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The Recent Progress China Has Made in Mining Method Transformation, Part I: Shrinkage Method Transformed into Backfilling Method

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Abstract: The shrinkage method is one of the earliest and most widely used mining methods in China's underground mines, but shrinkage mining is often accompanied by a number of problems and safety hazards. With the continuous improvement of the filling process and filling material preparation and transportation technology, the application of trackless equipment such as drill jumbo and LHD (Load-Haul-Dump), and the continuous promulgation of mine safety and environmental protection policies, a large number of mines have transformed from the shrinkage method to the filling mining method. Suichang Gold Mine has improved its technical and economic indexes after transformation from the mine shrinkage method to the filling method. Its daily production capacity has increased from 30 t/d to 110 t/d, the dilution rate has decreased from 40% to 10%, the comprehensive recovery rate has increased from 95% to 98%, and the cost saving and revenue increase in the middle section of the test area of +180 m~+240 m has totaled 18,151,000 RMB.

Keywords: shrinkage mining method; backfilling method; green mine

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1. Introduction

The mining method occupies a central position in the production of mines, and whether the mining method adopted by mines is reasonable directly affects the economic benefits, survival and development of mines. According to the different ways of controlling the ground pressure, mining methods in China are divided into three categories: stoping method, backfilling method and caving method. The shrinkage method is a kind of stoping method, and it is also one of the earliest and most widely used mining methods in China's underground mines, even in the early 1960s. When the rock gold mines were developed before the 1960s in Northeast China, Inner Mongolia, Shandong Province, Hebei Province, etc. they were almost exclusively developed using the shrinkage method.

However, foreign mines have been gradually reducing the proportion with the shrinkage method and replacing it with other efficient mining methods in the last century. Hamrin, Hustrulid [1] proposed the shrinkage method as an important recovery method used in the days when there were few underground mining machines. This method is less important today and therefore alternative methods have been proposed to replace the shrinkage method, such as subsevel stoping, vertical retreat stoping, sublevel caving, and cut-and -fill mining. These are methods that can usually be employed under similar mining conditions. In the UK and Australia, thin-vein mining has been carried out using a highly mechanized deep-hole mining method, while the shrinkage method is only used to recover ore that can only be recovered using the shrinkage method [2–4]. However, in China, due to the late development of mine mechanization equipment and filling processes, especially in non-ferrous and gold mines, the shrinkage method is still used in a significant proportion

of the mining volume due to the large proportion of mining volume of extremely inclined thin veins and small ore bodies.

While the shrinkage method has been scaled back in some countries, it continues to be used in others and has been optimized to some extent. For example, in response to the problem of ore loss from the ore shrinkage method, Rysbekov, Bitimbayev [5] proposed a continuous mining method to recover the rib pillar of the shrinkage method. Artificial concrete pillar replacement is also a way to recover the ore pillars with recovery value, and the construction of LHD access roadways not only reduces the loss of ore from the bottom pillar, but also improves the efficiency of the ore discharge [6,7]. In response to the ore dilution problem of the ore shrinkage method, the dilution of the ore proposed by the static shrinkage method was controlled to some extent. Chen and Wu [8] proposed the "synchronous filling mining technology" in mining technology, which solved the problem of loss and dilution in the ore release process of the shrinkage method by setting up flexible barriers and filling, and they conducted many in-depth studies on the basis of this method [9–13]. Shyrin, Koroviaka [14] proposed a blasting method to optimize the dilution of the shrinkage method, while Abdellah, Hefni [15] investigated the factors affecting the dilution of the goaf of extremely inclined veins. The overall shrinkage stoping method was proposed to accommodate better ore body dip variations, and the ensuing stoping method was proposed to solve the problem of dilution in the back-mining of high-grade very thin veins [16].

Although the shrinkage method has been optimized to a certain extent, it still has problems such as low mechanization, low labor efficiency, safety hazards, high pressure on tailings surface stacking, high loss and dilution, and ore capital stockpiling [2], which is no longer suitable for China's safe production or the development concept of green mines. With the deepening of China's development concept of safe production and green mines, the shrinkage method has gradually failed to meet the current needs. With the Chinese government's emphasis on safety and environmental protection, the shrinkage method is gradually being replaced by the green and efficient backfilling method. The new policy advocates accelerating the upgrading and transformation of mines and promoting the mechanization of small and medium-sized mines. At the same time, it stipulates that the backfilling method shall be adopted in principle for the construction, reconstruction or expansion of metal and non-metal mines; if there are special circumstances where it cannot be applied, it must go through a strict argumentation procedure.

The backfilling method is a mining method that uses filling slurry to manage goafs, filling as a part of mining, filling slurry filling into the mining area to provide a stable working platform for miners, and the filling body can also play a role in supporting the role of the mining goaf, preventing the collapse of the mining room, and the safety hazards brought by the goaf can be effectively eliminated [17]. At the same time, the backfill method can fully recover the ore pillars and increase the recovery of ore, and it also reduces the dilution of the ore to a certain extent due to the flexibility of the backfilling method during the process of ore recovery. Finally, most of the mines are using tailings as filling aggregate to fill the goaf. This filling allows a large amount of tailings to be stored underground (more than 50%), which largely reduces the operating costs of tailings storage, relieves the pressure of day-to-day management, and reduces the environmental impact of the tailings surface stockpile, which is very good at avoiding the impacts of the use of the shrinkage method. Meanwhile, the use of trackless equipment such as drill jumbos, LHDs and scaling rigs can greatly improve the safety and efficiency of the operation and reduce the labor intensity of the workers in the process of applying the filling method. Therefore, the filling method is a very good transformation direction for the shrinkage method. With the development of technology, China has made good breakthroughs in the research on the filling process, filling material preparation and conveying technology, and the low-cost filling mining process has become more mature [18–27].

Since the 1960s, China's filling technology has passed through different stages, including water-sand filling, graded tailings filling, and full tailings filling. With the gradual

increase in the concentration of the filling slurry and the addition of cement, the strength of the backfill increases. At the same time, the development of high-concentration paste filling has also been realized [28]. Moreover, the long-distance transportation theory, pipeline materials, and filling equipment of the filling slurry that are highly matched with the high-concentration filling slurry have been developed [19,29].

In addition, a large number of researchers have studied the stress distribution in the filling body. Li and Michel used the improved Marston method to propose an analytical solution of the vertical stress σ_v and horizontal stress σ_h of the backfill in the near-vertical backfill stope [30]. Li and Michel used FLAC2D software (FLAC 6.0) to simulate the effects of stope inclination, backfill material characteristics and filling sequence on the stress distribution of the backfill [31]. Ting et al. proposed an analytical solution to the vertical stress of the backfill for an inclined stope with non-parallel walls on both sides [32]. Falaknaz et al. (2015) used numerical simulation to study the stress distribution and interaction of two adjacent vertical filling stopes [33]. Krzysztof Skrzypkowski studied the backfilling time using the backfill CAD Model [34]. At the same time, with the increase of depth, waste rock filling has also shown its own transportation advantages, and a large number of scholars have studied the research law of waste rock filling. Although the shape and size of the backfill sample adopted in the current research on the strength of the waste rock cemented backfill are different, it is found that the strength of the waste rock cemented backfill is mainly affected by the mix ratio of waste rock and cemented material (cement), and the strength of the backfill sample shows the law of first increasing and then decreasing with the increase of the proportion of waste rock [35,36]. In order to further reveal the reasons for the change in the strength of the waste rock cemented backfill, some scholars used CT scanning imaging technology to record the whole process of the mechanical failure of the waste rock cemented backfill sample [37,38]. In terms of waste rock gradation, relevant studies have shown that the mechanical properties of Talbot cemented filling with a Talbot grading index between 0.4~0.6 are the best [39]. Krzysztof Skrzypkowski presented a comparative laboratory strength test of three-point and four-point wooden crib models. The study found that filling three- and four-point cribs with gangue increases their maximum load several times compared to empty cribs [40]. The above research not only successfully solved the problem of preparation and transportation of high-concentration filling slurry, but also improved the strength of the stope backfill, and also reasonably analyzed the stress condition of the backfill to ensure the stability of the stope backfill. Therefore, the safety of stope operators is fully guaranteed, and at the same time, the storage pressure of the tailings pond is effectively relieved, and the potential safety hazards of the goaf are eliminated.

However, the development of filling theory not only provides security, but also brings significant economic benefits. Not only can the filling method improve the recovery rate of ore, so as to produce good economic benefits, but in addition, as the slurry concentration increases, the amount of cement used is reduced, which further reduces the cost of filling [28]. In addition, during the construction of the filling system, the construction cost of the filling system is effectively reduced by using low-cost filling equipment to build various filling systems [18]. In the practice of filling, in recent decades, a variety of green filling cementitious materials have been developed using pozzolanic solid wastes, such as slag, steel slag, fly ash, calcined coal gangue, and red mud, which significantly reduces the cost of filling cementitious materials [21]. In the field of filler slurry transport, the researchers have improved the filling slurry using foaming technology. This innovative measure has succeeded in reducing the transport resistance of the filling slurry, thus effectively reducing conveying costs [41]. In specific filling operations, the filling method reduces costs by combining backfills of different strengths. For example, a layered filling strategy is used, with a low-cement, low-cost, low-strength filling material used for the bottom layer, and a high-strength filling material for the upper layer to meet production requirements. The application of the filling method not only brings significant economic benefits to mine production, but also has a huge economic contribution in terms of corporate taxation. The

Environmental Protection Tax Law of the People's Republic of China stipulates that environmental protection tax (15 RMB/t) will be levied on tailings discharge from January 2018. On 4 September 2023, the Ministry of Finance issued a notice that, in order to encourage the intensive mining and utilization of coal resources, the resource tax on the coal replaced by fill mining will be reduced by 50% from 1 September 2023 to 31 December 2027 [42–46]. And the introduction of these policies has, to some extent, promoted the use of the filling method in Chinese mines.

There are a large number of domestic and international examples of the transition from the shrinkage method to the efficient, environmentally friendly, safe and economical filling method. In the 1950s, Canada began to develop fillings, and then the use of the backfilling method instead of the shrinkage method was used to mine the extremely inclined thin veins [47]. For example, the jaduguda underground mine in India made the transition from the initial shrinkage method to filling in the 1980s [48]. The broken and water-rich Jiashi Tonghui Copper Mine in China was also transformed from the original shrinkage method to the filling method due to the increased depth and difficulty of mining [49]. This paper, through the specific case of the Suichang Gold Mine in Zhejiang Province, tells us in more detail about the limitations of the shrinkage method in specific mines and the good results achieved after the transition to the filling method.

2. Brief Introduction of Shrinkage Method

The shrinkage method is characterized by the following: the stage is divided into ore blocks, which are divided into rooms and pillars. The ore room recovers ore in layers from the bottom up; each time the collapse of the ore releases about 1/3, and the rest of the storage in the ore room is a working platform to continue to mine upward. After the entire mine is mined, all of the remaining ore will be released, as shown in Figure 1.

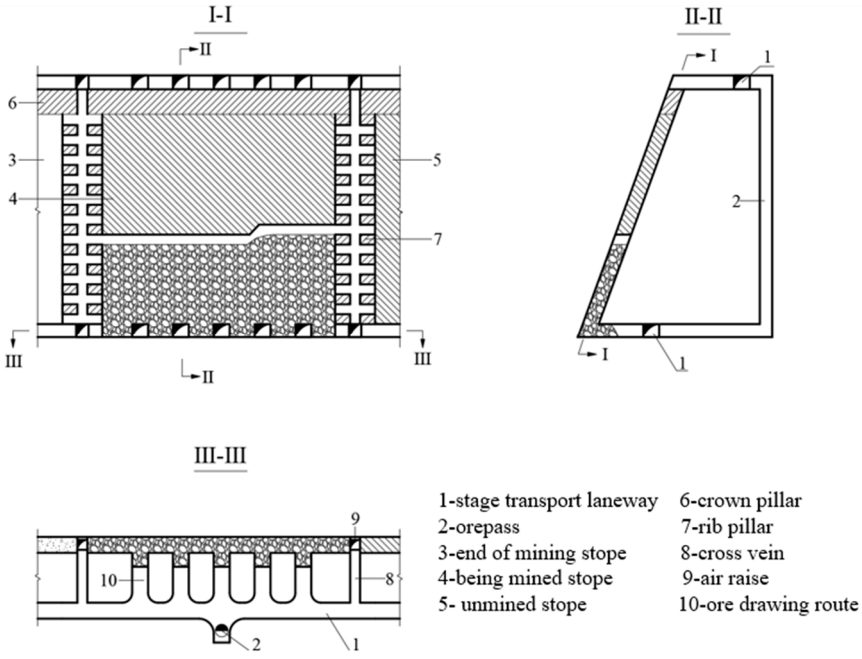


Figure 1. Diagram of the shrinkage mining method.

The shrinkage method has the advantages of a simple structure, convenient management, small development engineering, easy to master process, and easy to acquire the required equipment, but its disadvantages are also particularly obvious, mainly including the high dilution rate of recovery losses.

The loss rate of ore and the dilution rate of ore are the two most important indicators for mining enterprises in production management. The dilution rate refers to the ratio of the difference between the industrial grade of the ore and the grade of the mined ore in the

stope to the industrial grade of the ore, and the ore loss rate is the ratio of the difference between the metal content of the ore in the mine and the metal content of the ore mined to the metal content of the ore in the mine. The comprehensive recovery rate is also a commonly used indicator, and the sum of the comprehensive recovery rate and the ore loss rate is 100%. Higher dilution and loss of ore is a problem that causes waste of mineral resources and adversely affects the economic benefit of mining enterprises. In the process of mining, the reserved pillars are usually not mined, and only in the case of high value of the pillars will they consider using concrete pillars for replacement, but the construction of such concrete pillars is extremely complex and inefficient. At the same time, if the mining area is high in sulfide or clay-like minerals, the crushed ore may bond in the mining area, which may also cause problems in centralized ore release, leading to a loss of ore volume. Zhang's statistics on the ore loss rate of various mining methods in mines around the world show that the average loss rate is 14.9% for the shrinkage method and 5.3% for the fill method [50].

Ore dilution is a major problem in shrinkage mining, which can increase the cost of ore recovery, including the cost of discharge, transportation, crushing, hoisting and milling, and thus reduce the overall profitability of the mine enterprises [51]. The cause of dilution is the mixing of low-grade ore or waste rock with the ore during the recovery process. Ore dilution is a major problem in shrinkage mining, which can increase the cost of ore recovery, including the cost of discharge, transportation, crushing, hoisting and milling, and thus reduce the overall profitability of the mine enterprises [51].

The cause of dilution is the mixing of low-grade ore or waste rock with the ore during the recovery process. There are three classifications of ore dilution: one is internal dilution and the other two are planned and unplanned dilution. Internal dilution is unavoidable unless you abandon the entire ore body, and planned dilution exists due to the fact that the ore body tends to be thinner when the shrinkage method is used in order to create space for the operation. Also, unplanned impoverishment often develops due to overbursts and spalling of unstable surrounding rock; thus, due to the presence of internal, planned, and unplanned dilution (see Figure 2), the shrinkage method dilution rate is generally high [15]. According to Dominy, S., et al., additional dilution within shrinkage stopes is typically less than 15%, but depending on the surrounding rock conditions, it can reach 50% or more. The additional dilution is typically around 10~15% at the South Crofty and Geevor mines and between 20% and 25% at the Wheal Pendarwes mine [3].

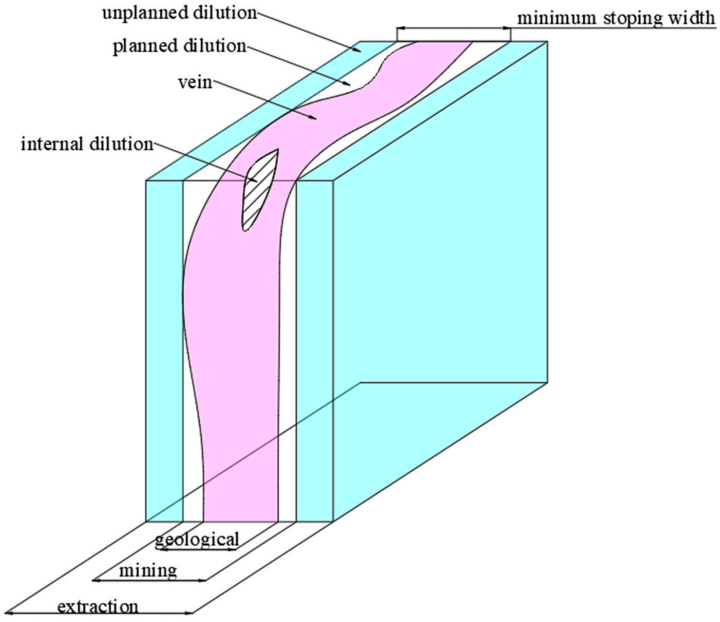


Figure 2. Schematic diagram of dilution by shrinkage method.

High labor intensity and low operating efficiency of manual production

Hamrin, Hustrulid [1] argues that the shrinkage method is considered to be a mining method used in the days when mechanization was rare. Due to the limitation of space in the mining operation of the shrinkage method, mechanized equipment is difficult to be applied, which is why many countries have converted the shrinkage method to other mining methods [2]. The shrinkage method uses pneumatic rock drills in the mining area and electric rakes to discharge the ore (see Figure 3), whereas other mining methods, which can be better utilized, use drill jumbos to drill the rock and LHDs to discharge the ore. Dominy, S., et al. [2] suggested that the productivity of the shrinkage method is also related to the proficiency of the workers in cooperation with the geo-engineers, and that the labor-intensive mining method of the shrinkage method does not allow it to be widely used in modern mines.



Figure 3. Diagram of rock drilling operation of wind driven rock drill (**left**), electric rake ore discharge process (**right**).

Tailings disposal difficulties

In the process of ore recovery, due to the low content of useful components in the ore, after beneficiation [28], it often produces a large amount of tailings. And when the mine uses the shrinkage method, tailings are not disposed of by filling the mining area and are often disposed of in a tailings pond. Studies have shown that improper handling of tailing ponds can cause many problems. During the dry season, the tailings particles are small and can easily drift into the surrounding area, polluting the air and soil and even jeopardizing people's health. Similarly, heavy metals and residual agents in the tailings can cause water, air, and soil pollution, and even endanger human health [52–54]. Tailing dams constructed to stockpile tailings also have a high risk of dam failure during the rainy season [55]. In addition, the storage of tailings takes up a large amount of land and requires additional investment to manage. Therefore, tailings have become a heavy burden for mineral enterprises [56]. Tailing dams constructed to stockpile tailings also have a high risk of dam failure during the rainy season [55]. In addition, the storage of tailings takes up a large amount of land and requires additional investment to manage. Therefore, tailings have become a heavy burden for mineral enterprises [56].

Potential safety hazard in stope

The safety of mining operations is paramount. As a method of mining, the shrinkage method requires workers to enter the stope to operate, but it is easy to cause surrounding rock collapse accidents after blasting, which significantly increases the safety risk of workers. For example, on 6 July 2022, a roof fall accident occurred at the Guangyuan Sunping Gold Mine due to the use of the shrinkage method. The main cause of the accident was the excessive height of the exposed walls of the hanging wall and the foot wall, which was unstable during mining using the shrinkage method, resulting in a 20-tonne rock measuring 3.8 m × 3.9 m × (0.3 to 0.9) m sliding off the hanging wall and crushing the victim under the rock of the foot wall of the mine. The accident eventually resulted in one death and a direct economic loss of 1.5 million RMB. A schematic diagram of the scene after the accident

is shown in Figure 4. It is important to emphasize that this risk increases with the depth of mining [2].

In addition to the safety hazards of personnel operating in the stope, the overall collapse of the stope is also a serious problem. The ore pillars retained by the shrinkage method to support the stope and the surrounding rock experience decreasing strength under long-term creep and groundwater, and the pillars undergo continuous instability or a sudden roof fall, while generating surge and shock gases; these bring great safety hazards to personnel, equipment, facilities, buildings, etc., and can even cause earthquakes and surface subsidence [57,58]. For example, the use of the mine shrinkage method in the Wa mine in New Zealand left an open area, which eventually caused a surface collapse [59]. In Canada, the Hollinger and McIntyre mines used cut-and-fill and the shrinkage method to mine a series of parallel, narrow and steeply dipping gold veins in the Porcupine–Destor Fault. The Hollinger Mine ceased operations in 1968 and the McIntyre Mine ceased operations in 1989. However, as recently as 1999, a series of subsidences (sinkholes) occurred at different locations in the mining area, particularly on the surface near the goaf that was created as a result of ore recovery by the shrinkage method. As the years went by, the subsidences had an impact on numerous properties, especially near the intersection of Highway 101–655 (Figure 5) [60]. In China, the Shirengou Gold Mine is a major example. In the Shirengou Gold Mine in China, a collapse of a mine void created by the shrinkage method occurred, with the goaf created by the shrinkage method collapsing from the top −210 m level to the −165 m level, with a collapse height of 45 m [58].

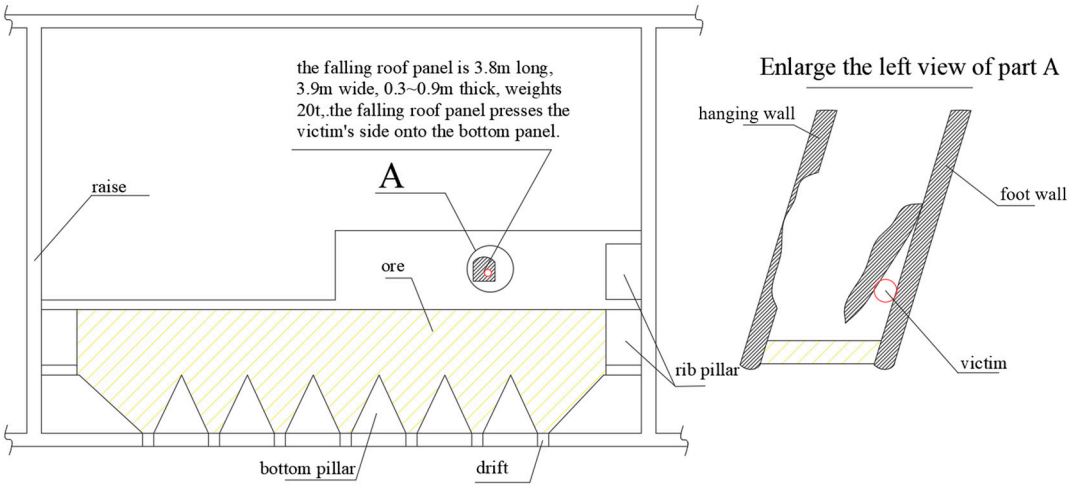


Figure 4. Schematic diagram of the accident site of the ore shrinkage method.

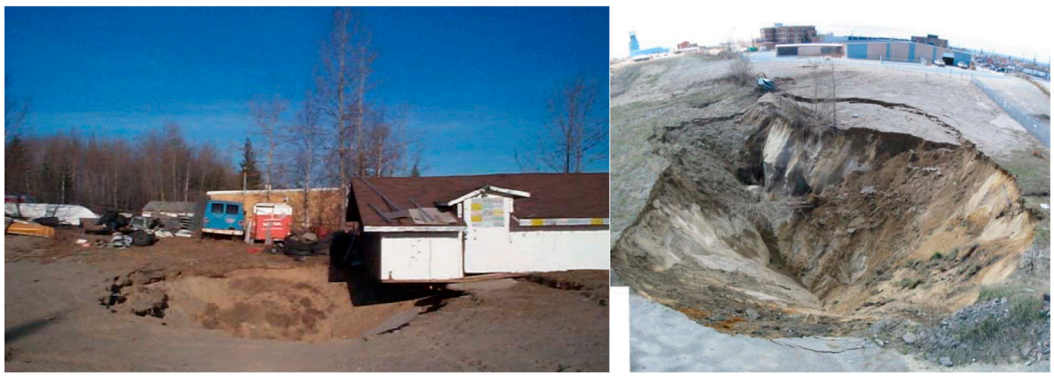


Figure 5. Foundation settlement (**left**) and highway settlement (**right**) due to mine shrinkage method mining goafs [60].

Loss of funds and security risks in centralized mine releases

Due to the mining process characteristics of the shrinkage method, 60% of the chipped ore remains in the mine as a working platform for the next layer of mining until the work in the mining area is completed, which can take months and is expensive in terms of stockpile costs. Also, the final centralized ore release process is prone to the formation of blockages, which can be dangerous to deal with, requiring access to the mining area, the use of water or compressed air jets and/or secondary blasting. Blockages in contact lanes are equally common and in some cases may require complete cleaning and rebuilding. This is an extremely dangerous task as it requires workers to operate in an environment with broken rock on both sides [2].

3. Suichang Gold Mine Shrinkage Method to Filling Method Case

3.1. Overview of the Mine

Suichang Gold Mine is located in Zhilingtou Village, Lianzhu Township, Suichang County, Lishui City, Zhejiang Province. The ore body occurrence elevation is +140 m~+460 m, the ore body dip angle is 45~55°, the horizontal thickness of the ore body is 2 m~20 m, and the average thickness is 4 m. The mine adopts the combined development of adit (located at +420 m level)-blind shaft, and the mining method is the shrinkage method.

In the process of using the shrinkage method in Suichang Gold Mine, due to the high ore grade, in order to improve the recovery rate, the shrinkage method first adopts concrete replacement pillars, and then mining rooms, which leads to the complexity of the mining process and low efficiency. At the same time, the current use of concrete pillars construction of manual labor intensity is extremely high, with extremely low efficiency, and the concrete replacement ore pillar cost is extremely high (see Figure 6). The use of pneumatic rock drills and electric rakes in production has resulted in low mining efficiency, which is only able to reach a production capacity of 30 t/d. The primary dilution rate of mining is as high as 40%, while there is a secondary dilution rate of up to 5%.



Figure 6. Construction diagram of pillar replacement.

Due to the long-term use of the shrinkage method to recover ore, a large number of goafs have been formed underground. In the vicinity of the mine, there are a large number of residential areas and a National Mine Park (see Figure 7). The development of these goafs over time may lead to surface subsidence, posing a great safety hazard. In addition, the shrinkage method does not use the large amount of tailings generated after beneficiation for backfilling in the goaf. As shown in Figure 7, the tailings pond of the Suichang Gold Mine is close to the design elevation, and the tailings pond is a major source of danger, according to China's "Opinions on Further Strengthening Work Safety"; once the tailings pond reaches the design elevation, the mine must be closed and production stopped, which

means that the mine is facing the dilemma of suspending production. Therefore, Suichang Gold Mine plans to use tailings to form a backfill, treat the original goaf and the existing goaf mined by the shrinkage method, and transform the existing mining method into an upward horizontal layered filling method.



Figure 7. Geographic location of the mine (**left**), tailings pond (**right**).

3.2. Upward Horizontal Layered Filling Method

The upward horizontal layered filling method is one of the most widely used backfilling mining methods at home and abroad, which is characterized by the following: the ore block is divided into rooms and pillars, and the ore rooms are mined first, and then the pillars are mined. Both the upward horizontal layered filling method and the shrinkage method use a bottom-up layered method to recover ore, but there are significant differences between them. The shrinkage method uses the recovered ore to maintain the stability of the surrounding rock in the hanging wall and foot wall and create the conditions for further ore recovery. In contrast, the upward horizontal layered filling method uses a backfill formed by tailings and cementitious materials to maintain the stability of the surrounding rock in the hanging wall and foot wall and to create conditions to support personnel and equipment to continue recovering ore. In addition, after the stope operation is completed, the backfill remains in the goaf to provide support for the goaf, ensure the safety of the stope, and effectively prevent surface subsidence. However, in the shrinkage method, as the ore is fully recovered, the goaf loses its support, which may eventually lead to goaf collapse and surface subsidence. The three views of the backfilling method are shown in Figure 8.

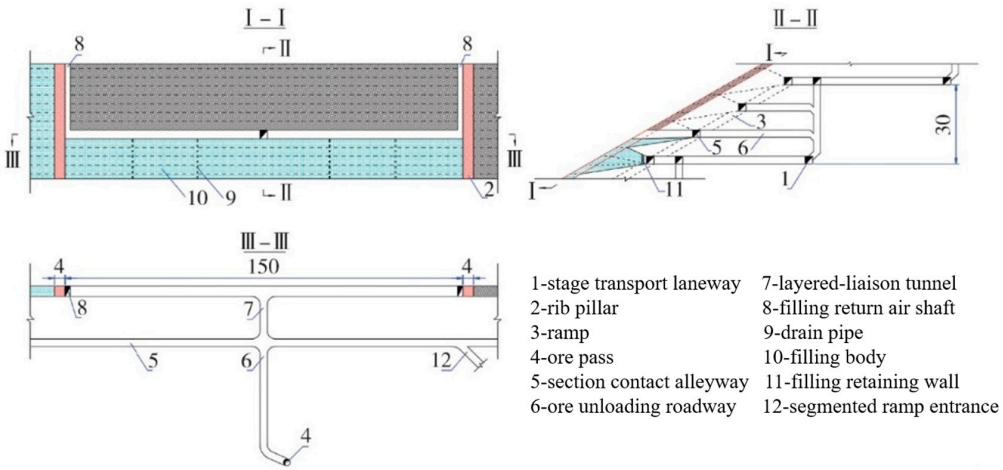


Figure 8. Mechanized upward horizontal layered filling method. I-I is the front view of the mining method, II-II is the left view of the mining method, and III-III is the top view of the mining method.

In the practical application of upward horizontal layered filling in Suichang Gold Mine, the dimensional parameters of the mine house are determined by an engineering analogy. Specifically, the length and height of the mining room were set at 150 m and 30 m, respectively, while the height of the layers was set at 3.3 m. When determining the size of the pillar, it is necessary to consider both the loss of ore and the safety and security. Larger pillars, while providing better security, can lead to more ore loss; smaller pillars, while able to recover more ore, can pose a safety hazard. In view of the high ore grade of the Suichang Gold Mine and to ensure the safety and stability of the stope, the decision was made to use a 4-metre-wide rib pillar.

3.3. Comparison of the Effectiveness of Mining Methods

A comparison of mining technical and economic indicators between the Suichang Gold Mine shrinkage method and the mechanized horizontal layered filling method is shown in Figure 9.

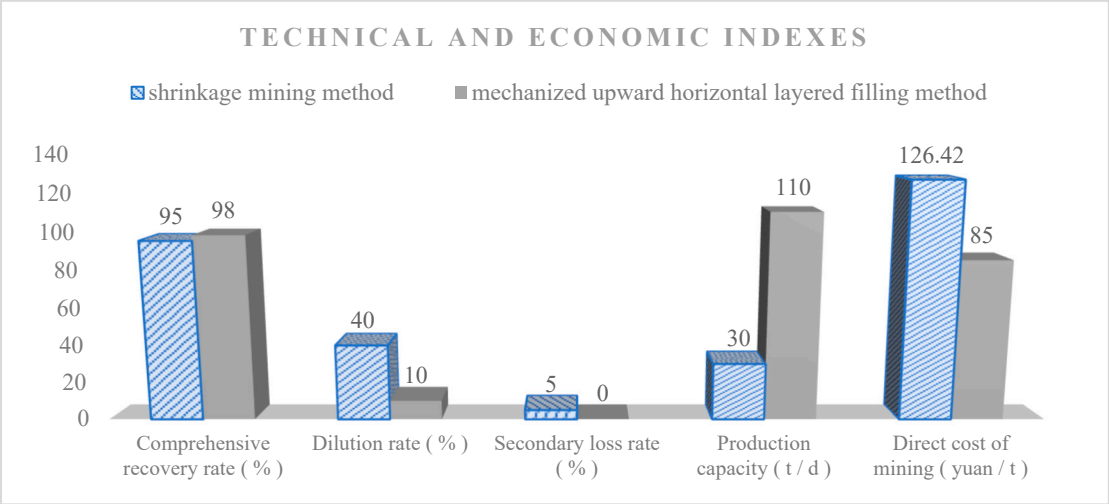


Figure 9. Comparison of techno-economic indicators.

At the same time, summarizing and analyzing the on-site construction practice and applicability of the two mining methods in the test section, we can conclude that the upward horizontal layered filling method has the following advantages:

1. High productivity

In the implementation of the Suichang Gold Mine, the upward horizontal layered filling method was used to drill horizontal blast holes with a drill jumbo. The spacing between the contour hole and the mining contour line is set at 0.3 m, the hole spacing is 1.1 m, and the row spacing is also 1.1 m. Each hole has a diameter of 45 mm and a depth of 3.5 m. The explosives for blasting are emulsified explosives, which are detonated by detonating cords and digital electronic detonators, and the method of differential blasting is used between the blast holes of each row. The mined ore is transported by LHD to the ore chute.

In order to ensure that the mechanized equipment can operate effectively on the backfill, the backfill must have the necessary strength. However, an increase in strength is usually accompanied by an increase in the amount of cement used, which leads to an increase in costs. Therefore, in the actual filling operation, the following strategy is adopted for the 3.3 m of filling layer: the bottom 3 m adopts the non-cemented filling method, using tailings to fill, without adding cement, and in the top 0.3 m of layering, the cemented filling technology with a lime-to-sand ratio of 1:10 is adopted to ensure that the strength of the backfill body reaches at least 1 Mpa within 7 days, which meets the use standard of mechanized equipment.

Compared with the shrinkage method, which adopts pneumatic rock drills to drill rock and an electric rake to get out the ore, the mechanized upward horizontal layered filling mining method adopts a drill jumbo and an LHD (see Figure 10), and the mining process mechanization degree is high. Therefore, the labor intensity of workers is low and the productivity of the mining field is high (see Figure 9).



Figure 10. Rock drilling process with rock drilling cart and ore discharge process with LHD.

2. Low loss dilution rate

As shown in Figure 11, due to the discontinuity of the ore body and the existence of small ore body branches, the shrinkage method will lead to ore dilution and loss. The upward horizontal layered filling method can solve the problem of loss and dilution by separating the ore chute and waste rock chute and mining the ore and not mining the waste rock when it is encountered.

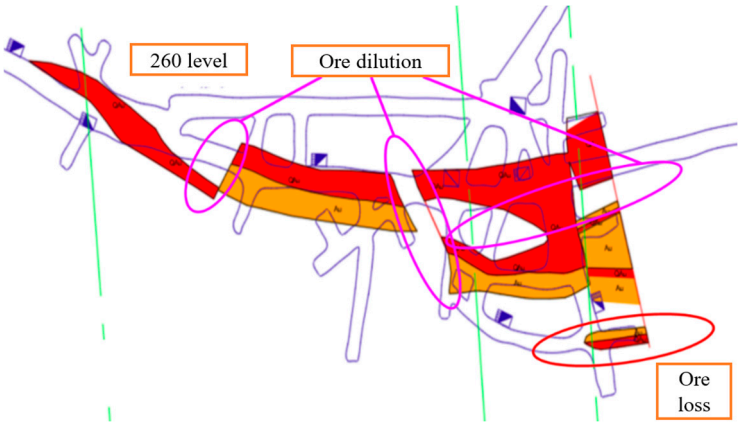


Figure 11. Schematic diagram of loss dilution in the case of interrupted or branching ore bodies.

As shown in Figure 12, because the electric rake can only linearly rake the ore, it is very easy to lead to the mining area being prone to secondary losses. And the use of an LHD out of the way leads to high efficiency and a good effect, which greatly reduces the loss of high-grade ore in the mining area.



Figure 12. Comparison of electric rake and LHD.

3. High operational safety

The stability of the ore rock in the test section is extremely poor, and the shrinkage method is very prone to produce the disaster of falling and unstable collapse, which jeopardizes the safety of the operators. The upward horizontal layered filling method adopts the technology of horizontal drilling with a drill jumbo and downward ore-dropping (as shown in Figure 13), and the mechanized supporting equipment of an LHD, which has a higher mining efficiency, a very short exposure time of the mining area, and makes it easy to deal with the upper loose rock, and the maximum height of the empty roof is small, which makes the safety of the mining operation greatly improved.

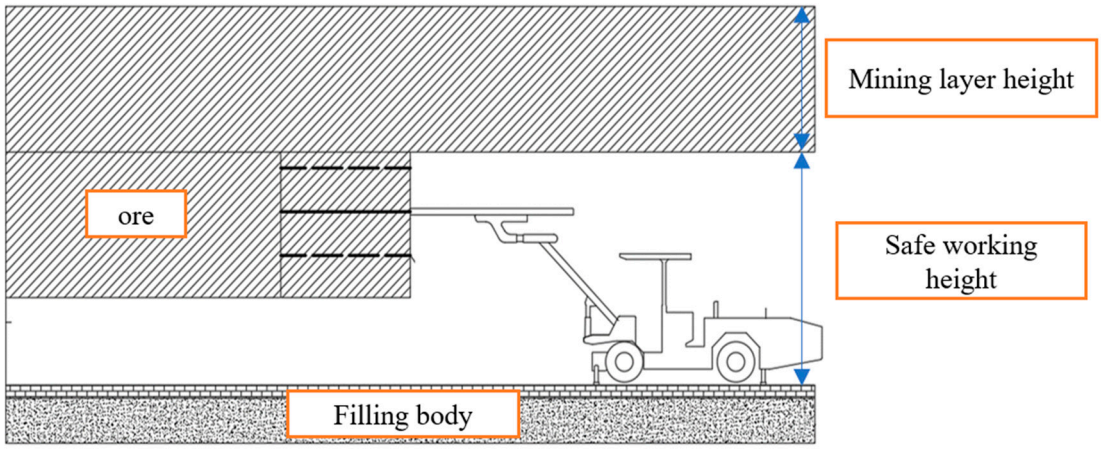


Figure 13. Downward pressure mining process with rock drilling dolly.

4. Simple process, low production cost

Compared with the artificial concrete pillars of the mine shrinkage method, the upward horizontal layered filling method does not require the construction of artificial pillars, has a simple mining process, has a high degree of mechanization, and can realize efficient mining, efficient ore removal and efficient filling, which in turn can greatly reduce the cost of production in the quarry.

In summary, compared with the shrinkage method, the upward horizontal layered filling method has a higher degree of mechanization, uses fewer workers, has better applicability to the variation of the ore body inclination and thickness, has better loss dilution indexes, has a higher mining efficiency, has better safety of the ore recovery operation, has a simpler ore recovery and filling process, and is especially suitable for the complex characteristics of the ore body and the technical conditions of the mining.

3.4. Economic Benefits of Transformation

Taking the test mining area in the middle section of the V-1 ore body of Suichang Gold Mine from +180 m to +260 m as an example, the expected economic benefits brought by adopting the mechanized upward horizontal layered filling method are divided into the following: labor cost, concrete construction cost, increased mining cost due to depleted ore, reduced lifting and transportation cost, reduced beneficiation cost, direct economic benefits created due to grade enhancement and increase in the amount of metal, and the equipment purchase cost and mining calibration engineering costs.

After the transformation, due to the adoption of mechanized equipment, the operating personnel are reduced to 70% of the original, and the labor cost is reduced; through the reasonable allocation of the ratio of high and low intensity filling body, the filling cost is also reduced after the transformation, compared with the replacement of the original high intensity filling body of the mining pillar mining of the shrinkage method. The dilution rate is reduced from 40% to 10%, and therefore, the mining cost, lifting and transportation cost, and the cost of beneficiation is reduced; the rate of dilution and loss rate is reduced, and the amount of metal recovered is increased and good benefits are created. Only in the two items of equipment purchase and development engineering is the cost increased compared with the shrinkage method. Overall, after the transformation of the mining method, the total cost saving and revenue increase is 18,151,000 RMB (see Table 1 for specific details).

Table 1. Analysis of direct comprehensive economic benefits of Suichang Gold Mine test quarry (unit: RMB 10,000).

Factor	Shrinkage Method	Upward Horizontal Slicing Filling Method	Benefit Value
1. Labor costs	400	280	120
2. Concrete construction costs	237.7	191.0	46.7
3. Mining costs due to dilution	219.2	130.0	89.2
4. Lift transportation costs	151.6	104.2	47.4
5. Beneficiation costs	2888.0	1986.1	901.9
6. Direct economic benefits of increased metal volume	31,752.4	32,755.1	1002.7
7. Equipment acquisition costs	167	407	−240
8. Costs of the development engineering	266.5	419.3	−152.8
Total cost savings, revenue enhancement			1815.1

In China, many mines facing mining difficulties similar to those of the Suichang Gold Mine. This is because China's mineral resources are dominated by small and medium-sized deposits, of which 65.7% are small gold deposits, 88.4% are small copper deposits, and 95.2% are small and medium-sized iron ore deposits. In the face of these mining difficulties, many mines actively seek to transform and adopt the backfilling method, which has achieved significant technological progress and economic benefits.

The Dadiangou Gold Mine is one of the examples of successful transformation. Due to the fragmentation of the ore body, the mine faces problems such as poor mining technical conditions, large loss rates and dilution rates, and poor stope operation safety conditions. Through the transformation from the shrinkage method to the horizontal layered filling method, the Dadiangou Gold Mine successfully controlled the loss rate below 5% and the dilution rate below 8%. At the same time, this transformation measure has brought significant economic benefits, with an annual output value of 35.5956 million RMB and an annual net profit of 26.6967 million RMB. In addition, the Daliuhang Gold Mine in Penglai City, Shandong Province has also increased its stope production capacity to 60.32 t/d by transforming the shrinkage method to the backfilling method, reducing the ore dilution

loss to 8% and 12%, respectively, and increasing the economic benefits of a single stope by 760,000 RMB.

Therefore, Suichang Gold Mine is one of the many successful cases of the transfer from the shrinkage method to the backfilling method, and the successful transformation of the Suichang Gold Mine shrinkage method not only improves its own technical indicators and economic benefits, but also provides a feasible transformation plan for other small and medium-sized mines to adopt the filling method.

To sum up, we can make the following summary of the transformation of mining methods in Suichang Gold Mine:

1. Before the transformation, Suichang Gold Mine had extensively utilized the shrinkage method for ore recovery, leading to the creation of numerous underground goafs. These goafs pose significant safety risks to the nearby residential areas and the National Mine Park. Furthermore, the mine's tailings pond is nearing its designed capacity. If the shrinkage method continues to be employed, the substantial amount of tailings generated will continue to accumulate in the tailings pond. In accordance with China's "Opinions on Further Strengthening Work Safety," the mine is at risk of an imminent shutdown.
2. Before the transformation, the use of pneumatic rock drills and electric rakes in production resulted in low mining efficiency, which was only able to reach a production capacity of 30 t/d. The primary dilution rate of mining was as high as 40%, while there was a secondary dilution rate of up to 5%.
3. After the transformation, the risk of surface subsidence caused by goafs generated by ore recovery by the shrinkage method was eliminated, the pressure of tailings storage in the tailings pond was relieved, and the production life cycle of the mine was extended.
4. After the transformation, the number of operators was reduced by 70% due to the use of mechanized equipment. The dilution rate was reduced from 40% to 10%, the recovery rate increased from 95% to 98%, and the daily production capacity increased from 30 t/d to 110 t/d. The use of the upward horizontal layered filling method in the test area of +180 m to +260 m in the middle of the V-1 orebody of Suichang Gold Mine can bring the expected economic benefits of 18,151,000 RMB to the mine.

4. Conclusions

1. The shrinkage method is one of the earliest and most widely used mining methods in underground mining in China, with the advantages of a simple structure, convenient management, small development engineering, easy to master process, and easy to acquire the required equipment. However, its disadvantages cannot be ignored, including high ore loss and dilution rate, high manual labor intensity, low production efficiency, difficulty in tailings disposal, safety hazards in void areas, and financial losses and safety hazards from centralized dumping of ores.
2. Compared with the shrinkage method, the backfilling method shows significant advantages in ore recovery. It has a larger daily production capacity and a lower loss and dilution rate. At the same time, the filling method can also bring significant economic benefits. More importantly, the filling operation not only ensures the safety of the operators in the ore recovery process, but also effectively eliminates the potential threat of goaf collapse to surface personnel and buildings. In addition, the backfilling method also helps to relieve the storage pressure of tailings on the surface.
3. Suichang Gold Mine has experienced many years of ore recovery by the shrinkage method, and is now facing many problems. Through the transformation from the shrinkage method to the filling method, the safety of workers' operation is guaranteed, the trouble of full loads in tailings ponds is alleviated, and the safety of a large number of residential areas on the surface and the national mining park is ensured. Both technical and economic indicators have improved. Taking the test quarry of +180 m to

+260 m in the middle section of the V-1 orebody of Suichang Gold Mine as an example, the total revenue increased by 18,151,000 RMB.

4. In conclusion, due to the shortcomings of the mining shrinkage method, it is difficult to meet the country's requirements for high-quality development of the mining industry and the development needs of enterprises themselves. However, due to the advantages of the backfill method, the backfill method has become a better choice than the shrinkage method.

In conclusion, the authors state that this paper only serves as a guide to start the conversation. In future research, the authors will continue to study the transformation of mining methods in domestic mines, and hope that more experts and researchers will be interested and become involved in this area of research.

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