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Application Research of Mine GPR in Advanced Detection of Geological Anomalies in Coal Seam

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Abstract

Mine GPR has the advantages of high detection efficiency, high precision, good portability, explosion-proof, and accurate detection of small structures in coal seam structure. According to the radar wave anomaly characteristics of three kinds of typical geologic anomalies detected by mine GPR in fault fracture zone, fissure dense zone and water enriched zone, the explosion-proof GPR system with the dominant frequency of 100MHz and 50MHz antenna were used to test and detect the geological anomalies in coal seam of some working face of a mine in Yunnan to obtain the radar response characteristics in this paper. And the obtained radar data are compared and analyzed with the anomaly characteristics of the radar wave of the typical geologic anomalies, which is used as the reference for inversion interpretation of the measured data and verified in the measured application. Therefore, mine GPR has a wide application value in the advanced detection of geological anomalies in coal seam, and has a good guiding significance for the safety of coal mining.

Keywords

Mine GPR; Geological anomalies of coal seam; The response characteristics; Anomaly analysis.

1. INTRODUCTION

Coal is one of the indispensable energy sources for human production and life. The supply of coal is related to the development of China's industry and social stability. In recent years, the depth of coal mining continues to increase, resulting in more and more difficult coal mining. Coal mining safety has become an important part of China's energy security.

The geological conditions of coal mining are very complicated, so it is necessary to predict the geological anomalies in the working face in advance and formulate a reasonable coal mining plan to ensure safe and efficient production. At present scholars using a variety of mine geophysical technology to detect geological anomalies in coal seam, has made many achievements [1-4]. These methods to determine the structure of coal mine, exploration, collapse column, fault fracture zone and other complex geologic anomalies has a certain

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advantage, but for some small anomalies (such as faults, collapse, etc.) can't explain well, and in the complex terrain may form the target deviation. Mine GPR has the advantages of high detection efficiency, high accuracy, good portability and explosion-proof [5-6], which can accurately detect small geological anomalies. Cheng Jianyuan, Lu Ziqing et al. used borehole GPR technology to detect the geological structure and water-rich anomaly area within 30 m of the borehole radial direction, which solved the conflict between advance detection and rapid excavation in construction time, operation space and detection environment [7]. Based on the principle of finite-difference time-domain numerical analysis, Luo Shoutao et al. carried out forward simulation of small fold GPR advance detection and effectively detected the small fold in front of the tunneling roadway [8]. Qiu Nianguang conducted radar detection for known geological anomalies in Xinjing Mine. Based on the detection results and forward modeling results, he summarized the geological radar reflection characteristics of 10 geological anomalies or phenomena [9]. In recent years, mine GPR is more and more widely used in the exploration of coal seam structure and provides the basis for the safe mining of coal mines.

This paper analyzes the radar wave anomaly characteristics of several typical geological anomalies in the previous geological radar detection data. Taking the advance forecast of a mine in Yunnan province as an example, the radar response characteristics of typical disaster sources were analyzed, and the radar response characteristics were obtained, which were used as the reference basis for inversion interpretation of measured data, and verified in the measured application.

2. BASIC PRINCIPLES OF GPR

GPR is a geophysical method which uses antennas to transmit and receive high frequency electromagnetic waves to detect the properties and distribution of materials in media. According to the propagation theory of electromagnetic wave, the propagation law of radar wave in the medium conforms to Maxwell's equations [10], namely:

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = j + \frac{\partial D}{\partial t}$$

$$\nabla \cdot H = 0$$

$$\nabla \cdot D = \rho$$

In the formula, E is electric field intensity, H is magnetic field intensity, B is magnetic induction intensity, D is electric displacement vector, j is conduction current, ρ is free charge density.

When GPR is used to detect geological anomalies in coal seam, high-frequency electromagnetic waves are emitted from the transmitting antenna to the coal seam. If the electromagnetic wave is transmitted to the interface of two different media, such as fault, karst cave and rock interface, the electromagnetic wave will be reflected and refracted at the interface due to the difference of the electrical properties of the two media. The propagation of incident, reflected and refracted waves follows the laws of reflection and refraction, and the reflected waves return and are received by the receiving antenna (Fig. 1) [11].

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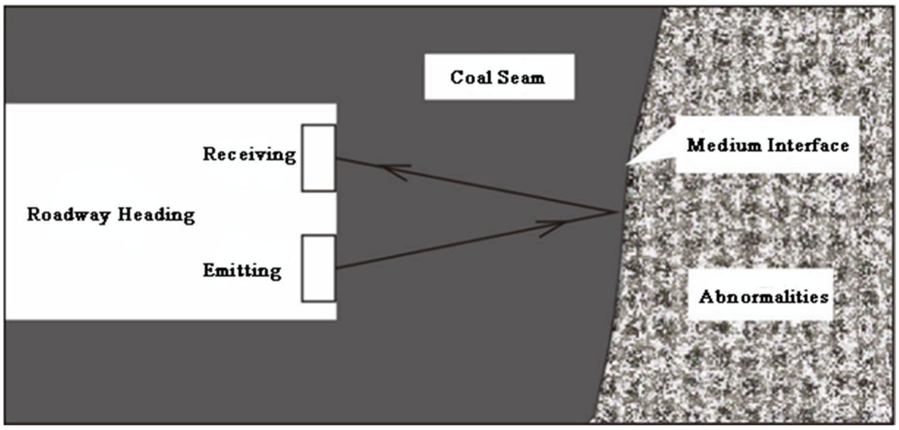

Figure 1. Schematic diagram of mine GPR detection

3. RADAR WAVE ANOMALY CHARACTERISTICS OF TYPICAL GEOLOGIC ANOMALIES

Through the research of the previous GPR detection data, the radar wave anomaly characteristics of the following three typical geologic anomalies are obtained, that is, fault broken zone, fracture dense zone and water enriched zone [12].

3.1. Fault Broken Zone

The two plates of the fault move relative to each other and crush each other, breaking the nearby rocks and forming a fracture zone roughly parallel to the fault plane, which is a destructive geological structure. The fractured rock mass, mud or groundwater are usually developed inside the fault. The medium is very uneven with large electrical difference, and the rock mass on both sides often develops joints and folds, resulting in poor medium homogeneity. In the process of advancing coal mine tunnel face, the coal seam near the fault becomes soft, the dip angle changes, the leaching increases, and the roof is broken [13]. The abnormal reflection of GPR wave is obvious in the region of coal seam bedrock crushing and mud inclusion with different media loss, and the intensity and amplitude of reflected wave are large (Fig. 2 (a)) [14]. Compared with the general soft surrounding rock, the most difference of fault fracture zone is that the fault fracture zone is broken and the soft surrounding rock is weak, and the fault fracture zone has higher uniaxial compressive strength but lower self-stabilizing force.

3.2. Fracture Dense Zone

Fracture zones usually exist in the affected zones of faults, dikes and weak interlayers. There are also various non-uniform filling materials in the fractures, with great dielectric difference. Fracture zone geological radar images and waveform characteristics usually show the higher attenuation coefficient. The reflection coefficient near the reflection surface increases, the amplitude of GPR wave train increases, and the interface reflection is obvious. The reflection of radar wave on the crack surface is strong, and diffraction and scattering phenomenon will occur in some pinching area. The high frequency part of electromagnetic wave energy in deep strata attenuated rapidly, and its reflection was not obvious. The line of reflection wave in phase axis on fracture plane was the location of joint fracture zone or fracture zone (Fig. 2 (b)) [15].

3.3. Water Enriched Zone

Groundwater often exists in fault zone, fissure zone and karst zone. The GPR images and waveform characteristics of the water enriched zone are generally shown as follows: GPR waves reflect strongly on the surface of the aquifer; When the electromagnetic wave penetrates the aquifer, it will produce several strong reflections with certain regularity, and produce diffraction and scattering phenomena in the water enriched zone, concealing the detection of rock mass in

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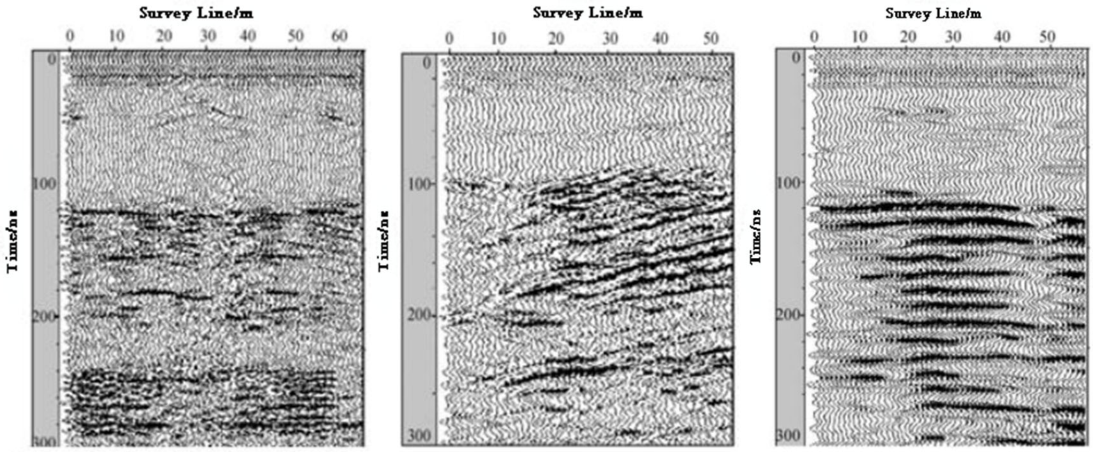
the water enriched zone and in the deeper range; The electromagnetic wave frequency changes dramatically from high frequency to low frequency, the pulse period increases obviously, the electromagnetic wave energy decreases rapidly, the energy group distribution is not uniform, and the automatic gain gradient is large; Because the water surface is usually distributed continuously, the reflection wave has great continuity in phase axis and relatively uniform waveform; The transition from bedrock to aquifer is a change of high impedance to low impedance medium, and thus its phase can be polar reversed (Fig. 2 (c)) [16].



(a)fault broken zone (b)fracture dense zone (c)water enriched zone

Figure 2. Image of typical geologic anomaly characteristics

4. APPLICATION RESEARCH

The experimental exploration was carried out in a mine in Yunnan. The geomorphology of the mine is composed of two types: the plateau denudation middle-mountain area and the plateau karst area. The surface limestone covers a large area, and the geomorphology is often characterized by erosion, denudation peaks and valleys. The exposed section of soluble rock is relatively easy to dissolve and the groundwater activity is strong.

4.1. Acquisition Parameters and Survey Line Design

The ZTR-12 intrinsically safe explosion-proof GPR system independently developed by China University of Mining & Technology, Beijing was selected for test detection. It was equipped with 100MHz and 50MHz antennas to reduce interference signals and improve detection accuracy. The sampling window was set to 900 ns, and the sampling points were set to 2048, and stacked for 3 times.

Four round-trip survey lines parallel to the roadway floor are designed on the heading face of roadway face, and a marker point is designed every 0.5m on the survey line for data positioning. There are 50 radar data between each two marker points. In a 5m wide roadway, 11 markers are designed for each survey line, 44 markers are designed for 4 survey lines, and 2000 radar data are collected (Fig. 3). In the process of data acquisition, the antenna and the face of the roadway are closely aligned and move uniformly along the survey line to ensure the good coupling between the antenna and the face of the roadway. In data acquisition, in order to improve the detection accuracy and avoid the impact of random interference on the data, the data will be collected based on the survey line for several times during the detection, and finally comprehensive interpretation and analysis of the data.

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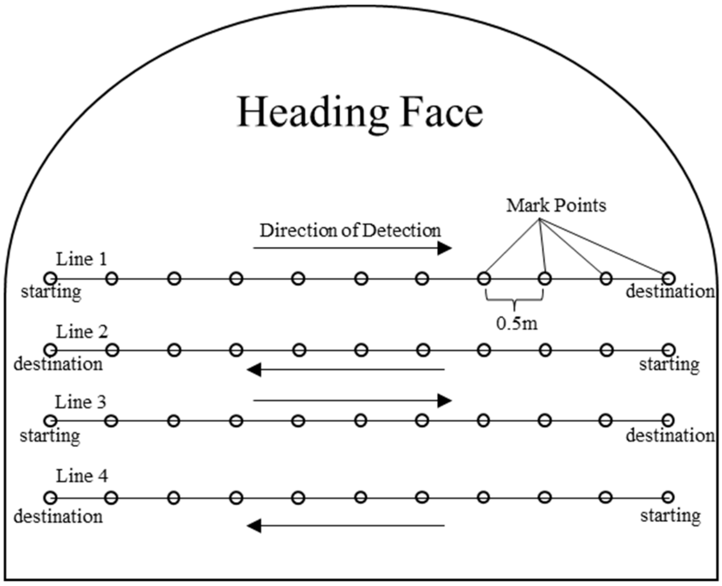

Figure 3. Schematic diagram of GPR detection line layout

4.2. GPR Data Analysis

4.2.1 Detection of fault broken zone and fracture dense zone

The advanced detection GPR data of K0+149.5m heading face in the lower section of track roadway of 1010201 working face of the mine were comprehensively processed and analyzed, and the GPR interpretation profile was obtained (left of Fig. 4). In the interpretation profile, there are two anomaly areas, namely YC-1 and YC-2, with depths ranging from 12-34m and 43-48m respectively. In the depth range of 12-34m, the radar wave in-phase axis is obviously misaligned, accompanied by diffraction, scattering and other phenomena, but its reflected energy is not abnormal. According to the waveform characteristics and reflected energy, combined with the specific geological situation, it is speculated that YC-1 is the development of coal seam breakage and fissure joints caused by structure.

The advanced detection GPR data of K0+963.8m heading face in the lower section of track roadway of 1010201 working face of the mine were comprehensively processed and analyzed, and the GPR interpretation profile was obtained (Fig. 4). In the interpretation profile, there are two anomaly areas, namely YC-3 and YC-4, with depths ranging from 1-3m and 14-16m respectively. In the shallow abnormal area within 5m, the in-phase axis of the radar wave is obviously misaligned. In the abnormal area of 14-16m, the radar wave has strong reflection energy and large reflection coefficient. According to the radar pop, the phase and amplitude of the radar wave are obviously changed, but the in-phase axis is not misaligned. According to the waveform characteristics and reflected energy, combined with the specific geological situation, it is speculated that YC-3 is the development of joints and fractures, and YC-4 is the fault.

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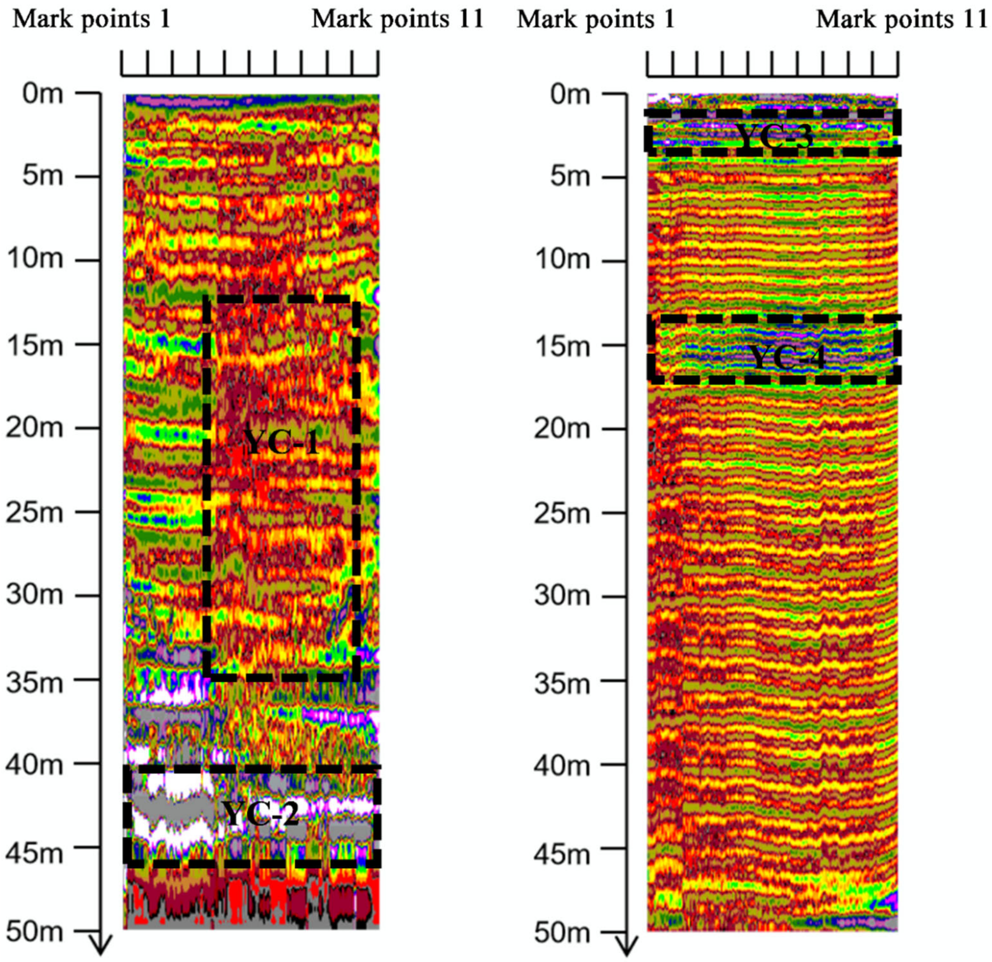

Figure 4. GPR profile interpretation of fault broken zone and fracture dense zone

4.2.2 Detection of water enriched area in coal seam

The advanced detection GPR data of K0+295.2m heading face in the lower section of track roadway of 1010202 working face of the mine were comprehensively processed and analyzed, and the GPR interpretation profile was obtained (left of Fig. 5). In the interpretation profile, there are two anomaly areas, namely YC-5 and YC-6, with depths ranging from 2-3m and 8.5-11m respectively. The radar wave in-phase axis along the horizontal direction has no obvious dislocation, the reflection energy is strong, the reflection coefficient is large, and the phase changes. According to the waveform characteristics and reflected energy, combined with the specific geological situation, it is speculated that YC-5 is the interface between the shallow surface floating layer and bedrock medium, and there is broken rock with large water content, resulting in shallow oscillation of radar wave and low SNR of deep signal.

The advanced detection GPR data of K0+269.9m heading face in the lower section of track roadway of 1010202 working face of the mine were comprehensively processed and analyzed, and the GPR interpretation profile was obtained (right of Fig. 5). In the interpretation profile, there are three anomaly areas and one disturbance, namely YC-7, YC-8, YC-9 and GR-1, with depths ranging from 11.5-13.5m, 18.5-23m, 30-33m and 3.5-5m respectively. The radar wave in-phase axis along the horizontal direction has no dislocation, the reflection energy is strong, the reflection coefficient is large, and the phase changes. According to the waveform characteristics and reflected energy, combined with the specific geological situation, it is speculated that YC-7, YC-8 and YC-9 are coal and rock medium under roadway floor. Water-bearing floating layer about 0.4m thick is detected on the surface of floor, which causes radar wave attenuation and coupled oscillation in air medium, and makes local concave strong reflection interface appear in radar interpretation profile.

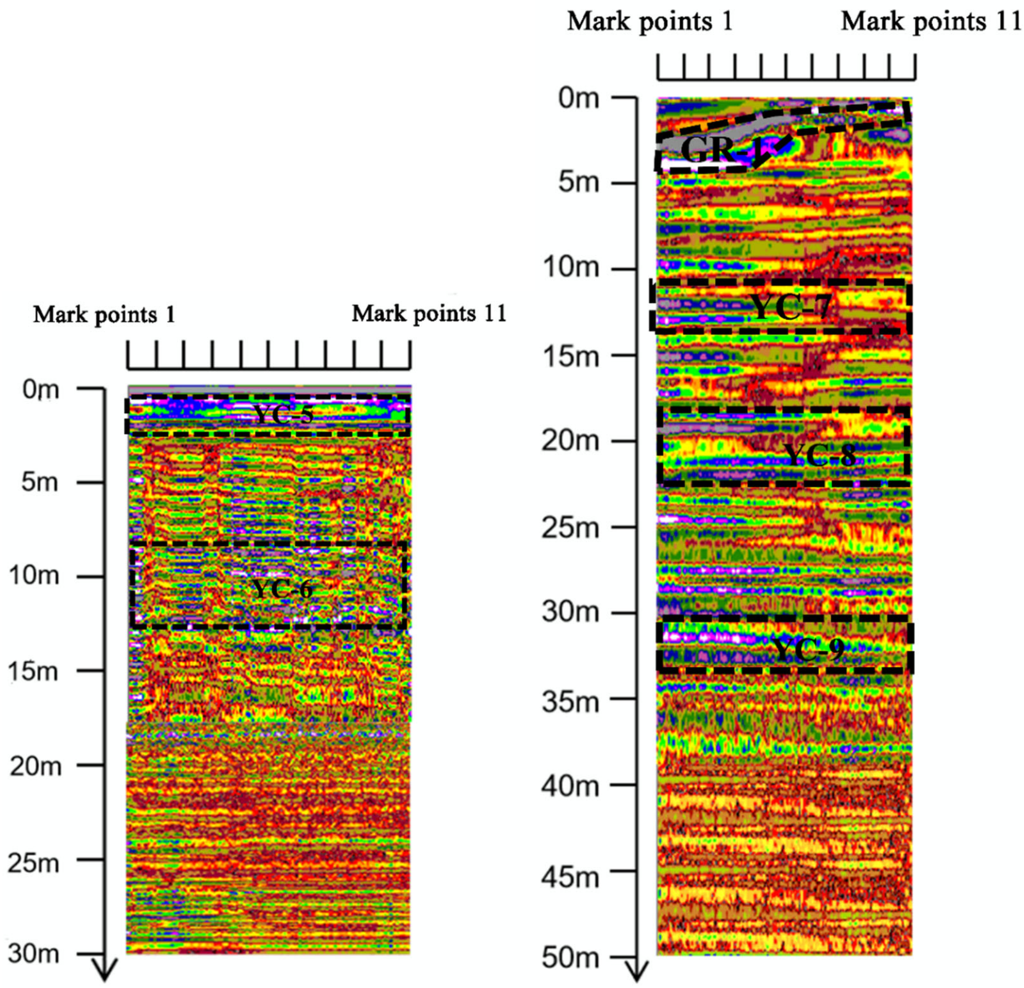

Figure 5. GPR profile interpretation of water enriched area in coal seam

5. CONCLUSION

Through the analysis of the detection results of practical engineering examples, it is concluded that the GPR anomaly characteristics of the typical geologic anomalies in the previous non-mine advance prediction are basically the same as the interpretation results of the geological anomalies detection data of coal mine.

These anomaly characteristics of GPR can be used to guide the calculation, analysis and summary of GPR detection data in advance prediction of geological anomalies in coal seam of mine. More reliable basic geological prediction parameters of mine and coal seam anomalies can be obtained by estimating the scale and geological distribution of each anomaly characteristic of typical geologic anomalies. It can also provide reference for mine geological advance forecast work in similar geological environment and strengthen the interpretation effect of mine geological advance forecast data.

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