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Using the geopolariton tomography based on UAV to explore and monitor coalfield subsurface structures in Shaanxi, China

S. I. Prokopenko *(Hebei DSF-GEOS Technology Co., Ltd, China)*, ****O. O. Vodopianov*** *(Hebei DSF-GEOS Technology Co., Ltd, China)*, ***X. Chen*** *(Hebei DSF-GEOS Technology Co., Ltd, China)*

SUMMARY

Geopolariton tomography technology is a passive geophysical method that uses nonequilibrium geopolariton radiation of the Earth to explore the stress-strain state of rocks. The use of technology makes it possible not only to assess the prospects of a mining area at the design stage of work but also to control the safety of mining operations by monitoring the stress-strain state of rocks. This exploration was carried out to identify the subsurface structures of a coalfield as part of the project 2022-05-JSFU-01 commissioned by Yulin University, China. Aerogeophysical work was carried out in Shaanxi Province in northern China at the licensed area of the mining company Shenmu Shimengou Mining Co., Ltd. Shaanxi is among the provinces with abundant coal resources. An area of 2.5 km^2 was investigated according to the geological task. As a result of the study, in the coalfield, at a depth of 127 m, abandoned mine workings were found. According to the obtained geophysical information, the coal mining design plans for this section of coalfield have been adjusted. Coalfield monitoring agreements were achieved. Ministry of Emergency Management published a recommendation for using geopolariton tomography to monitor the safety of underground mines.

Introduction. In recent years, thanks to continuous innovations in the field of passive electromagnetic exploration technologies, geopolariton tomography technology is gradually being implemented by the industry for geological exploration. The technology was firstly used in the exploration and accounting of oil, and natural gas reserves at relatively large depths. These explorations achieved good results (Bogdanov et al., 2019; Xu et al., 2014). An innovative solution is using DSF geopolariton tomography equipment installed on a UAV to explore and monitor the subsurface structures at relatively small depths (Bogdanov et al., 2020). This solution was successfully tested on the coalfield of the mining company Shenmu Shimengou Mining Co., Ltd. Shaanxi is among the provinces with abundant coal resources in North China. These enormous coal resources (approx. 4143 Gt) are widely distributed in the Ordos Basin and its marginal fold belts (Yuan et al., 2021). According to the geological task, an area of 2.5 km^2 was investigated. The scope of work amounted to 51 measuring profiles, 11 of them are longitudinal and 40 – transverse with a total length of 56 km. The licensed coalfield area is located in the northern part of the Loess Plateau and on the southern edge of the Mu Us desert. A loess ravine relief form mainly prevails in the deposit area. The general trend of the relief is high in the south and low in the north. The highest point with a height of 1292.7 m is located on the northern drainage field in the southern part of the field, and the lowest point with a height of 1106.6 m is located in the northeastern corner of the field. The total height is 1120 ~ 1250 m, and the relative maximum height difference is 186.1 m. The general feature is that the plateau surface is relatively wide and the ravines are relatively narrow, the slopes of the ravines are steep, and the loess is eroding vertically, often forming narrow and short ditches.

Method and Theory. Geopolariton tomography technology (GPTS) is a passive geophysical method that uses nonequilibrium geopolariton radiation of the Earth to explore the stress-strain state of rocks. The magnetic component of the Earth's geopolariton radiation is received in the low-frequency range from 1 to 50 kHz (Bogdanov et al., 2008). Geopolariton radiation, registered on the earth's surface, is the reflection and indicator of the nonlinearity of mechano-electromagnetic transformations in the lithosphere as a distributed gain medium. The main process, which occurs in this medium, is the process of self-organization. (Bogdanov et al., 2010) The power source of geopolariton waves that "shine through" the mantle, asthenosphere, and lithosphere of the planet is the energy of slow waves and natural elastic vibrations of the Earth's core (Bogdanov, 2017).

The technology of geopolariton tomography has advantages in the explorations of active local structures, active faults (including their intersection nodes), and tectonic stress zones, it can adapt to complex terrain.

Hardware and software. The software and hardware complex includes:

- DJI Unmanned Aerial Platform Matrice 300 RTK (UAV).
- UAV remote control and management device.
- DSF equipment for the geopolariton tomography of the Earth (GPTS).

The appearance of the equipment is shown in figure 1. Table 1 shows the technical characteristics of the UAV and DSF equipment.

Table 1 *The main characteristics of the UAV and DSF equipment*

Platform (quadcopter)	DJI - Matrice 300 RTK
Maximum flight speed, m/s	23
Take-off weight, g	2700
Maximum wind speed resistance, m/s	12
GPTS Hardware Complex	DSF
Spectral range, kHz	1-50
Weight, g	2000
- signal processing unit	1500
- antennas unit	500
Overall dimensions, mm:	
- signal processing unit	160 x 100 x 65
- antennas unit	100 x 100 x 90

Figure 1 *DSF geopolariton tomography equipment based on the UAV*

Structurally, DSF equipment consists of two units - receiving antennas unit and a signal processing unit. Enclosures of the units have a certain degree of environmental protection IP64. The receiving antenna unit contains three antenna modules, each of which has a special electrical shield. The antennas' patterns are located in three mutually perpendicular planes. The main advantages of GPTS hardware and software complex:

- Exploration of the coal drift surfaces, not only at the upper part but also with a significant slope.
- Making a geological and geophysical section of the interested sector.
- Monitoring of chosen structural horizons of the selected area.
- Monitoring of seismic and microseismic processes activation level in the coalfields area.
- Inspection of large areas in a short time.
- Detection of dangerous geodynamic areas at an early stage, which allows for taking timely action to minimize damage.
- Detection of rock underground mining zones.
- Performing aerogeophysical work in any climatic and difficult terrain conditions.

Results of investigations. During the implementation of the project, the UAV-based DSF geopolariton tomography equipment was tested in difficult mountain terrain and weather conditions with strong winds. It met all the declared technical characteristics. Equipment effectively coped with the task of identifying places with high mountain pressure, flooded mountain ranges, rocks loosening areas, and coal seam 3^{-1} development zones. Underground mine workings were discovered. Geopolariton radiation intensity map, radiating horizon of coal seam 3^{-1} map, and vertical cross-sections were created. The correlation method and Laguerre spectral method were used to build the vertical cross-sections (Bogdanov and Vodopianov, 2017). GPTS software made it possible to create structural and density 2D and 3D models of the studied volumes of geological rocks with spatial reference to global coordinates (Prokopenko et al., 2021).

Figure 2 shows the location of coalfield (a) and a map of coalfield geopolariton radiation intensity (b). There are three zones with reduced intensity of geopolariton radiation highlighted in blue on this map. The reduced intensity of geopolariton radiation indicates that the rocks have less dense in these places and it can be assumed that mining operations were carried out in these areas previously. This map can be generated automatically from survey data and can be used for area monitoring.

The map of the density distribution characteristics of the radiating horizon of the coal seam 3^{-1} is shown in figure 3a. Places with low density are shown in blue, which indicates dislocations of the coal seam. A geophysical cross-section along the 1.1 km length line PR-SSK2 is shown on the top of figure 3b. Four zones of rock extraction are shown with red dashed circles. A speed cross-section (figure 3b, bottom) shows the layered structure of the mountain massif. The section is consistent with the drilling data of the well SSK2 with high accuracy.

Conclusions. Based on the results of the survey of a 2.5 km^2 area by GPTS technology, a map of the geopolariton radiation intensity, a distribution map of the density characteristics of the coal seam 3^{-1} radiating horizon with an indication of reduced density areas on it, geophysical and velocity sections up to the depth of 200 m along the 1.1 km line PR-SSK2 were created. The zone of underground mining workings at the depth of 127 m in the area of well SSK2 has been confirmed.

On the cross-sections and on the distribution map is shown that coal mining operations have already been carried out in this area which confirms the corresponding assumption. Taking into account the received geophysical information, the design plans for the coal mining in this coalfield section have been adjusted. As a result of the work, the flying platform with DSF equipment was tested to visualize the current state of the controlled object with spatial reference.

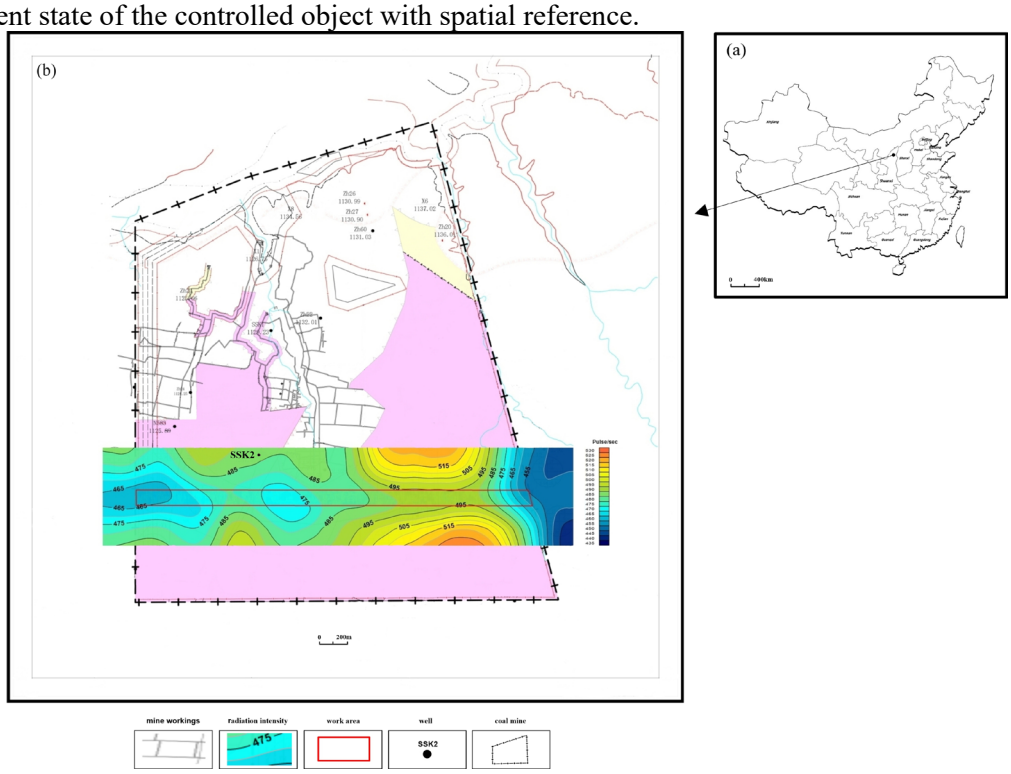

Figure 2 *(a) Location of coalfield; (b) the map of coalfield geopolariton radiation intensity. The color indicates the radiation intensity (red - high, blue – low)*

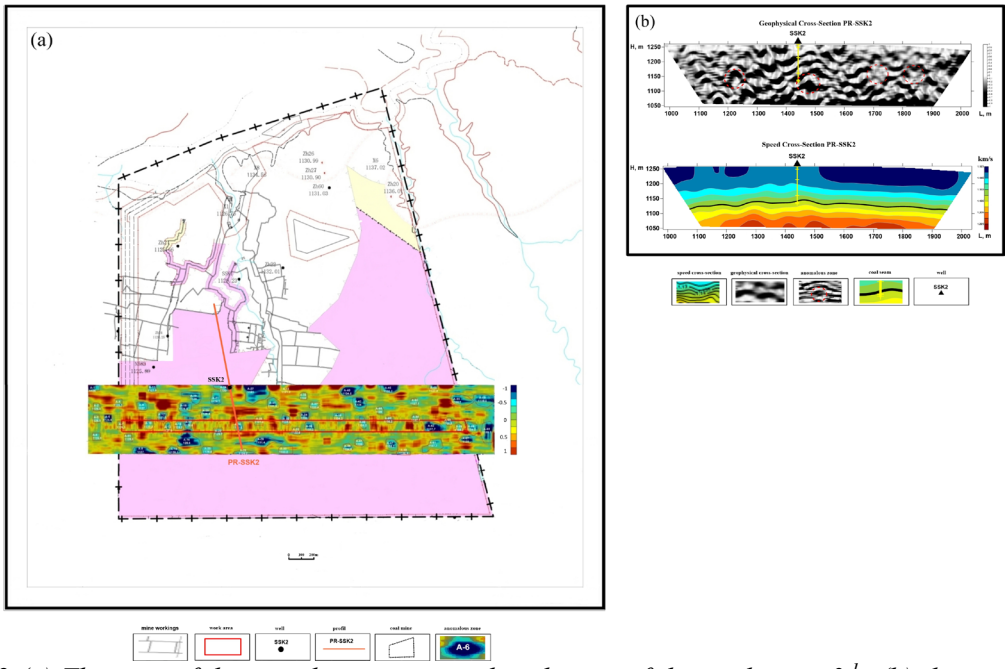

Figure 3 *(a) The map of density characteristics distribution of the coal seam 3^{-1}; (b) the geophysical (top) and the speed (bottom) cross-sections along the orange line PR-SSK2. The color on the map and speed section indicates the density of rocks (red is high, blue is low)*

With the regular inspection of the same object by GPTS technology, it becomes possible to control the evolution of geodynamic processes of the rock state and control the boundaries of rock production. The use of the UAV-based GPTS hardware and software complex for aerial monitoring of the geopolariton activity of rocks greatly simplifies the development of large coal deposit areas and increases the efficiency of detecting dangerous geodynamic manifestations. As a result of this and a series of other similar projects, carried out with GPTS technology (Li et al., 2022), the Ministry of Emergency Management published a recommendation for using geopolariton tomography to monitor the safety of underground mines[1].

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