

Overburden Failure and Water-Sand Mixture Outburst Conditions of Weakly Consolidated Overlying Strata in Dananhu No.7 Mine

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Research Article

Keywords: Weakly consolidated strata, Overburden failure, Water-sand mixture outburst, Critical hydraulic gradient

Posted Date: July 19th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-3164550/v1>

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Abstract

This study introduces a case of weakly consolidated strata developed in Dananhu No.7 mine, and we investigate the overburden failure behaviour and the risk possibility of water-sand mixture inrush during excavation through an approach of combining numerical simulation, field measurement comparison and criterion of the critical hydraulic gradient for sand-water outburst into working sites. The following findings consist of the main conclusions. The caving zone is approximately 37.3m with a caving-mining ratio of 3.55, and the water-conducting fractured zone is 160.5m with a crack-mining ratio of 15.29 or so. The predictive results are in line with those measured in nearby and similar geological conditions mines. A crack without obvious subsidence is formed at the front edge of mining direction, and some groups of parallel stepped cracks behind the goaf could be easily observed. The subsidence characteristic of ground and below strata along the goaf center transforms an asymmetric into a symmetrical and wide-gentle “U” shape. The critical hydraulic gradients of Toutunhe Formation aquifer, aquifers of 3 coal and 3 ~ 7 coal in Xishandao Formation affected by mining are 1.314, 1.351, and 1.380, the corresponding actual hydraulic gradients are 0.692, 2.089, and 7.418. It is inferred that water-sand mixture outburst will not occur in the Toutunhe Formation aquifer, while the potential risk of outburst exists in the Xishanyao Formation aquifer. Through drainage and depressurization projects, water-sand mixture outburst accidents do not occur during excavation. The research results can lay technical and theoretical foundations for the safety mining of coal mines in western China.

1 Introduction

Because the mining area in western China is in the continental arid and semi-arid climate zone, the water resources are deficiency, the ecological environment is extremely fragile, and the coal mining has a great impact on the geological environment (Bai et al. 2022; Fan and Ma 2018; Fan et al., 2016; Zhang et al., 2017). Xinjiang, Northern Shaanxi, Shandong and other mining areas have large reserves of coal resources, high calorific value, shallow buried depth, simple geological structure and other natural advantages of mining, and have become the main coal energy base of hundreds of millions of tons (Zeng et al. 2022; Liu et al., 202). Currently, some mines in western China mainly exploit coal seams deposited in Mesozoic Jurassic and Cretaceous coal-bearing strata. However, relatively shorter sedimentation leads to poor consolidation of rock mass, and the strata have formed the characteristics of weak cementation, easy weathering, poor permeability and argillization and disintegration in water (Liu et al., 2019; Cai et al., 2020; Zhang, 2021; Ji et al., 2023). From the microscopic point of view, the rock mineral structure and cementation modes determine the physical and mechanical properties and failure mechanism, which is the main reason for the difference from the strata in the central and eastern mining area. According to the geological and hydrogeological conditions of the western mining area, high-intensity and large-scale underground mining may cause water-sand inrush, roadway support problem caused by poorly cementation, hydraulic support crushing, ground surface subsidence, phreatic and confined water level decline and many problems in other safety and environmental impact (Ju et al., 2015; Lv et al., 2021; Sun et al., 2017). Therefore, it is of great significance for mine safety operation and

regional ecological protection to study the failure and deformation of overlying strata with weak cementation and the condition of water-sand inrush under the influence of mining in western mining area.

Based on this research background, relevant experts and scholars at home and abroad have carried out a lot of work on weakly cemented strata. Starting from the rock physical and mechanical properties, the relationships between rock physical and mechanical parameters and buried depth of typical coal mines in Xinjiang mining area and Ordos mining area are analyzed, and the differences between rock physical and mechanical properties in the western China and rocks with the same lithology in the middle and east region are proposed (Sun et al., 2019). Based on the analysis of the microstructure of Jurassic weakly cemented sedimentary rocks in Shendong mining area, the mineral composition of the rock is quantified, and the quantitative relationship between mineral composition and rock physical and mechanical parameters is determined by regression analysis method (Wang et al. 2019). Using numerical and similar simulation tests, it is concluded that the failure mode of thick weakly cemented overburden is “beam-arch shell” pattern, and the failure boundary is arched (Zhang et al. 2020 & 2021). The discrete element numerical simulation software PFC^{3D} is used to visually show the caving characteristics of overlying strata under different mining heights. The probability of water-sand inrush disasters under different mining thicknesses is analyzed from the aspects of the formation process of water-sand inrush channels and the water pressure change (Shi, 2020). Based on the background of Tarangaole coal mine in Dongsheng coalfield, the lithological characteristics and stability evaluation of 3^{-1} coal roof were analyzed, and the risk zonation of water-sand inrush was completed. The mechanism and influencing factors of water-sand inrush disaster in weakly cemented thick glutenite with large mining depth were proposed (Ren, 2019). Similar simulation experiments were used to qualitatively analyze the migration characteristics of overlying strata in weakly cemented strata during mining in Yili No.4 mine, Xinjiang. Besides, a FLAC^{3D} fluid-solid coupling numerical model was constructed to quantitatively study the permeability evolution law of overlying strata during mining, and to explore the dynamic response law of overlying strata migration, permeability evolution and mining technical parameters of weakly cemented strata to groundwater system (Ma et al., 2020). The stability of weakly cemented aquiclude under mining in Ehuobulake mine in Xinjiang was studied. The mechanical model of mining stability was constructed, and the influencing factors and criterion of instability were proposed (Chen et al. 2023). The fractal geometry theory and discrete element numerical simulation were used to study the evolution law of the fracture network during the layered mining of thick coal seams in the western mining area. The fractal evolution of overburden fractures experienced four stages, and the self-similarity between its development and expansion was high (Chen et al., 2021). Active and passive prevention and control mechanisms are proposed for the prevention and control mechanism of water-sand inrush in the high potential energy environment. It is considered that the easily disintegrating argillaceous rocks such as sandstone and mudstone with weak argillaceous cementation will cause water-sand inrush due to disintegration under the combined disturbance of mining and high-confined water (Sui, 2022). Under the circumstances of multi-coal seam mining, the influence of plastic failure zone and pore pressure in surrounding rock, development law of overburden fracture, and evolution characteristics of seepage field in Yixin mine was determined (Liu et al., 2022). Through theoretical analysis, physical and numerical

simulation, in-situ monitoring and other means, the surface subsidence of the ecologically fragile western mining area under repeated mining is predicted and analyzed. The surface subsidence, settlement coefficient and separation development height of repeated mining are obtained, and the maximum surface subsidence model verified by actual production is established (Li et al. 2020; Vierrether 2013).

Currently, some work still need to be done on the study of weakly cemented sedimentary strata in western mining areas, and the research on overburden failure and water-sand inrush is not comprehensive enough. Taking Dananhu No.7 mine in Hami as an example, this paper discusses the failure characteristics of overlying strata and water-sand mixture inrush conditions, and serves as technical support for the “coal-water” resources dual synergistic effect, resource development and environmental protection.

2 Geological setting

The Dananhu No.7 mine in Hami city is located in Nanhu town, 40.0 km southwest of the city. The geographical coordinates are $93^{\circ}19'06''\text{E} \sim 93^{\circ}26'30''\text{E}$, $42^{\circ}22'30''\text{N} \sim 42^{\circ}24'30''\text{N}$. The study area is located in the Gobi area, with less annual rainfall. There is no surface water system or other surface water bodies in and nearby areas, which is a desert area without surface vegetation (Fig. 1). The mine adopts the inclined shaft exploitation method. The mine is designed with five mining areas and three horizons. The first mining area is a horizontal mining area. At this stage, the main mining coal seams are 5 coal and 6 coal (due to a thin mudstone between 5 coal and 6 coal, combined mining of 5 coal and 6 coal) and 7 coal.

According to the actual geological drilling in the area, the strata are Quaternary (Q), Neogene Putaogou Formation (N_{2p}), middle Jurassic Toutunhe Formation (J_2t), Xishanyao Formation (J_2x), upper Carboniferous Wutongwozi Formation (C_2wt), where the coal-bearing strata are Xishanyao Formation. The aquifers are Quaternary permeable sand layer, Putaogou Formation aquifer, Toutunhe Formation aquifer and Xishanyao Formation aquifers including aquifer above 3 coal, aquifer of 3 ~ 7 coal and aquifer of 7 ~ 10 coal (Wu et al., 2018). According to the borehole pumping tests, it is known that the water abundance of Putaogou Formation aquifer and Toutunhe Formation aquifer is extremely weak, the water abundance of the aquifer above 3 coal is weak to medium, and the water abundance of the aquifer of 3 ~ 7 coal and 7 ~ 10 coal is weak (Yang et al., 2015). The aquifuge is quaternary clay aquifuge, sand-mudstone aquifuge at the bottom of Toutunhe Formation, sand-mudstone aquifuge at the bottom of upper Xishanyao Formation, sand-mudstone aquifuge at the roof of 7 coal and sand-mudstone aquifuge at the roof of 10 coal. The development of main strata is shown in Fig. 2.

3 Materials and methodology

3.1 Sampling and Experiment

During the construction of the ground survey drilling in No.1 and No.3 mining areas, the total of 14 boreholes were sampled. The total number of core samples was about 200, and the location of the sampling points was shown in Fig. 3. Since the size of on-site core samples cannot meet the test requirements, it is necessary to process the original rock samples into standard samples before carrying out testing. Processing and sample size error qualify the recommended standards of the International Society of Rock Mechanics (ISRM 2014). The test was conducted in the State Key Laboratory of China University of Mining and Technology with WES-D1000 electro-hydraulic servo universal testing machine. This equipment can be controlled by microcomputer and manually operation. The maximum test force is 1000 KN, the measuring span is 4-1000 KN, the minimum resolution is 0.01 KN, and ten sets of data can be recorded per second. Additionally, the deformation state of the sample under compression can be observed. Through the rock mechanics tests, the physical parameters such as compressive strength, tensile strength, shear strength, poisson ratio and elastic modulus are obtained, laying basic data for the subsequent theoretical research and analysis.

Besides, we conducted the disintegration experiments of weakly cemented rock for sandstone and mudstone samples. According to the chemical test of aquifer water, the water quality is generally characterized by high salinity and alkalinity. To present actual interaction between rock and water as much as possible, we place samples into the prepared alkaline water. We observe disintegration degree of rocks with different lithologies as time goes by. The disintegration experiment result may serve as an explanation for materials source analysis of water-sand mixture inrush.

3.2 Numerical simulation

Currently, the first mining area is located at No.1 mining area of the first level with extraction of 6 coal and 7 coal, where the 11701 working face is being mined. From the previous research and actual operation situation, we know that when the coal seam is excavated, the aquifer in the weakly cemented overburden may be disturbed and destroyed, and the roof water-sand inrush accident may occur (Yang et al., 2015; Gao et al., 2019). In order to investigate the damage of weakly cemented strata and post-mining surface subsidence over the working face, the development characteristics of water-conducting fracture zone and the risk prediction of water-sand inrush are preliminarily mastered. In this paper, COMSOL Multiphysics (CM) numerical simulation based on finite element method is applied to study the overburden stress-strain, plastic failure zone and surface subsidence during excavation. On the basis of the surface supplementary survey data of the mining area, the geological model is simplified into six layers, which are Quaternary and Neogene strata, 6 coal overburden, 6 coal, 7 coal overburden, 7 coal and 7 coal floor. The physical and mechanical parameters of each stratum are derived from this test and previous test data, as shown in Table 1. The design size of the model is 300 m×500 m, and the coal seam zone is finely meshed. The total number of complete grid units is 4040, and the size of the grid unit ranges from 0.0625 m to 18.5 m. Considering the influence of mining boundary effect, 50 m protective coal pillars are reserved on the left and right sides, and the mining is step by step excavated from the left direction of coal seam, and the total excavation length is simulated to be 400 m. The mesh generation and distribution of initial stress field before excavation is shown in Fig. 4.

Table 1
Mechanical parameters of rock strata for the simulation

Layers	Young modulus /GPa	Poisson	Density /kg·m ⁻³	Cohesion /MPa	Friction angle /°	Thickness /m
Quaternary and Neogene	3.02	0.33	2200	2.7	34.1	25.0
6 coal overburden	6.22	0.34	2580	3.7	33.2	182.0
6 coal	3.30	0.35	1350	2.1	36.0	5.0
7 coal overburden	4.08	0.35	2540	3.8	34.0	27.5
7 coal	3.60	0.34	1500	3.2	35.8	10.5
7 coal floor	6.14	0.35	2510	3.4	33.8	50.0

4 Results

4.1 Overburden deformation and failure

When the coal seam was excavated for 100 m, local stress concentration occurred in the coal pillar behind the goaf and the surrounding rock in front of the excavation face. Under the action of self-weight and compressive shear stress, the direct roof of the working face began to collapse, and the main roof appeared transverse cracks, but no obvious vertical displacement was produced. As the working face continued to advance to 200 m, the range of stress concentration area gradually expanded, affecting about 40 m of 6 coal roof. The plastic failure zone appeared at the excavation face and the reserved coal pillar behind the goaf. Meanwhile, the direct roof of the working face completely collapsed. The extension length of the transverse crack in the main roof increased, and the vertical displacement of the rock stratum increased. There was no plastic change in the 6 coal and overlying strata.

After that, the excavation continued for 100 m, and the supporting force on the excavation face and the coal pillar behind the goaf increased significantly. Due to exceeding its ultimate strength, the rock mass had obvious plastic failure, and the area affected by high ground stress in the overburden increased. Plastic deformation began to occur between the top of the working face and 6 coal. When the working face was fully extracted, namely, the coal seam is excavated to 400 m, the stress of the strata below the bottom of Neogene (the strata of Toutunhe Formation and Xishanyao Formation) increased sharply, and the stress field was symmetrically distributed along the center of the coalface. 6 coal and overlying strata had obvious plastic failure, and the plastic failure zone developed to about 160.5 m above the roof. The stress distribution and plastic deformation of strata in different mining stages were shown in Fig. 5 and Fig. 6.

Based on the above analysis and research, we confirm that the development height of the caving zone is about 37.3 m, and the height of the water-conducting fracture zone is about 160.5 m, that is, the caving-mining ratio is 3.55 times and the crack-mining ratio is 15.29 times. Besides, the adjacent Dananhu No.1 mine, Dananhu No.5 mine and Shajihai mine with similar geological conditions also conducted the "two zones" height measurement projects (Gao, 2018; Duan, 2022), and the comparison results are shown in Table 2. Although some deviations between the predicted results and the actual results exist, the simulated results are approximate to the measured results of each mine on the whole, meaning that the simulation results are reliable.

Table 2
Comparison results between simulated and measured "two belts"

Mine	Mining thickness/m	Caved height/m	Fractured height/m	Caving-mining ratio	Crack-mining ratio
Dananhu No.1 mine	6.3	20.89	94.0 ~ 98.0	3.32	14.92 ~ 15.56
Dananhu No.5 mine	3.0	14.5 ~ 15.7	58.2 ~ 60.3	4.83 ~ 5.23	19.4 ~ 20.1
Shajihai mine	6.0	78.52 ~ 81.54	16.32 ~ 16.86	2.72 ~ 2.81	13.09 ~ 13.59
Dananhu No.7 mine	10.5	35.3	160.5	3.36	15.24

4.2 Water-sand mixture outburst conditions

The roof water-sand inrush accidents often need to meet the following conditions: (1) Material sources: the sources of water-sand inrush are usually the Quaternary loose sand layer in Northern China coalfields, while the ancient weathering crust and weakly cemented sandstone and mudstone in the contact zone between the bottom of Cretaceous and the top of middle Jurassic (K_1/J_2) in Western China (Zhang, 2021; Li et al., 2022; Shi, 2022); (2) Flow channel: the primary fractures including joints and beddings, water-conducting faults, poorly sealed boreholes and mining-induced water-conducting fractures serve as main channels for water-sand inrush, among which mining-induced water-conducting fractures are the ideal and common channels causing disasters; (3) High potential hydrodynamic conditions: water-sand inrush usually do not happen in the low-potential hydrostatic environment. The reason is that the actual hydraulic gradient does not reach the anti-permeability critical hydraulic gradient of sand-mud particles (Ding et al., 2021; Sui, 2022). If sand-mud particles are in the high potential hydrodynamic environment, the critical hydraulic gradient value of particles flow is easily exceeded, and the likelihood of water-sand mixture inrush will be significantly increased; (4) Storage space: the water-sand mixture flowing along the channel finally converges in the working face or roadway. If the accident occurs in a closed blind roadway or goaf with small space inhibiting the disaster, it is difficult to form a large-scale water-sand inrush.

The geological structure of study area is simple and no poorly sealed geological boreholes exist, and we exclude the possibility of water-sand inrush accidents caused by them. Based on the study of overburden

failure, the failure layer of overburden was determined to Toutunhe and Xishanyao Formation aquifer, and while the loose layers was not affected. In terms of the boreholes sampling, rock masses in Xishanyao and Toutunhe Formation are poor in weak cementation and easy to break down once they are encountered by the alkaline water, mainly consisting of medium-coarse sandstone and mudstone, as show in Fig. 8. Thus, the weakly cemented sandstone and mudstone have the characteristics of the water-sand inrush source. The disintegration experiment of weakly consolidated sandstone and mudstone immersed in the alkaline water environment shows that the weakly consolidated rock samples have significant disintegration and argillization characteristics when encountering water. As seen in the Fig. 8, except for coarse sandstone, other sandstone (fine sandstone and siltstone) and mudstone have been seriously disintegrated after immersion, and disintegrating materials have fluidity under hydrodynamic conditions, forming a water-sand mixed flow.

$$J_{cr} = G_s - 1 \quad 1 - n + 0.5n$$

1

$$J = \frac{1.366 \quad 2H - M}{2\pi r_w (lgR - lgr_w)} \geq J_{cr}$$

2

Where G_s is the specific gravity of sand ($\text{KN}\cdot\text{m}^{-3}$); n is the rock porosity; J is the actual hydraulic gradient; J_{cr} is the critical hydraulic gradient of sand into the aquifer; H is the aquifer head (m); M is the thickness of aquifer (m); R is the influence radius under water-sand inrush (m); r_w is the radius of the fracture channel (m). Here, we assume that the water-conducting fracture channel is circular, and half of the fracture width is the radius of the fracture channel.

Based on the tests of rock physical and mechanical properties, pumping tests and aquifer water table observation, the index values of each calculation parameter of the above formula are obtained as shown in Table 3. After the theoretical calculation, the critical hydraulic gradients of Toutunhe Formation aquifer, aquifer above 3 coal and aquifer of 3 ~ 7 coal are 1.314, 1.351 and 1.380, respectively, and the corresponding actual hydraulic gradients are 0.692, 2.089 and 7.418. Therefore, although the mining-induced fractures have been developed in Toutunhe Formation aquifer, the critical hydraulic gradient is greater than the actual value, so we infer that water-sand inrush accident will not occur in this aquifer.

Table 3
Hydraulic gradient calculation parameters for aquifers

Aquifers	Volume weight/ $\text{KN}\cdot\text{m}^{-3}$	Porosity	Head/m	Thickness/m	Fissure channel radius/m	Influenced radius/m
Toutunhe Formation aquifer	2.53	0.21	15.25	20.20	2.58	46.18
Xishanyao Formation aquifer (above 3 coal)	2.62	0.24	42.17	47.31	2.48	88.66
Xishanyao Formation aquifer (3 ~ 7 coal)	2.56	0.17	95.80	30.79	2.84	129.95

5 Discussion

5.1 Characteristics of ground subsidence

During the operation of 11701 working face, the geological department dynamically observe the ground subsidence caused by mining. The results show there are different degrees of settlement cracks, and cracks with no obvious subsidence begin to develop at the front end of the working face advancement. Multiple sets of parallel step cracks behind the goaf are formed, as shown in Fig. 9. Besides, the subsidence displacement of the surface and below strata at different mining stages are simulated and predicted.

In the initial stage, the subsidence displacement of surface and underground strata is relatively smaller, the two sides of the goaf center zone along the mining face are asymmetrical, and the subsidence displacement after mining is relatively large. The simulated results are basically consistent with the actual survey results. With the continuous advancement of the working face, the subsidence displacement of the surface and below strata gradually increases. When working face advances to 400 m, the maximum subsidence displacement of the ground is expected to be greater than 1.70 m. The subsidence of the surface and below strata is characterized by a symmetrical wide-gentle 'U' shape along the center of the goaf, as shown in Fig. 10.

5.2 Prevention measures of water-sand mixture outburst

The height of mining-induced fracture spreads to the aquifer of Toutunhe Formation, however, it can be seen from Table 3 that the critical hydraulic gradient is greater than the actual value, so there will be no water-sand outburst caused by it. The actual hydraulic gradient values (aquifer above 3 coal and aquifer of 3 ~ 7 coal) are greater than the critical hydraulic gradient. Although the water yield of 3 ~ 7 coal aquifer

is weak, considering that this aquifer has high potential energy head, the risk of water-sand inrush is relatively higher, and the mining of working face is bound to be threatened by water-sand inrush disasters.

Therefore, multiple sets of roof drainage boreholes are constructed in the return laneway and haulage roadway in the 11701 working face and the subsequent 11604 working face of the first mining area, and the final hole bottom reaches Toutunhe Formation aquifer, as shown in Fig. 11, and the many target aquifers are dewatered and depressurized. Through the continuous drainage of the target aquifers, volume of water output or water-drip in the local roof become smaller than before, the water pressure of aquifers has fallen below range of the critical safety value, and water-sand inrush accidents rarely take place during the mining.

6 Conclusions

Based on the analysis of hydrogeological conditions of Dananhu No.7 mine, this paper uses CM to study the failure deformation characteristics and surface subsidence law of weakly cemented overburden under shallow coal seam mining. Additionally, theoretical analysis is used to analyze the potential risk of water-sand inrush in aquifers affected by mining damage, and active prevention and control measures are taken for aquifers to transform the hydrodynamic environment. The main conclusions are as follows:

Using numerical simulation analysis, it is determined that the height of the caving zone is about 37.3 m, and the height of the water-conducting fracture zone is about 160.5 m, the caving-mining ratio and the crack-mining ratio are 3.55 times and 15.29 times, respectively. Compared with the measured results of adjacent coal mines, the predicted results are in good agreement with the actual ones.

During the mining period, different degrees of settlement cracks appear on the surface above the goaf, showing that a crack with no obvious settlement begins to develop at the front end of the mining direction, and there are multiple sets of parallel stepped cracks behind the goaf. In the early stage, the subsidence displacement of surface and below is smaller, and there is asymmetry on both sides of the goaf center, and the subsidence displacement behind the mining is relatively large. As the working face continuously advancing, the settlement displacement of the surface and below strata gradually increases, and the subsidence shows a symmetrical wide-gentle "U" shape along the goaf center.

According to the 'two zones' development height, the aquifer of the Toutunhe Formation, the aquifer above 3 coal and aquifer among 3 ~ 7 coal are affected by extraction of 7 coal seam. Using the hydraulic gradient criterion, the critical and actual hydraulic gradient of the corresponding aquifer are quantified. It is inferred that water-sand inrush will not take place in Toutunhe Formation aquifer, and while the potential risk of water-sand inrush in Xishanyao Formation aquifer still exists. In view of the safety risk, the mine adopted the active prevention and control measures-construction of roof drainage and depressurization boreholes. The effect of drainage is obvious through the validation of engineering practice, and water-sand inrush has been eliminated.

Declarations

Author contributions All the authors contributed to publishing this paper. JZ performed the technological development and visual processing and prepared and wrote the manuscript. WL revised and reviewed the manuscript. BT and QL participated in data collection during the research process. DL and LL conducted the experiment and provided input to the study.

Funding This research was supported by the National Natural Science Foundation of China (Grant No. 41931284), the project of “Enlisting and Leading” of China Coal (Grant No.2022JB01), the Postgraduate Research & Practice Innovation Program of Jiangsu Province (Grant No. KYCX23_2760), the Fundamental Research Funds for the Central Universities (Grant No.2023XSCX003), and the Graduate Innovation Program of China University of Mining and Technology (Grant No. 2023WLKXJ003).

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Bai, E., Guo, W., Zhang, H., Tan, Y., Ma, Z., Wu, D., et al. (2022). Coal mining method with near-zero impact on the ecological environment in a high-intensity mining area of Northwest China. *Bulletin of Engineering Geology and the Environment*, 81(2), 80. <https://doi.org/10.1007/s10064-022-02574-6>.
2. Cai, J., Tu, M., Zhang, H. (2020). Deformation and instability mechanism and control technology of mining gateway for Jurassic weak-cemented soft rock roadways [J]. *Journal of Mining & Safety Engineering*, 37(06):1114-1122.
3. Chen, K., Ge, Y., Zhang, Q., Chen, L., Liu, Z. (2021). Rete element simulation for crack fractal evolution laws associated with slicing mining in super thick coal stratum[J]. *Journal of Engineering Geology*, 2021,29(04):1113-1120.
4. Chen, C., Zhang, S., Fan, G., Zhang, D., Chen, L., Ni, H., et al. (2023). Mining stability criterion of weakly cemented aquiclude and its application. *Minerals*, 13(1), 83. <https://doi.org/10.3390/min13010083>.
5. Duan X. (2022). Fully mechanized mining of weakly cemented water-rich roof in Dananhu No.5 well study on overburden movement law[D]. Xuzhou: China University of Mining and Technology.
6. Ding, J., Dong, D., Hu, Z., Zhang, L. Zhang, B. (2021). Resistance to permeability damage and pillar safety of coal mining under giant thick loose seam—take Kouzidong mine as an example[J]. *Journal of Engineering Geology*, 29(4):1071-1083
7. Fan, L., & Ma, X. (2018). A review on investigation of water-preserved coal mining in western China. *International Journal of Coal Science & Technology*, 5(4), 411–416. <https://doi.org/10.1007/s40789-018-0223-4>.
8. Fan, L., Ma, X. (2016). Research progress of water inrush hazard in shallow buried coal seam mine [J]. *Coal Science and Technology*, 44(01):8-12.

9. Ji, H., Sun, L., Song, C., Zhang, Y., Wang, J., Meng, Z. (2023). Research progress on stability control of surrounding rock in weakly cemented strata engineering in western China mining area [J]. *Coal Science and Technology*, 51(01):117-127.
10. Guo, W., Han, M., Yang, W., Ma, Z. (2023). Research and application of maximum surface subsidence model under the condition of repeated mining in weakly cemented strata [J/OL]. *Coal Science and Technology*:1-10[2023-03-18]. <http://kns.cnki.net/kcms/detail/11.2402.TD.20230217.1540.008.html>.
11. Gao, H., Feng, G., Liu, J., Wu, X. (2019). Prediction of water inrush risk in No. 7 No. 3 coal mine of Dananhu mining area, Hami, Xinjiang [J]. *Science Technology and Engineering*, 19(25):118-124.
12. Gao S. (2018). Study on the development law and hydrogeological effect of the water flowing fractured zone in the western Jurassic strata—a case study from the Dananhu mining area in Hami coalfield [D]. Xuzhou: China University of Mining and Technology.
13. International Society of Rock Mechanics. (2014). In: *Dictionary Geotechnical Engineering/Wörterbuch GeoTechnik*. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-41714-6_91469.
14. Ju, J., Xu, J., Zhu, W. (2015). Influence of overlying key strata structure pre-sliding on support failure disaster while mining in the lower coal seam cut across below the upper adjacent coal pillar under shallow cover[J]. *Journal of China Coal Society*, 40(9):2033-2039
15. Liu, H., Xiao, J., Zhen, W., Zhu, C., Chen, Z., et al. (2022). Study on permeability evolution law of overburden under repeated mining in weakly cemented strata [J]. *Safety in Coal Mines*, 53(12):218-225.
16. Liu, Q., Sun, Y., Xu, Z., Wang, X., et al. (2019). Pore media characteristics of Jurassic weak cemented sandstone and its significance for water-preserved coal mining [J]. *Journal of China Coal Society*, 44(03):858-865.
17. Li, X., Ren, X., & Zhang, J. (2020). Study on the Deformation Law and Mechanism of Weakly Cemented Gas Drainage Under Environmentally Development Principles. *Fresenius Environmental Bulletin*, 29(12A), 11642–11651.
18. Lv, W., Du, M., Guan, Y., Zhao, B., et al. (2021). Development height of “two zones” in weakly cemented soft stratum [J]. *Coal Engineering*, 53(08):92-97.
19. Li, W., Zhu, T., Wang, Q., Yang, Y., et al. (2022). Material source and disaster model of mud-sand inrush in coal mining under extremely thick Cretaceous in Ordos basin [J]. *Journal of China Coal Society*, 47(01):360-370.
20. Li J W. (2016). Water bursting quicksand critical hydraulic gradient computation and its application in coal mining under ditch [J]. *Coal Geology of China*, 28(06):55-57+77.
21. Ma, J., Tong, X., Li, C. (2020). Study on movement laws and permeability evolution features of mining-induced overburden in weakly cemented strata[J]. *Coal Science and Technology*, 48(S2):11-16.

22. Ren, S. (2019). Study on disaster of water and sand inrush of weakly cemented thick conglomerate on deep mining coal seam[J]. *Coal Science and Technology*, 47(09):249-255.
23. Sui, W. (2022). Catastrophic mechanism and its prevention and control of seepage deformation and failure of mining rock mass : A review of water inrush from seam floor [J]. *Journal of Engineering Geology*, 30(06):1849-1866.
24. Sun, L., Ji, H., Yang, B. (2019). Physical and mechanical characteristic of rocks with weakly cemented strata in western representative mining area [J]. *Journal of China Coal Society*, 44(03):866-874.
25. Shi L. (2020). Numerical simulation study on law of water and sand inrush in working face under condition of weakly cemented stratum [J]. *Coal Science and Technology*, 48(07):347-353.
26. Sui, W. (2022). Active prevention and control of water-sand mixture inrush with high potential energy due to mining based on structural hydrogeology [J]. *Journal of Engineering Geology*, 30(01):101-109.
27. Shi, L. (2022). Study on mechanism of water and sand inrush in weakly cemented strata and prediction method in Yibei mining area [D]. Beijing: China Coal Research Institute.
28. Sun, L., Ji, H., Jiang, H., Zeng, P., et al. (2017). Experimental study on characteristics of broken caving and regularity of compaction deformation of rocks in caving zone in the weakly cemented strata [J]. *Journal of China Coal Society*, 42(10):2565-2572.
29. Wang, Z., Li, W., Wang, Q., Liu, S., Hu, Y., & Fan, K. (2019). Relationships between the petrographic, physical and mechanical characteristics of sedimentary rocks in Jurassic weakly cemented strata. *Environmental Earth Sciences*, 78(5), 131. <https://doi.org/10.1007/s12665-019-8130-6>.
30. Vierrether, C. B. (2013). Urban development in karst and collapse-prone geologic environments. *Carbonates and Evaporites*, 28(1–2), 23–29. <https://doi.org/10.1007/s13146-013-0153-6>
31. Wu, X., Zhao, F. (2018). Study on initial mining division hydrogeological condition in Dananhu No 7 Coal Mine of Xinjiang [J]. *Coal Science and Technology*, 46(S2):210-215.
32. Yang, Z., Cui, F., Chen, Z., He, Y., Zhang, B., et al. (2015). Hydrogeological Type Analysis of Dananhu 7th Coal Mine in Hami Prefecture [J]. *Coal*, 24(07):7-9+16.
33. Zhang, G., Guo, G., Shen, S., Guo, Q., Zhang, S., & Wu, J. (2021). Numerical simulation study of the strata movement rule of deep mining with the super-thick and weak cementation overburden: a case study in China. *Mathematical Problems in Engineering*, 2021, 6806703. <https://doi.org/10.1155/2021/6806703>.
34. Zhang, Z., Sui, W. (2017). An evaluation model for geological environmental impact of coal mines in Xinjiang [J]. *Journal of China Coal Society*, 42(02):344-352.
35. Zhang, S. (2021). Water-resistance property evolution of Yili weakly cemented rock strata in response to mining activity and its control mechanism [D]. Xuzhou: China University of Mining and Technology.
36. Zhang, G., Guo, G., Lv, Y., & Gong, Y. (2020). Study on the strata movement rule of the ultrathick and weak cementation overburden in deep mining by similar material simulation: a case study in China. *Mathematical Problems in Engineering*, 2020, 7356740. <https://doi.org/10.1155/2020/7356740>.

37. Zhang, M. (2021). Study on seepage failure of loose aquifer mining with sand proof coal (rock) pillar [D]. Huainan: Anhui University of Science and Technology.

Figures

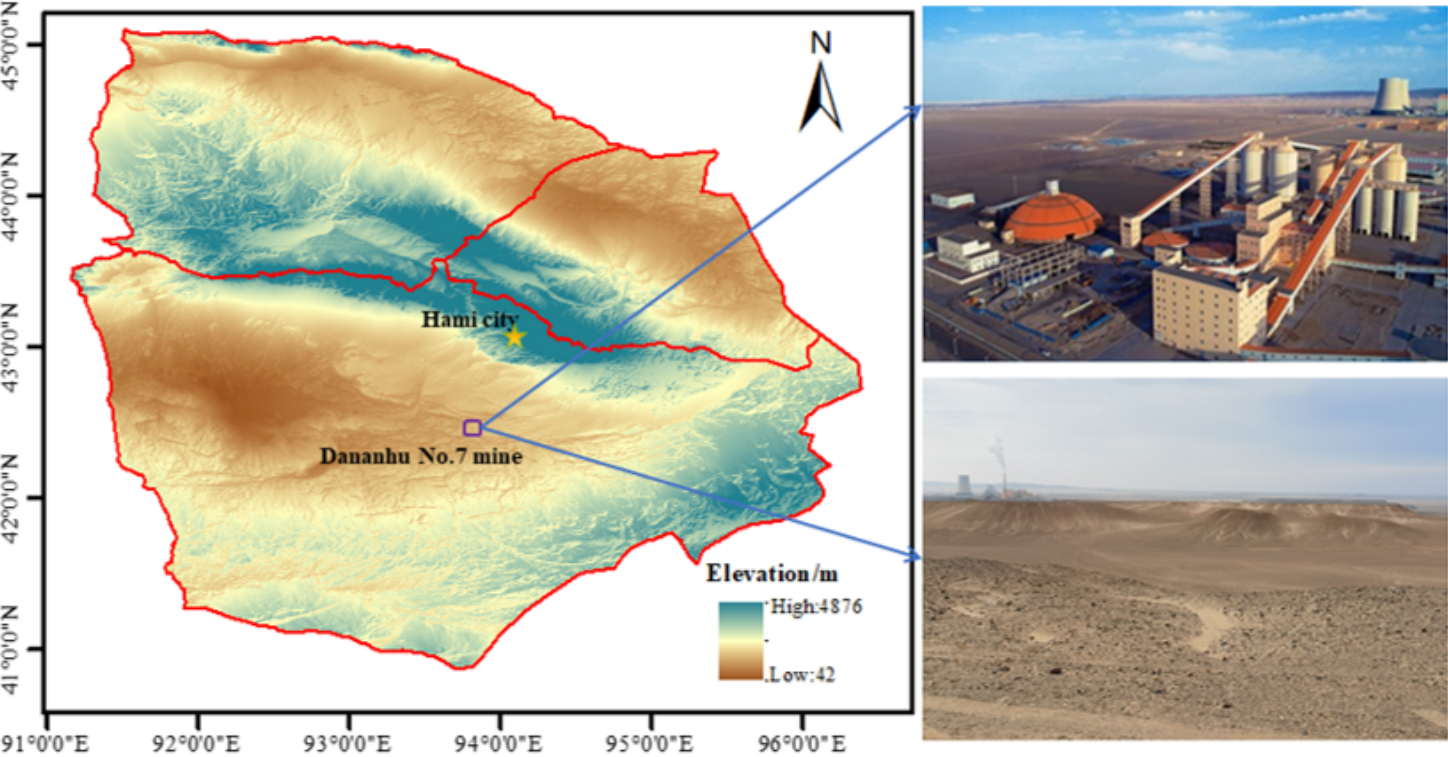


Figure 1
Location and geomorphology characteristics of the study area

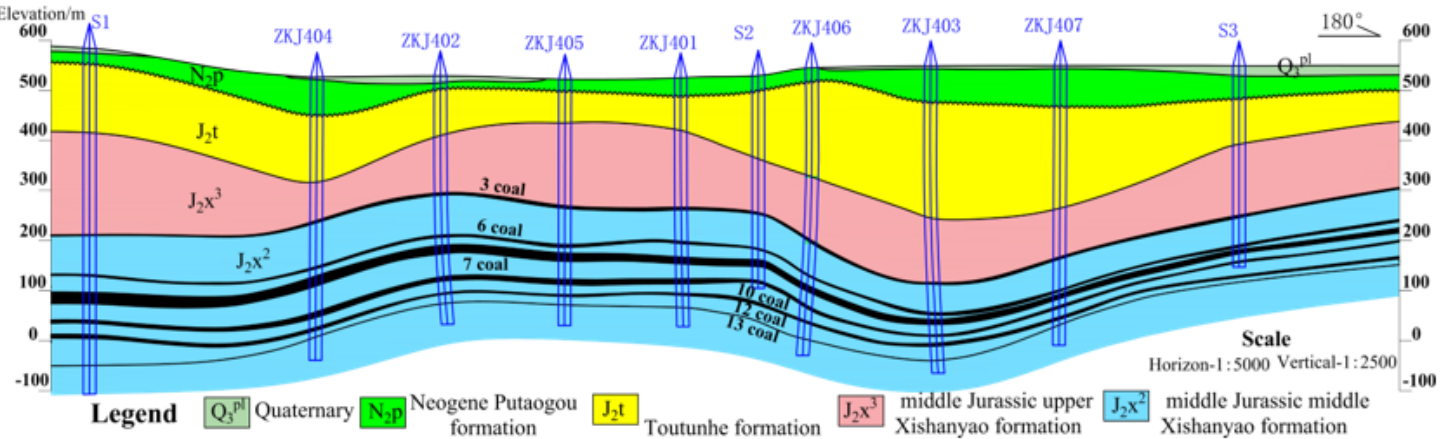


Figure 2
Typical strata section of Dananhu No.7 mine

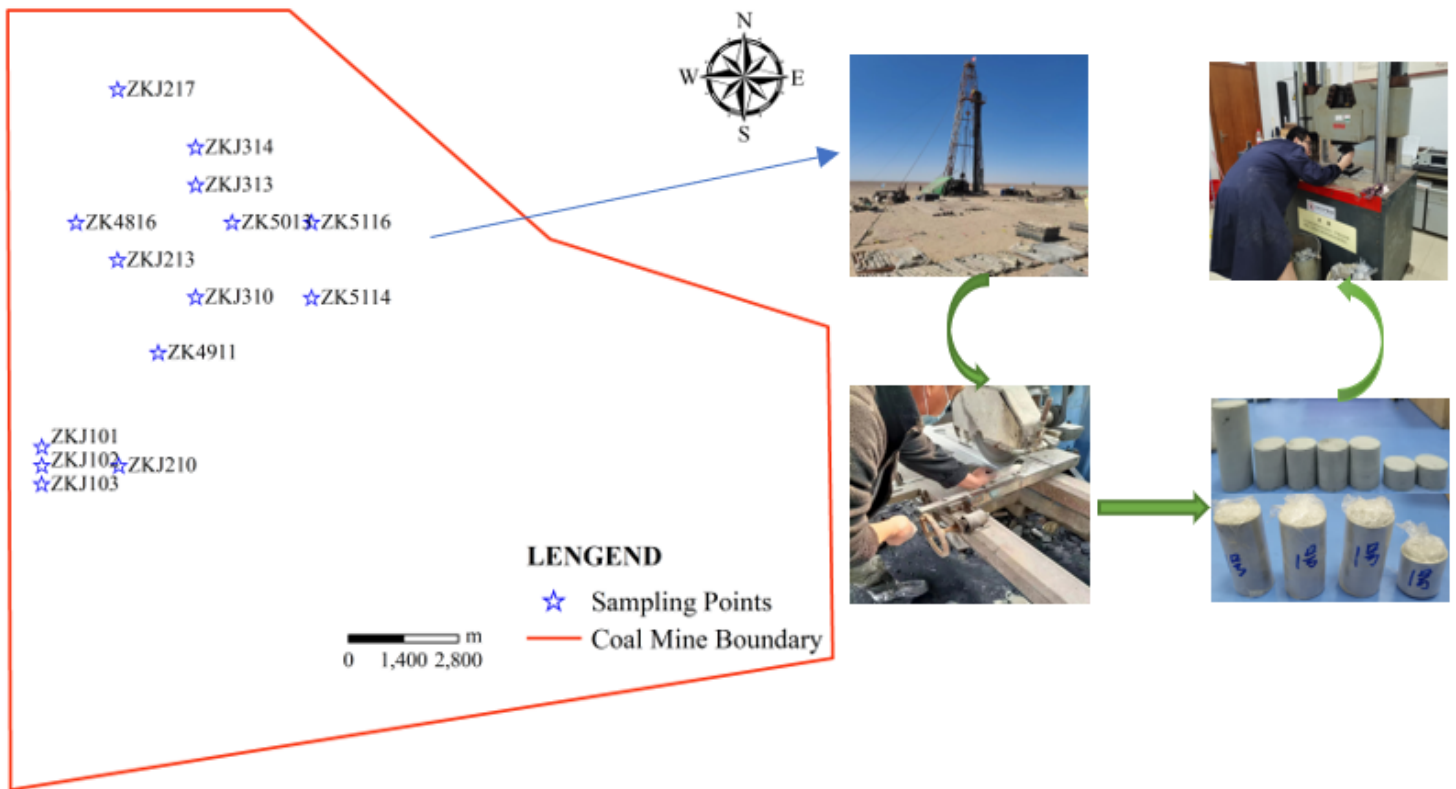


Figure 3

Sampling location, sample preparation and testing

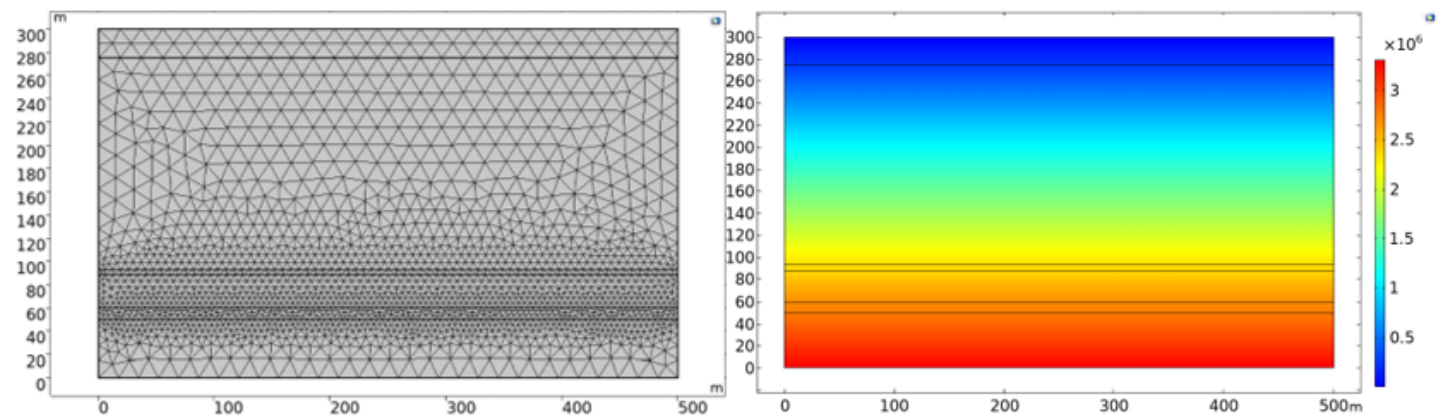


Figure 4

Meshing generation and initial stress field distribution

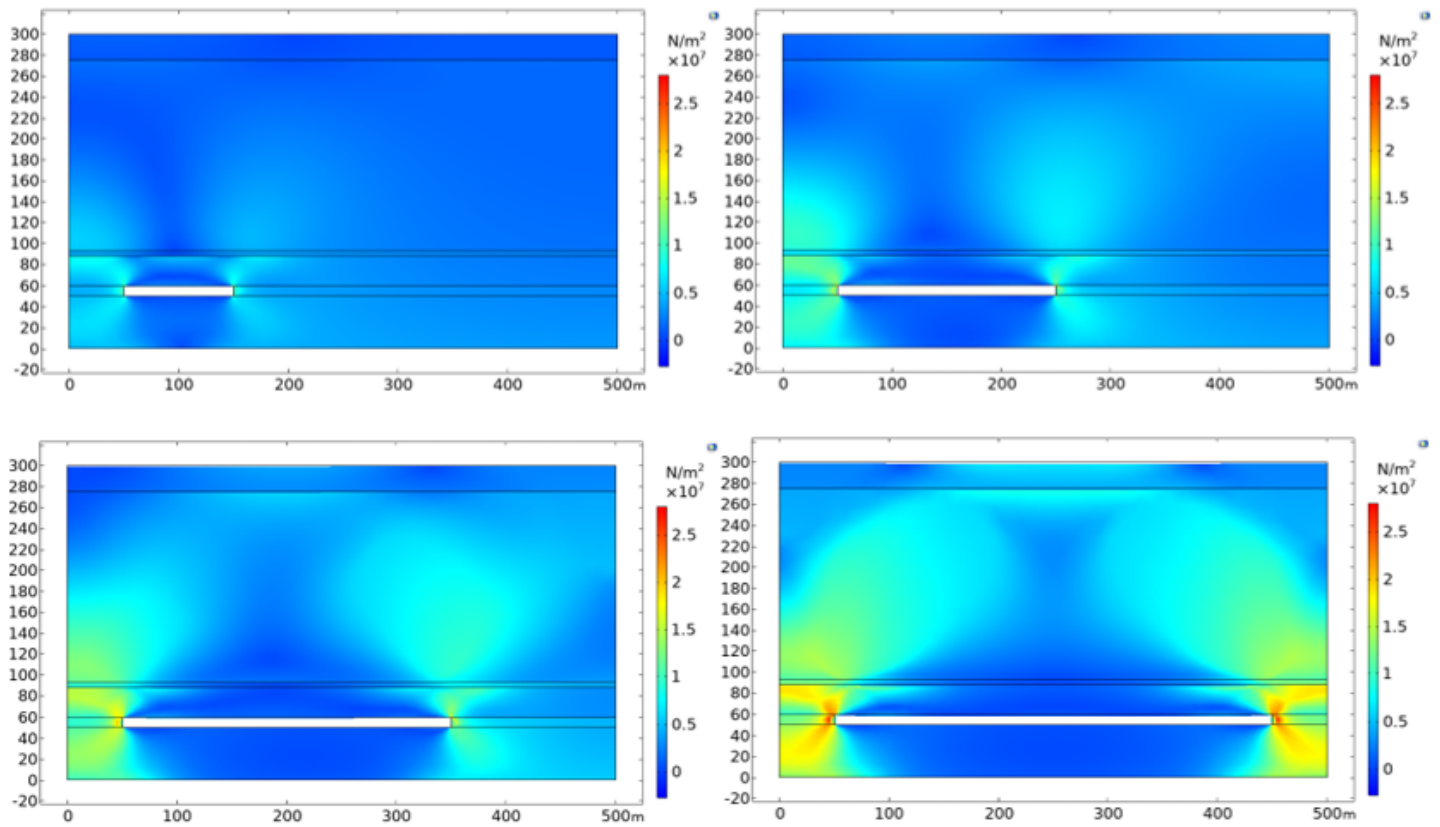


Figure 5

Stress field distribution at different mining stages (100m, 200m, 300m and 400m successively)

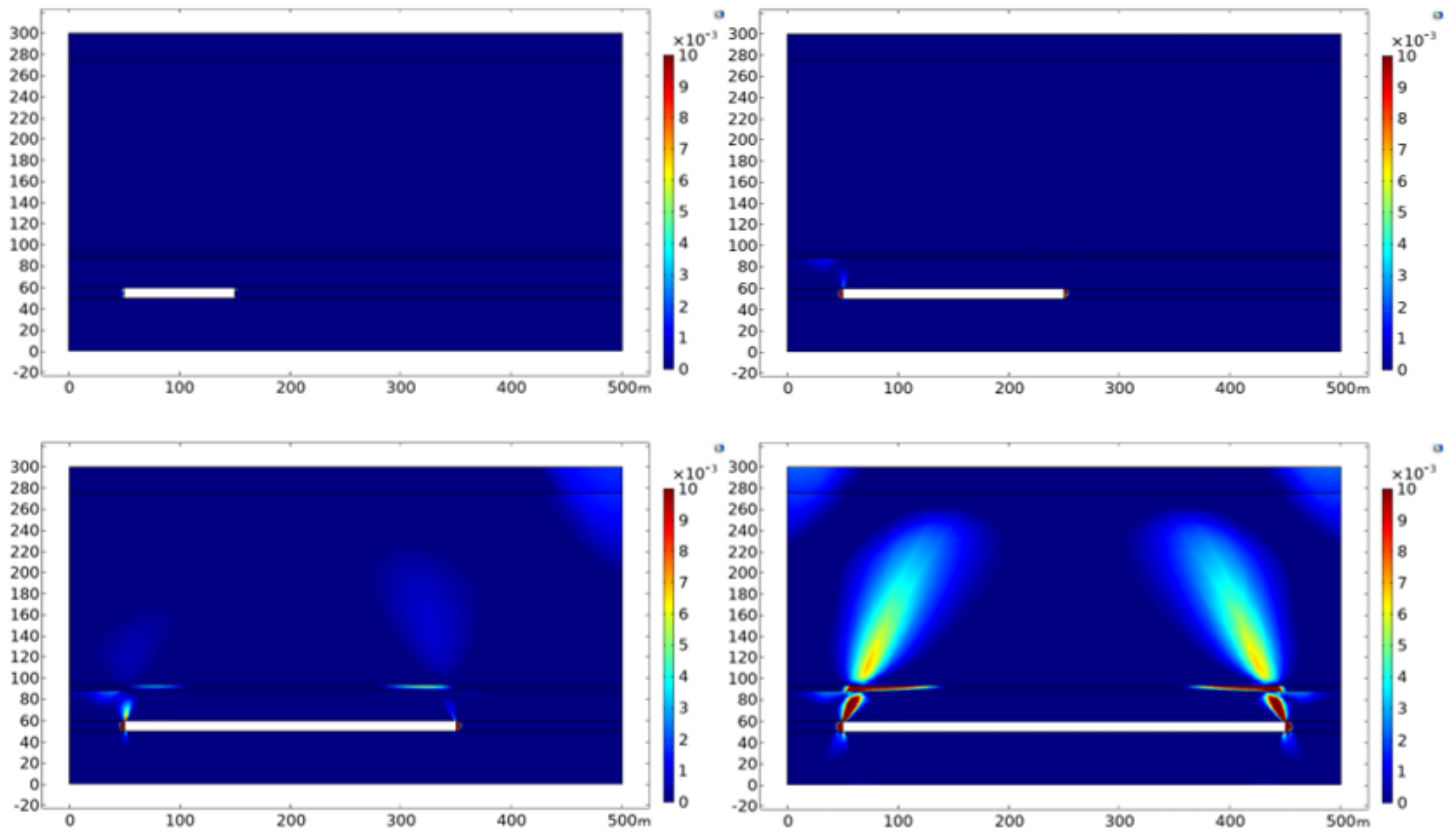


Figure 6

Plastic deformation at different mining stages (100m, 200m, 300m and 400m successively)



Figure 7

Cores of Toutunhe Formation and Xishanyao Formation (cores from ZK4911 borehole)

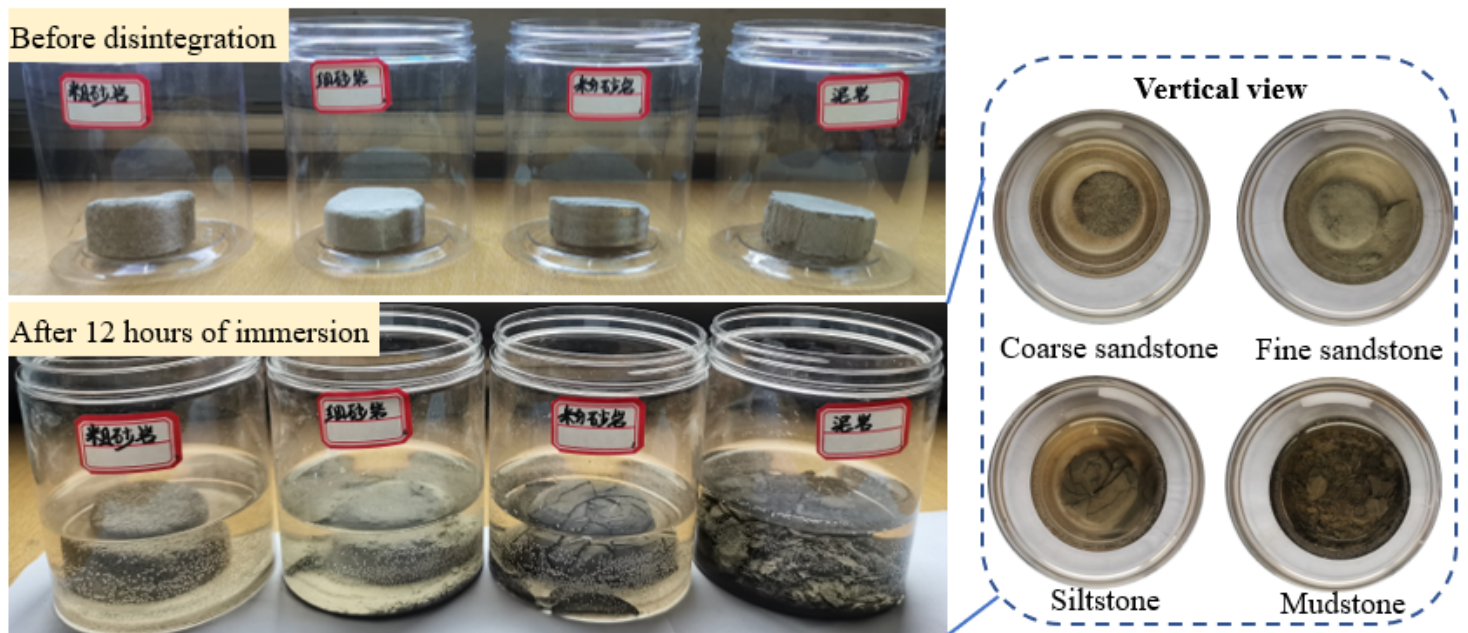


Figure 8

Disintegration test of weak cemented sandstone and mudstone



Figure 9

Post-mining ground surface fracture development

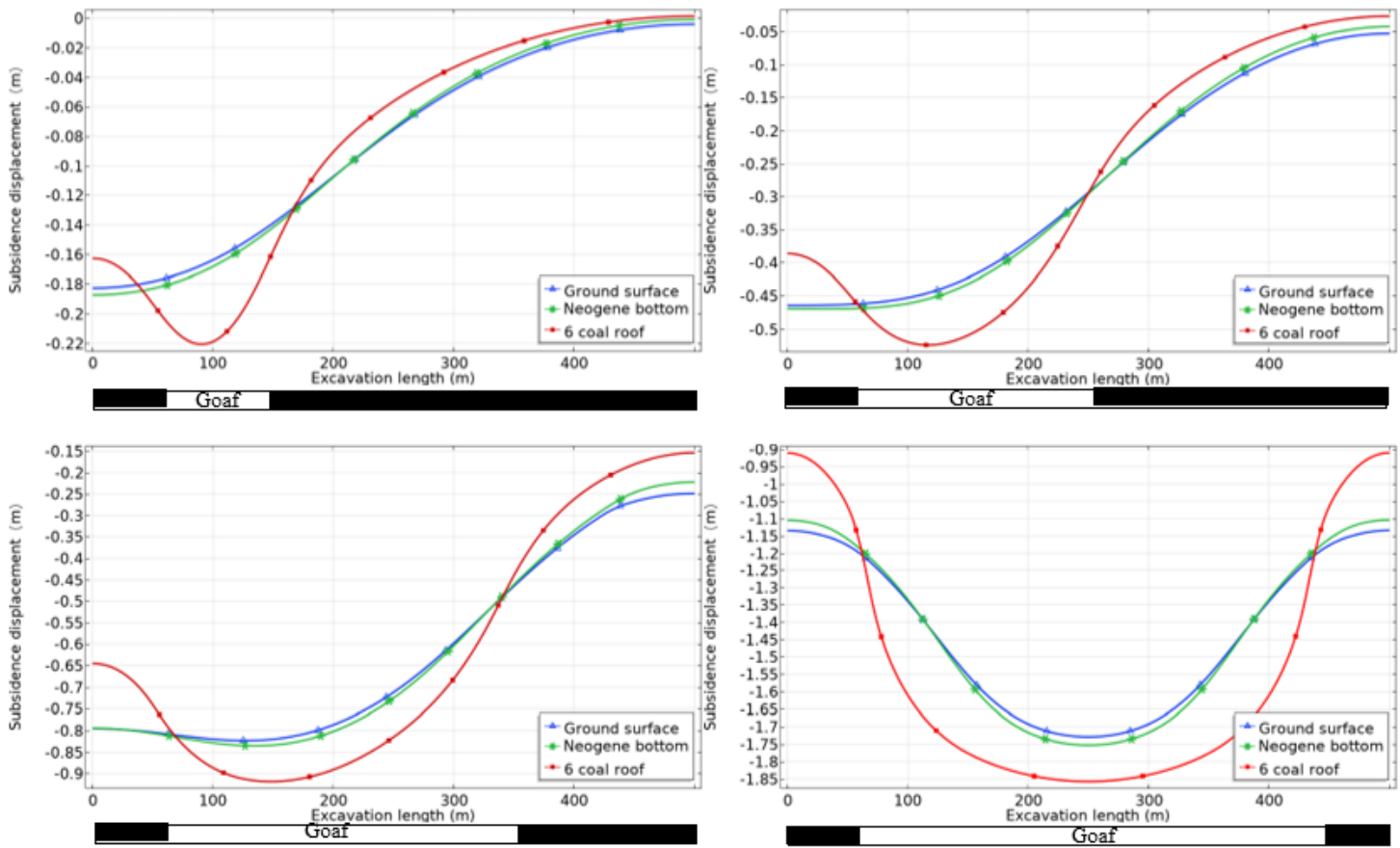


Figure 10

Subsidence characteristics of strata at different mining stages

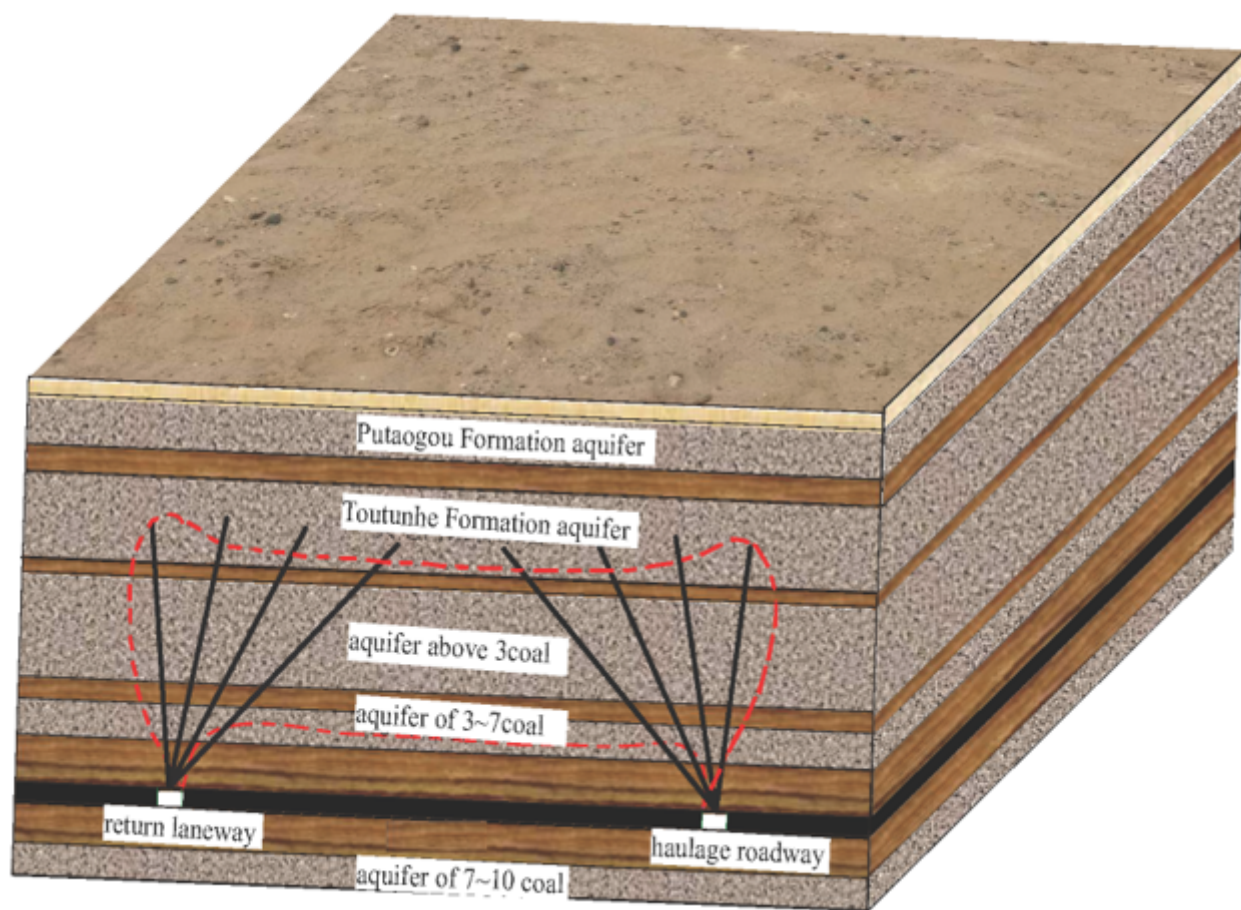


Figure 11

Layout of coalface roadway drainage depressurization boreholes