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ORIGINAL PAPER

Performance Analysis of Soft Roadway Surrounding Rock in Yushujing Coal Mine

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Abstract There are soft rock layers in Yushujing coal mine, especially the roof-floor lithology of 11,501 working face shows the characteristics as soft rock, resulting in the drift floor-heave and failure of bolt in the process of coal extraction, which affects safe and efficient mining. To solve these problems, rock samples are taken from the roof and floor, and then the strength and deformation parameters of these samples are tested in the laboratory. Moreover, minerals components and microstructure of the rock samples are measured and observed through X-ray diffraction, scanning electron microscope and energy dispersive spectrometer techniques. The results show that the surrounding rock mainly consists of kaolinite, illite, smectite and chlorite. Among these minerals, the smectite's great hydroscopicity and high expansibility take the main factor for the deformation of surrounding rocks. Therefore, it is suggested that reinforcing the surrounding rock and reducing the deterioration of water might be effective ways to keep the stability of surrounding rock in soft rock roadway.

Keywords Soft rock · Roadway · Mineral · Heaving floor

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1 Introduction

In China, it is fact that thousands of kilometers laneways are excavated every year, and approximately 70% of these laneways are located in soft rock layers, resulting in large deformation. Thus, these laneways need to be reinforced, but spending tremendous amounts of money (He 1996). However, research shows that soft rock generally contains clay minerals, which have characteristics of expansion and disintegration after absorbing water, Hence the surrounding rock possibly brings large deformation and rock mass failure (He 2014; He et al. 2008; Niu et al. 2011; Reza et al. 2019; Sun et al. 2009; Wen et al. 2019; Zhou and He 2008). The surrounding rocks with components of montmorillonite and kaolinite can affect the stability of laneways because these minerals dramatically decrease the strength of rocks (Bai et al. 2011; Chen et al. 2016; He and Fang 2009; Meng et al. 2012; Yu et al. 2014; Zhang et al. 2011; Zhou et al. 2005). Therefore, it is important to analyze the mechanism of surrounding rock deformation and take measures to control this situation.

The paper selects Yushujing coal mine where the surrounding rock deformation is very serious as engineering background (Liu 2015). Figure 1 shows the location of Yushujing coal mine, which has an area of 24.56 km^2. Its geological reserves and recoverable reserves are 389 million tons and 235 million tons respectively. Meanwhile, its design production capacity is 3 million tons per year.

11,501 working face using longwall mining technique is the initial working face in Yushujing coal mine. The geological parameters of the working face are as follows. The thickness of coal seam ranges from 3.4 to 4.2 m, averaging at 3.75 m, and the width of 11,501 working face is 200 m and advance length 748 m. Although the depth of cover is 255–285 m, the laneways at both sides of 11,501 working face experience very large deformation because of its soft rock nature and high stress. As a result, the metal mesh and anchor bolt were broken and failure in the entries and working faces, which are shown in Fig. 2.

2 Rock Specimen Preparation and Strength Test

It is fact that the properties of rocks are mainly reflected by strong characteristics and deformation features. Figure 3 shows the lithological sequence of the rock layers in 11,501 working face. So, the rock specimens were obtained through boreholes with a diameter of 76 mm drilled into the roof and floor for purpose of research soft rock properties as shown in Fig. 4.

Figure 3 shows the thickness of 5 # coal seam is 3.4–4.2 m, averaging at 3.75 m. And the immediate roof is mudstone with a thickness varying from 0 to 0.5 m, and the main roof is medium grained sandstone, with a thickness ranging from 6 to 12 m. Further up, the overlying strata is 4 # coal and fine-grained

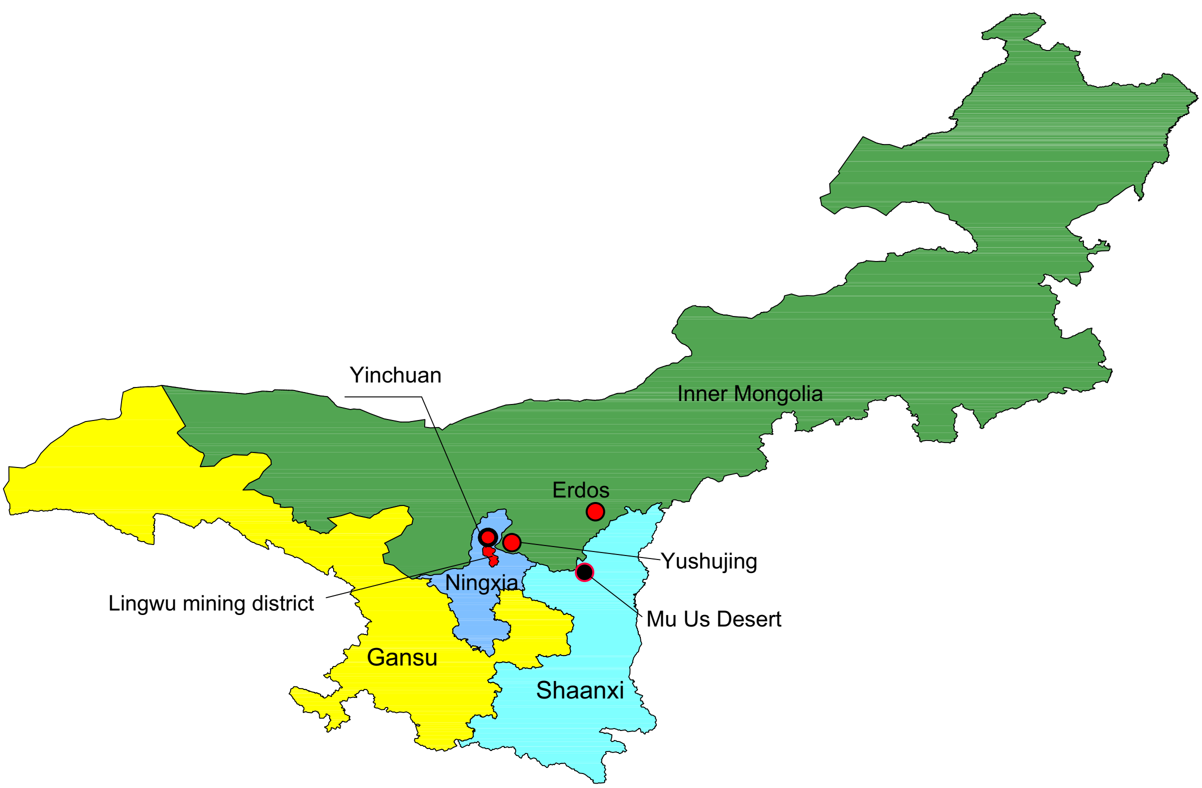


Fig. 1 Location of Yushujing coal mine

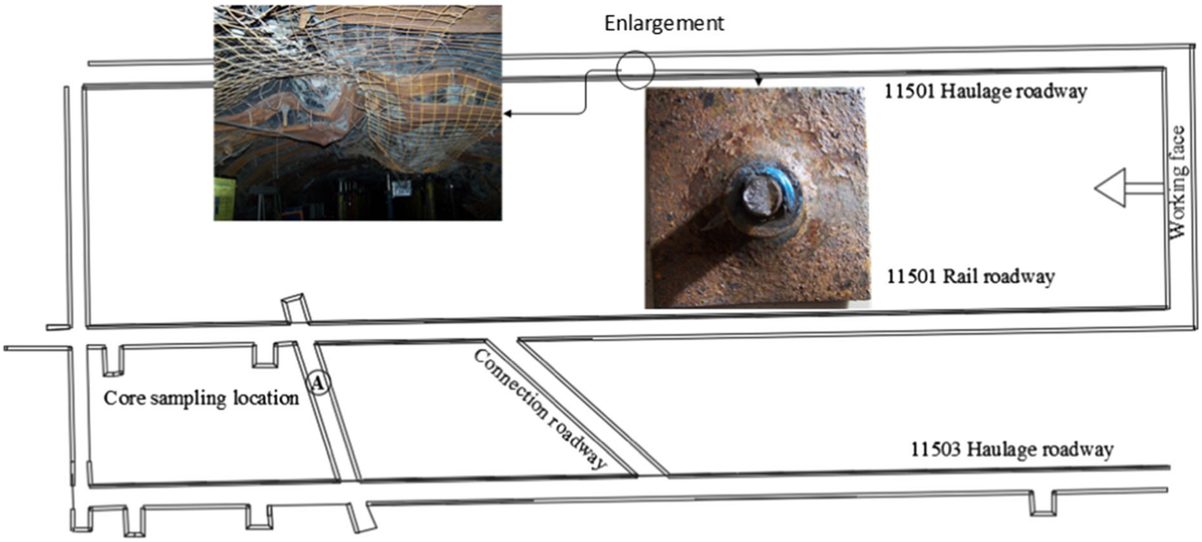


Fig. 2 Arrangement of 11,501 working face

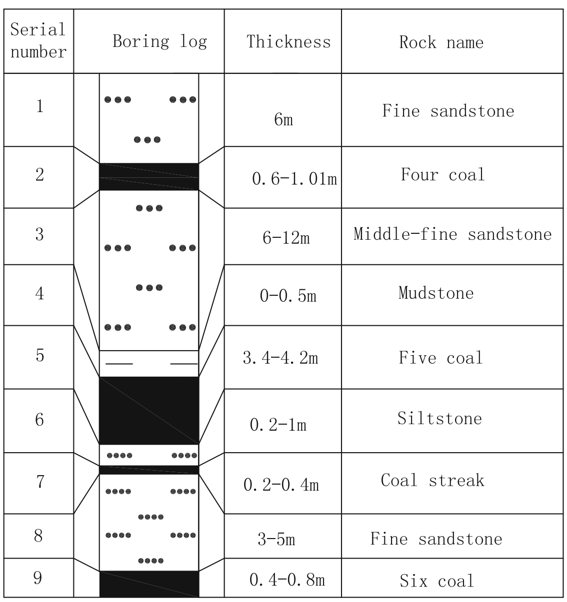


Fig. 3 Lithological sequence of different rock layers

sandstone from bottom to up. On the other hand, the immediate floor is siltstone, followed by a thin coal layer, fine grained sandstone and 6 # coal seam.

A total of 46 specimens were obtained from Yushujing coal mine. Among of these, 24 specimens were taken from roof stratum (9 specimens for uniaxial compression test, 7 specimens for Brazilian disk splitting tests and 8 specimens for shear test), 1 specimen from floor rock for uniaxial compression test

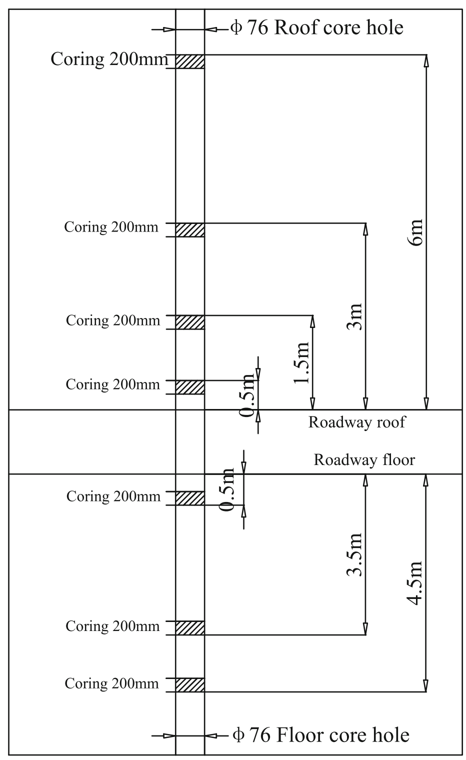


Fig. 4 A schematic showing sample collection

and 21 specimens from the floor strata for other three different kinds of mechanical tests. The shapes and sizes of specimens are shown in Table 1 and Fig. 5.

Table 1 The shapes and sizes of standard specimens

Test type	Specimen shape	Diameter/length (mm)	Height/thickness (mm)
Uniaxial compression test	Cylindrical or rectangular	50	100
Brazilian splitting test	Disk	50	25
Shear test	Cube	50	50

(a) Roof **(b) Floor** **(c) Coal**

Fig. 5 Standard specimens' preparation

(a) Uniaxial compression deformation test

(b) Tensile strength test **(c) compression-shear test**

Fig. 6 Experiment procedure

The specimens as showed in Fig. 5 were used for uniaxial compression test, Brazilian splitting test and shear test in the laboratory. The experimental procedures are shown in Fig. 6.

According to these tests, the basic physical and mechanical parameters of roof and floor rock are obtained and shown in Table 2.

The results of density test show that the density of mudstone and sandstone in roof strata is 2.13 and 2.55 g/cm^3, respectively, the mudstone's density in floor strata is 2.02 g/cm^3 and coal's density is 1.20 g/cm^3.

At the same time, the results of deformation tests and strength tests show the mechanical parameters of coal and its roof and floor rock as follows. The elastic modulus of mudstone and sandstone in roof strata, mudstone in floor stratum, coal samples are 0.91 GPa, 3.32 GPa, 0.47 GPa and 0.59 GPa respectively. Meanwhile, their Poisson's ratio is 0.15, 0.19, 0.05 and 0.14 respectively. However, the compressive strength of mudstone and sandstone in roof strata and coal specimens is 8.08 MPa, 22.54 MPa and 14.15 MPa respectively. And their tensile strength is 1.65 MPa, 2.55 MPa and 1.07 MPa respectively. Their shear strength is 0.95 MPa, 4.42 MPa and 0.95 MPa respectively. Their cohesion is 3.52 MPa, 4.38 MPa and 1.85 MPa respectively. At last, their internal friction angle is 20.89°, 34.24° and 37.64° respectively.

3 Scanning Electron Microscope and Energy Spectrum Analysis

The mineral components of rocks and coal are analyzed by using Scanning Electron Microscope (SEM) and Energy Spectrum Analysis (ESA) techniques. The pictures in Fig. 7 are enlarged by 1000 times for analysis.

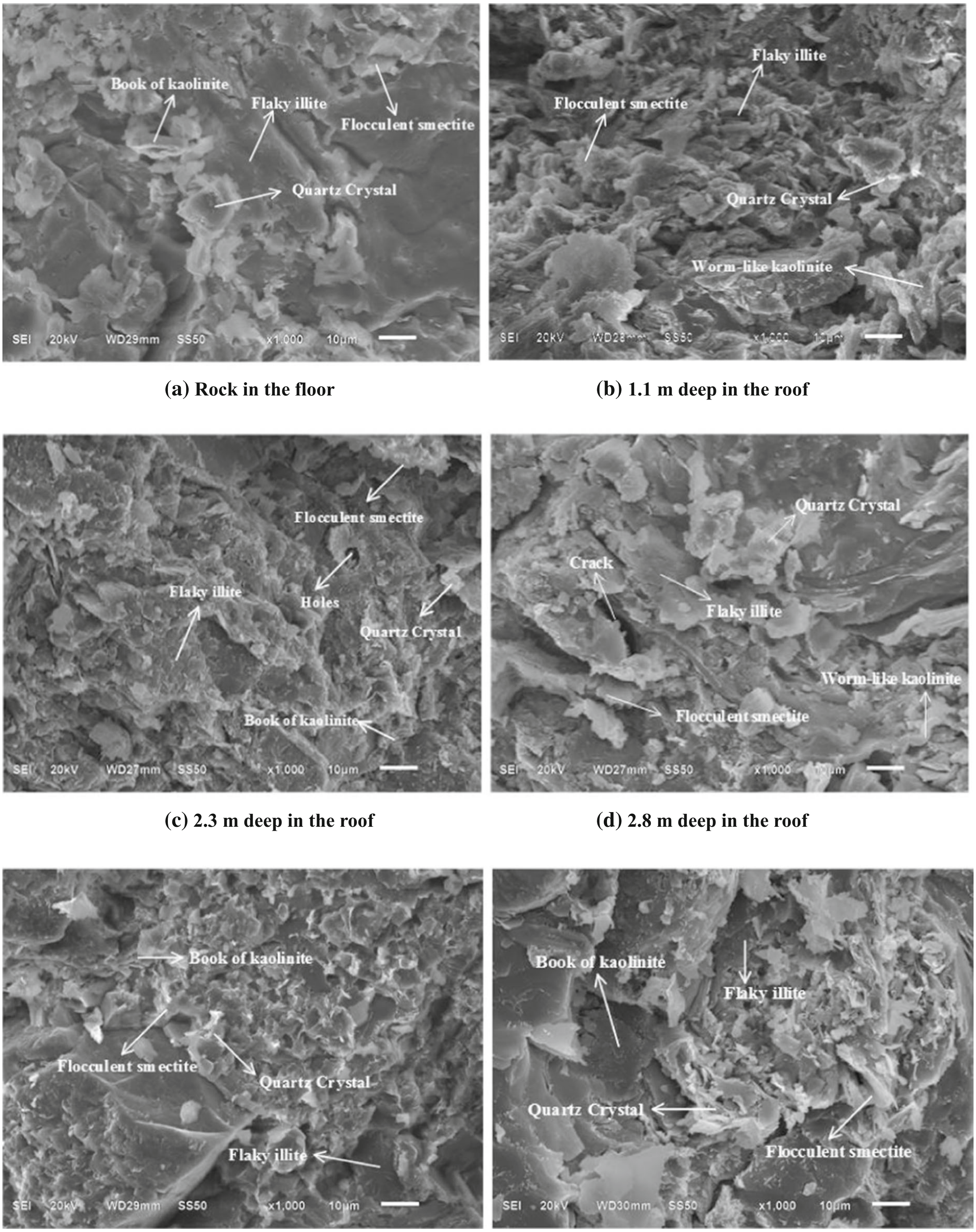
Figure 7a shows the ESA photo of the floor strata in 11,501 working face. And from this picture, the mineral status is very clear. Firstly, the high-transparency quartz and illite are shown in angular crystal and flaky respectively. Besides, the kaolinite is shown like pages in a book. Therefore, it can be found that mineral status is easy to be distinguished. Secondly, there is a dark flaky illite assembly, and few amounts of smectites are flocculent occurring on the surface of particle. Besides, less kaoliniteis like book aggregates occuring in intergranular.

Spectrum measurements show that the main elements of floor strata are carbon (C), oxygen (O), silicon (Si), aluminum (Al), magnesium (Mg), potassium (K), iron (Fe), titanium (Ti) and zirconium (Zr). Because immediate floor is close to the coal seam, its carbon content, oxygen content and potassium content are much higher than other states, ranging from 10.1 to 17.96%, varying from 38.68 to 51.56%, changing from 0.73 to 1.61%, respectively. However, it is likely that illite is also shown in the floor strata. Figure 7b shows 1.1 m deep in roof rock has very similar mineral composition and distribution with that of the floor rock. They are mainly quartz grains, which is less than that of contained in the floor sample. Illite, smectite and kaolinite in different morphological structure occur in the surface of the particle. Spectroscopy measurements show that the main elements are carbon (C), oxygen (O), silicon (Si), aluminum (Al), magnesium (Mg), potassium (K) and iron (Fe).

Figure 7c shows 2.3 m deep in roof rock has much illite with flaky aggregates, and book mode occurrence of kaolinite. Quartz grains are higher in transparency, reflective crystal surface, and angular, but they are significantly less than that of the floor sample. A small

Table 2 The basic physical and mechanical parameters of coal and its roof and floor rock

Position	Lithology	Density (g/cm^3)	Elastic Modulus (GPa)	Poisson ratio	Compressive strength (MPa)	Tensile strength (MPa)	Shear strength (MPa)	Cohesion (MPa)	Internal friction angle (°)
Roof	Mudstone	2.13	0.91	0.15	8.08	1.65	0.95	3.52	20.89
	Sandstone	2.55	3.32	0.19	22.54	2.55	4.42	4.38	34.24
Floor	Mudstone	2.02	0.47	0.05	4.37				
Face	Coal	1.20	0.59	0.14	14.15	1.07	0.95	1.85	37.64



(a) Rock in the floor

(b) 1.1 m deep in the roof

(c) 2.3 m deep in the roof

(d) 2.8 m deep in the roof

(e) 4.0 m deep in the roof

(f) 6.2 m deep in the roof

Fig. 7 Electron-microscope photo

amount of smectite with flocculent occurrence is found on quartz grain surface. Spectroscopy measurements show that the main elements are carbon (C), oxygen (O), silicon (Si), aluminum (Al), magnesium (Mg), potassium (K), titanium (Ti), and iron (Fe).

Figure 7d is the electronic photos at the depth of roof rock 2.8 m, and it's easy to see that major containing is quartz crystal, flocculent smectite, worm-like kaolinite, flaky illite and cracks. Spectroscopy measurements show that the main elements are oxygen (O), silicon (Si), aluminum (Al), magnesium (Mg), potassium (K), iron (Fe). However, Carbon (C), titanium (Ti), and zirconium (Zr) are unstable.

Figure 7e, f have the same mineral composition, and mainly contains book of kaolinite, flocculent smectite, flaky illite and quartz grain. Energy spectrum shows that the main elements of the rock are carbon (C) and oxygen (O), silicon (Si), aluminum (Al), magnesium (Mg), potassium (K), iron (Fe).

According to the test analysis, mineral samples diffraction results as shown in Table 3.

4 X-Ray Diffraction (XRD) Analysis

After scanning electron microscope and energy spectrum analysis, we have performed the X-ray diffraction experiment, and diffraction spectrum is shown in Fig. 8.

Figure 8 shows that the main minerals are quartz, illite, kaolinite, kaolinite–smectite, smectite and chlorite at roof and floor of 5 # coal seam. Samples of each mineral formula as follows:

Q—(Quartz): SiO_2
K—(Kaolinite): $Al_4(OH)_8Si_4O_{10}$
I—(Illite): $KAl_2(OH)_2(AlSi)_4O_{10}$
S—(Smectite): $(Na, Ca)_{0.7}(Al, Mg)_4(OH)_4(SiAl)_8O_{20}\cdot nH_2O$
Cl—(Chlorite): $(Mg, Fe, Al)_6(OH)_8(Si, Al)_4O_{10}$

Mineral quantitative analysis results of each sample as shown in Table 4.

5 Conclusions

Through scanning electron microscope, energy spectrum analysis and x-ray diffraction (XRD) analysis, it is resulting that kaolinite, illite, smectite and chlorite are the main mineral composition of Yushujing soft rock, accounting for about 63% of the total weight. Among of those, kaolinite, illite, and smectite account for 14.5%, 20% and about 22% respectively. In these minerals, the volume of smectite can expand several times or even ten times after absorbing water, which is responsible for the deformation of the surrounding rocks and damage of the supporting structure system. At the same time, the strength of the surrounding rocks is easy to suffer weathered and weakened by water.

Table 3 Qualitative analysis of mineral samples diffraction

Figure 8	Sample location	Qualitative analysis
(a)	5 Seam floor	Mineral composed mainly of quartz,contains more carbon, illite, might have kaolinite and smectite
(b)	5 Seam roof 1.1 m	Mineral composed mainly of quartz,contains more carbon, illite, might have kaolinite, smectite and chlorite
(c)	5 Seam roof 2.3 m	Mineral composed mainly of quartz,contains more carbon, illite, might have kaolinite and smectite
(d)	5 Seam roof 2.8 m	Mineral composed mainly of quartz,contains more illite, might have kaolinite, smectite and chlorite
(e)	5 Seam roof 4.0 m	Mineral composed mainly of quartz,contains more carbon, illite, might have kaolinite, smectite and chlorite
(f)	5 Seam roof 6.2 m	Mineral composed mainly of quartz,contains more carbon, illite, might have kaolinite, smectite and chlorite

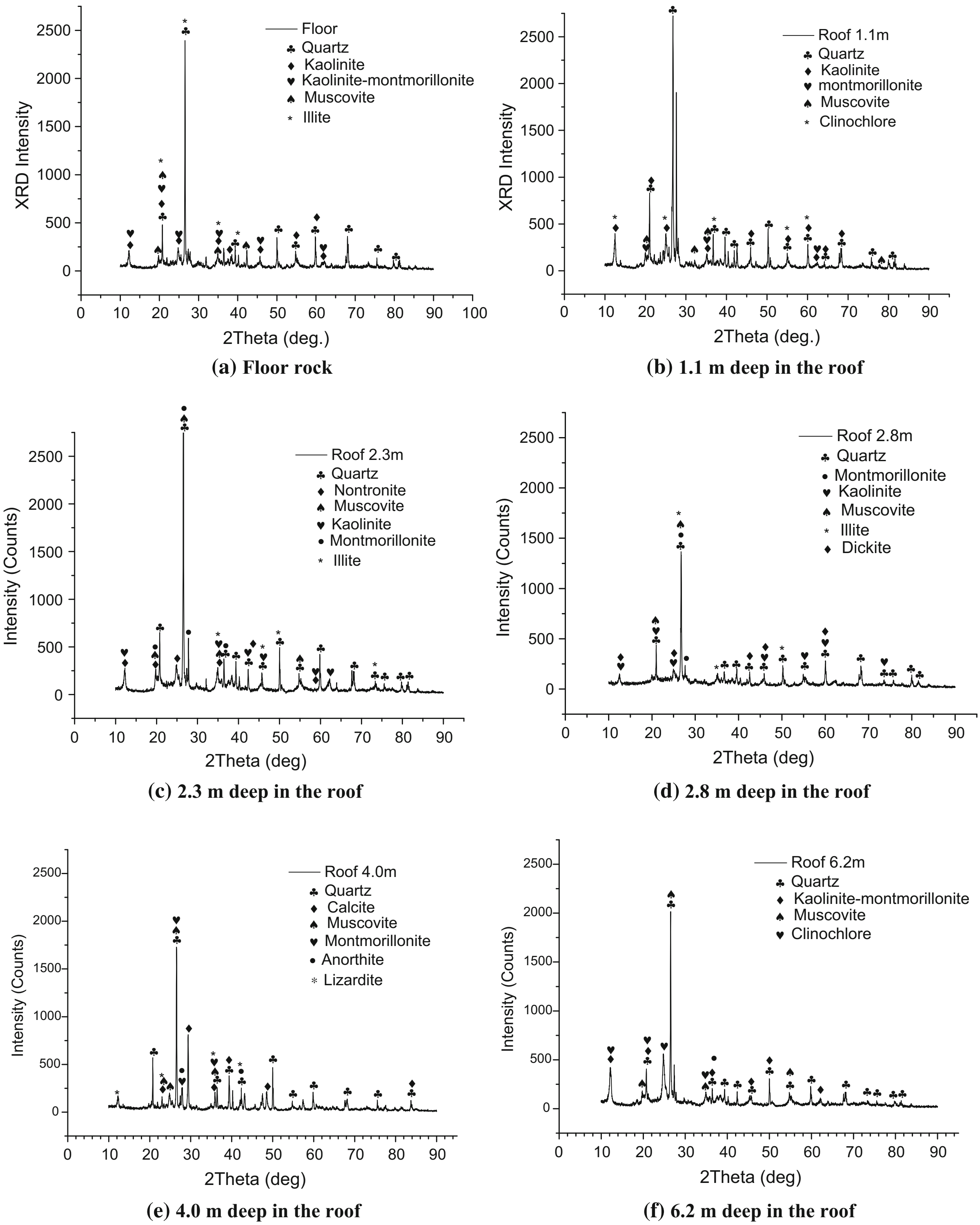


Fig. 8 X-ray diffraction spectrum

Table 4 Mineral quantitative analysis results (weight percentage)

Figure 8	Sample location	Q	K	I	S	CL
(a)	5 Seam floor	46.7	25.6	18.8	8.9	0
(b)	5 Seam roof 1.1 m	32.2	17.7	20.9	19.8	9.4
(c)	5 Seam roof 2.3 m	36.8	9.4	14.5	39.4	0
(d)	5 Seam roof 2.8 m	37.8	21.5	14.9	12.9	12.9
(e)	5 Seam roof 4.0 m	35.1	0	24.7	29.2	11.0
(f)	5 Seam roof 6.2 m	36.6	8.2	26.1	18.2	10.9

Thus, it should be reduced the influence of water during the excavation of longwall face.

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