



平成28年熊本地震

KUMAMOTO EARTHQUAKE (review)

Miroslav Hallo¹
「ミロ斯拉ヴ ハロー」

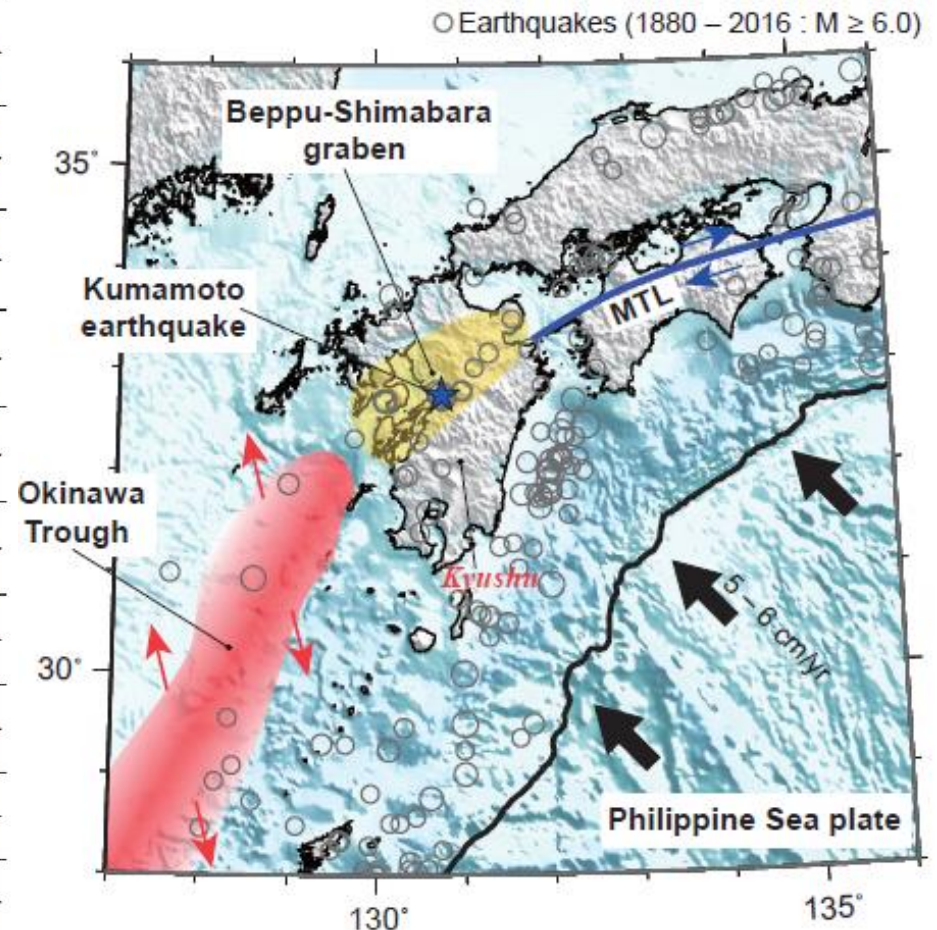
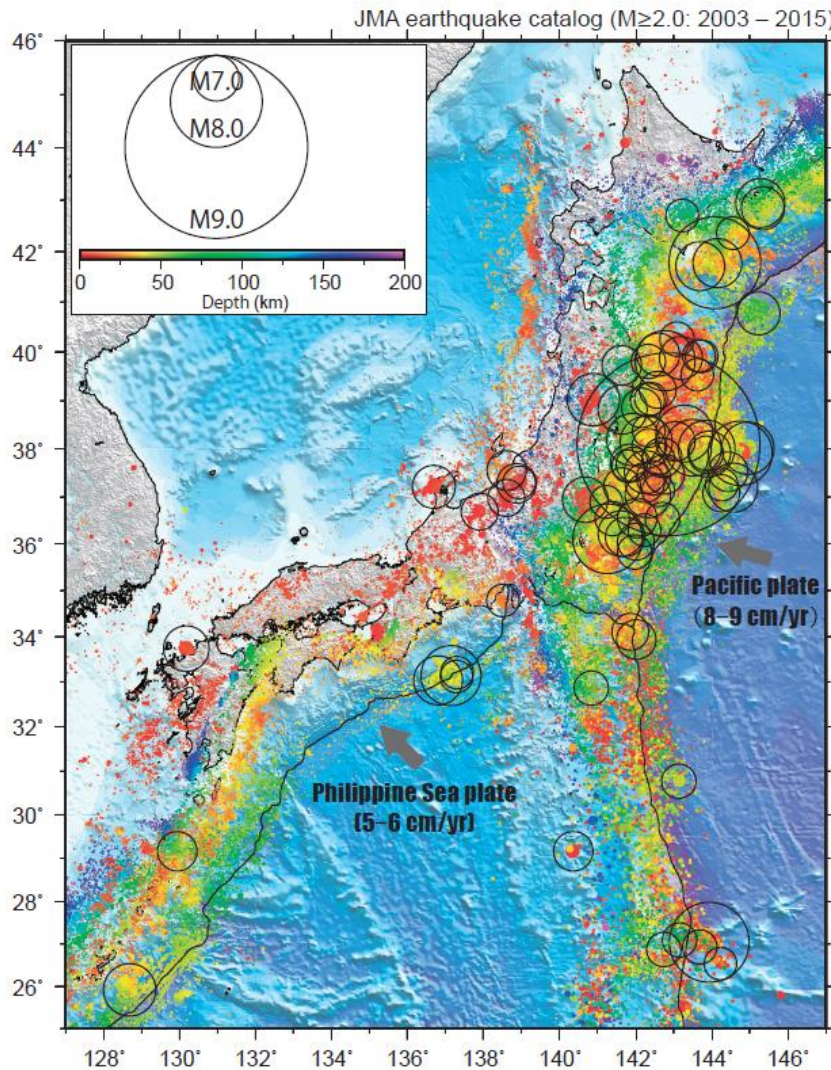
¹ Charles University, Faculty of Mathematics and Physics, Czech Republic,
「チェコ」

Overview

- Shallow earthquake sequence in central Kyushu
- M_{JMA} 6.5 foreshock on April 14th 2016
- M_{JMA} 7.3 mainshock on April 16th 2016
- Maximum intensity 7 during both shocks
- 49 killed, 1 missing, and cca 1000 wounded people
- Long zone of surface ruptures

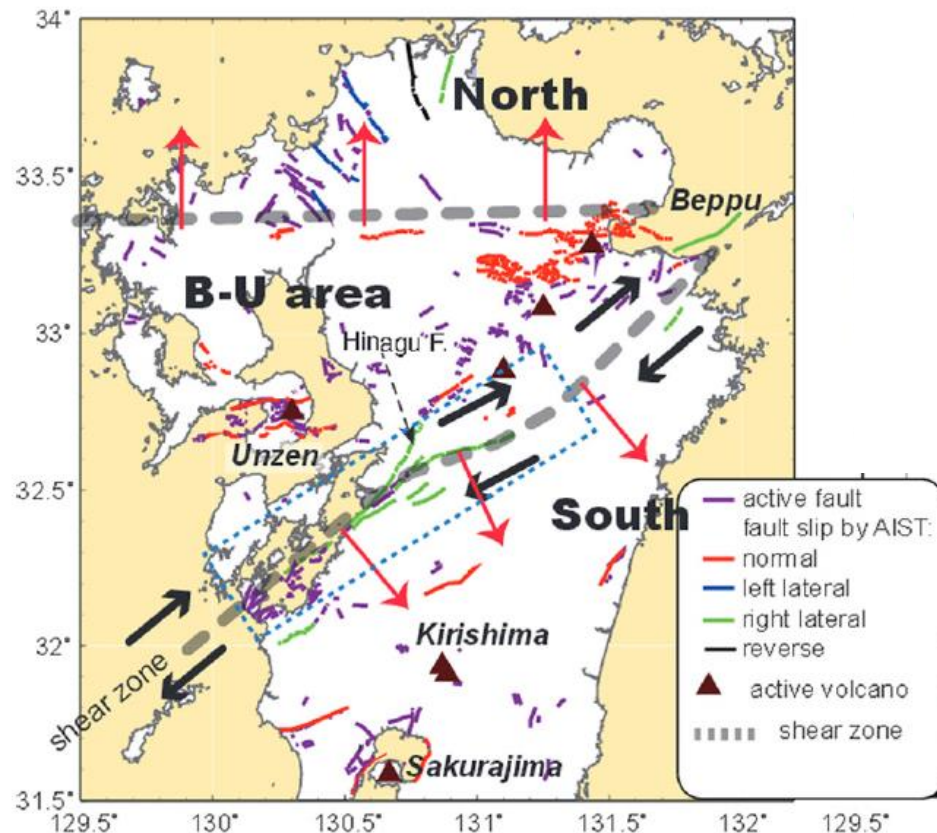
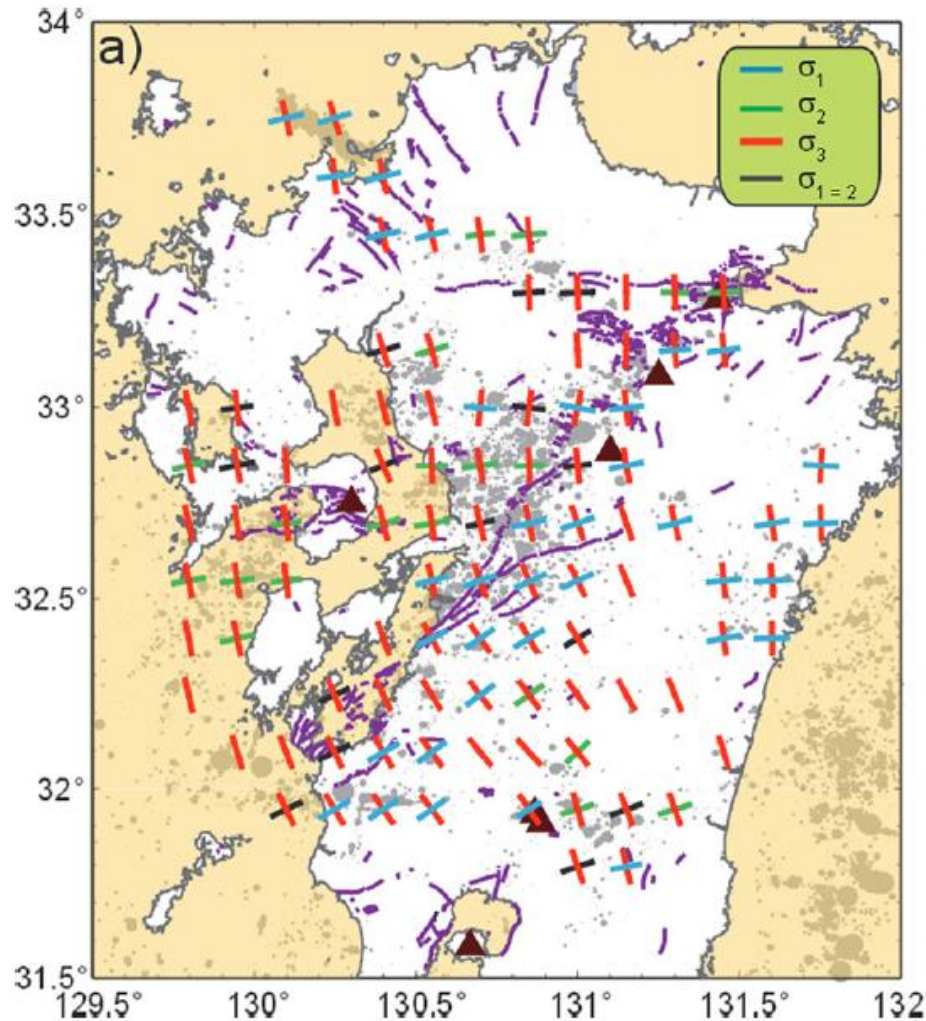


Tectonics and geologic setting



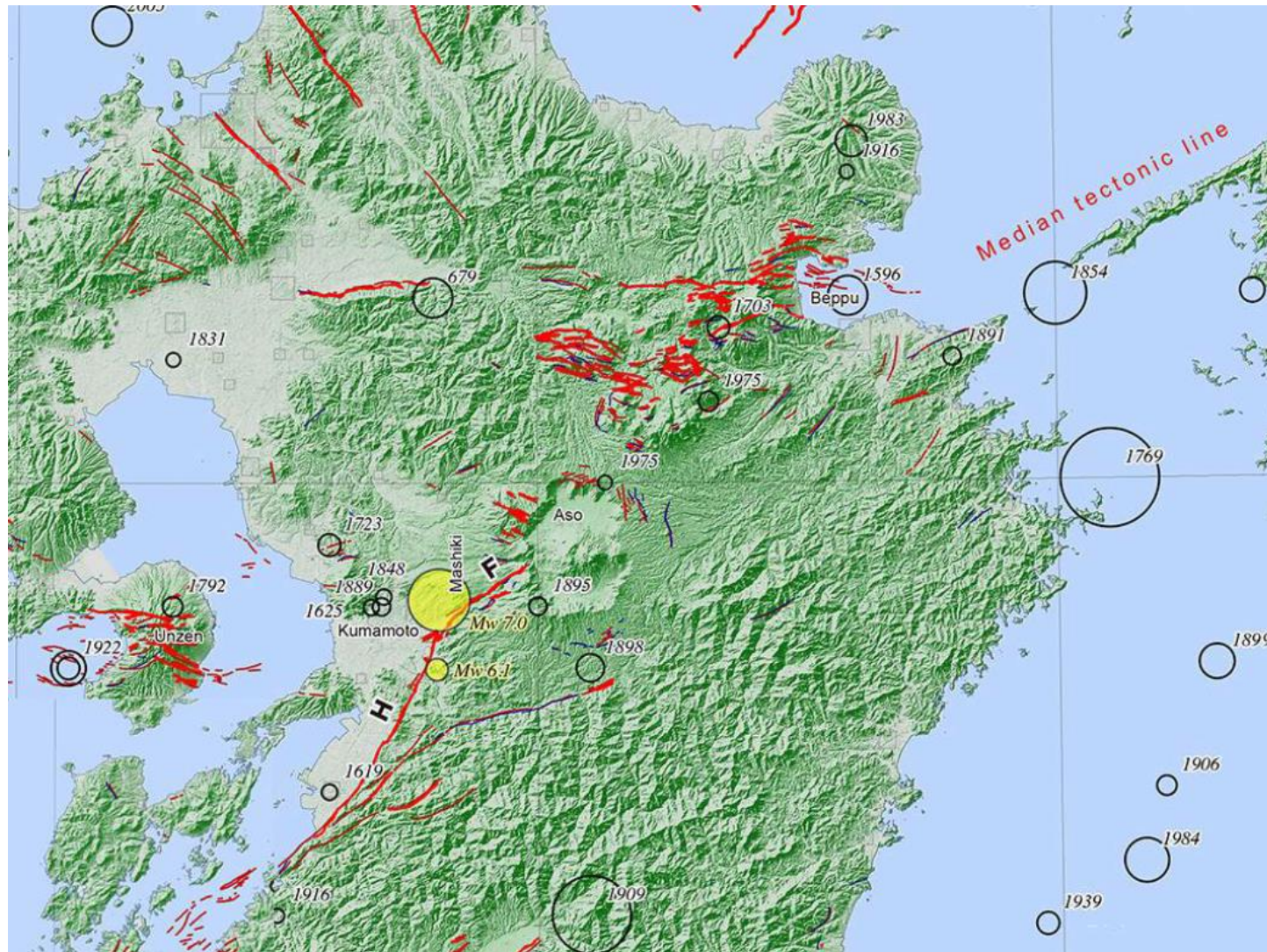
- Figures from: Kato, A., Nakamura, K., Hiyama, Y., (2016): The 2016 Kumamoto earthquake sequence, *Proc. Jpn. Acad., Ser. B* 92.

Tectonics and geologic setting



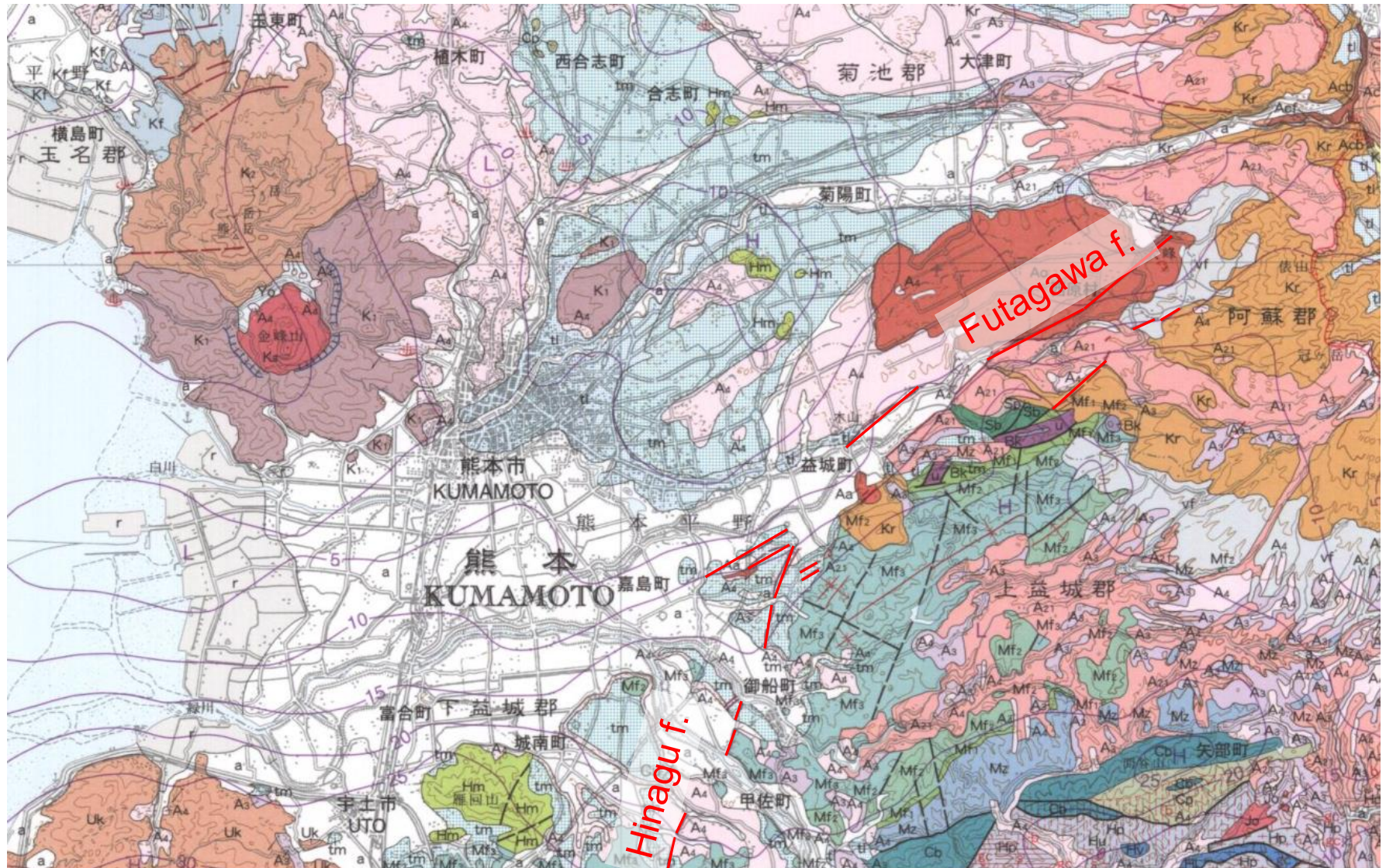
- Figures from: Matsumoto, S., Nakao, S., Ohkura, T., Miyazaki, M., Shimizu, H., Abe, Y., Inoue, H., Nakamoto, M., Yoshikawa, S., Yamashita, Y., (2015): Spatial heterogeneities in tectonic stress in Kyushu, Japan and their relation to a major shear zone, *Earth, Planets and Space* 67:172.

Tectonics and geologic setting



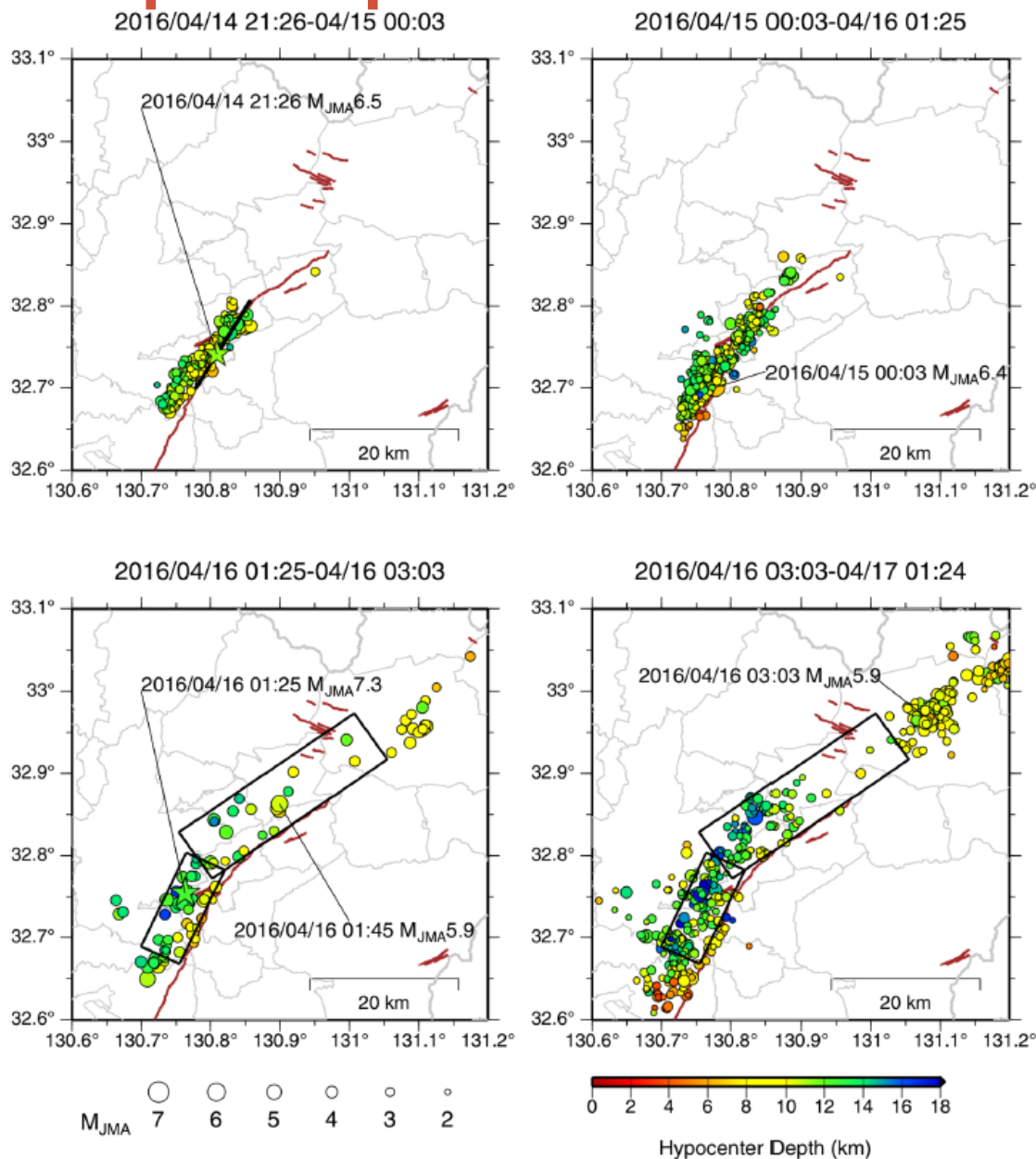
- Figure from: Okumura, K. (2016): Kumamoto earthquake: a complex earthquake sequence with large strike-slip ruptures, ONLINE: <http://home.hiroshima-u.ac.jp/kojiok/kumamoto2016KOreport2.pdf>

Tectonics and geologic setting



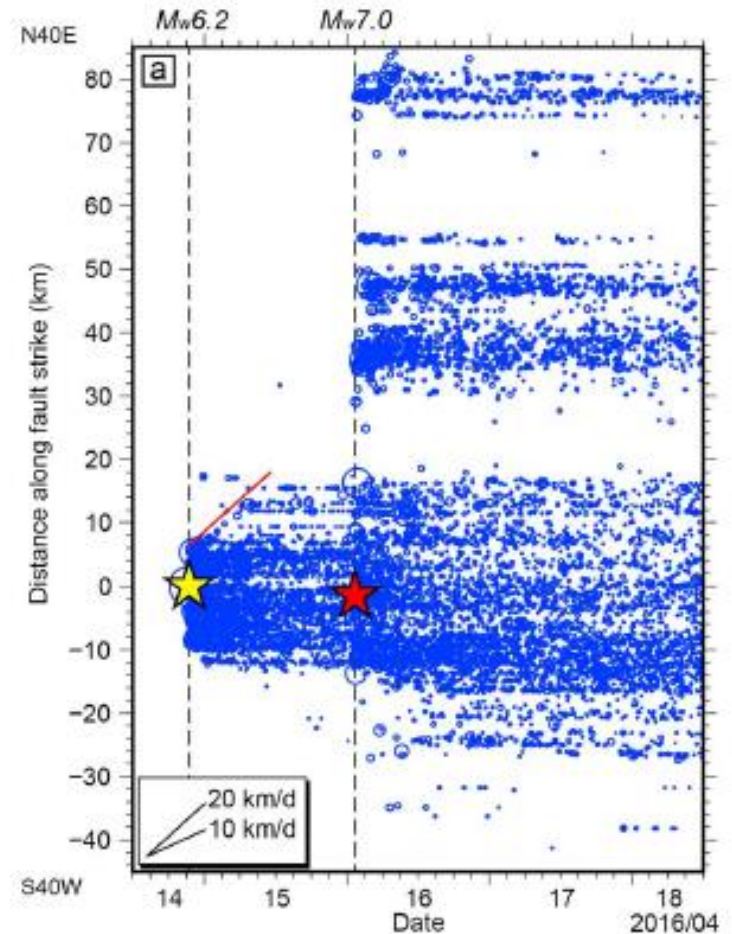
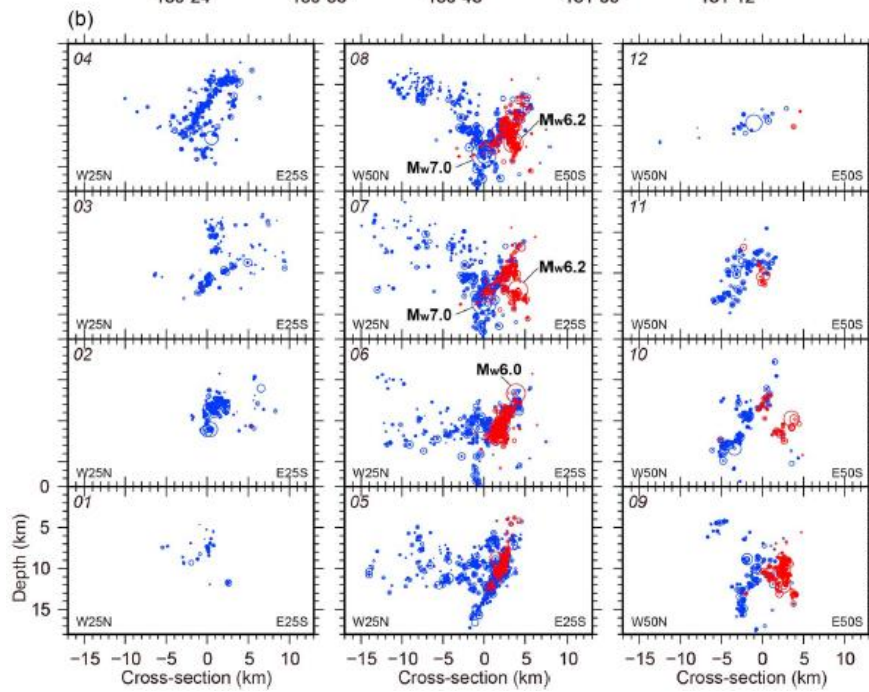
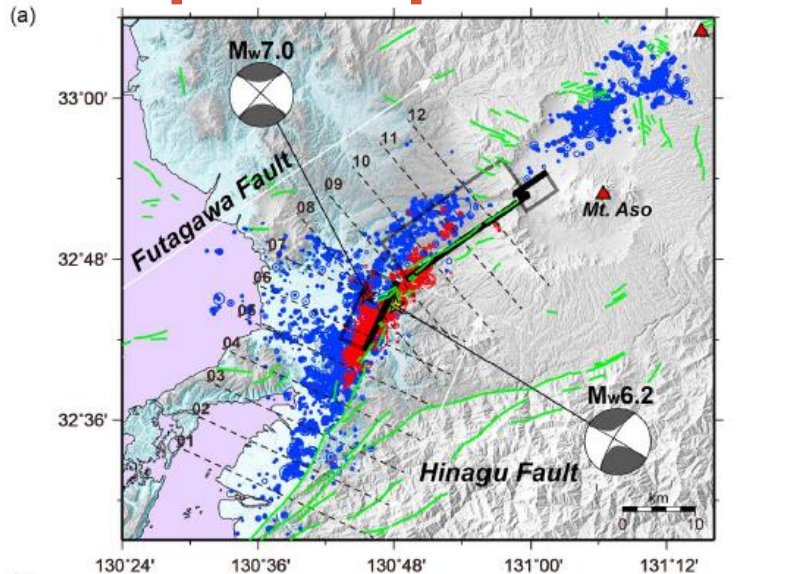
- Figure from: *Geological map of Japan 1:200,000, Kumamoto, Geological Survey of Japan, AIST.*

Temporal-spatial distribution of Kumamoto seq.



- Figure from: Asano, K., Iwata, T. (2016): Source rupture processes of the foreshock and mainshock in the 2016 Kumamoto earthquake sequence estimated from the kinematic waveform inversion of strong motion data, *Earth, Planets and Space* 68:147.

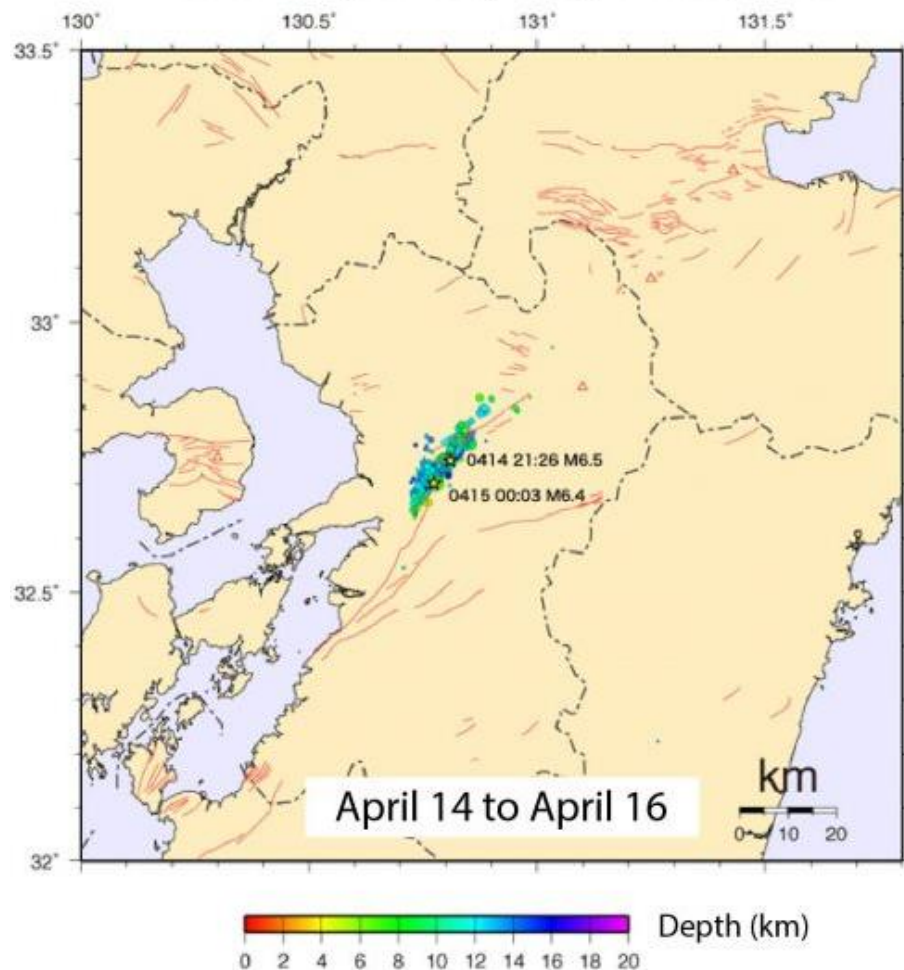
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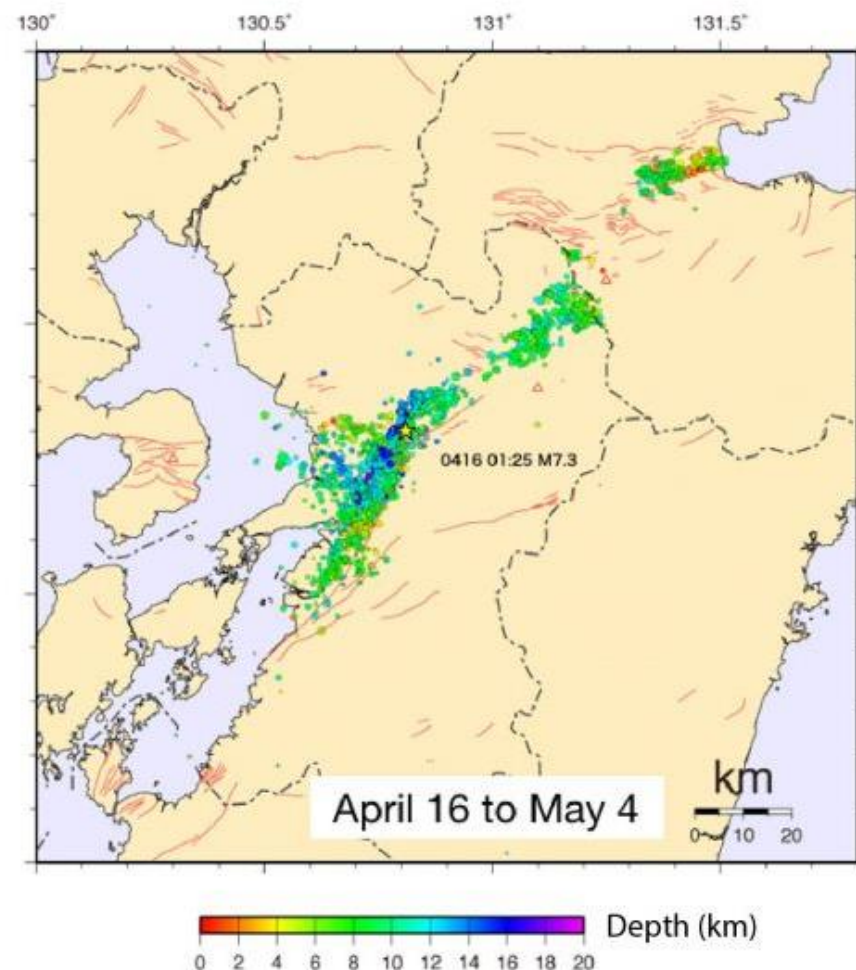
- Figures from: Kato, A., Fukuda, J., Nakagawa, S., Kazushige, O. (2016): *Foreshock migration preceding the 2016 Mw 7.0 Kumamoto earthquake, Japan*, *Geophys. Res. Lett.*, 43, 8945-8953.

Temporal-spatial distribution of Kumamoto seq.

After April 14 (M6.5) earthquake
before April 16 (M7.3) earthquake



After April 16 (M7.3) earthquake



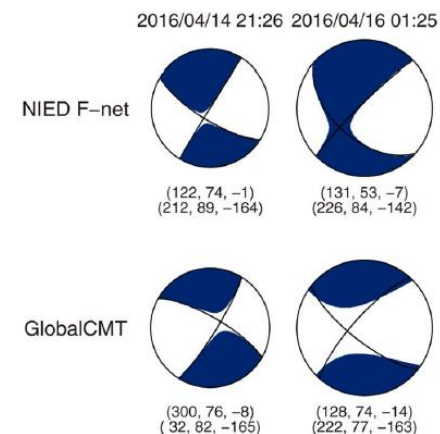
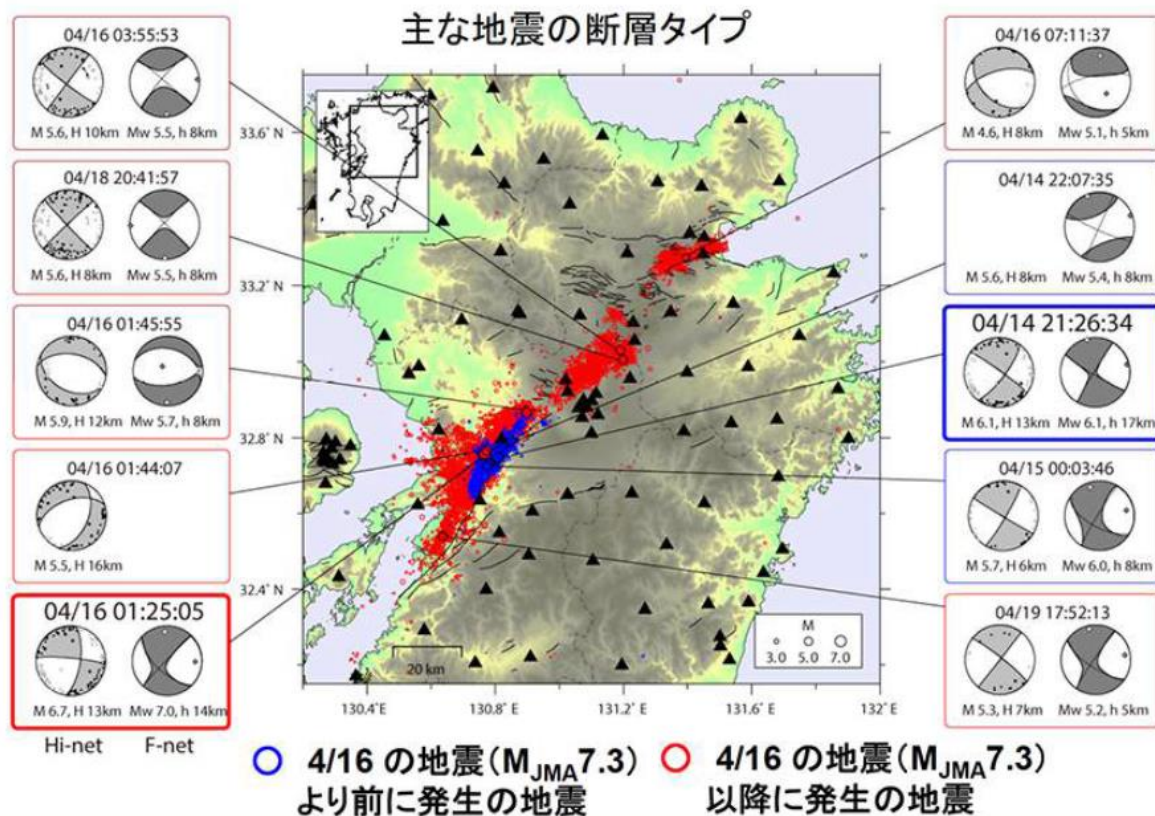
- Figure from: Stein, R., Toda, S., (2016): How a M=6 earthquake triggered a deadly M=7 in Japan, IRIDeS, Tohoku University, ONLINE: <http://temblor.net/earthquake-insights/how-a-m6-earthquake-triggered-a-deadly-m7-in-japan-1304/>.

Moment tensor solutions



震源域周辺およびその周辺における震源分布

田中・浅野



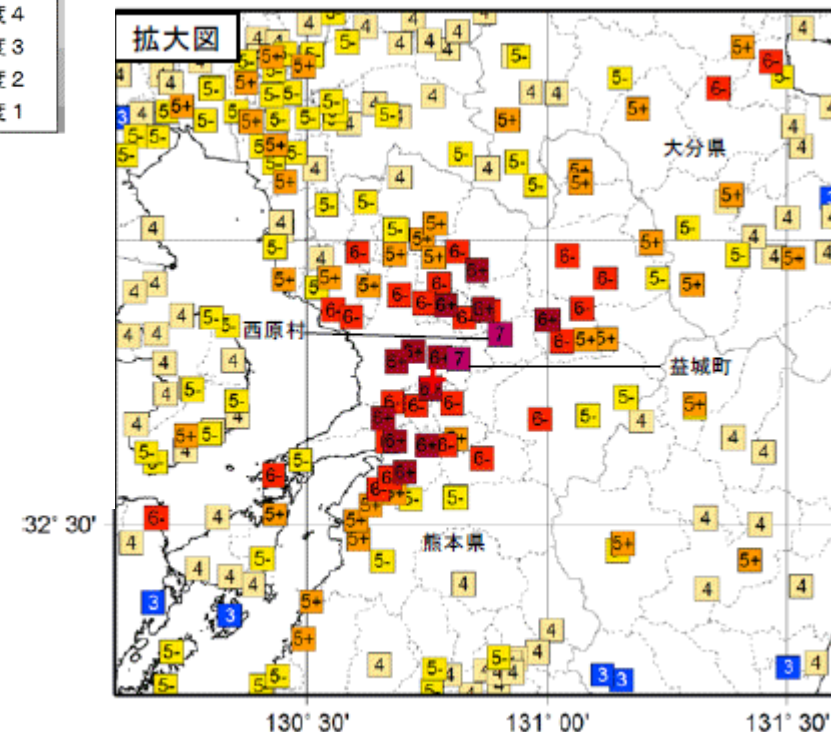
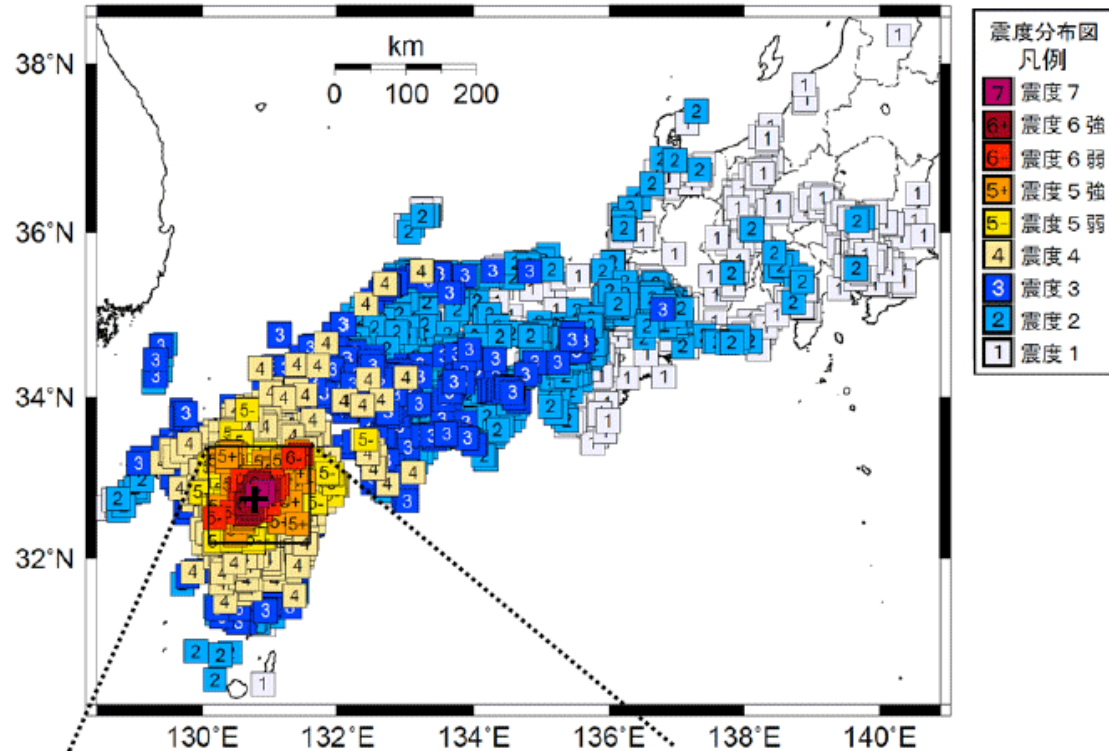
- Figure from: NIED (2016), Network center for Earthquake, Tsunami and Volcano.

- Figure from: Asano, K., Iwata, T. (2016): Source rupture processes of the foreshock and mainshock in the 2016 Kumamoto earthquake sequence estimated from the kinematic waveform inversion of strong motion data, *Earth, Planets and Space* 68:147.

Seismic intensity by mainshock M7.3

ア. 最大規模の地震の震度と加速度

最大規模の地震の震度分布図を図3-1に、計測震度及び最大加速度を表3-1に示す。



- Figure from: *The Headquarters for Earthquake Research Promotion ONLINE*:
<http://www.jishin.go.jp/main/index-e.html>.

Instrumental PGA by mainshock M7.3

都道府県	市区町村	観測点名	震度	計測震度	最大加速度 (gal=cm/s/s)				震央距離 (km)
					合成	南北成分	東西成分	上下成分	
熊本県	益城町	益城町宮園 *	7	6.7	899.1	775.5	825.4	668.5	6.4
熊本県	西原村	西原村小森 *	7	6.6	904.0	742.1	770.0	531.3	15.8
熊本県	菊池市	菊池市旭志 *	6強	6.4	977.4	799.2	857.4	535.8	22.7
熊本県	南阿蘇村	南阿蘇村河陽 *	6強	6.2	1316.3	1111.8	954.6	654.4	25.1
熊本県	宇土市	宇土市浦田町 *	6強	6.2	802.0	572.0	792.4	466.2	12.3
熊本県	嘉島町	嘉島町上島 *	6強	6.2	622.3	564.8	597.1	474.1	2.0
熊本県	合志市	合志市竹迫 *	6強	6.2	705.3	398.8	690.8	306.6	14.5
熊本県	大津町	大津町大津 *	6強	6.1	1791.3	1379.6	1740.1	594.7	16.8
熊本県	宇城市	宇城市豊野町 *	6強	6.1	751.7	573.4	575.1	724.7	13.2
熊本県	宇城市	宇城市松橋町 *	6強	6.0	564.1	492.8	342.6	313.9	14.2
熊本県	宇城市	宇城市小川町 *	6強	6.0	474.9	389.8	369.4	233.4	19.1
熊本県	熊本市中央区	熊本中央区大江 *	6強	6.0	656.9	626.8	478.2	403.4	6.3
熊本県	熊本市東区	熊本東区佐土原 *	6強	6.0	843.5	827.5	616.5	534.2	4.2
熊本県	熊本市西区	熊本西区春日	6強	6.0	677.5	606.0	551.6	405.3	7.5
熊本県	南阿蘇村	南阿蘇村中松	6弱	5.9	855.0	794.5	606.8	653.1	32.3
熊本県	美里町	熊本美里町馬場 *	6弱	5.9	538.7	402.4	526.6	355.3	13.4
熊本県	宇城市	宇城市不知火町 *	6弱	5.9	629.4	539.0	441.9	516.6	15.1
熊本県	熊本市南区	熊本南区城南町 *	6弱	5.9	850.8	681.2	521.5	803.1	6.2
熊本県	熊本市南区	熊本南区富合町 *	6弱	5.9	594.5	427.1	411.9	591.4	9.0
大分県	由布市	由布市湯布院町川上 *	6弱	5.9	540.0	479.0	368.9	465.9	79.2
熊本県	阿蘇市	阿蘇市内牧 *	6弱	5.8	517.2	511.8	165.1	318.1	35.5
熊本県	菊陽町	菊陽町久保田 *	6弱	5.8	825.3	824.2	497.7	566.4	13.3
熊本県	熊本市北区	熊本北区植木町 *	6弱	5.8	1026.9	672.3	877.9	530.0	17.4
熊本県	南阿蘇村	南阿蘇村河陰 *	6弱	5.7	927.4	920.3	557.5	361.2	26.3
熊本県	玉名市	玉名市天水町 *	6弱	5.7	328.7	308.4	202.0	137.1	19.7
熊本県	菊池市	菊池市隈府 *	6弱	5.7	462.2	415.1	293.5	302.1	25.1
熊本県	大津町	大津町引水 *	6弱	5.7	669.1	525.4	482.2	396.9	17.1
熊本県	御船町	御船町御船 *	6弱	5.7	499.0	465.7	441.3	354.0	6.2
熊本県	山都町	山都町下馬尾 *	6弱	5.7	831.2	776.7	639.5	186.5	22.5
熊本県	氷川町	氷川町島地 *	6弱	5.7	346.7	300.5	312.9	206.3	21.2
熊本県	和水町	和水町江田 *	6弱	5.7	517.6	264.2	509.2	135.9	28.4
熊本県	玉名市	玉名市横島町 *	6弱	5.6	240.0	230.5	197.1	103.8	23.3
熊本県	菊池市	菊池市泗水町 *	6弱	5.6	564.6	485.0	339.3	182.2	18.3
熊本県	美里町	熊本美里町永富 *	6弱	5.6	778.0	597.6	602.6	254.8	18.5
熊本県	合志市	合志市御代志 *	6弱	5.6	715.1	401.4	571.6	467.8	14.7

- Figure from: *The Headquarters for Earthquake Research Promotion ONLINE*:
<http://www.jishin.go.jp/main/index-e.html>.

PGA and PGV by mainshock M7.3

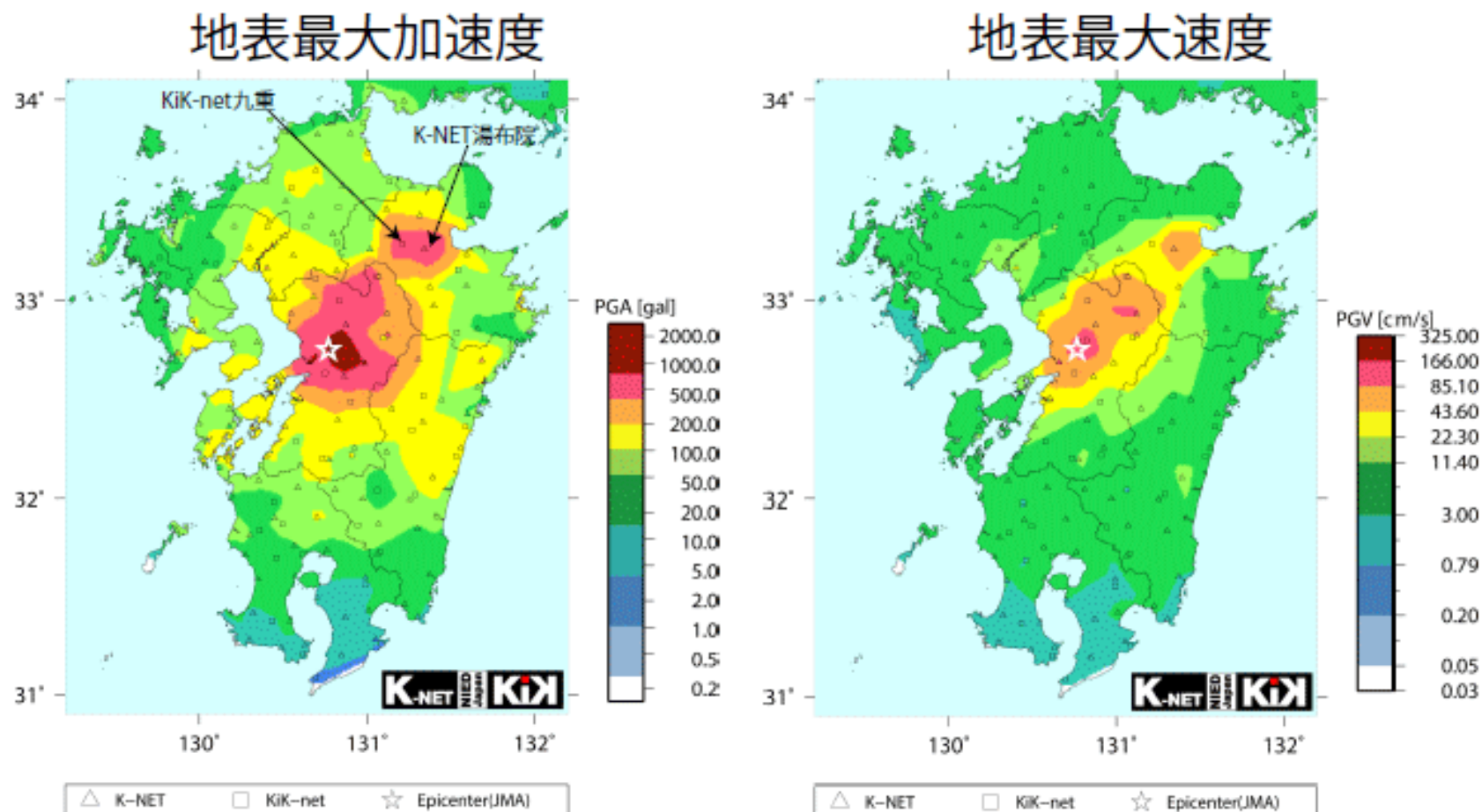
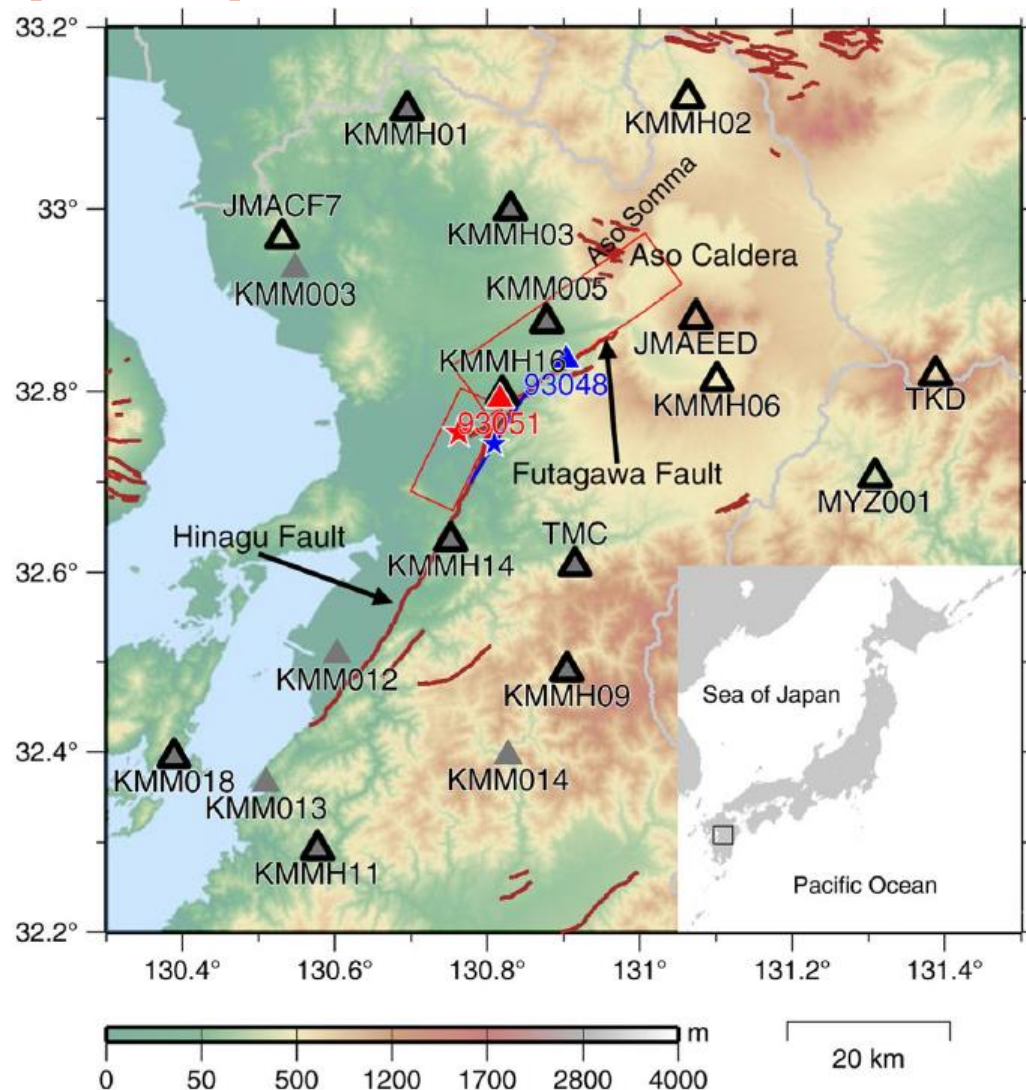


図1：平成28年(2016年)熊本地震(M7.3)で観測された地表最大加速度(左)および地表最大速度(右)の分布。

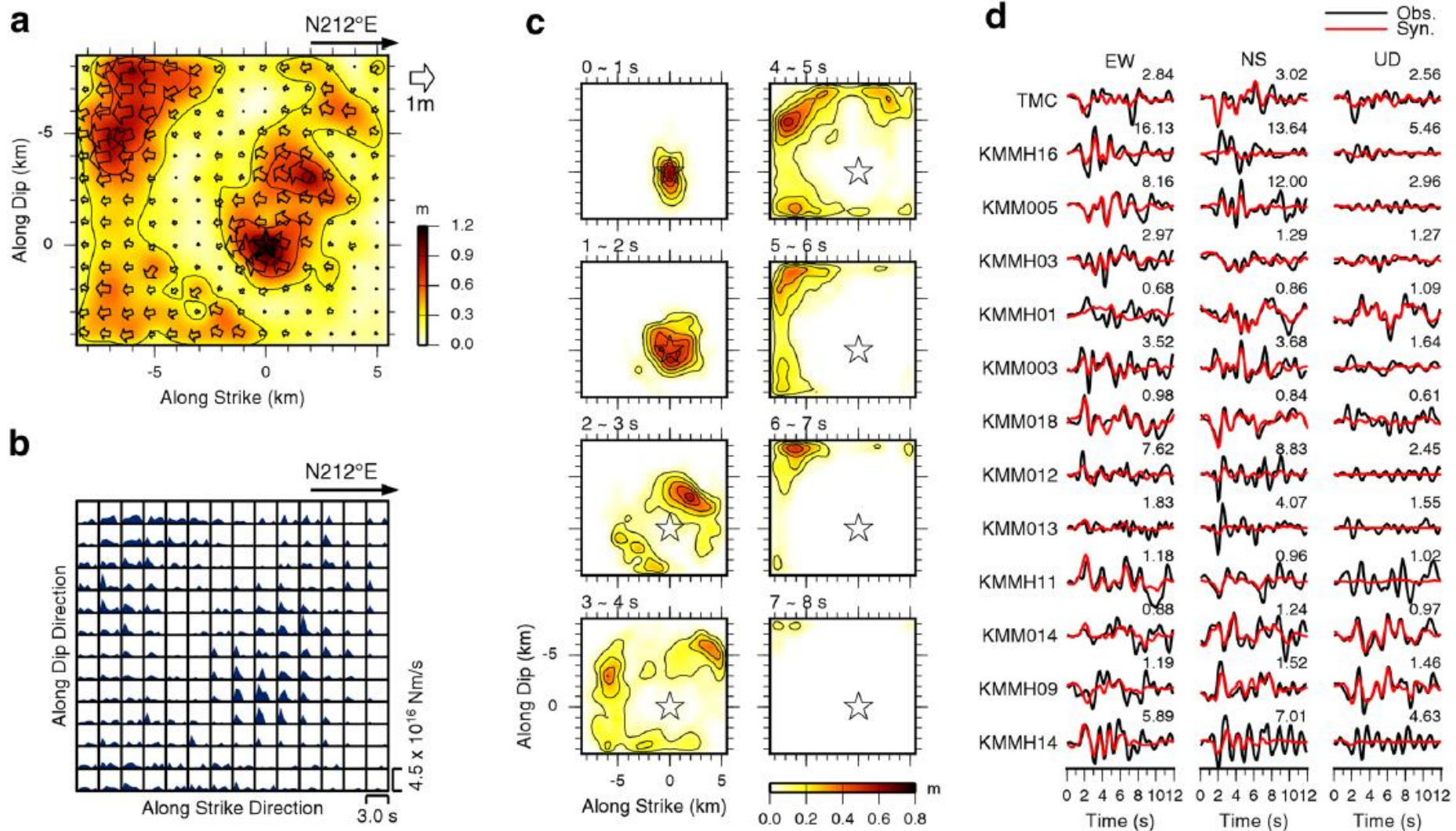
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Source rupture processes



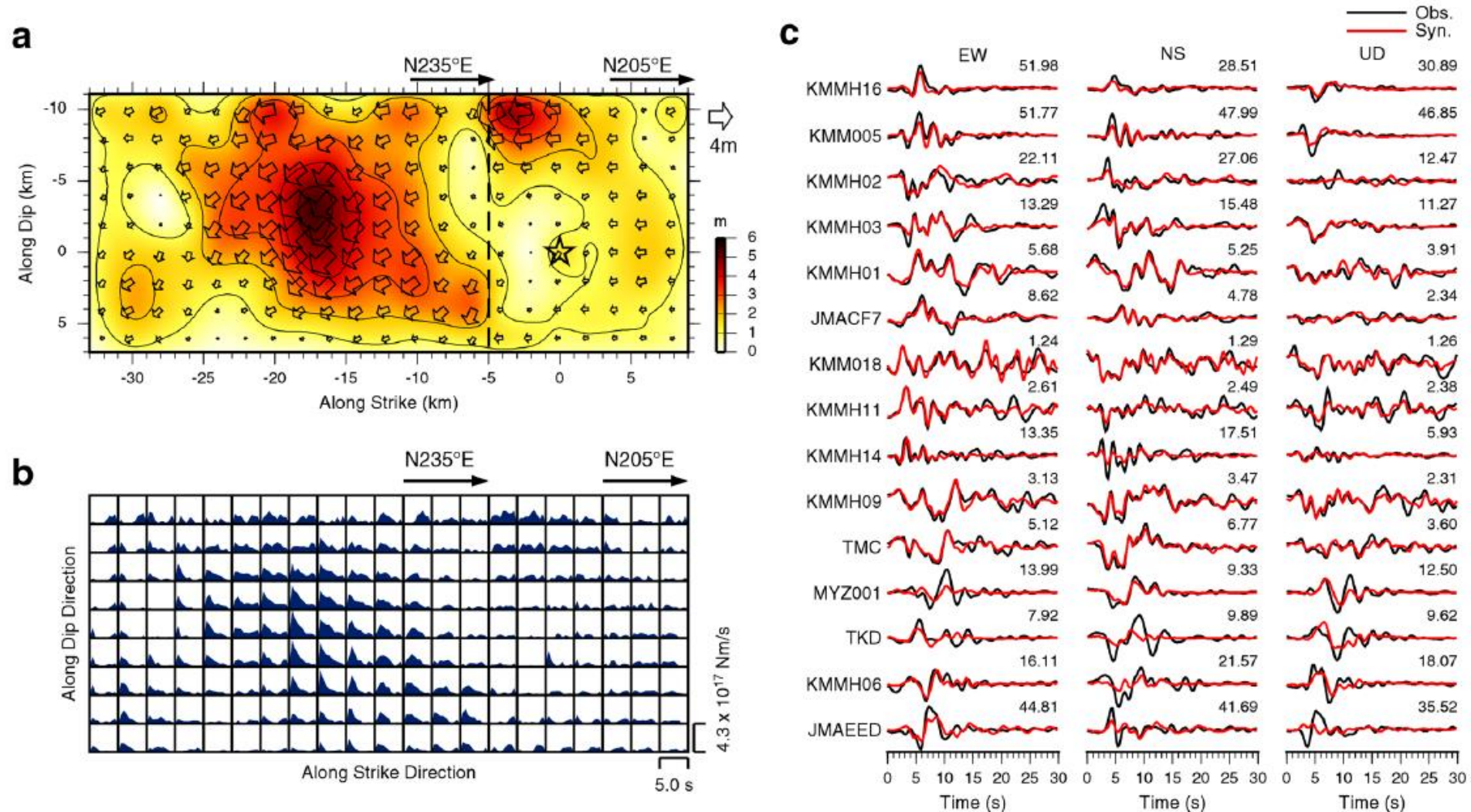
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Source rupture processes of foreshock M6.5



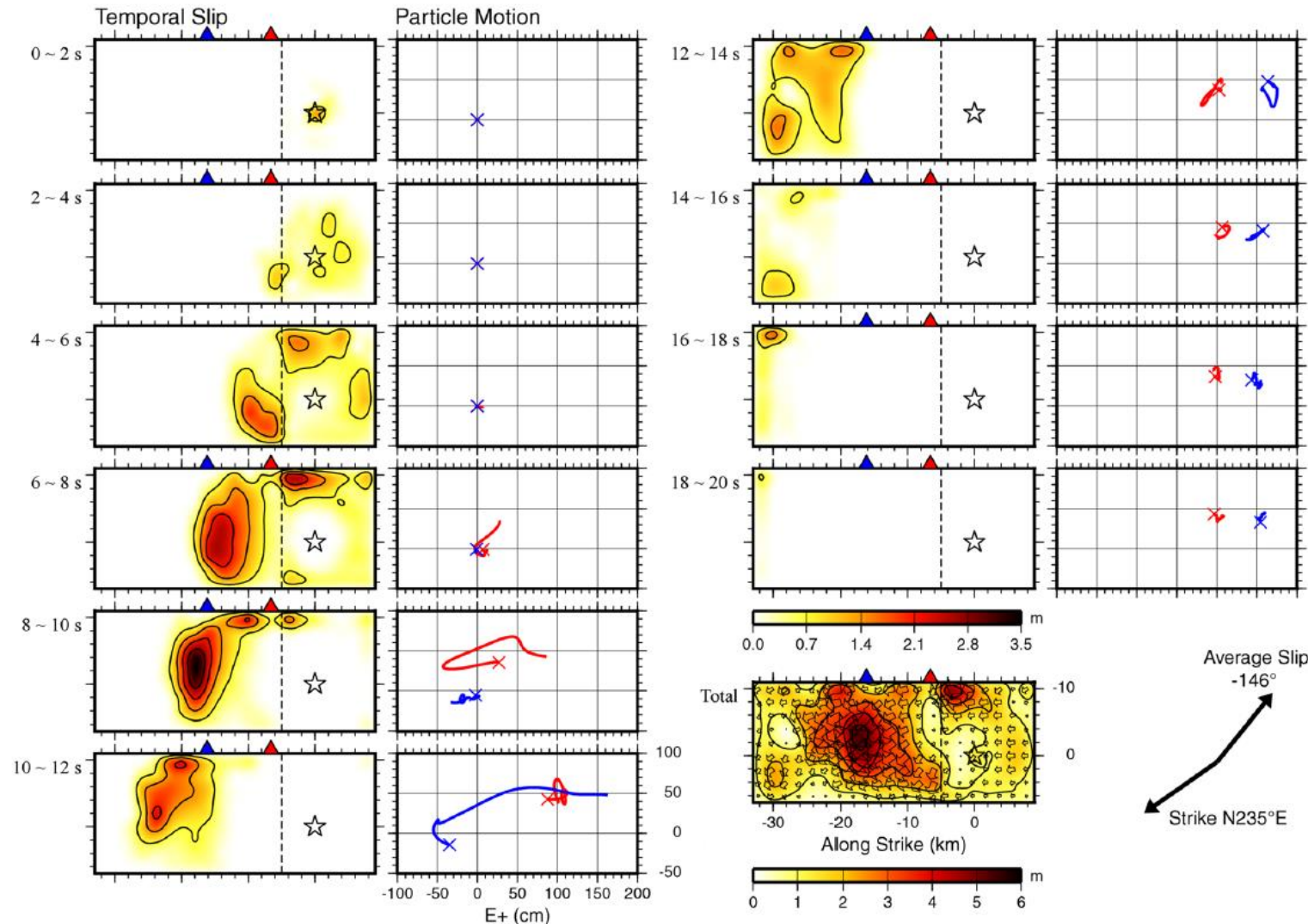
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Source rupture processes of mainshock M7.3



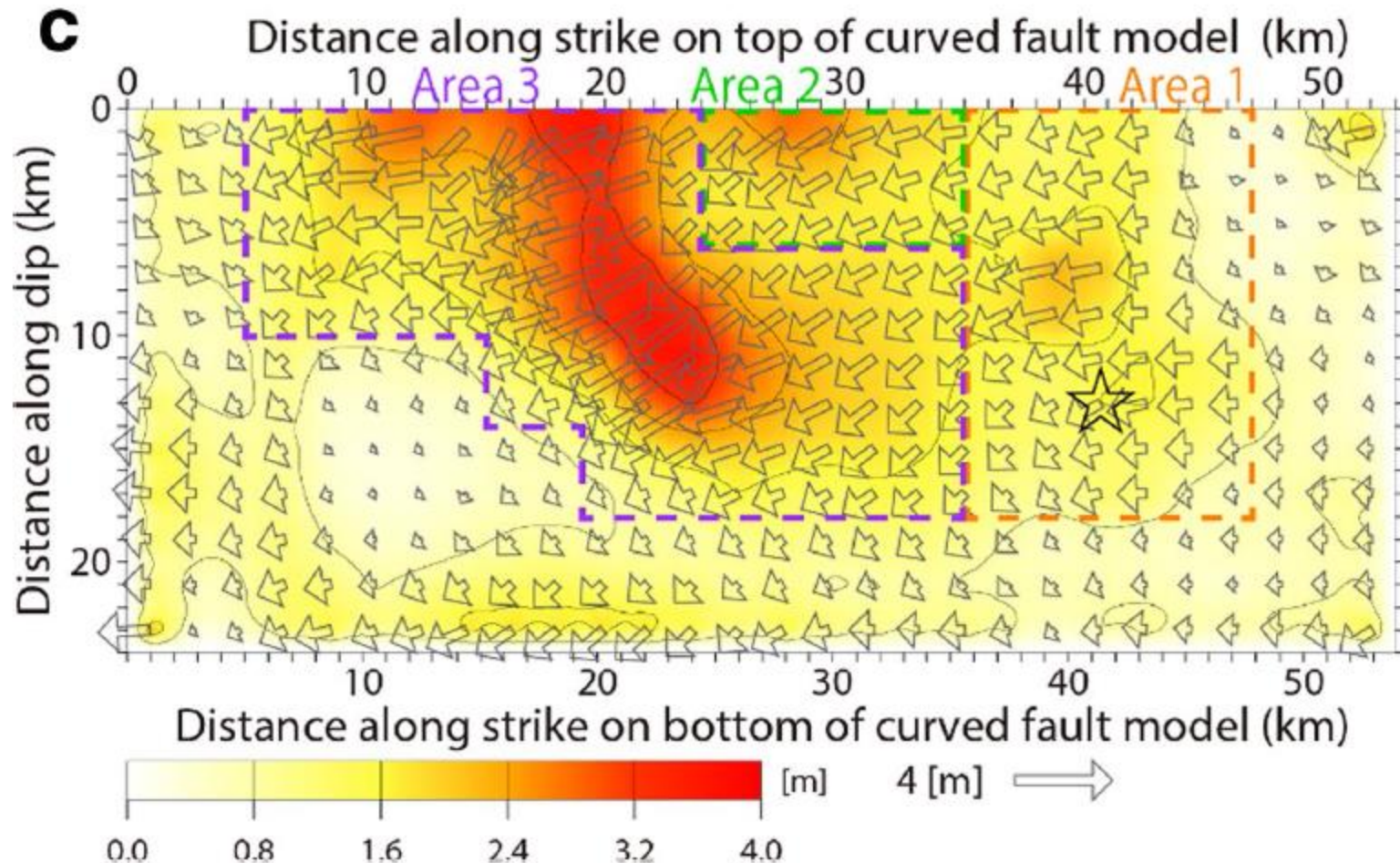
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Source rupture processes of mainshock M7.3



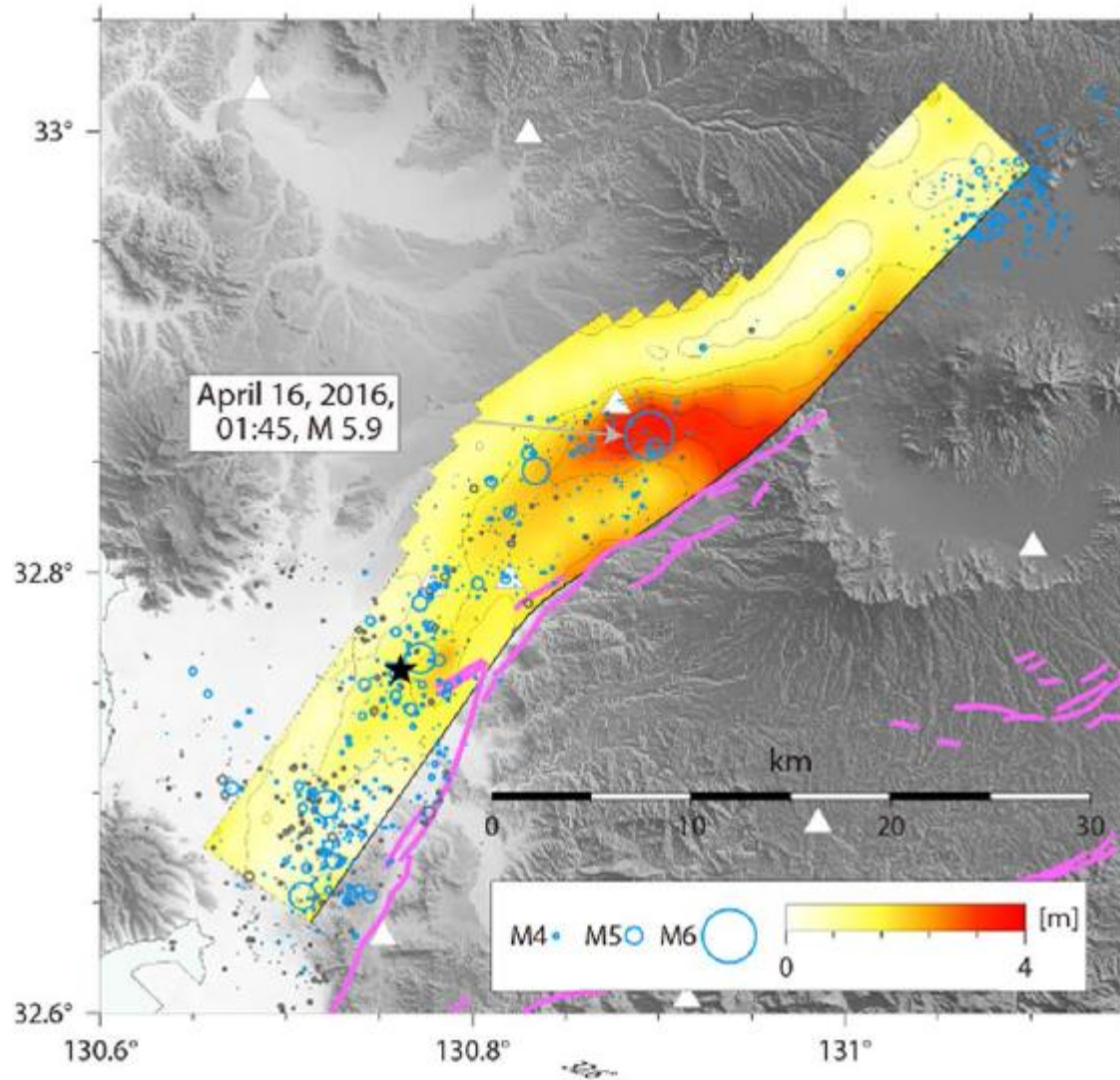
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Source rupture processes of mainshock M7.3



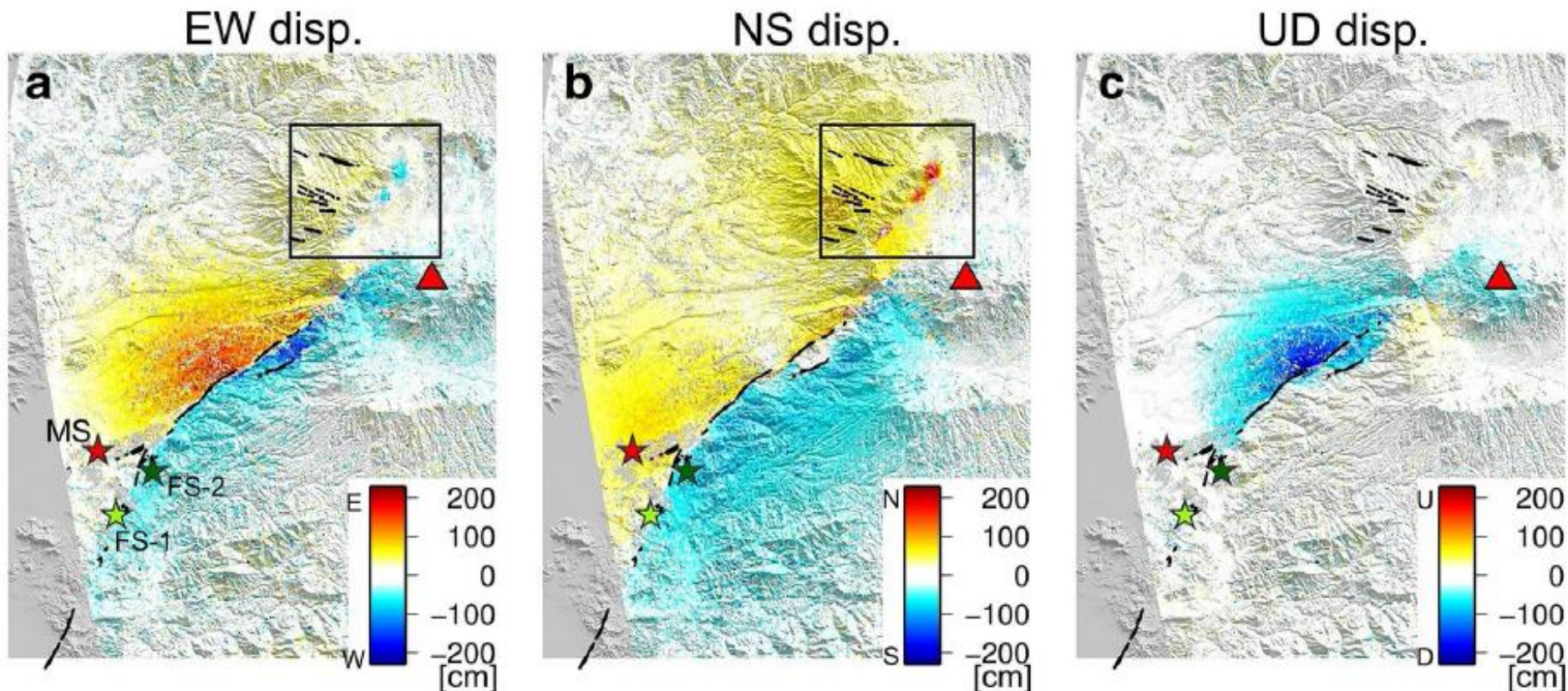
- Figure from: Kubo, H., Suzuki, W., Aoi, S., Sekiguchi, H. (2016): Source rupture processes of the 2016 Kumamoto, Japan, earthquakes estimated from strong-motion waveforms, *Earth, Planets and Space* 68:161.

Source rupture processes of mainshock M7.3



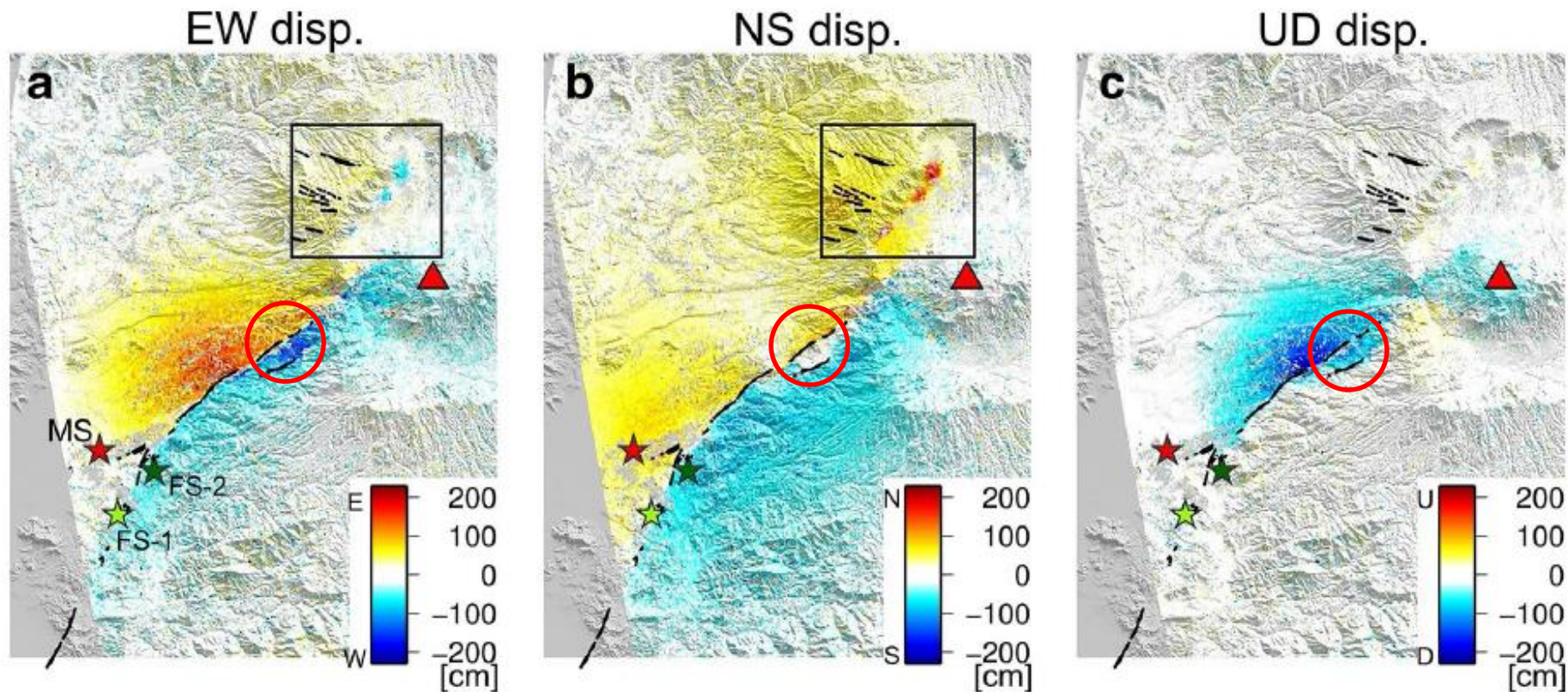
- Figure from: Kubo, H., Suzuki, W., Aoi, S., Sekiguchi, H. (2016): Source rupture processes of the 2016 Kumamoto, Japan, earthquakes estimated from strong-motion waveforms, *Earth, Planets and Space* 68:161.

Cumulative surface 3D displacement based on ALOS-2/PALSAR-2 pixel-offset



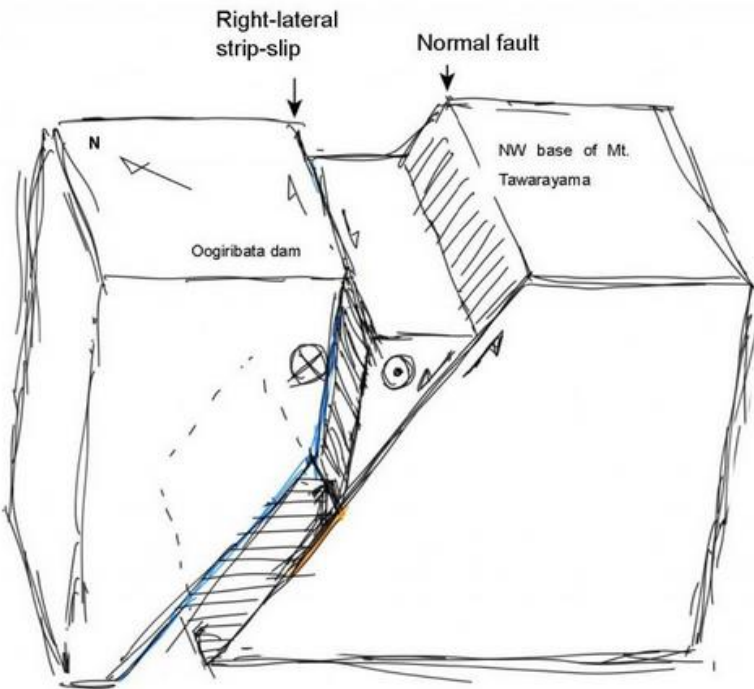
- Figure from: Himematsu, Y., Furuya, M. (2016): Fault source model for the 2016 Kumamoto earthquake sequence based on ALOS-2/PALSAR-2 pixel-offset data: evidence for dynamic slip partitioning, *Earth, Planets and Space* 68:169.

Cumulative surface 3D displacement based on ALOS-2/PALSAR-2 pixel-offset



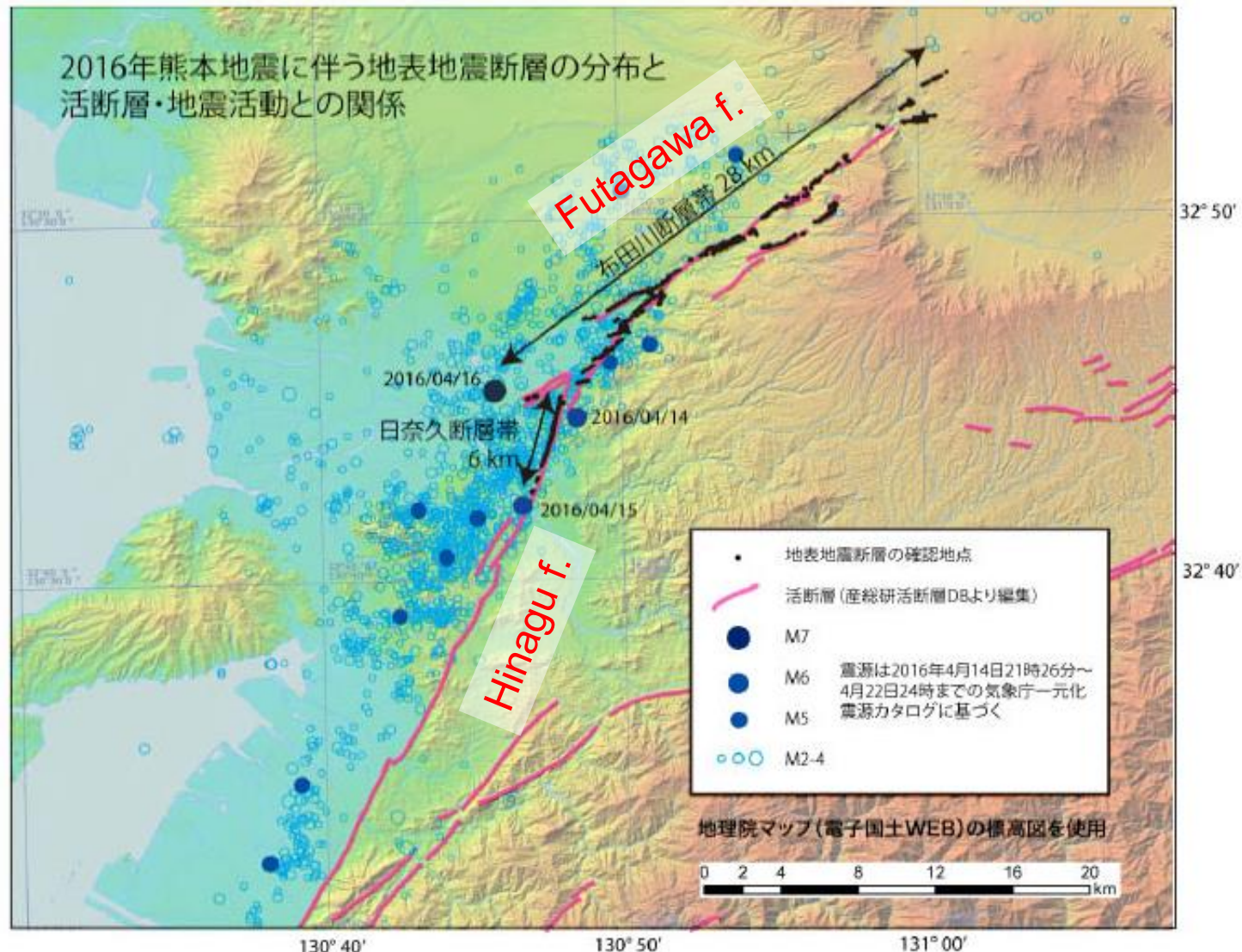
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Two parallel active faults (normal + strike-slip)



- Figure from: Toda, S., Ishimura, D., Yoshida, H., IRIDeS NEWS, Tohoku University, ONLINE: <http://irides.tohoku.ac.jp/irides-news/20160425/969>.

Faults geometry



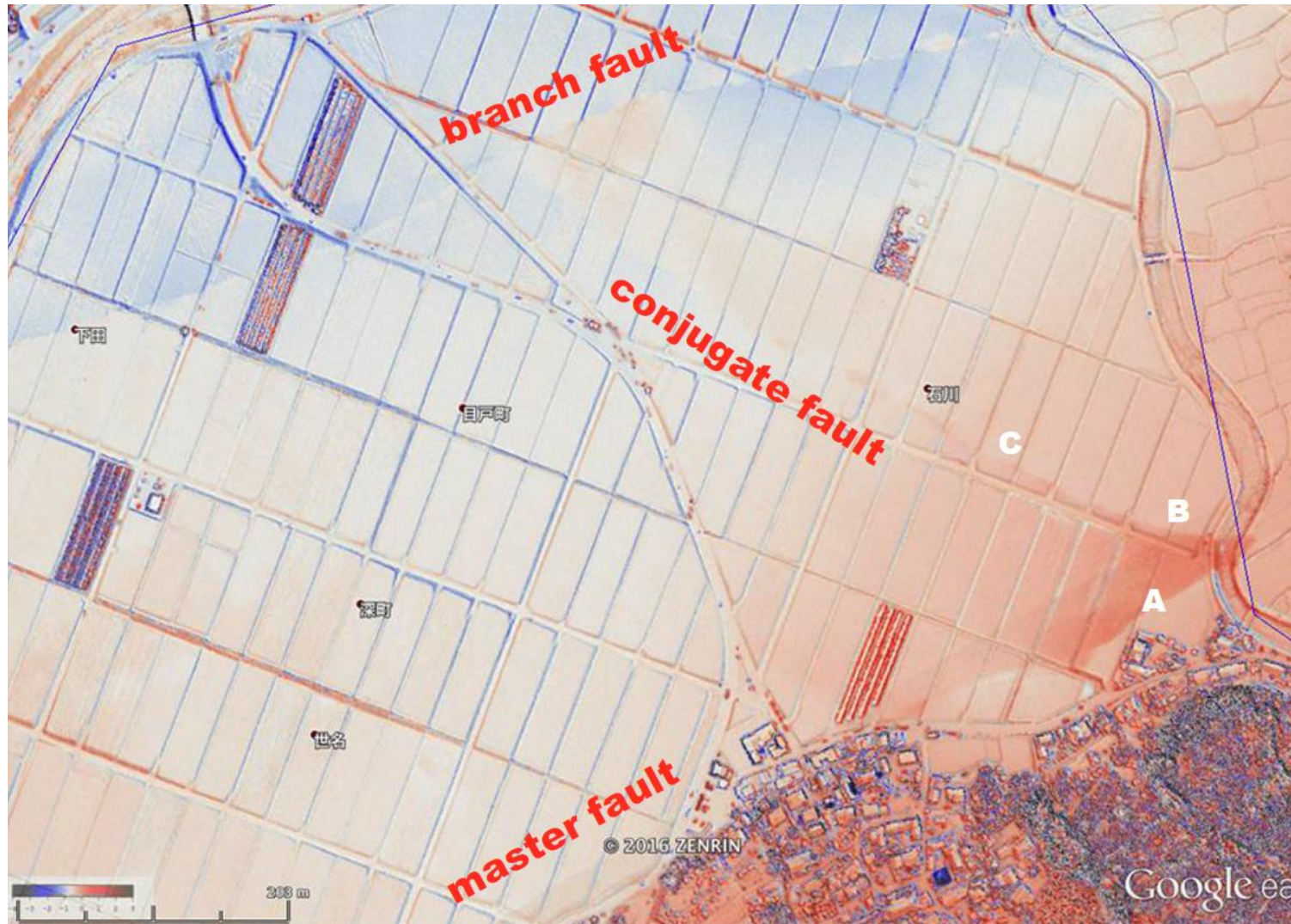
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Faults geometry



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Faults geometry



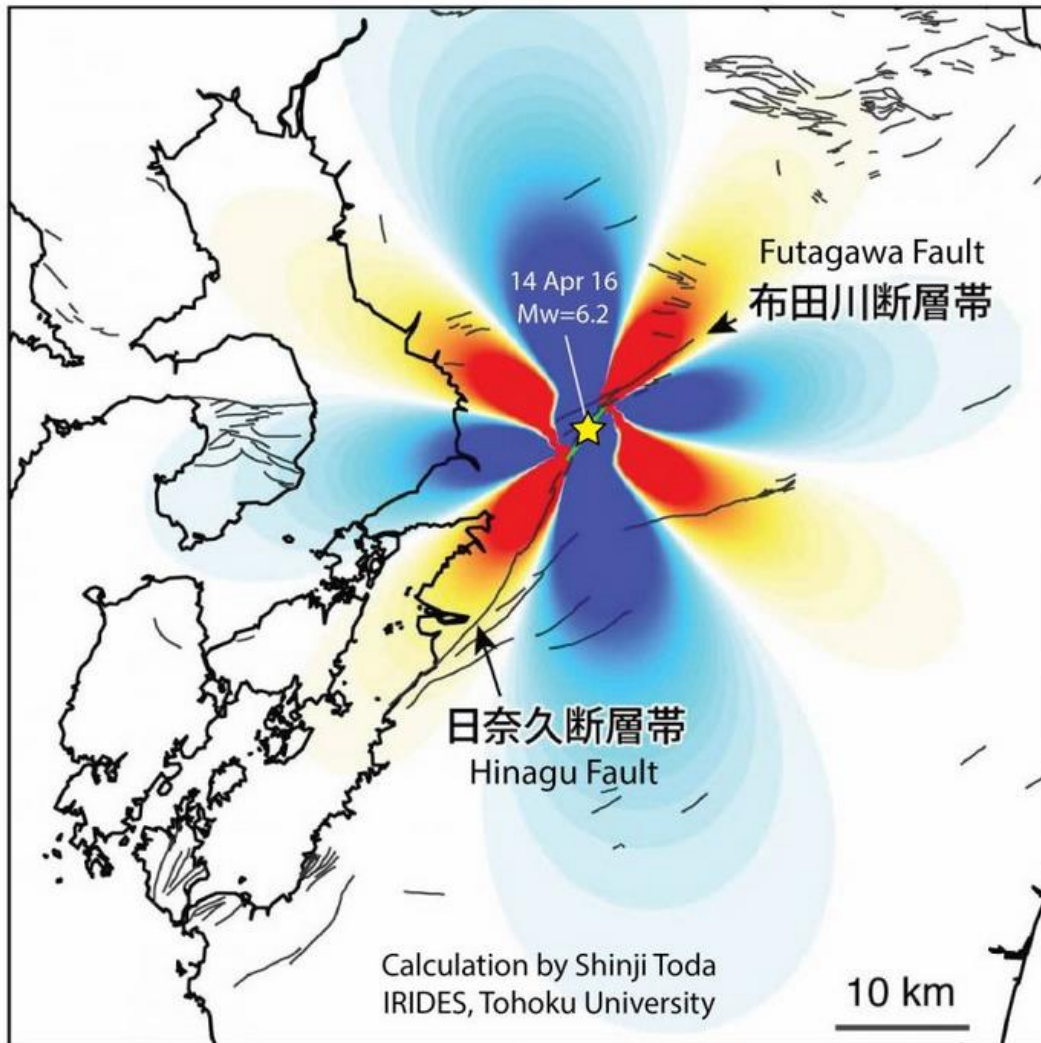
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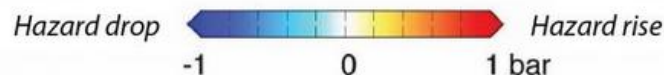
How M6.5 earthquake triggered M7.3



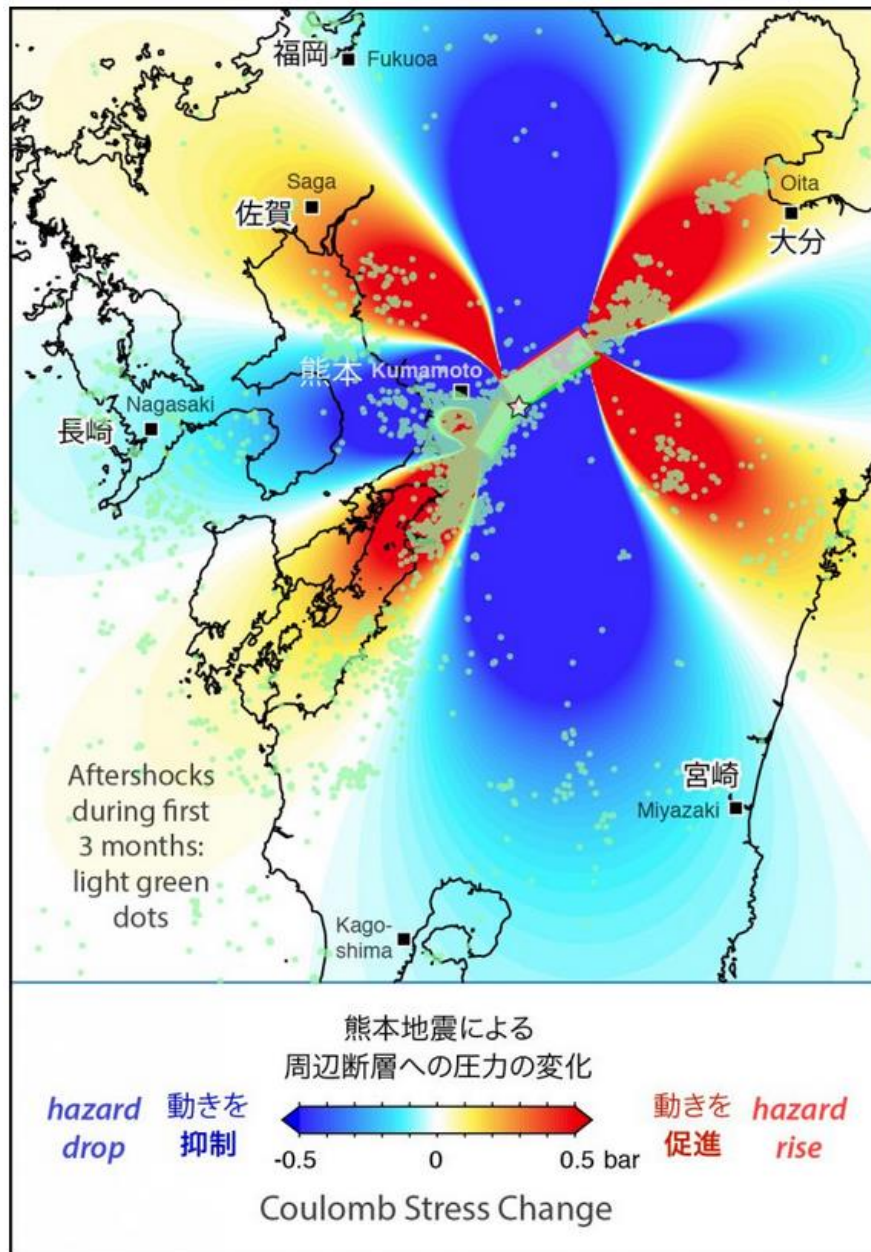
Coulomb stress imparted by the rupture as a result of the M6.5 shock

- Figure from: Stein, R., Toda, S., (2016): *How a M=6 earthquake triggered a deadly M=7 in Japan*, IRIDES, Tohoku University, ONLINE: <http://temblor.net/earthquake-insights/how-a-m6-earthquake-triggered-a-deadly-m7-in-japan-1304/>.

Coulomb stress imparted by the 14 April 2016 Mw=6.2 quake



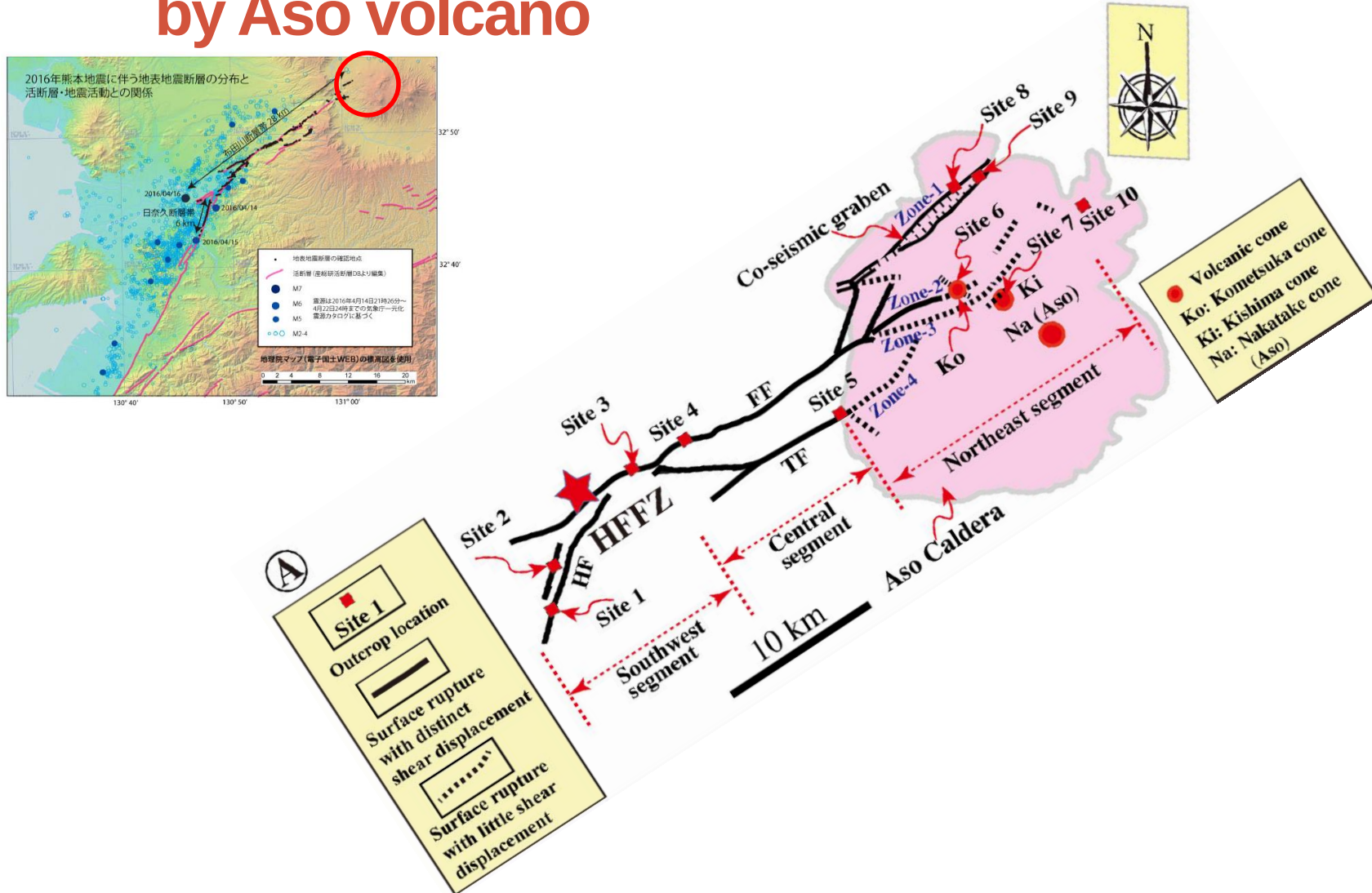
How M6.5 earthquake triggered M7.3



Coulomb stress imparted by the mainshock ruptures to the surrounding crust as a result of the combined M6.5 and M7.3 shocks

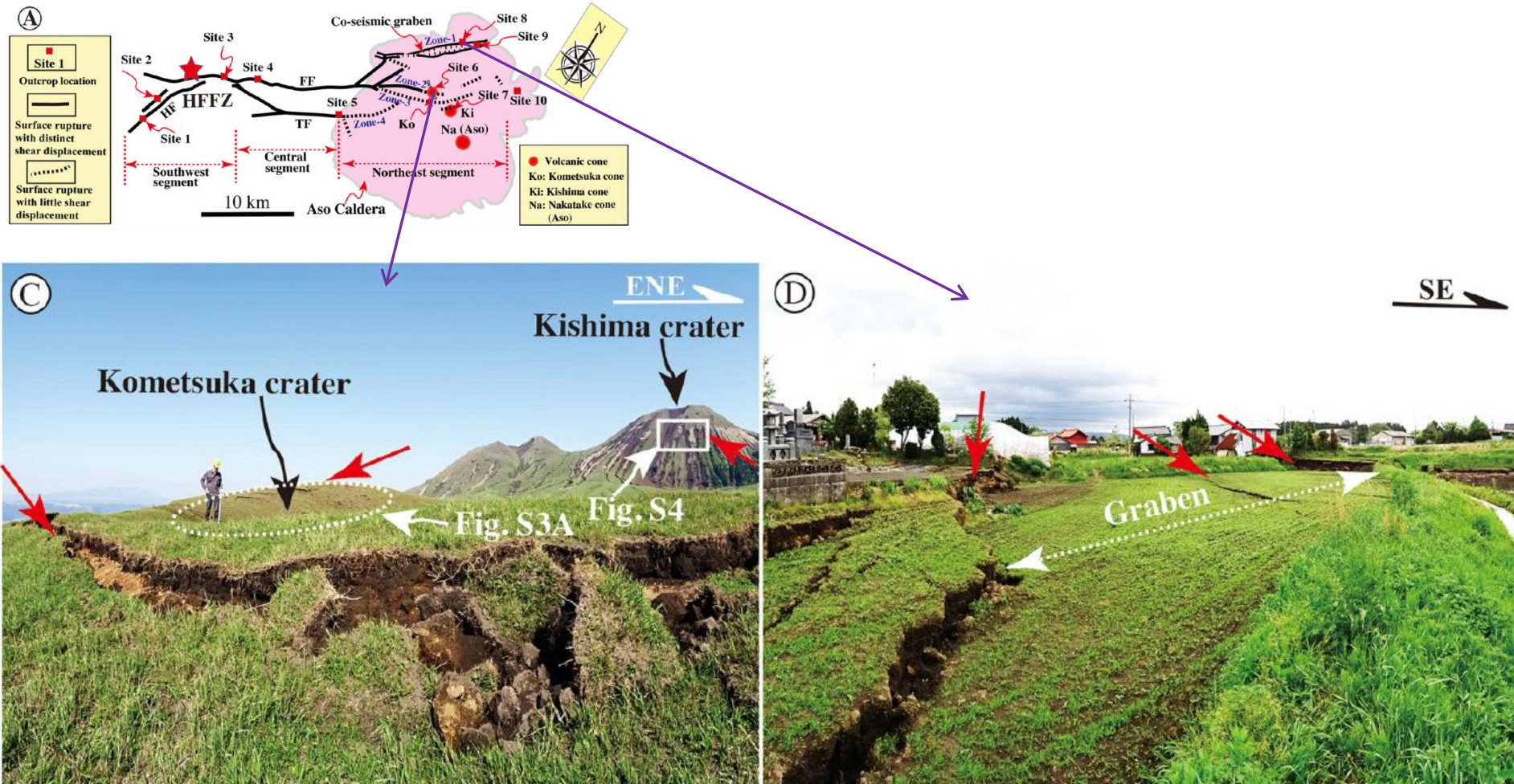
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Coseismic rupturing of mainshock M7.3 stoped by Aso volcano



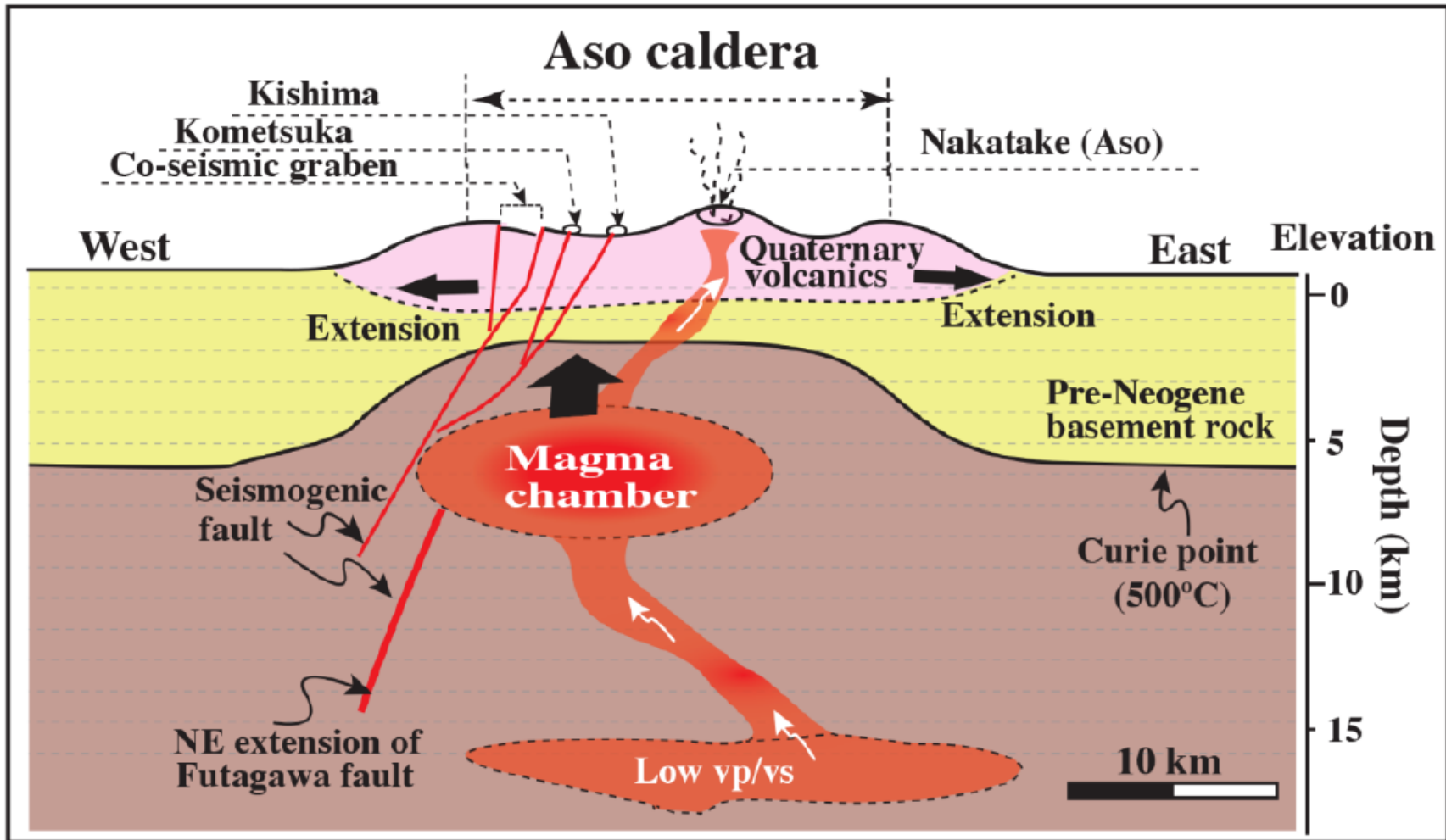
- Figure from: Lin, A., Satsukawa, T., Wang, M., Asl, Z.M., Fueta, R., Nakajima, F., Coseismic rupturing stopped by Aso volcano during the 2016 Mw 7.1 Kumamoto earthquake, Japan, *Science* 10.1126/science.aah4629 (2016).

Coseismic rupturing of mainshock M7.3 stoped by Aso volcano



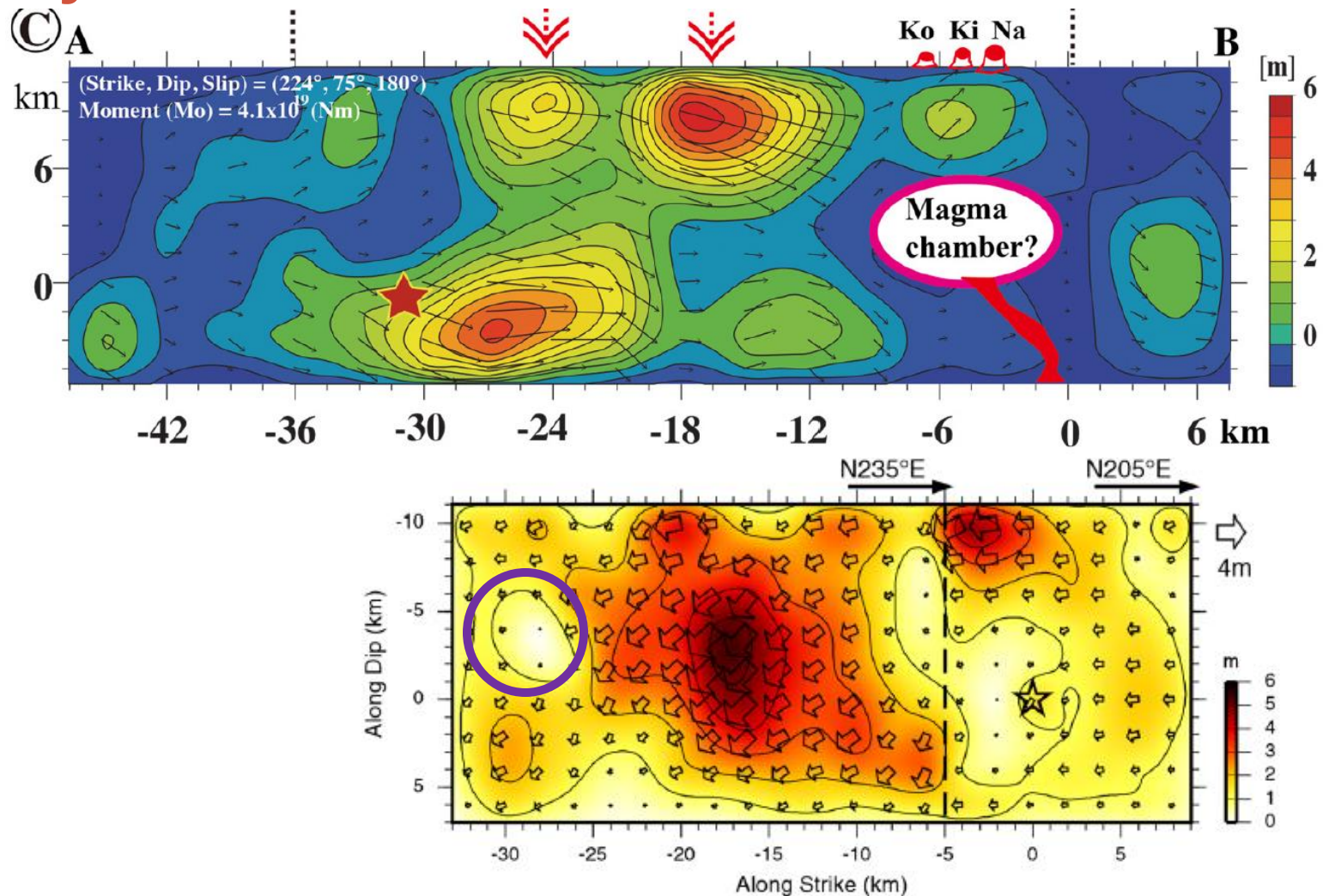
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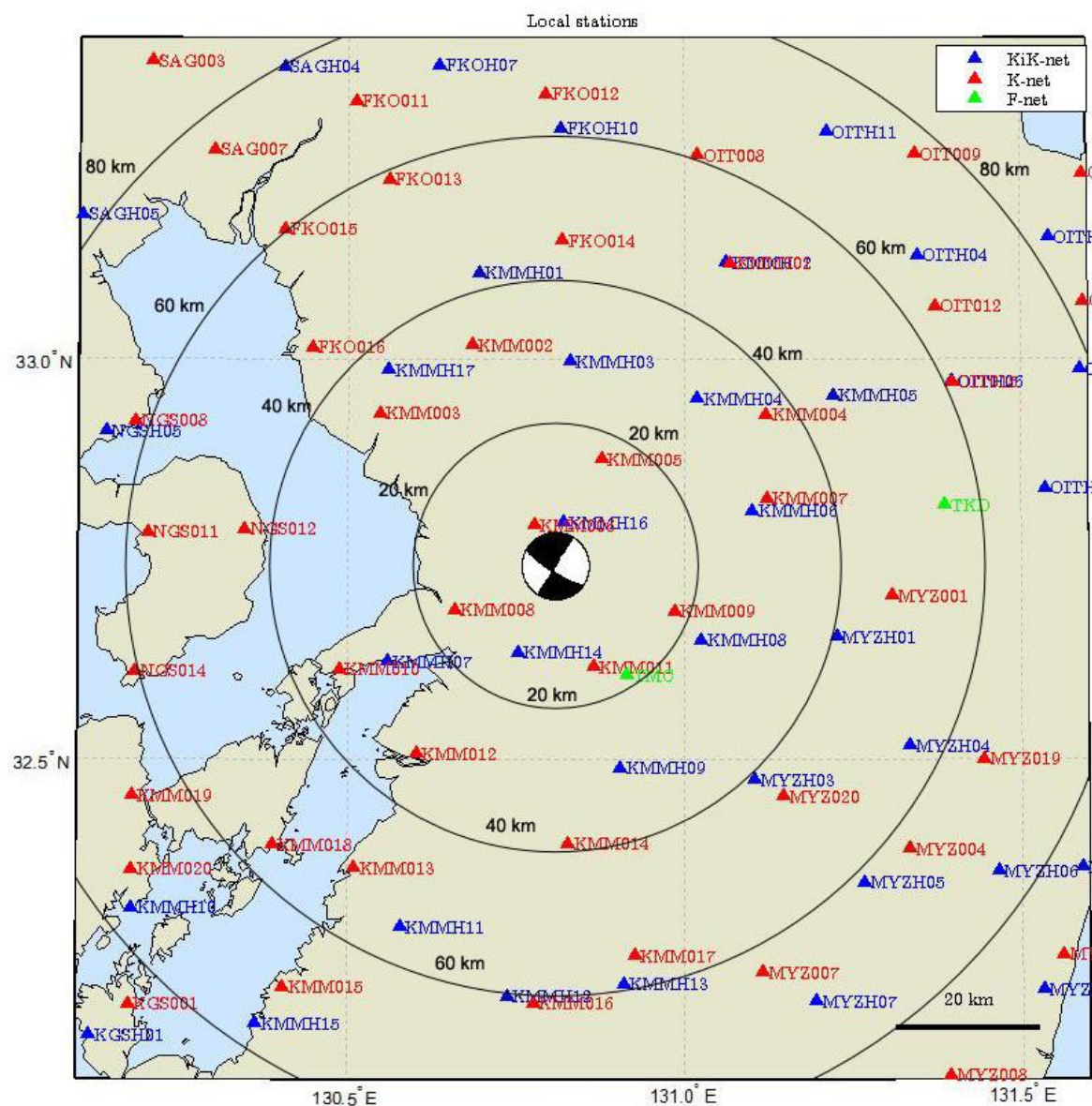
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Research in DPRI, Kyoto



- Moment tensors by ISOLA-ObsPy of the foreshocks. Including uncertainty of the GF by means of covariance matrix.
- Data from NIED strongmotion networks K-net (surface) and KiK-net (surface + downhole).