Extraction technology of fine vein gold ores

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Abstract
The article discusses about an effective system development for mining of thin deposits using small-sized self-propelled machines for high efficiency and completeness of mineral extraction.
Furthermore, in this research are given the results of development of fine vein lodes by using sublevel system and high-performance, compact self-propelled machines.
The developed technological scheme of ore extraction and delivery by self-propelled VSD is recommended to use in mining enterprises which develop vein deposits with varying thickness of ore and a wide range of occurrence angles.
Keywords: MINING, ORE, GOLD, PRODUCTION, DEVELOPMENT SYSTEM, DELIVERY, TRANSPORTATION, SELF-PROPELLED MACHINES

1. Introduction

Kazakhstan is one of the largest mining regions in the world. Gold mining has important role in the mining industry of Kazakhstan, however small part of the deposits which are strategic resource of the country is in exploitation.
The research shows that in the most vein-type gold ores of Kazakhstan are about 40-50% of deposits are defined in inclined and steeply inclined deep areas with intense fracturing of the ore and host rocks and variable deposit items.
Vein deposits in Kazakhstan have significant distribution. The majority of ore minerals, such as gold, tin, tungsten and rare metals are in a vein structure [1, 2, 3].

Complex geological conditions of lode occurrence (thickness of ore bodies vary from a few centimetres to 1-2 m or more, the incidence angle from 0 to 90^0, the nature of the mineralization is unseasoned, a lot of tectonic faults, irregular distribution of minerals and so on) caused to derivation of a great variety systems, lode development technologies and their mining difference from other types of ore deposits. The high value of the ores requires reduction of the thickness of the groove and improvement of the quality of the produced vein mass, which is still an important problem. Thus a radically improvement of the systems and mining processes are required for increasing the effectiveness of vein deposits.

One of the main directions of economic development of the Republic of Kazakhstan is the rational management of natural and labour resources [4]. Economic development plan of the Republic of Kazakhstan will provide a dramatic increase of the ore extraction and processing of rare and precious metals, many of them are represented by vein structure. Complex geological conditions of vein structure deposits result in a high laboriousness and low mining intensity. Development of vein deposits are characterized by complex geological conditions: most vein deposits have unseasoned thickness, unstable host rocks and tectonic faults, intermittent mineralization, changeable incidence angle. Thus there are used various mining ways as a result of diversity and complexity of geological conditions.

Impossibility of the use of existing machines and the self-propelled high-performance equipment for the cleaning space with small width cause of slight thickness of ore bodies (1.0-1.5 m) makes laborious and expensive development of this type of deposits [5, 6, 7].

Thus there was a need for intensification of the vein ore mining technological processes by innovative technologies using modern high-performance equipment at all stages of the mining industry.

2. Mining technology of thin lode of mining camp "Akbakai"

Gold deposit "Akbakai" is one of the largest deposits of "Akbakai" ore field and is the basis of the resource base of Akbakai cluster.

In the geological structure of the ore field [8] participate terrigenous sedimentary rocks of Ordovician – the thick of interbedded sandstones, siltstones, conglomerates, grits and volcanic-sedimentary rocks of the Devonian - tuffs, tuff sandstones. Cainozoic sediments are represented by clays, loams, takyr-saline and eluvial-diluvial formations. Intrusive bodies are presented bygranitoid and gabbrodiobretic complexes of Devonian age. Post-Devoniansub volcanic and dike complexes are represented by small bodies of quartz porphyry, granite porphyry dikes and granodiorite, diorite and diabase porphyry, lamprophyre.

"Akbakai" refers [8] to the fields of gold-quartz-sulphide formation.

Main composition of the ore veins are quartz and secondary compositionsare non-metallic minerals which are calcite, sericite, and chlorite.

Pyrite and arsenopyrite are dominated among the minerals (up more than 75% of the sulphides in the ore bodies). Other ore minerals are chalcopyrite, sphalerite, galena, antimonite, gray ores, and marcasite. The amount of sulphides decreases depending on depth (from 7-10% in the upper levels to 1.5-5.0% in the lower levels, mainly due to the reduction in the number of arsenopyrite).

According to the degree of distribution and weight there are 4 groups of minerals and elements:

- Pyrite, arsenopyrite - first percent;
- Gray ores - tenths of a percent;
- Chalcopyrite, galena, sphalerite, stibnite, marcasite - hundredths of a percent;
- Gold, silver, bismuth - thousandths of a percent.

The main valuable ore components are gold and silver. The main part of the gold (80-85%) is in a free form; remaining part is in finely divided form and contained in sulfides (mainly arsenopyrite). The finely divided form of minerals is more suitable for steeply dipping veins (17-18%) than for shallow lode (5-6%). The size of 50-70% of free gold particles is about 0.1 to 1.0 mm. The gold form is lamellar and isometric.

The ore was mined from the end of sublevel drift in receding order. The 2.6 m² supporting pillars are left inside the block to provide the necessary stability of the cleaning space roof. In the top sub-stage is left sub-drift pillar with thickness up to 3.0 m, in order to maintain the upper-vent and haulage drifts of horizon 370 m.

Between haulage drift of horizon 310 m and the last lower sublevel drifts are left pillars with thickness of 5 m, which are worked out after horizon mining.

Scraper winches type 17 LC-2s and 30LC-2s were used for transportation in production areas. The deflecting and snatch blocks type BL-300 were set up.

Further, the rock mass unloaded to the central ore pass, through which the ore was loaded on a trolley type UVB-2.5 m3 and stood out to the surface.

After drilling and blasting works about 50% of broken ore is remained in the block and it is not reached to scrape sublevel drift due to the shallowness of the incidence angle of the ore body. The delivery of the broken ore to scraper drift is intractable. Therefore, the exploded ore is delivered mechanically by using scraper winches.

In 2011, the company's management decided to reconstruct the factory to increase the productivity up to 1 million tons. Thus it has been tasked to increase the productivity of the mines to supply factories. However previous mining system was not satisfied to the new criterion because of low productivity and laboriousness. Thus there was a need to intensification the vein ore mining technological processes by innovative technologies using modern high-performance equipment at all stages of the mining industry.

Consequently a new mining system of the thin flat dipping ore deposits of the mine camp "Akbakai" has been developed and implemented by using high-performance, compact self-propelled machines.

3. The developed mining technology using small-sized self-propelled machines

Ore bodies of the Akbakai industrial area are represented by thin quartz veins [8, 9, 16], located in the resistant host rocks and only at the conjugations of inclined and dipping areas can be observed weakened zones. The stability of rocks and ores in these areas is average.

The vein thickness of Akbakai deposits is low and ranges from 0.5 m to 3.0 m. The average thickness is about 1.7 m.

In the corners of falling the vein can be divided into two groups:

- Steeply dipping with 55^0-85^0 incidence angles;
- Inclined with 25^0-55^0 incidence angles.

The steeply dipping veins are "Glavnaya", "Frolovskaya" and "Yuzhnaya", which operating reserves are up 40%;

The inclined veins are "Glubinnaya", "Pologaya -1", "Yubeleinaya" and "Pologaya -6", which reserves are 60%.

The "sublevel chamber system with layered ore mining by deep wells and delivery by explosion force" was established for mining of inclined veins (Figure 1). This system provides mining of 2 types of veins in the corners of the fall:

- Inclined up to 35 °;
- Inclined from 35 to 50 °;

The thin vein thickness is from 1.51 m to 1.92 m.

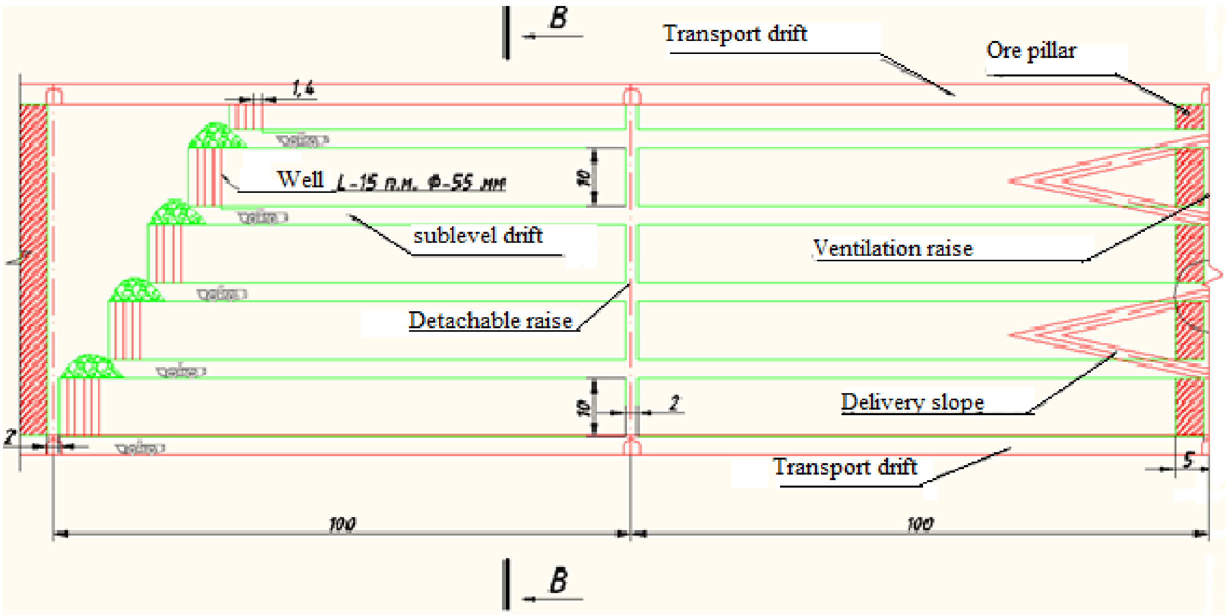
The system is provided to mine the following veins:

- "Yubileynaya" with the incidence angle - 40 ° -55 °, and an average thickness -1.51m;
- "Glubinnaya" with the incidence angle - 35 ° - 55 °, and an average thickness -1,61m;
- "Pologaya -1" with the incidence angle - 45 ° -50 °, and an average thickness -1,92m;
- " Pologaya -6" with the incidence angle - 30 ° -35 °, and an average thickness -1,74m.

On this system the veins are divided into the groups depending on following parameters:

- The length of the block along vein strike - 100m;
- The height of the block along the strike of the ore fall with breaking into sub-stages - (camera) L - 10,0 m.

The block development is carried out from the centre to the flanks of veins, and the cameras development is carried out on uprising, in descending order.



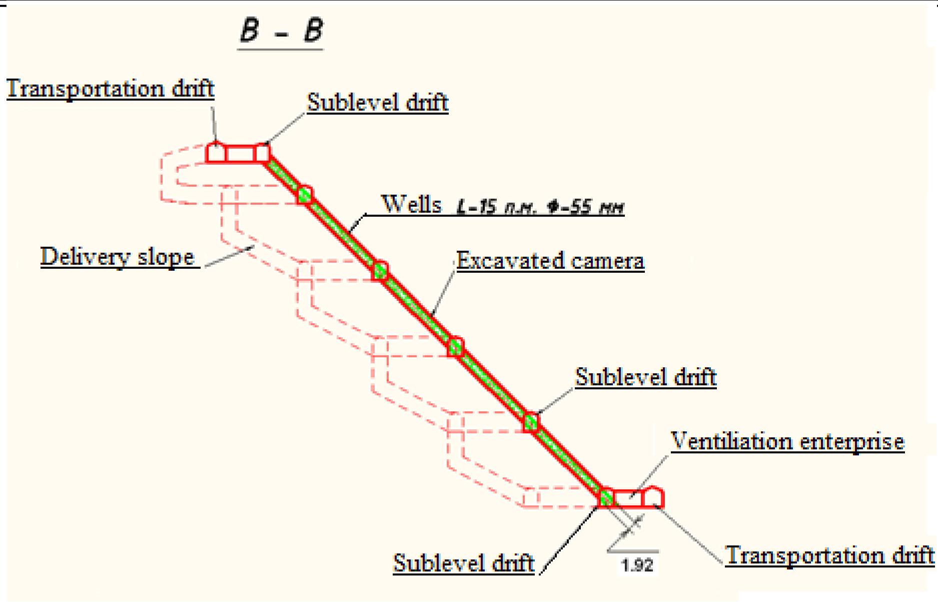


Figure 1. The developed mining system of the vein with an incidence angle 30^0- 55^0

The preparatory works of the excavation block consist of mining of transport drift, undercutting the exploration drift (sublevel drift) which traversed on vein at the level of the horizon for refining the contour of the ore body within the boundaries of the block (Figure 2). The winch niche is passed through the hanging wall of the exploration drift sweeps for mining the inclined cutting raise by using scraper winch 30LC-2CM and scraping 0.25-0.3 m^3. Cutting raise extends to the overlying sub-stage every 50 m. The width of raise increases to thickness of the chamber and serves as a compensation space (cough) for working out and transporting ore from sublevel drifts. The distance between the sublevel drifts (roof-soil) is 8-10 m. These excavations are worked out from the block slope that extends at an angle of 10^0 every 200 m along the vein. In this, the preparatory works are finished [8, 9, 13, 14, 15].

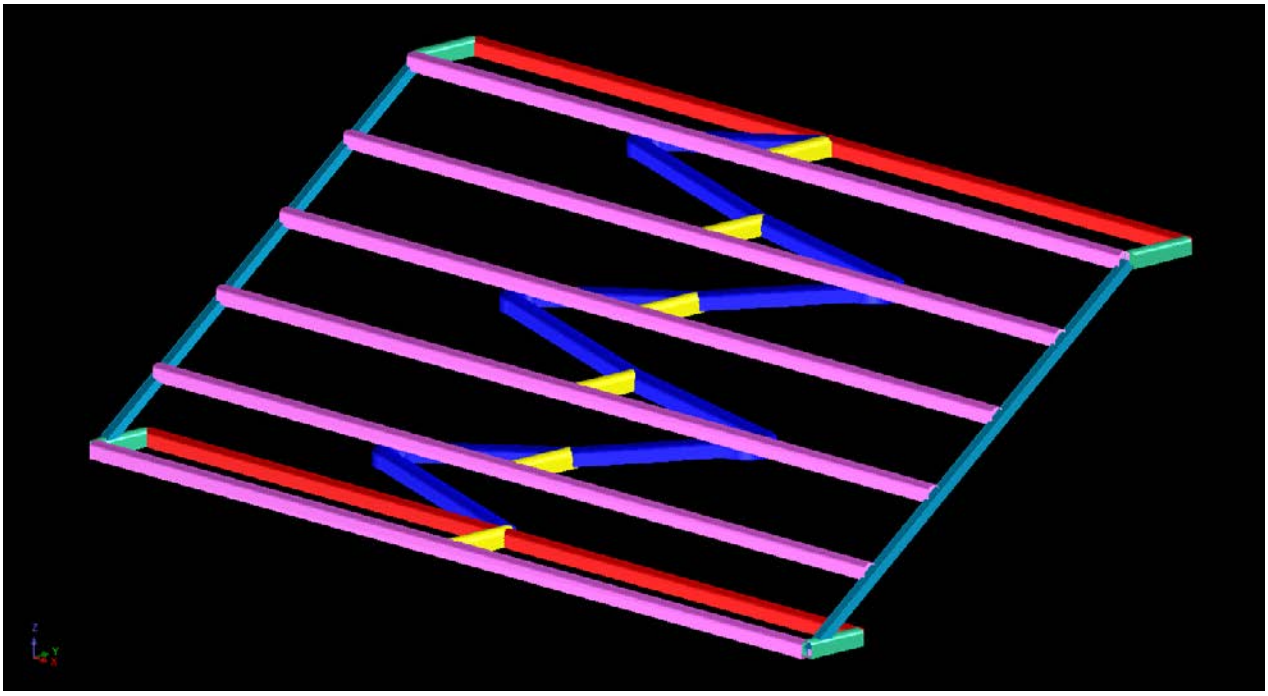


Figure 2. The extraction of block by inclined races and preparation by sub level-method

According to technical and economical basis for the mining of "Akbakai" deposit was offered the option of inclined transport unit (ITU) at an angle of $\alpha = 10^0$ from eastern flank, with the use of underground self-propelled equipment (SPE) and shaft deepening of "Glavnaya" and RESH-1 to horizon -104 m (580).

The worked out rock mass and ore will be produced by the combined method - through the elevator in the shaft of the "Glavnaya", RESH-1 and dump truck through the ITU-1 and ITU-2.

The rock mass of the central part of the deposit which is above of horizon + 296 m (180) will be transported through the ITU-1 dump trunk. The rock mass of the eastern flank of the deposit which is above horizon +136 m (340) will be transported through the ITU-2 dump trunk. Thus, the capacity of the ITU-2 is going to be 200 thousand tons per year. The remaining 300 thousand tons ore is going to be transported through the shaft "Glavnaya" and RESH-1.

The use of SPE for drilling and transportation of rocks significantly reduce the cost and increase productivity. Furthermore, it can reduce the period of construction and operation of the mine by increasing the speed of tunnel works.

4. The technical and economical effectiveness of the developed system by using self-propelled machines

The comparative technical and economic substantiationof the use of the sublevel chamber development system by using self-propelled machines is done as a result of research.

Comparison of the two mining options of the excavation block "Glubinnaya" of the mine camp "Akbakai" was made.

The main technical and economic indicators of mining blocks in two variants are shown in Table 1.

Table 1. Main parameters of block excavation by 2 options

Name	Measurement unit	In block mining		Comparison of the options in %
		Sublevel camera system using the SCE (mechanically)	Sublevel drifts development system (manual method)	
		Option1	Option 2	
1	2	3	4	5
Balance reserves of the block				
	ton	126235,2	15759,68	
	Au, g/t	5	5	
	metal, kg	631,176	78,798	
The height of the block along the fall	m	85	85	
The height of chamber along the strike	m	67		
The block width	m	400	47	
The average incidence angle of ore	degree	45	45	
The average thickness of ore	m	1,445	1,445	
Shipment ore				
	ton	174589,7	15392,673	
	Au, g/t	3,43	3,977	
	metal, kg	599,617	61,227	
including from the cleaning works	ton	127419,2	11467,95	
	Au, g/t	3,83	3,925	
	metal, kg	488,058	45,015	
from preparatory and rifled work	ton	47116,1	3924,709	
	Au, g/t	2,879	4,13	
	metal, kg	135,844	16,211	
Dilution				
	%	28,53	20,45	139,51%
	ton	49809,1	3147,26	

Name	Measurement unit	In block mining		Comparison of the options in %
		Sublevel camera system using the SCE (mechanically)	Sublevel drifts development system (manual method)	
		Option1	Option 2	
1	2	3	4	5
including from the cleaning works	%	23,4	21,49	
	ton	29807,5	2464,83	
in preparatory and rifled work	%	42,4	17,38	
	ton	20001,6	682,43	
Loss	%			
	%	5	22,3	22,42%
	ton	6311,76	3514,27	
	kg	31,558	17,571	
Preparatory works				
	linear metre		183	
	m^3	9243	700,4	
Rifled works				
	linear metre	2272	312	
	m^3	17088	780	
Cleaning works				
	linear metre			
	м^3	46795	4210,751	
Total rock mass				
	linear metre			
	m^3	73126	5691,15	
Mining rifled works/ cleaning works	m^3/thousand ton	52,9	45,5	
Mining preparation works/ cleaning works	m^3/thousand ton	97,9	50,67	
The time spent on block mining including ODA PLR OR (down time is not taken into account)				
	Days	304	322	
The average daily productivity per block				
	t per day	574,13	47,773	
	Kg Au per day	1,972	0,19	
Ore mining prime cost including	**$/t**	**40,4**	**52,23**	**77,35%**
		365,763	**492,094**	**74,327%**
Personnel costs	$/t	2,1	10,1	20,79%
Main and additional materials cost	$/t	19,2	21,2	90,57%
PPEandtoolscost	$/t	0,9	1,1	81,82%
ServicecostsofSCE	$/t	1,5	1,23	121,95%
Costs for fuel and tires	$/t	6,7	5,0	134,00%
Amortization costs	$/t	6,0	4,98	120,48%

Name	Measurement unit	In block mining		Comparison of the options in %
		Sublevel camera system using the SCE (mechanically)	Sublevel drifts development system (manual method)	
		Option1	Option 2	
1	2	3	4	5
Cost of general mining	$/t	4,08	8,38	48,68%
Profits from processing the mined ore at a cost $ 1300oz., prime cost of processing $ 14 and removing 70% gross income - (production costs + processing costs)				
	$	8 048 388	588 076	1368,6%

The table 1 shows that the dilution of the 1st variant is more for 39,51% than the 2nd variant, while the loss of the 1st variant is less for 77,58% than the second variant.

The average daily ore mining productivity of the first and second variants including whole cycle are 574.13 tons per day or 1,972 kg of gold per day and 47.77 tons per day or 0.19 kg of gold per day respectively.

The production costs of ore were $ 40.4 per ton for the first variant against $ 52.23 per ton for the second variant. In terms of an ounce, they are $ 365.763 oz. and $ 492.094 oz. respectively.
Based on the above mentioned calculations can be concluded that the vein mining with an incidence angle of 30^0-55^0 is should be done by sublevel camera system with layered mining by deep wells. Currently gold mine "Akbakai" is mined by our developed technology (Figure 3). The annual output of the mine has tripled, with 220-250 thousand tons up to 600-650 thousand tons due to the implementation of the new development systems and full mechanization of mining operations in thin vein deposits mining conditions from 2011 to 2014.

The delivery of worked out rock mass to the ore pass is done by machine with a further issuance of ore and rock through the inclined transport unit.

Preparation of stocks carried by ore drifts andraise. Crosscuts and roundabout excavations are located on the rock. The ore warehousing is in the ore stockpile of the crushing mill complex.
The ore losses in blocks consist of pillars which left to save the vertical and horizontal workings. Some losses are formed from interblock pillars, upper- drift pillars and intra-block supporting pillars [16].

Figure 3. The current state of delivery and transportation of the ore deposit "Akbakai"

Conclusion

The research shows that the development of new innovative technologies with new technics which provides high completeness of mineral extraction, ensuring high stability of extracted rock mass quality, increase productivity and safety of mining operations is necessary for increasing the productivity of the gold mining enterprises.

The inclined vein deposit mining systems and technologies using high productive equipment and deep well with small diameter allow mining the vein in variable geological and morphological conditions of deposit.

Sublevel development system of inclined vein deposits using high-performance equipment and deep wells with small diameter can be effectively used in a sudden change of thickness, incidence angle and strength of the rocks - along strike, raiseand fall veins.

The dependence pattern of the technical and economic performance of the VSD from the lumpiness of the worked out ore and loading and unloading time of the machine are identified. It allows finding rational schemes and calculating the delivery distance of the ore.

It is found that when choosing the rational self-propelled VSD must be strived to achieve a rational productivity of VSD on conditions of merchantability and completeness of their potential abilities.

The economic and practical effectiveness of the proposed technology are based on scientific and experimental substantiation of rational parameters of sublevel-chamber system development with the delivery of ore by explosion force with the use of a small-size and other high-performance equipment, and deep wells of small diameter in all kinds of processes and works in blocks.

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