International Journal of Energy
ISSN: 2957-9473 | Vol. 7, No. 1, 2025

Application of Comprehensive Geophysical Exploration Methods in the Disaster Treatment of Goafs in Gypsum Mines

Xiaoyu Jiao

The Third Exploration Team of Shandong Coalfield Geological Bureau, Tai'an Shandong, 271000, China

Abstract: This paper focuses on the application of comprehensive geophysical exploration methods in the disaster treatment of goafs in gypsum mines. Firstly, the research background is expounded, and the principles and advantages of the transient electromagnetic method and the microtremor method are introduced, with the significance of the combined application of the two emphasized. Then, the geological conditions of the study area, including the characteristics of the strata and structures, are described in detail. Subsequently, the geophysical characteristics are analyzed, providing a theoretical basis for the application of geophysical exploration methods. Finally, through practical cases, the specific application and effects of comprehensive geophysical exploration methods in the detection of goafs in gypsum mines are demonstrated, aiming to provide reliable technical support for the sustainable development and utilization of gypsum mine resources.

Keywords: Comprehensive Geophysical Exploration Method; Goaf in Gypsum Mine; Disaster Treatment; Transient Electromagnetic Method; Microtremor Method.

1. Introduction

Against the backdrop of the continuous deepening of the development and utilization of mining resources, as an important non-metallic mineral resource, the safe and efficient mining of gypsum mines and related geological research have received much attention. Precisely detecting the geological structure of gypsum mines, the distribution of goafs, and other situations is of great significance for ensuring the safe production of mines and improving the resource recovery rate. The Transient Electromagnetic Method (TEM) uses an ungrounded loop or a grounded power source to emit a primary pulsed magnetic field into the ground, and observes the secondary induced eddy current field during the intermittent period to detect the resistivity of the medium. This method has high construction efficiency, is sensitive to low-resistance bodies, has significant advantages in searching for low-resistance geological bodies in high-resistance surrounding rocks, and is not affected by topography. It can effectively identify water-bearing geological bodies, goafs, and other situations in gypsum mines. The microtremor method is based on the observation of natural field source microtremor signals by an array, extracts the dispersion information of surface waves (Rayleigh waves), and obtains the S-wave velocity structure of underground media through inversion. It has the advantages of strong resistance to electromagnetic interference and vibration interference, lightweight instruments, and convenient construction, and is suitable for detecting soil-rock interfaces, cavities, fault structures, etc. within gypsum mines. The combined application of the transient electromagnetic method and the microtremor method in the detection of gypsum mines can obtain geological information from different physical property perspectives and achieve complementary advantages. The combination of the two is expected to provide a more reliable basis for the fine detection of the geological structure of gypsum mines, the precise positioning of goafs, and the stability assessment, and contribute to the sustainable development and utilization of gypsum mine resources.

2. Geological Conditions of the Study Area

The Dige Depression Basin extends in the NWW direction, with a length of about 45 km and a width of about 10 km to 12 km. The Yicheng-Shaobu major fault controls the northern boundary of the basin, and the Hanzhuang-Zhangzhuang major fault controls the southern boundary of the basin. Fold structures are less developed in the basin, while fault structures are relatively developed. The strata show a monoclinic structure that dips northward. The Tiefogou major fault runs across the central part of the basin, dividing the basin into two parts. The Bianqiao Formation of the Paleogene Guanzhuang Group is distributed within the basin. The northern, western and southern parts of the basin are in contact with the Neoarchean Taishan Group, the Neoproterozoic Tumen Group, as well as the Cambrian and Ordovician systems respectively, and the eastern part of the basin is adjacent to the Cretaceous system. The thickness of the gypsum-bearing rock formation within the basin is greater than 100 m. The structures are mainly faults, with the F1 fault in the southern part of the exploration area being the main one. Its strike is NE30°, it dips northwestward, and its dip angle is 65°. The vertical throw can reach up to about 215 meters. The southeastern block rises, while the northwestern block drops, and it is a curved normal fault.

3. Geophysical Characteristics

3.1. Transient Electromagnetic Method

Theoretically, the resistivity of dry rocks and air is relatively large. However, in practice, the pores and fractures in rocks always contain water, and as the humidity or saturation of rocks increases, the resistivity drops sharply. Different rocks with the same water content have certain differences in resistivity, because the water has different degrees of mineralization. In this way, the resistivity of the fault does not depend on the size of the fault itself, but mainly on the degree of fragmentation of the fault and its water saturation; the resistivity of the rock formation does not depend on the resistivity of the dry rock itself, but mainly on the saturation of the rock and the mineralization degree of the water. Generally speaking, the resistivity of water-bearing faults and rock formations is much smaller than that of the surrounding water-free host rocks, which is the physical basis for electrical prospecting to evaluate the water abundance of faults and aquifers through electrical characteristics.

3.2. Microtremor Detection

Different rock formations have different velocities. Generally, the velocity values of mudstone, siltstone, medium-coarse sandstone, gravel layer, coal seam, and limestone increase successively. In the case of dense and intact rock formations, the velocity is relatively high. If there are structures such as fractures or karsts in the rock formations, or they are cut by faults, or there are goafs, it will cause obvious velocity differences between the rock formation and the surrounding rocks, which is the geophysical premise for detecting goafs by microtremor detection. The goaf shows the characteristics of independent low-velocity anomalies. The low-velocity anomalies in the form of circles, oblate shapes, and strip shapes in the contour map of the apparent S-wave velocity Vx and their morphological changes indicate the spatial position, occurrence, and development scale of the detected target body.

4. Geophysical Prospecting Working Methods and Principles

4.1. Transient Electromagnetic Method

First, the transient electromagnetic method, which is sensitive to low resistance and has obvious stratification, is used for planar control, and the control is intensified in abnormal areas. The PROTEM transient electromagnetic instrument produced by Geonics Company in Canada is used in this transient electromagnetic exploration. This instrument has the characteristics of short turn-off time, large amount of information, high resolution, large dynamic range, high signal-to-noise ratio, flexible observation device, and high stability.

4.2. Microtremor Detection

Microtremor detection refers to a geophysical exploration method that extracts the dispersion information of surface waves (Rayleigh waves, Love waves) from the microtremor signals of natural field sources observed by an array through data processing and analysis techniques, and then obtains the S-wave velocity structure of underground media through surface wave inversion techniques.

The continuous natural weak vibrations existing anywhere on the earth's surface are called "microtremors", which is a kind of vibration phenomenon that is extremely irregular in the time and space domains. They are generated by natural phenomena such as air pressure, wind speed, ocean waves, and tidal changes, and also originate from human daily activities, such as vehicle driving and mechanical vibrations. The microtremor signals contain both body waves and surface waves, and the surface wave energy in the microtremor signals accounts for more than 70%. Therefore, the surface wave information in the microtremor is often used to study the S-wave velocity structure of the subsurface. In practical applications, the Rayleigh waves in the surface wave signals are often used. This method has been widely applied to multiple exploration fields abroad, especially in Japan. In recent years, with the successful development of high-performance intelligent sensing microtremor instruments (such as MEMS geophones) in China, the in-depth theoretical research on microtremors and the continuous optimization of inversion algorithms, practical achievements have been made in multiple fields such as geothermal surveys, goaf detection, urban geological surveys, landslide surveys, and active fault detection, with the detection depth ranging from the near surface to 1m to 3000m.

The amplitude and morphology of microtremor signals change with time and space, but they have statistical stability within a certain spatio-temporal range and can be described by a stationary random process in time and space. The microtremor exploration method is based on the theory of stationary random processes, extracts the dispersion curves of surface waves from microtremor signals, and obtains the S-wave velocity structure of the subsurface through the inversion of the dispersion curves.

5. Processing, Interpretation and Three-dimensional Visualization Analysis

5.1. Transient Electromagnetic Method

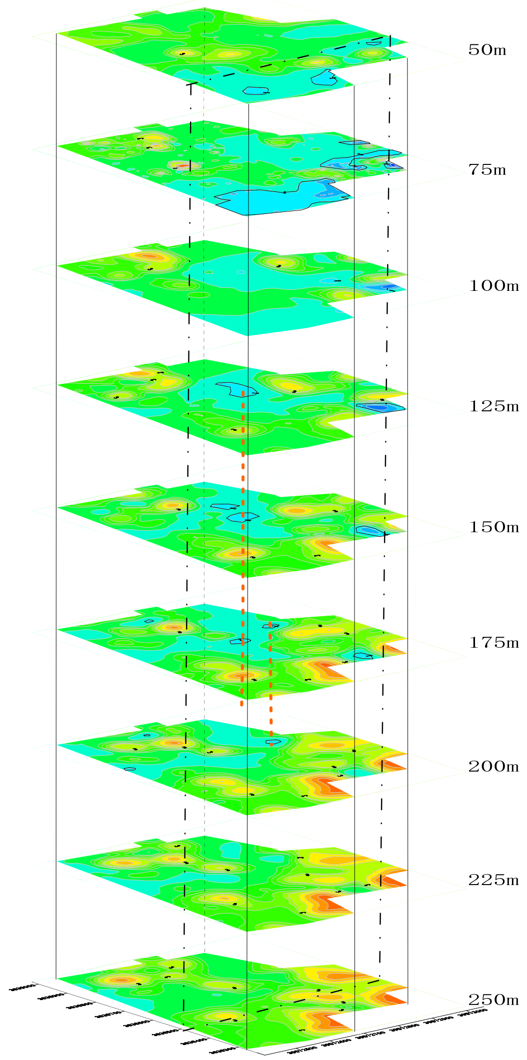

Figure 1. Three-dimensional slice diagram of transient electromagnetic field

Through the processing of the transient electromagnetic data in the study area, 13 profiles have been completed and combined to form a three-dimensional comprehensive profile; within the depth range of 0-300m, a total of 9 slices at 50m, 75m, 100m, 125m, 150m, 175m, 200m, 225m, and 250m have been completed. Since the gypsum ore layer in the study area is located in the shallow part within 250m, no more slices are made for the lower part, and a three-dimensional horizontal slice map is combined.

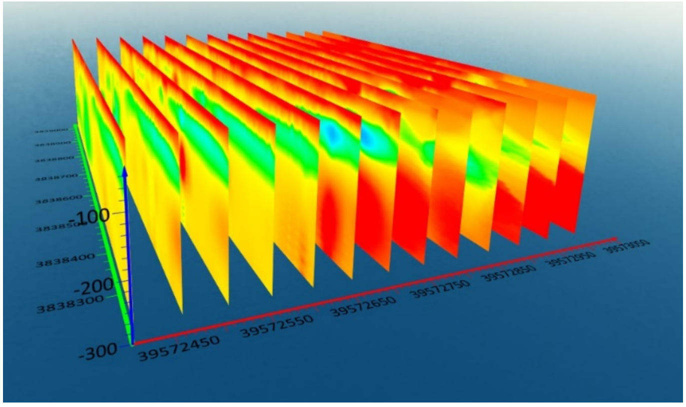

Figure 2. Three-dimensional sectional diagram of transient electromagnetic method

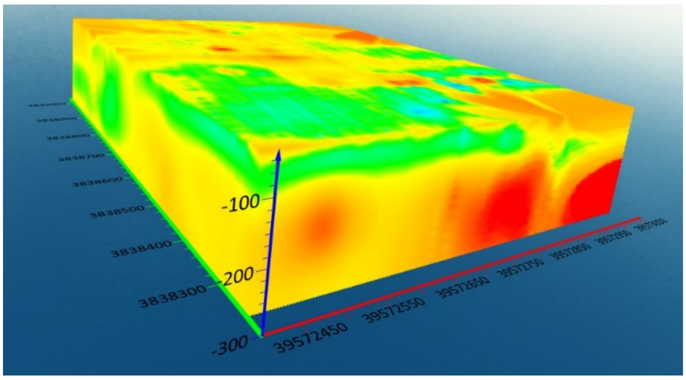

Figure 3. Three-dimensional transient model diagram

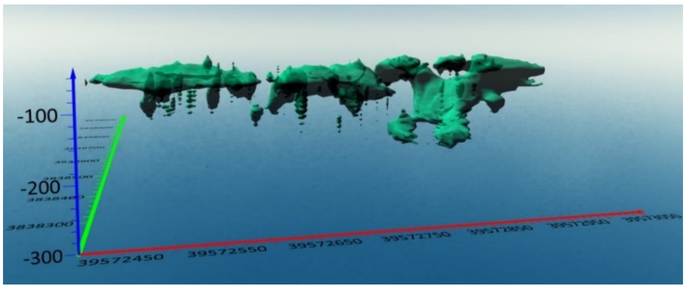

Figure 4. Curved surface model diagram of 1Ω.m

It can be seen from each three-dimensional diagram that each water-rich abnormal area has connectivity, and there is a certain degree of connectivity. Please refer to Figures 1-4 for details.

5.2. Microtremor Detection Method

The measuring point spacing in this measurement is 20m. Professional software is used for processing and analysis in the later stage. According to experience and the actual analysis results, the range of 1.5 times the point spacing is the blind area of this measurement, that is, the depth range of 30m in this measurement belongs to the blind area. For this geophysical exploration method, within the range of 10m, which is half of the point spacing near the goaf, the wave velocity will change, and the detected abnormal area is larger than the actual range. According to the requirements of geophysical exploration technology, the distribution range of the empty cavity of the underground goaf is inferred based on the wave velocity abnormal area. The error requirement of the detection result is ≤10m. The slice diagram of the detection result of the survey line is drawn, and the detection and interpretation depth are 0-300m. Among them, a slice diagram is drawn every 25m within the depth range of 0-250m. A total of 9 slices at 50m, 75m, 100m, 125m, 150m, 175m, 200m, 225m, and 250m have been completed for each survey area. Since the gypsum ore layer in the geophysical exploration area is located in the shallow part within 250m, no more slices are made for the lower part.

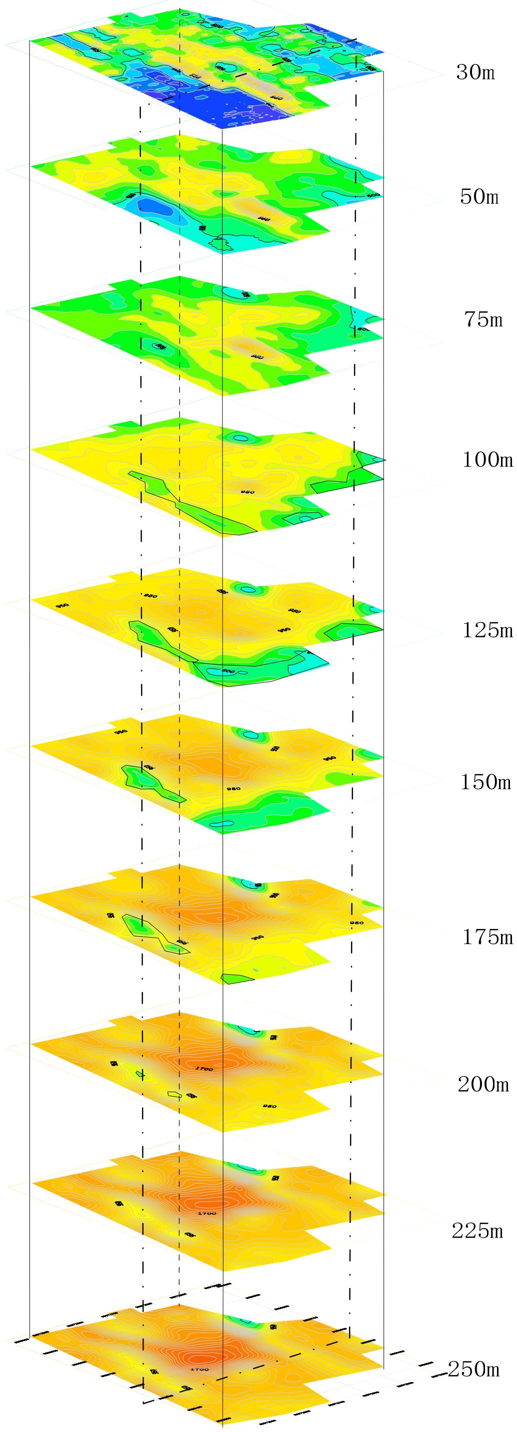

Figure 5. Three-dimensional slice diagram of microtremor detection

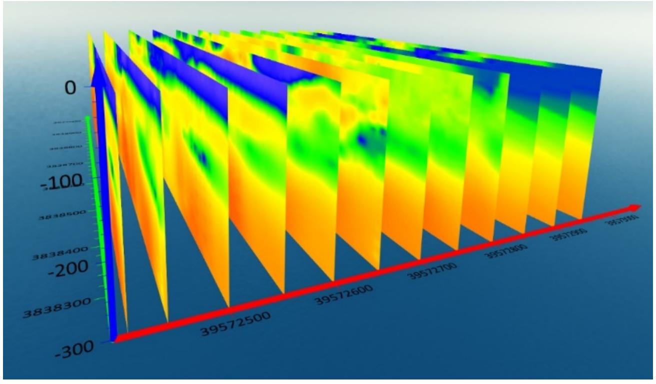

Figure 6. Three-dimensional sectional diagram of microtremor detection

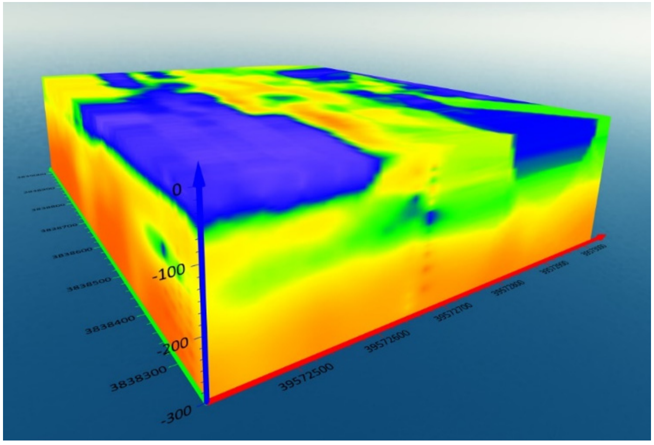

Figure 7. Three-dimensional model diagram of microtremor detection

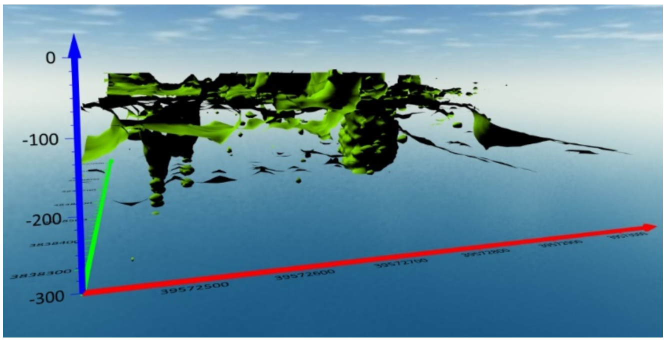

Figure 8. Curve diagram with a speed of 750 m/s

It can be seen from the three-dimensional diagrams of the microtremor method that each low-speed abnormal area has connectivity, and the range gradually decreases from top to bottom. Please refer to Figures 5-8 for details.

5.3. Comprehensive Analysis

Due to the long history of goaf in the exploration area, there may be collapses, and the internal structure may be loose or dense. Therefore, corresponding reactions may appear in the geophysical exploration results.

For the transient electromagnetic method, in the goaf, caving zone and stretching zone, obvious low-resistance anomalies will occur when there is rich water. If there is no rich water, corresponding high-resistance anomalies will occur; for the microtremor detection method, obvious low-speed abnormal areas will appear in the goaf, and certain relative low-speed anomalies will be shown in the caving zone and stretching zone.

It can be seen from the three-dimensional slices that there is a certain connection between the low-resistance abnormal area and the low-speed abnormal area from top to bottom, but the slice diagram also has its own limitations.

Comprehensively considering and combining each profile, slice and three-dimensional diagram, through research and analysis, the following 4 inferred goaf abnormal areas are formed. Among them, the planar area of the inferred goaf in the Z1 abnormal area is about 102,494 m^2, and the depth range is about 85-170 m; the planar area of the Z2 abnormal area is about 20,952 m^2, and the depth range is about 85-220 m; the planar area of the Z3 abnormal area is about 30,634 m^2, and the depth range is about 40-80 m; the planar area of the Z4 abnormal area is about 63,973 m^2, and the depth range is about 40-80 m. Due to the large number of deep goafs and the long time span, low-speed areas appear in the shallow areas, that is, the goaf collapse areas, which are basically consistent with the ranges of ground collapses and cracks in houses.

6. Conclusion

1) According to the geological environment characteristics of the goaf in the gypsum mine of the study area, a comprehensive geophysical exploration method combining the transient electromagnetic method and the microtremor detection method is selected to carry out the research on the detection and application of the goaf. The research results show that the two geophysical exploration methods have their own advantages, disadvantages and applicable ranges in the detection of the goaf in the gypsum mine. The transient electromagnetic method can be used to delineate the current situation of water filling in the goaf, and its exploration results are very important for the stability analysis and development trend prediction of the goaf in the gypsum mine; the microtremor detection method has obvious wave velocity reactions in the goaf and the collapse area, and can be used for the detailed exploration of the governance range of the goaf in the gypsum mine.

2) The practical application shows that the comprehensive geophysical exploration method can accurately find out the distribution, scale and stability of the goaf in the gypsum mine, provide a reliable basis for the governance of the goaf, help to ensure the safe production of the mine, improve the resource recovery rate, and realize the sustainable development and utilization of the gypsum mine resources. In the future, with the continuous development of geophysical exploration technology, the application prospect of the comprehensive geophysical exploration method in the disaster treatment of goafs in gypsum mines and other mines will be broader.

References

[1] Zhang Guangcheng, Fu Jundong, Liu Jianmin, et al. Research Progress of Natural Source Surface Wave in the Detection of Underground Structures [J]. Sichuan Building Materials, 2017(10): 174-175.

[2] Wang Zhendong. Key Points and Latest Progress of Surface Wave Exploration Technology [J]. Geophysical and Geochemical Exploration, 2006(1): 1-6.

[3] Li Lianying, Xue Junjie, Zhao Xuanxuan, et al. Application of Comprehensive Geophysical Exploration Method to Investigate the Goaf of Coal Seam [J]. Geophysical and Geochemical Exploration, 2017(2): 377-380.

[4] Zhang Xuedong, Feng Deshun. Application of Room-and-Pillar Caving Mining Method in Zaozhuang Gypsum Mining Area [J]. Shandong Building Materials, 2003, 24(4): 48-49.

[5] Liang Yongqi, Du Shouhua. Discussion on the Collapse Mechanism and Development Factors of the Goaf in Coal Mines [J]. The World of Geotechnical Engineering, 2007, 11 (8): 35-37.