GROUND SUBSIDENCE MECHANISM ANALYSIS OF LONGGUI SALT ROCK MINING AREA: Case Study

by

Nan ZHANG[a], Jie YANG[b], Xi-Lin SHI[c], Yin-Ping LI[c], Jian CHEN[d,e*], and Wei LIU[b]

[a] Key Laboratory of Western Mines and Hazard Prevention, Ministry of Education of China, College of Energy Engineering, Xi'an University of Science and Technology, Xi'an, China
[b] State Key Laboratory of Coal Mine Disaster and Control, Chongqing University, Chongqing, China
[c] State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, China
[d] Guangdong Bureau of Coal Geology, Guangzhou, China
[e] Guangdong Provincial Key Lab of Geodynamic and Geohazards, School of Earth Science and Engineering, Sun Yat-sen University, Guangzhou, China

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The water-soluble mining is often accompanied by ground subsidence, which could result in the severity of ground subsidence disasters. The roof of the salt-bearing strata in the Longgui salt rock mining area is close to the third aquifer, which is mostly composed of muddy conglomerate and other porous rocks with large porosity and permeability. The water-soluble mining for many years has caused serious ground subsidence in the mining area, and there is a tendency to accelerate subsidence. Taking Longgui salt rock mine as a case, the mining subsidence mechanism was analyzed and discussed through the water dissolution simulation test. This study is of great significance to the prevention and control of ground subsidence disasters in Longgui salt rock mine, and also has certain reference value for other similar mining areas.

Key words: *solution mining, ground subsidence, salt rock, water solution simulation, pillar dissolution*

Introduction

Underwater salt mining has a long history [1-4]. However, with water-soluble mining, the large-scale caverns formed underground often lead the movement, deformation, and collapse of overlying rock layers. It results in serious ground collapse disasters. Mining subsidence has caused great harm in two ways: mining subsidence directly affects and destroys underground and ground buildings, causing urban ground subsidence and other accidents, huge economic losses and even causing casualties [5]. The flooding of salt rock brine will destroy the underground and surface water systems, causing the alkalization of the land and great damage to the ecological environment, fig. 1. In recent years, many scholars have studied the mechanism of ground collapse caused by mining. Xiao and Hu [6] revealed that the mechanism model of surface subsidence is the erosion-gravity subsidence-compaction of the rock salt deposit in the Yun-Ying basin. Liu *et al.* [7] proposed a new method of surface subsidence prediction for natural gas storage cavern

* Corresponding author, e-mail: 390132024@qq.com

Figure 1. Typical salt mine ground subsidence hazards

in bedded rock salts. Shi *et al.* [8] analyzed the influences of filling abandoned salt caverns with alkali wastes on surface subsidence. These studies showed that the surface subsidence phenomenon is common during the water-soluble mining. Meanwhile, many studies have done about the characteristics of rock at different depths [9-16]. These researches are benefit for us to reveal the ground subsidence mechanism of Longgui salt rock mining area.

The Longgui Salt rock mine is located in the urban area of Guangzhou, Guangdong Province. The workers mainly mine underground 470-575 m depth rock salt and associated anhydrous glauber's salt. The area of the salt mine is about 2.35 km^2. After 20 years of mining, a volume of 909×104 m^3 has been formed underground in the mining area. According to the mining history and engineering geological characteristics of Longgui salt rock mining area, the surface subsidence mechanism of Longgui salt rock mining area was discussed combined with the water-soluble mining simulation test. This study has a certain reference value for the prevention and control of ground subsidence disasters in Longgui Salt rock mine, and it also has a certain reference value for other similar mining areas.

Engineering geological conditions

The third aquifer of the mine is in direct contact with the main salt mining layer, mostly muddy conglomerate. The roof is broken, and the water system is easily connected. Under the interference of water-soluble mining, the natural balance is easily damaged, and ground fissures and ground collapse may occur. The brine-bearing stratum on the roof is not good for mining because of its poor engineering geological conditions. Large-scale avalanches on the top of the salt layer in the later period are likely to cause serious ground subsidence during the brine extraction period. Recent drilling data and controlled source audio-frequency magnetotelluric (CSAMT) measurements have shown that the third aquifer has a high risk of collapse. The CSAMT is located near the settlement center. The measurement results, fig. 2, show that there is a low resistance area in the range of 300~500 m. It is inferred that part of the third aquifer collapsed after brine collapse and brine diffusion in the third aquifer.

Recent drilling data indicates that large-scale fracture zones have begun to appear in the Longgui Salt rock mine around 460 m. The core status is shown in fig. 3. The depth is within the range of the third aquifer. It can be inferred from the coring situation that the macro-cracks of the third aquifer are extremely developed and the mechanical properties of the rock mass are extremely poor. However, in the early stage of water-soluble mining in the Longgui mining area, due to the relatively regular amount of cavity dissolution in the oil cushion, the dissolution rate was controlled. The entire mining area was evenly settled, and the settlement rate was at a low level. The lack of pads and the large number of submerged brine pumps make it impossible to effectively control the dissolution of the salt cavity. The dissolution of the salt cavity quickly extends to the third aquifer. As the salt cavity expands to the roof, the aquifer will become the main channel for brine expansion. It is highly likely that large-scale collapse will occur.

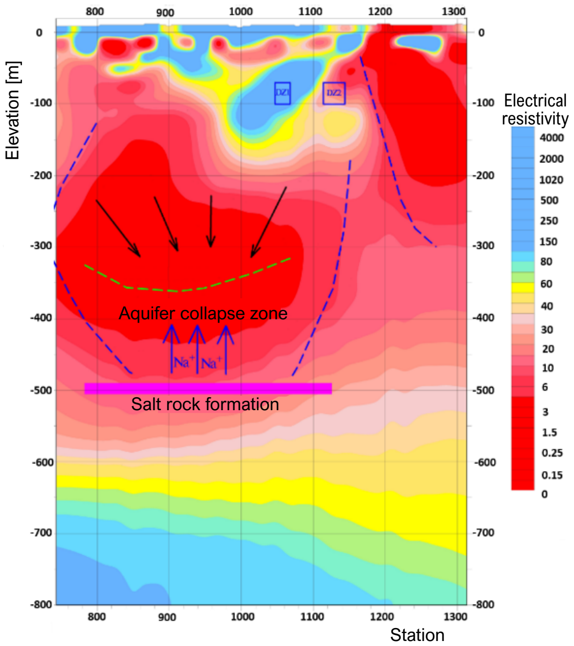

Figure 2. The CSAMT interpretation and inference results diagram

Water dissolution simulation experiment

Because the roof of the salt-bearing strata in the Longgui salt rock mining area is close to the third aquifer, and the aquifer is mostly composed of broken rock masses, with many holes and high permeability. Therefore, when it is extended to the roof aquifer, it is very likely that the cavity group will form a hydraulic connection through the aquifer laterally. It results in a large-scale lateral expansion of the adjacent cavity near the roof and causes the ore column to dissolve. This results in the phenomenon of *two cavities are combined to form a large cavity* and intensifies the ground subsidence. In this part, a dissolution simulation test of the ore pillar during the water-soluble mining process was designed in order to verify the rationality of the above reasoning and further reveal the ground subsidence mechanism of the Longgui Salt rock mine.

Figure 3. The core of the ZK-6 well in Longgui Salt rock mine about 460 m depth

Simulation experiment preparation and process

The construction stage of the test bench is mainly divided into two stages: Stage 1 – Put the salt brick into the glass box and fix it to the wall with adhesive to prevent the salt brick from dissolving on both sides. Glue the bottom of the middle salt brick. In addition to the bottom, glue the sides of the salt bricks on both sides close to the box wall, respectively. Stage 2 – Use rubber plugs and iron clips to fix the water injection pipe and the halogen discharge pipe in the middle of the salt brick respectively. The water injection pipe on the left is 12 cm away from the bottom of the tank, that is, 8 cm below the top of the salt brick. The water injection pipe on the right is located 17 cm below the top of the salt brick. The upper ends of the two pipe strings are connected to the advection pump and the peristaltic pump by transparent hoses. Complete the platform construction. The experimental platform is shown in fig. 4.

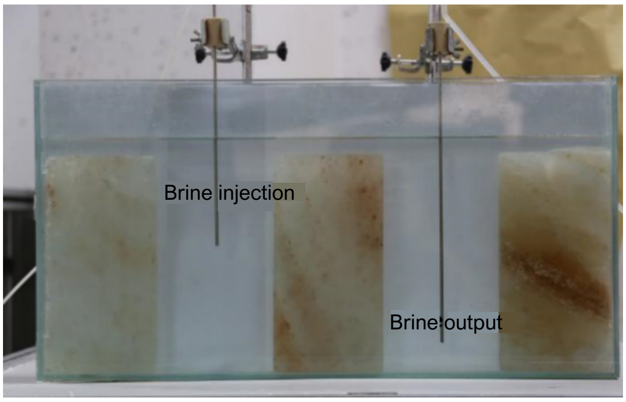

Figure 4. Dissolution simulation experiment platform

Experimental results

After processing the salt brick form and stain form recorded in the experiment, the change rule of the salt brick form during the dissolution process was analyzed. Then, the results of the water-soluble simulation experiment are analyzed using the stain distribution.

Pillar morphology dissolution change law

During the experiment, all pictures that recorded the shape of the salt bricks were taken at a fixed location. Then, the morphological pictures of salt bricks recorded during the experiment are summarized. Data are analyzed and extracted to obtain the morphological dissolution changes of the salt rock pillars during the entire process of water injection and brine drainage, as shown in fig. 5.

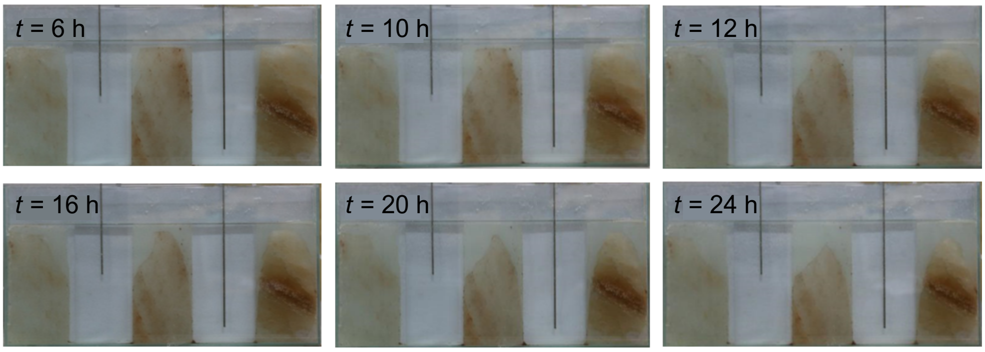

Figure 5. Morphological changes of salt bricks during the dissolution process

According to the process of injecting fresh water into the left water injection pipe mouth and discharging brine from the right brine pipe, the left and right chambers are continuously expanding, and salt bricks continue to dissolve on both sides of the chamber. The starting point of dissolution in each stage of the left cavity is near the height of the water injection pipe mouth, so it basically extends above the water injection pipe mouth level rather than the lower side. The centerline of the water injection pipe has a large and small *bowl* shape. As the dissolution proceeds, the top surface of the *bowl* shape continuously moves downward, and the left and right sides continuously move to both sides in the horizontal direction. And the angle between the two sides and the horizontal plane keeps getting smaller, that is, the *bowl* keeps flattening and widening. The lowest point of the right cavity each time is near the height of the halogen exhaust pipe mouth, extending above the halogen exhaust pipe mouth, and not extending below. The shape of the cavity is a symmetrical, long, narrow and long *cup* shape. As the erosion progresses, the *cup*-shaped top surface moves downwards, and the left and right sides move to both sides. The angle between the left and right sides and the horizontal plane becomes smaller, but the degree of the decrease is not obvious.

Flow field and concentration field in the model

When the fresh water mixed with the colorant is continuously injected, the red area in the water continues to expand, as shown in fig. 6. After the fresh water mixed with colorant flows out from the inlet of the water injection pipe, it first moves upwards along the pipe string, and after reaching the water surface, it starts to diffuse horizontally to the left and right sides. The height is higher, and the staining area diffuses downward when the leftward diffusion is slower. While waiting for the area between the top of the salt brick and its surface to approach inflation, the stained area moves down the outer contour of the salt brick. After 33 minutes later, the bottom surface of the staining area of the left salt cavity is kept near the height of the water injection nozzle. The bottom surface of the salt cavity dyeing area on the right side remains basically the same, but a part of the dye will slowly move down along the outer contour of the two salt bricks.

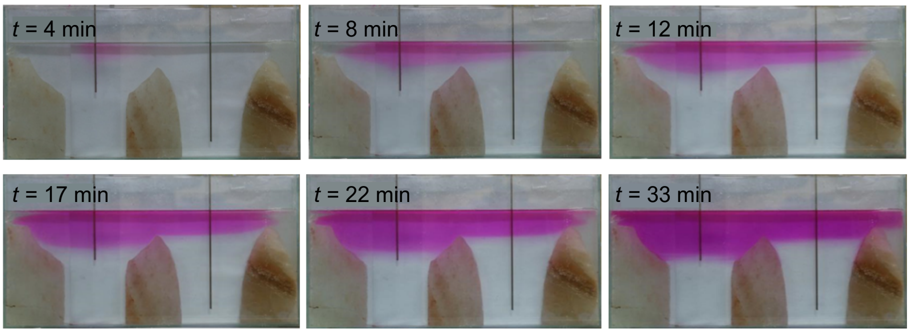

Figure 6. Change diagram of cavity group flow distribution

This experiment did not measure the brine concentration at a specific location in the glass container. Only the brine concentration at the outlet of the water outlet was measured at regular intervals. The result shows that the mass fraction of brine NaCl has remained above 25% during the experiment, indicating that the discharged brine is nearly saturated. The brine concentration distribution has a significant effect on the dissolution of the ore pillars. Through the simulation experiment of ore column dissolution, the water-soluble mining process after the expansion of the upper salt cavity after the broken roof aquifer can be simulated. By analyzing the dissolution of salt cavity and ore column and the distribution law of internal flow field and concentration field under this condition, it can be concluded that: When the uppermost layer of the water surface is approached, the brine concentration is the lowest, the higher the concentration, the upper boundary of the saturated brine in the salt chamber is located near the height of the water injection discharge nozzle, and under laboratory conditions, the top of the ore pillar has obvious dissolution phenomena. Especially the ore pillars located between the cavity groups are dissolved into different arc-shaped boundaries on the left and right sides. It is not only because of the problem of top flow and downflow in this area, but also because the brine is always at a low concentration state at the junction of the two salt cavity concentration fields. This intensified the dissolution rate of the ore pillars in the area, which eventually led to the phenomenon of *two cavities are combined to form a large cavity*.

Discussion

The test phenomenon is reflected in the mining process of Longgui Salt rock mine. When a single-cavity water-soluble mining area is used, since the dissolution expansion is not deliberately controlled, and the upper brine concentration is the lowest, the cavity will quickly dissolve to the third aquifer on the roof. Subsequently, the upper side of the cavity began to be dissolved continuously, as shown in fig. 7. Because of the existence of the third aquifer in the mining area, the hydraulic contact between the upper parts of the two or more salt chambers close to it leads to the overlap or overlap of the concentration fields in the salt chambers in the middle section, and the dense fields in the two side chambers. It affects the corrosion of salt ore pillars, and the fissure water in the aquifer also has the effect of dissolving the salt ore pillars. Superimposed on these conditions, the dissolution rate and degree of the apex of the middle salt ore pillar will increase. As the dissolution process progresses, both the apex and the bottom of the aquifer will be dissolved through. As the bottom of the aquifer continues to dissolve, the distance between the aquifers will increase. Until the upper aquifer in the salt layer loses the support of the salt column, the two single chambers eventually form an oversized chamber. Moreover, this process is likely to be the process of instability and destruction of the aquifer, causing a large number of roof mudstone collapses, thereby causing the surface settlement to increase.

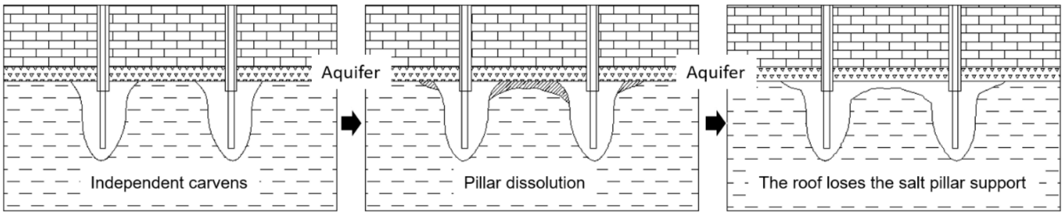

Figure 7. Schematic diagram of two cavities are combined to form a large cavity

Through the ore column dissolution simulation experiment, the dissolution mechanism of *two cavities are combined to form a large cavity* is revealed. That is, there is a hydraulic connection on the adjacent salt cavity. In the process of further water-soluble mining, the light brine can flow through the upper part of the pillar. The upper part of the pillar between the two chambers is in a light brine environment for a long time, which will promote the corrosion of the upper part of the pillar and gradually dissolve between the pillar and the roof. The pillar no longer supports the roof. Finally, the small cavity penetrates into a super large cavity.

Conclusion

The water dissolution simulation experiments show that if there is a hydraulic connection on the top of the adjacent salt cavity, it may cause serious corrosion of the ore pillar. In the late stage of water-soluble mining in the Longgui mining area, due to insufficient oil pads, a large number of submerged halogen pumps were used, which caused the salt cavity to dissolve and could not be effectively controlled. The upper dissolving salt cavity rapidly expands to the third aquifer, thereby causing hydraulic connection between adjacent salt cavities. The research results show that the mechanism of ground subsidence in the Longgui Salt Rock Deposit is that the extraction of the submerged pumps makes the salt cavity group penetrate in the aquifer on the top of the salt system. The ore pillar is dissolved in a large area, and the phenomenon of *two cavities are combined to form a large cavity* appears. The above can cause sudden collapse of the roof after extensive exposure, triggering earthquakes and severe settlement. This study is of great significance to the prevention and control of ground subsidence disasters in Longgui Salt rock mine, and it also has certain reference value for other similar mining areas.

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