Field Survey of Non-tectonic Surface Displacements Caused by the 2016 Kumamoto Earthquake Around Aso Valley

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Abstract

The 2016 Kumamoto earthquake caused a large number of surface ruptures (cracks, depressions) and surface earthquake faults emerged along known active faults. Depressional ruptures occurred in Aso Valley. Remarkable horizontal displacements were observed by satellite SAR analysis around the depressional (graben-like) ruptures area. As a result of field surveys around the area, shortening deformations of constructions were identified along the northern edge of the deformed areas as detected by SAR interferogram as well as opening ruptures around the southern edge of the deformed area. It is presumed that these horizontal displacements with depressional ruptures and shortening deformations were caused by lateral movement of shallow underground layers.

1. Preface

The 2016 Kumamoto Earthquake caused a large number of surface ruptures such as open cracks, shortening cracks, depressions, and surface earthquake faults emerged along known active faults. These surface ruptures were associated with surface earthquake faults, gravity deformation of slope, ground liquefaction, etc.

The Geospatial Information Authority of Japan (GSI) was able to clearly identify these ruptures in the aerial photos taken by GSI in the earthquake disaster area and then analyzed and interpreted these ruptures over a wide area (Nakano et al., 2016; Yoshida et al., 2016).

Among these surface ruptures, the surface ruptures that occurred in Aso Valley which is located to the north of Aso Volcano, were distinctive. Also, topical surface displacements were detected by satellite SAR analysis using ALOS-2 data around this area (Fujiwara et al., 2016a).

Therefore, field surveys were conducted in the area in order to confirm the actual condition of the surface displacements.

2. Outline of Study Area

Figure 1 shows the area of interest in this study. This area is located in the northwest of the Aso Valley which is formed at the north side of Aso Volcano within Aso Caldera.

Between ca. 21,000 years ago and ca. 8,000 years ago, there was a lake in Aso Caldera where lake sediments deposited (Ono and Watanabe, 1985; Uchikoshiyama and Hase, 2011) and flatland (flood plain) extended into Aso Valley. This flood plain was formed to reclaim the Caldera Lake, and marsh zones are distributed in northern part of Aso Valley where reclamation was delayed (GSI, 1994). Also, natural levees and former river beds formed by Kurokawa River which was flowing east to west in Aso Valley are distributed on the flood plain. Alluvial fans formed by erosion debris from central cones of Aso Volcano and taluses formed by depositing of debris from caldera wall are distributed at the periphery of the flood plain (GSI, 1994).

Highest seismic intensity during the Kumamoto Earthquake in this area (Uchinomaki, Aso City) was 6- (Japan Meteorological Agency, 2016).

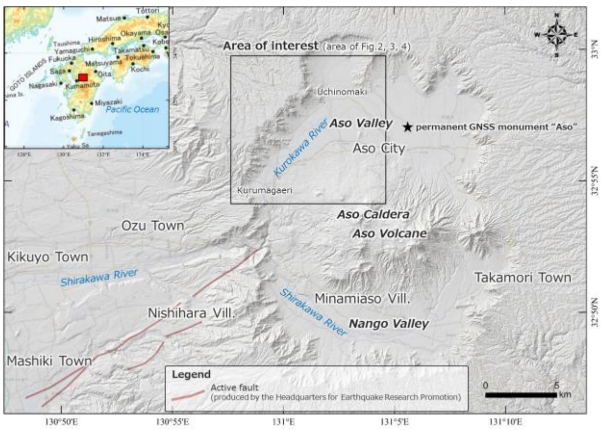

Fig. 1 Study area (GSI Maps is used as the background map. Shaded-relief map is created by using 10 m DEM data of GSI)

GEONET, which is the continuous GNSS observation network operated by the GSI, recorded approximately 13 cm horizontal displacement in the northwestward direction and vertical subsidence of approximately 8 cm at the Aso site (GSI, 2016a).

3. Observed Phenomena in the Study Area

3.1 Surface Ruptures Identified From Aerial Photos

Figure 2 shows the distribution map of surface ruptures identified from aerial photos taken after the 2016 Kumamoto Earthquake in the study area. The background map shows landform classification of the 1:30,000 scale land condition map of volcano "Mt. Aso".

In this area, clear surface ruptures were identified from the Kurumagaeri area to Uchinomaki area, Aso City. The surface ruptures are arranged linearly or in a meandering pattern, and as a whole are arranged in north-east to south-west direction.

Stereoscopic vision interpretation of aerial photos made it possible to confirm that the ground between some major parallel surface ruptures collapsed in graben-like shapes around the Matoishi area and the Shimonohara area, Aso City.

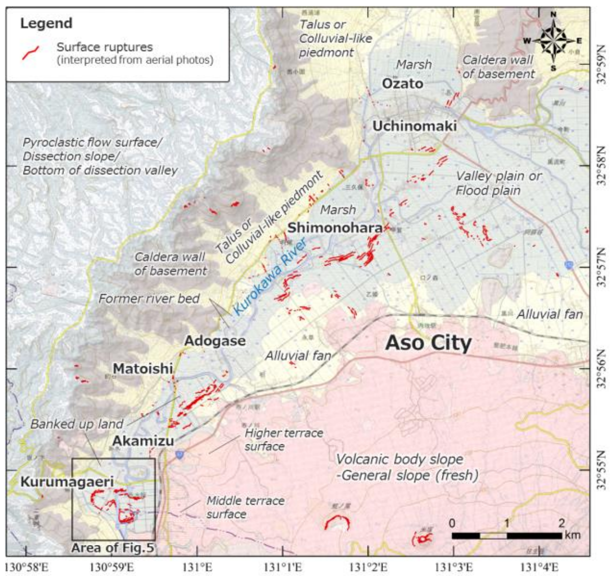

Fig. 2 Distribution map of surface ruptures as identified from aerial photos taken in the study area. GSI Maps and the 1:30,000 scale land condition map of volcano "Mt. Aso" are used as the background map.

Also, as the shape of the meandering surface ruptures in the Kurumagaeri area matches the shape of the banked-up land of the former river bed, it is presumed that these meandering surface ruptures were caused by ground subsidence associated with ground liquefaction of former river bed. However, the relationship between location of surface ruptures and landform does not always match in other areas.

3.2 Surface Displacements Detected by SAR Analysis

Figure 3 shows the surface ruptures as overlaid on a representative SAR interferogram using ALOS-2 data in the study area.

A non-interference zone approximately 1.3km in diameter can be identified in the Matoishi area. Around Shimonohara area, there is a mixture of non-interference zones and interference fringes in the range of approximately 2 km from east-to-west and approximately 1.3 km from south-to-north. The diameter of this interference fringe zone is approximately 2.5 km around the Uchinomaki area. According to Fujiwara et al. (2016a), surface deformations can be observed in these areas having a horizontal displacement of more than 2m in a north-northwest direction.

Many surface ruptures are distributed around the southeastern periphery of these surface displacements. Also, GSI (2016b) suggests that these surface displacements have almost no vertical component and displace mostly horizontally toward the caldera wall (Fig. 4). These features are also clarified by the differential analysis between pre- and post-earthquake digital elevation model (DEM) produced by airborne laser survey (JSEG 2016 Kumamoto-Oita Earthquake disaster investigation team, 2016a). In comparison with landform classification of Figure 2, the surface displacements in the Shimonohara area and Uchinomaki area seem to move toward the marsh zone.

The SAR interferograms indicate that these surface displacements only occur within certain areas and do not occur in other areas. This phenomenon suggests that large-scale surface displacements were located in extremely shallow zones (Fujiwara et al., 2016a).

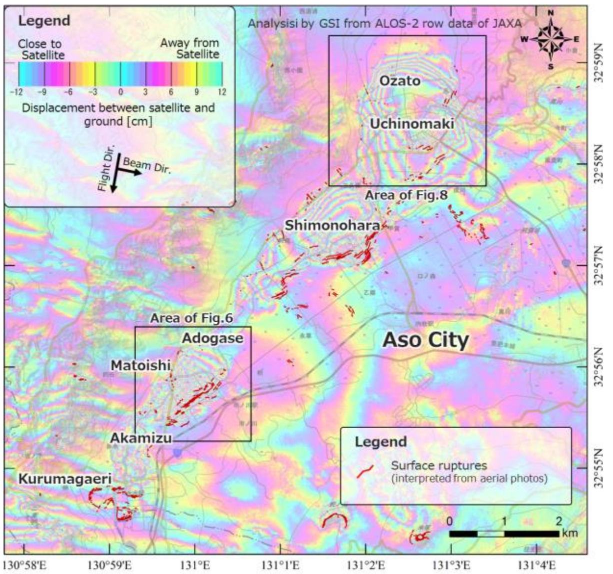

Fig. 3 Surface ruptures distribution and representative SAR interferogram by ALOS-2 data (Apr. 15, 2016-Apr. 29, 2016) of study area

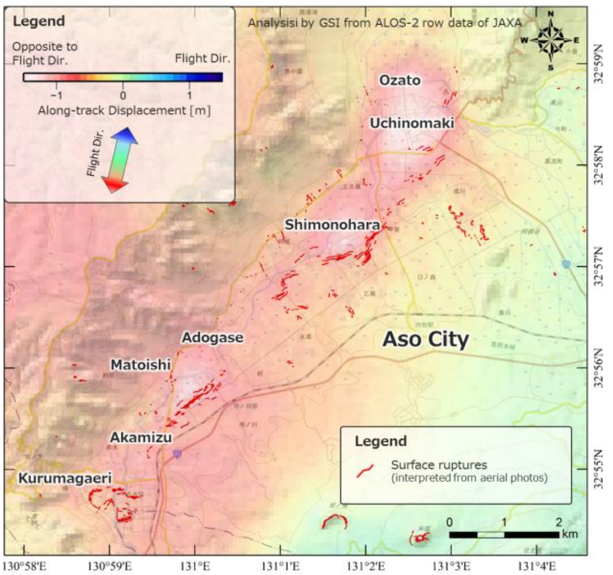

Fig. 4 Surface displacement map around the study area as revealed by MAI (Multiple Aperture Interferometry) analysis (modified from GSI (2016b)). MAI is a technique for measuring ground displacement along flight direction of the satellite (azimuth offset) using two SAR images.

4. Outline of Field Survey

Field surveys were conducted at the distinctive interference fringe areas in order to understand the actual condition of the surface displacements. Our main survey areas were Kurumagaeri, Matoishi and Uchinomaki (Fig. 2, 3).

The field surveys were carried out on May 11 and August 15, 2016. Surveys were carried out at the following places in each area: 1) places of clear graben-like ruptures located along the southern edge of horizontal displacement as detected by SAR interferogram, 2) places located around the northern edge of horizontal displacement as detected by SAR interferogram; although clear ruptures could not be identified from aerial photos.

It was expected that open cracks associated with extension field would be found at the points as described at above item 1) and shortening cracks associated with compression field would be found at the point as described at above item 2).

5. Findings by Field Survey

5.1 Kurumagaeri Area

Figure 5 shows a close up figure of the Kurumagaeri area shown in the Figure 2. In this area, graben-like ruptures were confirmed along former river bed. Major ruptures cross a paddy field surface and a road, which matches the result of aerial photos interpretation (Photo 1), and the portion of the road between two ruptures subsided approximately 30 cm (Photo 2).

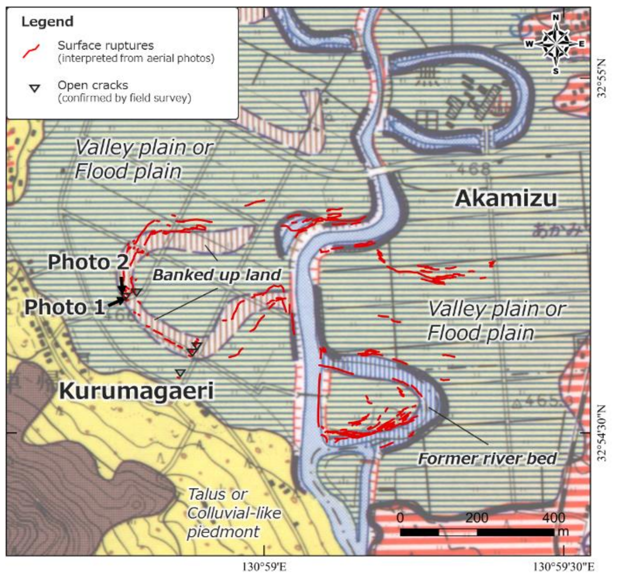

Fig. 5 Distribution map of surface ruptures around Kurumagaeri (The 1:30,000 scale land condition map of volcano "Mt. Aso" is used as the background map)

Photo 1 Graben-like ruptures along former river bed in Kurumagaeri area (taken towards the northeast on May 11, 2016)

Photo 2 Western edge of graben-like ruptures along former river bed in the Kurumagaeri area (taken towards the south on May 11, 2016)

5.2 Matoishi Area

Figure 6 shows a close up image of the Matoishi area as shown in the Figure 3. At spots with graben-like ruptures located along the southern edge of the horizontal displacement areas as detected by SAR interferogram, there were open cracks with vertical offsets of up to 70 cm (Photos 3, 4). The total width of open cracks was approximately 95 cm.

Around the northern edge of the horizontal displacement areas (Adogase, Aso City), a large number of shortening and open cracks perpendicular to the road were found on the road running north-northwest to south-southeast (Photo 5). The total shortening length of multiple shortening cracks was approximately 130 cm.

Also, at the Taisho Bridge over the Kurokawa River, the boundary between the bridge and embankment was greatly shortened with approximately 280 cm relatively towards the north (Photo 6). A bulge-like up-lift of the river bed can be identified on the aerial photo taken after the earthquake (Fig. 7). These damages were also reported by other organizations (e.g. JSEG 2016 Kumamoto-Oita Earthquake disaster investigation team (2016b)).

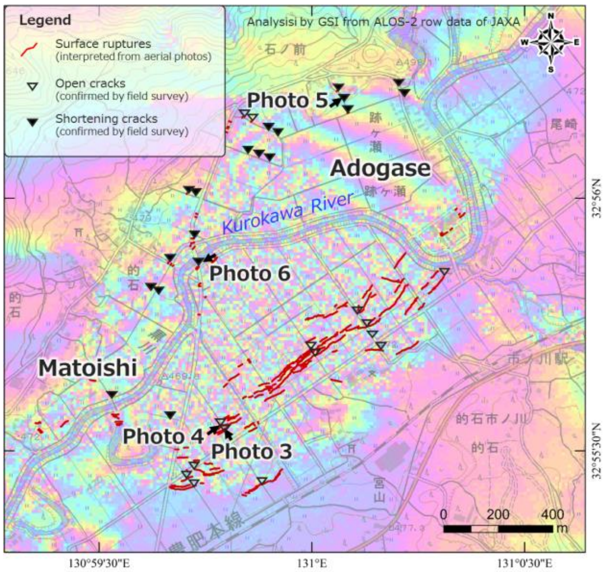

Fig. 6 Overlay of ruptures distribution and field surveyed-cracks on the SAR interferogram (Apr. 15, 2016-Apr. 29, 2016) around the Matoishi area

Photo 3 Graben-like rupture in the Matoishi area (taken toward the northwest on May 11, 2016)

Photo 4 Graben-like rupture in the Matoishi area (taken toward the northeast on May 11, 2016)

Photo 5 Shortening deformation of the road and lateral gutter (taken toward the northeast on May 11, 2016). The lateral gutter was shortened approximately 20 cm.

Photo 6 Shortening deformation of Taisho Bridge (taken toward the west-southwest on Aug. 15, 2016). Embankment was displaced approximately 280 cm relatively towards the north (right side of photo).

Fig. 7 Bulge-like uplift of Kurokawa River bed identified by aerial photo (taken on Apr. 16, 2016)

5.3 Uchinomaki area

Figure 8 shows a close up image of the Uchinomaki area shown in Figure 3. At spots with graben-like ruptures located along the eastern edge of the interference fringe (Ozato/Yuyama, Aso City), a depression was identified between two major ruptures extending in the north-northeast to south-southwest direction (Photo 7). The vertical offset of the ruptures was approximately 50 cm with a side slip of approximately 5 cm.

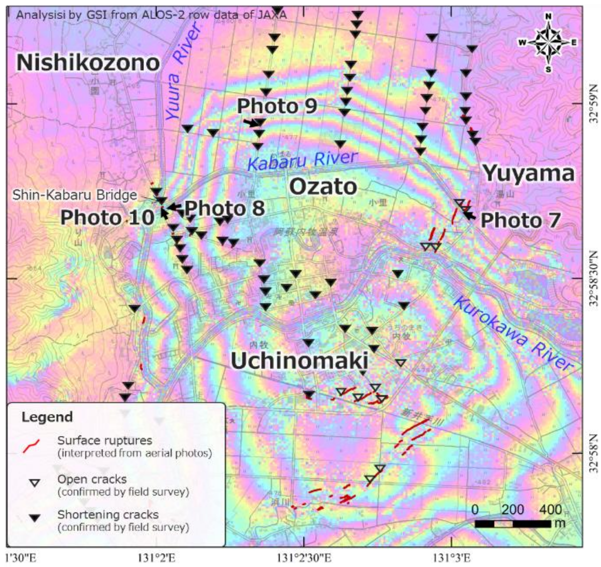

Fig. 8 Overlay of the surface ruptures and field surveyed-cracks on the SAR interferogram (Apr. 15, 2016-Apr. 29, 2016) around the Uchinomaki area

Around the northern and northwestern edge of horizontal displacement (Ozato/Nishikozono, Aso City), a large number of shortening cracks were identified on the roads and bridge around the junction of Yuura River and Kabaru River and roads around paddy fields located in marsh zones (Photos 8, 9). Shin-kabaru Bridge over the Yuura River was lifted up due to a shortening deformation (Photo 10).

Photo 7 Graben-like rupture at the Ozato/Yuyama area (taken toward the northwest on May 11, 2016)

Photo 8 Shortening cracks at the junction of Yuura River and Kabaru River (taken towards the west on May 11, 2016)

Photo 9 Shortening cracks of road and curbstone around paddy fields located in marsh zone (taken toward the east on May 11, 2016)

Photo 10 Uplifting of Shin-kabaru Bridge (taken toward the north on May 11, 2016)

6. Discussions

Here, the generating factors of graben-like ruptures and shortening deformations identified around Matoishi and Uchinomaki area are discussed based on the result of field survey and interpretation of SAR interferograms.

The SAR interferograms and the result of MAI analysis indicated the block shapes with over 2m horizontal displacement without clear vertical displacement in the Aso Valley (Fujiwara et al., 2016a; GSI, 2016b), and it was indicated that the horizontal displacement occurred in the shallow zone relatively (Fujiwara et al., 2016a).

In the field survey, the graben-like opening ruptures were identified along the southern or eastern edge of the horizontal displacement as detected by SAR analysis located on the extensional field, and a large number of shortening deformations were identified around the northern or northwestern edge of the horizontal displacement located on the compressional field. The amount of horizontal displacements measured on-site coincided with the observation amount by SAR interferometry in order level.

These results show that the horizontal displacements were non-tectonic displacements caused by lateral movement of blocks nearby shallow underground layers.

In the Uchinomaki area, there are sediment layers on the bottom of former lake near the depth of 50 m (Hase et al, 2010). Also, in some of the thermal wells of Uchinomaki hot springs, breakage of the well was confirmed near the depth of 50 m (Kyushu Environmental Office, 2016).

From these facts, it is presumed that the former lake bottom sediments with high water content liquefied with the strong motion of the Kumamoto Earthquake, which became a sliding zone and the block of each area uniformly moved laterally (Fujiwara et al., 2016b). However, the detailed mechanism and driving force are unclear at present and remain open question to future study.

7. Conclusions

The field surveys were conducted in and around surface ruptures areas as identified from aerial photos and remarkable surface displacement areas as detected by satellite SAR analysis, and the actual ground conditions of the surface displacements were investigated.

As a result, a large number of graben-like open ruptures were identified along the southern or eastern edge and a large number of shortening deformations were identified around the northern or northwestern edge of the horizontal displacements using SAR analysis.

Taking into account these results comprehensively, while the formation mechanism is still unclear, it can be speculated that the large horizontal displacements are non-tectonic displacements such as lateral movement.

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