M7.2 Kumamoto Earthquake
14 and 15 april 2016

A compilation of data and results with focus on surface rupture

By Stéphane Baize (IRSN) for the INQUA Project

SURFACE
Main sources of information:

• GSI: Geospatial Information Authority of Japan
• GSJ: Geological Survey of Japan
• AIST: Active Fault Database of Japan
• J-SHIS: Japan Seismic Hazard Information
• USGS: United States Geological Survey
• IPGP: Institut de Physique du Globe de Paris
• PASCO Corporation, Japan
Geodynamics of the area

1. Tectonics and Geologic Setting

Central Kyushu Rift
NS-extension with
ES-compression, and
Quaternary volcanism

Credit: K. Okumura
Geodynamics of the area

Neogene Volcanics
Cretaceous Trough
(Median Tectonic Line)
(High-P metamorphic)
Jurassic — Paleogene
Accretionary Complex

Credit: K. Okumura

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Geodynamics

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)

Matsumoto et al. Earth, Planets and Space (2015)
The earthquake sequence

Focal mechanisms of sequence

1 big foreshock

1 mainshock

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)

Credit: USGS (19 April)
**Mainshock**: strike N225°, dip 70°
Right-lateral with normal component

Surface faulting during 2016 Kumamoto
Earthquake - Compilation by S. Baize (IRSN)
Map of foreshocks, mainshock & aftershocks

2016/03/25 21:00:00 ~ 2016/04/24 21:00:00 (N=6292)

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Foreshock

Mainshock

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)

Credit: http://sms.dpri.kyoto-u.ac.jp/k-asano/
**Active faults**

- **Futagawa fault**: 0.9 mm/y; Slip/event 2.8 with RI 3 ka; 60° dipping to the NW
- **Hinagu fault**: 0.5 mm/y; 2.2 m; 4.4 ky

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Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Active Fault Map and 2016 epicenters

Credit: GSJ
Modeled Seismogenic Sources

Credit: j-shis

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
A snapshot of the sources parameters for the 2016 ruptures faults

Credit: j-shis
Surface Rupture

• Occurred on a mapped fault...

Red segments and dots were surface deformation is inferred from aerial photos

Source: GSI

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Paleoearthquake information

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
AIST Database → Paleoeartquake information
Ex. Futagawa Fault

<table>
<thead>
<tr>
<th>trend</th>
<th>60°</th>
</tr>
</thead>
<tbody>
<tr>
<td>dip</td>
<td>60° N</td>
</tr>
<tr>
<td>length</td>
<td>24 km</td>
</tr>
<tr>
<td>sense of faulting</td>
<td>R-lat.</td>
</tr>
<tr>
<td>upthrown side</td>
<td>S</td>
</tr>
<tr>
<td>slip rate</td>
<td>0.9 m/ky (estimate based on vertical displacement of sediments (Kumamoto, 1996))</td>
</tr>
<tr>
<td>slip per event</td>
<td>2.8 m (calculated based on empirical relationship between segment length and slip per event proposed by Awata, 1999)</td>
</tr>
<tr>
<td>recurrence interval</td>
<td>3.1 ky (calculated from the slip rate and the slip per event)</td>
</tr>
<tr>
<td>age of the last faulting</td>
<td>AD 4772 to 270</td>
</tr>
<tr>
<td>field data</td>
<td>estimated from the exposures at the bank of the Shirakawa River (Genshiryokuhatsuden-lijutsukiko, 1997) and Tanaka trench (Yoshioka et al., 2007)</td>
</tr>
<tr>
<td>historical record</td>
<td></td>
</tr>
<tr>
<td>elapsed time rate</td>
<td>1.44</td>
</tr>
<tr>
<td>rupture probability in next 30 years (by BPT distribution model)</td>
<td>ca 6%</td>
</tr>
<tr>
<td>rupture probability in next 30 years (by Poisson process model)</td>
<td>ca 1%</td>
</tr>
</tbody>
</table>

Investigation Sites
Displacements
Faulting Events

GO
InSAR cumulating the effects of the M6 foreshocks

Foreshocks’ Surface faulting may have been observed here...

Source GSI

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
InSAR cumulating the 3 shocks deformation

Source GSI

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Sentinel1 SAR interferogram and derived deformation map
http://www.kkc.co.jp/service/bousai/csr/disaster/201604_kumamoto
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
4/15計測 DSMデータによる赤色立体地図
益城町 津森小学校周辺

4/15計測 DSMデータによる赤色立体地図
上屋地区周辺

http://saigai.gsi.go.jp/1/H28_kumamotojishin/nishihara0416/photo/qv/0269-qv.jpg
http://www.ajiko.co.jp/saigai/kumamoto_2016_04_2/gif_a.gif

Animated GIF from LIDAR
Video Footages available on GSI website (Futagawa Fault)
https://www.youtube.com/watch?v=umKIDwxkuYg&feature=youtu.be
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Field survey

地点3（堂園）
右横ずれ 約2m
Was there Rupture during foreshock?
The PASCO team reports evidences of fractures with displacement before the mainshock
“Right lateral dislocations cross the road way. The gap was approximately 30cm. The dislocation may be a part of surface faulting. This is because no landslides are expected in the area, the crack azimuth agrees with the fault strike, and its location is almost on the fault surface. **According to the neighbor, the dislocation slightly appeared after the 1st event, and it grows to the current size after the 2nd event.**”
Rupture during mainshock
Mall track caused by the right-lateral displacement and displacement seen in the fields of Birds Nest village. Picture taken toward the northeast direction. Fault passes through the right of the blue vinyl house, leading to the mountains. White arrows fault position, the red arrows indicate the displacement sense. (2016 April 16 shooting)
Right-lateral displacement seen in the fields of Birds Nest village. Picture taken toward the northwest direction. Right-lateral displacement amount of time relative to the footpath is about 200 cm. (2016 April 16 shooting)
Shortening deformation seen in the pavement of the photo 3 Kamijin settlements. Picture taken toward the southeast direction. Vertical displacement weight of about 40 cm. Fault continues to N70E direction. (2016 April 16 shooting)
Right-lateral displacement and mall track seen in photo 4 Shimojin village west. Picture taken toward the northeast direction. Right-lateral displacement weight of about 100 cm, vertical displacement weight of about 20 cm. (2016 April 16 shooting)
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)

6- Flexure deformation of the paddy field with a left-lateral strike-slip component of N70W strike seen in Shimojin village west. Picture taken toward the west-northwest direction. Vertical displacement weight of about 15 ~ 20 cm, left-lateral strike-slip displacement amount is about 20 cm. (2016 April 16 shooting)
7- Right-lateral displacement seen in photo 7
Mitake village southwest of paddy. Picture taken
toward the northeast direction. Fault passes
through the road from the distortion part of the
guardrail, through the right of the back of the
house, continuing to photograph 5. (2016 April 16
shooting)
8-Akai village "mashiki townspeople rest of the house," parking lot to see is right-lateral displacement. Picture taken toward the northwest direction. Right-lateral displacement amount is about 40 ~ 50 cm. (2016 April 16 shooting)
10 - Right-lateral displacement seen in Togawa village west of paddy. Picture taken toward the south-southeast. Right-lateral displacement amount of time relative to the cultivation mark is about 50 cm. (2016 April 16 shooting)
11- Vertical displacement displacement seen in photo 11 lino elementary school south of National Highway 443 Highway. Picture taken toward the west-southwest direction. Vertical displacement weight of about 15 cm. (2016 April 16 shooting)
12- Right-lateral displacement seen in photo 12 Tsuchiyama village west of the paved road. Picture taken toward the west direction. (2016 April 16 shooting)
13-Right-lateral displacement seen in the rice paddies of the photo 13 Takagi village. Picture taken toward the south direction. Right-lateral displacement amount is about 50 cm. (2016 April 17 shooting)
14- Right-lateral displacement seen in the pavement of Kamikoya village. Picture taken toward the east direction. Right-lateral displacement amount of time on the basis of the gutter is about 50 cm. (2016 April 17 shooting)
15- Open cracks with a vertical displacement seen in the paved road along the photo 15 Kushito village southern margin. Picture taken toward the east-northeast direction. Up and down the amount of displacement is approximately 10 cm. Crack intermittently distributed in the northeast southwest direction of the field. (2016 April 16 shooting)
Deformation of the fence caused by the south open cracks and the south side of the deflection-up of the rise that occurred at the boundary between the photo 16 Kushito village south of topographical growing and rice paddies. Picture taken toward the west-southwest direction. Up and down the amount of displacement is approximately 20 cm or more. Deflection and opening cracks in the south rise is seen continuously along the terrain boundary. White arrows represent the shape of the deflection. (2016 April 17 shooting)
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Vertical 0.5m
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
loc073
In front of the Mimami-Aso landslide (see further)
Another perspective of the same area

Surface faulting
Conjugate rupture
loc007

Left Lateral on WNW-ESE
Left Lateral + Vertical on WNW-ESE
Secondary Faulting
Right Lateral Faulting on secondary rupture
Mole track with vertical offset?

loc012
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Main fault (strike-slip)

Secondary fault (normal)
Other pictures of Surface Ruptures
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Synthesis
• Surface rupture length
  – 26 km
• Maximum Displacement
  – 2 meters

http://jsaf.info/jishin/items/docs/20160420164714.pdf
Surface Fault Map according to the GSJ

- SRL larger than value in previous slide (~30 km)
- Rupture has been observed in the Aso Caldera
Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Slip distribution
Post-seismic deformation

Source GSI

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Post-seismic deformation

GPS campaigns: 21-22/4 → 3-5/5

Vertical motion due to subsidence / settlement

Source: GSJ
Landslides

Mimami-Aso
A landslide triggered by the Kumamoto earthquake, via Asia One, that destroyed an important bridge
Airborne LiDAR of the Mimami-Aso landslide
http://www.kkc.co.jp/service/bousai/csr/disaster/201604_kumamoto/

Surface faulting during 2016 Kumamoto Earthquake - Compilation by S. Baize (IRSN)
Damage to the Kurokawa Dai-ichi Power Station caused by the Kumamoto earthquake, via AFP
A flowslide triggered by the Kumamoto earthquake, via AP
A major cutslope failure on the Oita Expressway, triggered by the Kumamoto Earthquake, via AP