ACTIVE FAULT MAPPING AND PHOTOGRAMMETRICAL ANALYSIS OF FAULTING ACTIVITIES IN MONGOLIA

PI No. 407

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1. Background and Objective

A massive quake of 8.3 magnitude hit the northern Gobi-Altay Mountains of Mongolia in December, 1957. The surface rupture that occurred due to this quake was approximately 260 km long and 40 km wide.

The length, displacement etc. that occurred due to this surface rupture was of a massive scale globally. Even today, one can almost find the same formation, which occurred due to this phenomenon (quake). Moreover, the northern Gobi-Altay Mountains is one of the prime mobile belts of the world and it often develops a fault displacement terrain showing a cumulative variation. Thus, this region discloses the active fault distribution and displacement distribution for each of the active faults, and is ascertained as one of the best areas for the variation terrain research that aims at developing a sophisticated method (a forecasting method for a section that gets destroyed all at once during an earthquake) to forecast the scale of a massive earthquake caused by intraplate active faults.

Typically, the interpretation of a three-dimensional view of the aerial photograph and the local topographical survey for research on tectonic landforms are conducted in order to have a clear detailed understanding of the terrain. Measuring active fault displacements as well as GIS digitizing active fault distributions based on digital photogrammetry is essential in forecasting massive earthquakes.

However, these investigations cannot be accomplished with ease if you exclude special regions such as Japan, because of various constraints such as access issues and the restrictions to use aerial photos.

In this context, the high definition satellite images are expected to function as substitute data for aerial photos. These are satellite images that had been captured from 1960s to 1970s by the US armed forces with a reconnaissance spacecraft CORONA. Satellite images have a spatial resolution of several meters and can be viewed three dimensionally since it is photographed stereoscopically. Thus, it is used for researching tectonic landforms-which continue to show significant results. But on the other hand, it has some problem areas such as distortion of the image around the edges. However, based on the recent available ALOS/PRISM, it is expected that, for triplet images, a detailed geomorphic analysis can be done in a broad homogenous spectrum. It has a spatial resolution of 2.5 m that exceeds CORONA satellite images and it is highly sensitive because BH ratio is close to 1. In addition to this, topography measurement can be done based on the photogrammetry.

In this study, the northern mountains of Gobi-Altay are targeted; and CORONA satellite images and ALOS/PRISM images are used. Here, a topographical variation method is used for interpreting the three dimensional view and then the mapping of an active fault is attempted. Based on this, the possibility of recognizing the active faults for each satellite image is compared and considered. Further, stereoscopically taken ALOS/PRISM images are used for digital photogrammetry. Based on this, an attempt is made to measure the fault displacement terrain, which refers to surface rupture and cumulative variations; and the possibility of creating a displacement and distribution map is considered. Simultaneously, the possibility of creating a topographical map of scale 1:25,000 through digital photogrammetry is considered.

2. Research Plan

In order to conduct active fault mapping with high precision, a high definition three-dimensional pair with excellent broad-spectrum (wide-area) and homogeneity is required.

Since 2005, we have been using CORONA satellite images (photographs from the 1960s, resolution around 5m) and aerial photos of scale 1:45,000 (taken during 1970s and 1980s) of a certain area. And since then, we have been interpreting the three-dimensional view and conducting the local survey.

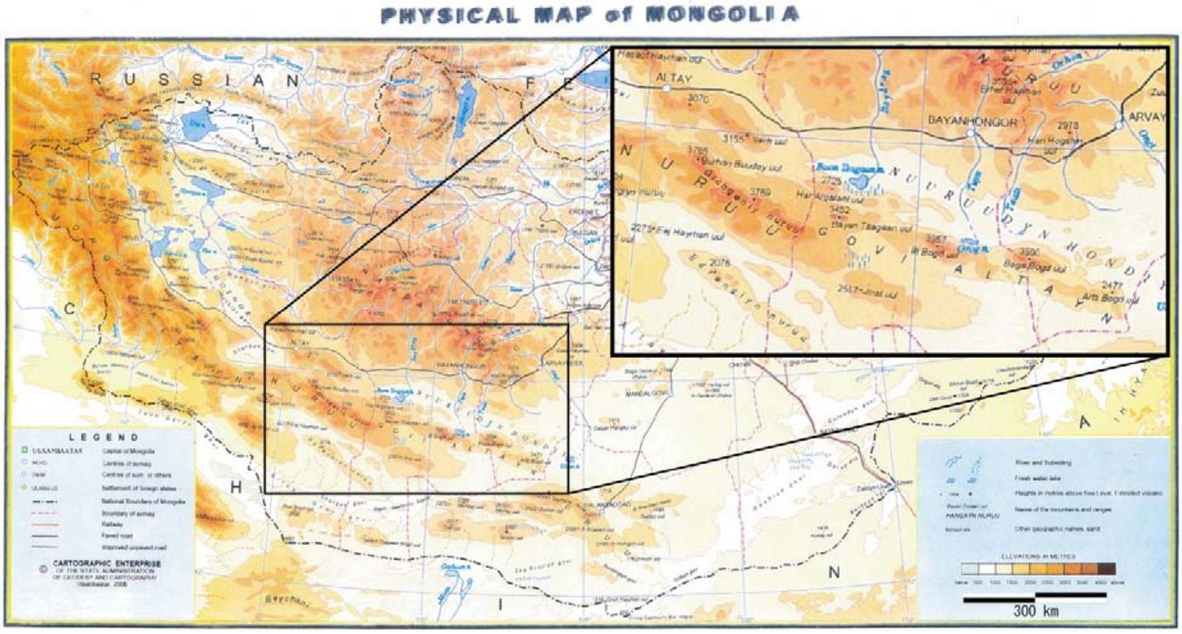

Fig. 1 Physical map of study area—northern ridge of Gobi Altay mountains.

CORONA satellite images bear sufficient resolutions for interpreting the three-dimensional view of fault displacement terrain. These images are more easily available; and thus they have been commonly used for researching tectonic landforms (for example, Kumahara Nakata 2000: Watanabe 2002 etc.). However, there are many deformations at the edges of the image, which makes it difficult for interpreting three-dimensional views (lacks homogeneity). Even for aerial photos, maintenance of all the geographical areas is difficult due to various restrictions (lack of wide area). Moreover, to carry out digital photogrammetry, GCP is required for each image/photo. Hence, active fault interpretation remained qualitative, and digitalization of local information and measurement of displacement were not realized.

Thus, in this research, by using images of ALOS/PRISM along with the CORONA satellite images, a more detailed mapping of the active faults, as well as measuring the GIS digitization of active fault distribution based on digital photogrammetry is attempted, and the effectiveness of the ALOS/PRISM images is verified. Regarding displacement measurement, a suitable spot is chosen and a topographic cross-section is created, and then a measurement of the relative elevation of the low fault escarpment is attempted. The ground truth of a topographic cross-section is obtained through a local survey.

Simultaneously, whether the topographical map, scale 1:25,000, a base diagram of active fault distribution diagram can be created by the digital photogrammetry of ALOS/PRISM image is considered. Topographical map of scale 1:100,000 exist only for (targeted) geographical areas and there is a usage limitation for foreigners. Since the distortion just beneath the ALOS/PRISM image is relatively small, this can also be used as base diagram. However, this research is about creating a topographical map of scale 1:25,000 based on the digital photogrammetry. It is indeed worth creating a topographical map of scale 1:25,000, which indicates detailed positioning and shape of the active fault for it has merit to prevent earthquake disaster by grasping accurately the positional relationship of the feature with active fault.

3. Research Procedure and Data Used

3-1. Preparing satellite images to be used

This research solely focuses on terrain, thus there should not be any screen of cloud over the terrain. As a result of searching for images that have been captured that meet this condition, the geographical areas taken by the CORONA satellite shown in figure 2 and those taken by ALOS/PRISM in figure 3 were selected respectively. CORONA satellite image cover all the geographical areas subject to this research. These images are stereoscopic pictures that had been captured in 1970— this is digitized data at a pitch of 6μm and the nominal accuracy is 6 ft. On the other hand, ALOS/PRISM images are stopped at several places within the geographical area subject to this research. The process level is right under 1B1 and has three scenes- normal mode, forward view and rear view.

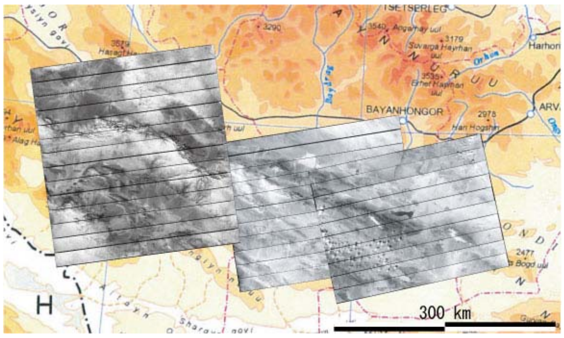

Fig. 2 Areas imaged by CORONA satellite.

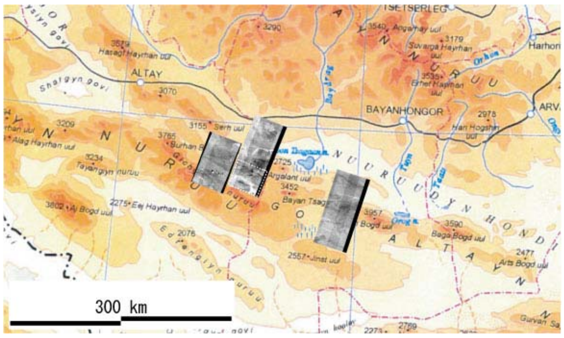

Fig. 3 Areas imaged by ALOS/PRISM satellite.

3-2. GCP Acquisition useful for the standardization of ALOS/PRISM and Local survey for the preparation of topographical profile as Ground truth

Originally, GCP is not required when analyzing ALOS/PRISM image with digital photogrammetry. But the fact of the matter is that GCP will is useful in improving the standard of accuracy. For this research, a local survey had been conducted on August 2007 in order to obtain GCP. 3D (three-dimensional) coordinated measurement was carried out by GPS for 52 spots located all along the 110 km active faults that include Chandman district and Chandman Mountain periphery (Position is shown in figure 4) confirming the presence of ALOS/PRISM images. And its result is shown in figure 4 and table 1. Since the geographical area subject to this research does not have any artificial structure, only those spots identifiable in the ALOS/PRISM image-like locations where the river intersects with the base of low fault escarpment, summits with distinctive elevation etc. have been selected and measured (photo 1).

Moreover, for 14 locations, a topographical profile was created that comprises the ground truth of the topographical profiles measured by photogrammetry and active faults based on the local survey (photo 2). A laser distance meter has been used to measure the topographical cross-section. Figure 5 shows an example of a topographical profile diagram that has been created. However, most of the locations where the topographical profiles were created, since ALOS/PRISM images are not maintained, the verifications for this research is limited mainly to one location.

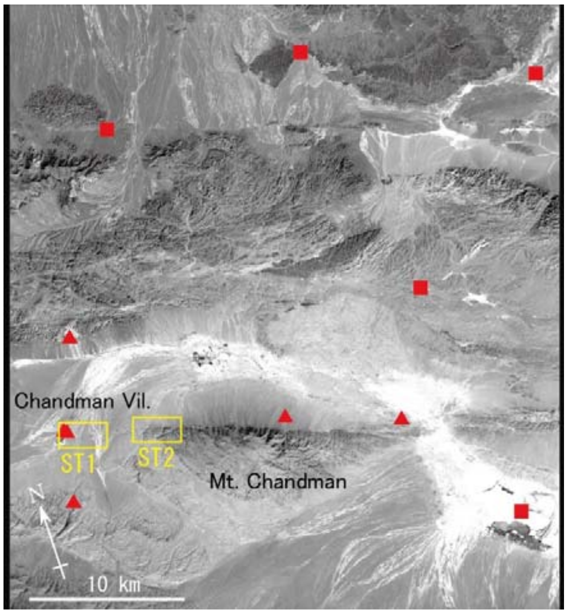

Fig. 4 An example of ALOS/PRISM image. Red triangles show GCPs. Red squares show pass points for photogrammetry.

Photo 1 Photograph taken during the field survey conducted for GCP measurements. Because there are no artificial structures at the site, only locations such as topographic summits with distinctive elevation can be considered for the measurements.

Table 1 Three-dimensional coordinates of GCPs obtained using GPS.

POINT.ID	N (degree)	E (degree)	Height (m)
081201	45.55134646	97.37418852	1655.194631
081202	45.55134606	97.37418833	1655.361288
081203	45.51240313	97.43270413	1931.147264
081204	45.53681758	97.45609676	1770.757819
081205	45.53883429	97.48618227	1848.044248
081206	45.54971962	97.51081228	1787.707592
081207	45.54971613	97.51081022	1787.648356
081208	45.52708474	97.48823356	1883.303753
081209	45.52708738	97.48822477	1883.265595
081301	45.47274402	97.65396619	1969.553731
081302	45.47274621	97.65396683	1969.917175
081303	45.42867089	97.5584685	2262.419075
081304	45.42867136	97.5584678	2261.604224
081305	45.49433362	97.62693676	1958.498113
081306	45.49434457	97.62691403	1958.499839
081307	45.44769802	97.72807736	2043.349128
081308	45.44769595	97.72807957	2045.183506
081309	45.43434903	97.6944436	2114.557211
081310	45.43434795	97.69444309	2114.765916
081311	45.33380604	97.99054487	2233.547105
081312	45.33380383	97.99054461	2233.751302
081313	45.33326626	97.99047982	2233.395388
081314	45.33326532	97.99047204	2234.559819
081315	45.33479968	97.98942797	2228.56658
081316	45.33479732	97.98943181	2228.474898
081317	45.33264329	97.98848643	2230.900007
081318	45.29772653	97.98050463	2322.30134
081319	45.29773999	97.9805163	2329.926954
081320	45.34953025	97.99596627	2220.63901
081321	45.34954028	97.99597445	2219.611022
081322	45.39054703	98.00595203	2318.069677
081323	45.3905492	98.00593517	2317.372677
081401	45.31243435	98.17190565	2194.882823
081402	45.31243013	98.17190538	2194.685002
081403	45.29461025	98.26651613	2100.870428
081404	45.29461046	98.26651603	2099.123217
081405	45.24459852	98.41180679	2117.419073
081406	45.24459887	98.41180654	2117.47608
081407	45.25465337	98.42778995	2180.043223
081408	45.25465247	98.42778898	2180.124714
081409	45.26369142	98.8131581	2383.701873
081410	45.26372251	98.81319901	2380.367873
081411	45.26585835	98.79359045	2288.375516
081412	45.26585893	98.79359358	2288.375822
081413	45.26600491	98.79323973	2281.827762
081414	45.26600627	98.79323949	2280.814933
08145	45.27463207	98.79447468	2201.357563
081416	45.27463537	98.79447066	2201.321742
081417	45.26591596	98.79679353	2302.05774
081418	45.26591509	98.79679559	2301.551762
081501	45.27477298	98.80002331	2208.038541
081502	45.2747711	98.80002042	2208.473695

Photo 2 Photograph taken while a laser distance meter is being used for the measurement of topographic profiles.

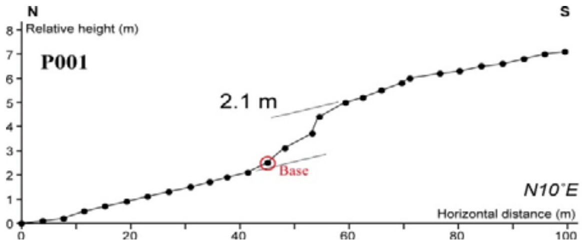

Fig. 5 Sample of topographical profiles of 14 locations. A laser distance meter was used for the measurement.

3-3. Analyzing the images of ALOS/PRISM for the Digital Photogrammetry System

Software "WinATLAS" (made by KLT Co: http://harbour.jp/products.html) was used for conducting three-dimensional interpretations, image visualizations and digital photogrammetry (figure 4) from ALOS/PRISM images. This software uses pose information of ALOS/PRISM and conducts image synthesis and measurements. However, RPC files are not distributed publically. As a result, a request was put forth to JAXA/EROC and we were provided with a sample data of higher artifacts. Based on the points mentioned above and digital photogrammetry, preparations were complete for the image data being used for three-dimensional interpretations and creating a diagram of the topographical cross-sectional view.

4. Result

4-1. Interpretation Results of Satellite Image

Fault displacement terrain (topography) was recognized based on the three-dimensional interpretation of CORONA satellite image. Figure 6 is the example of a pair of stereoscopic images that had been created for a three-dimensional view. The result of the interpretation is shown in figure 7. Next, a three-dimensional interpretation of ALOS/PRISM image was conducted. The images are distinct and we can clearly recognize the fault displacement terrain.

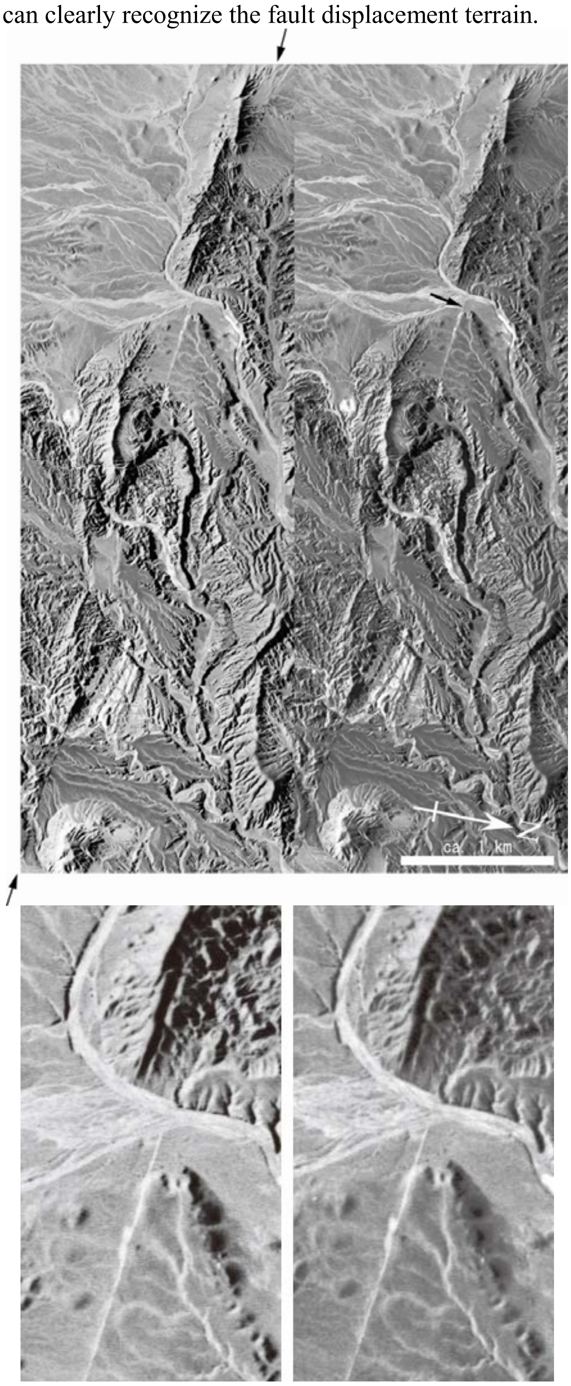

Fig. 6 An example of a pair of stereoscopic images generated from CORONA satellite imagery. The lower images are magnified views of the area indicated by the arrows in the upper images.

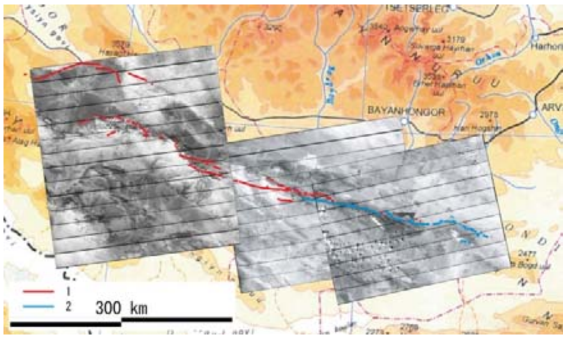

Fig. 7 Interpretation results of CORONA satellite imagery. Red lines show the active fault, and the blue lines are thought to be the surface ruptures caused by the Great Gobi Altay Earthquake of 1957 because these ruptures are fresh.

For the possibility of active fault recognition, the CORONA satellite images were compared to the ALOS/PRISM images. An example of a pair of stereoscopic images of the same area has been shown in figure 8 and 9 respectively (range is shown with ST1 and ST2 in figure 4). When CORONA satellite images are compared with ALOS/PRISM images, it has been observed that due to a distortion in the images of the former, the three-dimensional view is not clear. On the contrary, one can clearly see the images of the ground surface taken by the latter. It is therefore obvious that the images of the ALOS/PRISM are far superior to those of the CORONA satellite images in terms of quality. In each diagram, active faults recognized through three-dimensional interpretation are shown with a red arrow.

4-2. Results of Displacement Measurement

The ALOS/PRISM images and the GCP obtained from the local survey were used to carry out digital photogrammetry. A topographical cross-sectional diagram was created and then displacement measurement was attempted. The target is the site shown in yellow line in figure 8. The distinct ruptures, being projected on the southern side, can be confirmed here. Since this rupture is the minimal rupture escarpment that can be read from the photographic interpretation, the limitations of the ALOS/PRISM can be determined by measuring the relative elevation.

For photogrammetry-based measurement, since polarized glasses are being used to observe the screen while grasping the elevation of the ground surface,

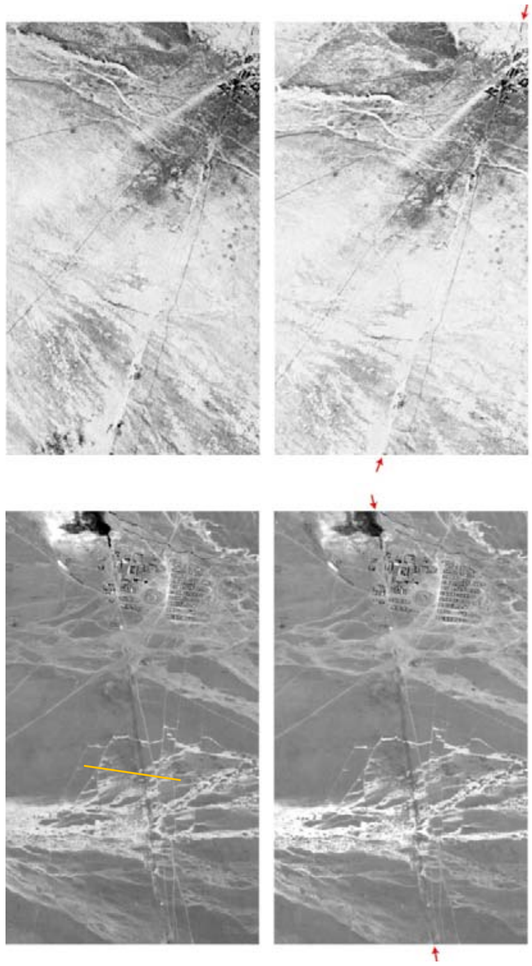

Fig. 8 Comparison of stereoscopic images of location ST1, shown in figure 4. CORONA satellite images (upper) and ALOS/PRISM images (lower). CORONA satellite images are unsuitable for stereo viewing. The yellow line shows the location of the topographic profile shown in figure 10.

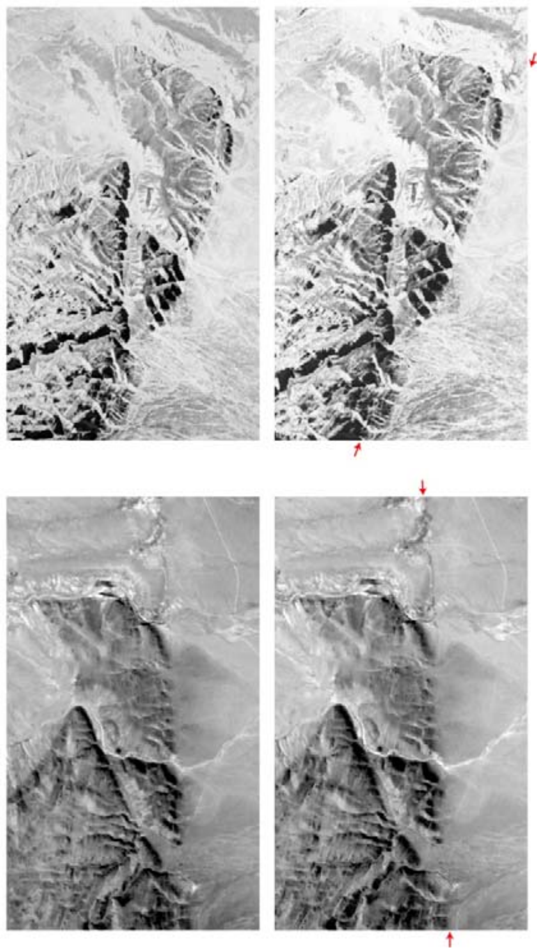

Fig. 9 Comparison of stereoscopic images of location ST2, shown in figure 4. CORONA satellite images (upper) and ALOS/PRISM images (lower).

the length of the survey line must be elongated to a certain extent. This is because it is necessary to have a spatial expansion of a certain amount (several to more than a dozen pixels). Therefore, a straight-line approximation is done respectively for the topographic cross-section of the elevated active faults and the topographic cross-section of the lower side. The severe discrepancy that prevails at the intersection of the survey line and active fault has been calculated as the displacement. The result is shown in figure 10a and the displacement measured is approximately 50 cm.

On the other hand, in the local survey, the displacement that has been obtained by topographic cross-section measurement is also about 50 cm (figure 10b). The result of the digital photogrammetry is well accorded with this. Regarding the accuracy of the measurements based on the digital photogrammetry, since they could be affected by location, image quality etc, a careful study is required henceforth. Nevertheless, in this research, the results obtained by both sides were quite identical to each other.

When this result is combined with an entity that can clearly map the active faults on the basis of the three-dimensional interpretation of ALOS/PRISM images, then it signifies that, based on the digital photogrammetry of ALOS/PRISM, an accurate latitude, longitude and altitude of the active fault distribution can be obtained as digital information.

4-3. Results of creating a 1:25,000 scale topographical map

We attempted to create a topographical map of scale 1:25,000 through digital photogrammetry. This result is shown in figure 11. The gap between the contour lines is 10 m. Henceforth, a more careful study is required for the accuracy of the created topographical map. However, if it is possible to measure a low fault escarpment of about 50 cm, as shown in the displacement measurement result in the preceding section, then it is believed that the creation of a topographical map with a scale of 1:25,000 is quite possible.

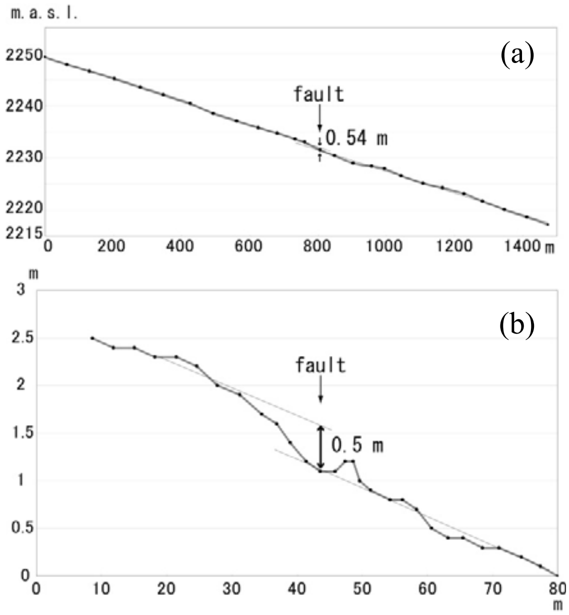

Fig. 10 Topographical profiles of the same location (a) measured by photogrammetry of ALOS/PRISM images and (b) measured in the field.

5. Conclusion

The objectives of this research are as follows:

(1) Creating distribution map for fault displacement terrain by using CORONA satellite images and ALOS/PRISM images of the northern Gobi-Altay Mountains of Mongolia.

(2) Based on digital photogrammetry of ALOS/PRISM image, measure the fault displacement terrain that shows surface rupture and cumulative variations, which occurred in connection with the earthquake of 1957 in the same region, as well as examine the possibility of creating a displacement distribution diagram.

(3) Examine the possibility of creating a topographical map with a scale of 1:25,000 based on digital photogrammetry.

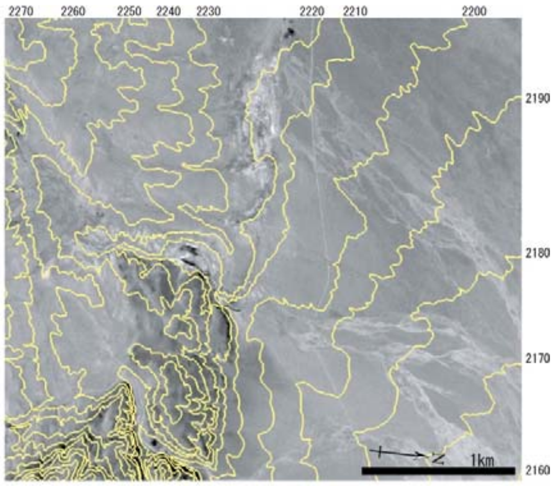

Fig. 11 Sample of contour map generated by photogrammetry of ALOS/PRISM stereo images.

The result of the research showed that we were able to create a distribution diagram of broad range active fault by interpreting the three-dimensional view of the CORONA satellite images. Further, by interpreting the three-dimensional view of ALOS/PRISM images, it has become clear that a detailed recognition of fault displacement terrain is possible. This is believed to be due to the images of the ALOS/PRISM compared to the CORONA satellite images, having a higher resolution with a lesser distortion.

However, the images that can be used for interpretation and photogrammetry, for large portion of the planned geographical areas, were not maintained. Unfortunately, the only thing that is conspicuous is that these images are of superior quality compared to the existing CORONA satellite images.

A digital photogrammetry was conducted by using the GCP obtained from the local survey. Then, displacement measurement of the fault displacement terrain was attempted. Based on the interpretation of the three-dimensional view, the measurement result of the topographic cross-section that crosses the location recognizable by the low fault escarpment is consistent with the measurement result that has been obtained from the local survey. This shows that it is possible to measure the fault displacement terrain with high accuracy. However, a more careful study is required in the future regarding accuracy.

Further, we have examined the possibility of creating the topographical map of scale 1:25,000 through digital photogrammetry. The results suggested that ALOS/PRISM images have satisfactory accuracy. These results show that it is possible to maintain digital information like- the position of the active fault, displacement etc.

However, there are also some challenges mentioned below, which still exist. Geographical areas spreading several hundreds of kilo meters are considered for the research purpose. But, the maintenance done by the ALOS/PRISM image is confined only to a part of the whole area. Moreover, block noise, what has been referred to as JPEG, is seen in some section or part of the ALOS/PRISM image. When the image on the display is enlarged for three-dimensional view, it is possible for it to interfere with capturing the ground surface accurately. Along with this, there is a possibility of an error to occur at the time of conducting stereoscopic matching through image analysis. The present challenges that exist are all about shooting (photographing) coverage and image quality.

Acknowledgement

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References

[1] Y. Kumahara and T. Nakata, “Application of the CORONA Satellite Photography to Geomorphological Studies in Developing Regions”, *ANREG*, Hiroshima University, 9, pp. 129 – 155. March 2000. (in Japanese)
[2] M. Watanabe, “Digitization of CORONA Satellite Photograph Positive Films and its Availability: In the Case of the Active Faults and the Historical Ruins of the Turpan Basin, Northwest China”, *Journal of Geography*, 111(5), pp. 759 – 773, 2002. (in Japanese)