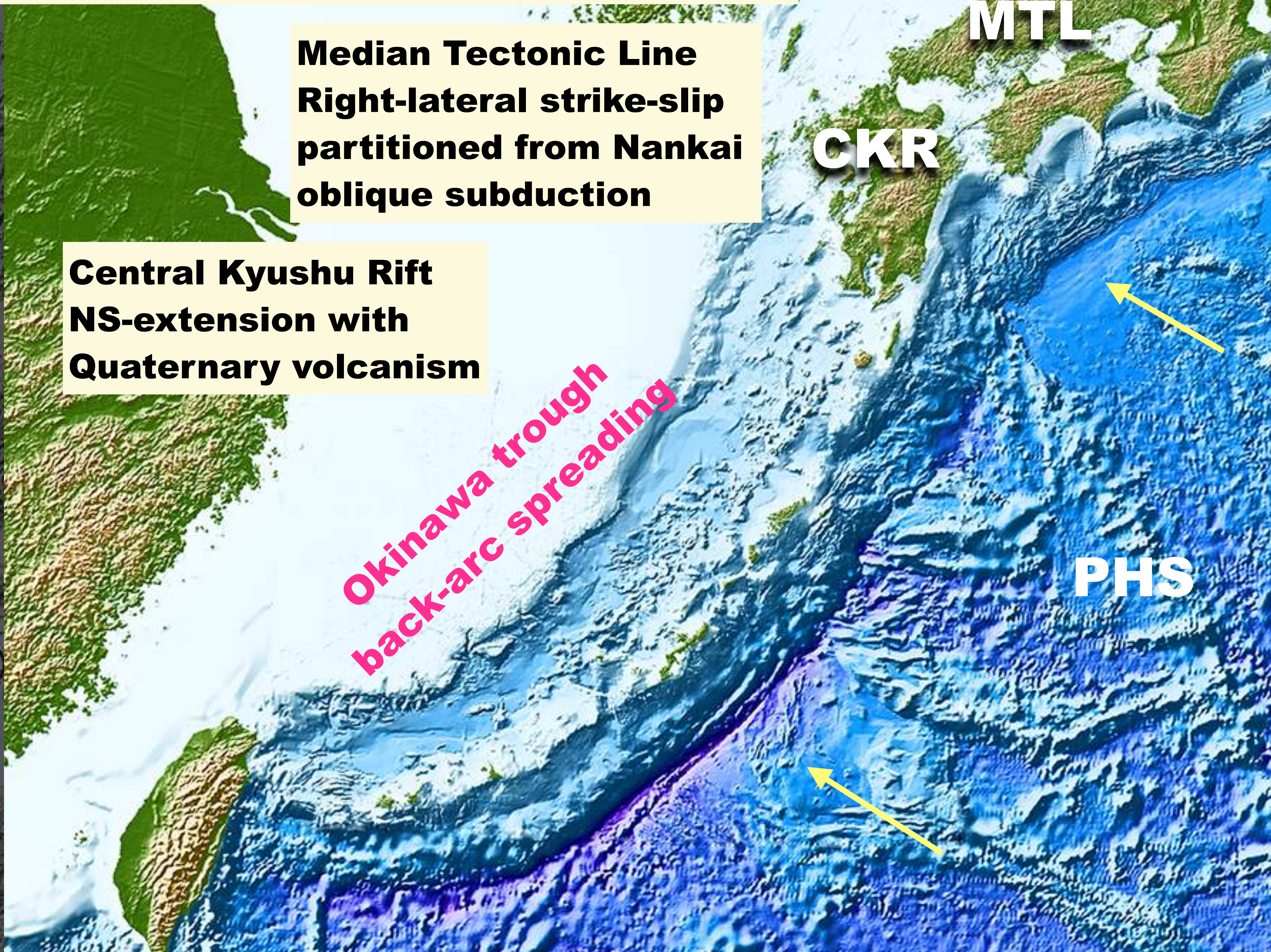
34 km long surface rupture along a mostly known faul

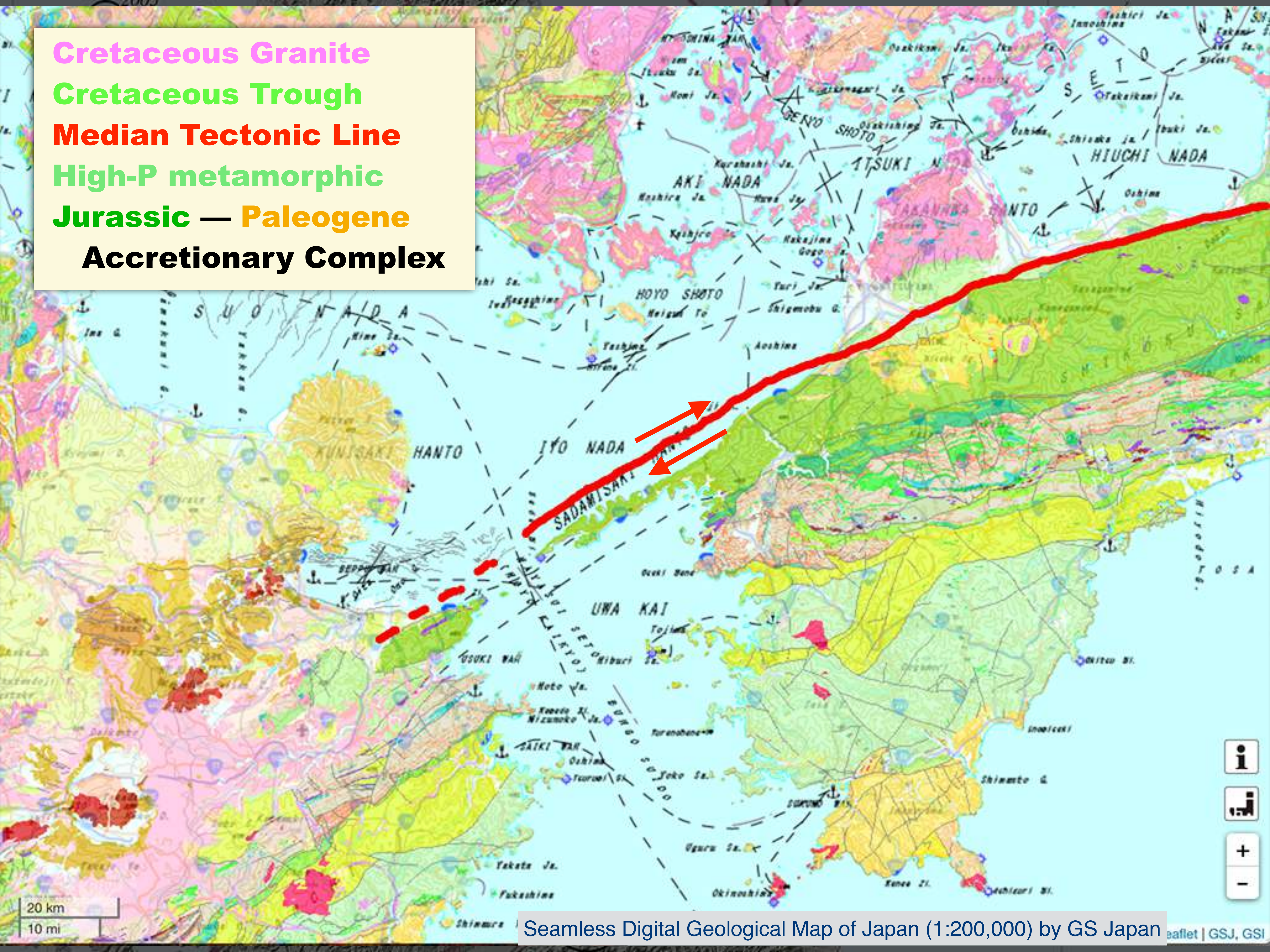
Limitations on hazard and ground motion forecasts.

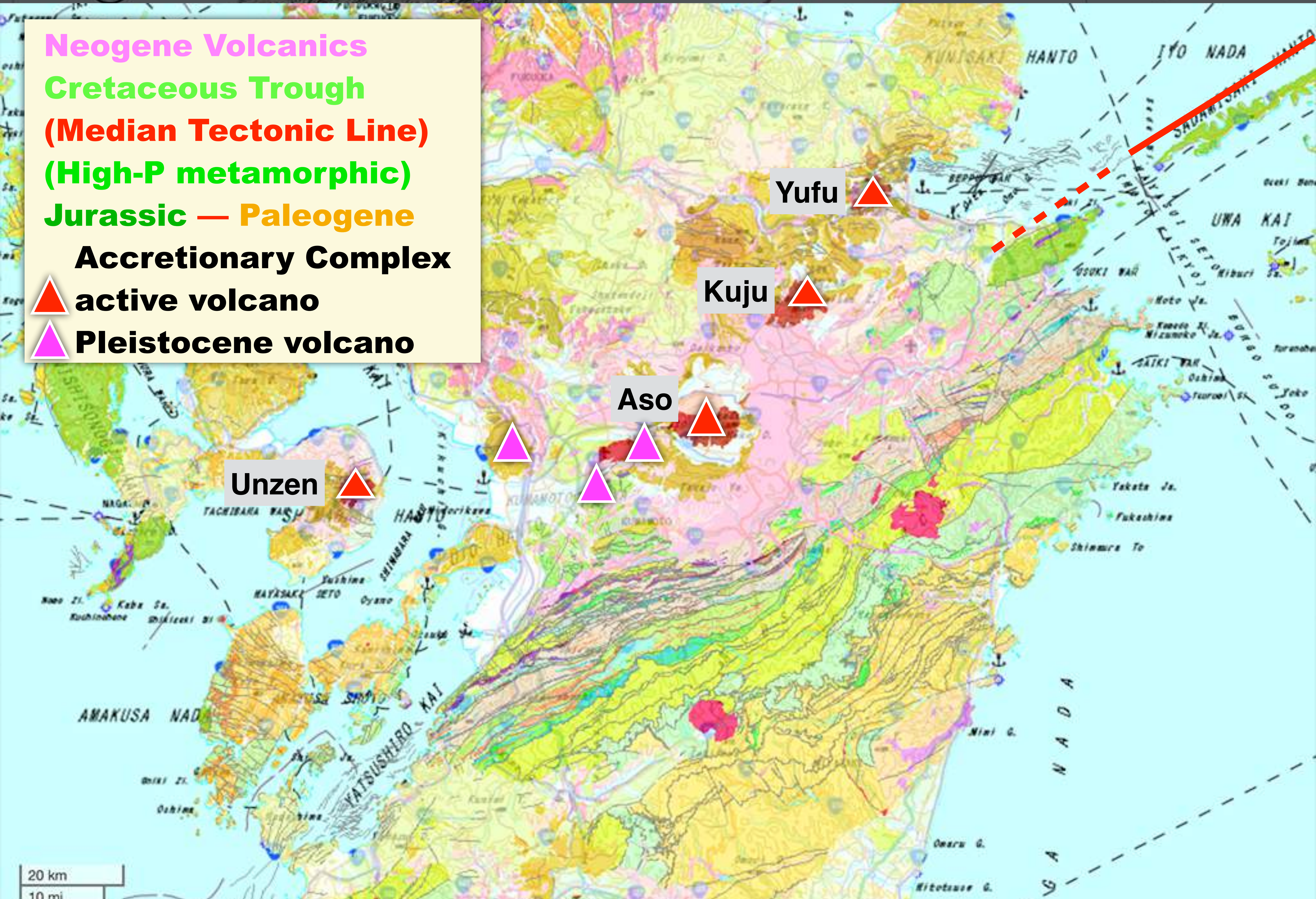


130°36'
130°42'
130°48'
130°54'
131°00'
131°06'
131°12'
33°00'
32°54'
32°48'
32°42'
32°36'
Mashiki Town
M
FUTAGAWA F.
Mw 7.0 Apr. 16, 01:25
Takano f.
Shirahata f.
Mw 6.1 Apr. 14, 21:26 no surface rupture
HINAGU F.
April 16 ruptures
Futagawa fault
Futagawa-Hinagu transitional faults
and above Apr. 14 blind rupture
Previously unknown strands

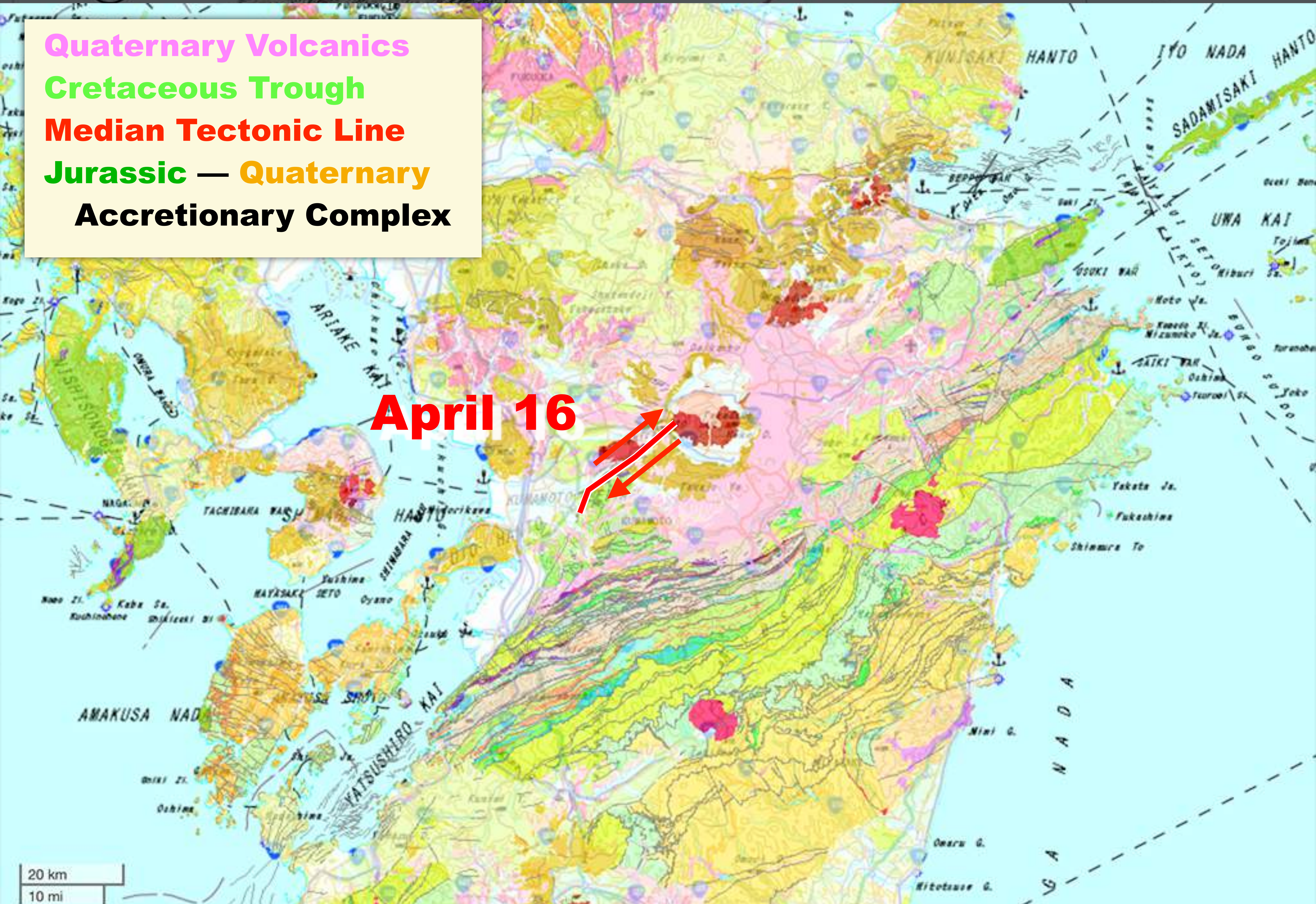
1. Tectonics and Geologic Setting

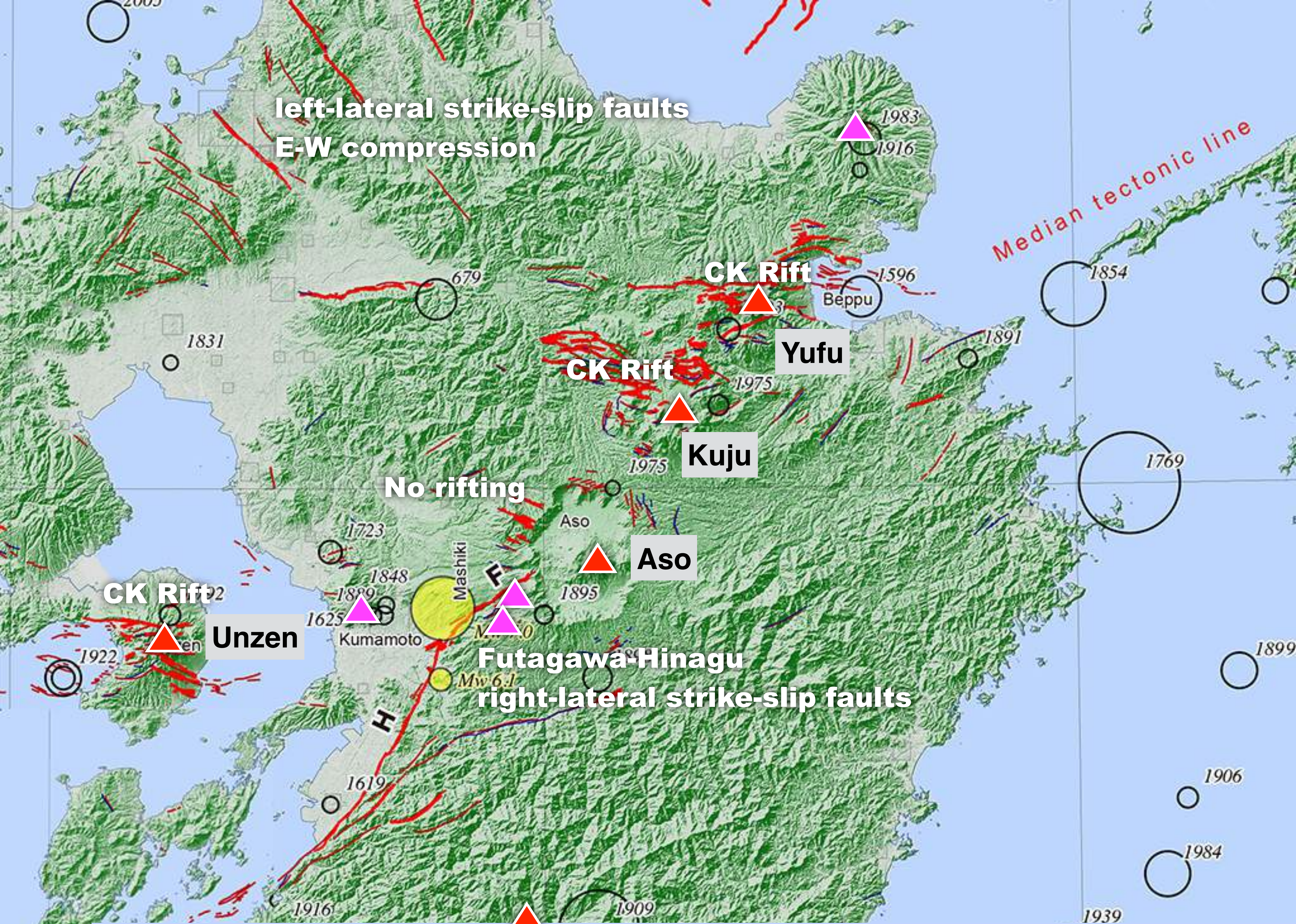



Cretaceous Granite
Cretaceous Trough
Median Tectonic Line
High-P metamorphic
Jurassic — Paleogene
Accretionary Complex
AKI NADA
HIUCHI NADA
HOYO SHOTO
IYO NADA
KUNISAKI HANTO
SADAMISAKI
UWA KAI
20 km
10 mi
Seamless Digital Geological Map of Japan (1:200,000) by GS Japan

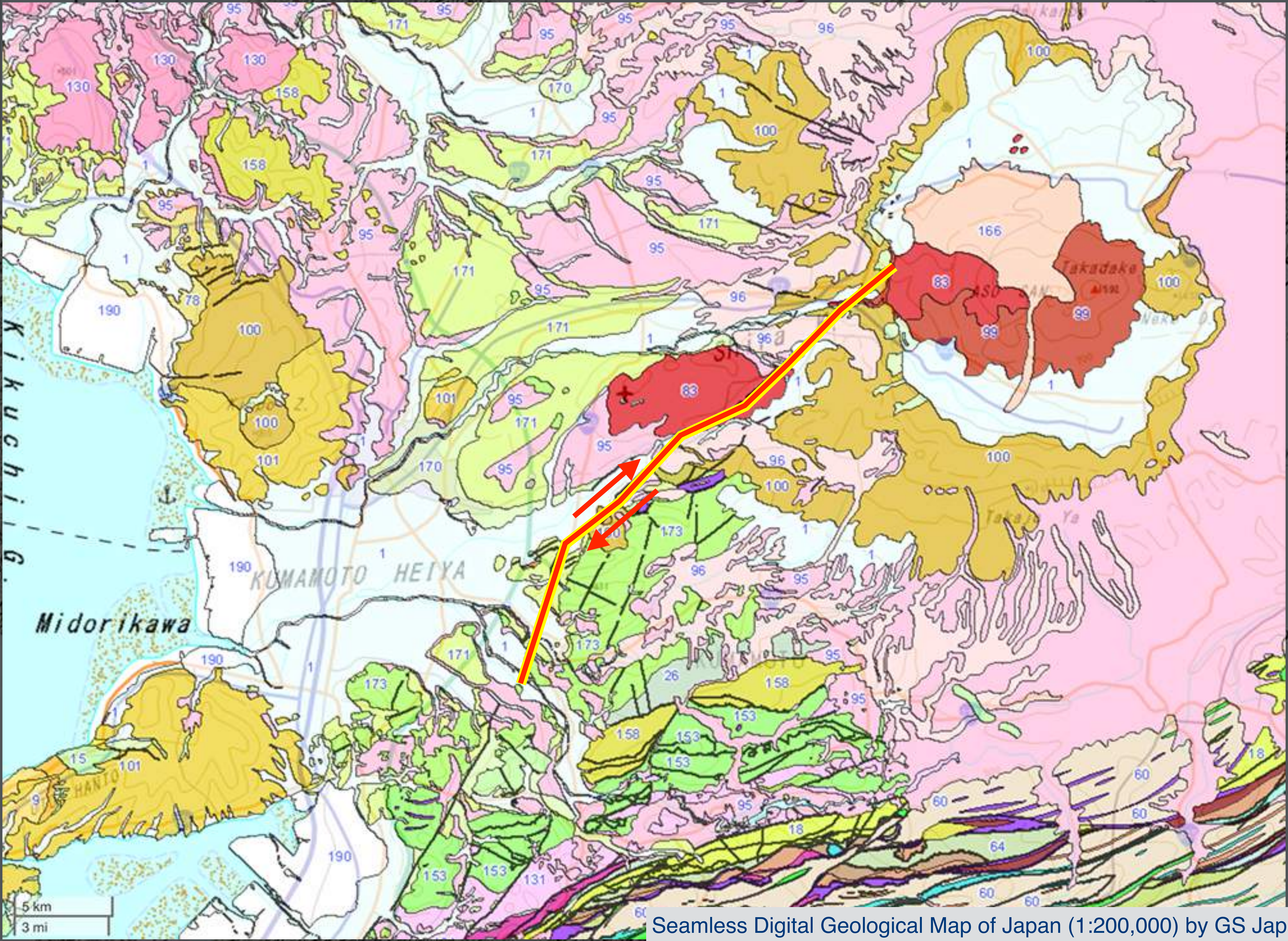


Seamless Digital Geological Map of Japan (1:200,000) by GS Japan


Quaternary Volcanics
Cretaceous Trough
Median Tectonic Line
Jurassic — Quaternary
Accretionary Complex
April 16
KUNISAKI HANTO
IYO NADA
SADAMISAKI HANTO
UWA KAI
ARIAKE KAI
TACHIBANA WAN
AMAKUSA NADA
YATSUSHIRO KAI
20 km
10 mi
Seamless Digital Geological Map of Japan (1:200,000) by GS Japan



Nakata and Imaizumi eds. (2002), Research Group for Active Faults of Japan (1995), Historic earthquakes: Usan (1996)



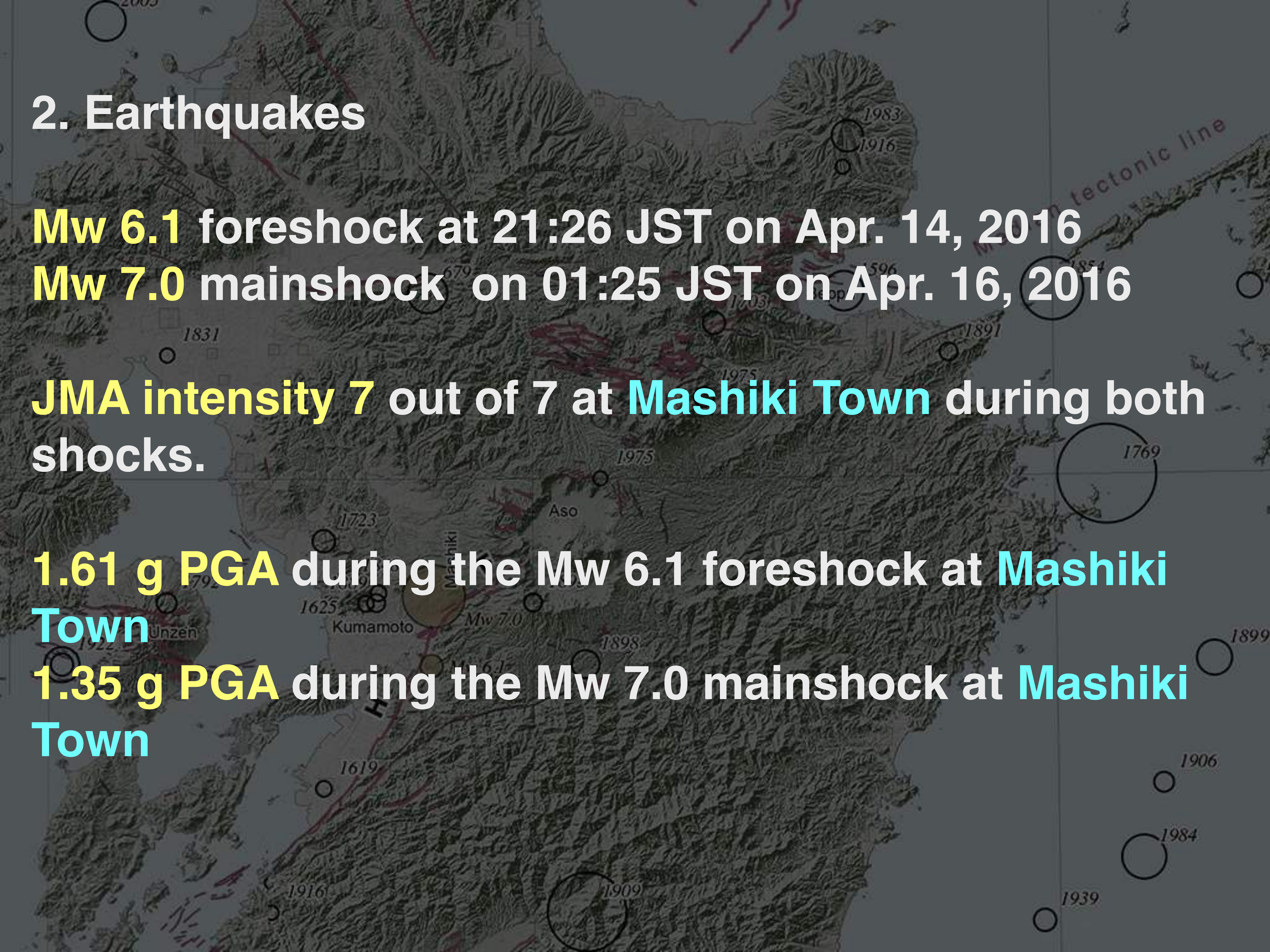
Seamless Digital Geological Map of Japan (1:200,000) by GS Japan

2. Earthquakes

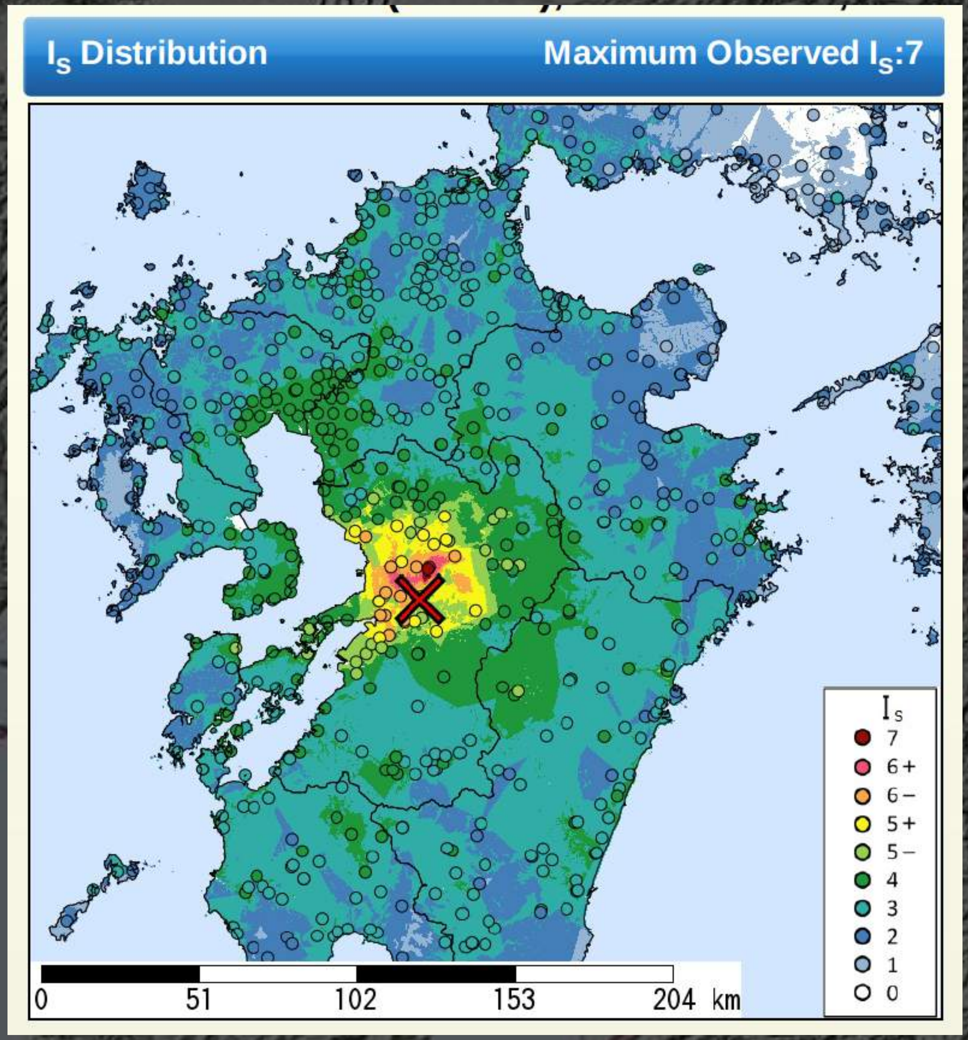
Mw 6.1 foreshock at 21:26 JST on Apr. 14, 2016
Mw 7.0 mainshock on 01:25 JST on Apr. 16, 2016

JMA intensity 7 out of 7 at **Mashiki Town** during both shocks.

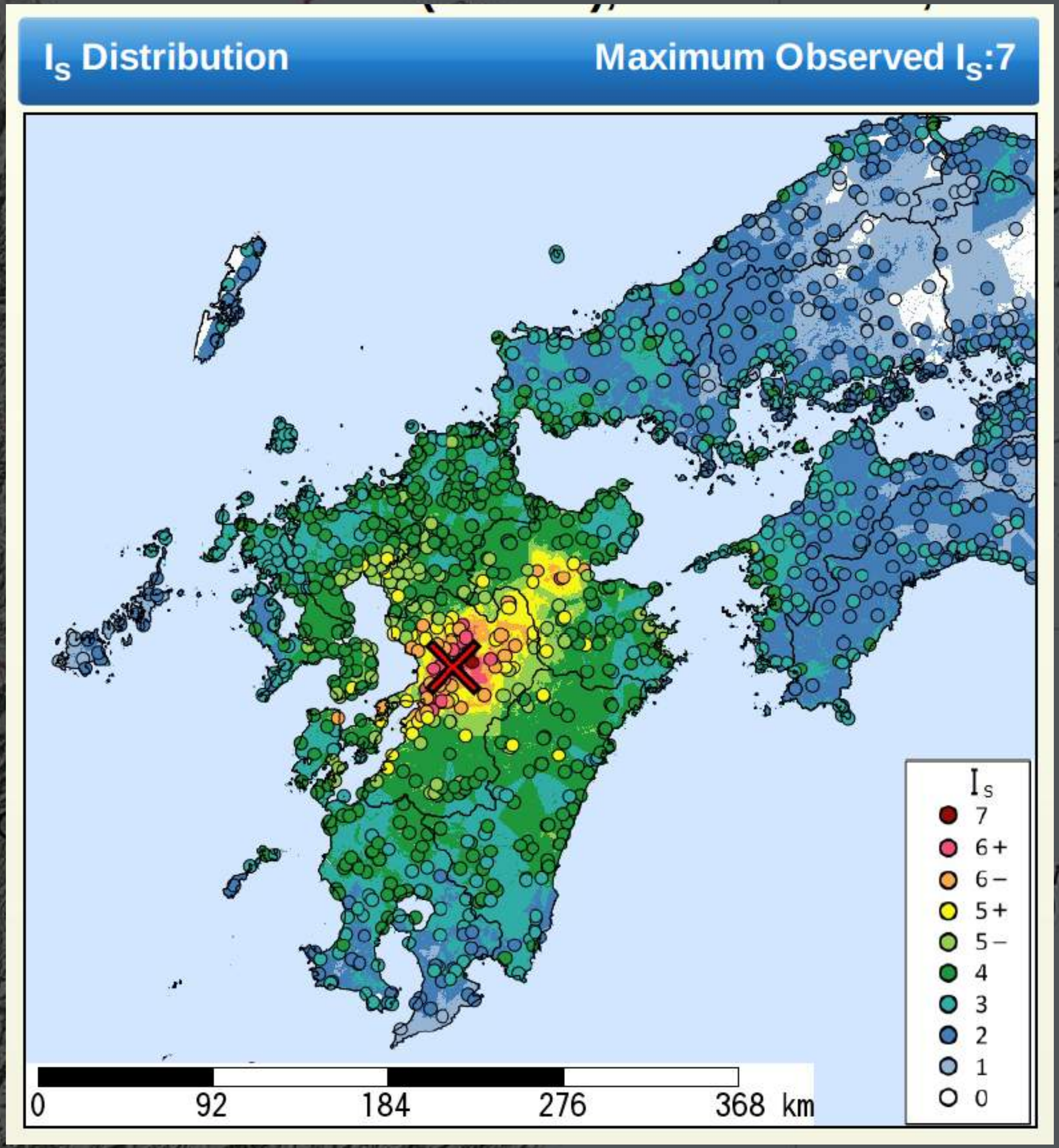
1.61 g PGA during the Mw 6.1 foreshock at **Mashiki Town**
1.35 g PGA during the Mw 7.0 mainshock at **Mashiki Town**



Exposed population to JMA Intensity scale 6+ and 7 (> MMI VIII~IX)
Mw 6.1: 100,000
Mw 7.0: 350,000



Mw 6.1 foreshock



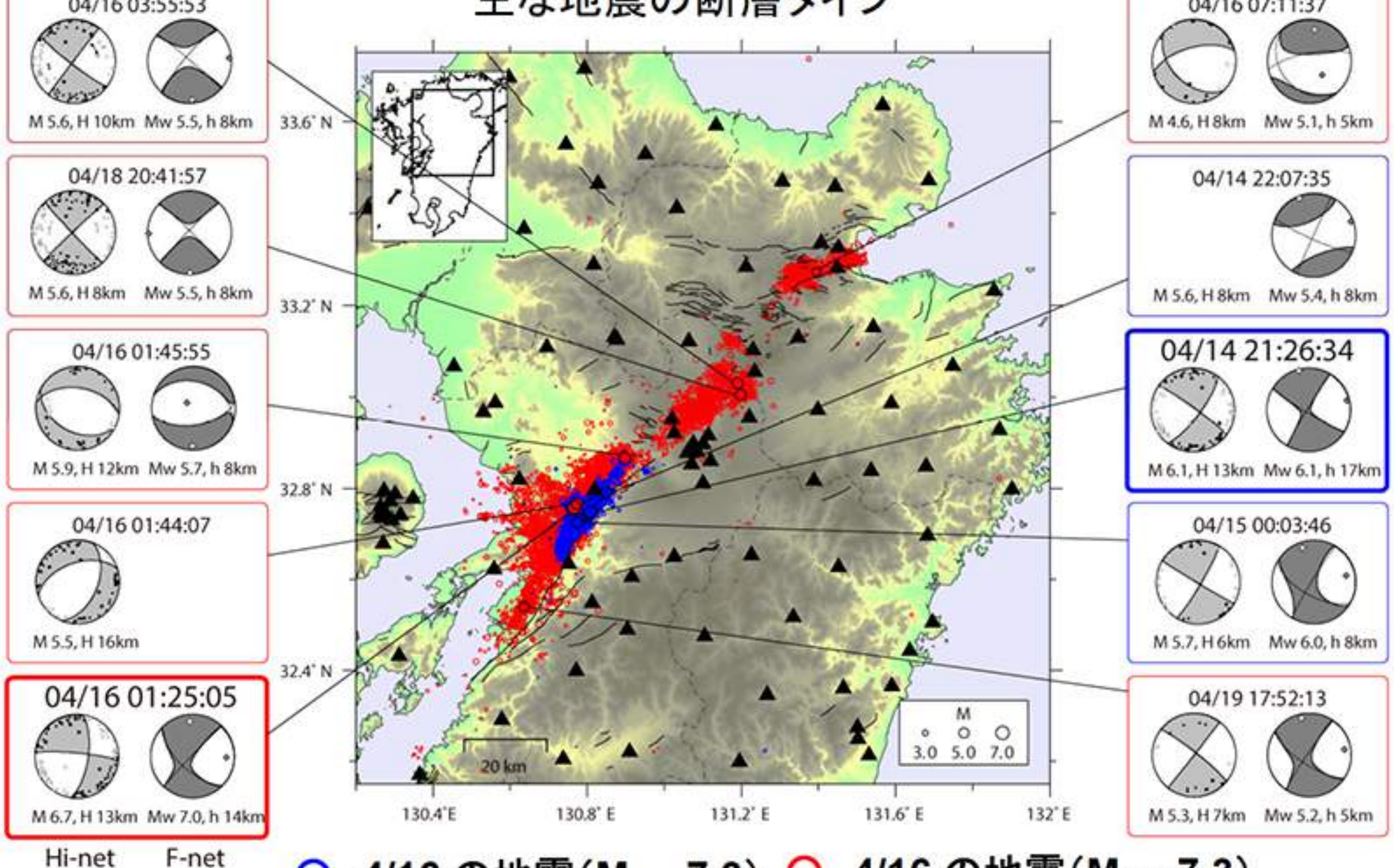
Mw 7.0 mainshock + triggered shock

NIED J-RISQ

震源域周辺およびその周辺における震源分布

田中・浅野

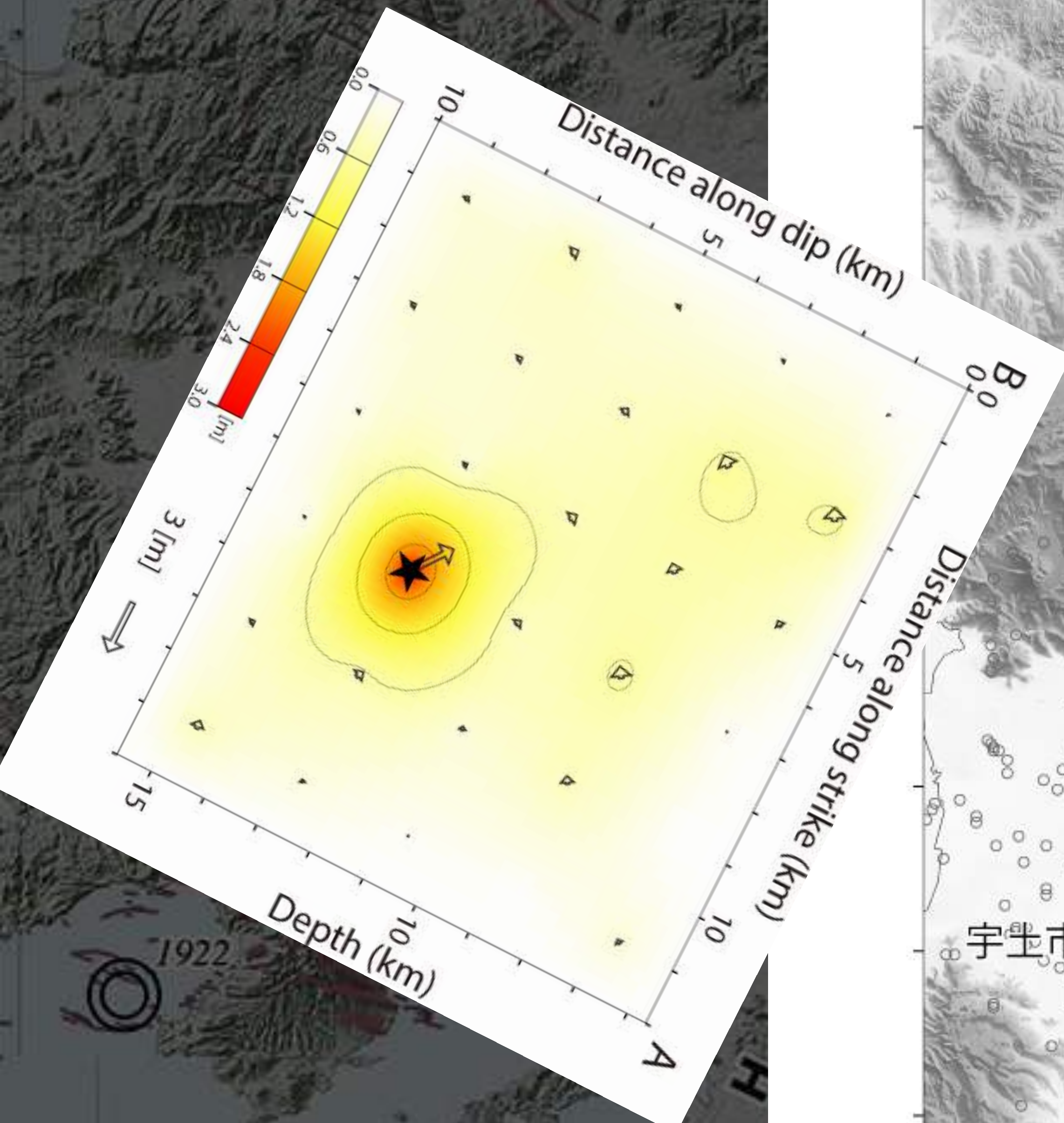
主な地震の断層タイプ



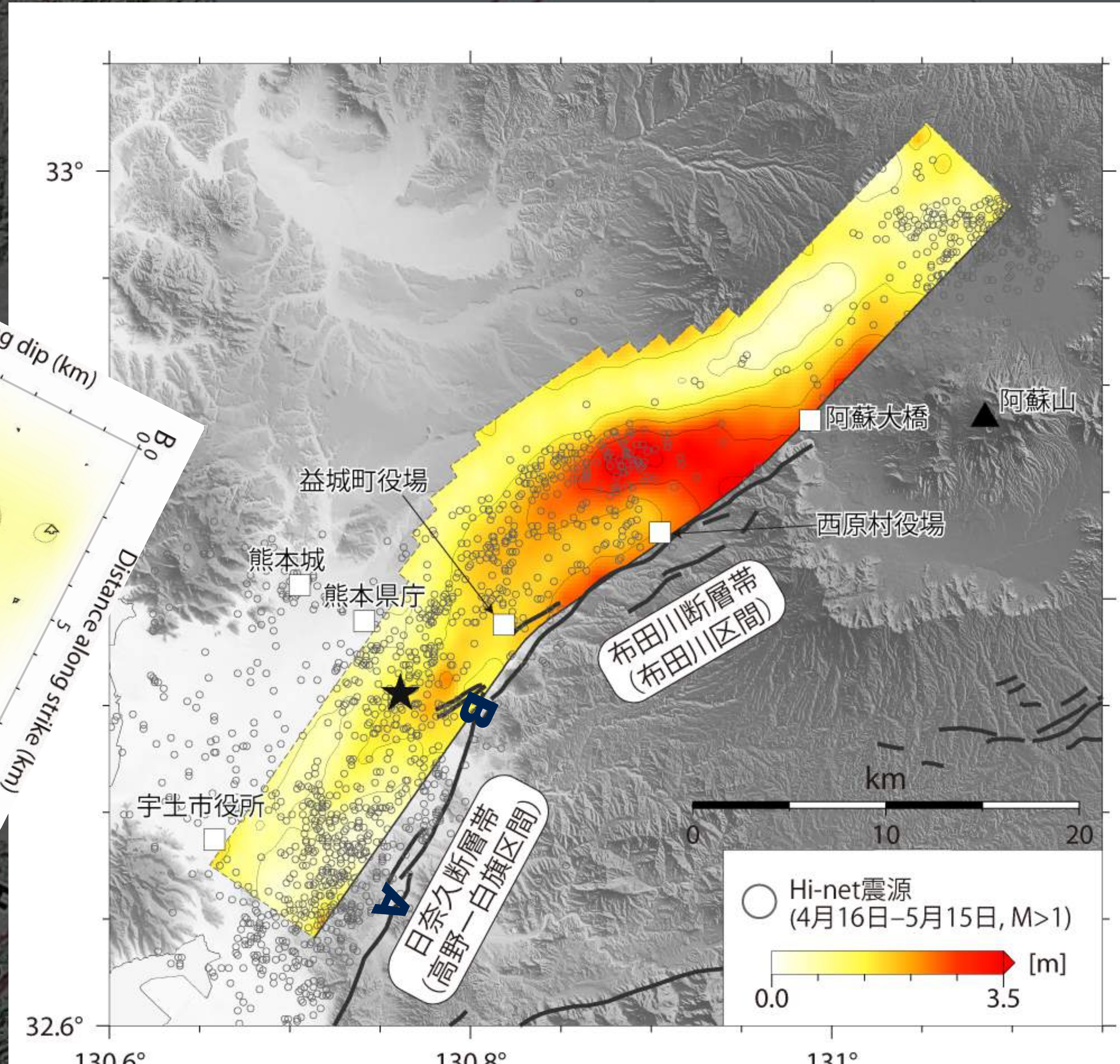
○ 4/16 の地震(M_{JMA}7.3)より前に発生の地震

○ 4/16 の地震(M_{JMA}7.3)以降に発生の地震

Blue: before Mw 7.0, Red: after Mw 7.0.
M. Aoi, NIED

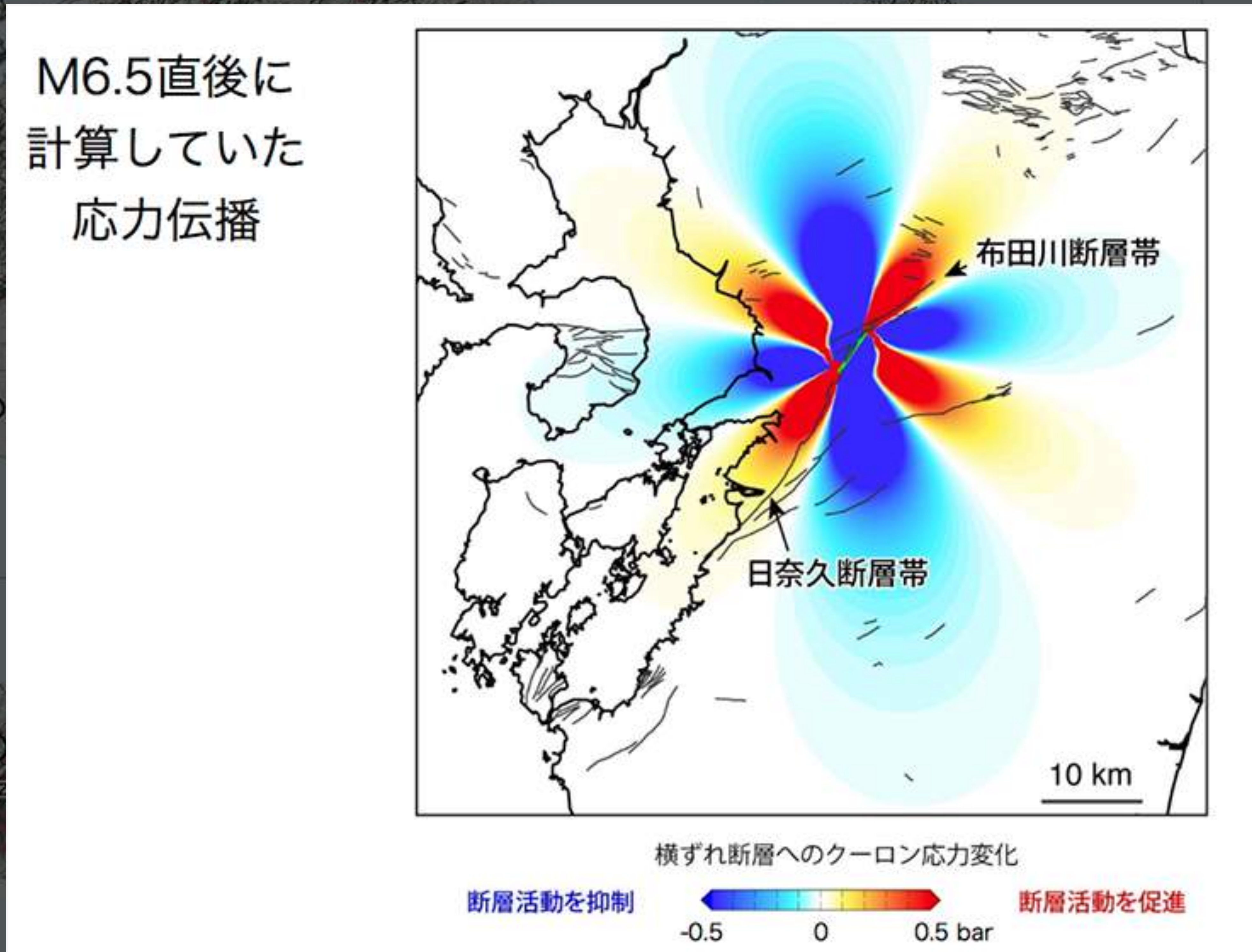


April 14, Mw 6.1



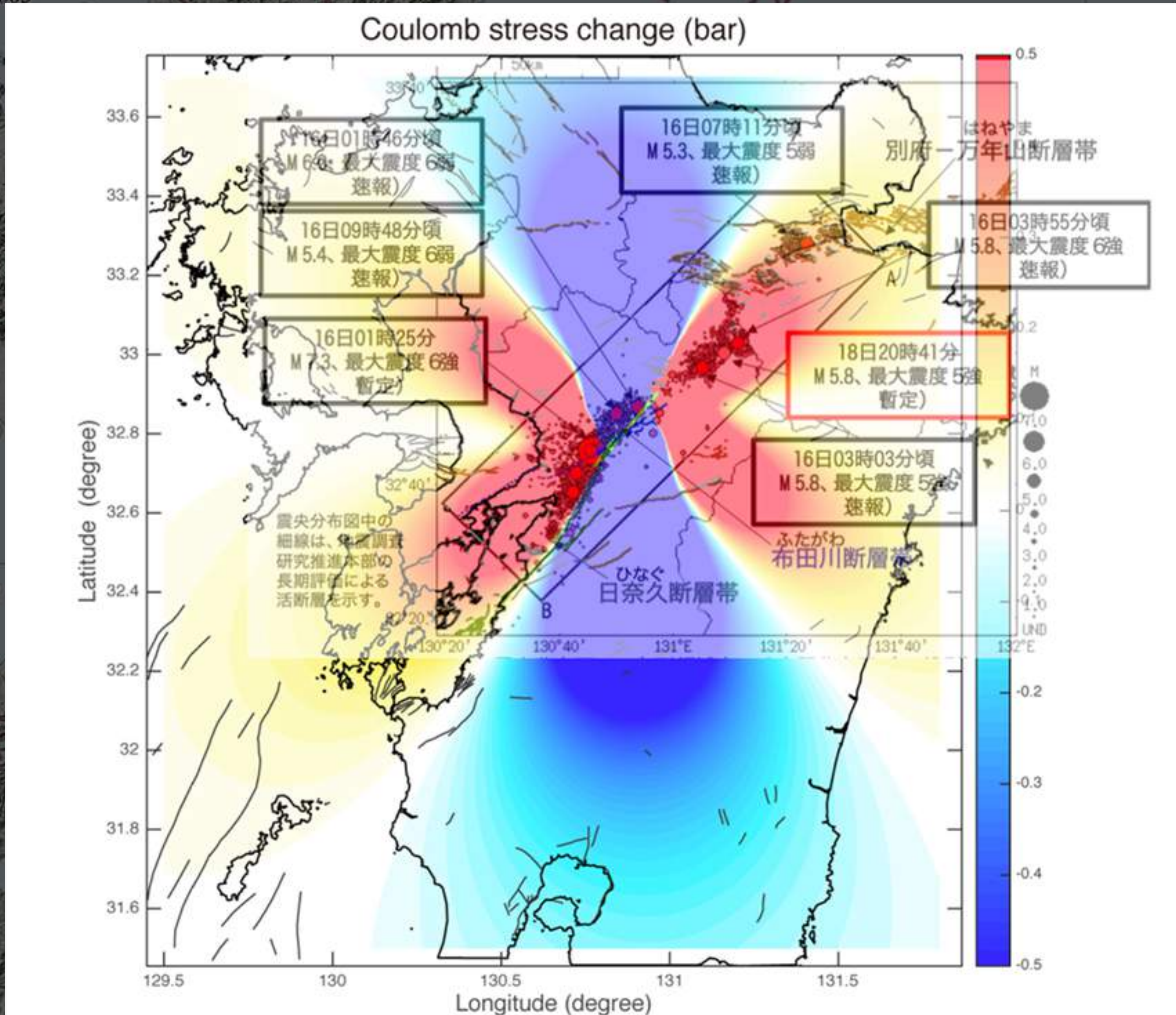
April 16, Mw 7.0

Proximal strong motion inversion by Kubo, Aoki, Aoi, and Sekiguchi, NIED



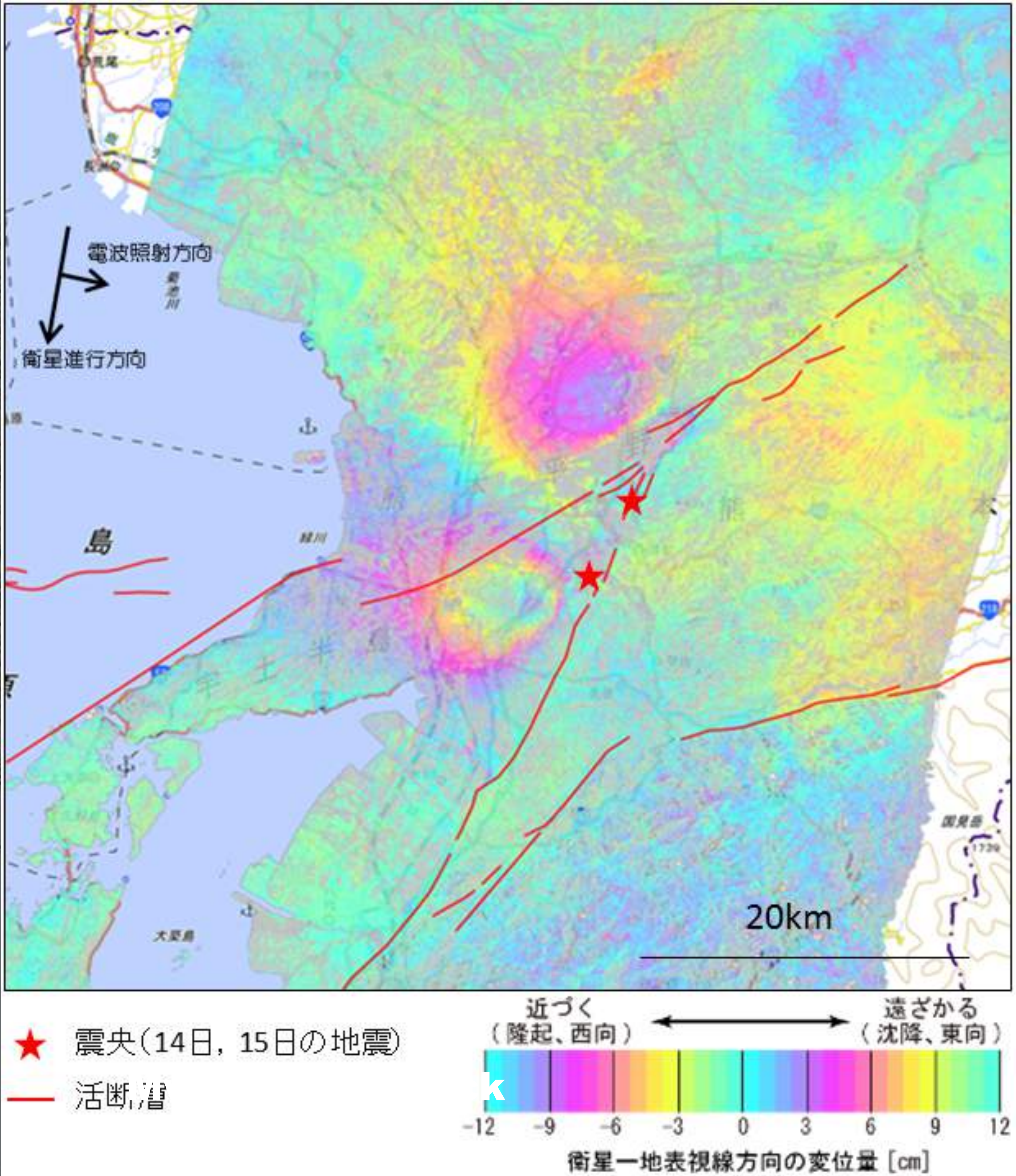
ΔCFF after Mw 6.1 on April 14. Futagawa fault is within a red zone.

Shinji Toda, Tohoku University



ΔCFF after Mw 7.0 on April 16 by Shinji Toda, Tohoku University

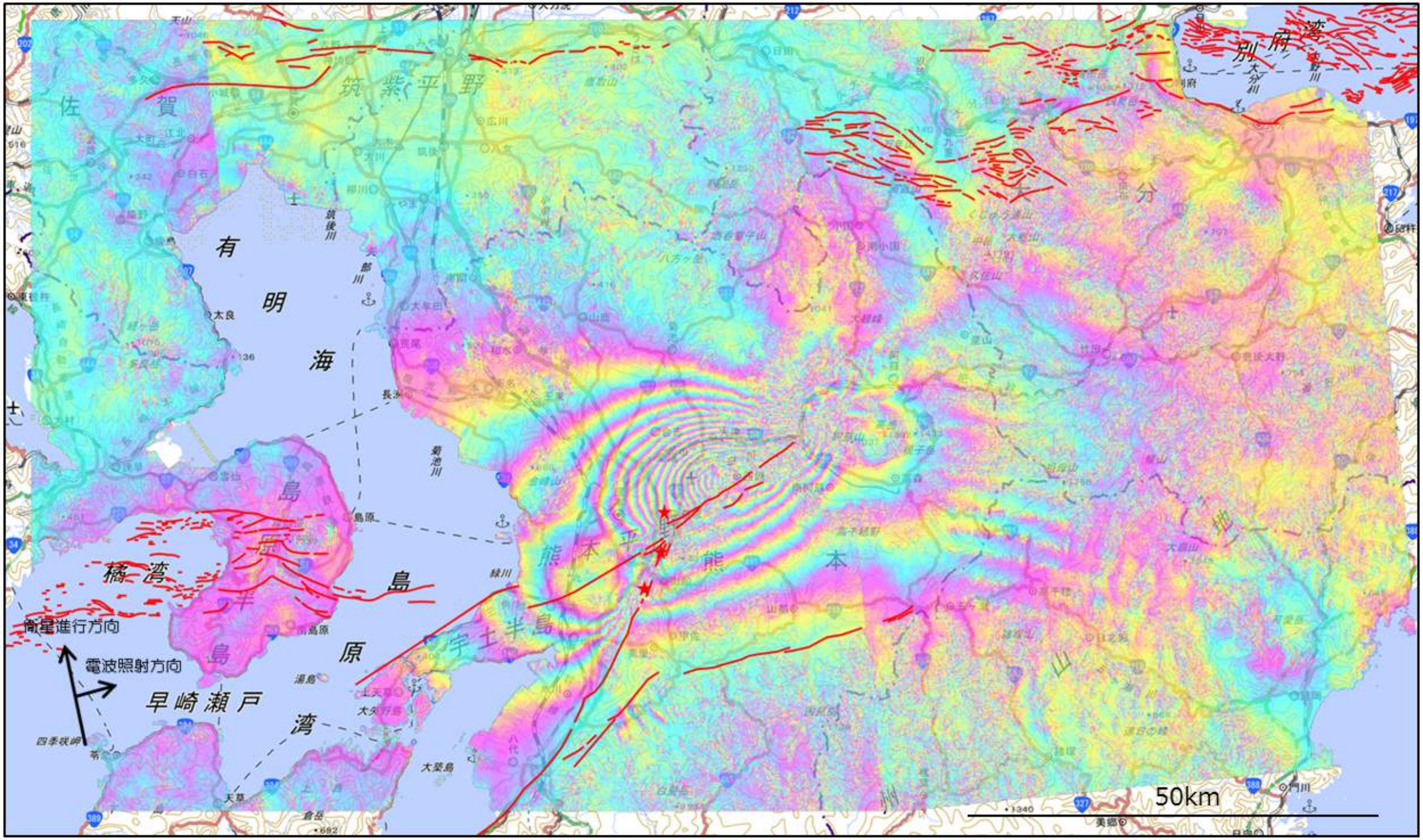
4. Crustal Movements



GSI ALOS-2 InSAR

2 major foreshocks

no surface rupture



★ 震央（14日，15日，16日の地震）

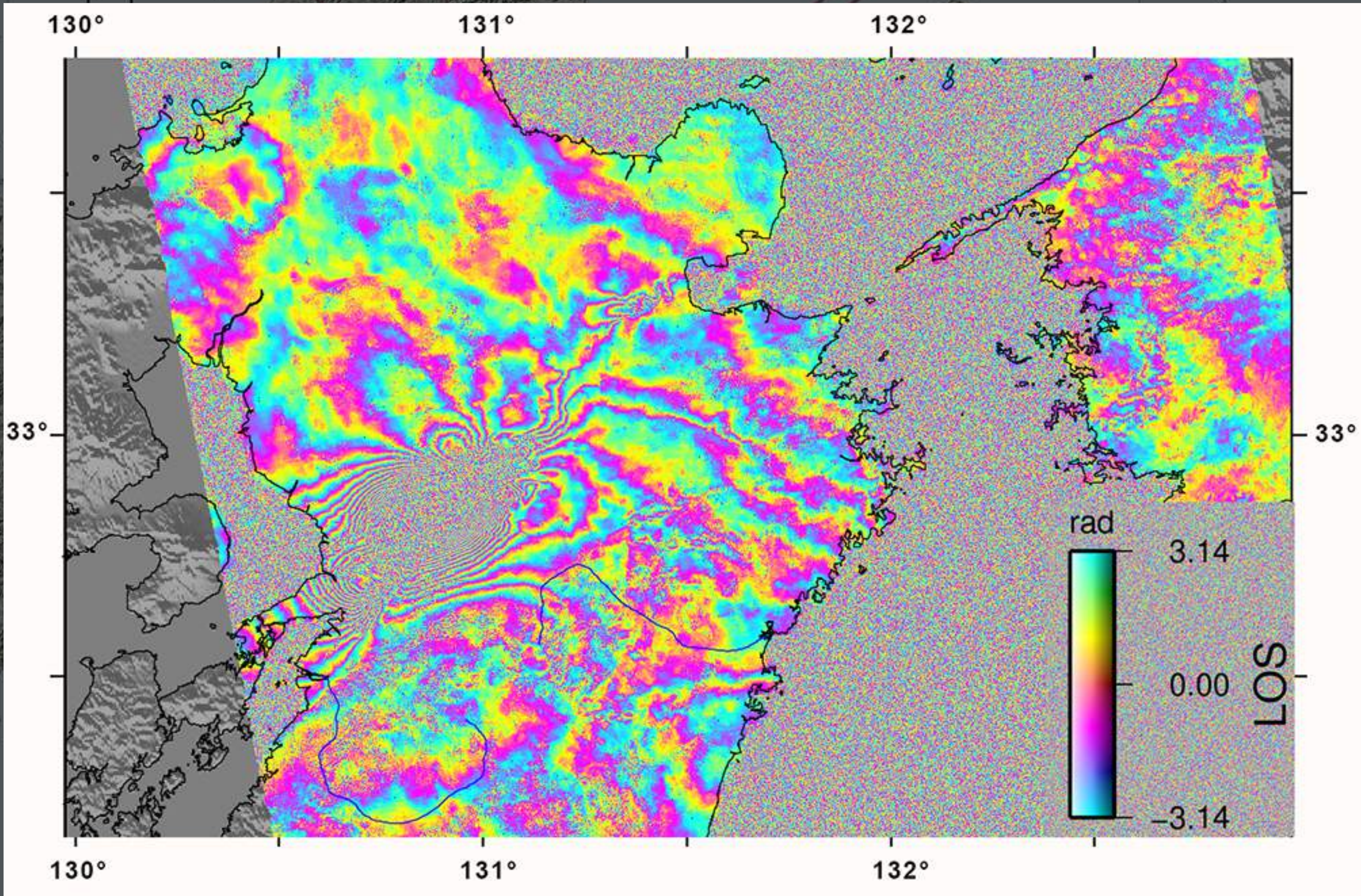
― 活断層（地震調査研究推進本部による）

近づく（隆起、西向） ⟷ 遠ざかる（沈降、東向）

-12 -9 -6 -3 0 3 6 9 12

衛星ー地表視線方向の変位量［cm］

GSI ALOS-2 InSAR 15/APR/2015—20/APR/2016



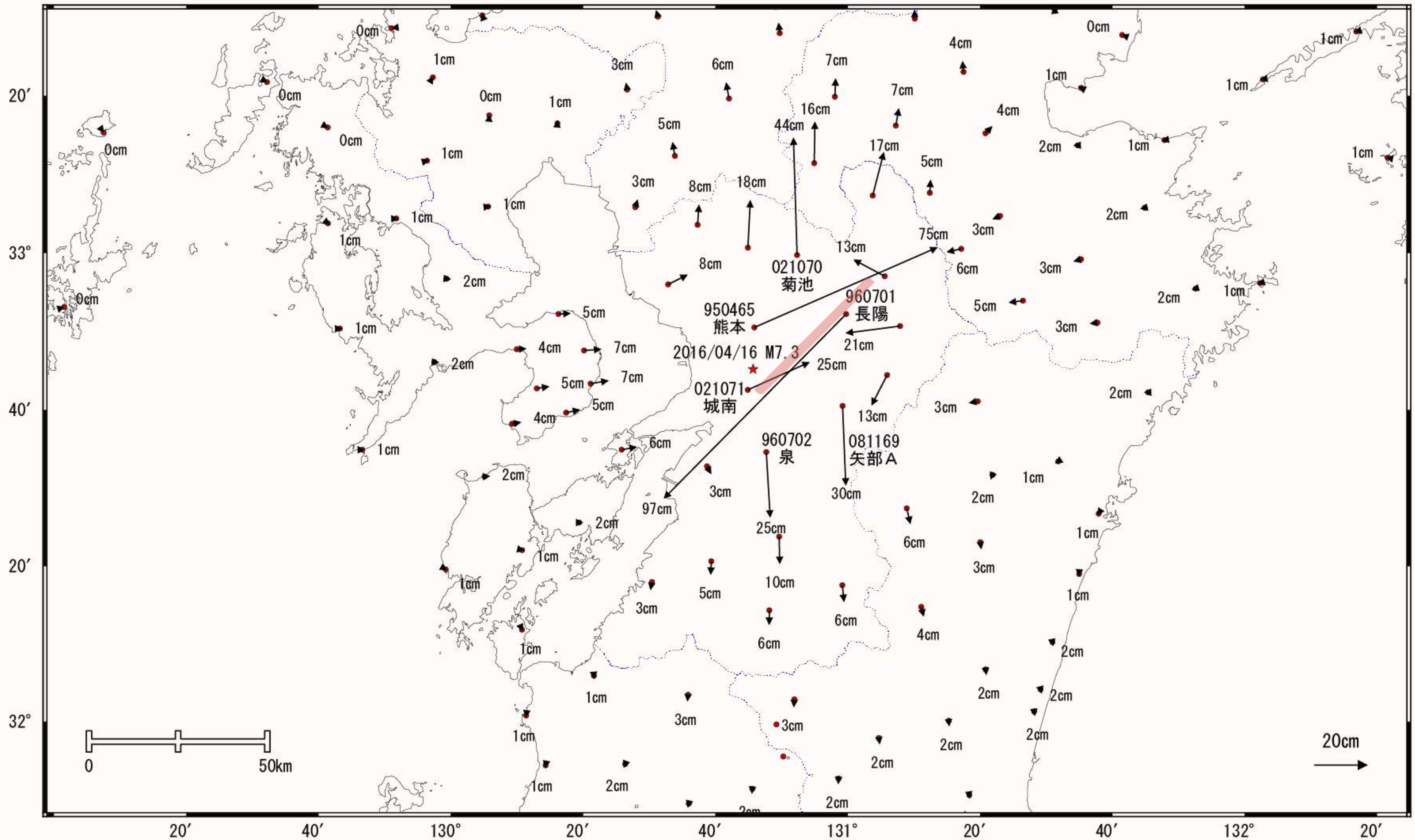
Sentinel-I InSAR, Raphael Grandin – IPGP – Copernicus (2016)

平成28年４月16日の熊本県熊本地方の地震(M7.3)(暫定値)前後の観測データ（１）

暫定

地殻変動(水平)

基準期間:2016/04/15 03:00～2016/04/15 23:59[Q3:迅速解]
比較期間:2016/04/16 02:00～2016/04/16 05:59[S3:迅速解]



☆ 固定局:福江(950462)

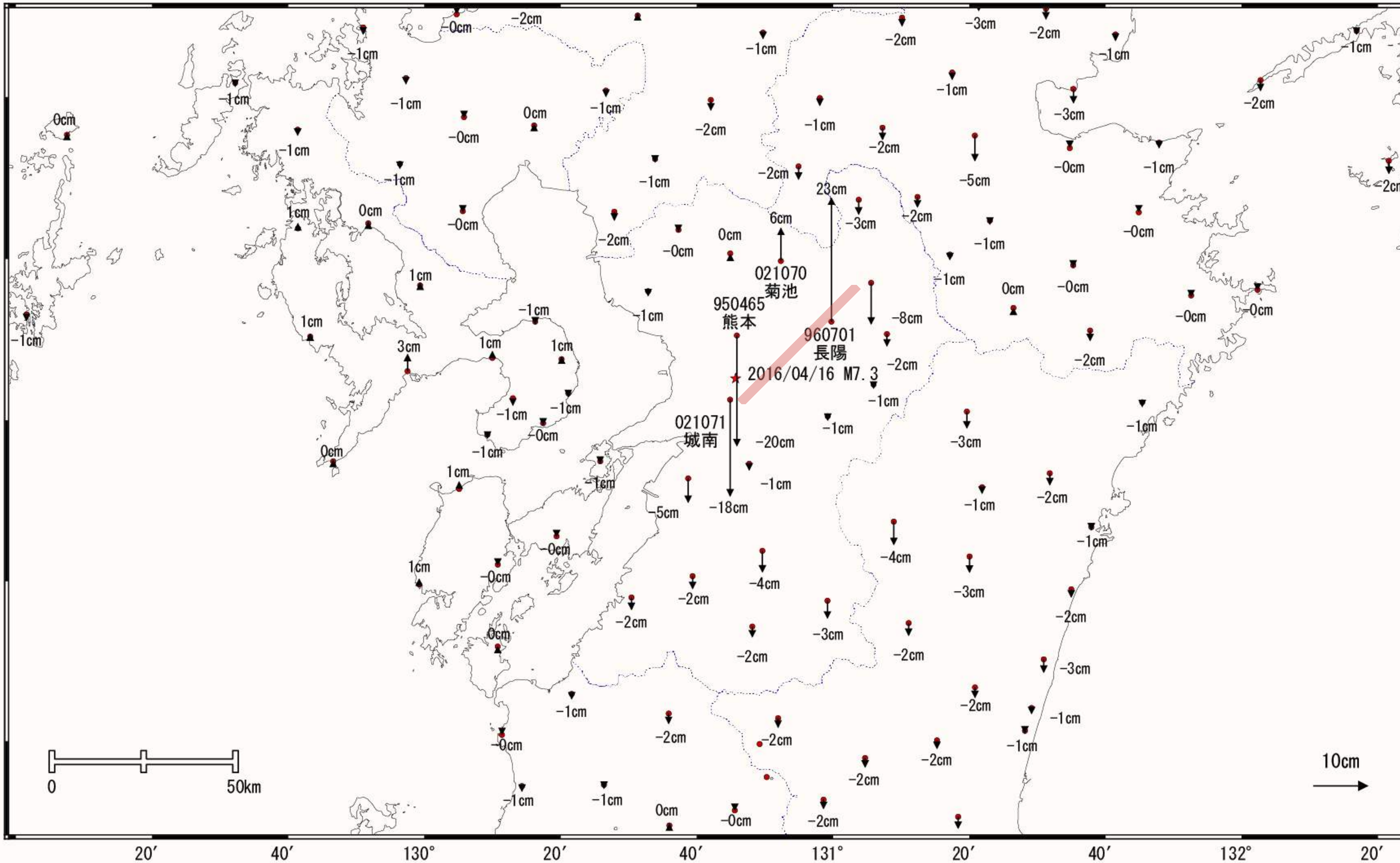
国土地理院

GSI Geonet GNSS horizontal movements: Dextral

平成28年４月16日の熊本県熊本地方の地震(M7.3)(暫定値)前後の観測データ（２） 暫定

地殻変動(上下)

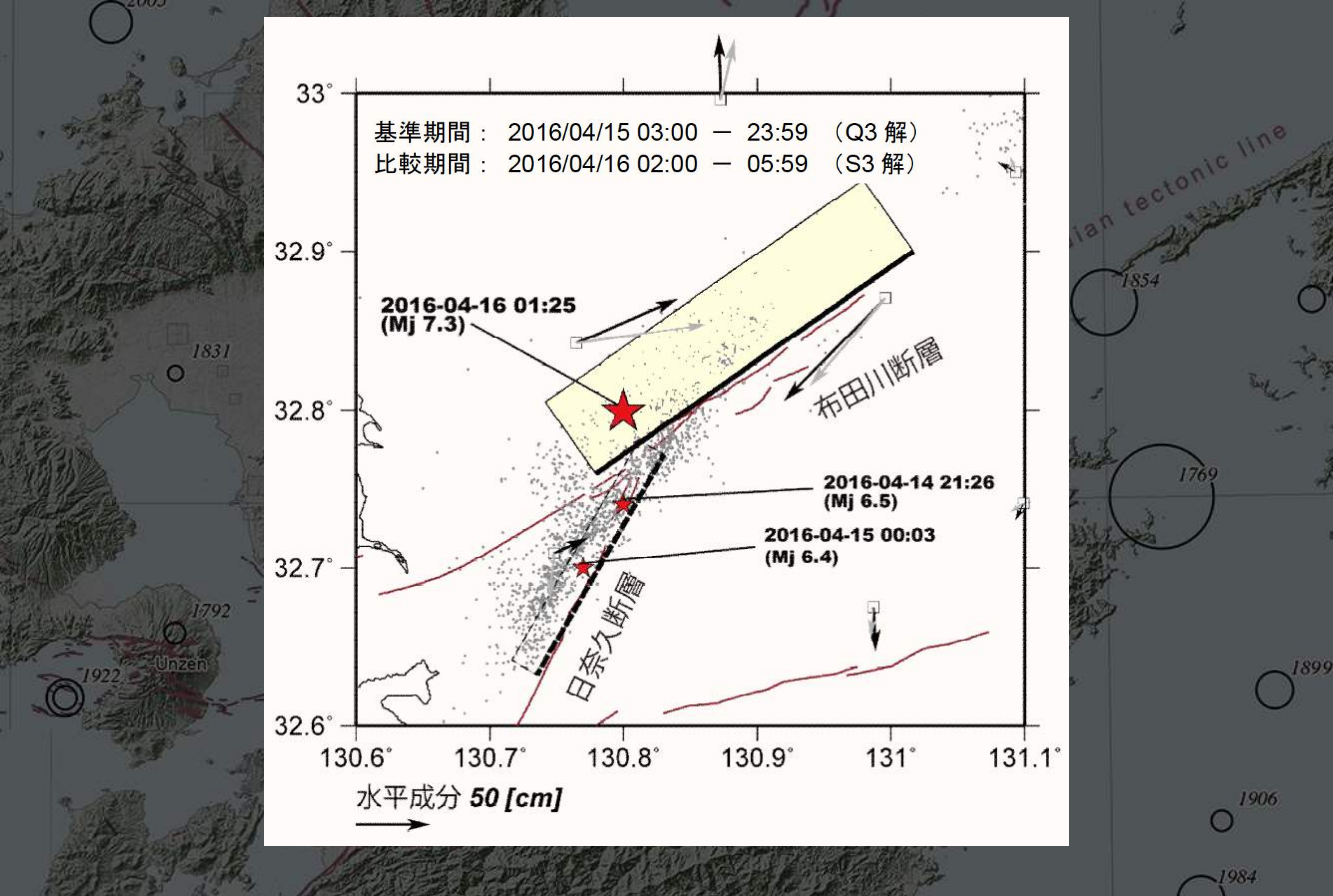
基準期間:2016/04/15 03:00～2016/04/15 23:59[Q3:迅速解]
比較期間:2016/04/16 02:00～2016/04/16 05:59[S3:迅速解]



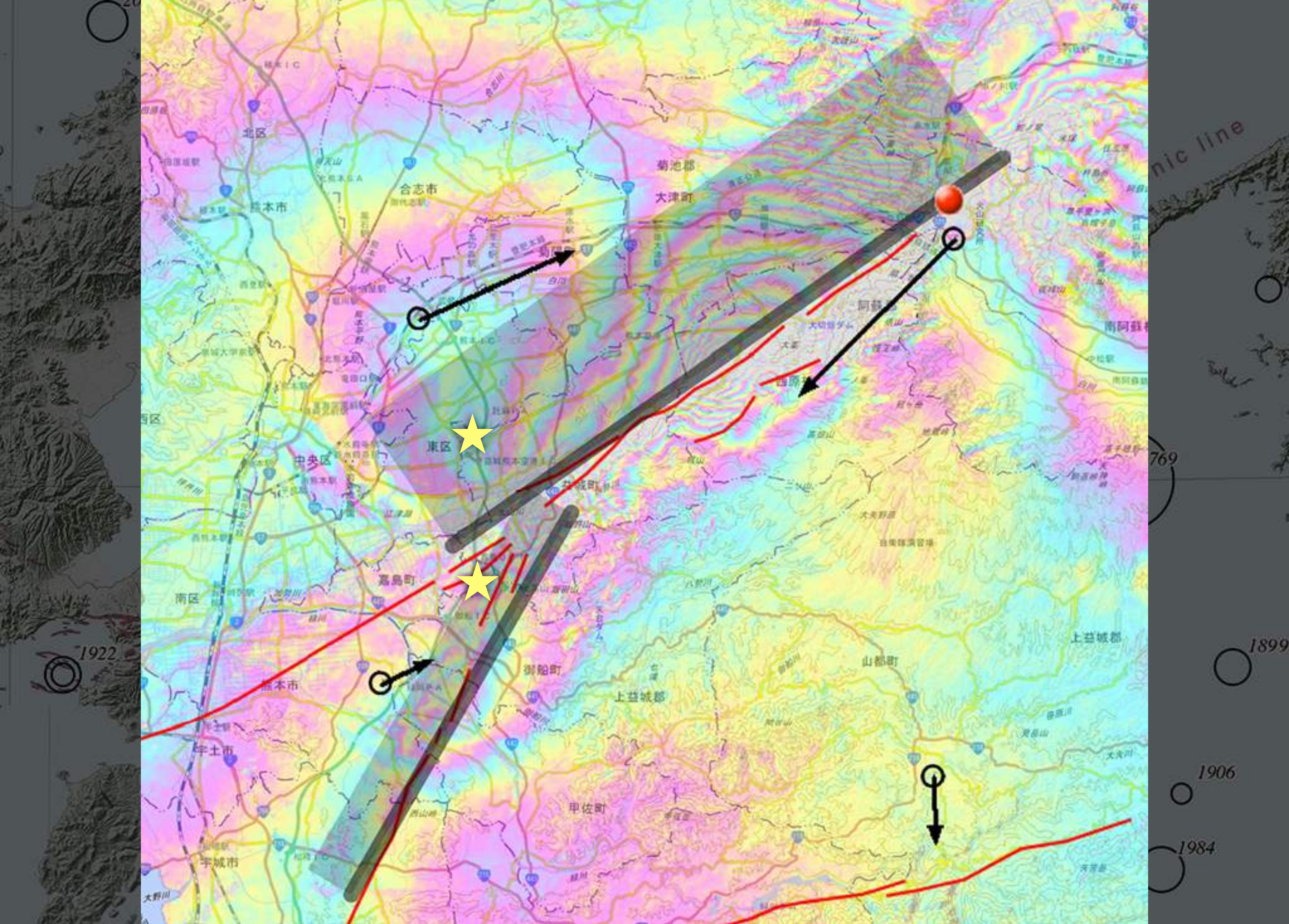
☆ 固定局:福江(950462)

国土地理院

GSI Geonet GNSS vertical movements: N-down.



GSI Geonet GNSS source fault model (L=27 km, dip=60°)



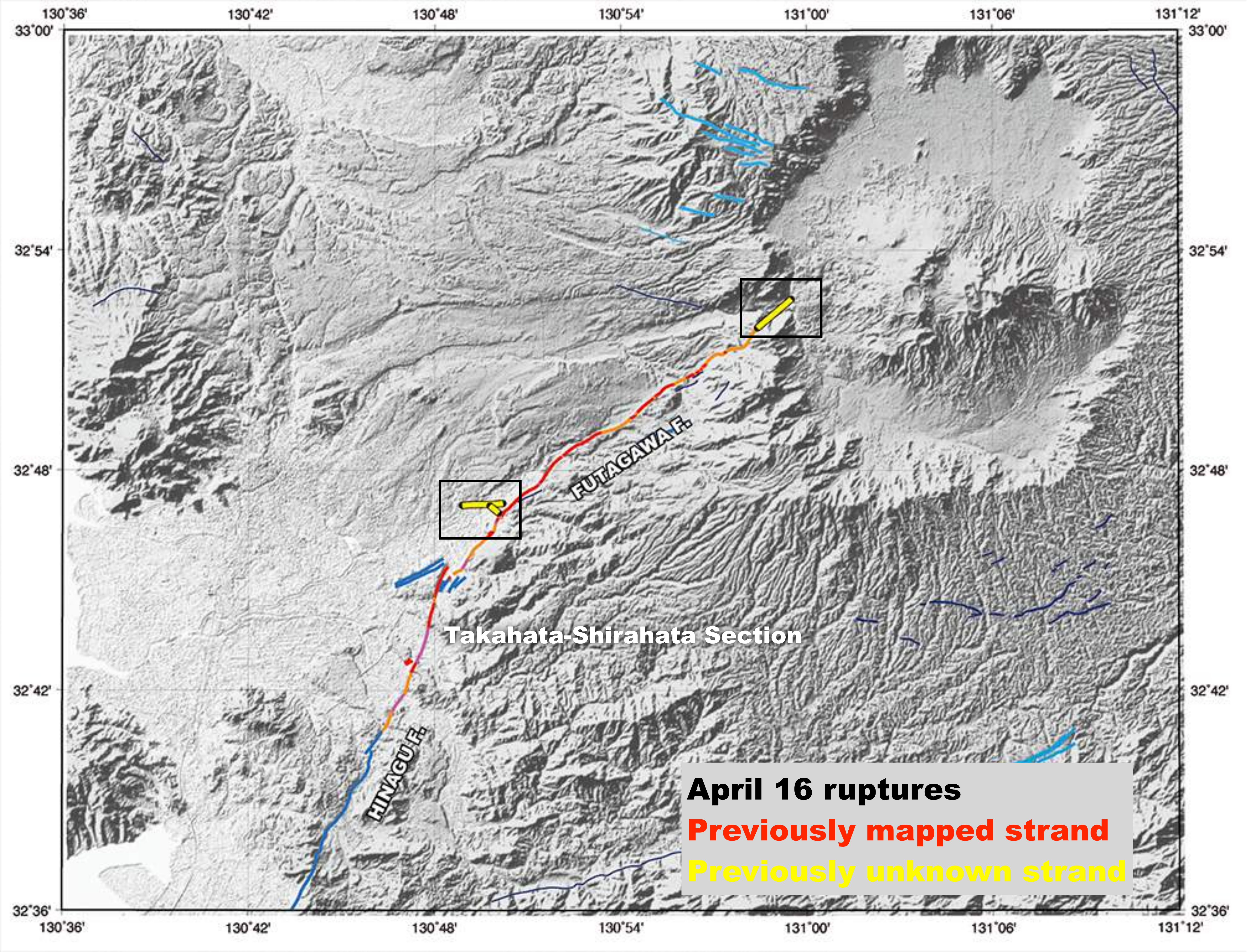
GSI Geonet GNSS source fault model and ALOS-2 InSAR

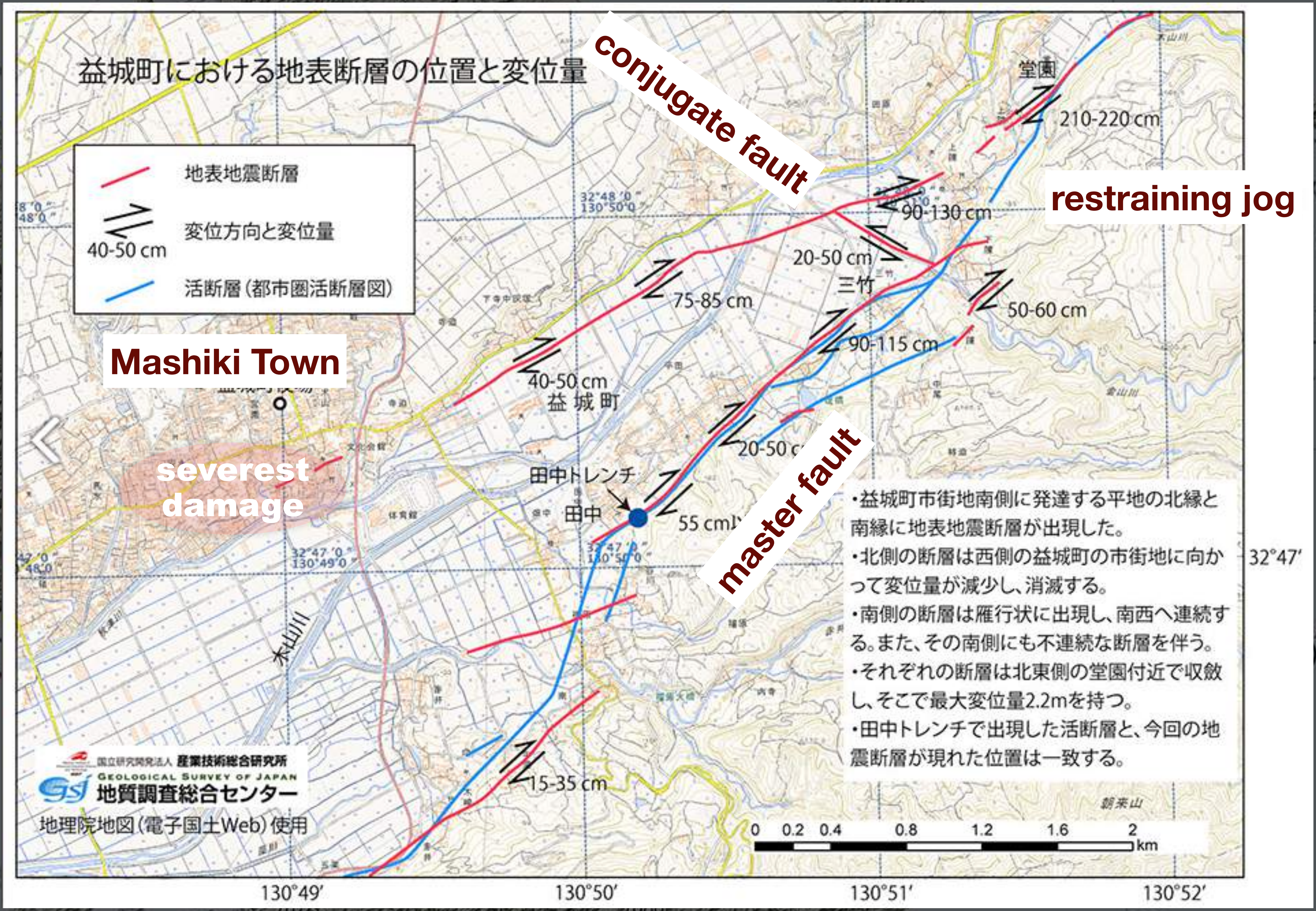
5. Surface faulting associated with Mw 7.0 mainshock

34 km long surface rupture along a mostly mapped fault.

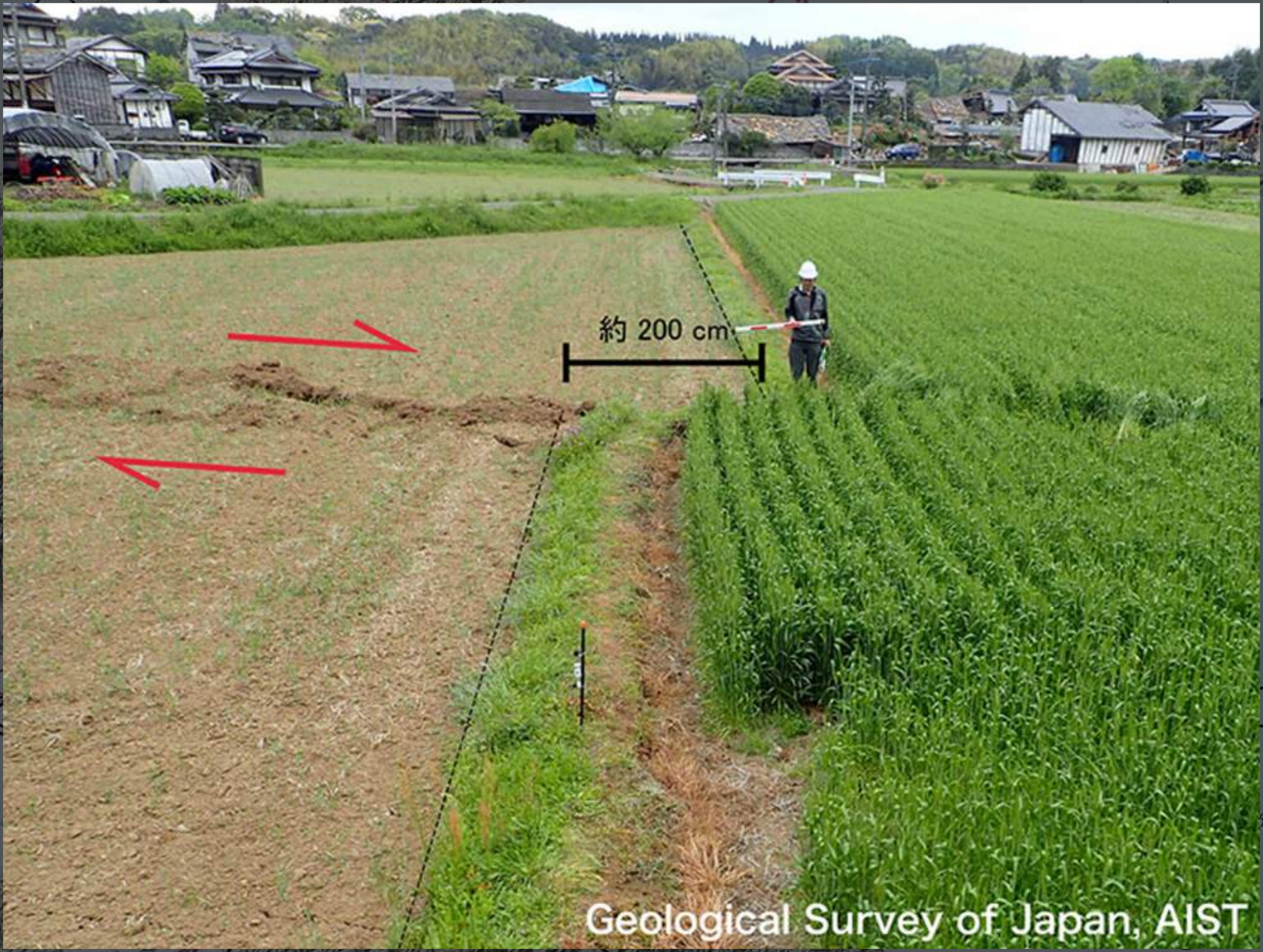
First quasi-perfect surface rupture (≈source fault) since 1930.

1995: 15 km on Awaji island out of 45 km source.
2004: Suspicious 15 cm short rupture in Chuetsu Eq.
2008: Discontinuous ~30 cm ruptures in Iwate-Miyagi Eq.
2014: ~0.9 m slip by a Mw 6.2 on 9 km length of ISTL.


130°36'
130°42'
130°48'
130°54'
131°00'
131°06'
131°12'
33°00'
32°54'
32°48'
32°42'
32°36'
FUTAGAWA F.
Takahata-Shirahata Section
HINAGU F.
April 16 ruptures
Previously mapped strand
Previously unknown strand



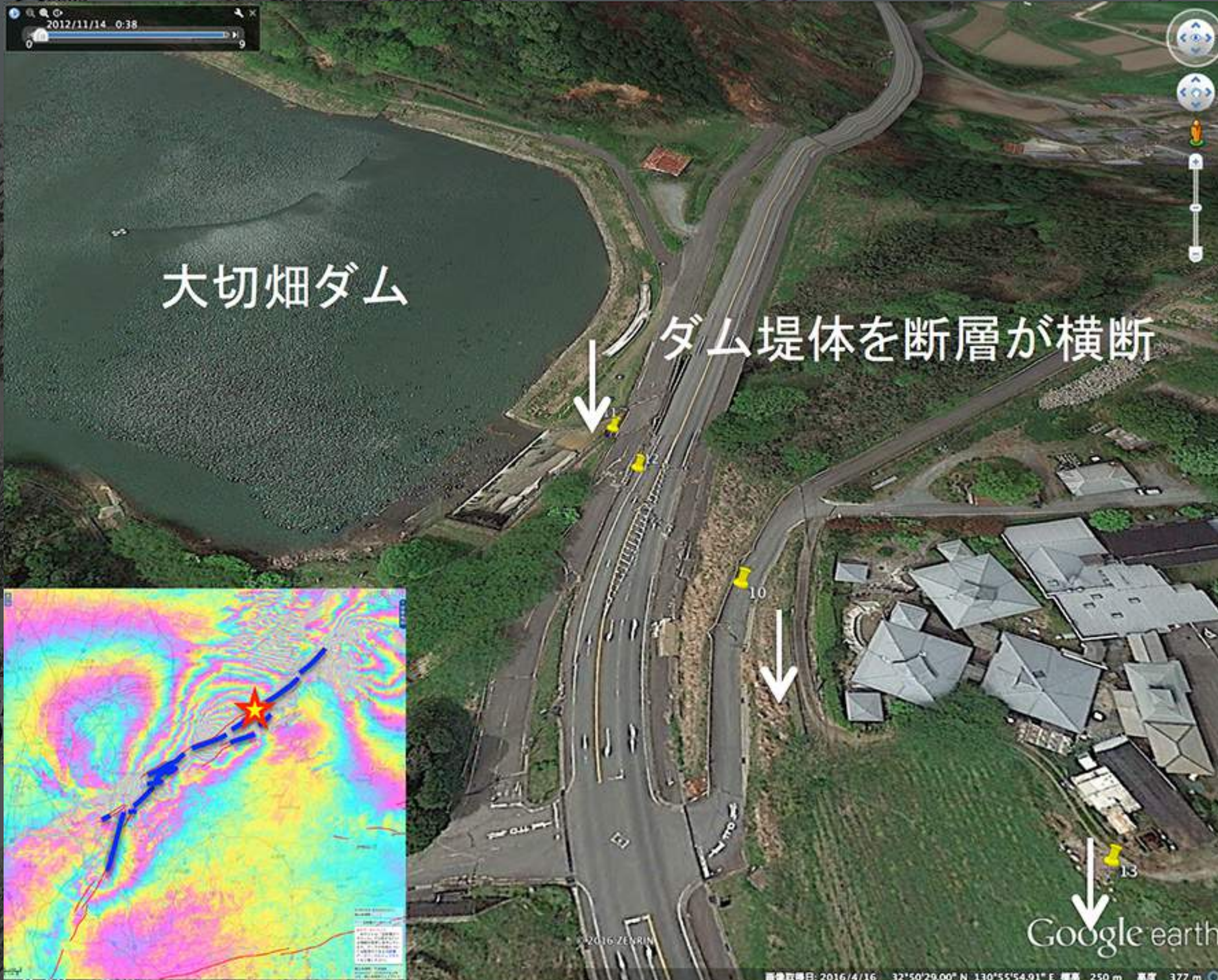
Shirahama et al., Geological Survey of Japan



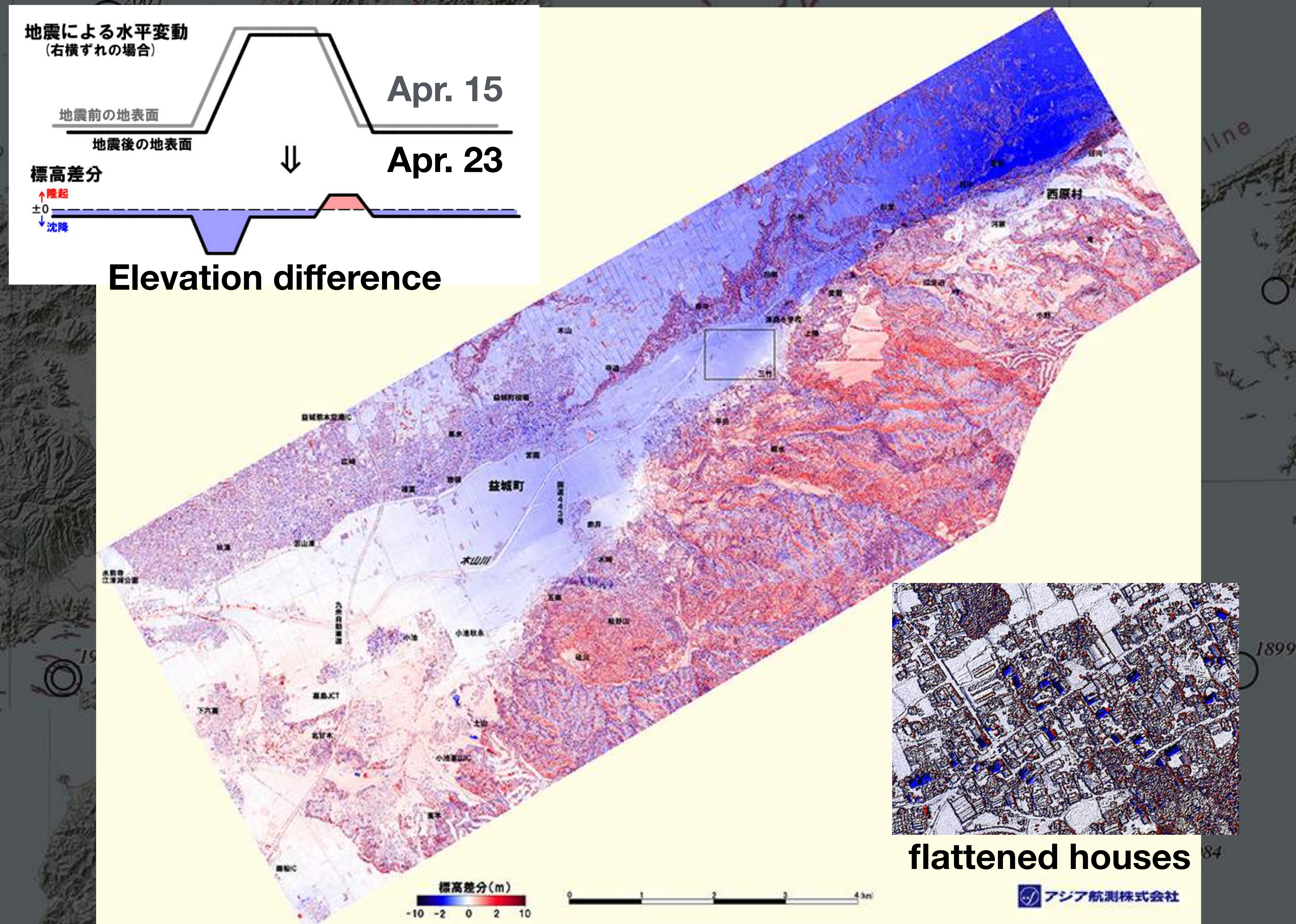
Shirahama et al., Geological Survey of Japan

2005
1916
1909
1939

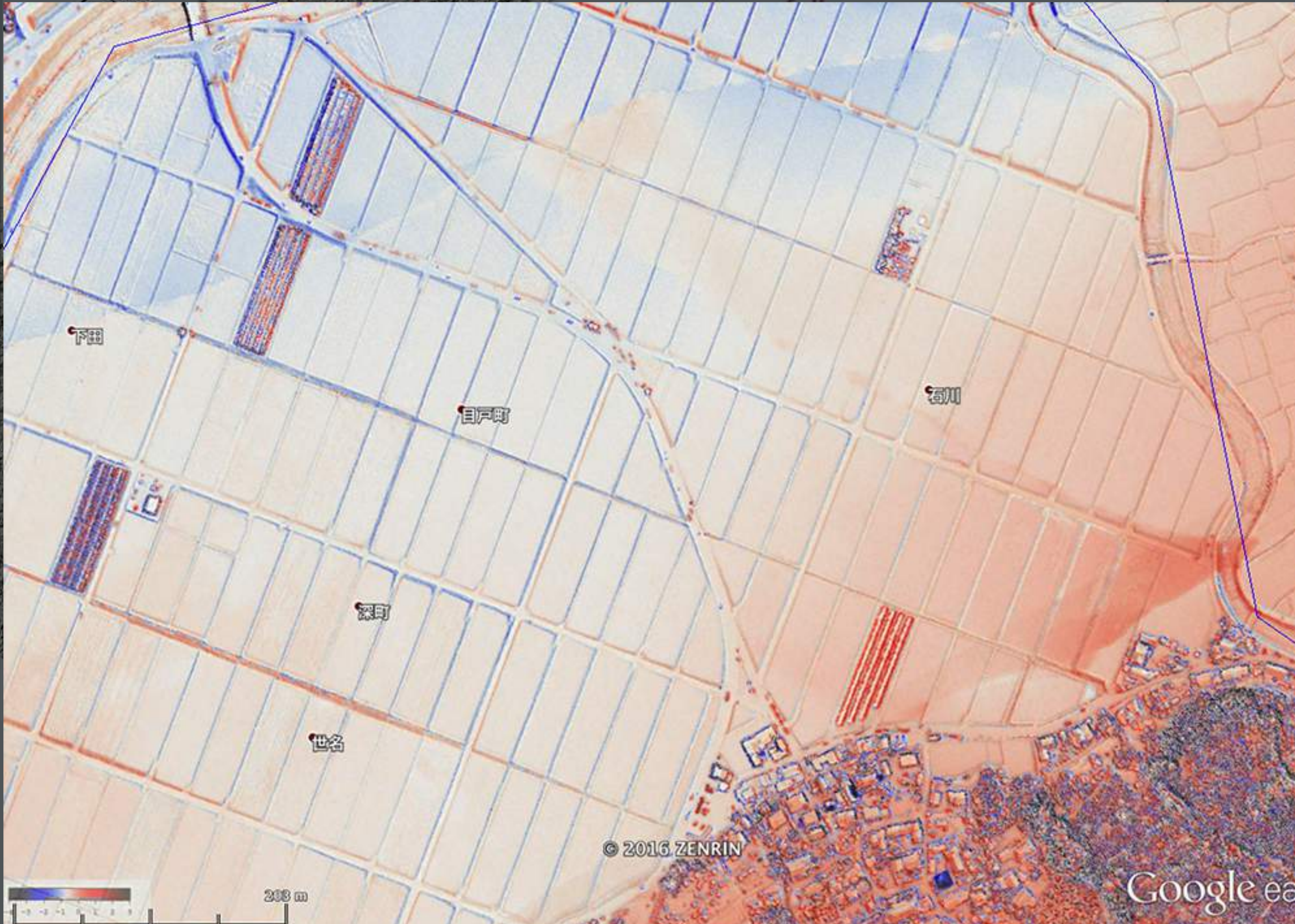

1916
1909
1939



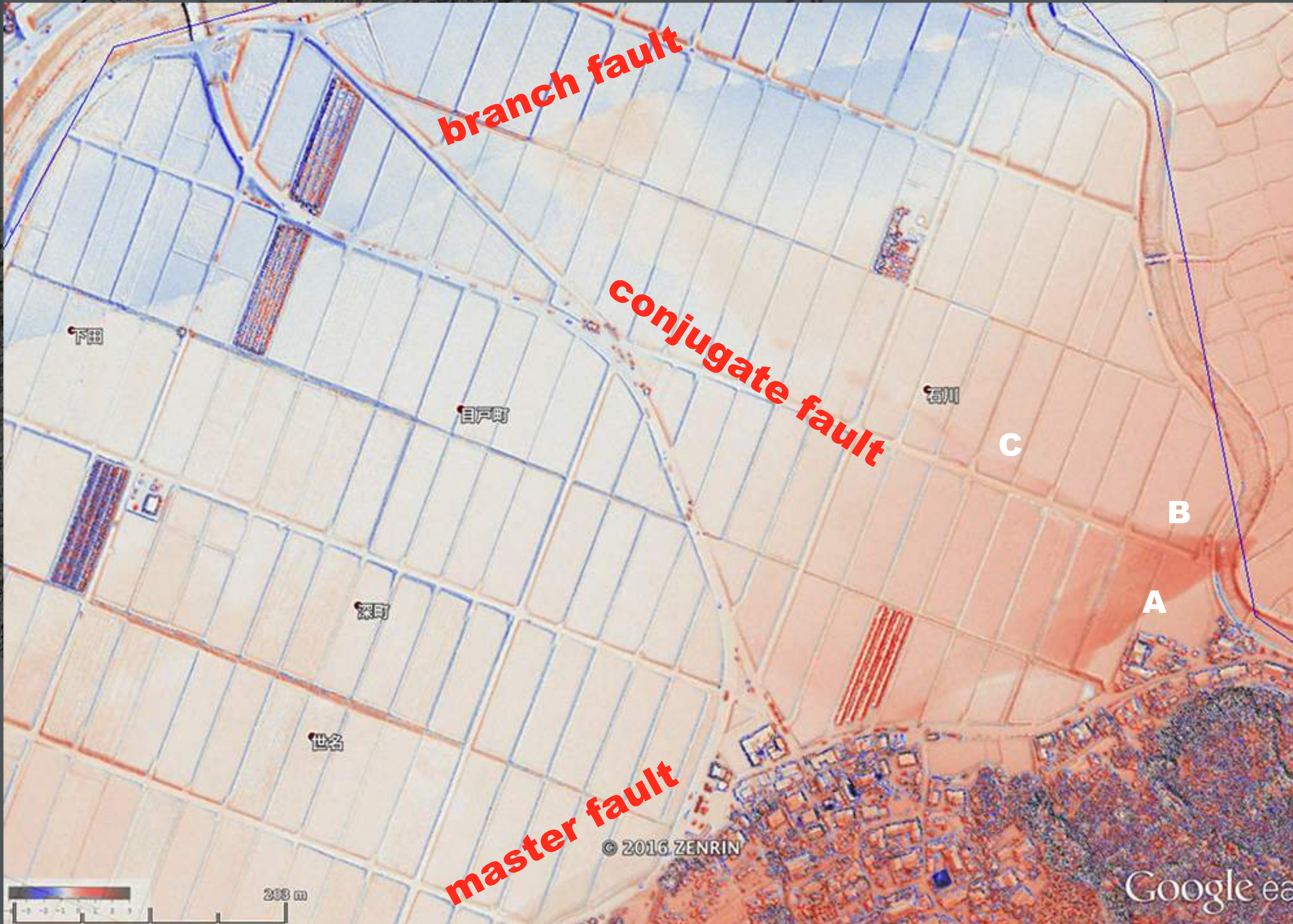
Faulted earth dam at Nishihara. Yoshimi et al., GS Japan



April 15 - April 23 LiDAR differential map by Asia Aero Service, Co.

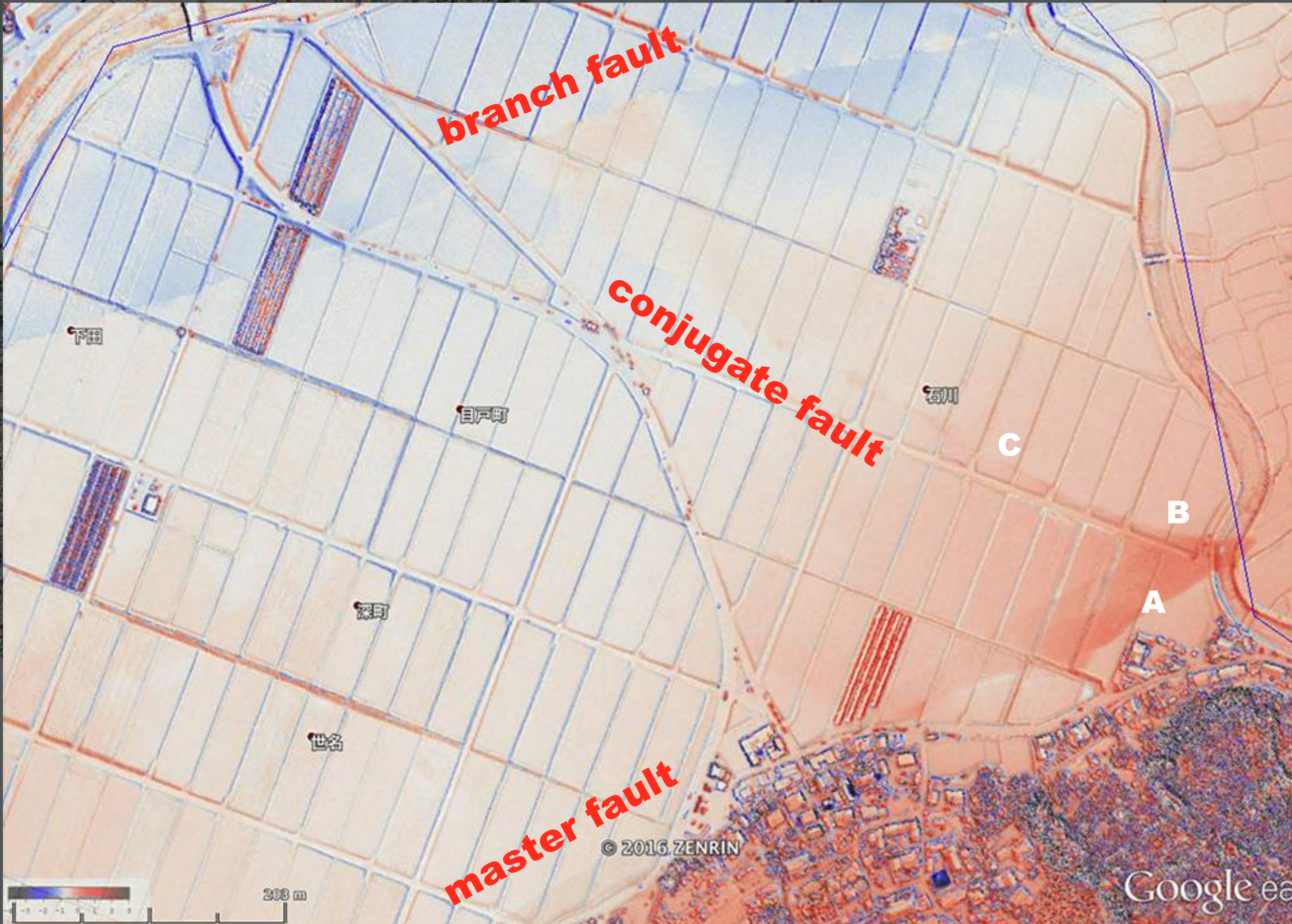


http://www.ajiko.co.jp/article/detail/ID56JI45Y2D/#v02 Asia Aero Service Co.



http://www.ajiko.co.jp/article/detail/ID56JI45Y2D/#v02 Asia Aero Service Co.

South-side-down master fault at loc. A.

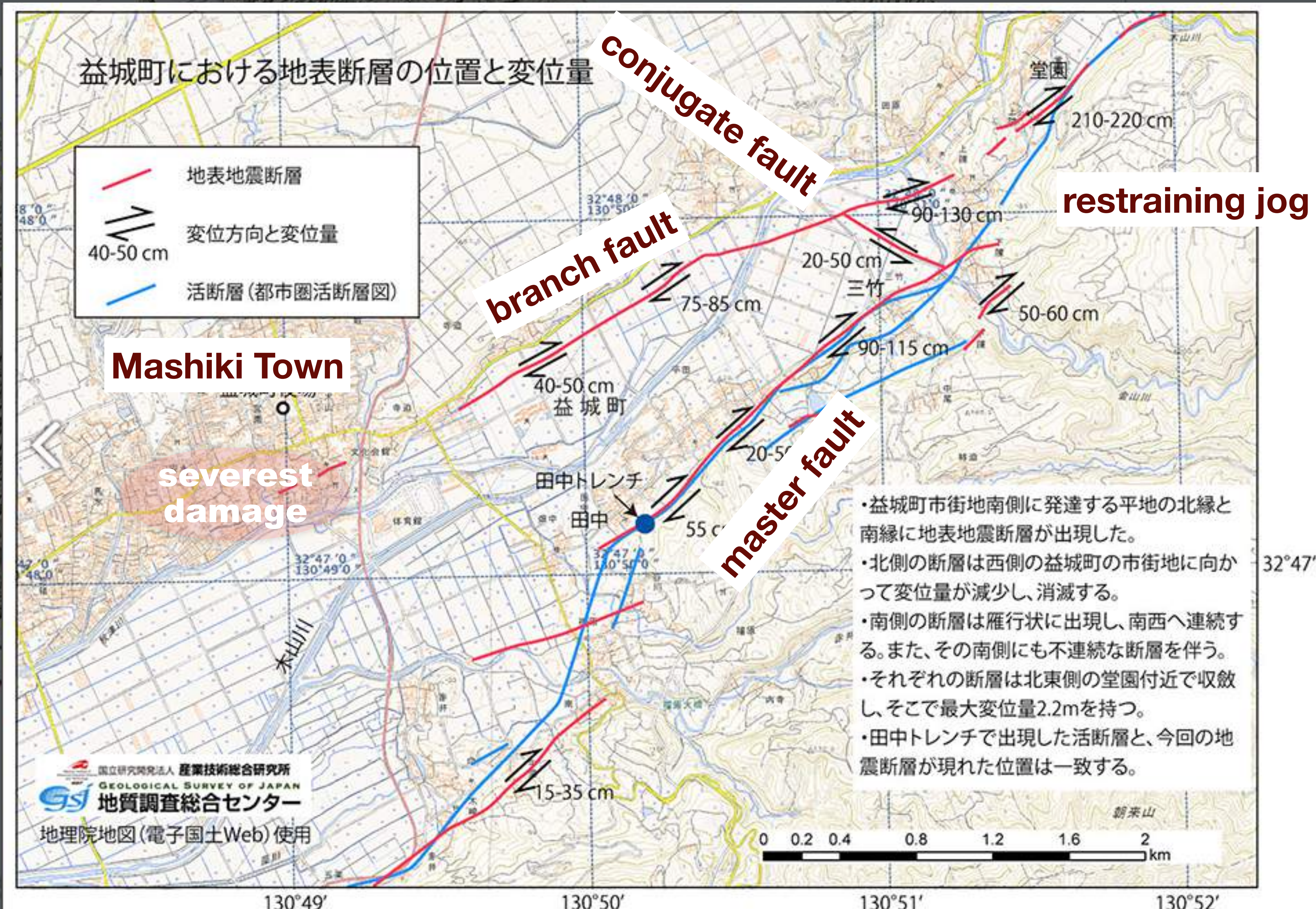


http://www.ajiko.co.jp/article/detail/ID56JI45Y2D/#v02 Asia Aero Service Co.

Deformed (or flexures) paddy at loc. B

Deformed (or flexures) paddy at loc. B

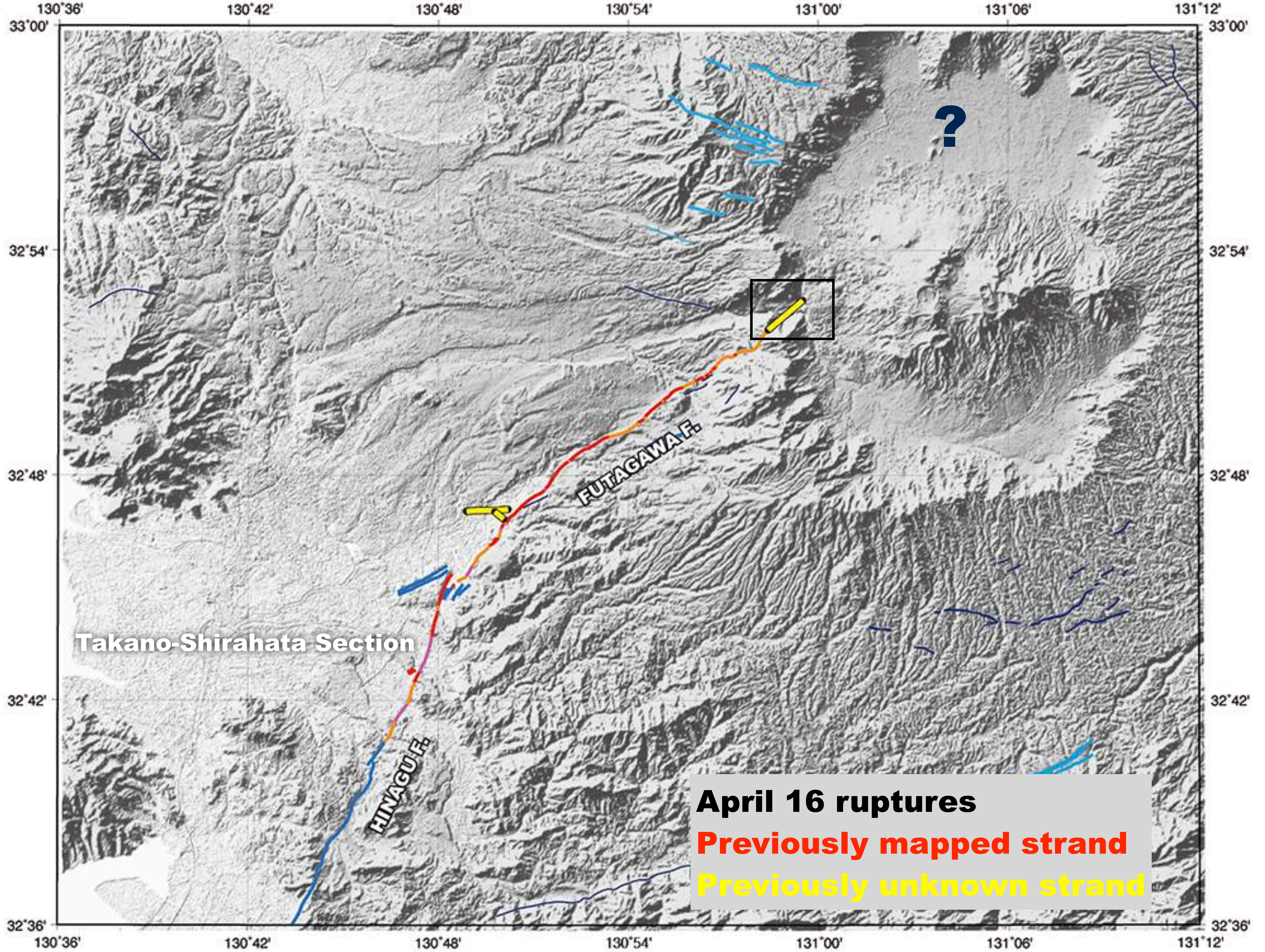
Left-lateral strike slip of rice stubble at loc. B

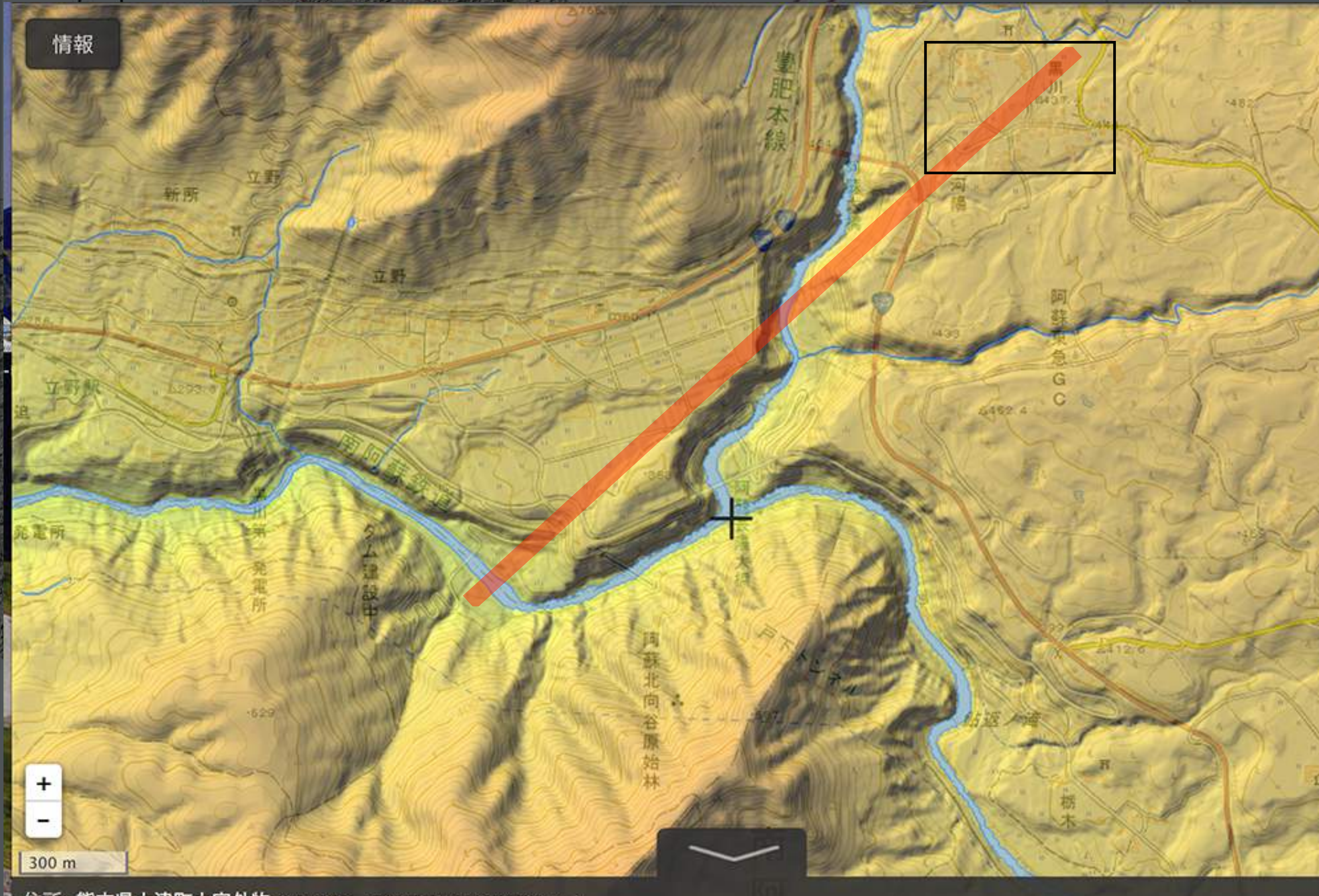


Shirahama et al., Geological Survey of Japan

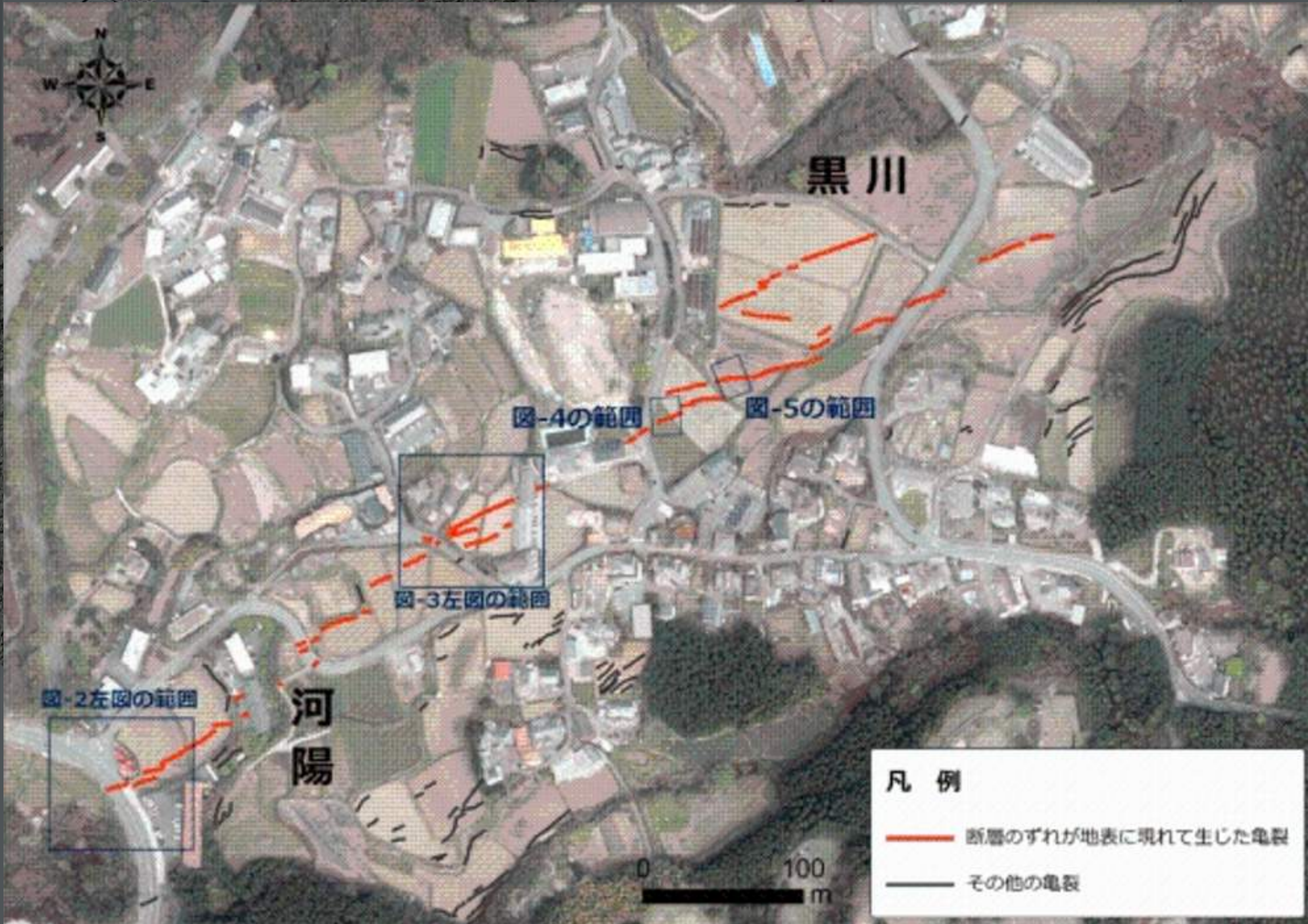
Kumahara et al.

Kumahara et al.

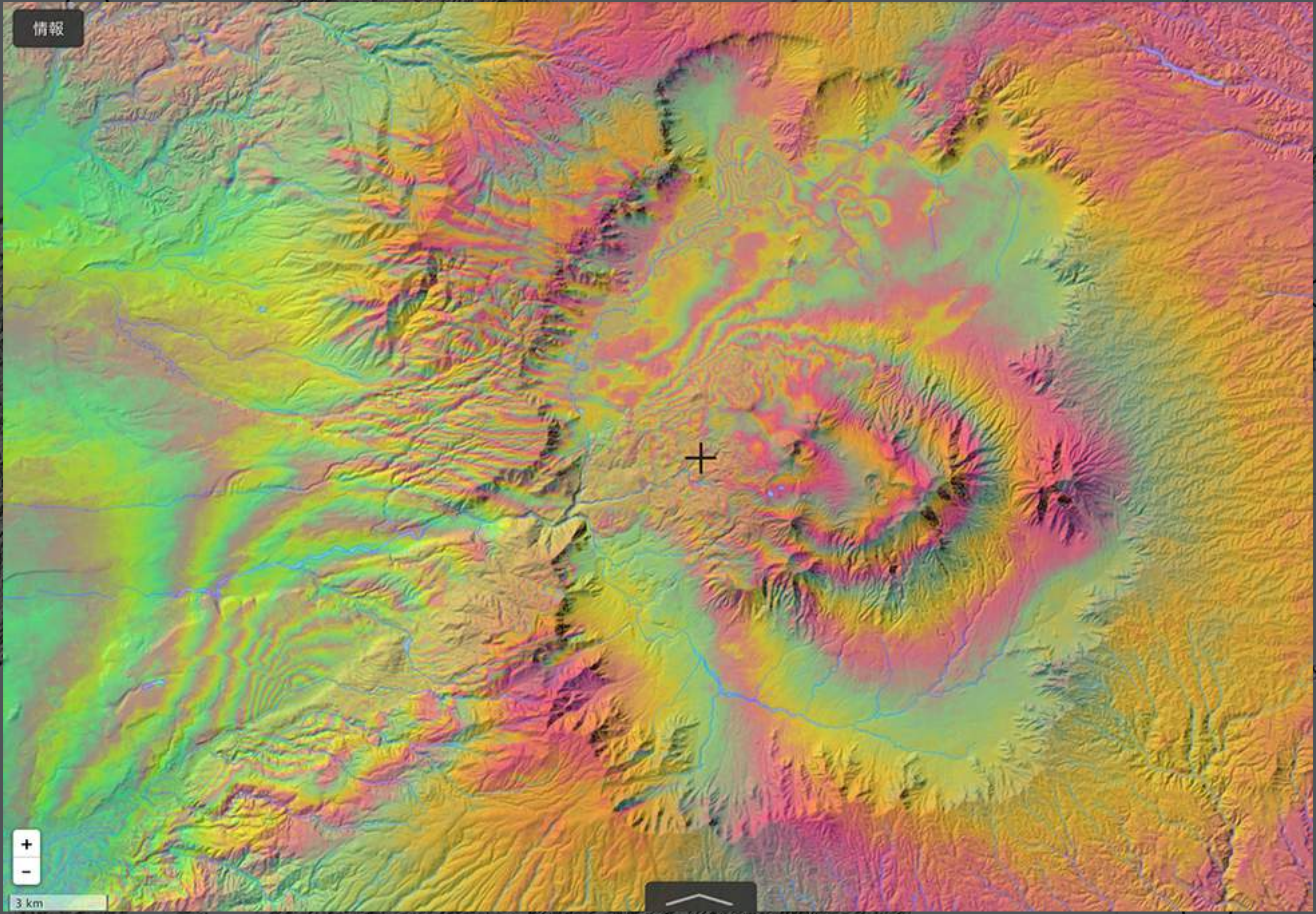

130°36'
130°42'
130°48'
130°54'
131°00'
131°06'
131°12'
33°00'
32°54'
32°48'
32°42'
32°36'
?
FUTAGAWA F.
HINAGU F.
Takano-Shirahata Section
April 16 ruptures
Previously mapped strand
Previously unknown strand



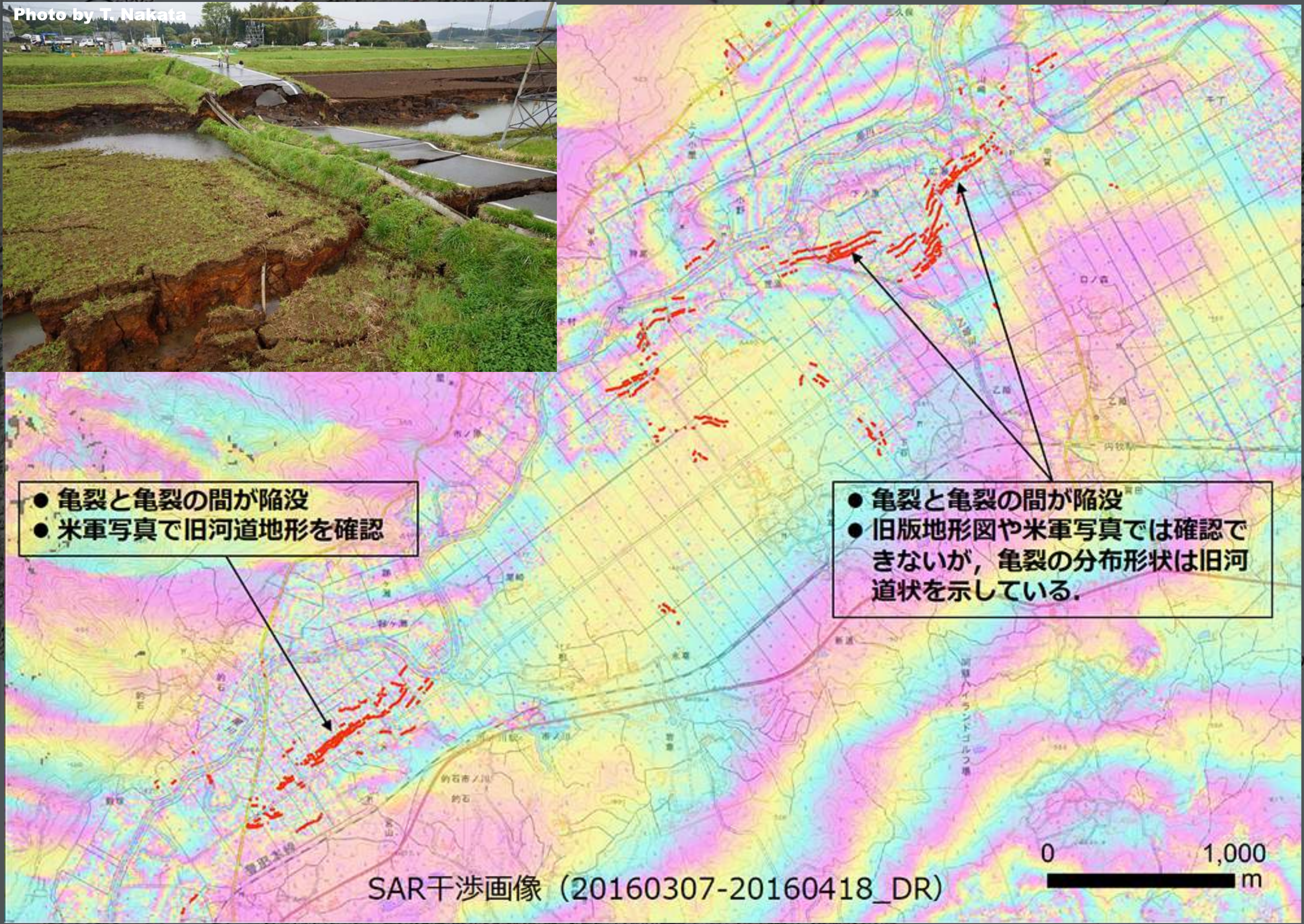
Previously unmapped fault across Aso caldera-rim.



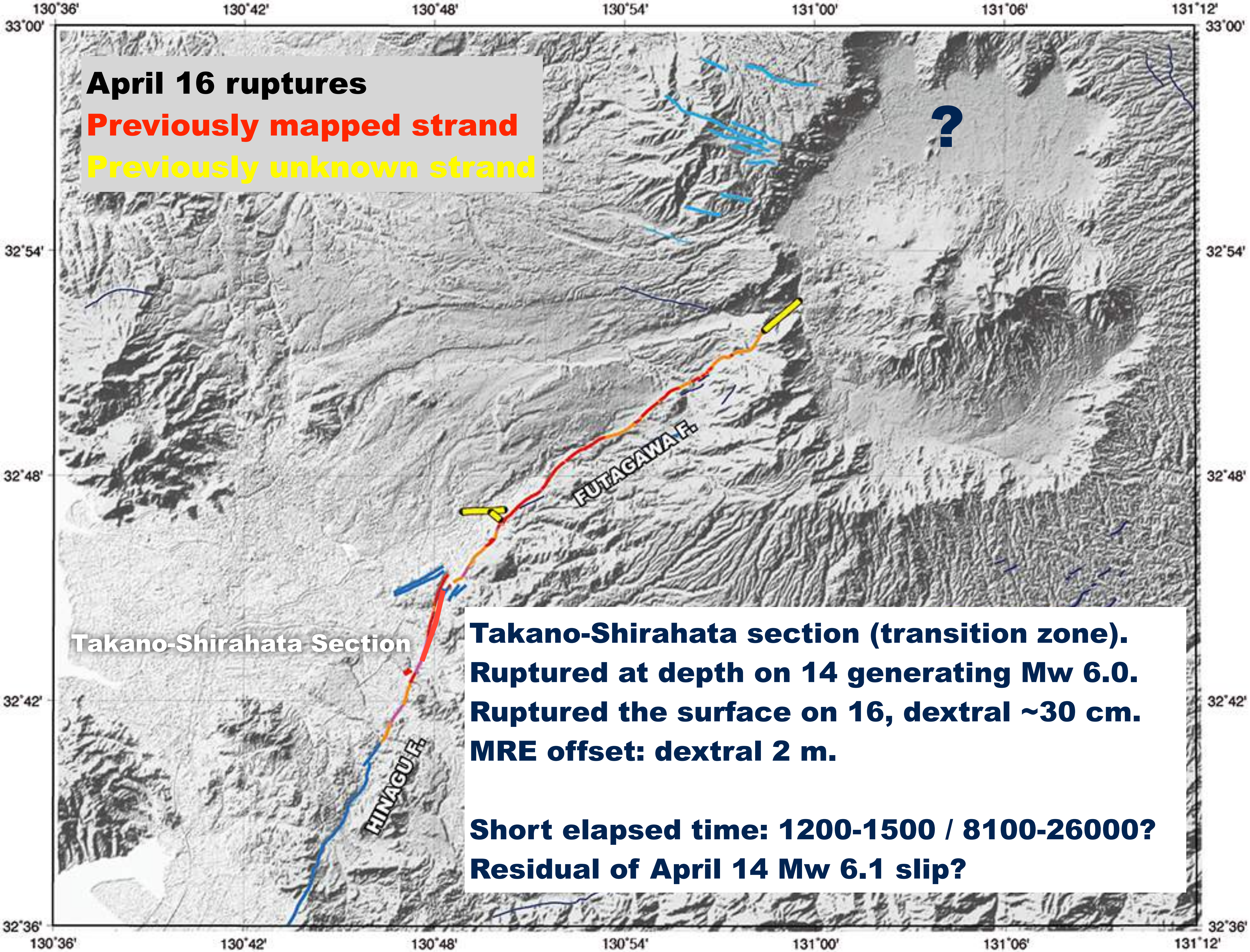
GSI, Kawayo surface rupture?



GSI ALOS-2 InSAR 15/APR/2015—18/APR/2016, subtle features



Preliminary and unpublished analyses by Nakano, GSI

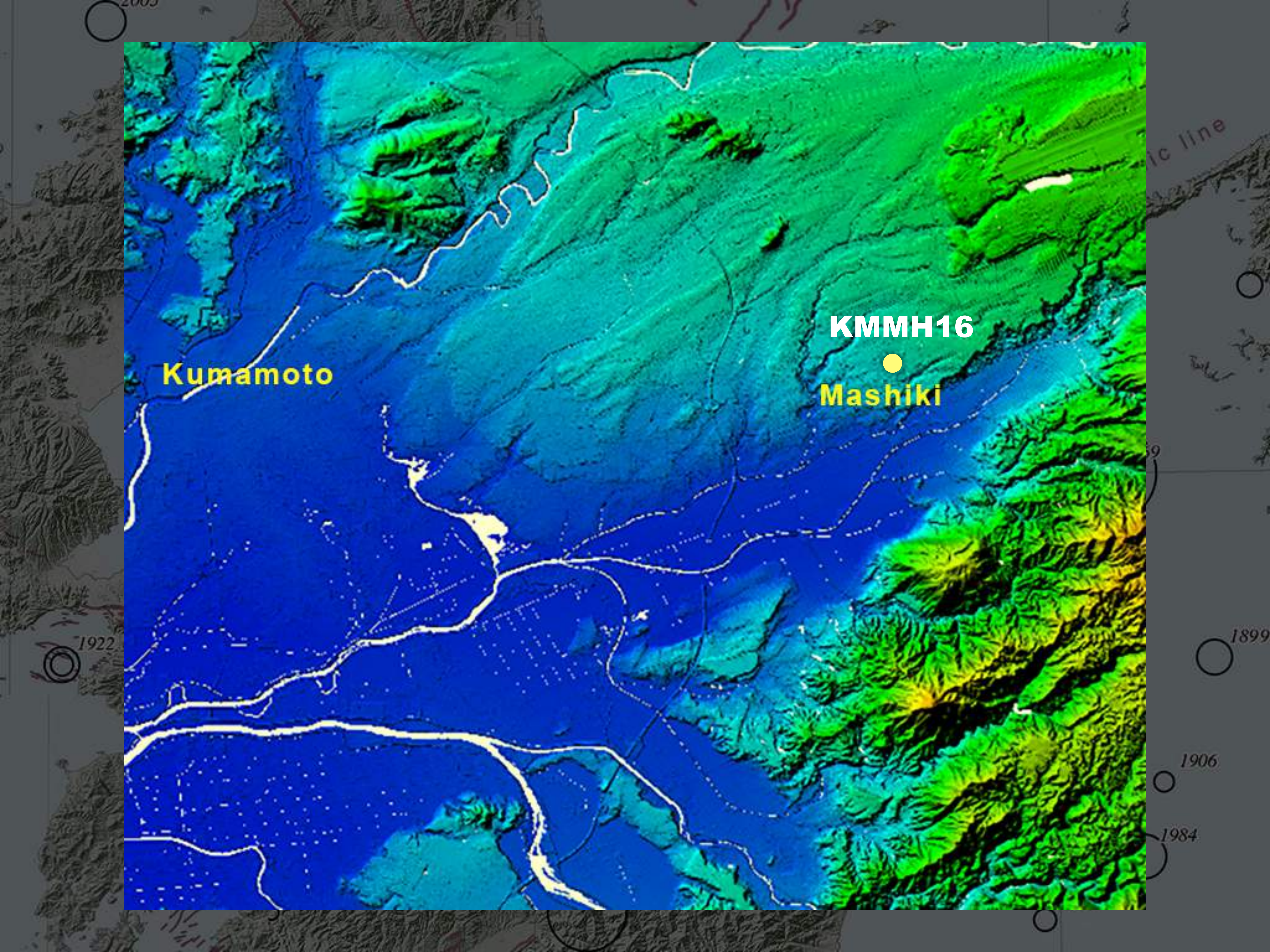


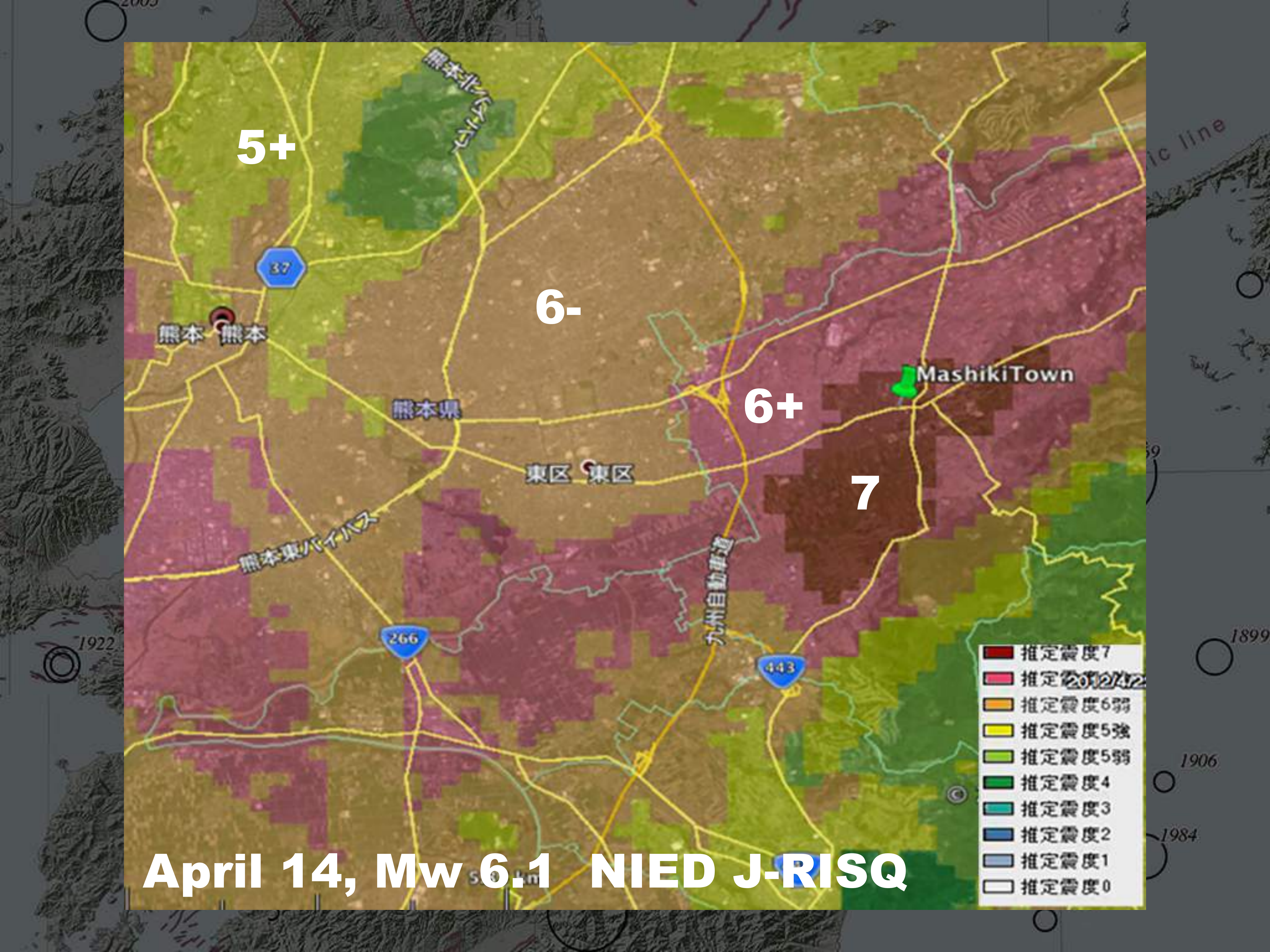
April 16 ruptures
Previously mapped strand
Previously unknown strand
?
FUTAGAWA F.
HINAGU F.
Takano-Shirahata Section
Takano-Shirahata section (transition zone).
Ruptured at depth on 14 generating Mw 6.0.
Ruptured the surface on 16, dextral ~30 cm.
MRE offset: dextral 2 m.
Short elapsed time: 1200-1500 / 8100-26000?
Residual of April 14 Mw 6.1 slip?
130°36'
130°42'
130°48'
130°54'
131°00'
131°06'
131°12'
33°00'
32°54'
32°48'
32°42'
32°36'

6. Strong shaking at Mashiki

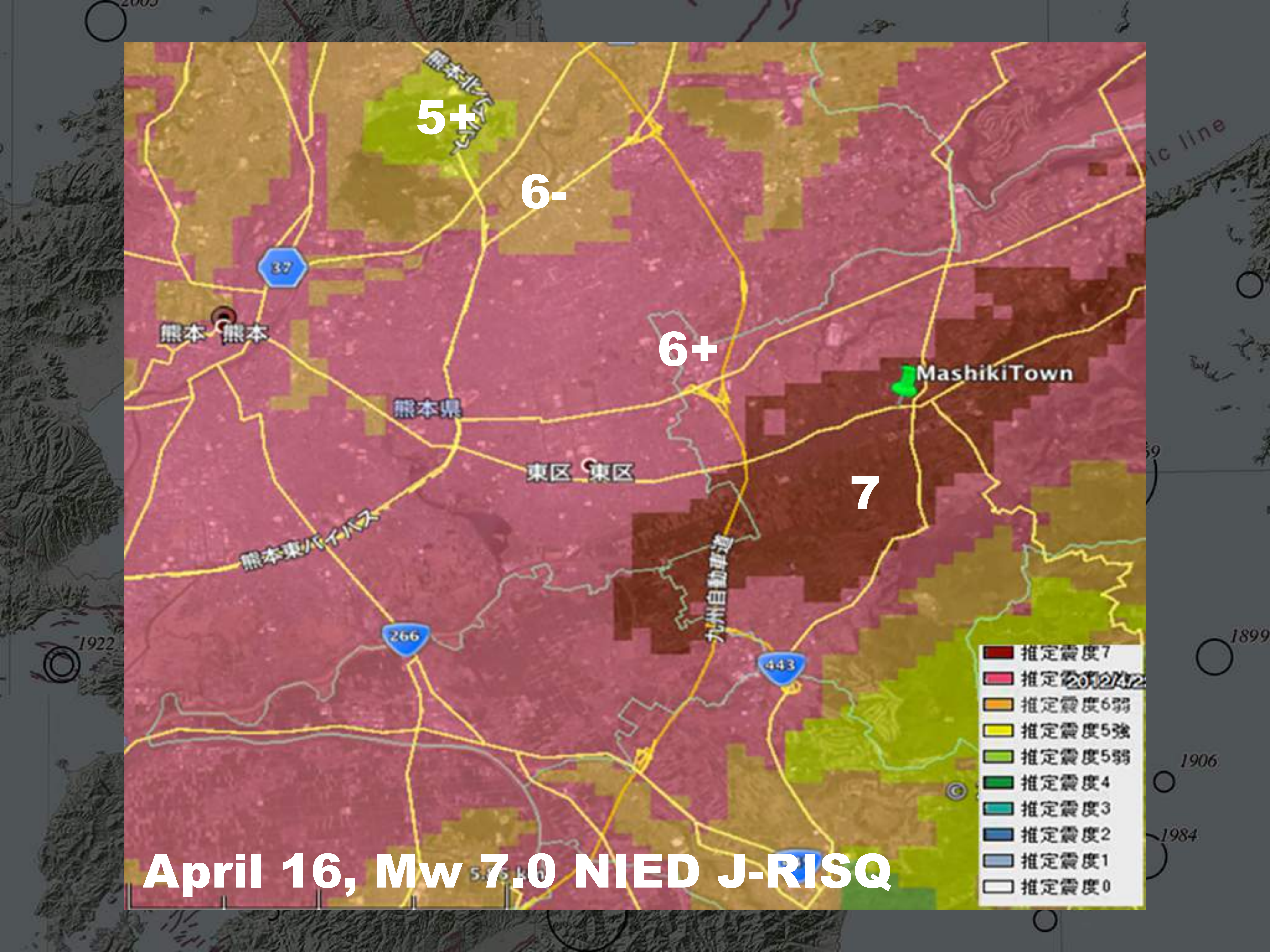
What are the causes of the severest damage:
forward directivity, radiation pattern, soil condition,
geologic setting, slope instability, or surface rupture?????

JMA Intensity 7 during both Mw 6.1 and 7.0.

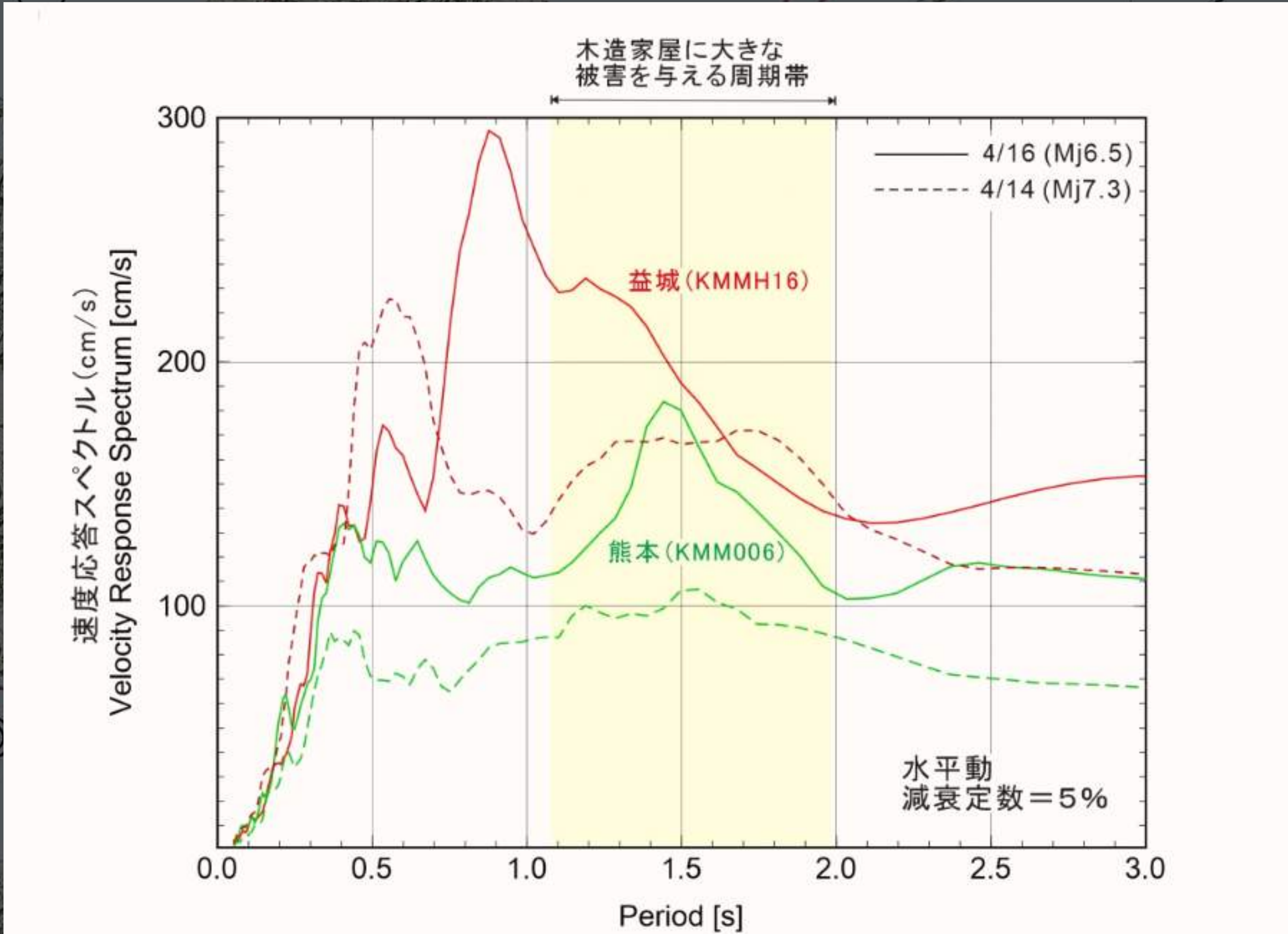

KMMH16
Kumamoto
Mashiki
1922
1899
1906
1984



April 14, Mw 6.1 NIED J-RISQ

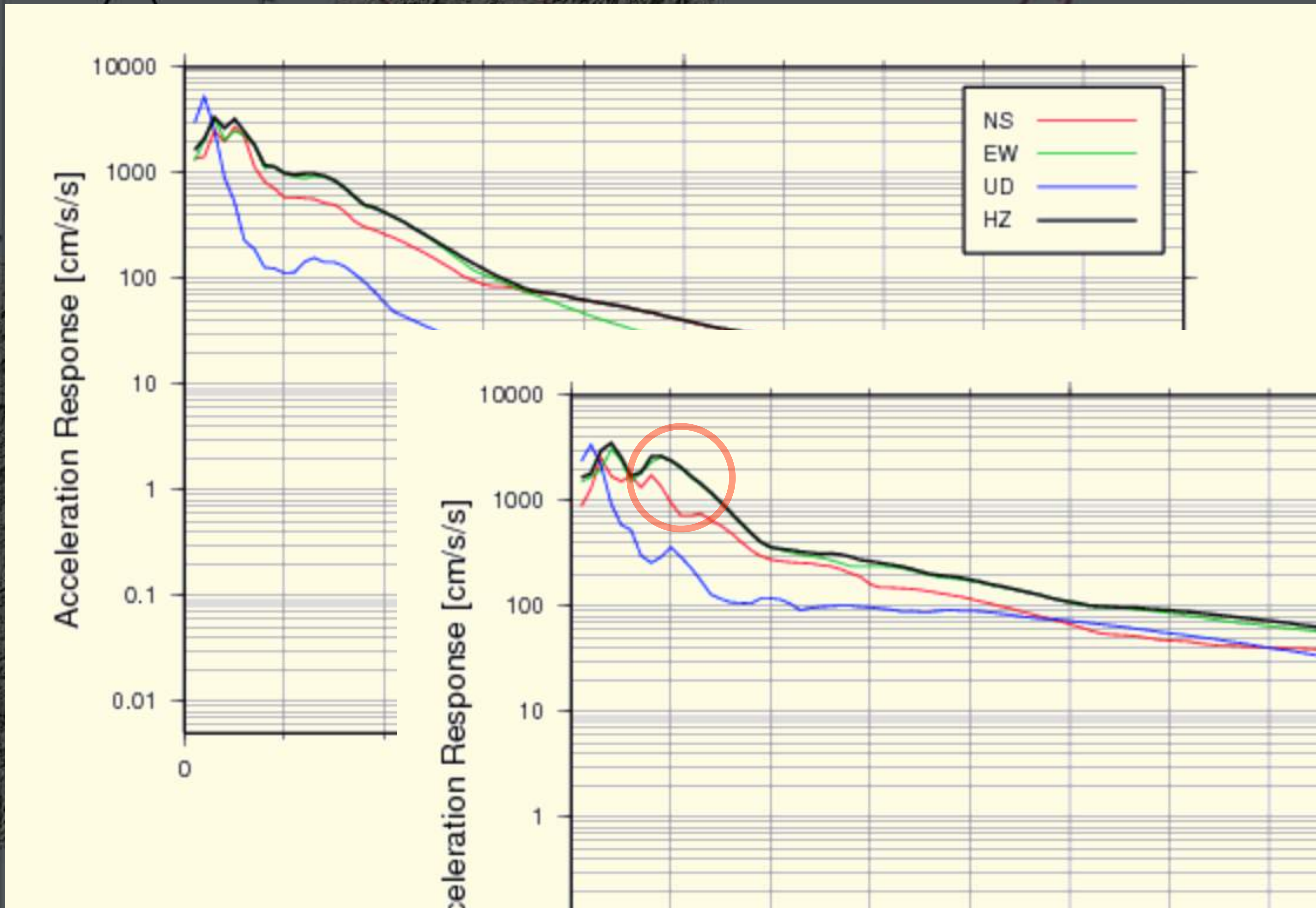


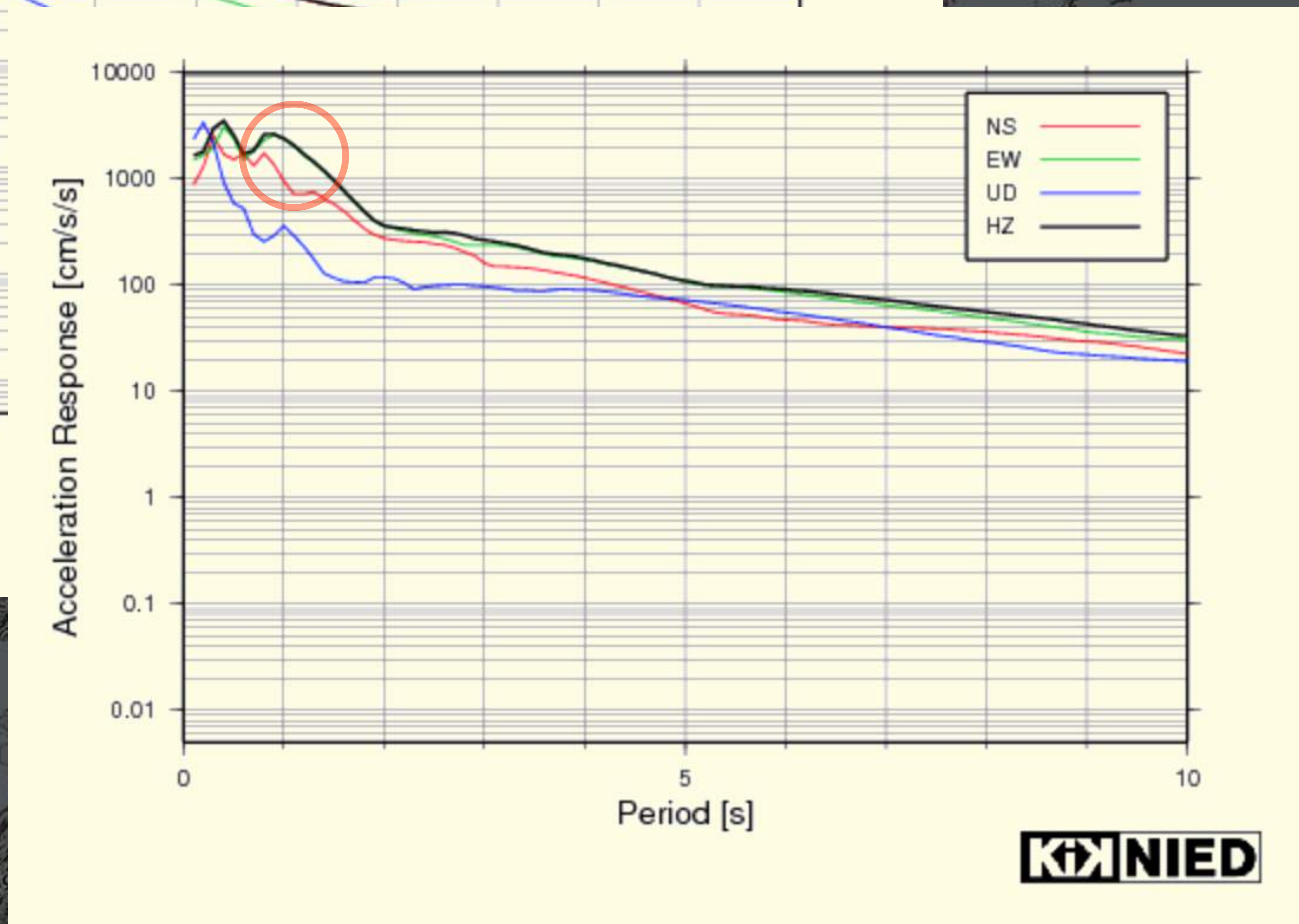
5+
6-
6+
7
MashikiTown
熊本
熊本
熊本県
東区
東区
熊本東バイパス
九州自動車道
37
266
443
推定震度7
推定震度6弱
推定震度5強
推定震度5弱
推定震度4
推定震度3
推定震度2
推定震度1
推定震度0
1922
1899
1906
1984
April 16, Mw 7.0 NIED J-RISQ



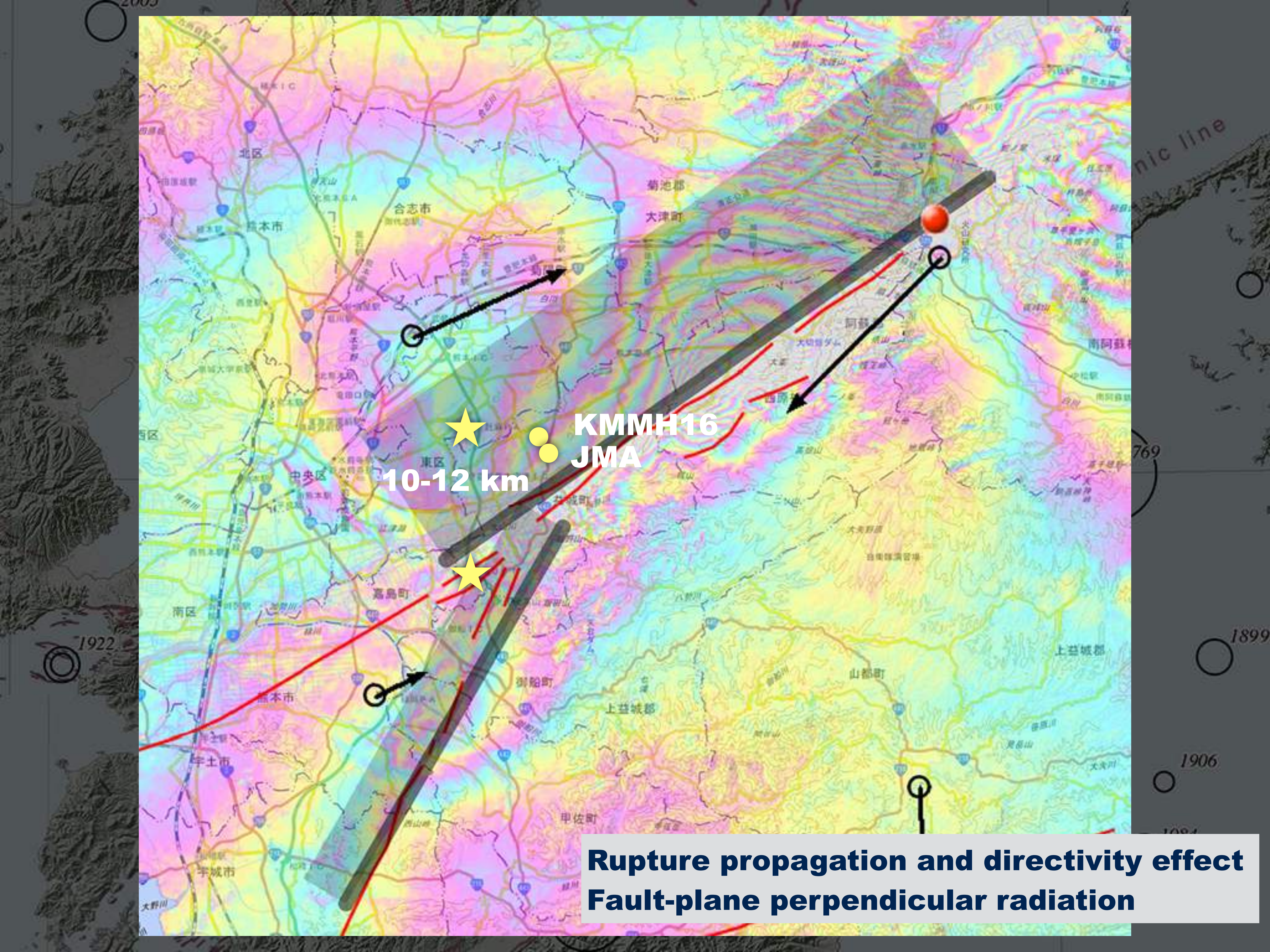
Velocity Response Spectrum by Furumura, ERI

Mashiki
KMMH16
foreshock
Total 1.61g

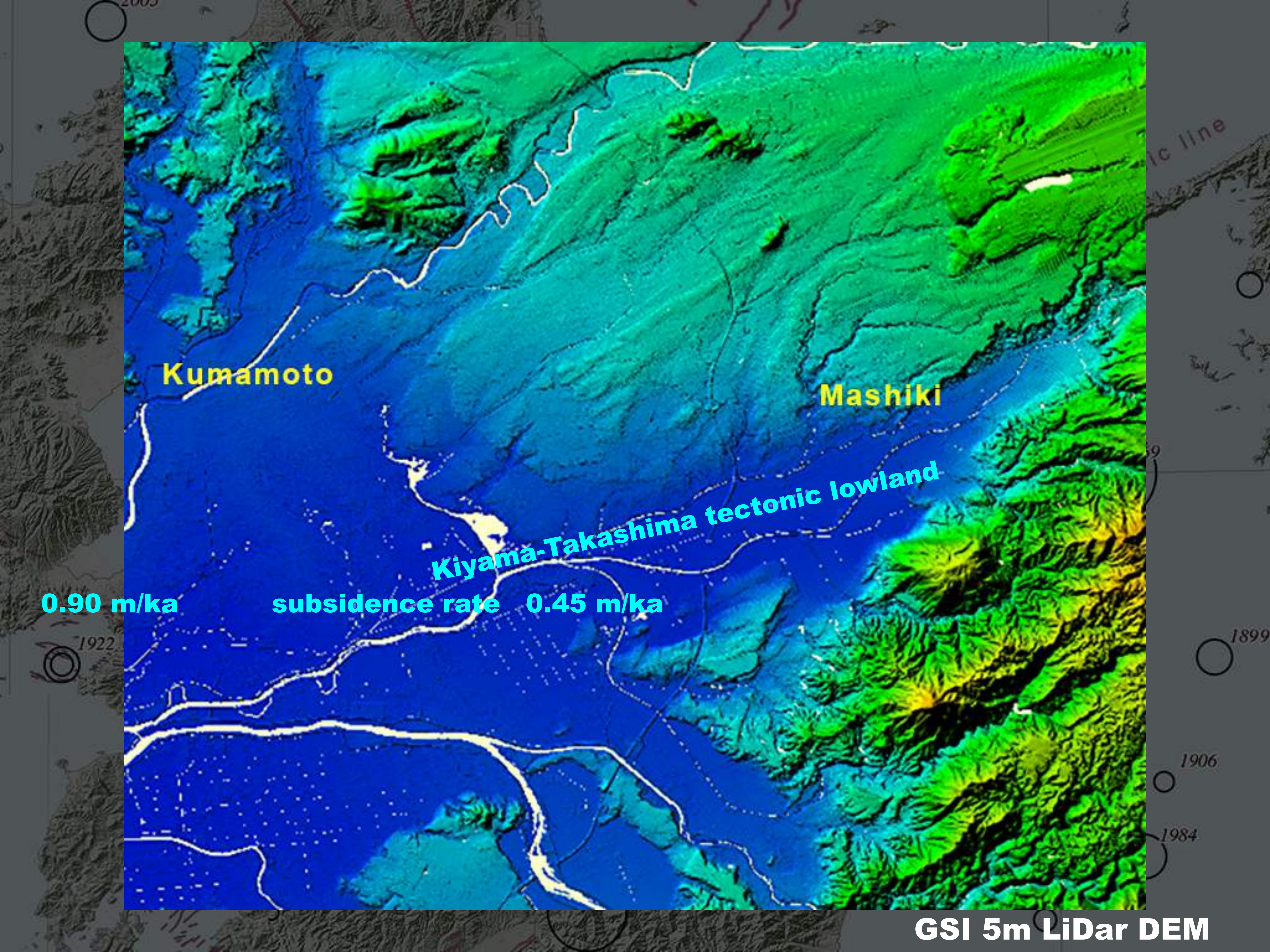




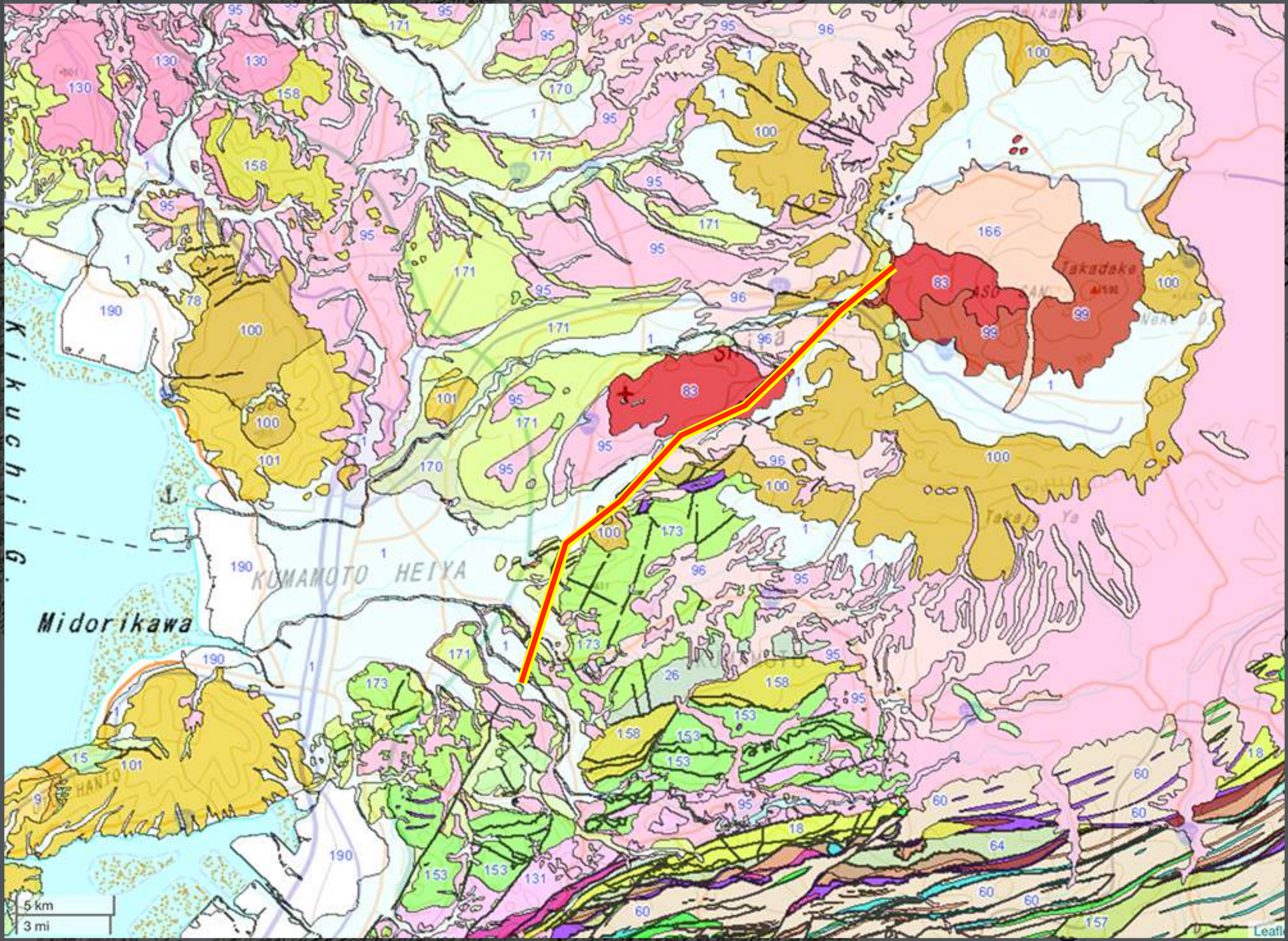
Mashiki
KMMH16
Mainshock
Total 1.35g



Rupture propagation and directivity effect
Fault-plane perpendicular radiation



Kumamoto
Mashiki
Kiyama-Takashima tectonic lowland
0.90 m/ka
subsidence rate
0.45 m/ka
1922
1899
1906
1984
GSI 5m LiDar DEM



Midorikawa
KUMAMOTO HEIYA
Takadake
5 km
3 mi

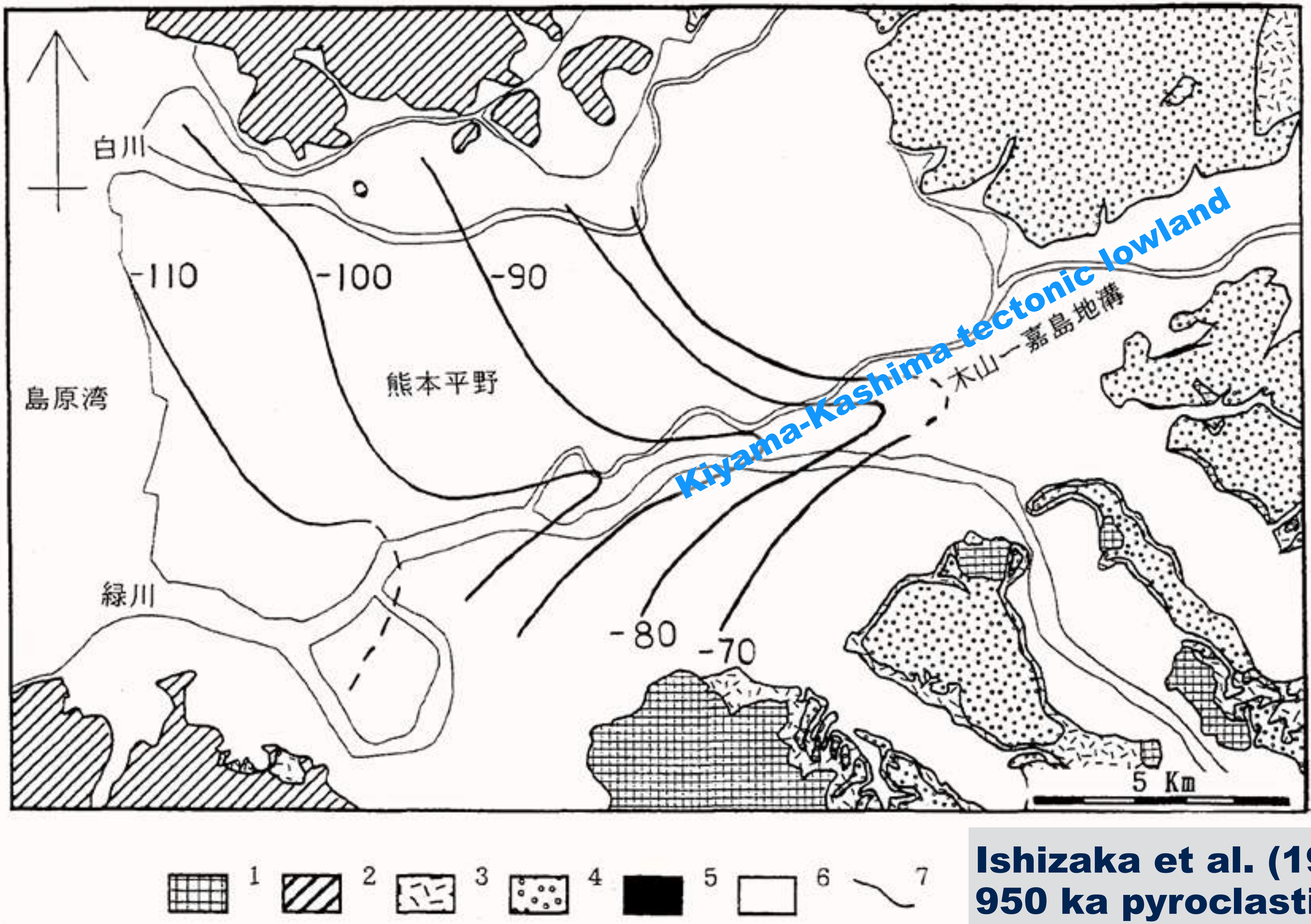
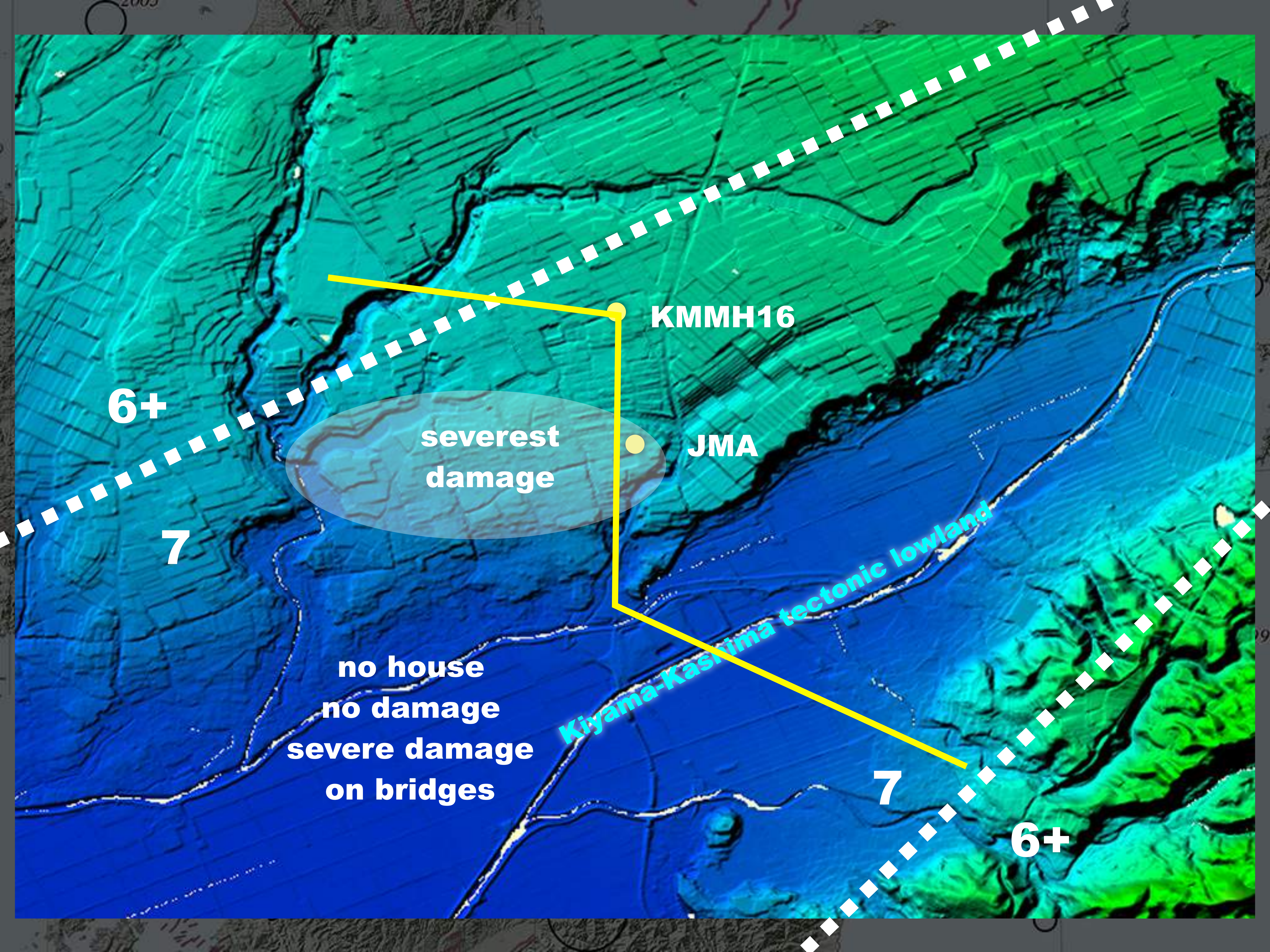
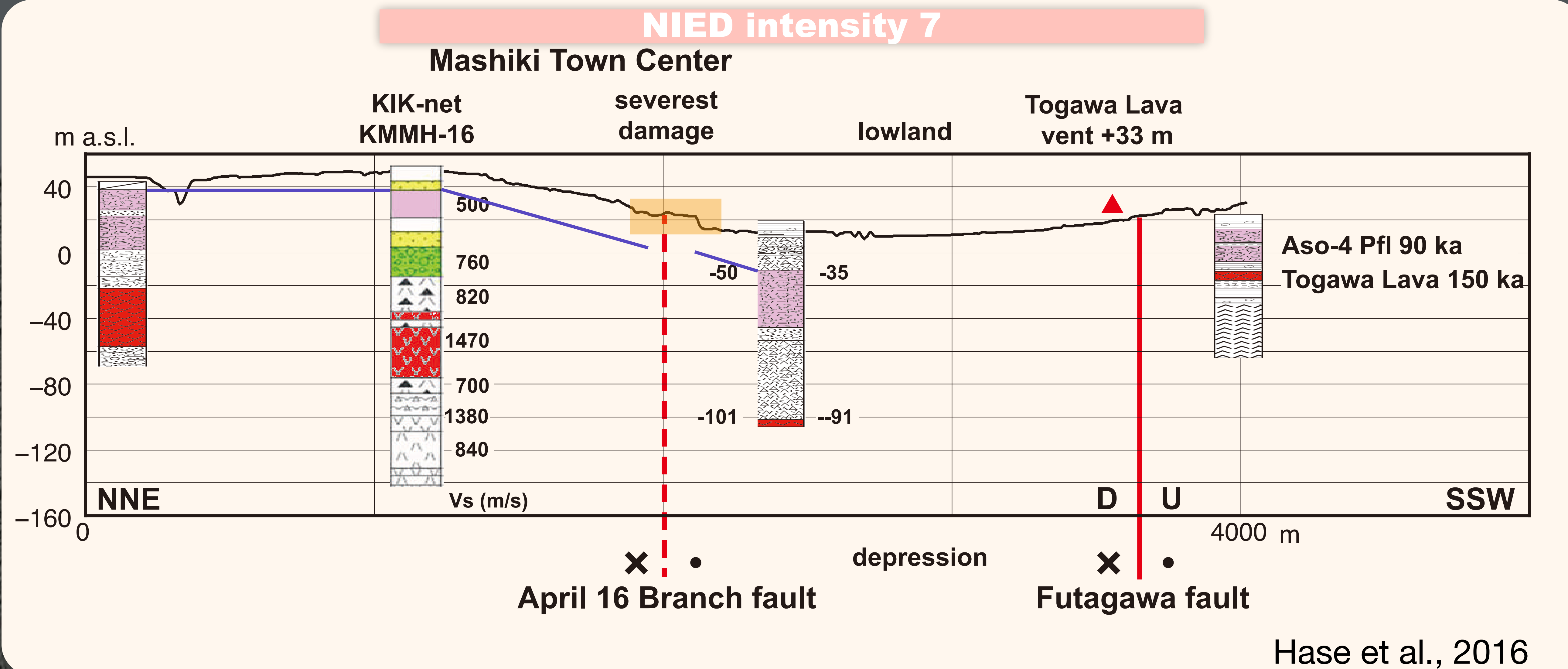


図 4　御幸層中部上面等高線図

1. 御船層群　2. 安山岩類　3. 火砕流堆積物　4. 砂礫層
5. 砥川溶岩　6. 沖積層　7. 御幸層中部上面等高線

Ishizaka et al. (1995) 950 ka pyroclastic flows under alluvial plain of Kumamoto.


KMMH16
6+
severest
damage
JMA
7
Kiyama-Kashima tectonic lowland
no house
no damage
severe damage
on bridges
7
6+



tilted surface

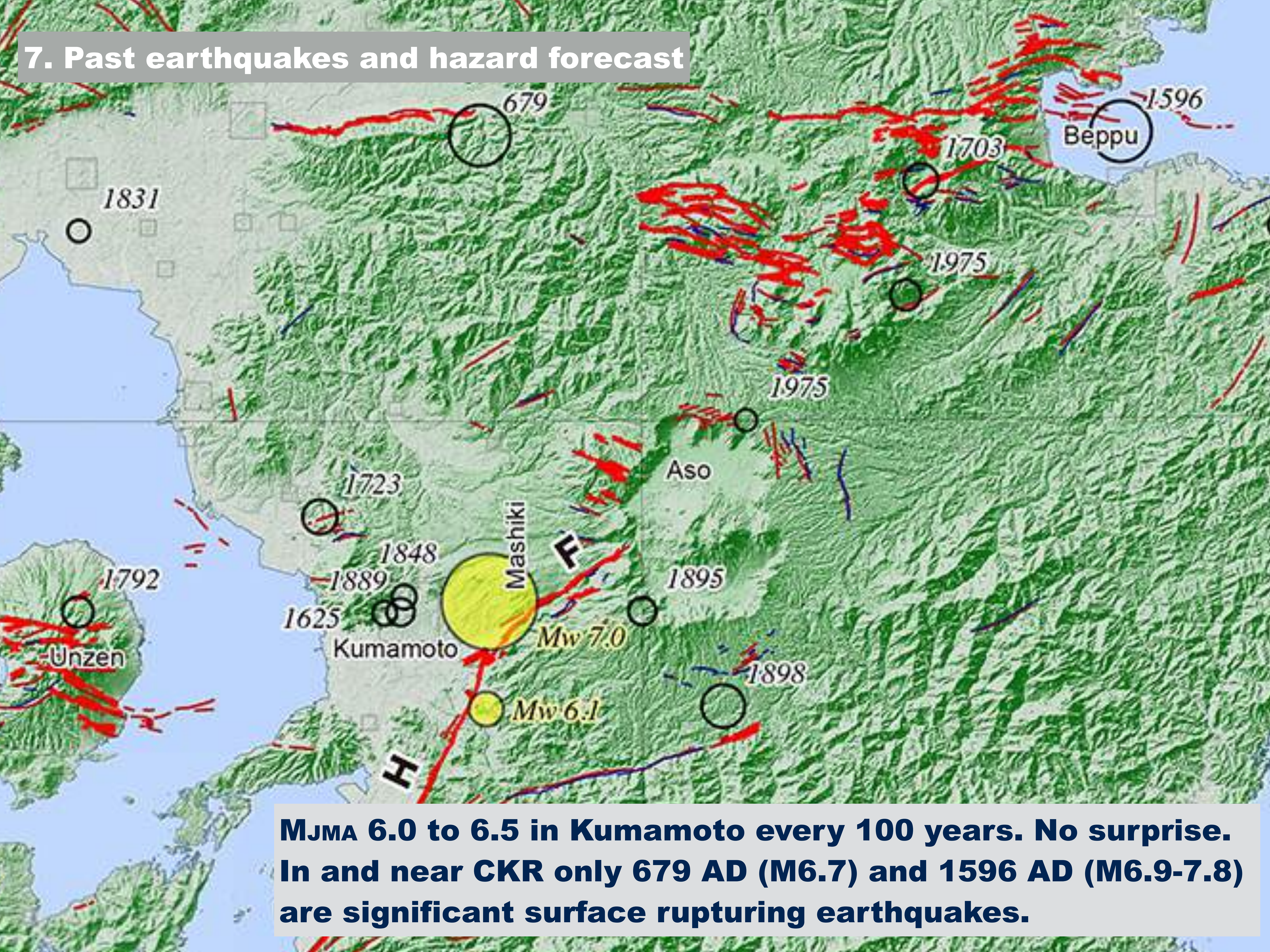
50 m drop in 90 ka

flexure?

blind normal fault?

Amplified ground motion by
- soft sediments in depression
- shallow anticline/syncline
- juxtaposition of soft and hard rocks

7. Past earthquakes and hazard forecast



M_{JMA} 6.0 to 6.5 in Kumamoto every 100 years. No surprise. In and near CKR only 679 AD (M6.7) and 1596 AD (M6.9-7.8) are significant surface rupturing earthquakes.

8. Forecasted earthquakes from Futagawa-Hinagu fault zone by HERP (2002 and 2013)

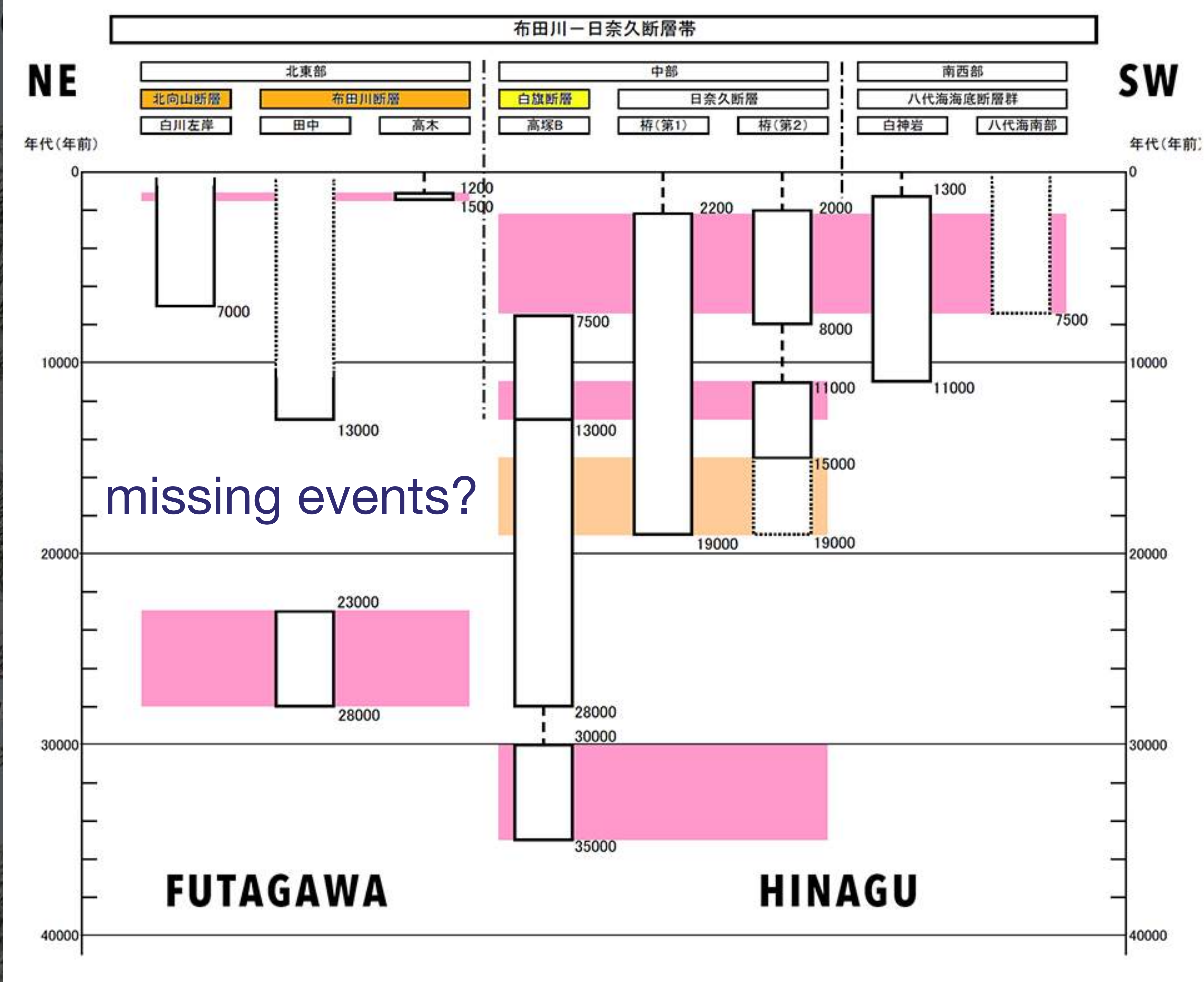
Futagawa forecast : M 7.0, 2 m RL offset, & 21 km ruptures.

Actual: M 7.3, 2.2 m RL offset, and 28 + 6 km ruptures.

Hinagu forecast: M 6.8, , 2 m, 16 km on the northernmost segment

Actual: Mw 6.1 ruptured deeper part for ~12 km.

Mw 7.0 ruptured to the surface, 30 cm, 6 km.



Headquarter for Earthquake Research Promotion, 2002 &2013

8. Conditional probability of ‘characteristic’ earthquake

30 yr conditional probability : 0 to 0.9 % (rather high).
>> Low probability owing to long interval, large variance.

Two events at 1200 - 6900 BP and 23000 - 26000 BP
Recurrence interval: 8100 to 26000 years.
There are missing events in geologic records.
No record from the main part of the Futagawa fault.

Temporal clustering is another way of explanation.

8. Conditional probability of ‘characteristic’ earthquake

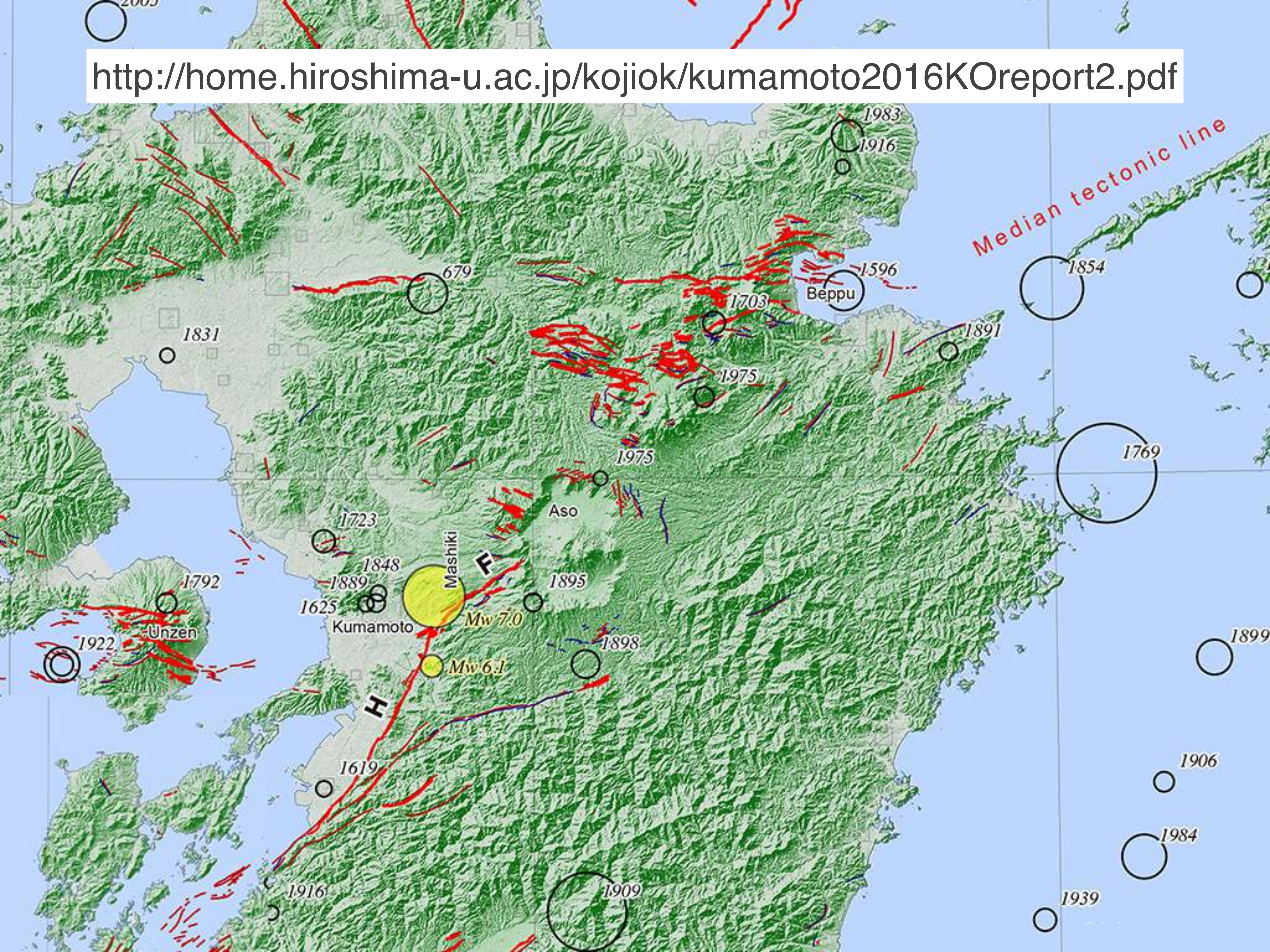
Insufficient data for reliable forecast on Futagawa fault.

Low probability does not mean the event would not occur.

Limitation of the long-term hazard forecast was obvious.

However, the public are not informed of the limitation.

The local governments were informed of the risks form the Futagawa-Hinagu fault zone, but local http://home.hiroshima-u.ac.jp/kojiok/kumamoto2016KOreport2.pdf




2005
1983
1916
Median tectonic line
679
1596
1854
Beppu
1703
1831
1891
1975
1975
1769
Aso
1723
Mashiki
F
1848
1792
1889
1895
1625
Kumamoto
Mw 7.0
Unzen
1922
1898
1899
Mw 6.1
H
1906
1619
1984
1916
1909
1939