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THE SELECTION OF OPTIMAL CONTOUR OF OPEN PIT "DELICI" NEAR UGLJEVIK

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ABSTRACT

In this article are presented the procedures and the results of open pit optimal contour "Delici" choice near Ugljevik, Republic of Srpska. By using of LG 3D algorithm for optimization in the Whittle Four-X^{TM} is determined a series of open pit shales based on the various income factors (Revenue factor) with iteration of 0.03 of change in coal prices according to the base price of 2.2 €/GJ. For each contour were calculated the cash flows, and the optimal contour of open pit was determined based on the maximum value of NPV (net present value). The access ramps, transport roads, geometric elements of benches, final slopes and calculations of the exploitation coal reserves were done inside of the optimal open pit contour. After determing of optimal open pit contour it was defined the mine plan, dynamics of exploitation and choice of waste disposal location.

Keywords: *optimization, NPV (net present value), open pit contour, waste disposal.*

INTRODUCTION

Determination of the optimal pit contour presents the key in the planning and mine design, because it allows the basic informations for evaluation of economic potential of ore deposit and have influence to long-term, medium-term and short-term plans and dinamics of production. The final contour defines the size and the shape of pit, the mine life based on technical, economic and geotechnical limitation and exploitation ore reserves with a certain overburden quantity which is necessary to remove [1,2].

The initial step in mine design was definition of the input parameters for pit optimization by using of Whittle™ Lerchs Grossman optimizer [3]. The mine boundaries were determined by combination of the profit values of coal production and the exploitation cost values on overburden transportation and disposal and coal exploitation, crushing and transport. The created stratigraphic models and models of coal quality are the basic for evaluation of volume of the blocks on whole deposit area. By application of the modifying factors and quality evaluation, all blocks were defined with the data on the expected total incomes and the exploitation costs.

WHITTLE OPTIMIZATION PARAMETERS

In Table 1 are shown the the important input parameters for Whittle™ optimization which are necessary for determination of the greatest economic effects or boundary contour of open pit. The several iterations of optimization were performed based on the various prices of coal.

Table 1 Whittle™ optimization parameters

Parameter	Unit	Value
Modifying factors:		
Roof and floor losses	m	0.1
Roof and floor dilution	m	0.05
Minimum mineable coal thickness	m	0.5
Mining Costs:		
Waste	€/m³ h m	3
Coal	€/t	1.5
Coal crushing and transport	€/t	0.5
Coal sale price: TE (fr. Waste dump)	€/GJ	2.2
Pit slopes:		
E&W – Slopes	degree	25
N&S – Slopes		20
Optimization method: DCF -discount rate	%	10

PIT OPTIMIZATION PROCEDURE

By using of the Whittle Four-X™ algorithms for optimization (LG 3D), a series of the open pit contours determined on the base of the variuos income factors (Revenue factors) with the iterative step 0.03 of change in coal prices in relation to the base price of 2.2 €/GJ [1]. Each generated contour represents the incremental increase of the reserve volumes to the incremental increase of coal sale price. Optimization is based on calculation of the net income values, respectively, on the incomes of coal selling minus total operating costs, as follow:

NPV = Coal tonage utilization (%) x Coal quality (GJ) x Selling price (€/GJ)
COST = Pit costs + Plant costs + Transportation costs

Optimal pit contour is determined on the basis of maximum value of NPV (net present value), which inludes the time factors of money values in definition of blocks which should be excavated and which should be left for duration of project life.

- Whittle Four-X™ economic analysis generates the three different types of cash flow [1,4] :
- Undiscounted operating cash flow,
- The best discounted cash flow - Any incremental open pit contour excavates before moving to the next incremental pit contour, and
- The worst discounted cash flow - Any bench excavates before moving to the next lower bench by using of block height optimization as the default height of bench.

OPTIMIZATION RESULTS

Analysis of discounted cash flows is used with the aim of determination of the optimal pit contour. After detailed consideration of possible production coal price, it was decided that for this analysis can to adopt a base selling coal price of 2.2 €/GJ. In optimization procedure the base rate was varied in the range of revenue factor of 0.5 to 2.0 and according that were designed a number of the potential contours of open pit [1,4]. The quantities of overburden and coal were determined for each open pit contour with operating cash flow discounted to 10%. For each open pit contour the three values of NPV were calculated: scenario of the best NPV (discounted and with no discounting), which assumes that the each inside contour was excavated in sequence one after the other, and scenario of the worst NPV, which assumes that each bench was separately excavated for a given open pit contour.

Table 2 [1,4] shows the cash flows for each open pit contour with a certain quantities of coal and overburden, while in Figure 1 is shown the resulting graph with optimization parameters, which is formed on the basis of annual open pit production of 2.0 milion tons of coal.

Table 2. The economic and technical aspects of optimization

Pit	The best discounted cashflow, €	The worst dicounted cashflow., €	The best cashflow no discounted, €	Coal, t	Overburden, t	Strip Ratio t/t	DTE MJ/t	Lifetime of mine, year
1	109.312.001	109.312.001	122.957.809	6.235.210	32.587.286	5.23	10,947	1,6
2	116.613.088	116.321.062	132.331.103	6.853.684	38.433.671	5.61	11,007	1,7
3	125.699.047	124.732.119	144.478.158	7.685.375	46.973.400	6.11	11,098	1,9
4	130.942.663	129.624.891	151.409.936	8.239.538	52.490.704	6.37	11,085	2,1
5	135.870.872	133.182.411	157.555.342	8.777.523	58.052.772	6.61	11,063	2,2
6	137.643.083	134.096.940	159.799.904	8.959.665	60.375.989	6.74	11,090	2,2
7	139.584.360	135.515.441	162.304.216	9.219.344	63.349.033	6.87	11,078	2,3
8	143.279.285	137.882.201	167.226.792	9.787.421	70.428.895	7.2	11,066	2,4
9	145.676.962	139.177.887	170.564.868	10.138.457	75.843.443	7.48	11,127	2,5
10	150.885.331	141.530.980	178.311.227	11.136.349	90.454.813	8.12	11,183	2,8
11	151.760.527	142.147.927	179.635.291	11.321.035	93.352.003	8.25	11,198	2,8
12	153.265.777	142.959.082	181.684.529	11.699.111	98.780.867	8.44	11,183	2,9
13	158.140.437	138.126.478	188.835.314	13.072.617	123.033.982	9.41	11,319	3,3
14	159.022.111	138.145.982	190.261.760	13.423.010	129.216.174	9.63	11,338	3,4
15	159.647.979	136.243.271	191.339.726	13.803.343	135.367.750	9.81	11,322	3,5
16	160.048.722	135.178.836	192.004.592	14.206.204	142.722.171	10.05	11,327	3,6
17	160.709.445	130.091.092	193.281.646	15.245.239	162.303.552	10.65	11,350	3,8
18	160.333.800	121.036.893	193.697.850	16.968.967	195.654.016	11.53	11,373	4,2
19	159.876.627	115.938.609	193.353.997	17.492.302	206.139.224	11.78	11,381	4,4
20	159.816.196	115.578.026	193.284.912	17.536.916	206.996.592	11.8	11,380	4,4
21	154.103.575	84.380.848	186.316.885	20.594.834	271.236.036	13.17	11,407	5,1
22	153.623.885	81.658.943	185.555.346	20.816.121	276.092.921	13.26	11,410	5,2
23	150.896.725	70.759.212	181.131.654	21.793.107	297.516.965	13.65	11,403	5,4
24	150.598.897	69.768.177	180.667.903	21.881.016	299.547.021	13.69	11,404	5,5
25	148.465.322	59.638.172	176.259.210	22.605.456	316.135.154	13.98	11,397	5,7
26	146.472.639	51.619.897	171.663.992	23.247.246	331.387.043	14.25	11,394	5,8
27	145.217.306	45.786.277	168.608.920	23.635.390	340.821.296	14.42	11,393	5,9
28	144.536.530	42.538.175	166.953.388	23.839.214	345.542.371	14.49	11,386	6,0
29	144.469.660	42.262.406	166.795.997	23.855.052	345.952.134	14.5	11,387	6,0
30	142.151.648	35.606.013	161.214.835	24.390.702	359.480.838	14.74	11,376	6,1
31	140.308.828	28.666.568	156.535.622	24.782.549	370.009.100	14.93	11,374	6,2
32	140.292.474	28.597.677	156.493.170	24.785.975	370.099.225	14.93	11,374	6,2
33	140.225.246	28.340.347	156.318.703	24.798.967	370.457.803	14.94	11,374	6,2
34	138.912.301	23.782.647	152.857.982	25.053.729	377.365.646	15.06	11,368	6,3
35	56.132.976	-169.229.651	-66.026.179	39.261.734	788.646.105	20.09	11,277	9,8
36	55.090.033	-174.337.279	-72.982.315	39.669.198	799.848.262	20.16	11,275	9,9
37	55.071.240	-174.404.117	-73.109.491	39.676.003	800.063.729	20.16	11,275	9,9
38	53.733.511	-178.595.693	-82.226.196	40.216.874	815.321.936	20.27	11,260	10,1
39	53.684.290	-178.893.831	-82.566.694	40.236.226	815.875.287	20.28	11,260	10,1
40	53.677.318	-178.929.109	-82.614.879	40.239.063	815.951.496	20.28	11,260	10,1
41	53.655.161	-178.991.646	-82.769.296	40.246.490	816.191.018	20.28	11,260	10,1
42	53.393.468	-180.085.918	-84.563.441	40.327.462	818.888.911	20.3	11,259	10,1
43	53.344.279	-180.327.956	-84.887.711	40.341.306	819.361.628	20.31	11,259	10,1
44	53.331.522	-180.388.848	-84.971.972	40.345.299	819.483.220	20.31	11,259	10,1
45	53.318.127	-180.453.845	-85.060.728	40.348.708	819.608.218	20.31	11,259	10,1
46	53.299.710	-180.542.977	-85.183.038	40.352.696	819.777.889	20.31	11,259	10,1
47	52.862.361	-182.311.751	-88.116.943	40.456.341	823.782.046	20.36	11,260	10,1
48	49.943.569	-190.863.422	-110.406.383	41.298.222	853.367.022	20.66	11,244	10,3
49	49.929.799	-190.927.497	-110.519.852	41.302.236	853.516.532	20.66	11,244	10,3
50	49.896.11	-191.127.705	-110.797.560	41.310.730	853.878.323	20.67	11,244	10,3

Optimal open pit is that one that generates the highest cash flows using the defined input parameters. The maximum profit is realized for pit no. 17. Also, the chart indicates that cash flow becomes almost equal for the pit contours no. 13 to 20 indicating that these pits have a relatively consistent strip ratio, which maintains the cash flows a relative constant. With increasing of income factor, after excavation of pit no. 20, the amount of overburden gradually increasesand reduces income to contour of open pit no. 34. After that, the next pit no. 35 has a sudden jump in the increase of the total amount of overburden, which generates the higher exploitation costs and the lower incomes.

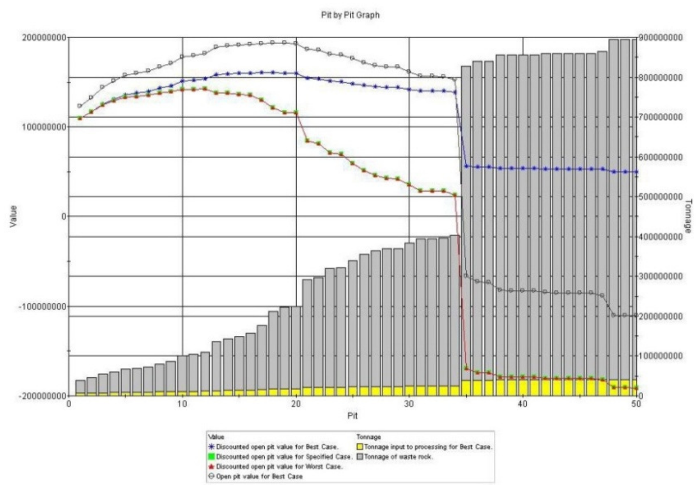

Figure 1 Summary of cashflows for pit shells

Figure 2 shows 3D interpretation of Whittle contour of pit no. 34. By these illustration, in fact can be seen that was formed the two open pits in the syncline zones of deposit.

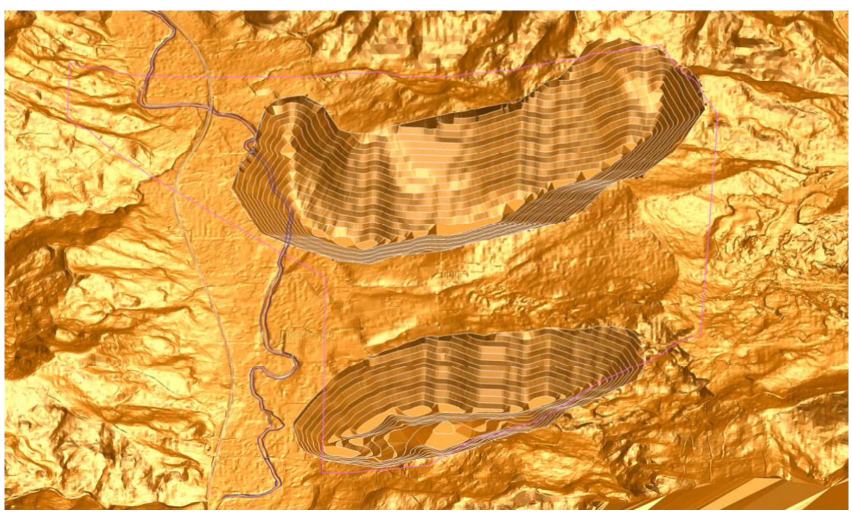

Figure 2. Whittle pit shell no. 34

DETAILED PIT DESIGN AND COAL RESERVES

Optimal open pit contour determined by Lerchs-Grossmann algorithm (pit no. 34) was used as guideline for the detailed design of the final contour of open pit "Delici".

The process of determining the final contour of open pit involves the access ramps to the bottom of the pit by using the geotechnical recommendations for geometry of the benches. At the end of this process the final contour was dimensioned according to the follow criteria [1,4]:

- pit construction on the west side is maximum possible follows the optimal contour due to the regional road Ugljevik- Tuzla
- minimize the ramps on the final contour in the northwest of mine
- locating the ramps in the southern final contour of North pit and north of the South pit to reduce the excavation costs of overburden and coal
- dimensione the berms, the final pit slope and angle of working slope according to the new data verification of the geo-mechanical parameters of the rocks

The geometric elements of the benches [1,4] are given in Table 3.

Table 3. The geometric elements of the benches

Open pit parameter	Delici - North		Delici - South	
	Unit	Value	Unit	Value
Bench height	m	10	m	10
Bench width	m	20	m	20
Bench face angle	degree	55	degree	55
Ramp width	m	25	m	25
Ramp grade	degree	8	degree	8
Pit slopes:				
East	degree	25	degree	22
West		20		25
North		22		23
South		24		25

The transporting roads are designed with maximum longitudinal slope of 8%, with the exception of the temporary ramps due to exploitation on the short distances that can be with maximum slope of 10%. The road was in zig-zag form so transport goes to the South final slope (north open pit), and the northern final slope of open pit (south open pit).

Ramp width is determined on the base of maximum assumed width of trucks that will be used on the open pit. For bidirectional transport, transporting width of road should be at least 3.5 time greater than the width of the largest vehicles. According that, the adopted road width is 25 m. The temporary ramps will be used in the initial working life of mine in order to shorten the transport distances to the crusher plant of coal or waste dump area. As depth of open pit increases with the time, the ramps will be developed in the final open pit slope to access of coal located on the lower exploitation levels.

All calculations of slope stability were done by methods of limit equilibrium for the predisposed sliding planes based on the presented data in the Study of the classification, categorization and calculation of the coal reserves in deposit "Delici" [5,6,7,8,9], available data from the other coal deposits in Ugljevik basin and data from references. Calculation of final slope stability is carried out on the profiles with position shown in Figure 3 [1].

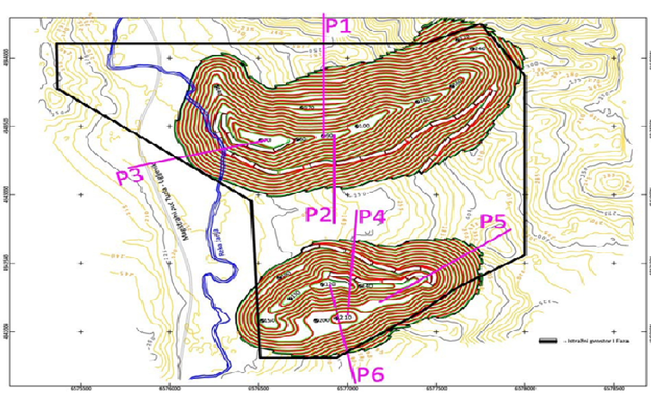

Figure 3 Position of profiles for final slope stability calculation at open pit "Delici"

In Table 4 are shown data of the final slope angles for open pit "Delici-North" and "Delici-South".

Table 4 Recapitulation offinal slope angles of the open pits

Open pit parameter	Delici - North		Delici - South	
	Unit	Value	Unit	Value
Final slope angle				
East	degree	25	degree	22
West		20		25
North		22		23
South		24		25

The final pit design is determined by an iterative procedure in accordance with dynamics of exploitation and overburden disposal at some waste dump area. The main aim of the iterative procedure was that as soon as possible create the conditions for overburden disposal within the open pits. In Table 5 are shown the final parameters of the open pits.

Table 5 Summary of pit design parameters

Open pit parameter	Delici - North		Delici- South	
	Unit	Value	Unit	Value
Bench height	m	10	m	10
Bench face angle	degree	55	degree	55
Ramp width	m	25	m	25
Ramp grade	degree	8	degree	8
Bottom of the pit	*m a.s.l	70	m a.s.l	220
Terrain	m a.s.l	310-330	m a.s.l	350
Open pit width (east-west)	m	2135	m	1450
Open pit length (north-south)	m	1130	m	850

* m above sea level

MINE PRODUCTION SCHEDULING

Plan of exploiatation dynamics is based on the coal and overburden reserves exploitation in the final pit contour. The exploiatation is planned on the annual level by determining of the coal and overburden quantities on the individual phases which need to be excavated.

Development of the mining operations is based on the following criteria[1,4]:

- working life of mine is 14 year,
- excavation of approximately $15x10^6$ t of investment overburden in 1^{th} year.
- the annual amount of coal which transported from open pit is $0.5x10^6$ t in 1^{th} year, $2x10^6$ t in the period of 2-12 year, and
- $1x10^6$ t in the last year of working life of mine.

In Table 6 are shown the planning results of long-term dynamics of exploiatation. In Table is shown that strip ratio (m^3/t) is in range of 7-7.5 of 2-9 year, and after that begin to decrease. The lowest value of 5.25 (m^3/t) achieves in the last year of exploitation.

Table 6 Detailed plan of coal and overburden exploitation per years

Year	Coal (t)		Overburden(t)		Waste dump site (m^3)			Strip ratio
	Delici North	Delici South	Delici North	Delici South	East disposal	Delici South	Delici North	m^3/t
-1		-	-	15.000.000	9.375.000	-	-	-
1	300.000	200.000	5.000.000	10.000.000	9.375.000	-	-	15.00
2		2.000.000	-	28.000.000	17.500.000	-	-	7.00
3	400.000	1.600.000	14.900.000	13.600.000	17.812.500	-	-	7.13
4	700.000	1.300.000	18.800.000	9.700.000	17.812.500	-	-	7.13

5	1.100.000	900	24.200.000	4.800.000	18.125.000	-	-	7.25
6	1.300.000	700	27.000.000	2.000.000	17.000.000	1.250.000	-	7.25
7	2.000.000	-	29.000.000	-	-	18.125.000	-	7.25
8	2.000.000	-	30.000.000	-	-	18.750.000	-	7.50
9	2.000.000	-	30.000.000	-	-	18.750.000	-	7.50
10	2.000.000	-	27.000.000	-	11.675.000	5.200.000	-	6.75
11	2.000.000	-	24.000.000	-	15.000.000	-	-	6.00
12	2.000.000	-	24.000.000	-	15.000.000	-	-	6.00
13	1.000.000	-	10.500.000	-			6.562.500	5.25
∑	16.800.000	6.700.000	264.400.000	83.100.000	155.112.500	62.075.000	6.562.500	
∑∑	23.500.000		347.500.000		217.187.500			7.40

On Figure 4 is given a graphical representation of the basic dynamics parameters of exploitation.

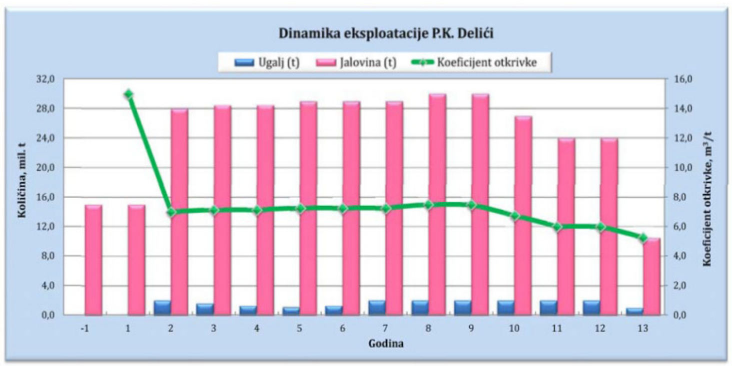

Figure 4 Annual material movement graph

WASTE DUMP DESIGN

In the Figure 5 are shown the three location of overburden disposal from the open pits "Delici-North" and "Delici-South".

Outside East Dump – On this waste dump overburden is dump until that disposed to the internal waste dump area "Delici-North" and "Delici-South" (of 1- 6 year and of 10-12 years).

Inside dump "Delici South" – After exploitation on open pit "Delici-South" the overburden disposal on this waste dump area and continue until the empty area of open pit not filled (of 7-10 years)
Inside dump "Delici North" – Overburden is disposed to this waste dump after disposal overburden to the inside waste dump area on open pit "Delici-North" (the last 13th year).

Figure 5 shows the layout of waste dump at the end of the mining operations, the state of mining operations at the end of exploiatation on Open pit "Delici" [1,4]. Capacity of waste dump area is calculated with bulk modulus of 1.25. Waste dump is constructed that can to accept the all overburden materials in period of open pit working life of the "Delici-North" and "Delici-South".

Waste dump will be constructed with benches 10 m height and and benches level about 52 m width, and final berm with the final slope angle of 8° -9°. The basis of overburden disposal is located on 235 m above sea level and disposal on the eastern side reaches 370 m above sea level height, while the height of the western part of eastern disposal is 330 m above sea level.

Table 6 shows the dynamics of overburden disposal from the open pits "Delici-North" and "Delici-South" per years and dumps. Table shows that total amount of overburden is 173.750.000 m^3 hard masses. The evaluated bulk modulus for overburden is 25%, and total volume of disposed overburden is 217.187.500 m^3. This volume is less then total designed capacity of waste dump area, which provides the enough storage space for disposal of the total amounts of overburden.

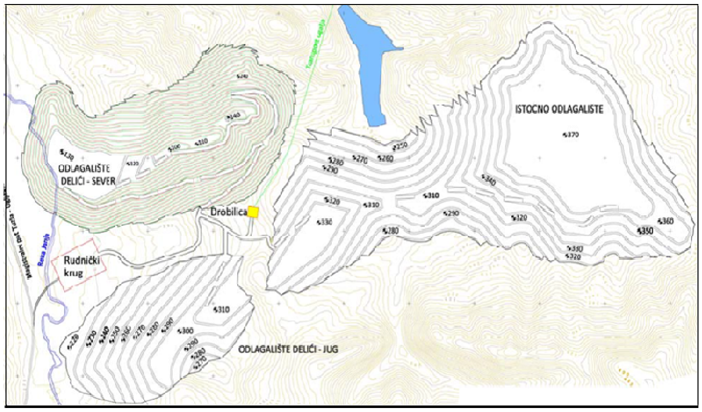

Figure 5 Waste dump area on the open pits "Delici-North" and "Delici-South"

CONCLUSION

The existing methods gives the results that ensure a successful exploiatation but a large number of factors have the in fluence to optimization and mine planning. Because that, it is necessary to the further a scientific examination of the in fluential parameters dependence. Optimization and long-term planning of coal deposit "Delici", was made with modern and current the most reliable methods and achieved the very good results. With development of mining operation it is necessary a constant monitoring and studing of the deposit verification, technology of exploiatation and geomechanic parameters, in order to improve the obtained results.

The exploitation of coal deposit "Delici", is designed to develop the surface exploitation with annual coal production of 2 million tons. The coal deposit "Delici", is type of syncline with total amount of coal as a mineral resource of approximately 68.9 million tons. Of listed total amount of coal, the measured quantities are approximately 41.4 million tons. Synclinal position of coal in the deposit requires a complex system of mining exploitation in extremely unfavorable overall strip ratio.

Practically, by the pit optimization, two open pits were designed, "Delici-South" and "Delici-North", which covers the peripheral and shallow parts of deposit. The central part of syncline (deposit), because the great depth of coal and needs of excavation a huge masses from hanging wall is not economically feasible to excavate.

By pit optimizing the exploitable coal reserves are reduced to 23.5 million tons, 6.7 milion tons of open pit "Delici-South" and 16.8 million tons on open pit "Delici-North". For excavation of these amount of coal is necessary to excavate and 173.75 million m^3 of overburden. These excavated mass will be disposed at the "Eastern waste dump area", in the open pit "Delici-South" after exploitation and in the open pit "Delici-North" when achieves the conditions for the inside dump. The relatively low coal recovery from deposit "Delici" (about 34%), with a reasonable capacity of around 2 million tonnes of coal per year, caused the short working life of the mine, only 13 years.

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