**JST J-RAPID Symposium on The 2016 Kumamoto Earthquake**
**March 4, 2017, Kumamoto**

# Mechanism of Fluidized Landslides due to the 2016 Kumamoto Earthquake and Risk Evaluation of Unstable Soils

## - A Factual Investigation by Japan-USA Joint Research –

## (平成28年熊本地震による流動性地すべりの発生機構と不安定土砂の危険度評価～日米共同研究による実態解明調査～)

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# Summary of Project Activities

- Surveying of the affected areas using UAV (Unmanned aerial vehicle), LIDAR (Light Detection and Ranging) and Resistivity Imaging
- Collection of acceleration and fault data, their analysis and evaluation
- Quantitative evaluation of fluidized flow using laboratory tests
- Modeling and analysis using energy-based approach
- Construction of hazard maps
- Regular meeting of the leaders/subleaders of Japan and USA
- Organizing  workshop to disseminate the information (Will be held at Kyushu University on March 6, 2017).

# International Workshop on the 2016 Kumamoto Earthquake

## – Japan-US Joint Workshop –

**March 6, 2017**
**Inamori Center, Kyushu University**
**Fukuoka, Japan**

**Organized by**
J-RAPID Project Team

**Co-organized by**
Kyushu University
National Disaster Research Council, Japan
National Disaster Information Center of Western Japan, Kyushu University
International Press-in Association (IPA)
Center for Reducing Disaster Risk, Kumamoto University

**Supported by**
Japan Science and Technology Agency
Japan Foundation Engineering Co., Ltd.

# Major Surveyed Locations

# Survey Schedule

1st Survey

5/11（Wed）

5/12（Thur）

5/13（Fri）

2nd Survey

June 25（Sat）

June 26（Sun）

3rd Survey

August 22（Mon）

August 23（Tue）

August 24（Wed）

# Survey using Modern Equipment (1)

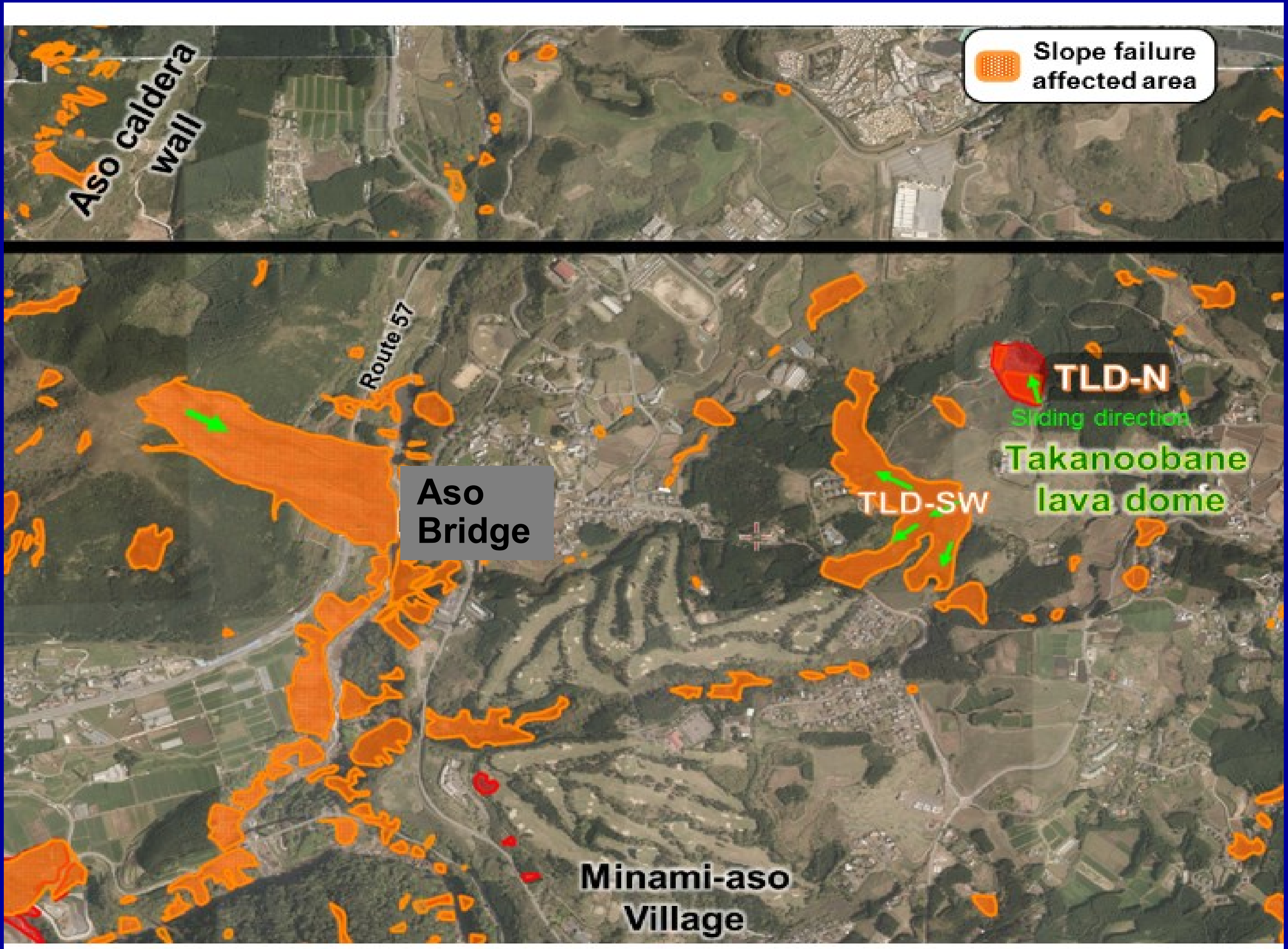
- **LIDAR (Light Detection and Ranging)**

# Survey using Modern Equipment（2）

- **UAV (Unmanned aerial vehicle):**

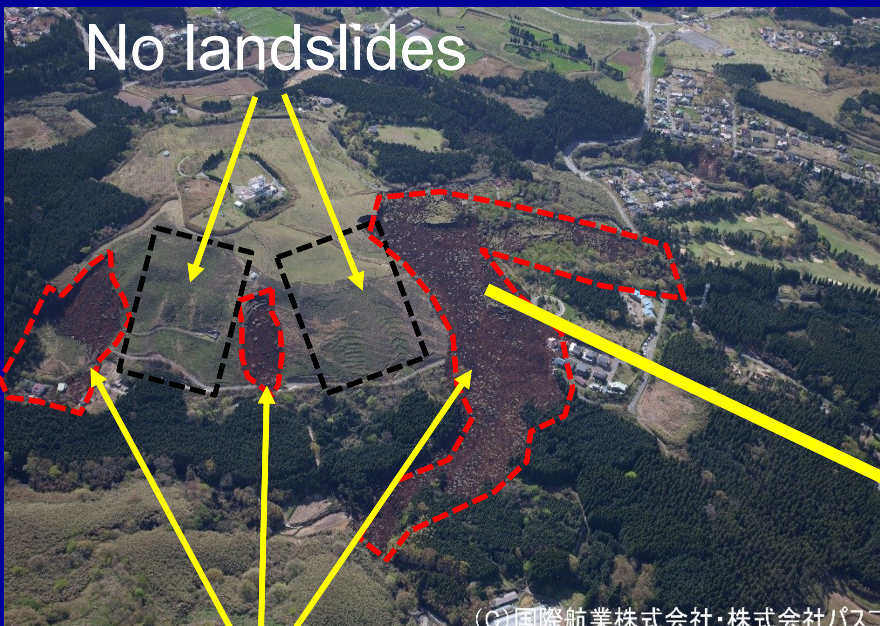
- **Resistivity Imaging**

# Landslides, Slope Failures and Debris Flows




(Based on photograph by Geospatial Information Authority of Japan(GIA)

# Huge Surficial Failure at Takanoobane




Landslides occurred in moderately inclined slope, thickness was small in relation to the width and length

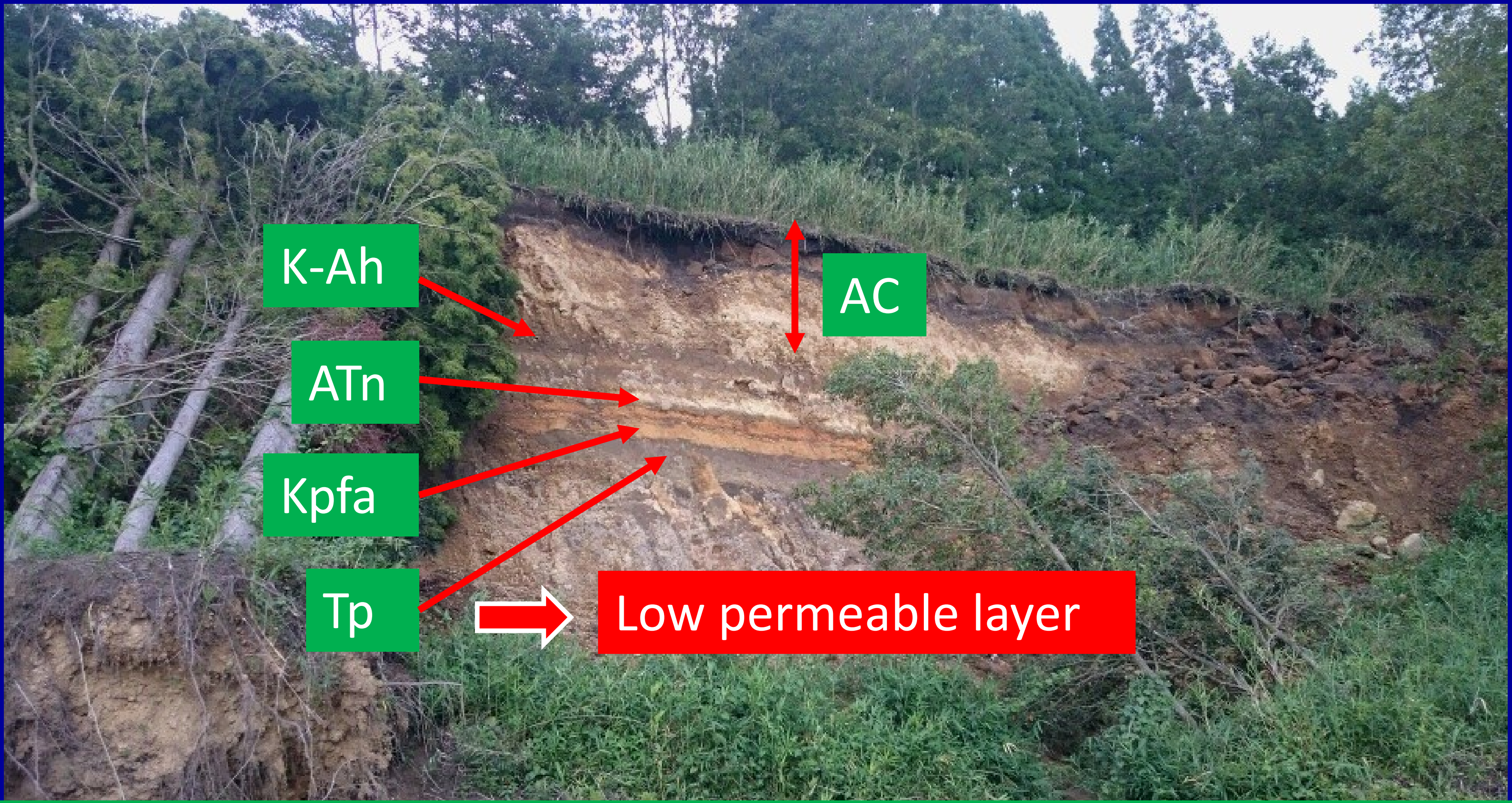
# Geological and Topographical Characteristics of the Landslide

- The landslide occurred on a moderately inclined slope (inclination: 10 to 15 ° ).
- Orange-colored pumice soils were found to be scattered here and there around the failed slope.
- Relatively consolidated tephra layers were found to exist beneath the orange-colored pumice layers in the slope geology, and they were found to be intact.
- Seepage flow was observed close to the pumice layers on the scarp during rainfall (heavy rain during our second field survey).

# Hinotori Hot Spring Disaster (Debris Flow)

- Non plastic volcanic soil (called Hido (灰土) in Japanese) which is very porous with low specific gravity
- Water content was found to be high
- Loses strength with very little load

# Geological Aspects in Aso Area




**AC:** Aso central cone tephra and pumice, 7.3 cal ka～up to now,
**K-Ah:** Kikai Akahoya ash,7.3 cal ka (Dark brown color)
**ATn:** Aira Tn ash,29 cal ka (Shiny white color (glassy))
**Kpfa:** Kusasenrigahama pumice,31 cal ka (Orange color(without biotite))
**Tp:** Pre Takanoobane lava pumice,51±5 ka (Blackish)

# Soil Properties

| Soil Properties | Values |
|---|---|
| Specific gravity | 2.24-2.38 |
| Dry density (g/cm$^3$) | 0.51-0.58 |
| Wet density (g/cm$^3$) | 1.23-1.30 |
| Water content (%) | 54.62-58.36 |
| Liquid limit (%) | 113.40 |
| Plastic limit (%) | 88.25 |
| Plasticity index (%) | 25.15 |
| Sand (%) | 35.8 |
| Silt (%) | 39.2 |
| Clay (%) | 25 |
| Soil classification (JGS 0051-2009) | Volcanic cohesive soil type II ($VH_2$) |

Low specific gravity (Lower than silt and clay

Properties similar to silt with high liquid limit (MH)

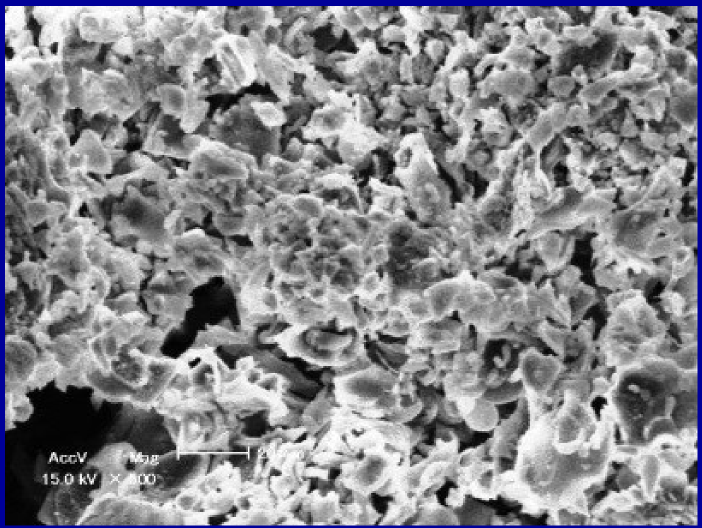
Found near volcano area

# Chemical and Mineral Contents (From XRF and XRD Tests)

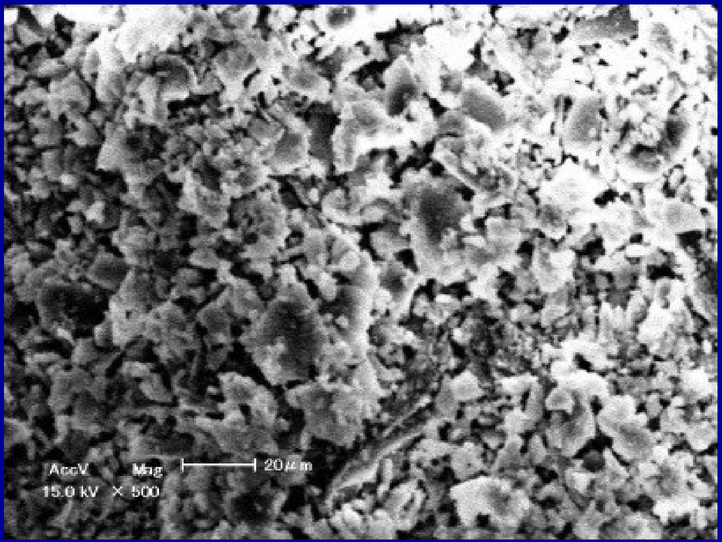
| Chemical content | % |
|---|---|
| $SiO_2$ | 48.832 |
| $Al_2O_3$ | 35.959 |
| Fe2O3 | 8.910 |
| CaO | 3.300 |
| $TiO_2$ | 1.843 |
| $P_2O_5$ | 0.489 |
| $K_2O$ | 0.259 |
| MnO | 0.172 |
| SrO | 0.069 |
| $ZrO_2$ | 0.065 |
| $SO_3$ | 0.060 |
| $Ag_2O$ | 0.018 |
| $Y_2O_3$ | 0.008 |
| ZnO | 0.008 |
| $Ga_2O_3$ | 0.007 |
| NbO | 0.003 |
| Mineral content | % |
| Albite | 57 |
| Bytownite | 40 |
| Sodium Hidrogensulfide | 2.0 |
| Calcium copper germanium oxide | 1.4 |

Contains 57 % Albite and 40 % Bytownite. Presence of these two minerals, known as mineral Plagioclase, contributes to brittle tenacity.

# Microstructure of Soils (From SEM Test)




Before cyclic loading



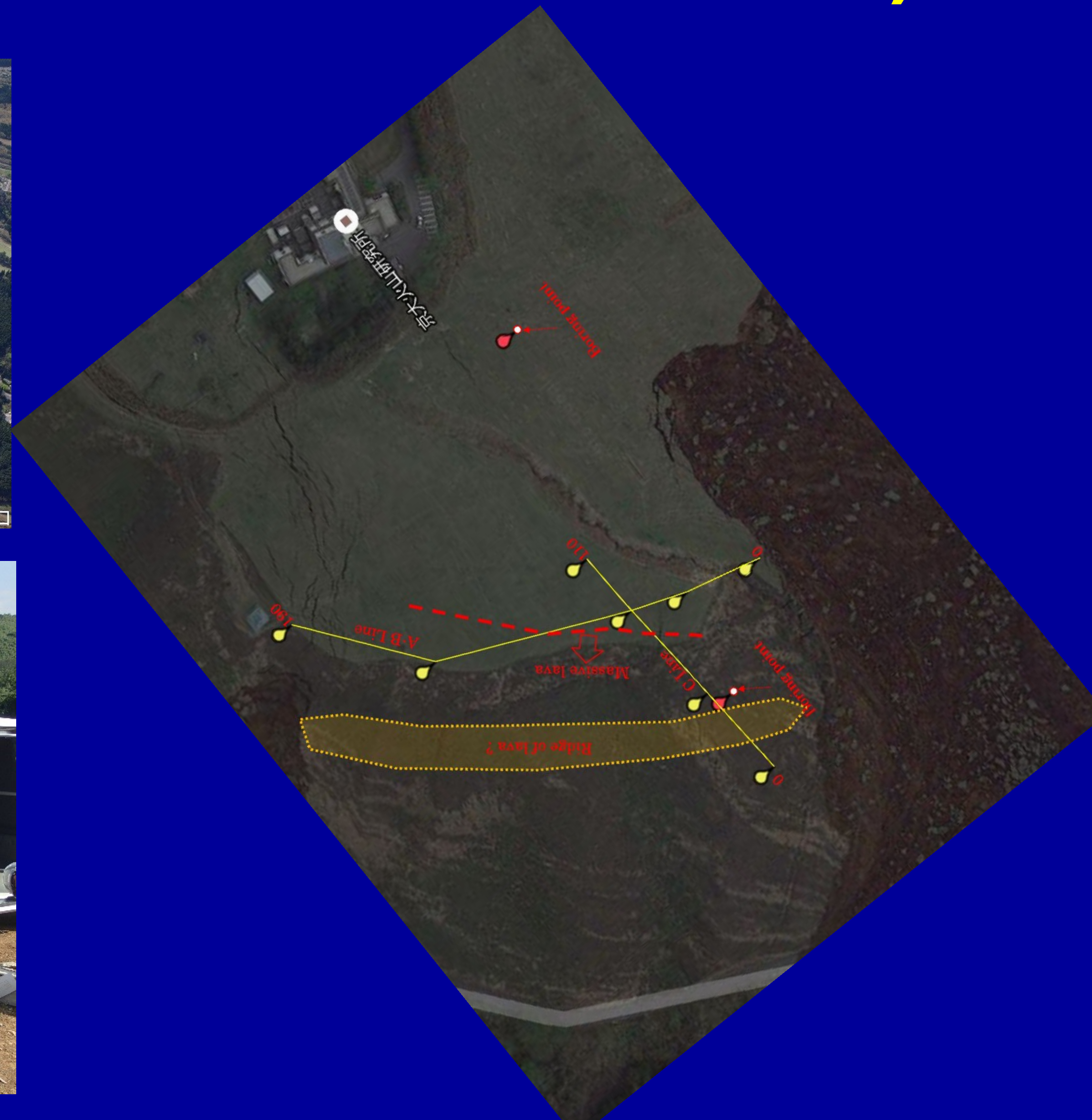

After cyclic loading

- Soil skeleton is formed by crystal flakes with high porosity
- By comparing two photographs (before and after cyclic loading), the amount of fine particles is found to be increased after cyclic loading

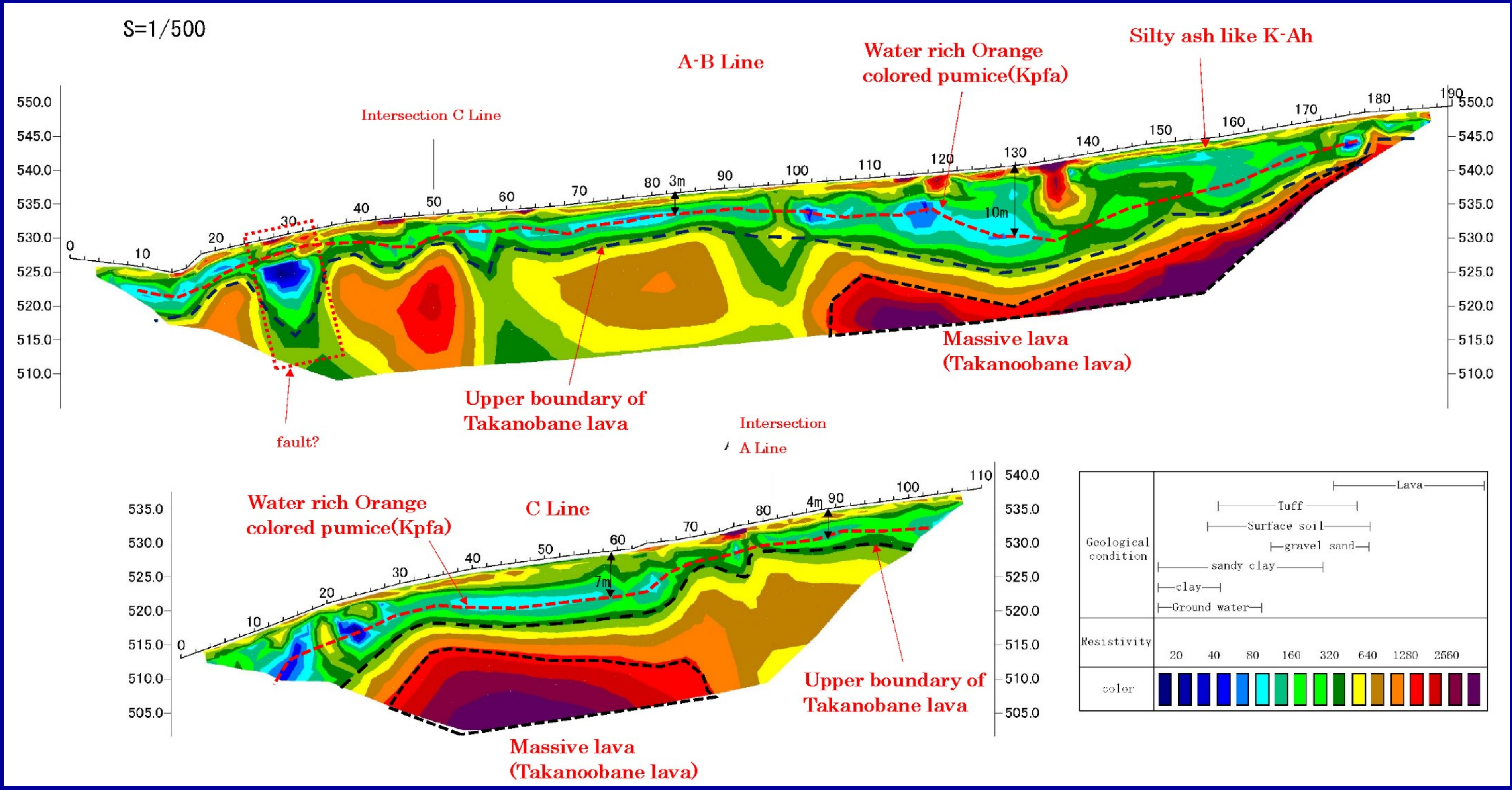
Reference：Paper to be presented by Ms. S. Ode at International Workshop on the 2016 Kumamoto Earthquake, March 6, 2017, Kyushu University, Fukuoka

# Arrangement of Resistivity Sensors (West Slope of Takanoobane)





# Resistivity Profiles

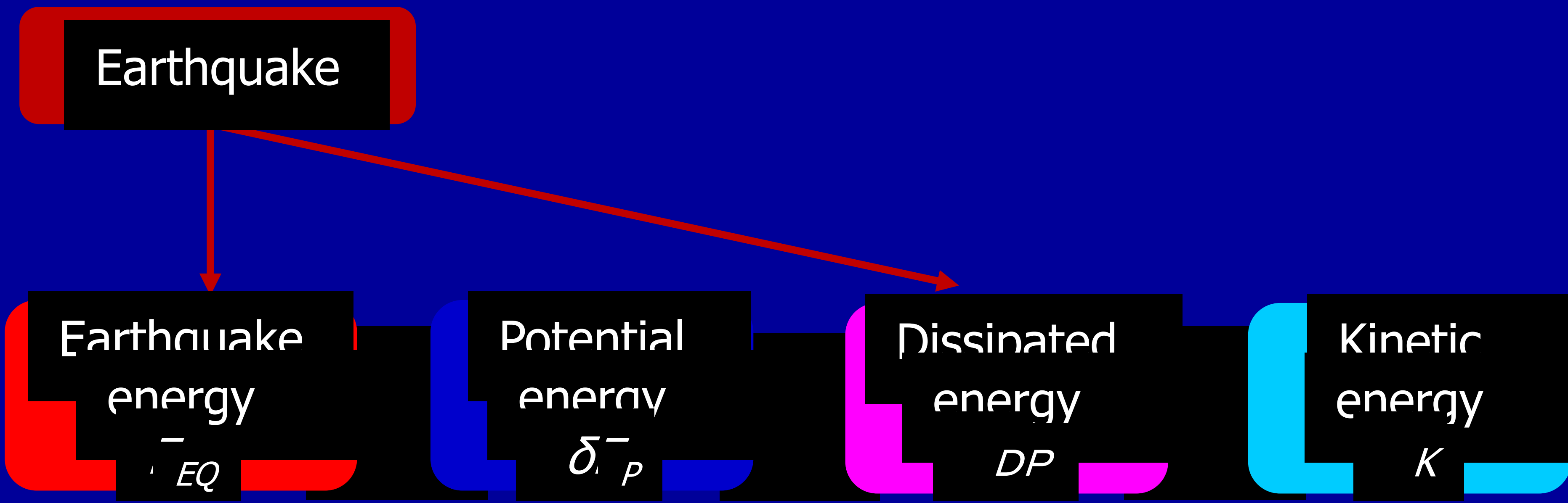



- Kpfa is distributed in a very shallow depth and not parallel to the terrain

Reference：Paper to be presented by Dr. Y. Kochi at International Workshop on the 2016 Kumamoto Earthquake, March 6, 2017, Kyushu University, Fukuoka

# Evaluation of Landslide by Energy-based Approach

## Energy balance in flow-type failure of slopes




$E_{EQ}$: Earthquake energy contributing to slope failure
$E_P$ : Potential energy due to gravity
$E_{DP}$: Energy dissipated in soil due to slope deformation
$E_K$ : Kinetic energy of sliding soil mass


Reference：Kokusho, T. et al. (2014): Energy approach to seismically induced slope failure and its application to case histories –Supplement-, *Engineering Geology*, Vol. 181

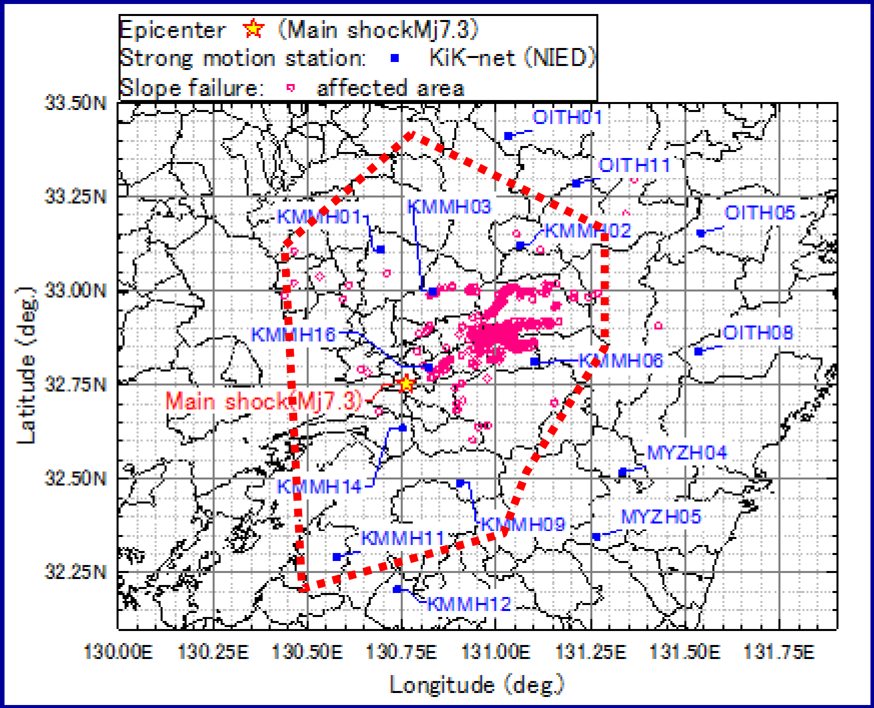
# Performance-based Evaluation of Landslide by Energy Approach

Evaluate Input energy $E_{IP}$

$$E_{IP} = \rho V_S \int (du/dt)^2 dt$$

$\rho Vs$ : Impedance,

$du/dt$ : Velocity time history



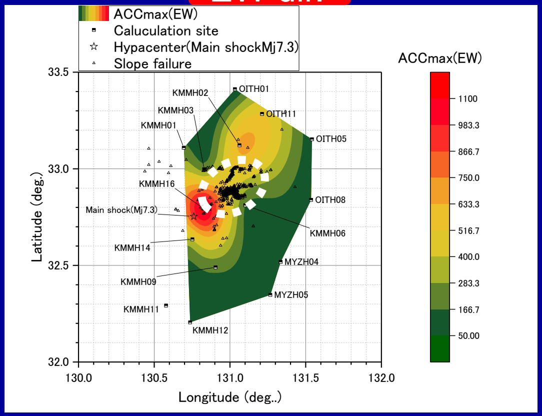

Locations of strong motion stations(NIED), slope failures and epicenter of the 2016 Kumamoto earthquake

# Simulation Results in Aso Area

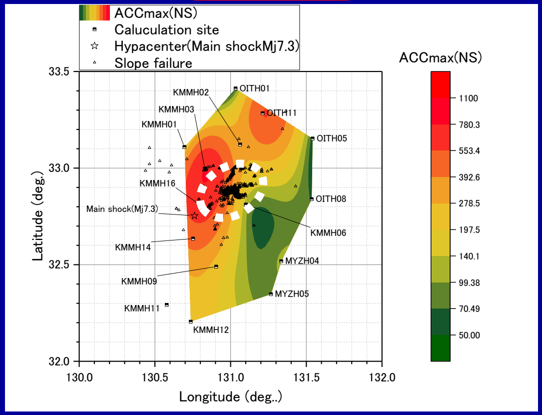
Input earthquake energy $E_{IP}$ at a base layer was calculated from multiple KIK-net vertical array records (NIED).

Maximum acceleration distribution map

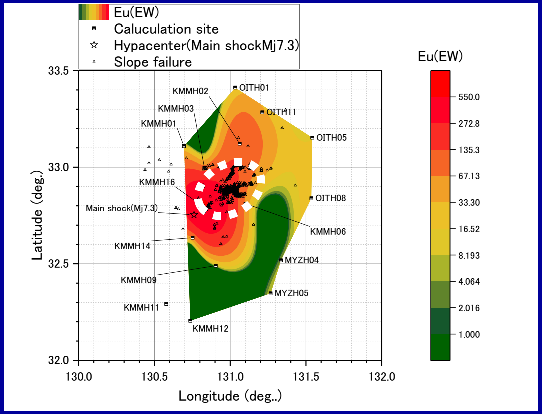
EW dir.

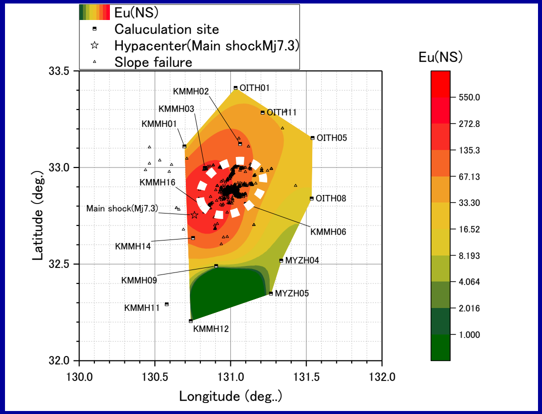



NS dir.




Input energy $E_{IP}$ distribution map




- Acceleration value ⇒ small
- Input energy value ⇒ large

# Energy Vs Hypocentral Distance

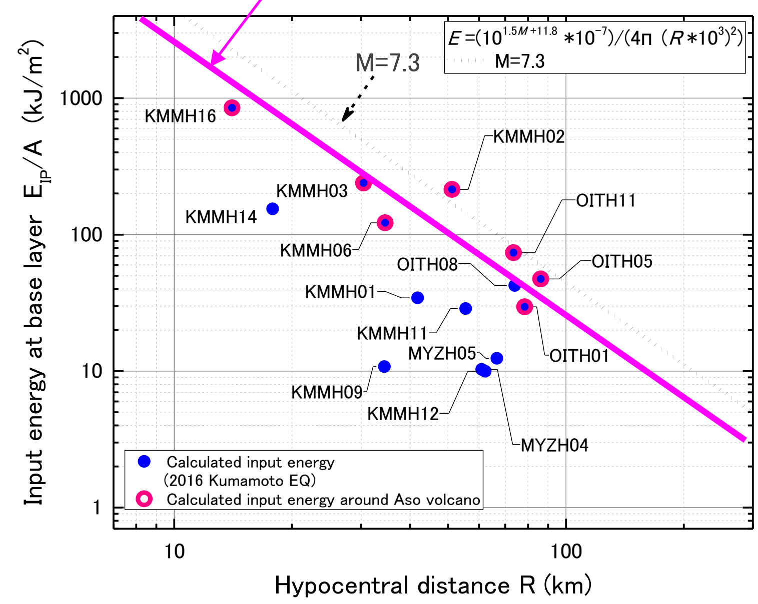
Simple theory of spherical energy radiation

Gutenberg and Richter (1956)

$$\log E = 1.5M + 11.8$$

Spherical energy radiation of body wave $E_{IP}/_A = E/_{(4\pi R^2)}$

Approximate line by M=7.1 Kumamoto EQ.



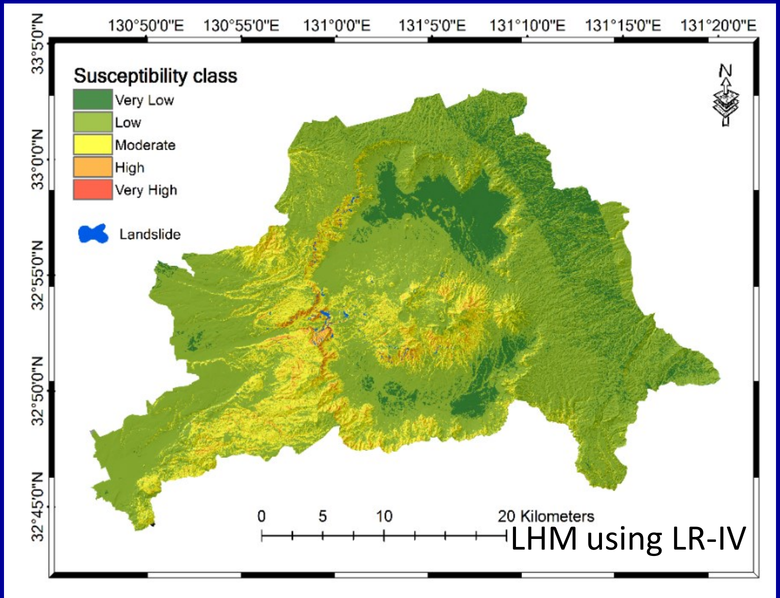

Reference：Paper to be presented by Dr. T. Ishizawa at International Workshop on the 2016 Kumamoto Earthquake, March 6, 2017, Kyushu University, Fukuoka

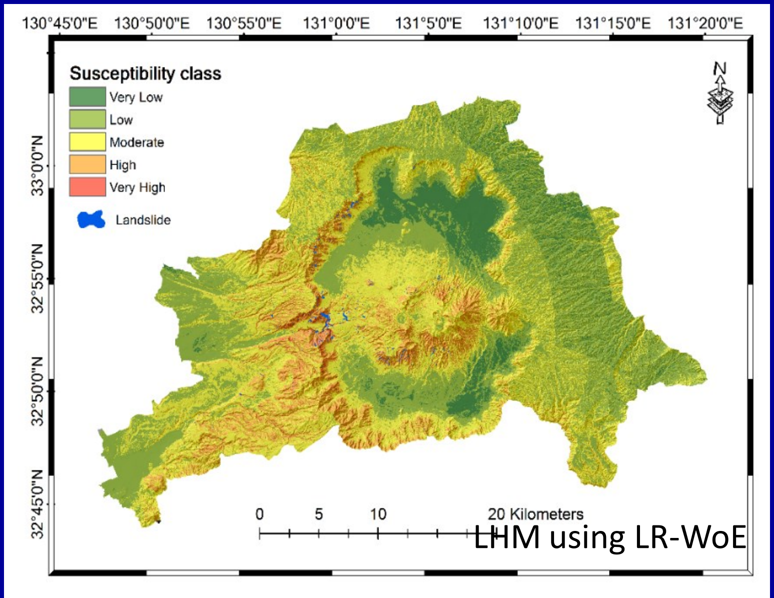
# Landslide Predictive Factors



| No. | Factor |
|---|---|
| 1 | Slope gradient |
| 2 | Aspect |
| 3 | Elevation |
| 4 | Plan curvature |
| 5 | Profile curvature |
| 6 | Terrain roughness |
| 7 | Lithology unit |
| 8 | Distance to seismic fault |
| 9 | SPI |
| 10 | TWI |
| 11 | Drainage density |
| 12 | Distance to stream |
| 13 | NDVI |
| 14 | PGA |
| 15 | Constant |

# Landslide Hazard Maps




- High and very high vulnerable zones are located in the central parts of the study area, especially around the Aso volcano.
- The area which contained volcanic ash, very high elevation and steep slopes was classified as the high and very high hazard zones.
- The developed landslide hazard map showed that the probability of landslide occurrence is large in high slope and high elevation areas.

Reference：Paper to be presented by Prof. G. Chen at International Workshop on the 2016 Kumamoto Earthquake, March 6, 2017, Kyushu University, Fukuoka

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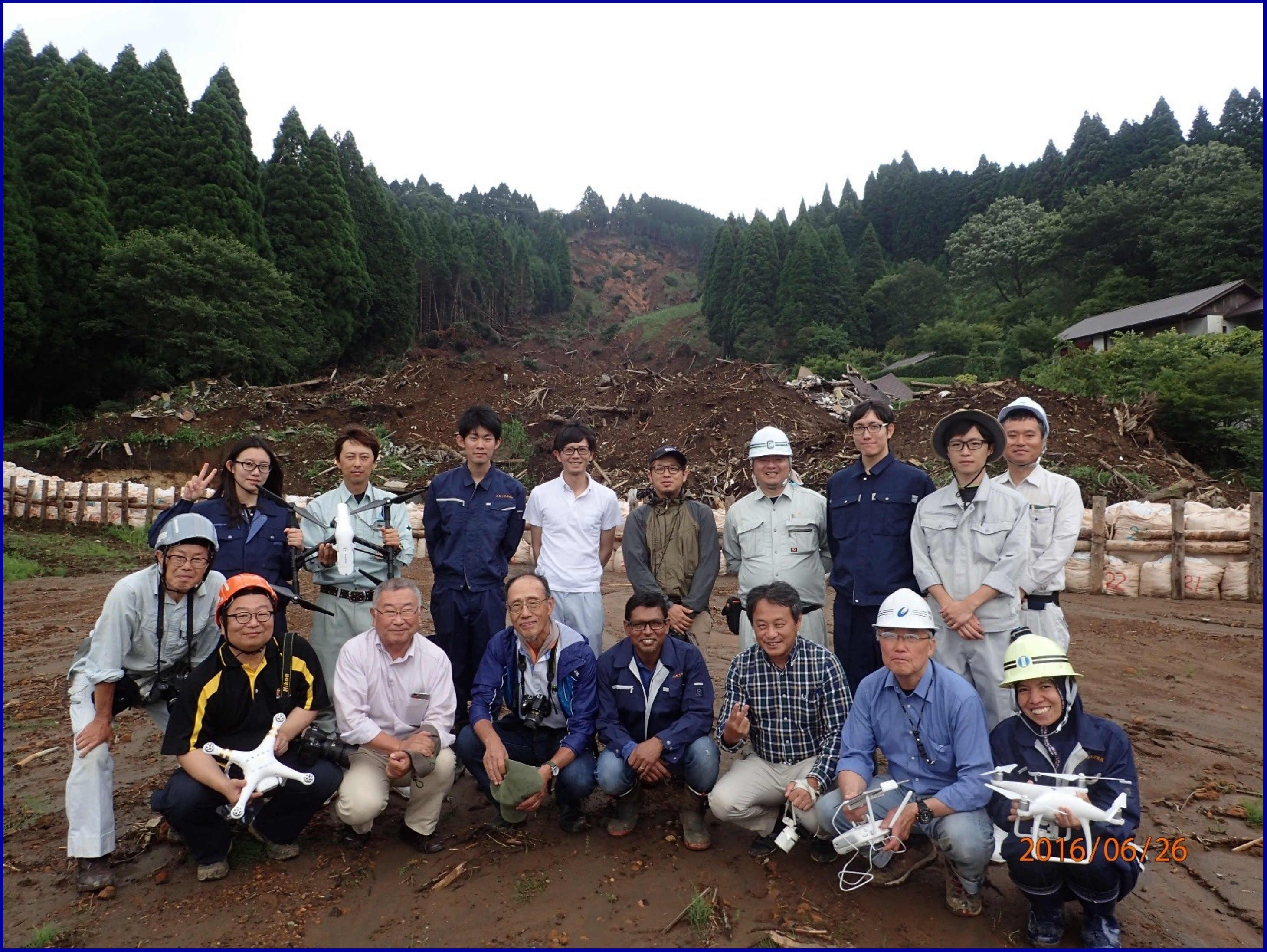
# Japan-USA Joint Investigation Team

# J-RAPID Project Team of Japan



**Thank you for your kind attention**