THE USE OF REMOTE DATA FOR MONITORING DEFORMATION PROCESSES IN HYDROCARBON DEPOSITS

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Abstract

The paper considers the issues of possible use of data on micro-amplitude displacements of points on the Earth's surface as indicators of manifestations of induced seismicity. The results of the performed processing of the X-ray interferometry data, presented by the corresponding graphs, in comparison with the data of the epicenter of borehole seismological observations on the field area for the same period of time testifies to the unconditional connection of manifestations seismicity with anomalous features of amplitude graphs.

The revealed regularities allow using the data of the interferometry radar not only for the purposes of areal mapping of deformation processes, but also as a tool for monitoring the manifestations of seismicity caused by the exploitation of the deposit and the accompanying disturbances of geodynamic equilibrium. This work is purely methodical in nature.

Keywords: technogenic seismicity, deformation processes, seismic risk, interferometry, development of hydrocarbon deposits.

I. Introduction

Manifestations of geodynamic activity in subsurface use areas in the form of techno- or endogenous seismic events are essentially the final phase of the cycle of accumulation and discharge of stresses in the geological environment. The consequences of such a discharge can be both tangible and tragic [1, 2]. Therefore, monitoring of the geodynamic activity of the territory with the integrated use of both ground-based geophysical methods and remote ones is an integral part of the field development process. The advantage of remote research methods is the possibility of obtaining data on geodynamic processes occurring not only in individual observation points, but also in the possibility of a holistic and one-time study of the entire area of the object.

Since all geodynamic processes proceed continuously, it is important to distinguish trend and anomalous components against their background. It is with the latter that manifestations of seismicity caused by man-made impact on the subsoil can be associated. And here, in order to understand what is happening, it is extremely important to establish and fix microseismic (micro-amplitude) events, which in the future can serve as a trigger in the onset and development of avalanche-like voltage discharges [3].

In this paper, the possibilities of radar survey as a tool for monitoring studies of technogenic seismicity at an active hydrocarbon field are considered.

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II. Methodology

Radar survey is a type of active survey in which a probing satellite system generates a radio wave pulse and receives a return signal reflected by the earth's surface.

To solve the problems of monitoring deformation processes, data obtained over a five-year period by the COSMO SkyMed satellite system (e-GEOS, Italy) was used. This system consists of four satellites that allow high-resolution (4 m) shooting with a frequency of up to 8 times a month, which ultimately made it possible to obtain in a short time the necessary set of images that meet the processing requirements in the system of the SARScape software complex (Harris Geospatial Solutions, USA), which is a set of additional program modules ENVI (Harris Geospatial Solutions, USA).

In total, at the final stage of processing, 71 images were used, obtained over five seven-month cycles in the same shooting geometry and having the same polarization.

For comparison, data from borehole seismological observations conducted independently for the purpose of monitoring seismic activity associated with the development of the field were used. The results of these observations are presented by tabular data of the time and coordinates of the hypocenters of micro-earthquakes recorded on the research area.

The purpose of the performed analysis was to simultaneously identify characteristic signs of induced seismicity over the entire research area using graphs of vertical displacements of points on the Earth's surface.

III. Results

The peculiarity of the data used is that, gathered together, they made it possible to track the development of deformation processes of the earth's crust, caused, among other things, by their technogenic component, over a relatively long period of time.

It was assumed that a confident correlation of the features of the graphs of vertical displacements at points distant from each other by a relatively large distance can serve as a sign characterizing the state of geodynamic equilibrium of the geological environment in the mining diversion zone.

Figure 1 shows a conceptual model of geomechanical evolution

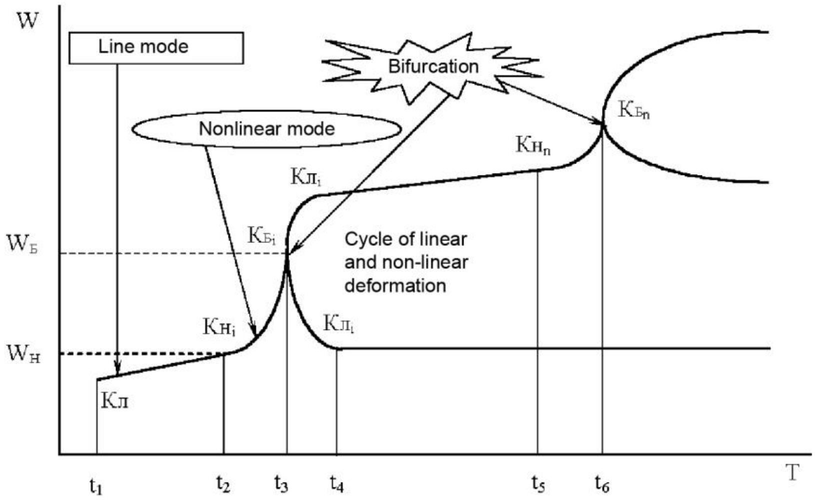

Figure 1: *Conceptual model of geomechanical evolution [3].*

The main control parameter of the model is the energy W. As it is noted in the works of Melnikov N.N. et al., (2001, 2009) at the initial stage of operation of the field, development proceeds in a linear-deterministic mode. At the same time, the geomechanical evolution of processes developing in the geological environment is carried out by alternating stages of linear and nonlinear deformation with the probability of abrupt transition or bifurcations (catastrophes).

When the control parameter W reaches the limit values, the natural-technical system enters the stage of nonlinear development, the consequences of which are expressed in the spatio-temporal localization of events, among which there may be dangerous geodynamic phenomena such as simultaneous catastrophic subsidence, large-scale landslides and man-made earthquakes [3].

Let us consider from these positions two series of graphs constructed for independent and remote points located on the area of the mining allotment (Figures 2, 3).

The graphs characterize the dynamics of deformation processes that occurred in the geological environment during 2015-2019. Each point marked on the graph with a red cross corresponds to the date of the survey of the corresponding period of monitoring observations. It is obvious that against the background of a relatively stable trend, there are characteristic areal manifestations of local geodynamic processes.

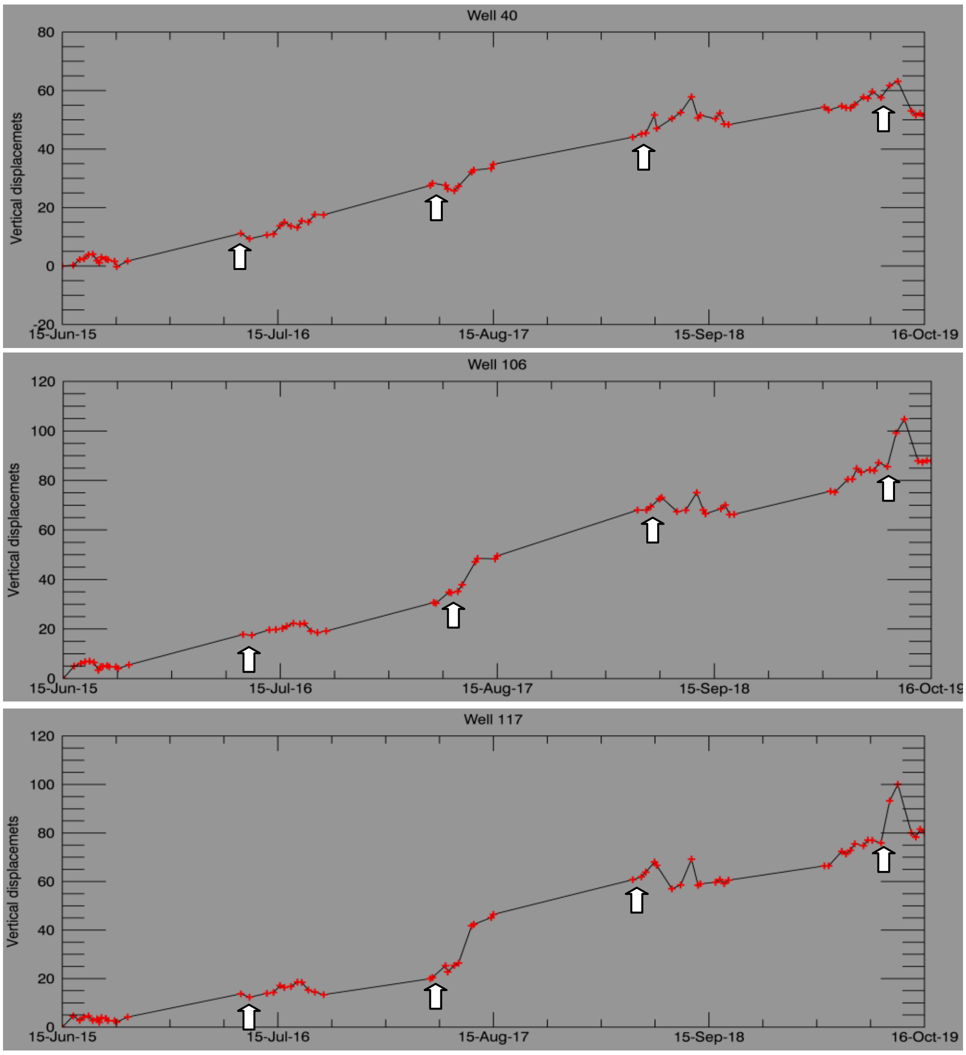

Figure 2: *Installation of graphs of vertical displacement amplitudes for "borehole" points*

On the presented graphs, the arrows indicate the time points of a possible transition of the geological environment to a state of new geodynamic equilibrium, accompanied by the discharge of accumulated stresses in the form of micro-earthquakes. It can be seen that, without exaggeration, in each cycle of monitoring observations, anomalous manifestations of vertical displacements are recorded almost everywhere and at the same time. Moreover, as will be shown below, the direction of the offsets is in full accordance with the direction of the trend.

In particular, it is possible to state the occurrence at the end of the 2017 cycle, which is steadily traced for the most part of the mountain branch, of an anomaly of displacements of a characteristic table-shaped shape, with an amplitude of about 20 mm, which existed until the beginning of the 2018 cycle (Figure 3).

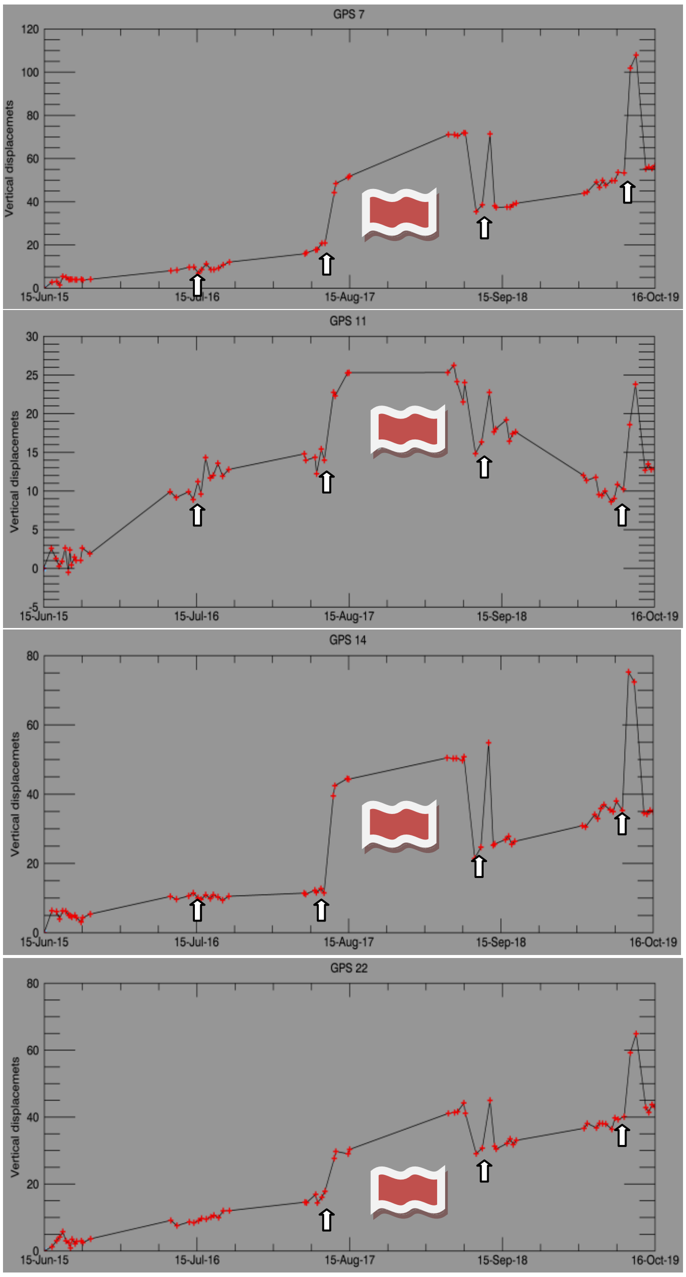

Figure 3: *Installation of graphs of vertical displacement amplitudes for GPS points*

Considering in detail the pulse anomaly that occurred at the end of July 2019, it can be stated that a one-time abrupt change in the amplitude of vertical displacements occurred in the territory of the mining allotment, recorded in a number of points remote from each other (Figure 4). Moreover, the displacement sign is in full accordance with the trend direction (Figure 5).

In accordance with the concept mentioned above, this event can be interpreted as the result of the discharge of accumulated stresses and the transition of the system to an updated state of geodynamic equilibrium, which is confirmed by the actual material.

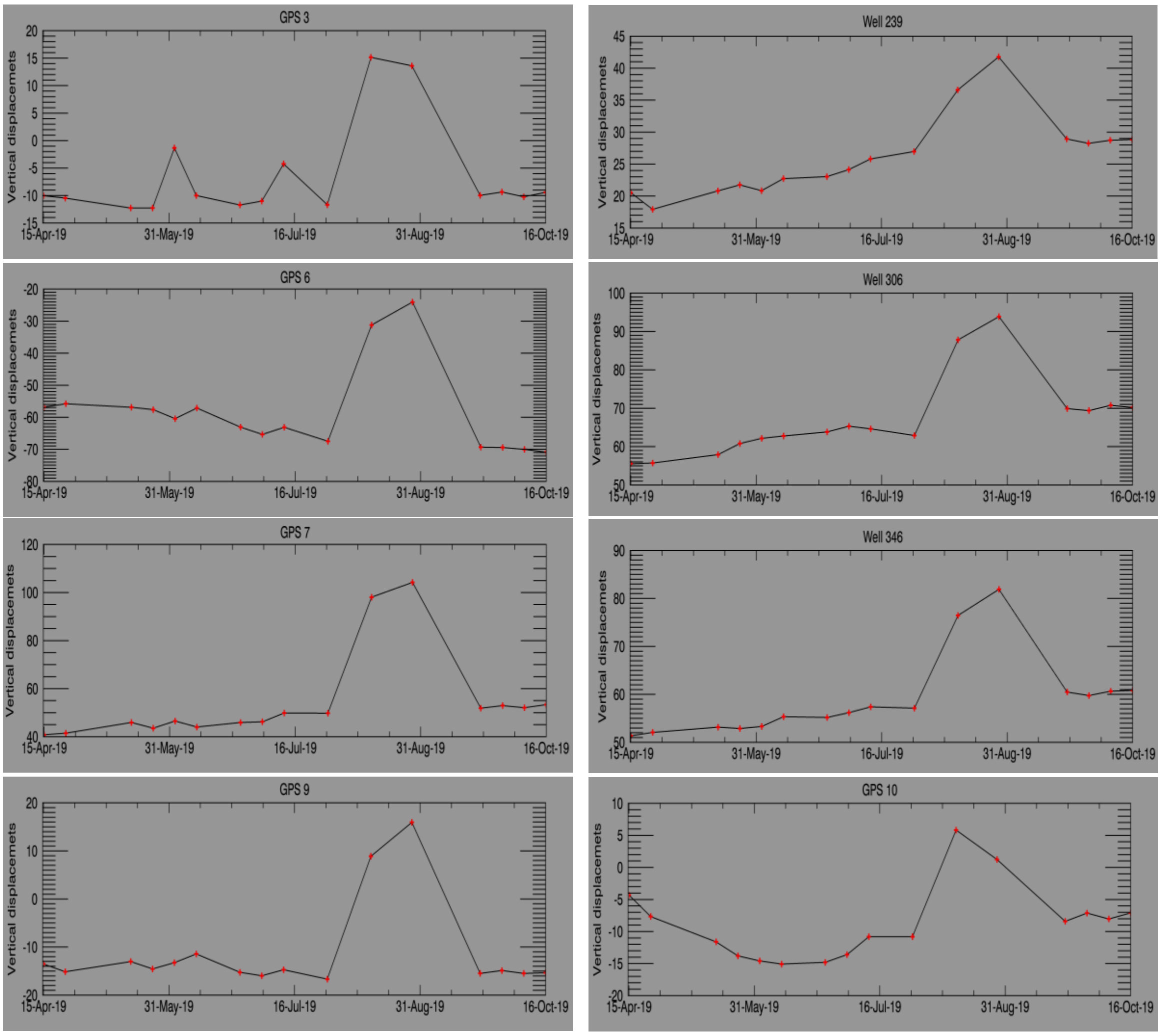

Figure 4: *Installation of graphs of vertical displacement amplitudes for the points "GPS" and "borehole" for 2019.*

The event that occurred was recorded at most points of the geodynamic polygon and, judging by the nature of the graphs, the next stage of linear permanent stress accumulation began in the geological environment at the end of the monitoring cycle in 2019.

The amplitude graphs shown in Figures 4 and 5 indicate that the recorded displacements cannot be attributed to random fluctuations. Moreover, the point where the sign change occurs (Figure 5) may indicate a section of the area experiencing various types of deformation processes for the current period of time.

To confirm the reliability of the above conclusions, the results of borehole seismometric observations were compared with the data of X-ray interferometry (Table).

Obviously, the 2019 event cannot be considered a coincidence, since all the earthquakes recorded before and after it do not correspond to the nature of the graphs shown in Figures 4 and 5.

The time scale of plotting for 2015-2018 (Figures 2 and 3) does not allow us to strictly identify the events shown in the table with the features of amplitude anomalies noted on the graphs. However, upon closer examination, their correlation is not in doubt.

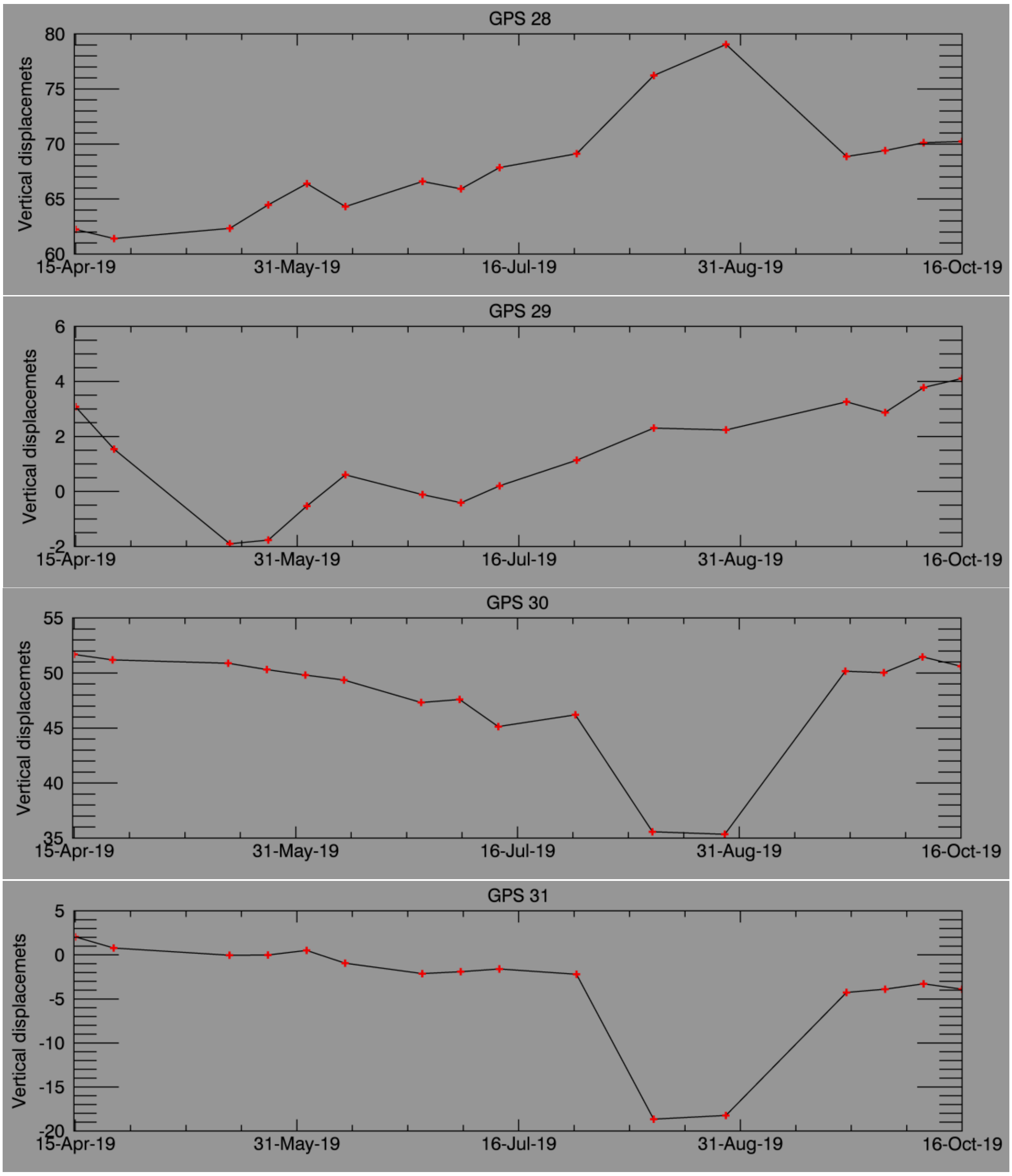

Figure 5: *Installation of graphs illustrating the change of the sign of vertical displacements for GPS points for 2019.*

Table: *Micro-earthquakes recorded in wells during periods conducting monitoring observations during 2016-2019*

No. no.pp.	Date			Time		Note
	year	month	number	hour	mines.	
1	2016	07	15	20	05	Registered events: before - 03.06. and after – 30.07
2				20	08	
3	2017	05	08	23	09	Registered events: before - 23.05. and after – 19.09
4	2018	09	08	15	25	
5		11	09	02	40	
6		29	09	18	14	
7				21	28	
8		30	09	12	42	
9	2019	20	07	00	11	Registered events: before - 07.07. and after – 27.07

Thus, the verification results allow us to conclude that, despite the discrete-time nature of satellite imagery, the data of detailed monitoring observations by X-ray interferometry can be used as an additional retrospective indicator of seismic events. Moreover, what is important, geodynamic zoning can be performed and areas of the area that have experienced certain types of deformation processes for certain periods of time can be shown. This kind of information may be of paramount importance for subsoil users as a technogenic factor indicating their hidden and possibly irreversible development.

IV. Conclusion

It is established that the trend nature of the displacements can be considered the background of abnormal manifestations, possibly of a technogenic nature.

The obtained graphs indicate the trend-impulse form of development of geodynamic processes dominating at the polygon, fitting into the conceptual model of geodynamic evolution

In accordance with the above-mentioned concept, geodynamic processes on the territory of the mining allotment proceed in a linearly deterministic mode, that is, in the mode of alternating periods of stress accumulation with subsequent discharge and the transition of the system to an updated state of geodynamic equilibrium.

It can be assumed that at the end of the monitoring cycle of 2019, the next stage of linear permanent accumulation of stresses due to man-made impact on the subsoil began.

Thanks

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References

[1] Sashurin A.D. Diagnostics of geodynamic activity at the subsurface use site. Seminar No. 8, GIAB, 2004, N6. pp. 185-187.

[2] Sashurin A.D. Modern geodynamics and the development of disasters at subsurface use objects., Geodynamics and the stressed state of the Earth's interior. Proceedings of the International Conference. Novosibirsk. IGD SB RAS, 2004. pp. 369-371.

[3] Melnikov N.N., Kalashnik A.I., Kalashnik N.A. Technogenic geodynamic processes in the development of oil and gas fields of the Barents Sea shelf. Bulletin of the Moscow State Technical University, volume 12, No. 4, 2009, pp. 601-608.