Ground fissures that appeared in Aso Caldera Basin in the 2016 Kumamoto Earthquake, Japan

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Key Facts
- Hazard Type: Earthquake
- Date of disaster: April 14th and 16th, 2016
- Location of Survey: Northwestern part of Aso caldera, Kumamoto, Japan
- Date of the field survey: April 29th to May 2nd, 2016
- Survey tools: Unmanned aerial vehicle (UAV), GPS

Key findings:
1) A swath of ground depression extends fragmentally over about a 10 km distance in the Aso Caldera Basin.
2) Detail features of the ground depression observed by using UAV photos showed neither clear indication of soil liquefaction nor lateral offset of the ground.

Key Words : *Kumamoto Earthquake, surface ruptures, UAV photogrammetry*

1. INTRODUCTION

Starting with a magnitude-6.5 shock on April 14, 2016, a series of major earthquakes including the magnitude-7.3 main shock on April 16 have hit the central Kumamoto area of Japan, causing deaths, injuries and widespread damage to various facilities along the fault rupture lines. One of the seldom-seen-before phenomena was an about 10 km-long swath of ground depression that appeared in the northwestern part of the basin of Aso caldera, one of the world's largest calderas stretching 25 km north to south and 18 km east to west, with its interior having been stable enough to cultivate land, lay railroads and highways. The damage to agricultural and forestry businesses caused by the twin quakes is very serious, reportedly reaching 23.6 billion JPY at least[1)], which surely include those along the swath of ground depression cutting irrigation canals, water pipes, roads and others, particularly at this time of rice planting.

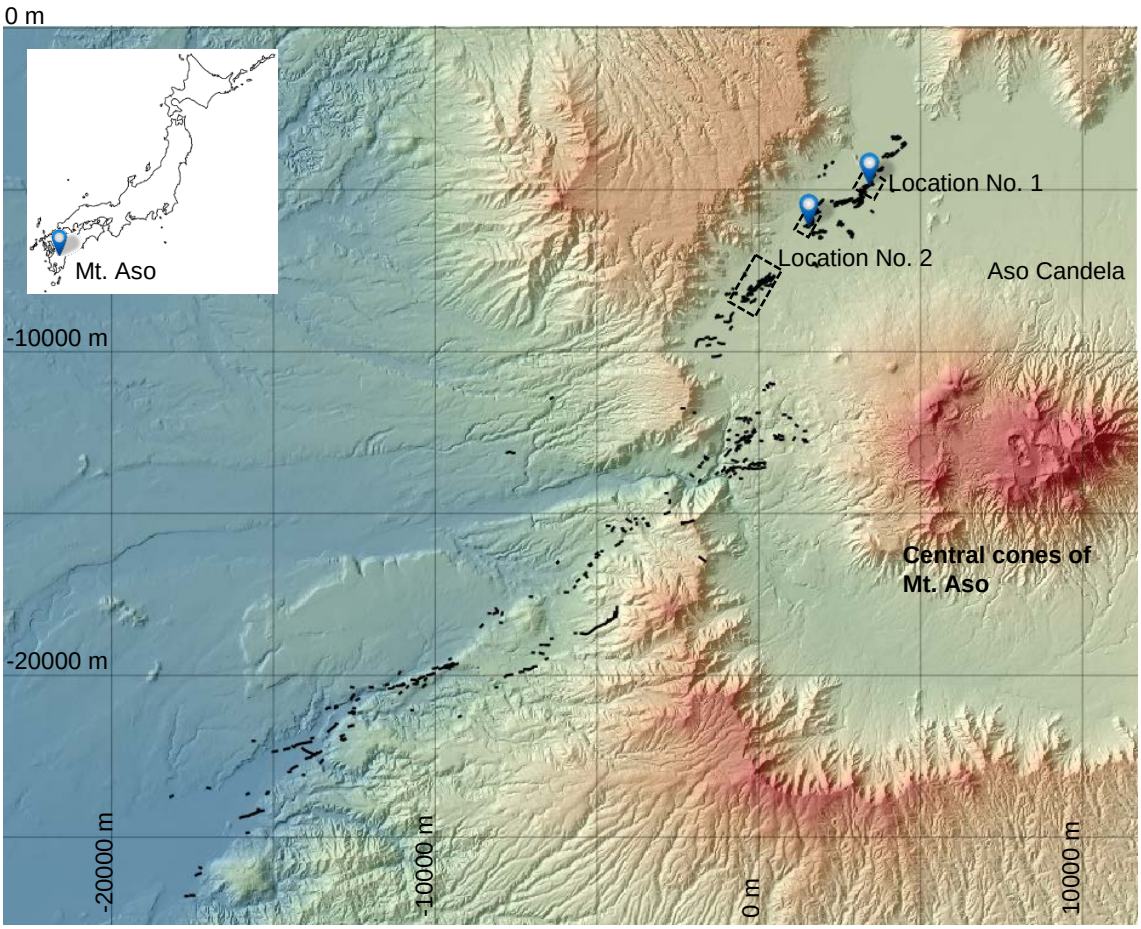

Fig. 1 Aerial photointerpretation of cracks that appeared on the ground surface: Interpretations of southwestern and northeastern segments of cracks were made by the Geospatial Information Authority of Japan[2)] and Kokusai Kogyo Co. Ltd.[3)], respectively. Authors' survey was conducted within areas enclosed in boxes of dashed line . UAV was flown over Locations 1 and 2 (Coordinate reference system: JGD2000 / Japan Plane Rectangular CS II)

The cause of this ground depression is not identified yet. However before the swath of ground depression is wiped off for quick recovery of farm lands, an unmanned aerial vehicle (UAV) is used for photogrammetry at some locations on the swath.

2. SWATH OF GROUND DEPRESSION

Fig. 1 shows cracks that appeared on the ground surface. Aerial photo-interpretations of southwestern and northeastern segments of cracks were made by the Geospatial Information Authority of Japan[2)] and Kokusai Kogyo Co. Ltd.[3)], respectively. They include every visible cluster of cracks no matter what their causes are. Majority of cracks of the southwestern segment appeared along the Hinagu and Futagawa fault system, whose presence had been recognized, while northeastern segment of cracks exhibits a complex, interwoven pattern of fractures diagonally across the basin sediment of Aso Caldera. Though complicated, the latter is clearly characterized by a swath of ground depression that extends fragmentally over about a 10 km distance.

Flying over at a particular point at around N32.9662º, E131.0364 for example, one notices that the swath of ground depression is about 40 to 50m wide and 1 to 1.5 m deep (Fig. 2). A pair of UAV photographs shown in Fig. 2 can be perceived as a single image in terms of depths. As can be perceived, southeastern ends of plastic greenhouses dropped down onto the depressed ground. Water is stopped along the southern vertical offset of the ground. No clear indication of either right-lateral of left-lateral offset can be seen at this location.

Being located several 10m NNE off the UAV picture frame, there is a house standing by the edge of northwestern offset of the ground at N32.9568º, E131.0368 (Fig. 3). The exposed soil wall shows a stratified structure of brownish volcanic ash, pumice and andosol, which is highly porous and dark-colored developed from volcanic ash mixed up with organic matters. The crack here was more than 1 m deep with no clear indication of sand ejecta. A lady, the owner of the house standing by the car on the right,

Fig. 2 A pair of UAV photographs of ground depression with the center of each photograph located at around N32.9662º, E131.0364, Location No. 1 in Fig. 1 (Flight altitude: 75m)

Fig. 3 House hanging a little over the northwestern offset of the ground at N32.9568º, E131.0368 (near Location No. 1)

witnessed that "her neighbor's house behind her dropped all at once, keeping its shape as it was, immediately when the intense shake of the main event of April 16th hit it. The drop of the ground was

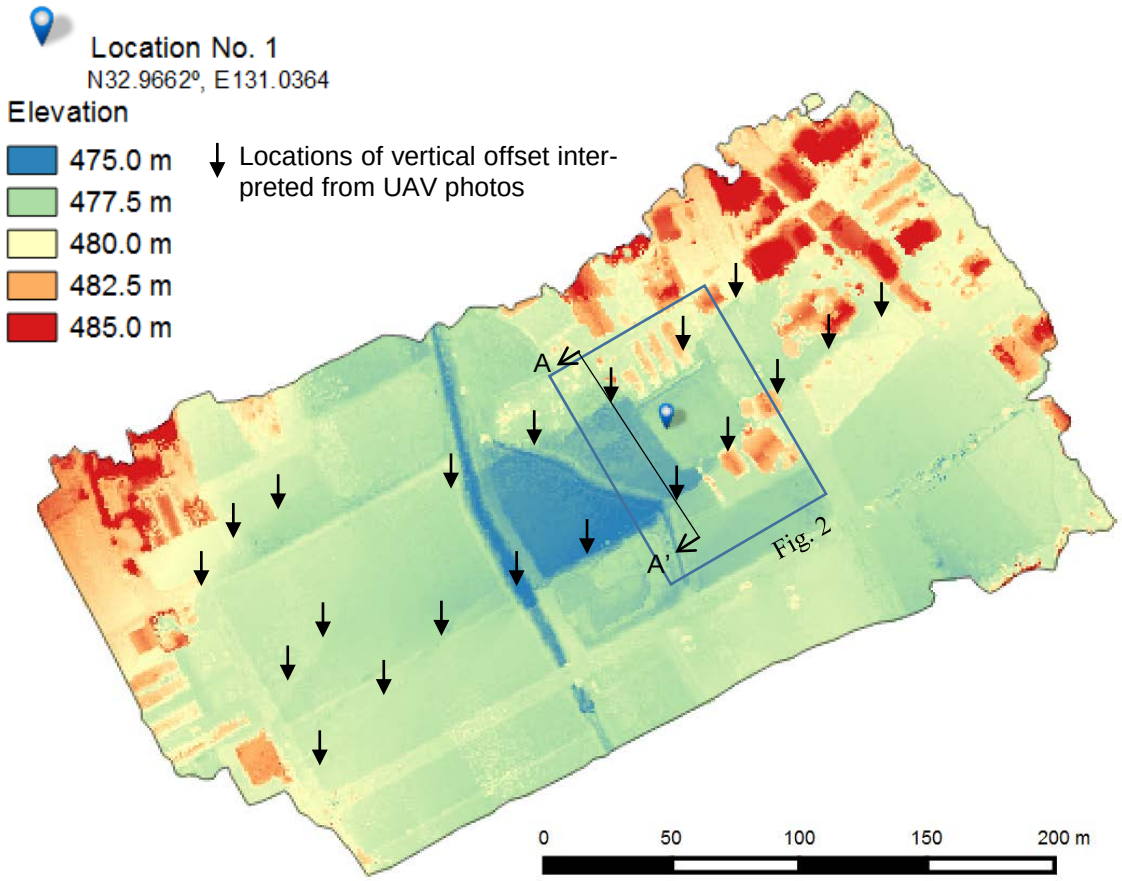

Fig. 4 Digital surface model of one part of swath of ground depression (Location 1, at N32.9662º, E131.0364º)

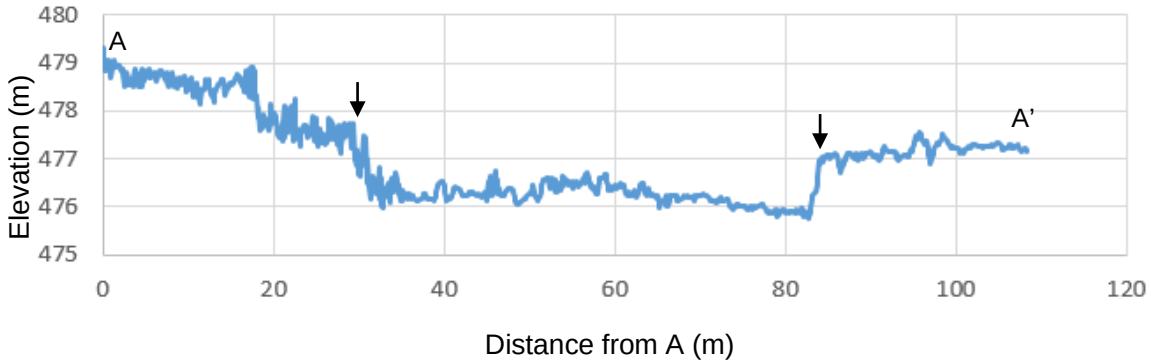

Fig. 5 Cross-section A-A' in Fig. 4

anything but slow".

A UAV-based 3D digital surface model (DSM) was prepared as shown in Fig. 4. To fully define the coordinate system for the extracted DSM, four points were chosen off the swath of ground depression. Exact absolute positioning of these points with an advanced system such as dual-frequency GPS is mandatory, but for a quick and preliminary discussion, the coordinate values for these points were taken from "CyberJapan", a digital Japan tile map layer provided by Geospatial Information Authority of Japan. The obtained DEM can be thus subject to change in later publications.

Though the cloud of points extracted from DSM shows not only the bare ground surface but also vegetation and artificial objects, the swath of ground can be clearly seen particularly in the middle of the covered area where the swath is narrowest and deepest enough to stop water. A cross-section was taken along Line AA' in Fig. 4 (Fig. 5). A pair of two clear ground offsets shows that the swath has fallen by about 1m here. The swath of ground depression becomes gradually shallower and wider towards west end of the UAV-covered area.

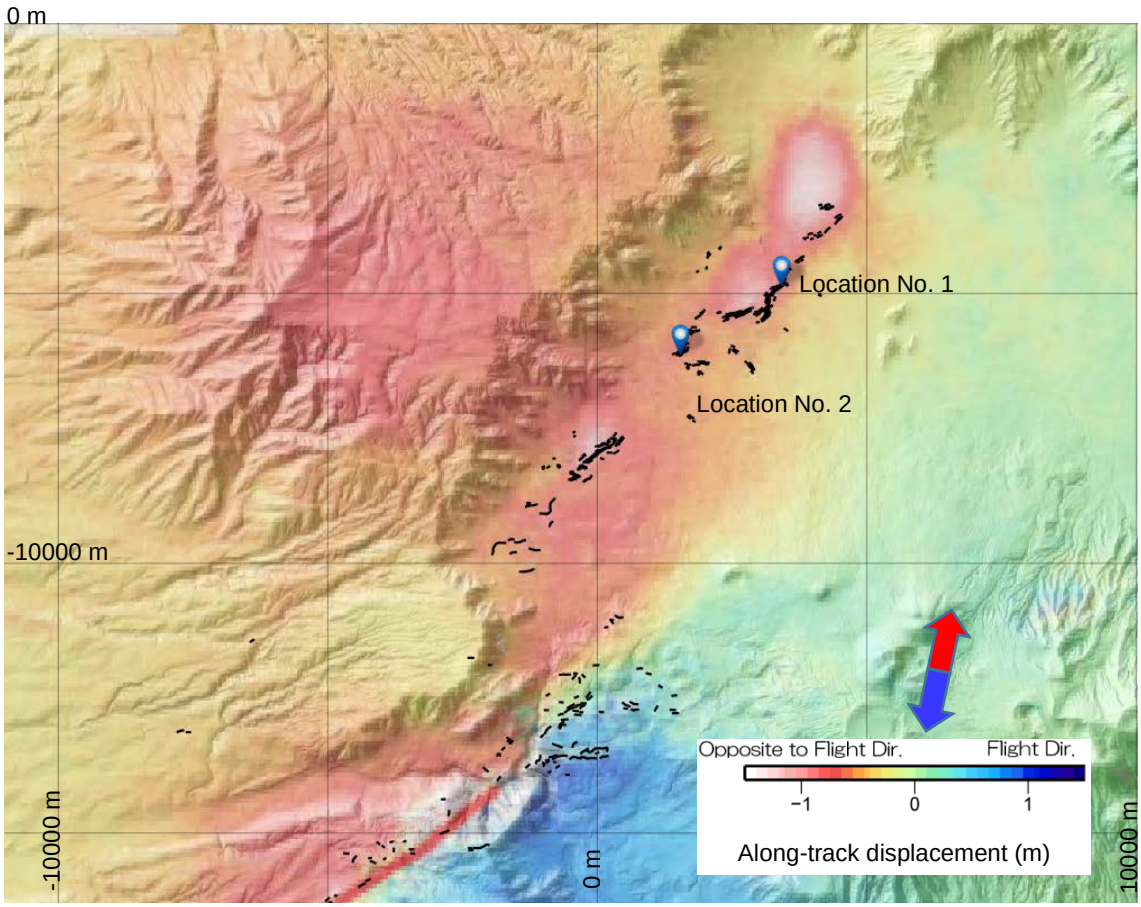

Fig. 6 Cracks laid over the along-track displacements pattern analyzed by the Geospatial Information Authority of Japan using MAI (Multiple Aperture Interferometry) method[5)]
(Coordinate reference system: JGD2000 / Japan Plane Rectangular CS II**)**

3. DISCUSSION AND SUMMARY

It is controversial if the abovementioned features of the ground offset represent all of the ground depression that appeared over a 10 km distance in Aso Caldera. However, as far as the locations that the authors have visited (Boxes of dashed line in Fig. 1), soil profiles exposed on the offset walls are much alike. No clear indication of sand ejecta was found, which ejecta may have canceled the soil volume that have subsided. This depression may be due to shaking-down settlement, grain crushing of porous volcanic products, and/or just a reflection of deep-seated tectonic movements which exhibits some tensile components in the transverse direction of the swath of ground depression. By way of trial, the cracks were laid over the along-track displacements pattern analyzed by the Geospatial Information Authority of Japan using MAI (Multiple Aperture Interferometry) method[5)]. The cracks seemingly appear where large tensile strain built up (Fig. 6).

Whatever the cause was, the swath of ground depression is to be recorded in a quantitative manner, because large ground deformations can be repeated in any extreme natural events as can be seen in the past major earthquakes.

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REFERENCES

1) Kumamoto farms, forestry suffered ¥23.6 billion damage in quakes, The Japan Times News, APR 27, 2016, http://www.japantimes.co.jp/news/2016/04/27/business/kumamoto-farms-forestry-suffered-%C2%A523-6-billion-damage-quakes/#.Vy3FCISLRD8.
2) Crack map along Futagawa fault, Geospatial Information

Authority of Japan, April 20th, 2016.
http://www.gsi.go.jp/common/000139899.pdf.
3) Map of landslides and ground fissures, No. 1, Kokusai Kogyo Co. Ltd.,
http://www.kkc.co.jp/service/bousai/csr/disaster/201604_kumamoto/pdf/0421_02.pdf
4) CyberJapan, Geospatial Information Authority of Japan
http://maps.gsi.go.jp/#15/32.956285/131.036832/&base=std&ls=std&disp=1&vs=c1j0l0u0f0
5) Crustal Deformation around the Faults Revealed by MAI analysis, Geospatial Information Authority of Japan, April 28th, 2016.
http://www.gsi.go.jp/cais/topic160428-index-e.html

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