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## Analysis of Radar Interferometry Results on the Deposit Territory

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### Abstract:

For effective and safe development of mining deposits, it is necessary to study the impact of natural and anthropogenic factors on the development of deformation processes, which provides an opportunity to regulate their impact on the rock mass, earth surface and engineering structures. The size of the deposit, geology and production volumes, affects the area of deformation, which can spread over huge areas. Accordingly, regional deformation monitoring is required for such fields. In order to provide high detail coverage of the area, traditional ground-based methods are impractical and costly. More timely and cost-effective for monitoring deformation of large territories is the use of differential radar interferometry.

The results of high-precision geodetic measurements for the period 2019-2021 revealed that more observation points have significant negative values. This indicates a stable process of subsidence of the earth, predominantly. Analysis and interpretation of the obtained results of geodynamic monitoring (high-precision leveling, radar interferometry), allowed to determine that the condition for the formation of vertical and horizontal deformations of the earth's surface is a natural-technogenic factor.

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## 1. INTRODUCTION

Intensive development of ore and oil deposits and certain geodynamic and geomorphological factors can have an adverse impact on the condition of the Earth's surface. Anthropogenic influence on the subsoil and the Earth's surface can lead to both natural settlements and abnormal deformations, which can cause economic and ecological damage [1].

As a result, there is a need to monitor the condition of the surface. Currently, there are several monitoring methods available for observing and detecting settlements of the Earth's surface [2]. Traditionally, such work involves the use of high-precision leveling and GNSS measurements. These geodetic measurement technologies provide millimeter-level accuracy. [3].

In recent years, the method of differential radar interferometry has become very relevant for monitoring deformations of the Earth's surface, which also allows for the detection of settlements with high accuracy.

Differential SAR interferometry uses methods of radar surveying of the Earth's surface from space satellites equipped with synthetic aperture radar (SAR) antennas [4]. The key data obtained from radar surveying are intensity and phase (signal time delay). Repeated radar surveys allow the calculation of phase differences caused by the movement of the Earth's surface [5]. Such displacements can be determined with high accuracy as a result of processing the radar survey.

This method has several advantages:

Scalability - monitoring large areas of the objects under study;

Cost-effectiveness - performing tasks without direct human involvement;

Promptness - radar images from space satellites can provide a picture of deformations in a short time.

## 2. LITERATURE REVIEW

Radar surveying is performed in the ultra-shortwave (ultra-high-frequency) region of radio waves, subdivided into X-, C-, L-, and P-bands. Each surveying band has its advantages and drawbacks. The bands are selected depending on the monitoring tasks, movements of the Earth's surface, buildings and

structures in each specific area, and depending on the type of terrain, vegetation cover, expected displacement magnitudes, etc.

The widespread use of radar data became possible with the advent of Sentinel-1 radar data. The article titled "Opportunities for Using Data from the New Sentinel-1 Satellite" [6] provides examples of Sentinel-1 radar data applications in various sectors.

The study [7] also shows a number of research projects for monitoring deformations of the Earth's surface over oil, gas, and mining deposits, where deformations over these deposits were identified, and the obtained results were compared with ground data to assess the accuracy of the results. The radar imaging data are suitable for monitoring tasks.

For this research, Sentinel-1 IW Single Look Complex (SLC) products are used.

The initial stage in interferometric processing involves the correct selection of SAR data. Sentinel-1 public data were chosen as the SAR data [8].

After a detailed analysis of available data, it was decided to use data for processing radar data from orbit 49. The polarization of these products is VV VH. The images were processed using the method of Persistent Scatterer Interferometry (PS) more than twice with different processing parameters in the Sarproz software.

The PS method is a technique for determining displacements of point objects that are constant reflectors for the radar satellite, which allows for measuring detailed displacements on infrastructure objects and is typically used for areas with urban terrain.

## 3. MATERIALS AND METHODS

The Persistent Scatterer method is based on analyzing a series of paired interferograms constructed relative to one fixed image, called the 'master'. Due to the finite resolution of the antenna, the value in each pixel of the interferogram is the vector sum of reflections of the satellite signal from all objects within the resolution cell. If reflecting objects within a pixel move chaotically, for example, if the area is covered with dense vegetation, then the total reflection will change randomly and the overall phase will not be correlated. However, if there is an object within the cell with a stronger reflection (for example, a rock outcrop, a

house roof, a tree trunk, or just an open space between trees), its contribution will dominate over random reflections from other objects, such as vegetation. If this ratio persists throughout the survey period, then this pixel can be identified as a 'persistent scatterer' [9].

This type of radar interferometry is characterized by the highest possible accuracy of displacement estimation (2–4 mm for buildings and structures, provided that at least 30 radar surveys are used over a period of at least one year). A total of 140 images were downloaded, of which 35 were selected for processing to obtain a displacement map for the period from 22.02.2020 to 22.07.2021.

To increase accuracy and eliminate orbit-related errors, additional files with orbital data corresponding to each image were downloaded. Afterwards, a master image was selected and co-registered.

Figure 1 shows the interferometric configuration of images used in the analysis, where the x-axis indicates the temporal baseline, and the y-axis indicates the perpendicular baseline. It is important to note that

almost all baselines for S1 images are precisely controlled at a distance of up to 100 meters. With shorter spatial/temporal baselines, as in our case, higher spatial coherence is usually achieved. Each point on the image represents a SAR survey, and each line represents one interferogram [10].

A star-shaped graph is a standard and optimized configuration for PSI processing. In this star-shaped connection, all images relate to one main image taken on August 20, 2020. Typically, the image obtained in the middle of the monitoring period is chosen as the main master image. Generally, the choice of master image does not affect the final result.

The next step, after successful co-registration, is the creation of a reflectivity map. The reflectivity map is the first result of the processing, which shows what the SAR image looks like and provides an overview of the backscatter characteristics of the SAR signal within the study area. The reflectivity map is generated by averaging the amplitude of all images in the stack [11]. Figure 2 shows the reflectivity map of one of its entire frames.

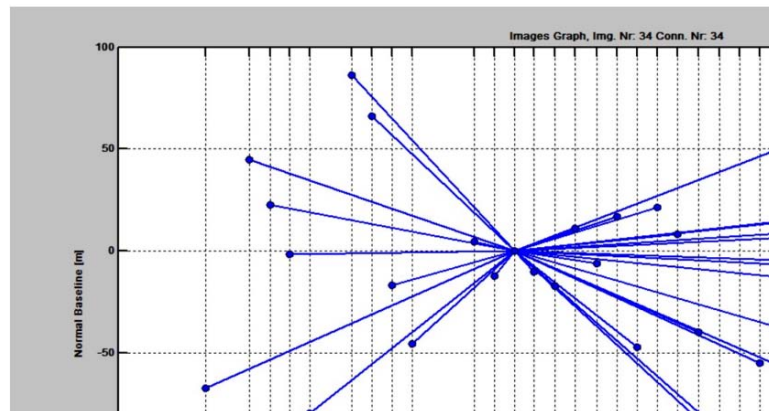


Figure 1: Interferometric configuration of images.



Figure 2: Reflectivity map and control point.

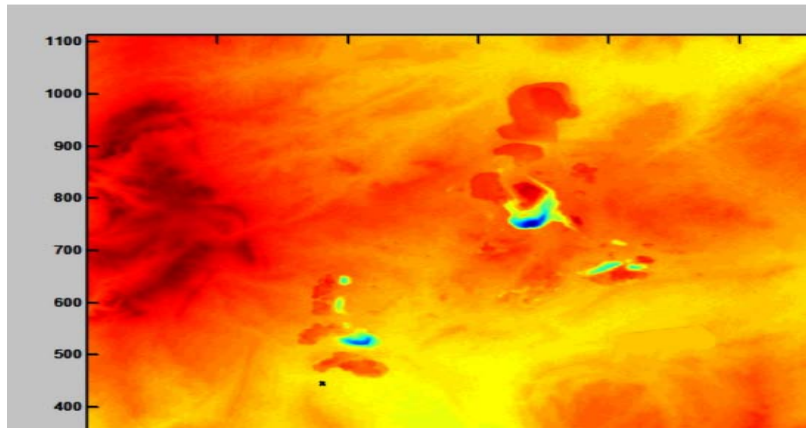


Figure 3: Digital Elevation Model.

To remove the topographic error, SRTM was used (see Figure 3).

**RESULTS AND DISCUSSION**

During the processing of the original data array using the PS method, a map of average displacement rate changes was created, which is a point vector file. The map contains more than 11,000 points, each of which is a stable reflector and has a set of attributes such as geographic coordinates, average displacement rates, date, coherence value, and others. Initially, a threshold from -100 mm to 100 mm was set for the displacement calculations, and a displacement map was obtained in which some points showed -90 mm over the specified period of time, while the resampled velocity indicated the presence of a point with a higher displacement value. Consequently, another series of processing was conducted where the requirements were lowered from 0.7 to 0.6 to increase coherence, and the displacement rate threshold values were set from -500 mm to 500

mm (see Figure 4) to explore the presence of points with higher displacement values.

Thus, the obtained displacement map shows deformations of some areas with maximum settlements up to -500 mm.

As a result of processing the radar images, a deformation map of the territory of the deposit was obtained. For a comparative analysis of the interferometric data obtained, a small area was selected where significant displacements of the Earth's surface were recorded. On this site, annual instrumental observations of settlements are carried out. High-precision leveling is performed along profile lines, which represent a network of benchmarks [12]. A total of three profile lines located in the deformation zone were selected for analysis. The position of the profile lines is shown in Figure 5. A fragment of the deformation map of the Earth's surface of the deposit is also shown here.

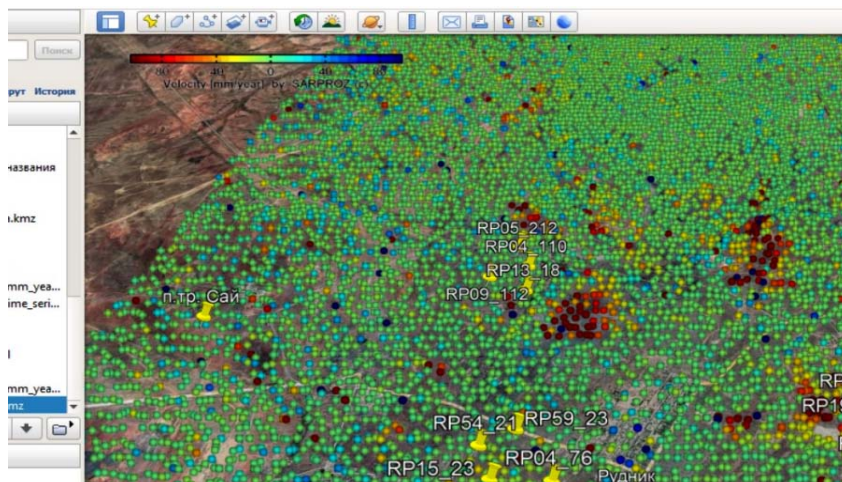


Figure 4: Displacement maps (from the final processing), where the calculation of maximum displacements was set within the range of -500 mm to 500 mm.



Figure 5: Fragment of the map, vertical displacements, location of selected profile lines.

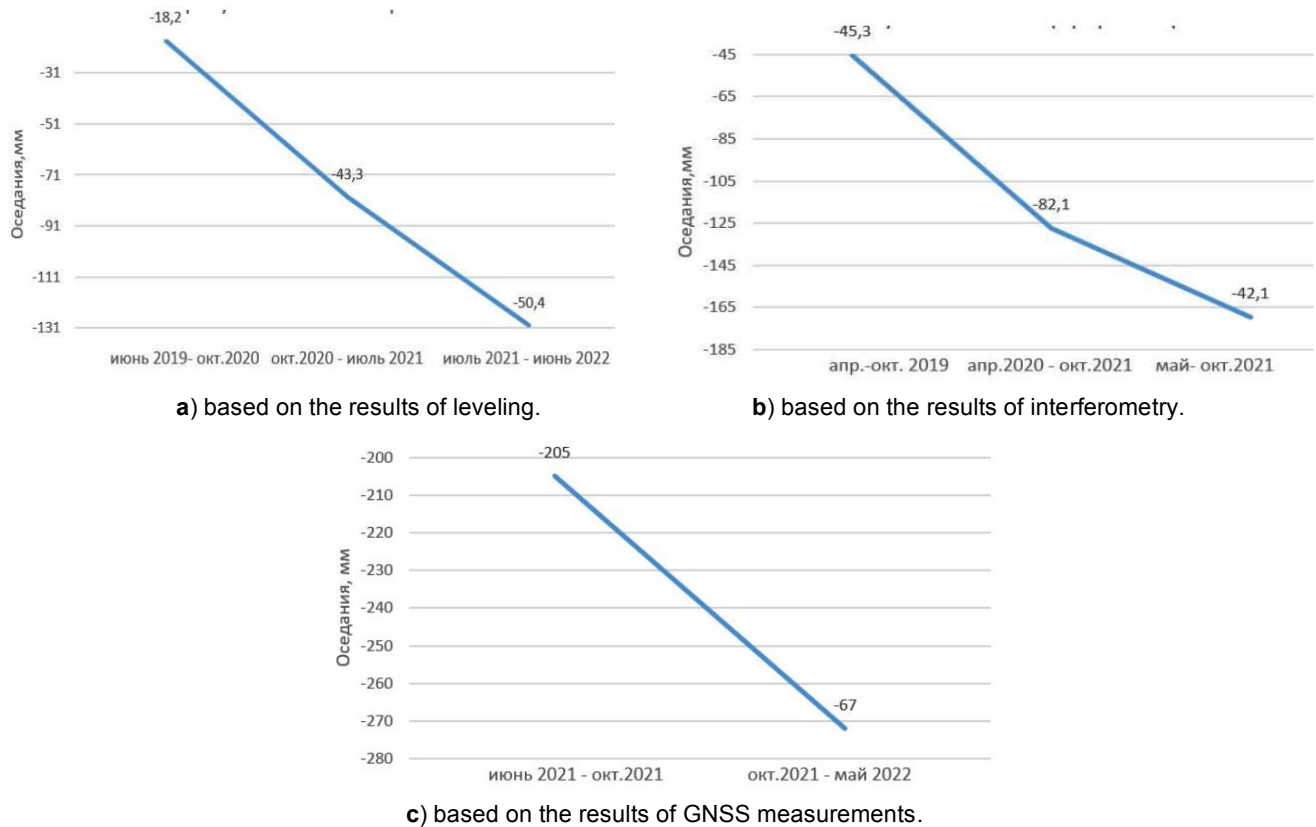


Figure 6: Verification of interferometry with GNSS measurements and leveling.

As shown in Figure 5, a trough of settlements has formed in the area. Over three years of observations, the maximum settlements in this territory reached values from -18.2 mm to -50.4 mm.

Figure 6 presents data on the development of displacements for one of the benchmarks. Analyzing these graphs, it can be concluded that the area subsided from 2019 to 2021.

The results of remote sensing are consistent with the results of high-precision leveling and GNSS measurements.

## CONCLUSIONS

Interferometric analysis of the selected area has yielded results about the activity of deformations. The correspondence of the analysis results with instrumental observation data suggests the feasibility of using radar interferometry for monitoring displacements of the Earth's surface or for predicting deformations and identifying potential hazard zones, where observation stations will need to be established in the future.

Thus, interferometric analysis of the territory of the deposit provides important and practical results about

the activity of deformations and their spatial distribution. This opens up the possibility of real-time monitoring of deformation processes over large areas.

## CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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