DINSAR ANALYSIS FOR TOPOGRAPHIC MODEL INTERPRETATION OF FAULT

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ABSTRACT: During long-term erosion after a strong earthquake, cracks in the soil gradually disappear, making it difficult to identify. The rapid development of modern high technology has opened up new and unexpected possibilities for the discovery and detailed study of such hidden structures. Recently, the development and progress in remote sensing allowed for the exploitation of a variety of data sources and techniques in the characterization of lineaments. Data fusion with a radar or the use of synthetic-aperture radar (SAR) images improved the number of lineaments extracted in several studies. Shaded relief models are also widely used and considered as a powerful tool for lineament enhancement in topographic data.
The aim of the present research was the interpretation of tectonic lineaments and faults over Ulaanbaatar city using the differential synthetic aperture radar interferometry (DInSAR) analysis. Ulaanbaatar is the capital city of Mongolia; approximately 50% of the national population lives in the city (1.6 million residents), and this number is rising.
The validation of the extracted lineaments is based on the several archive data of research Institute of Astronomy and Geophysics and published research papers last two decades.
In this study, attention was put to exclude the man-made linear features that do not correspond to geological structures in the study area such as roads and non-geo-structural lines in the remotely sensed data.

1. INTRODUCTION

During the 20th century, Mongolia was one of the most seismically active intra-continental areas in the world with four large earthquakes (above M 8) along its active faults in the western part of the country (Munkhuu et al., 2010; Schlupp et al., 2012).

The geology of Mongolia is divided northern domain and southern domain by the Main Mongolian lineament. In the northern domain, it is mainly composed of pre-Cambrian and lower Paleozoic rocks, while the southern domain is composed of Lower to upper Paleozoic rocks. The capital city Ulaanbaatar belongs to the northern domain of the geological unit. The geology of Ulaanbaatar city and its surroundings, from older order, is composed of lower Paleozoic Hara Formation, middle-upper Paleozoic Hentei Formation, Mesozoic granite, Cretaceous Zuunbayan Formation and Cenozoic sediments (Walker et al., 2008). Along the Tuul River and its tributaries, it was covered by sediments of sands, gravels and mud that transported by the rivers. Moreover, sands and gravels deposited on terraces and on small scale alluvial fans. As above description, the geology of city area of Ulaanbaatar is characterized by sands and gravels that mainly transported by the Tuul River, while the mountain and hilly areas are composed of older rocks.

Seismic activity around the capital, Ulaanbaatar, is increasing in small but noticeable amounts compared to the seismic activity in western Mongolia. This activity, which began in 2005, has been found to be more active not only in the vicinity of Ulaanbaatar, but also in two active faults that extend perpendicular to the west and north of Ulaanbaatar. These two faults are the Emeelt Fault, discovered in 2008, approximately 10 km west of Ulaanbaatar, and the Hustai Fault, 20 km west. The length and geomorphology of these faults indicate a magnitude 6.5-7.5 earthquake occurring there in the past. (Figure 1).

The Avdar and Sharkhai faults, both of a length of about 47 km and located at between 35 to 45 km South of the capital are left lateral strike slip faults. The length and morphology of these faults, most of them discovered during the last decade, indicate that they can produce earthquakes of magnitude 6.5-7.5 (Al-Ashkar 2015, Adiya 2016).

Based on the distribution of these earthquakes and the evidence of surface ruptures discovered after field investigations in this area, the question raised of the relation between this seismicity and the fault and the maximum magnitude that occurred in the past on it. We have done several geophysical and paleoseismic studies around Ulaanbaatar and its surrounding areas. Those areas, which could be one of most seismic active zones around Ulaanbaatar, dramatically increases the seismic hazard of the capital of Mongolia where is concentrated about of 1/3 of the Mongolia population and the majority of industries of the country.

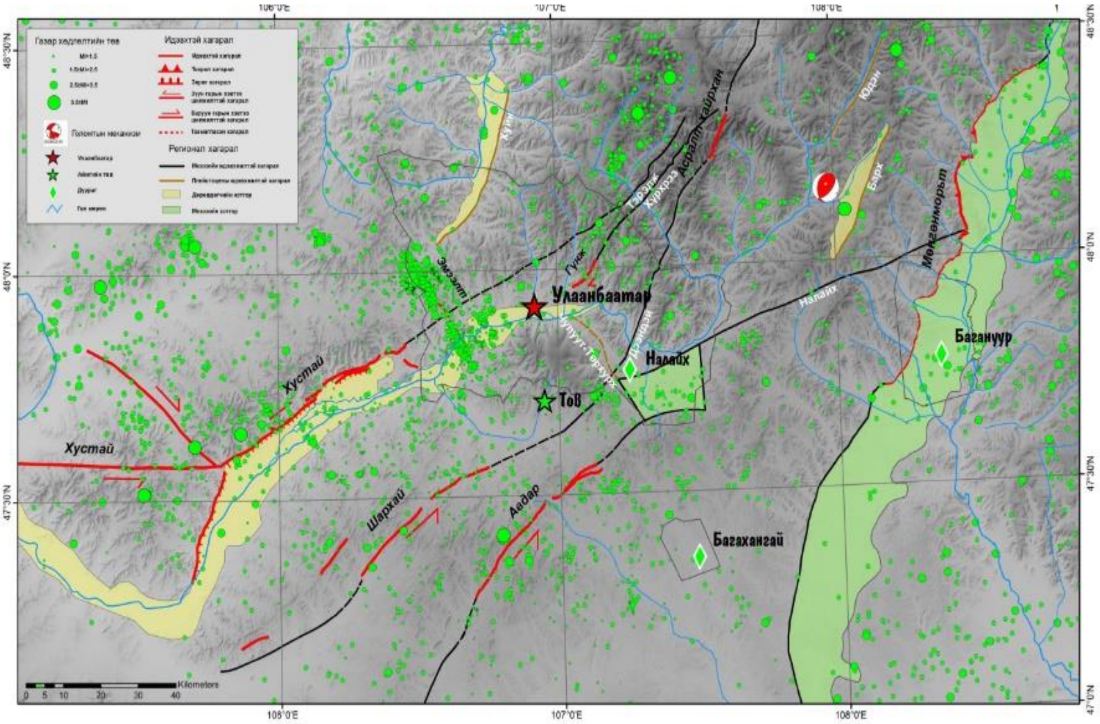

Figure 1. *Seismotectonic map of Ulaanbaatar area*
source: https://iag.ac.mn

2. RESEARCH METHODOLOGY

2.1. Research area

In 1971, a map of the seismic micro-region of Ulaanbaatar was drawn with the participation of Soviet scientists. This micro-region is zoned along the Tuul and Selbe rivers at 8 magnitude, rocky soil at 6 magnitude, and the rest at 7 magnitude. At the time, 25% of the total urban area was within 6 magnitude, 52% in 7 magnitude and 23% in 8 magnitude region. (Imaev et al., 2012; Smekalin et al., 2013). Based on this regional map, the buildings being built in Ulaanbaatar at that time were considered to be able to withstand 6-8 magnitude earthquakes. This didn't change until 2010. Between 2000-2006, an earthquake risk assessment of Ulaanbaatar was conducted in collaboration with French scientists (Ferry et al., 2010). As a result of the survey, a 1: 25000 scale map was made that divided Ulaanbaatar's area into 7-8 magnitude zones. During this study, it was determined that there were active seismic faults in Hustai, Emeelt, Gunj, Avdar, Sharkhai and Deren areas around Ulaanbaatar, but the detailed fault study was not studied further at that time. But in 2010, they were determined in detail (Нямбаяр, 2018; Al-Ashkar, 2013; Bayasgalan, 1999).

Due to the increasing seismic activity in Ulaanbaatar, it was necessary to determine the condition of the buildings and their earthquake resistance, and the inspections were carried out in stages. From 2006 to 2013, the General Agency for Specialized Inspection inspected 382 public apartment buildings in nine districts of the capital city.The survey found that there were about 330 pre-1970 apartment buildings that did not meet current earthquake resistance requirements, and needed to be re-planned and renovated. The inspection also concluded that 13 university and college buildings, 12 dormitories, and 38 out of 129 public hospitals in Ulaanbaatar were not earthquake-resistant.

According to a joint earthquake disaster assessment conducted by the Japan International Cooperation Agency (JICA) and the National Emergency Management Agency (NEMA) in 2013 determined a magnitude 6.5-7.6 earthquake occurring in Ulaanbaatar was predicted to destroy 20-50 percent of buildings, affect the lives of 200-300 thousand people, and the death of 30-60 thousand people.

The Institute of Astronomy and Geophysics mapped a 1:10,000 magnitude seismic micro-region of Ulaanbaatar in 2012-2014 and approved it by Order No. A / 201 of the President of the Academy of Innovation in 2016 and Order No. 198 of 2016 of the Minister of Construction and Urban Development. The seismic magnitude of the newly approved Ulaanbaatar seismic micro-region has been increased by one point by MSK. (Demberel et al., 2013; Schlupp et al., 2012; Schlupp, 2013).

In 2018, a joint Japanese-Mongolian researchers discovered the seventh fault that ran through the middle of Ulaanbaatar. The work to determine its exact location has been underway for the past three years. The crack, which allegedly ran through the central Ulaanbaatar, was difficult to identify due to construction and buildings. In the 2021 issue of the International Seismological Research Letters, the 7th Fault in Ulaanbaatar was called the "Ulaanbaatar Fault" and was described as an active fault (Suzuki et al., 2020). (Figure 2). Based on the length of 50 km fault, it was concluded that it could cause an earthquake of magnitude greater than M7. As a result, there is a need to update the existing seismic micro-regions, buildings and earthquake resistance of buildings under construction, due to the high risk of significant damage to buildings and cause serious damage to urban areas.

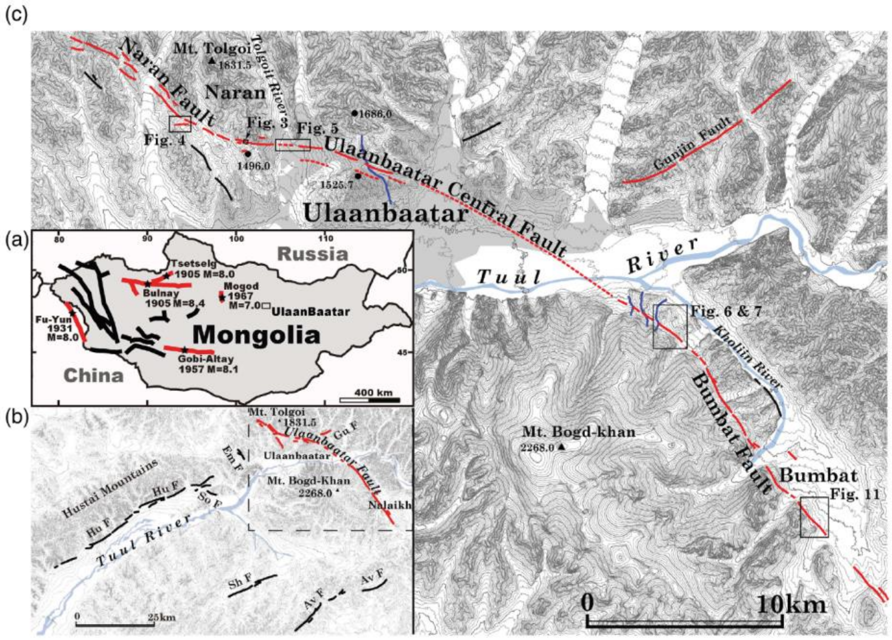

__Figure 2.__ Newly defined Ulaanbaatar cracks
a) Major earthquakes in Mongolia in the 20th century; b) - active cracks around Ulaanbaatar; c) -Ulaanbaatar crack source: Suzuki et al., (2020)

2.2. Research Methodology

The Sentinel-1 satellite (Foumelis, 2018), launched by the European Space Agency (ESA) in 2014, was selected for the study area in Ulaanbaatar and its suburbs with an area of 240 km2. Sentinel 1, an active sensing satellite, used 5.5 cm of C-wave data. This study used Sentinel 1 satellite data from September 20, 2017 and August 17, 2020.

The theoretical basis for the use of radio waves in the study of geological formations was laid down by G. Lovey and G. Leibach in 1910. In 1912, this became the basis for the possibility of searching for ore and groundwater by radio waves. The first georadar was established in Austria in 1929 to determine the thickness of glaciers. The Ground-Penetrating Radar (GPR) was first used in 1937 to test geophysical surveys using electromagnetic waves. Since then, the instrument has gradually evolved, and in 1972 it was first mapped to the lunar surface using radar imagery (Tseedulam, 2009; Нямбаяр, 2018).

Radar surveys are widely used in geology, environment, archeology, mining, construction, engineering networks, groundwater, snow and ice, and tunnels. The advantage of the device is the ability to use different polarity waves over a large area in a short time (Sun, 2015). Active sensing radar research method has been proven to be an excellent method for mapping cracks in radar wave reflections and for monitoring canals and canals buried underground via tests. (Walker, 2008; Gong, 2011; Hooper, 2008).

Synthetic aperture radar (SAR) uses shortwave radiation from an antenna to receive data from various levels of air and space. It is easy to process, analyze, and integrate with various thematic layers, as it is able to receive digital information directly from the various processes taking place on Earth. For radar devices that receive shortwave data, the wavelength and polarity characteristics used for surveillance are important, as well as the spatial resolution. In the case of SAR, the spatial resolution of the digital image is determined by combining the scattered radar pulses back from the object, and the pixels are scattered after the initial signal processing. Pixels represent a certain amount of image resolution, but typically use 2 pixels to perfectly define spatial resolution. (Baek et al., 2008; Delgado et al., 2019).

The synthetic aperture radar (InSAR) method of interferometry uses shortwave, which allows for high-precision study of topographic and physical surface shifts and changes, regardless of atmospheric factors. A digital surface model (DSM) is constructed using phase differences depending on location. By calculating the phase of the diffuse wave from any object, the surface elevation can be calculated with high accuracy, and the interferometer (InSAR) calculated using different time data allows the surface movement to be calculated with mm accuracy. (Yagüe-Martínez, 2016;).
This research is based on the interferometer method developed by Andy Hooper (2007, 2008) to map changes in the surface and to calculate the numerical model of its surface.
The height h was computed from the following equation

$$h = H - r_1 \ Cos \ (Sin^{-1}\left(\frac{\lambda\phi}{2\pi B}\right) + \alpha)$$

where H is the platform height, r1 is the earth's surface range, α is baseline roll angle, φ is interferometric phase, B is baseline length, λ is the observing wavelength. The baseline is defined as the vector between the phase centers of the inboard and outboard radar antennas

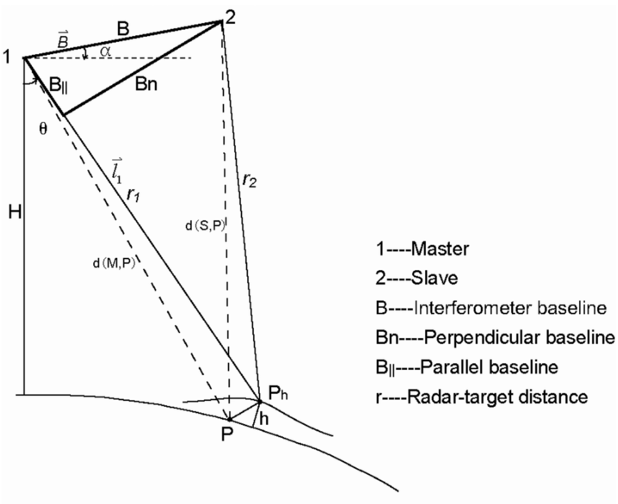

***Figure 3**. Geometry of repeat-pass interferometric SAR system. Where B is interferometer baseline, Bn is perpendicular baseline, B_{II} is parallel baseline, r is radar-target distance*
Source: Dong et al. (2008)

RESEARCH RESULTS AND DISCUSSION

The azimuth and region corrections produce a single image based on the orbital information and interpolation methods of the two images. The interferometer is calculated by multiplying the amplitude by calculating the phase difference between the two images, and the closer the two images are, the greater the confidence in the results (Foumelis, 2018). Low coherence values, on the other hand, have a negative effect on thinking results, and transient (excessive vegetation, rising water levels) and geometric (orbital message errors) reduce coherence values. The results of interferometer calculations can result in noise due to time and geometric corrections and volume dispersion.

Although the phase values cannot be changed, the results can be improved by using special phase filters, such as the Goldstein filter, which uses Fast Fourier Transofrmation (FFT) to improve the noise generated by the interferometer.

The results of interferometer processing reveal the natural boundaries, from which it is possible to create a numerical model of the surface. Figure 6 shows a comparative comparison of the numerical surface patterns obtained from the interferometer processing with the location of the 6 active faults around Ulaanbaatar.

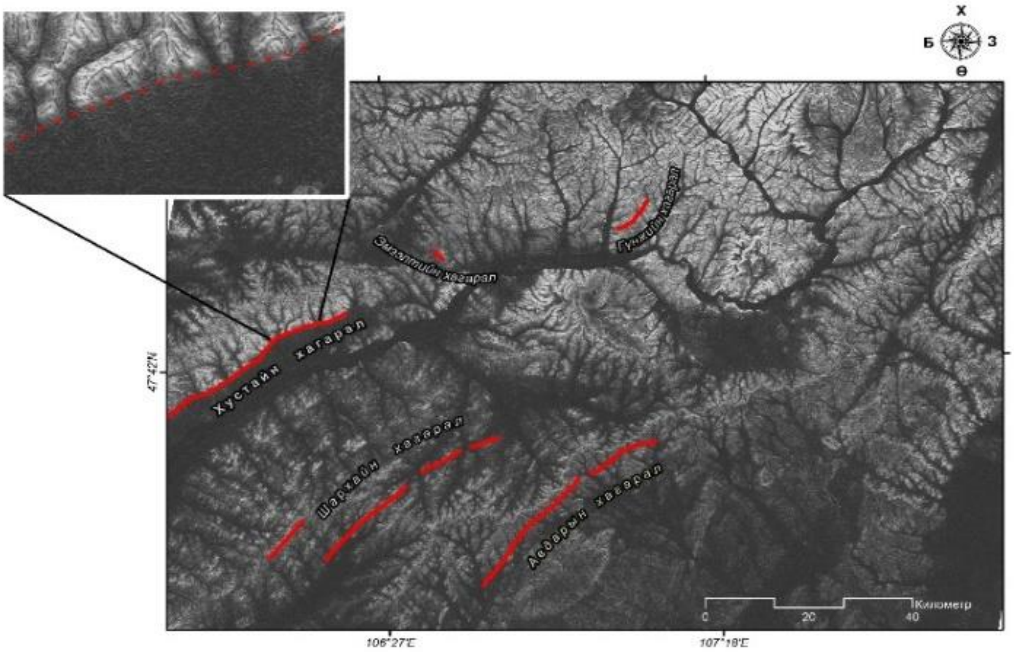

***Figure 4**. Overlap of 6 active faults around Ulaanbaatar on the surface digital anaglyph developed from interferometer images*

In addition, the 2014 geological boundary survey conducted by the Institute of Astronomy and Geophysics in Ulaanbaatar coincided with the geological boundary.

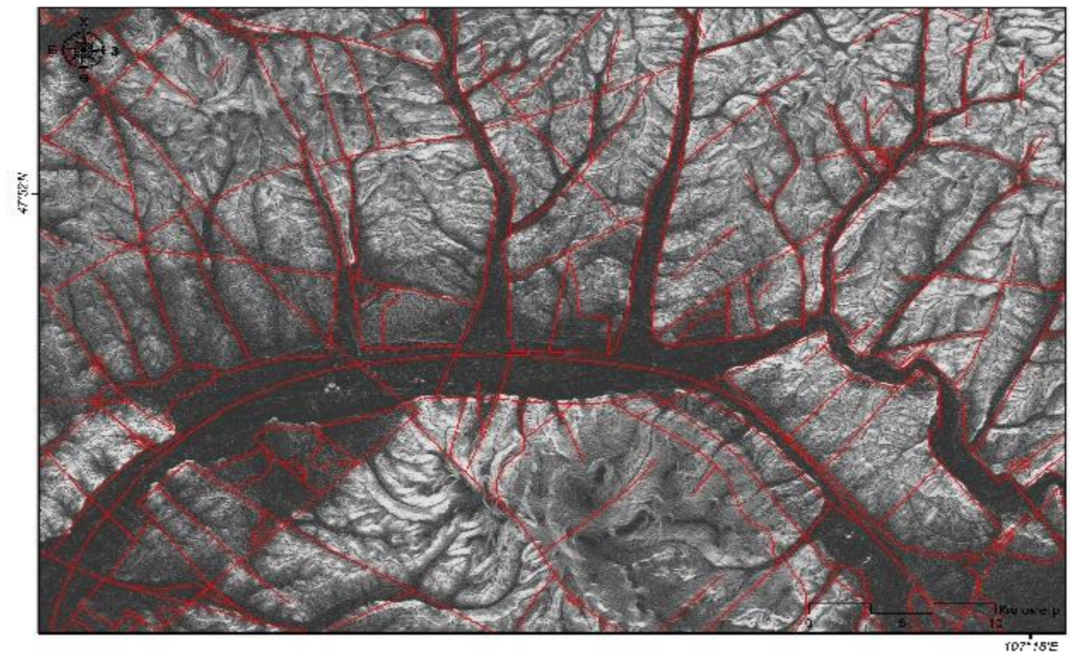

***Figure 5.** Overlap of the geological boundary on the numerical model anaglyph to complete the processing of the interferometer strip*

The results show that the new Ulaanbaatar fault is very clear and is consistent with the results of a study by Suzuki and other researchers (2020). Therefore, this study shows that it is necessary to change the micro seismic zoning due to the newly identified Ulaanbaatar fault.

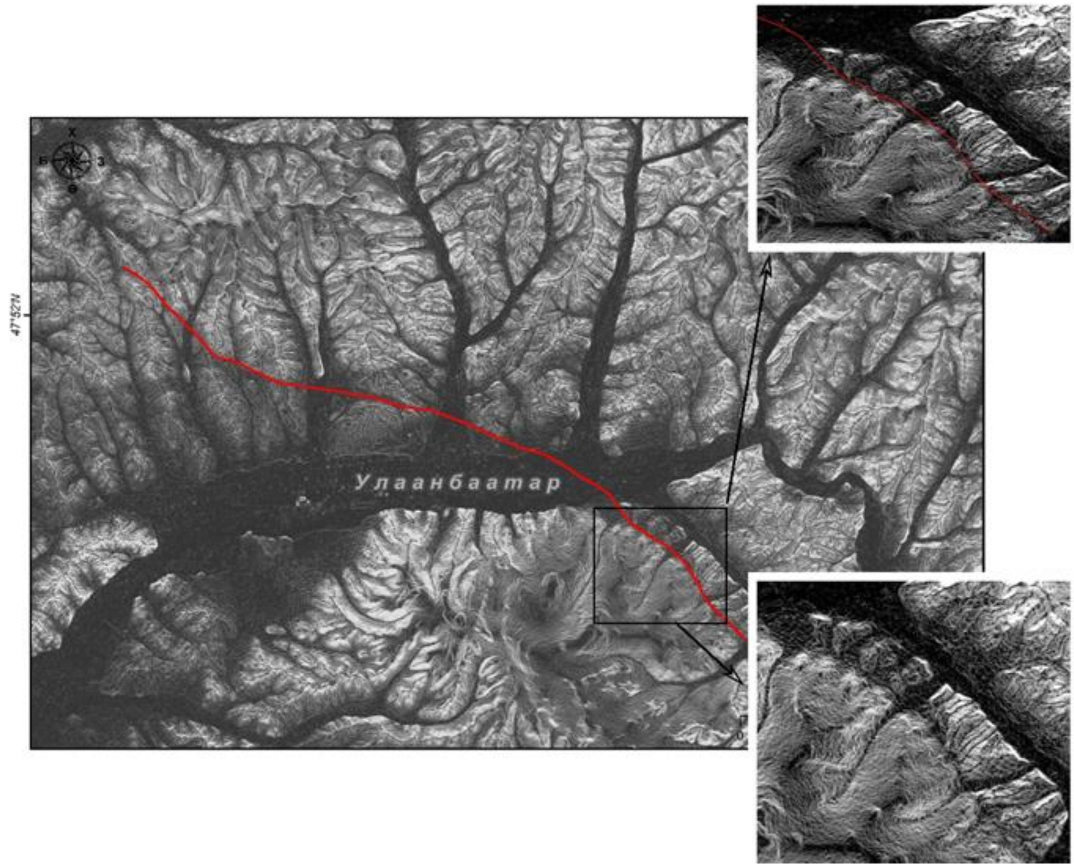

Figure 6. *Identification of Ulaanbaatar faults on an anaglyph of a digital model of a surface developed from interferometer images*

CONCLUSION

Although seismicity of Mongolia is not so active compare to regions of plate boundary, such like Circum-Pacific seismic belt, but it is a quiet active seismic region as an inland.

Over time, after a strong earthquake, the weakened soil around the crack becomes eroded, making the shape, size, and location of the faults on the fault surface difficult to determine with the naked eye. Therefore, modern remote sensing methods, including active surveillance satellite data, are widely used to predict short- and long-term potential natural phenomena such as earthquakes and surface changes, and to study the extent of disasters.

Resent studies allowed us to observe recent geological deposits, potentially datable, as well as sub-surface deformations induced by past earthquakes.

In this study, we calculated the 6th crack around Ulaanbaatar and the 7th crack through the settlement zone from satellite data by interferometric method, which is consistent with other researchers. This 7th Ulaanbaatar fracture was highlighted as an active fracture in a joint study by Mongolian and Japanese scientists. As a result, there is an urgent need to change the micro-region of Ulaanbaatar.
These non-destructive observations allowed us to observe recent geological deposits, potentially datable, as well as sub-surface deformations induced by past earthquakes.

Urban planners and researchers need to make changes to the assessment of the resilience of buildings and roads in Ulaanbaatar during earthquakes caused by active faults such as Emeelt and Gunjiin faults, which are highly dangerous due to the cracks around Ulaanbaatar.

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