Slipping-planes Detection with GPR following the 2015 Kumamoto Earthquake

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Introduction

In the aftermath of an earthquake and when a crack breaks the surface, scientists often measure the vertical and horizontal components of offsets to then eventually level the land surface back. This cosmetic surgery however only hides what has happened underneath and the complexity of a fault mirror or more minor cracks can hardly be fathom from surface data only. Although trenching is a possibility when the soil isn't loose [1], it is labor intensive and generate important impacts on the landscape, and volcanic soils are seldom prone to such approach and geophysical methods provide better results [2]. Moreover in hazards and disaster impacted areas, respecting local inhabitants' place, work and ethos would also mostly preclude digging holes inconsiderably in the name of Science.

In order to (a) better understand the vertical geometry of cracks and fault mirror visible at the surface, and (b) in order to do so with as little disruption as possible, the present contribution investigates agriculture terraces in volcanic terrain that were fractured and displaced by the 2015 Kumamoto earthquake, with the following main objectives:

(1) Image the geometry of the failure lines (planes in 3D);

(2) Find whether invisible failure planes exist underneath the surface;

Materials and Methods

For the present research, the authors have investigated in the Kyushu area (Fig. 1-a), a terrace that has shown signs of movements and the presence of failure planes along the Kurokawa River, and this was done using a Mala GPR mounted with a 500 Mhz antenna. The transects were captured across unused fields at the time (Fig. 1-c and Fig. 2).

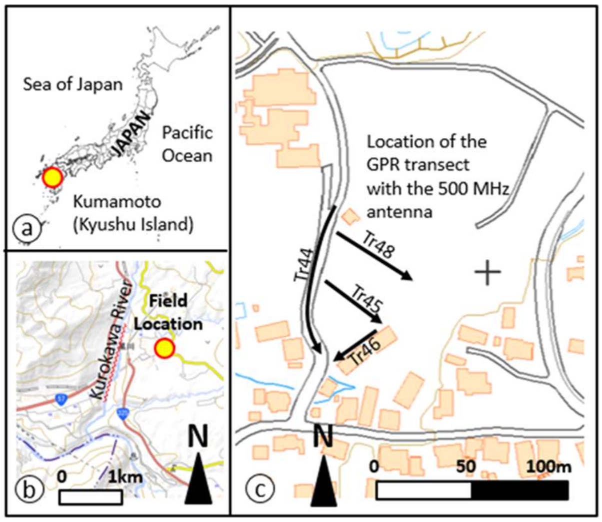

Figure 1 Location Map of the survey area. (a) Kumamoto in Japan; (b) Field location to the East of the Kurokawa River; (C) Spatial distribution of the GPR transects.

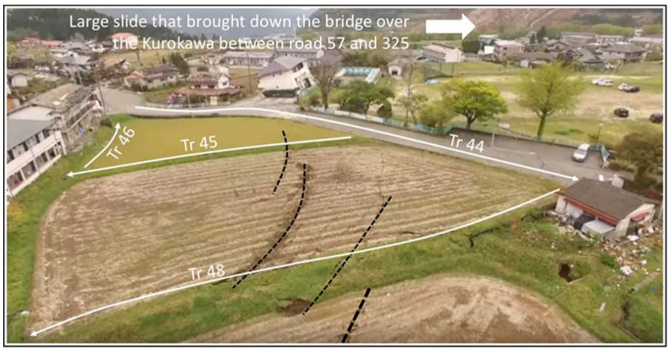

Figure 2 Impacts of the Kumamoto Earthquake on the location, from UAV drone imagery (courtesy of the Geospatial Authority of Japan – www.gsi.go.jp).

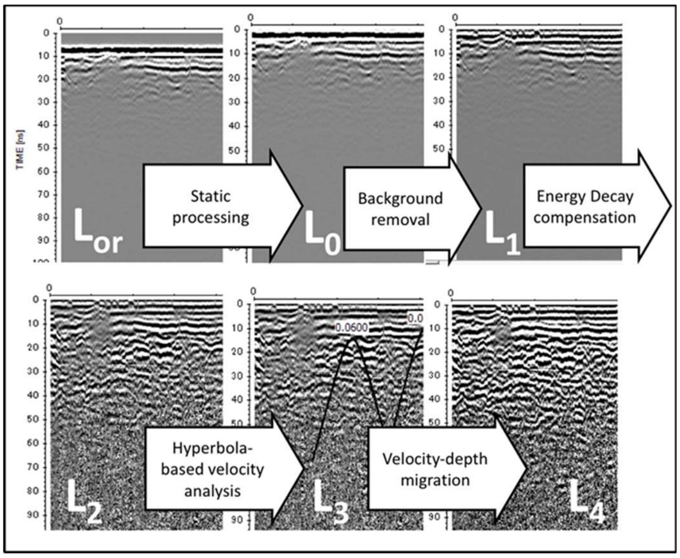

Figure 3 Processing steps of the GPR signal

Result and Discussion

Transect 44 (Fig. 4), oriented along a North-South transect displays a top layer of less than 40-50 cm, that is an originally subhorizontal layer placed for agricultural purposes. Underneath a material consisting of coarse material (a prep-soil or a mixture with the underlying material) extends to a depth of 1 meter to 1.5 meter. The topographic surface does not follow strictly the underlying bedrock and obvious anthropogenic land alteration generated the present surface. The subsurface is also presenting sets of subvertical discontinuities that break the otherwise continuous layers showing the presence of ruptures, or failure lines and planes (human impacts would not offset the left and right side of such break, and it can confidently be associated with the earthquake). Between 50 to 60 m, a wedge shape section seem to have also offset the underlying volcanic material vertically. Along transect 45 (Fig. 5), this time oriented in an East-West fashion, the subsurface structure is similar, but this time rupture lines are oriented towards the West, or the Kurokawa River. This time the signal was also able to reach through the lower underlying volcanic material, and the rupture lines (planes) could be seen to continue from the subsurface soil down to the underlying material, which also shows the presence of blocks or reflective layers (Fig. 5). In comparison with these two transects, the one along the building (Fig. 6: right of the top radargram) is composed of material that does not show clear breaks, and the material is coarser with multiple block reflections. A U-shape subsurface structure, suggests that either a hole or a buried-channel was also running in this location. Finally, all the transects show complex subsurface layers with a dip towards the East while at the same time displaying local subvertical breaklines with a slight dip towards the West. In transect 45 (Fig. 5), the subsurface breaklines are also continuing underneath the anthropogenic soil into the underlying volcanic material (bedrock?). Using a normalized amplitude imaging method, the phase inversion helps emphasize local variation and changes that can be obstructed by the presence of blocks and other object hyperbolas (Fig. 6). For the transects used in the present study, the phase change confirm that the rupture lines have misaligned the different layers, but also modified characteristics (most probably the density, expressed in differences in soil moisture and gas content). It also shows that the seemingly presence of a hole or a buried channel is most probably a land-fill rather than a natural features and at the contact of this landfill with the natural feature, there is a zone at the end of the transect, which is of different material characteristics (most probably density). The same feature appears in transects 44 and 45, when close to the buildings. One hypothesis is the natural density difference due to the building mass on the subsurface material, another one is the effect of the mass of the building during earthquake acceleration, generating differences in the soil, finally it is also most probable that the landfill underneath the house is different from the one in the cultivated field, and it might be only a man-made feature.

Conclusion

This study shows that GPR needs to be an integrant pa rt of the post- sediment-disaster remediation and emerge ncy work. As antennas on UAV are now available, it s hould come as a complement to UAV imagery.

Acknowledgement

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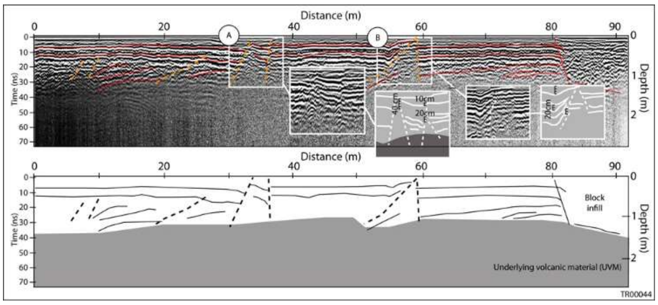

Figure 4. GPR transect 44 with a 500 Mhz antenna on the road. The movement has deformed the soil layers and basculated some of them along rupture planes.

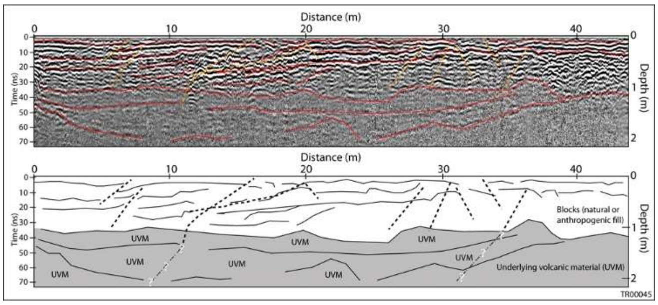

Figure 5. GPR transect 45 across the agriculture terrace. The visible surface rupture are all oriented towards the valley with almost horizontal bedding structures that show higher reflectivity and the creation of potential sliding surfaces.

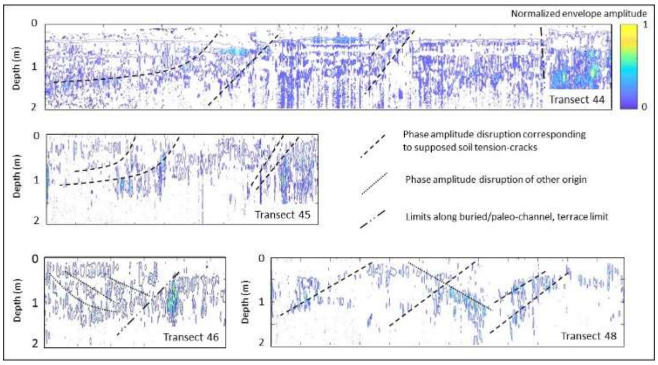

Figure 6. Signal normalized envelope distribution across the 4 transects showing the soil structure's discontinuities and anomalously concentrated amplitude returns.

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