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MINE WASTE SEQUENCING ON AN IRON ORE PROJECT

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RESUMEN:

Los recursos minerales disponibles en nuestro planeta son finitos, aunque su potencial no sea conocido en su totalidad. El diseño de un proyecto minero, desde las actividades de exploración para conocer el depósito mineral, explotarlo y el cierre de una mina, puede influir la vida útil de la mina. El objetivo de este estudio es evaluar la forma de disposición selectiva de los residuos de una mina de hierro y su posible reutilización en el futuro, destacando su uso y posibles repercusiones en la extensión de su vida útil de una mina de hierro localizada en el Quadrilatero Ferrifero. Recursos y reservas han sido evaluados, así como las fases finales e intermediarias, la secuencia de minado y disposición de residuos. La metodología ha sido empleada en un depósito de hierro brasilero en operación. En donde se pretende demostrar la importancia de evaluar los materiales residuales a fin de prolongar la vida útil del yacimiento mineral.

Palabras Clave: planificación minera, metodología, residuos, yacimiento de hierro

ABSTRACT:

The available mineral resources on our planet are finite, although its potential is not fully known. The design of a mining project, from exploration activity for knowledge of a deposit, through mining and closure of a mine, can influence the life extension of the mine in a mining operation.
This study aims to evaluate the waste material of iron formation in mining for selective disposal and future reuse, highlighting its use and potential impacts on life extension in an iron ore mine in the Iron Quadrangle. Resources and reserves were evaluated, the final and intermediate pits, mine sequencing and waste disposal. The methodology was applied to a case study of an operating mine. It is intended to demonstrate the importance of evaluating the waste materials in order to extend de life of mine.

Key Words: mine, planning, design, methodology, waste, iron ore

1. INTRODUCTION

A mine project is the set of studies necessary for the implementation of a mine, where such studies require a wide variety of technical expertise and cover different types of engineering, which are complementary [1] .The mining industry, like any other enterprise, has as its basic economic objective to maximize its future wealth. However, it is characterized by the economic exploitation of an exhaustible and non-renewable capital asset, which is different from other industries [2].

Iron ore deposits are most often mined as open pit operations, where relatively high ore grade and high-tonnage production generates significant amounts of solid waste, subdivided generally into two major categories: mill tailings and waste rock [3]. According to [4] a waste dump design is usually not as critical or as detailed as mine design. However, good waste dump design can be critical in minimizing costs and increasing the value of the ore produced. As discussed by [5] to achieve the desired degree of stability, selective placement of competent, free-draining waste rock in critical areas is required to promote drainage and provide integrated buttressing. The reserve block model can be adapted for this purpose.

Each block of waste must be classified based on its predominant alteration type, mineral content or other parameters of interest. Both the mine plan and the waste dump development sequence must be adjusted to ensure that there was sufficient high-quality waste available during a given year to meet the minimum requirements for construction of critical dump components [5]. It is necessary to manage waste in the pit similar to those used to selectively mine the ore, even with grade control support.

In the absence of an international consensus, [6] proposes a set of principles to guide the disposal of mining and mineral processing wastes, in order not to significantly disturb the ecosystems, communities and economies overlying and surrounding ore deposits and processing facilities. It and can be applicable to manage different types of solid wastes. One of the fundamental principles attests that mining, mineral processing and waste management technologies which offer improved environmental and social performance and a smaller surface footprint should be preferentially adopted. Opportunities for re-use of waste material should be pursued when practicable [7]. This case study represents only one possible scenario for re-using waste rock from an open pit iron ore mine.

2. METHODS

The selected property is an operation located at Itabira iron ore complex, north-east extreme of the Iron Quadrangle, at Minas Gerais state, as shown in Fig. (1). The geology information and the topography map have been graciously provided by Vale mining company. The mineral deposit rocks belongs to the Cauê formation, group Itabira, supergroup Minas. Mineralization is represented by two major lithological types: itabirites and hematites. There are other ferruginous materials, such as anphiboles, besides non-ferruginous rocks such as phyllites, schists and quartzites, quartz, goethite and breccia. A superficial ferruginous crust denominated locally as canga (cangue) is very frequent in the superficial areas [8].

In terms of the conventional mine proposal, the materials classified as mine waste are generally the materials without enough economic value to pay its process or without an available mine process flow sheet. For example, in a traditional exploitation of hematite, the itabirites may be considered as mine wastes. However, considering the exhaustion of the hematite reserves, it is important to study the possibilities for disposing the itabirite selectively as a marginal ore for a future recovery. In the same way, the same principles may be applied to others ferruginous materials such as poor and compact itabirites and other ferruginous wastes [9]. This methodology gets to an increase in the life of mine, improving the mine cash flow and generating several direct and indirect benefits for the surrounding communities, such as employment, taxes and services. The negative impacts of the exploitation are an increase in the average haulage distance, fleet and costs to legal and environmental regulation of the waste dumps [10].

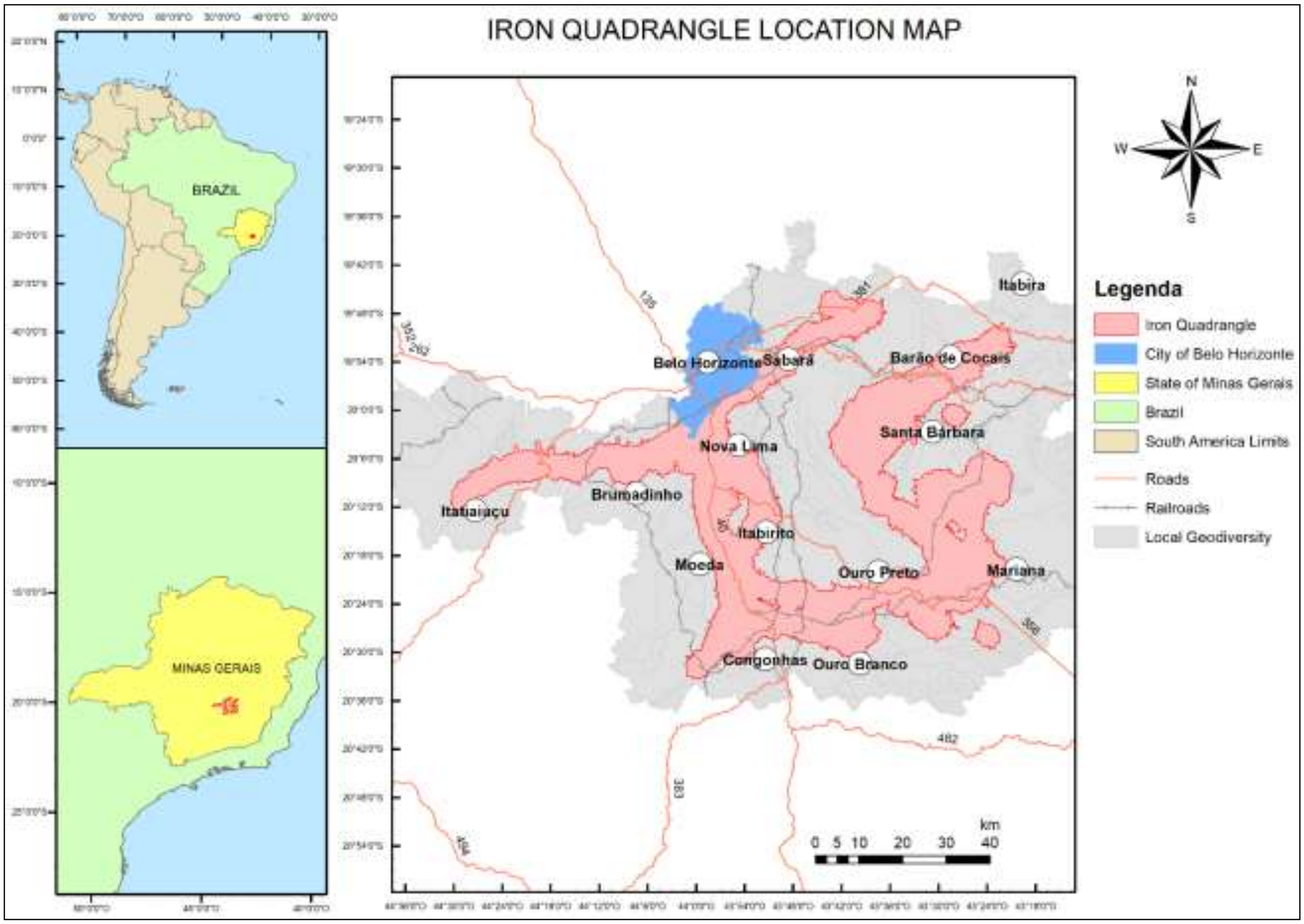

Fig. 1: Itabira iron ore complex is located on the north-east extreme of Iron Ore Quadrangle

Nowadays, at Itabira complex the mines "Conceição" and "Minas do Meio" are in exploitation of the iron ores (hematites and itabirites). Total production is approximately 50 million tonnes (Mt) of sinter feed and pellet feed.

Fig. 2: Mines "Conceição" and "Minas do Meio" at Itabira complex

The geological model has lithologies and respective densities listed in the Table 1.

Rock type	Density (t/m³)	Description	Rock type	Density (t/m³)	Description
HC	4,67	compact hematite	IS	2,97	semi-compact itabirite
HF	3,79	friable hematite	IDO	3,38	dolomitc itabirite
HDO	3,84	dolomitc hematite	IH	3,71	itabirite+hematite
HP	3,58	powdery hematite	IMN	2,53	manganiferous itabirite
HMN	3,31	manganiferous hematite	CG	3,17	canga
IC	3,29	compact itabirite	SO	1,79	soil
IF	2,8	friable itabirite	IN	2,02	intrusive
XI	2,11	Xist	QT	2,1	quartz

Table 1: Rock types and density

To evaluate iron ore reserves and perform ore and waste mine scheduling the following methodology was used:

1) Classification of the material according to available processing plant;

2) Reserves evaluation;

3) Sequencing of the mine blocks according to production targets.

2.1.- CLASSIFICATION OF THE MATERIAL ACCORDING TO AVAILABLE PROCESSING PLANT

Currently the mine has two mineral processing plants, according to Reserves and Resources evaluation report from [11], one for hematite and another one for rich itabirites, generating as products sinter feed and pellet feed. In 2014 started the operation of a new mineral processing plant for poor and compact itabirites.

The itabirites plant requires minimum 48% of iron ore. The cut off grades were obtained by the technique of parametrization considering measured, indicated and inferred blocks and the basic topography of 1980. Lithologies were grouped according to list below:

- **Hematites (he):** including lithologies hc, hf, hp, hmn;
- **Itabirites (it):** including lithologies ic, if, is, ih, imn, cg.

For the hematite the cut-off is geological, considering that its iron content is even greater than 60%. Table 2 shows the parameterization for the itabirites, where a cut-off off 42.5 % results in a ROM (Run of Mine) of 48.8% Fe, according to grades required by the current processing plant. Furthermore, in the incremental column it is possible to observe that the mass below 42,5% corresponds to 650 Mt of itabirites, with an average grade of 39% of iron. Potentially this mass below the cut-off could be processed anytime in the future with the development of the mineral processing technologies.

Finally, rockypes are defined considering the cut of grade, lithotypes and available mineral processing plant as is presented next:

- **Hematites (he):** hc, hf, hp and hmn; measured, indicated and inferred resources, iron grade above 42,5 %;
- **Itabirites (it):** if, ih, cg; measured, indicated and inferred resources, iron grade above 42,5 %;
- **Poor and compact Itabirites (ic):** ic, is, imn; measured, indicated and inferred resources, iron grade between 27.5 % and 42,5 %;
- **Ferriferous waste (ff):** ido and hdo; measured, indicated and inferred resources;
- **Others Ferriferous waste (ffne):** others ferriferous lithotypes not estimated;
- **Waste (estfr):** all the others blocks with non-ferriferous lithotypes.

Cut-off	**Cumulative**		**Incremental**			
	Fegl (%)	**Mass (Mt)**	**Range**		**Fegl (%)**	**Mass (Mt)**
27.5	44.96	1.630	27.5	30.0		1
30.0	44.96	1.630	30.0	32.5	31.88	39
32.5	44.97	1.628	32.5	35.0	33.99	113
35.0	45.24	1.590	35.0	37.5	36.44	228
37.5	45.91	1.476	37.5	40.0	38.84	269
40.0	47.2	1.248	40.0	42.5	41.22	293
42.5	48.84	980	42.5	45.0	43.82	224
45.0	50.99	687	45.0	47.5	46.18	182
47.5	53.31	463	47.5	50.0	48.72	107
50.0	56.28	281	50.0	52.5	51.03	44
52.5	59.52	174	52.5	55.0	53.59	24
55.0	61.51	130	55.0	57.5	56.24	22
57.5	62.7	106	57.5	60.0	58.84	21
60.0	63.71	84	60.0	62.5	61.19	46
62.5	64.55	63	62.5	65.0	63.99	17
65.0	66.04	17	65.0	67.5	66.04	
67.5			67.5	70.0		
70.0						

Table 2: Parameterization of the itabirites

2.2.- MINERAL RESERVES EVALUATION

According to [12], the economic value for each block is calculated from the block grades and estimated mining costs, using a method called benefit function (BF) to define the economic net value of each block, by calculating the difference between the revenue based on contained metal and the costs of metal production. From the economic block values, the final pit may be calculated using one of the several available optimization techniques. In this case the L&G algorithm from Vulcan software was used. A bi-dimensional vision for open pit block model restricted by topography and ultimate pit limits is presented in Fig. (3).

Plan 2014 separates the operation into two periods. Before 2014, main ores are hematites (in red) and rich itabirites (light blue). After 2014, it’s also possible to use compact itabirites (dark blue). The compact itabirite mined before 2014 should be disposed separated from non-ferruginous waste, as shown in next sections.

Thus, mine reserves are presented in 2 cases:

- **Case 1:** between topography from 1980 and 2014 mine plan;
- **Case 2:** between 2014 mine plan and final pit.

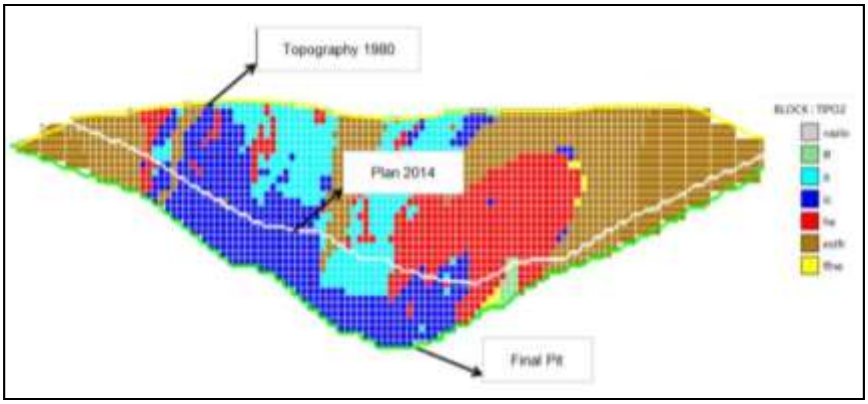

Fig. 3: Evaluation of the reserves between 1980, the mine plan of 2014 and the ultimate open pit for the mine. Source: designed using Vulcan software

Results for two situations are shown in Table 3.

Rocktype	1980 to 2014		2014 to final pit		Total	
	Mass (Mt)	Fegl (%)	Mass (Mt)	Fegl (%)	Mass (Mt)	Fegl (%)
he	210.5	67.5	84.1	67.3	294.6	67.4
it	345.6	48.3	53.8	47.8	399.4	48.2
ic	179.2	42.1	445.2	41.3	624.4	41.5
ff	0.6	44.8	54.2	43.7	54.8	43.7
ffne	2.8		0.9		3.7	
estfr	264.3		192.1		456.4	
Total	**1002.9**	**38.4**	**830.4**	**34.9**	**1833.3**	**36.8**

Table 3: Reserves by rocktype and situation

2.3.- SEQUENCING OF THE MINE BLOCKS

The block model sequencing was established considering the basic premises described below. Production objectives in case 1:

- exploitation of hematite;
- production of 10 Mtons per year of rich itabirite ("it" with iron grade above of 42,5 %);
- stock compact and poor itabirites ("ic" with iron grade between 27.5 and 42,5 %).

As 2014 is the start up for processing poor itabirites, production objectives in case 2 are:

- production of 48 Mtons per year of itabirites (rocktypes "it" and "ic");
- production of 8 Mtons per year of hematites.

There is an additional case, which is stock recovery, as follow:

- Production of 48 Mtons per year of itabirites from the stockpile (rocktypes "it" and "ic").

Figure 4 presents the current configuration of the Conceição mine. The green and yellow polygons are the mineral processing plants, being the current mineral processing plant on the right and the new mineral processing plant on the left.

Table 4 presents the results of the results of the proposed annual mine sequencing during the period of 1980 through the final life of the mine on 2030. The mass of poor and compact itabirites mined between 1980 and 2014 was of 208 Mt. The exhaustion of the mine will be in 2025. After 2025, the marginal waste stock pile can be mined using the same mineral processing plant. The stock has enough quantity for a 5 years period.

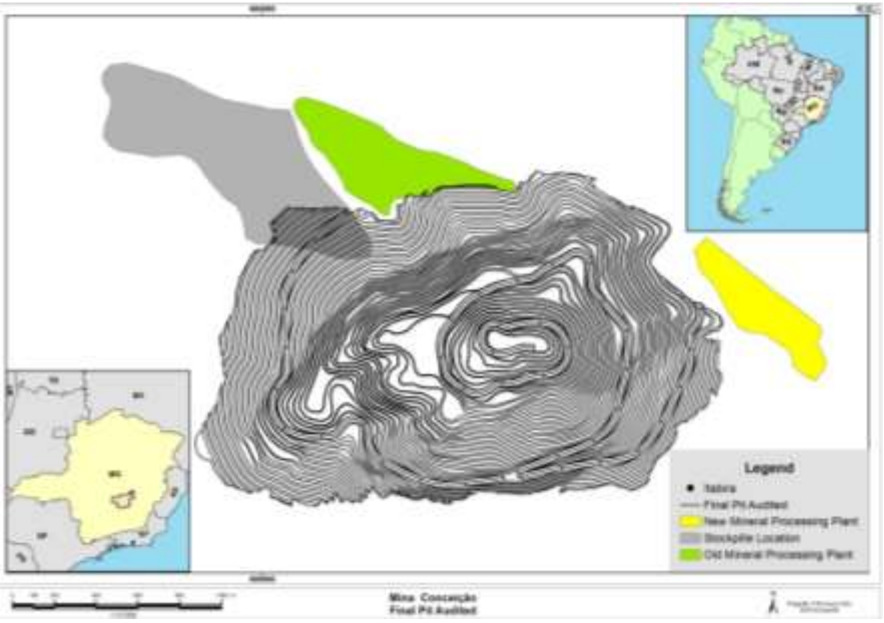

Fig. 4: Waste pile location (grey) and the new mineral processing plant (green polygon)

3. RESULTS AND DISCUSSIONS

Figure 5 presents the mine sequencing (mine scheduling) for the entire life of mine, the annual production in terms of the "Run of mine" (ROM), waste, marginal waste stockpiled, and marginal waste processed after the exhaustion of the mine, between 2025 and 2030.

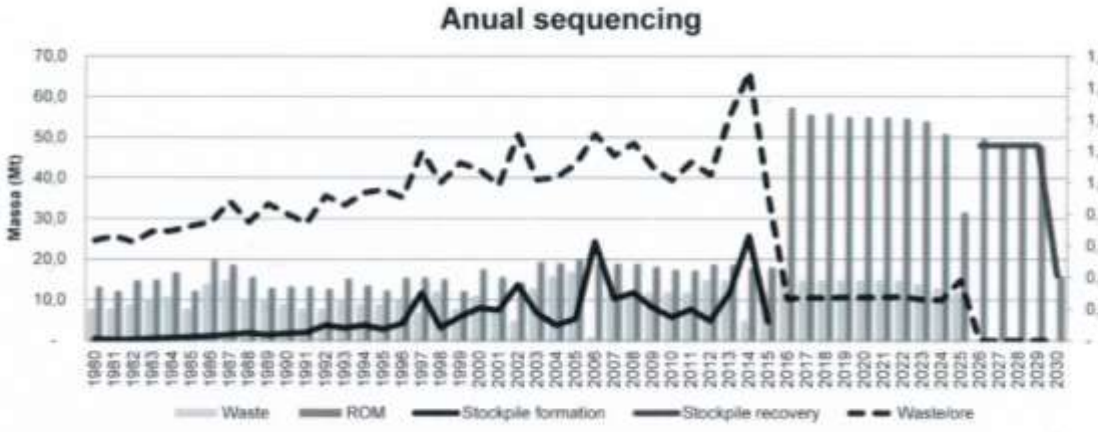

Fig. 5: Annual sequencing

Year	IC	HE	IT	Stockpile	Stockpile	Waste	ROM	Waste/ore	Waste + stock
1983		5.1	10.0	0.4		10.0	15.1	0.7	10.4
1984		6.8	10.0	0.6		11.0	16.8	0.7	11.6
1985		2.2	10.0	0.8		8.0	12.2	0.7	8.8
1986		10.1	10.0	1.0		14.0	20.1	0.7	15.0
1987		8.7	10.0	1.4		15.0	18.7	0.9	16.4
1988		5.8	10.0	1.8		10.0	15.8	0.7	11.8
1989		3.1	10.0	1.3		10.0	13.1	0.9	11.3
1990		3.4	10.0	1.7		9.0	13.4	0.8	10.7
1991		3.4	10.0	1.9		8.0	13.4	0.7	9.9
1992		2.8	10.0	3.7		8.0	12.8	0.9	11.7
1993		5.4	9.9	3.1		10.0	15.3	0.9	13.1
1994		3.5	10.1	3.7		9.0	13.6	0.9	12.7
1995		2.5	9.9	2.8		9.0	12.4	1.0	11.8
1996		5.6	10.0	4.1		10.0	15.6	0.9	14.1
1997		5.6	10.0	11.6		7.0	15.6	1.2	18.6
1998		5.2	10.0	3.1		12.1	15.2	1.0	15.2
1999		2.3	10.0	5.8		8.0	12.3	1.1	13.8
2000		7.6	10.0	7.9		11.1	17.6	1.1	19.0
2002		4.3	10.0	13.6		5.0	14.3	1.3	18.6
2003		9.4	10.0	6.7		13.0	19.4	1.0	19.7
2004		9.1	10.0	3.7		16.0	19.1	1.0	19.7
2005		10.0	10.0	5.3		17.0	20.0	1.1	22.3
2006		9.3	10.0	24.2		1.0	19.3	1.3	25.2
2007		9.0	10.0	10.2		12.0	19.0	1.2	22.2
2008		8.9	10.1	11.7		12.0	19.0	1.2	23.7
2009		8.3	10.0	8.1		12.0	18.3	1.1	20.1
2010		7.5	10.0	5.7		12.0	17.5	1.0	17.7
2011		7.5	9.9	7.6		12.0	17.4	1.1	19.6
2012		8.9	10.0	4.8		15.0	18.9	1.0	19.8
2013		8.7	10.0	11.6		15.0	18.7	1.4	26.6
2014		8.0	10.0	25.6		5.0	18.0	1.7	30.6
2015	6.0	8.2	3.9	4.6		12.0	18.1	0.9	16.6
2016	33.2	9.4	14.8			15.0	57.4	0.3	15.0
2017	43.5	7.7	4.5			15.0	55.7	0.3	15.0
2018	40.9	7.8	7.2			15.0	55.9	0.3	15.0
2019	43.5	7.3	4.4			15.0	55.2	0.3	15.0
2020	44.1	7.0	4.1			15.0	55.2	0.3	15.0
2021	46.8	7.0	1.2			15.0	55.0	0.3	15.0
2022	46.9	6.7	1.1			15.0	54.7	0.3	15.0
2023	465	6.5	1.1			14.0	54.1	0.3	14.0
2024	43.3	6.1	1.6			13.0	51.0	0.3	13.0
2025	20.4	6.5	4.7			12.0	31.6	0.4	12.0
2026			1.8		48.0		49.8		
2027					48.0		48.0		
2028					48.0		48.0		
2029					48.0		48.0		
2030					16.0		16.0		
Total	**415.1**	**294.2**	**400.4**	**208.2**	**208.0**	**515.2**	**1317.7**	**0.4**	**723.4**

Table 4: Reserves by rocktype and situation

The mine scheduling gets to a stock of 208 Mt of poor and compact itabirite. It will be necessary to choose an appropriate area to stockpile this material facilitating its recovery in the future. The material must be placed on a separate marginal waste stockpile from the non-ferriferous material. Considering the location of the projected mineral processing plants the best location for the marginal waste pile will be in the yellow area, nearest to both mineral processing plants, as shown in Fig. (4). In this place was constructed a marginal waste pile to stock 100 Mt of the poor and compact itabirites and this stockpile can be expanded to stock 200 Mt.

CONCLUSION

The mineral reserve evaluation considering the block model and the original topography in the year 1980 resulted in stock of 200 Mt of compact and poor itabirites. The material should be placed in a separate marginal waste pile and not comingled in the same stockpile for non-ferriferous material. This methodology brings a significant increase of 5-years to life of mine at full production. There will be direct benefits to the surrounding communities through continued employment, tax revenue, and to the environment through the generation and rational use of mine wastes. Considering that the mine started its operation on the 1950's, the results would be greatly improved.

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LIQ – MIN 1.0
ALGORITMO PARA CÁLCULO DE LIQUIDACIONES MINERAS

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Proyecto que obtuvo el 3er lugar en la 8va Feria de Investigación, Ciencia y Tecnología de la Universidad Técnica de Oruro – FICyT 2021

Resumen

La presente investigación ha desarrollado un algoritmo para el cálculo de las liquidaciones mineras, en Excel, sencillo de usar, desarrollado para que los mineros cooperativistas reciban un pago justo por la venta de sus minerales, además este algoritmo calcula el porcentaje de realización (porcentaje que gana la casa comercializadora) y el porcentaje que recibe el trabajador minero por la venta del mineral.

En base a este algoritmo, el minero cooperativista que comercializa cualquier mineral desde ahora va a recibir el pago que merece por el esfuerzo realizado.

El algoritmo ha sido convertido en una aplicación de celular “LIQMIN” de propiedad exclusiva del CISEP de descarga libre para que los mineros cooperativistas puedan acceder a la aplicación, se tiene una versión del algoritmo en un programa para computadoras que ha sido instalado en la mayoría de las oficinas de las cooperativas mineras del departamento de Oruro.

A partir de la implementación de este algoritmo, el SENARECOM ha subido a su WEB una versión propia del LIQMIN, esto indica la repercusión que ha tenido la investigación desarrollada, llegando a que instancias como el SENARECOM puedan generar este tipo de ayudas al sector.

Se han realizado capacitaciones a las cooperativas del departamento de Oruro sobre el uso del algoritmo LIQMIN con la ayuda del CISEP, fueron 11 las cooperativas que han recibido esa capacitación, el algoritmo en su versión de aplicación para celulares ha sido entregado a la comunidad minera en un acto llevado a cabo en la Universidad Técnica de Oruro.

Palabras clave:
Algoritmo, comercialización, cooperativa, minería, liquidación.

Abstract

The present research has developed an algorithm for the calculation of mining settlements, in Excel, easy to use, developed so that cooperative miners receive a fair payment for the sale of their minerals, in addition this algorithm calculates the percentage of realization (percentage that the trading house wins) and the percentage that the mining worker receives from the sale of the mineral.

Based on this algorithm, the cooperative miner who commercializes any mineral from now on will receive the payment he deserves for the effort made.

The algorithm has been converted into a free download "LIQMIN" cell phone application of exclusive property of CISEP so that cooperative miners can access the application. There is a version of the algorithm