MIJUN WANG
XIANCHENG MAO
and
HAIDONG JIANG

Effective utilization of gold mineral resources based on 3D visualization

This paper attempts to make effective use of gold mineral resources based on 3D visualization. To this end, the authors developed a techno-economic evaluation system for gold resource exploitation on 3D visualization platform. Based on the technical indices and production costs, a techno-economic model was created by data mining and geological statistics methods like regression analysis and time series analysis. Then, the mineral resources were evaluated economically to timely adjust the cutoff and economic grades. The proposed system and models offered valuable guidance on the mining design, resource utilization, and reserve management. This study supports the the scientific decision-making for mining investment and operation, and maximizes the economic profits of mineral resources.

Keywords: *3D visualization, economic evaluation, block model, dynamic reserve management*

1. Introduction

Under the economic new normal, the mining industry is faced with unprecedented difficulties. The prices of minerals continue to decline in the international market, and prices in the gold market become more volatile. What is worse, there is an increasing lack of back-up mineral resources with the expansion of production scale. Against this backdrop, it is urgent to compute the cutoff and economic grades, manage reserves in a dynamic and meticulous manner, and make optimal use of resources [1].

Currently, the dynamic management and techno-economic appraisal of mineral resources mainly rely on traditional manual operation using 2D drawings and forms. The method is laborious, inefficient and inaccurate. It is difficult to compute the ecnomic grade and adjust excavation plan according to the changing market prices. Targeted at open pit mining or plan optimization, the popular reserve calculation software, e.g. XERAS (Runge Limited), in foreign countries does not apply to mining in China. In terms of gold mining, the current software cannot satisfy the simple, digital, programmatic, and 3D visual requirements for modern mine resource evaluation. This calls for advanced 3D visualizaiton software for evaluation of mineral exploitation.

In answer to the call, a techno-economic evaluation system for gold resource exploitation (hereinafter referred to as the evaluation system) was developed on 3D visualization platform. Based on the technical indices and production costs in the evaluation system, a techno-economic model was created by geological statistics methods (e.g. regression analysis and time series analysis) and data mining, with the aim to evaluate economic grade, prepare mining design and optimize mining operation. Focusing on gold mineral resources, the evaluation system was applied to the evaluation of mining investment and the optimization of mining. The purpose is to realize the dynamic management of mineral resources and the maximum economic benefits through the efficient use and sustainable development of mineral resources [2-3].

2. Evaluation of mineral resources investment

2.1 Geological survey

The study area is a super-large altered-rock type gold deposit. Northeast-trending fractures are well developed in the area. The orebodies are occurred in the fracture zone, and the mineral deposits belong to class I. According to the report released in a previous geological survey, there are 34 orebodies in the study area, with the main orebody being I-4. The evaluation system was adopted to verify the reserves and evaluate the investment before investment. During the verification and evaluation, the orebodies were redelineated, the type of mineral deposit was identified, the mineral reserve was estimated, and the investment risk was assessed.

2.2 Digital database

A digital database was created to record such geological information as drillholes and trenches. Through detailed analysis of the survey data, a total of 91 drillholes were extracted, and the corresponding data were imported to the database.

2.3 3D orebody modelling

The orebodies were modelling with general industrial

Messrs. Mijun Wang, School of Geosciences & Info-Physics, Central South University, Changsha 410012, China, Shandong Goldsoft Technology. Co. Ltd,, Zhaoyuan 265400, China, Xiancheng Mao, Shandong Goldsoft Technology. Co. Ltd,, Zhaoyuan 265400 and Haidong Jiang, School of Recourses and Environment Engineering, Guizhou Institute of Technology, Guiyang 550003, China. Email: 59366197@qq.com

parameters: the cutoff grade is 1.0g/t; the lowest industrial grade is 2.5g/t; the average deposit grade is 4.0g/t; the minimum mining thickness is 0.8m for steep orebodies and 1.5m for gently inclined orebodies. When the orebody is thinner than the minimum mining thickness, but has a relatively high grade, it can be delineated as minable orebody if the product of its thickness and grade reaches the m×g/t value.

A series of prospecting line profiles were identified based on the digital database on drillholes. In each profile, the borders of the orebodies were delineated with the orebody indices. Then, the contour lines of adjacent profiles were connected into triangular faces. In this way, the authors built up a 3D model consisting of I-1, I-2, I-3, I-4 and many other large orebody blocks and several small blocks (Fig.1).

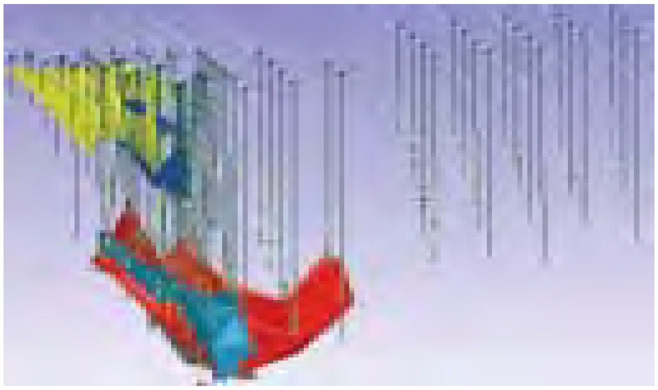

Fig.1 Acomprehensive mine orebody model

2.4 Resource reserve sstimation

The sampling points were extracted by a composite length of 1m, laying the basis for structural analysis and curve drawing of the variation function.

Through analysis, the exponential model was fitted with the I-4 orebody variation function and ellipsoid parameters, including variation = 350.96, base station value = 33.5, nugget value = 10.57, azimuth of the search ellipsoid = 135°, dip –40°, spindle/secondary axis = 1.00, and spindle/minor axis = 1.00. Next, a block model was set up according to the scope of the 3D orebody model. In view of orebody grade distribution, the ordinary kriging method was employed to estimate the grade. According to the known sample points in the area, the linear,

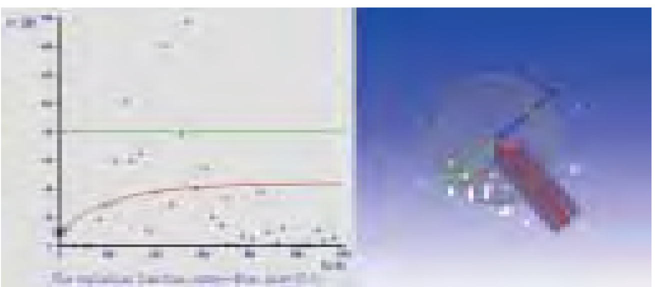

Fig.2 Variation function structure

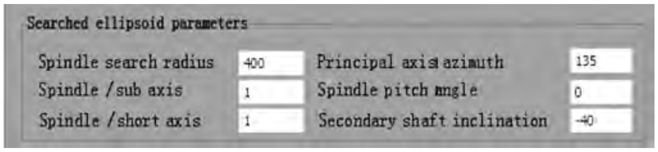

Fig.3 Ordinary kriging valuation parameters

unbiased and minimum variance estimates were obtained for the local variables of the estimated block. Then, the ordinary kriging valuation parameters were set up based on the variation function parameters and the geological features of the mining area.

The grade of I-4 orebody was evaluated by ordinary kriging valuation parameters. In the light of the results, the authors built a grade model (Fig.4).

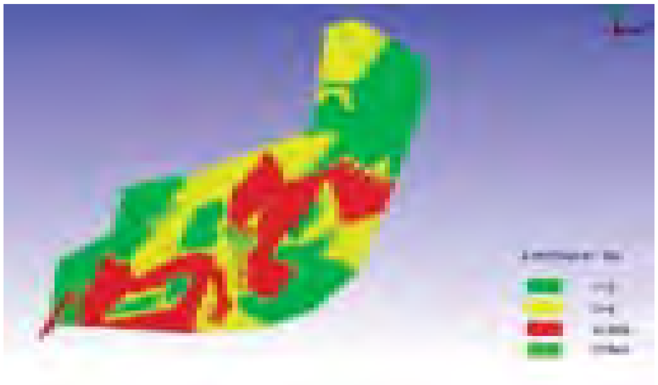

Fig.4 I-4 ore grade distribution

The other orebodies were evaluated in turn by the above methods to complete the reserve estimation. The estimated results were automatically reported by the evaluation system. The metal amount in the report differs from that in the survey report by 45%. The difference can be attributed to the following reasons, excluding manmade factors and the profit-driven factors of mining rights trade.

(1) The exploration type determined in the survey is unreasonable. Due to the limitation of the prospecting technologies, many I-1 orebody blocks were mistaken for I-3 or I-4 orebodies, and the control system used the spacing of 320×320 (m). After adjusting the type of orebodies, the reserve was re-estimated by the conventional method. The estimated amount of metal was only 4.7% different from the value estimated by the evaluation system.

(2) The conventional grade calculation was performed with the weighted average method. The results are often excessively high. By contrast, the evaluation system adopts the widely accepted geological statistics method, which can yield the optimal and unbiased results in the light of all kinds of information [4-5].

2.5 Economic evaluation of mineral resources investment

Based on our 3D reserve model, the technical mining

TABLE 1. MAIN ECONOMIC INDICES

	Index name	Unit	Quantity		Index name	Unit	Quantity
1	Geological			4	Investment		
1.1	Geological resources			4.1	Total investment	Ten thousand yuan	390448
	Orereserves	Ten thousand tons	6492		Of which: construction investment	Ten thousand yuan	334735
	Grade	g/t	3.68		Construction period interest	Ten thousand yuan	36177
	The amount of metal	t	238.9056		Liquidity	Ten thousand yuan	19536
2	Mining			5	Costs		
2.1	Design and utilization of resources			5.1	The total cost	Ten thousand yuan/a	115251
	Ore reserves	Ten thousand tons	6492	5.2	Operating costs	Ten thousand yuan/a	89265
	Grade	g/t	3.86	5.3	Unit Cost	yuan/t	380.38739
	The amount of metal	t	250.59	6	Operating income, taxes and profits		
2	Mining			6.1	Operating income	Ten thousand yuan/a	288142
2.2	The amount of infrastructure projects	Ten thousand cubic meters	0	6.2	VAT	Ten thousand yuan/a	0
2.3	Time Infrastructure	Year	5	6.3	Business tax and surcharges	Ten thousand yuan/a	1320
2.4	Length of service	Year	22.6	6.4	Total profit	Ten thousand yuan/a	171571
2.5	Production scale	Ten thousand tons	330	6.5	Income tax	Ten thousand yuan/a	42893
2.6	Dilution Rate	%	8	6.6	Net profit	Ten thousand yuan/a	128678
2.7	Loss rate	%	8	6.7	EBIT	Ten thousand yuan/a	173569
2.8	Myriaton excavation ratio	Cubic meters/ ten thousand tons	958	6.8	Earnings before interest, taxes, depreciation and amortization	Ten thousand yuan/a	197556
2.9	Normal production year	Year	7	7	Economic indicators		
3	Ore-dressing			7.1	Investment		Income after
3.1	Ore processing capacity	Milliont / a	330		NPV (i=0.1)		2068118
3.2	Feed Grade	g/t	3.86		The payback period		8.95
3.3	Mineral dressing recovery	%	96	7.2	Total investment yield		44.45
3.4	Gold concentrate grade	g/t	60	7.3	Investment profit		43.94
3.5	Gold concentrate gold	kg	240566.4	7.4	Investment tax rate		44.28

indices, production and management costs, and gold market prices were deducted by analogy. Then, a techno-economic model was built to obtain the economic grade of deposit and the benefit of investment.

2.5.1 Establishment of techno-econominc model

The techno-economic model aims to derive production and management costs and other technical mining indices. As shown in Fig.5, the production cost and other technical parameters put directly.

2.5.2 Economic evaluation

The evaluation system automatically read the production cost, technical indices and other data in the techno-economic model, and calculates the breakeven grade based on the gold price forecast of the current gold price. The resource reserves of the above breakeven grade were automatically estimated by the 3D reserve model, and an evaluation report was automatically generated according to the cost and technical parameters in the techno-economic model. The main evaluation indices are listed in Table 1.

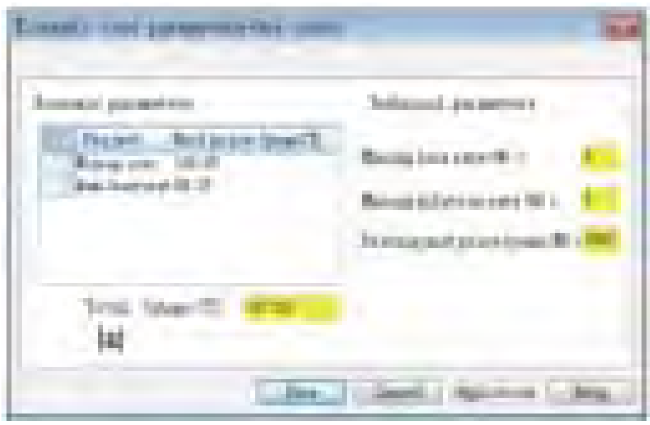

Fig.5 Economic cost parameters

The 3D reserve model, grounded on statistical methods, produces optimal and unbiased results. The techno-economic model is based on the gold market price, and considers technical indices like production cost. Using the basic data report of Excel, the model can rapidly generate a report on the economic evaluation of the deposit, and integrate the economic data on 3D reserves. Overall, our models greatly facilitate the techno-economic evaluation, provide new insights to mining investment, and reduce the acquisition cost and investment risk.

3. Economic evaluation of mine production

3.1 Geological survey

The target mine is a concealed altered-rock type gold deposit in the medium-temperature hydrothermal zone. The area is featured by strong tectonic activity is strong and developed faults. The mine mainly contains I1 and I2 orebodies on both sides of the main fault and other 24 types of orebodies. In general, the orebodies have a deep buried depth, low grade, big horizontal thickness. The distribution of orebodies is strictly controlled by fracture structure, and the size and grade of orebodies are closely correlated with the fracture development, rock alteration and type of ore.

During the three-decade long mining process, a lot of geological data and production management data have been accumulated. Based on these data and the changing gold price, the authors improved the existing mining and dressing techniques, and applied the evaluation system in the dynamic reserve management, economic evaluation, mining design, and ore processing optimization.

3.2 Digital database and modelling

Relying on the evaluation system, the drillholes, pit drills and tunnel samples were collected in a new digital database. The database lays the root for the 3D model, the block model, and the grade evaluation. The reserve distribution is presented in Fig.6.

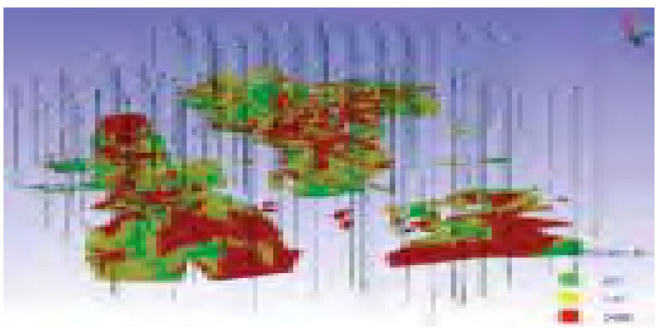

Fig.6 Resource reserves distribution

3.3 Establishment of economic cost database

The economic cost database was established in the light of perennial production management costs and technical indices. Through statistical mining of the data, a time series model was developed to sum up the rules and fitting formula, paving the way to the techno-economic model (Fig.7).

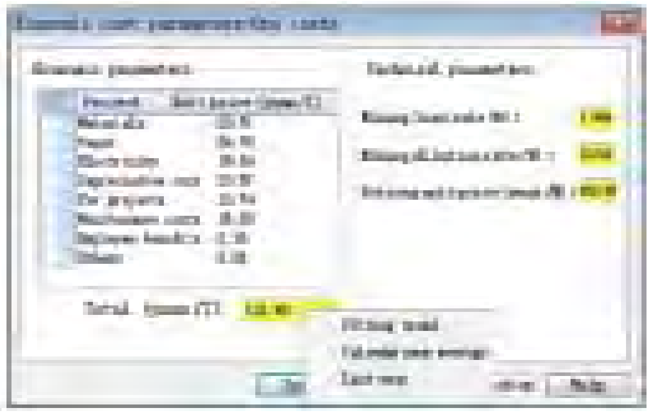

Fig.7 Technoeconomic model of ore costs

3.4 Differential cost

With the excavation of the shaft, the requirements on the boundary grade are gradually relaxed. The total capital input and labour cost increase through the mining phases, such as exploitation, cutting, extraction, etc. On the contrary, the capital input and labour cost of each phase is progressively reduced over time [6].

The mining process was divided into four phases (exploitation, cutting, extraction, dressing and smelting). The differential cost of each phase was specified according to the job content (Fig.8). According to the differential levels of the corresponding production cost, the differential cost was computed, and combined with the market price to derive the breakeven grade at each differential level (Table 2).

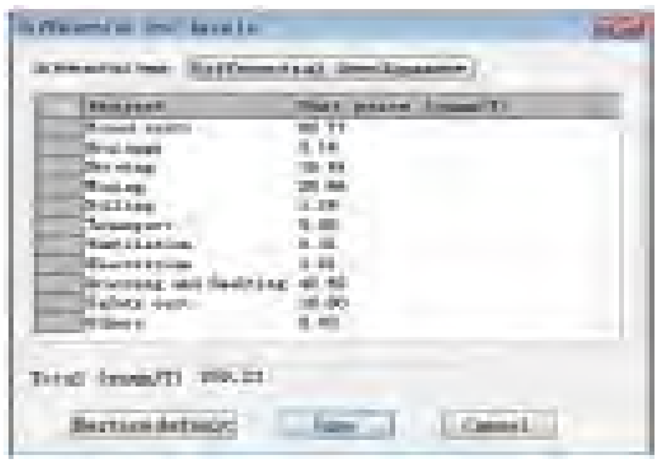

Fig.8 Differential cost

TABLE 2 DIFFERENTIAL STATE CUTOFF GRADE THE PRODUCT PRICE HE00YUAN/GRAM

Category	Cost (yuan/ton)	Cut-off grade ut-off ggr
Exploiting stage	159.24	1.08
Mining and cutting stage	95.39	0.65
Extracting stage	84.98	0.58
Dressing and smelting stage	52.62	0.30
The uper limit of low-grade	1.08	
The lower limit of low-grade	0.58	

The difference in marginal grade of the cutting phase and that in the extraction phase was calculated by the ratio of corresponding investment to the original cost of mining prepration and exploration engineering. The marginal grade of the extraction phase was considered as the economic breakeven grade, after the minerals had been extracted, transported to the surface, and reached the dressing area. Therefore, the utilization value of low grade resources can be mostly recycled in practice. The actual grade is higher than the marginal grade of the extraction phase, and lower than the marginal grade of cutting and exploitation phases. In other words, the marginal grade of the extraction phase is the lower limit of the low-grade resources, and the marginal grade of the exploitation phase is the upper limit [7].

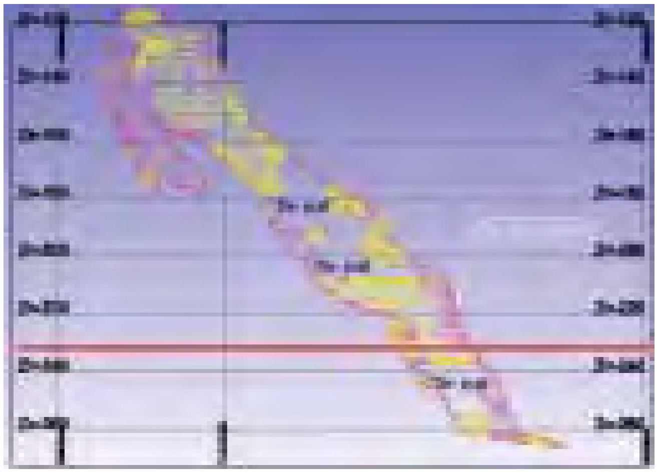

Fig.9 Line 69 of prospecting line profile

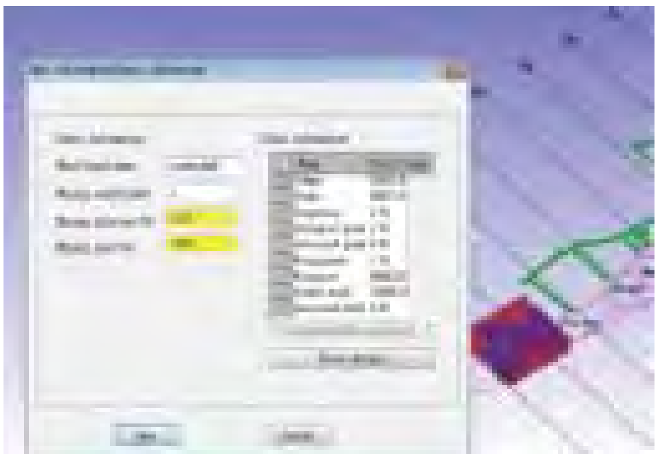

Fig.10 Stope and grade information

3.5 Identification of non-mined areas

First, the mined areas were removed from the block model to leave the non-mined areas. Then, the prospecting line profiles were automatically cut away by the evaluation system. For example, line 69 is illustrated in Fig.9.

From Fig.9, it can be seen that a non-mined area existed above the elevation of -232m. There was also a non-mined area in the red box near line 69 on the -232m elevation plane. The latter can be exploited in future. Using the evaluation system, a 12m high extraction block was created to read the grade information of the reserve model, and automatically estimate the reserve, grade, metal amount and other information (Fig.10).

3.6 Economic evaluation

The evaluation system was implemented in the mining design, aiming to specify the driving, mining, dressing and management costs (Fig.11).

After assigning the detailed cost, the authors analysed the profits of the mining block and obtained a brief block evaluation report (Table 3).

3.7 Ore blending optimization

The economic evalutation results must be considered in the context of the actual production plan. Although the low-grade ore can be mined economically, the grade still falls short of the demand for dressing operations. Therefore, it is better to blend the low-grade ore with high-grade ones. Several extraction stopes were selected for blending. The ore grade was 2.0g/t, and the output was 150,000 tonnes. The grades and ore quantities of the stopes are shown in Fig.12.

The blended results were put according to the blending target. More than one blending plans were provided. To

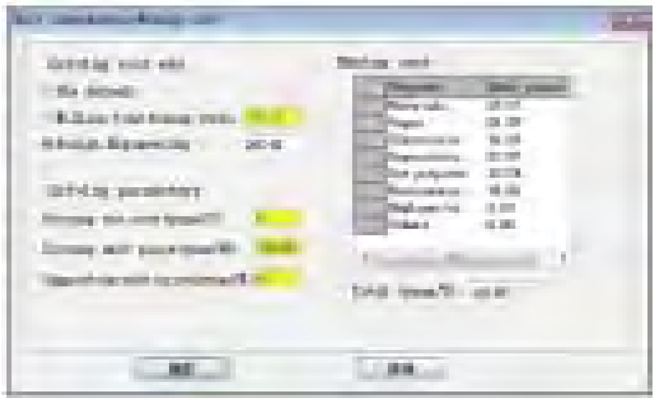

Fig.11 Detailed mining cost

Table 3 Block evaluation report

Ore block	Mined ore (Ten thousand tons)	Mined grade (g/t)	The amount of metal products (kg)	Ore block value (Ten thousand yuan)	The total cost (Ten thousand yuan)	Profit (Ten thousand yuan)	Net profit (Ten thousand yuan)
A stope	6.999	1.611	108.366	2355.885	1466.626	889.259	889.259
Subtotal	6.999	1.611	108.366	2355.885	1466.626	889.259	889.259

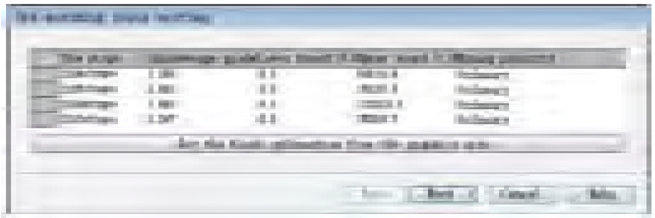

Fig.12 Stope information

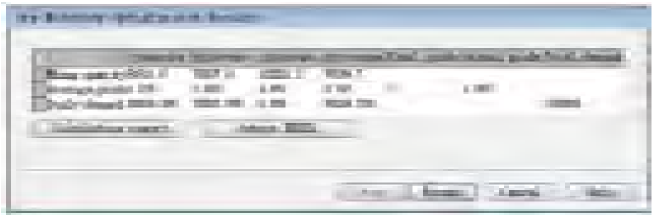

Fig.13 Ore blending results

obtain the desirable result, the corresponding target was added into the model, and the blending results were put through repeated iterations.

4. Conclusions

Following the principle of geological statistics, the evaluation system can quickly capture the features and rules of orebody thickness, grade and 3D distribution. The results reflect the real-time changes in mineralization, space form and grade of orebodies, laying the basis for the dynamical reserve management.

The mining phases were treated by different evaluation methods. The evaluation system can swiftly assess the economic efficiency of mining in the case of price fluctuations. The assessment results are of guiding importance to mining production, efficient resource use, and waste reduction.

The evaluation system has been applied in a number of gold mines. Field application shows that the system is conducive to alleviate the risks in mining low-grade mineral resources, discover mineable ore blocks, and enhance resource utilization.

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