International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2020): 7.803

Research Problem on the Profitability of Mining Activities in DRC, Face to New Technologies: Critical Analysis of the Extraction Chain of Copper and Cobalt Deposits (From Raw Materials to Metal)

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Abstract: ***The value of ore depends on various parameters, susceptible to influence its aptitude in subsequent processing. We could mention the grade, the presence of accompanying elements, the nature of its gangue and its useful mineralogical components, the grain size, its physical and chemical properties. Every mining activity usually starts with easy-to-value deposits that generally offer a short-range profitability, which are soon depleted. This causes lower quality ore and more and more fine and disseminated deposits to be exploited. Apart from huge investments, the development of these deposits requires, to treat greater and greater volumes of materials in order to obtain a given quantity of metal. This goes through a thorough milling of ores, to obtain a sufficient liberation, while ensuring the profitability of the whole process from raw material to metal. The price of raw materials, the increasing costs of labor and chemical reagents, the growing competition and environmental obligations no longer enable to use these techniques, and a judicious choice is needed. With the passage of time, the Democratic Republic of the Congo has been able to acquire new techniques in terms of Reserves evaluation, planning, valuation and characterization of copper and cobalt ores.Government measures forbidding the exportation of raw ores in Katanga have favored the construction of a lot of metallurgical plants, nearby concentrators and mines. Softwares like Geovia Surpac and Minesched have come to the assistance to the mining industry.Compared to analytical and empirical methods, these tools present some advantages such as easiness and accuracy of calculations which were once difficult. In the valuation beyond gravity, physicochemical (flotation) techniques, leaching combined with solvent extraction and electrolysis has increased the quality of mining products exported, with an increase in the profitability of mining. In the valuation by flotation, the use of the "Image J.145" software allowed us in our doctoral research to predict the behavior of Ruashi I ore in grinding. X-ray diffraction has also enabled us through semi-quantitative analyses to control the quality of flotation products, while guiding this process for better profitability. Other new techniques at the laboratory or pilot stage are also being tested in the world we cite: centrifugal gravity concentration, advanced flotation, bacterial leaching and Geometallurgy. All of these technologies can only be used to the extent that the entire extraction chain is proven to be profitable, as each technology has a cost.***

Keywords: Profitability, Extraction chain, Technologies, Flotation, Ore

1. Introduction

Many sectors of the world economy depend on mineral or mineral raw materials. All areas of the industry at large (civil engineering, cement factories, glassworks, stationery, chemistry, petrochemicals, mechanics, electricity and electronics, aeronautics, shipbuilding, agri-food, etc.) use mineral and metal materials to manufacture the goods that surround us and serve us daily.

Currently examples in new technologies are legion. The manufacture of electric cars is in dire need of cobalt for its batteries. Electronics today needs colombo-tantalite (Coltan), an ore as precious as black gold, from which niobium (colombium once) and tantalum are extracted. It can be said without exaggeration that without mineral raw materials, our civilization would not exist. One should simply look around to be convinced.

The earth's crust is made up of rocks, which consist of useful and non-useful minerals called "ores". In 1893, the eminent Belgian geologist Jules Cornet rightly exclaimed that the Congo is "a geological scandal" so much so that the mineral resources contained in its subsoil are abundant, impressive and the metals very diversified (Kanzundu M., 2018). Indeed, the Democratic Republic of Congo abounds in a varied range of mineral resources, which are irregularly distributed throughout the national territory, including those of copper and cobalt located mainly in Katanga. Thanks to the abundance and variety of these mineral resources, the mining industry constitutes a vital and essential sector of its economy. Thus, the exploitation of this mining potential can largely contribute to the increase of the State budget and, consequently, lead to its development at all levels. Currently, mining products account for an average of 95% of the total volume of exports from the DR Congo.

For an ore to be of economic interest, it must exist in the form of "deposits", i.e. be accumulated in sufficient quantities in the same place. Its quality must also be acceptable and it must be technically upgradeable. In other words, all costs related to their extraction at the mine, concentration and metallurgical levels must be below the market price. With all of the above, an ore will be defined as any mineral substance that can be exploited in an economically profitable manner according to the extraction techniques available in time and space. We can therefore say, that a mineral association is an ore only if it can be economically extracted from mineral or metallic phases, having a commercial value (Ancia. P, 2007). Otherwise, the rock is left in place and constitutes "a simple mineral deposit, a mineralized heap or a mineralized showing", which may become an ore according to technical, economic or strategic developments.

2. Problems of industrialization and technology transfer

An engineer is the one who is able to realize, design and innovate. He analyzes a concrete problem by taking into account its complexity, without getting lost in it. He relies on scientific and technological advances to implement solutions. The development of the world and of all humanity necessarily involves industrialization. According to their sectors of activity, industries or companies can be classified into three sectors: the primary, secondary and tertiary sectors. The primary sector refers to the production activity that provides raw materials, i.e. unprocessed. The secondary sector refers to the activity of transformation of raw materials into semi-finished or finished products. It includes all the so-called processing industries, while the tertiary sector is that of activities that do not produce goods but rather services.

We can say that the concept of "new technologies" can also vary as the concept of ore, in time and space. A technology that appeared many years ago in a given continent or country can be considered as new elsewhere, in the context of technology transfer. This is the case in the mining sector of the DR Congo, where several technologies that have been used elsewhere for a very long time may appear as new in the DR Congo. Some countries with hegemonic ambitions hold technologies that they do not prefer to transfer to others, less powerful than them, in order to keep them in the primary sector, in order to keep the transformation process of these raw materials in the processing industries of their countries. Africa has suffered for a long time and today things are changing, with the emergence of several African countries.

The mining sector in DR Congo has long remained an extractive industries sector classified in the primary sector. Efforts made by the Congolese State by prohibiting the export of raw minerals, have led several mining companies to turn to the secondary sector, using appropriate technologies, to create mineralurgical (concentration: flotation, classical gravimetry, HMS Heavy Medium Separation) and metallurgical (Hydrometallurgy: Leaching-Extraction by Solvent Electrolysis and Pyrometallurgy) plants.

Every technology has a cost, whether it is the so-called traditional or the so-called new technologies. The wise engineer or the investor will never look for the most efficient technology to solve his problems if it does not guarantee a certain profitability. Around the world, companies that have gone from good to great think differently about the role of technology (TLTN, 2018). They never use technology as a fundamental means to ignite transformation, yet they are pioneers in the application and use of selected technologies. In the micro characterization of solids, for example, there are currently nearly 400 techniques used in geology, geochemistry, mining, mineralurgy, metallurgy, etc. (TLTN, 2018). (Ammou M., David D., 1989). This number makes any attempt to classify them random, given their multiplicity and diversity. A characterization problem most often requires the use of different analytical techniques, implemented jointly, and this way of doing things proves fruitful for both scientific and industrial results.

To solve a given characterization problem, it will therefore be necessary to choose not the best method, but the combination of complementary techniques that is most effective and best suited to the study being carried out. In order to select a characterization method judiciously, before and during a study, a researcher must know the main characterization methods or techniques, on the one hand, and their respective fields of application, as well as their possibilities and limitations, on the other hand. Among the characteristics of the mining industry, we can say that it is a heavy industry in terms of the capital involved, compared to other types of industry. Before putting millions of dollars at stake, we must be sure that the technology is capable of adapting to the minerals to be exploited, with a view to generating a significant gain. We would also point out that the mining industry exploits non-renewable resources and is also exposed to the system of influence and risks of all kinds. Finally, let's say that the acquisition of technology leads to job creation, through the creation of several processing companies in the secondary sector. On the other hand, the automation of several industrial processes reduces the use of manpower. Thus, a balance must be found to reconcile these two aspects.

3. History and state of the art of copper and cobalt mining in the DRC

The world production of copper is about 15 million tons per year, and Chile alone already accounts for 35%. In recent years, the prices of basic mining products have risen sharply, mainly due to the high consumption of non-ferrous metals in China, India and other emerging countries. At the beginning of the third millennium, the price per ton of copper was US$3,000. In 2008, it reached US$8,000, and in 2011 it even reached US$12,000. In March 2012, the price per ton of copper was US$8,500 and the price per pound of cobalt was US$16 (BCC, March 2012). The rapid development of countries such as China and India could keep the price of a ton of copper between US$4,000 and US$8,000 (Goossens P.J., 2009). However, the prices of these products are highly cyclical, and their forecasts vary considerably depending on the global political and economic climate.

Mining of the Congolese subsoil historically began with the creation of the Union Minière du Haut-Katanga in 1906. With the first pouring of copper from the deposit of Etoile in 1911, this exploitation has seen many economic and technological advances, but still faces many challenges after almost a century of industrial exploitation. To meet this demand, the world will also have to rely on the D.R. Congo, which has very significant mining potential. It has 10% of the world's copper reserves and 65% of the world's cobalt reserves (Ministry of Mines, 2007). In the so-called peak years, i.e. between 1972 and 1980, D.R. Congo produced 450,000 tons of copper and 16,000 tons of cobalt per year thanks to Gécamines, one of its mining companies. It had thus become the first cobalt producing country and the fifth copper producing country in the world. Figures 1 and 2 show the evolution of copper and cobalt production from 2005 to 2018.

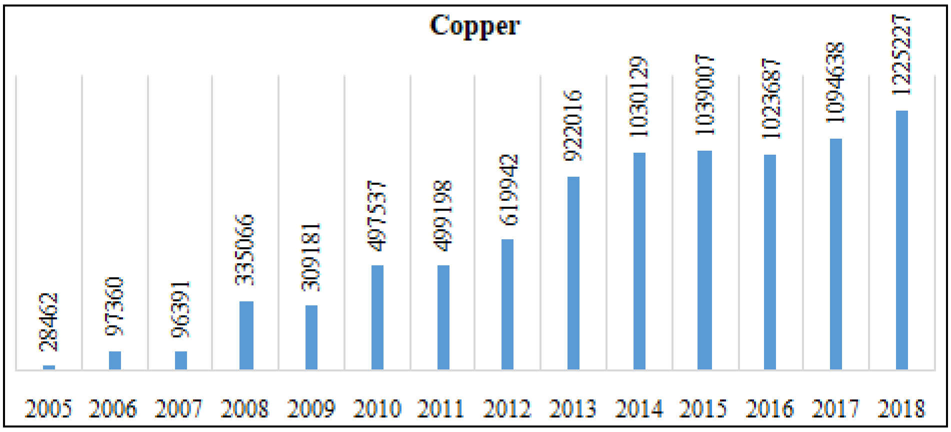

Figure 1: Evolution of copper production in tons over 14 years (Source: Central Bank of Congo, 2019a, b)

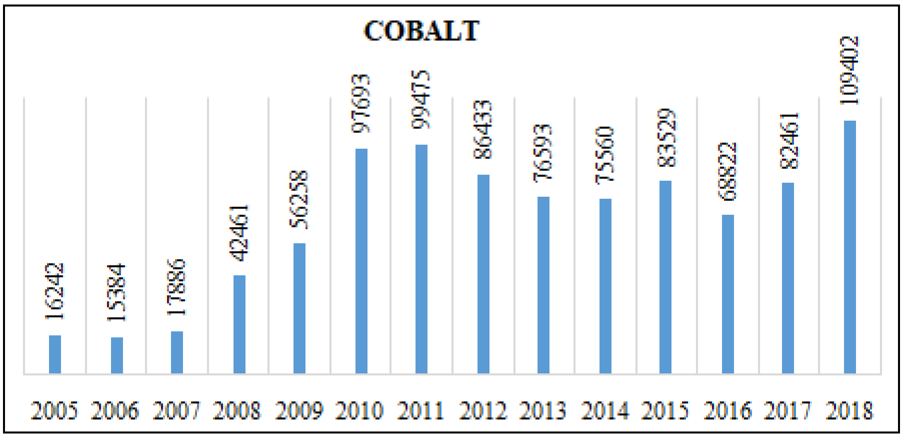

Figure 2: Evolution of cobalt production in tons over 14 years (Source : Central Bank of Congo, 2019a,b)

Table 1 shows the evolution of copper and cobalt production during the first six months of 2019. There is therefore a strong increase in this production compared to all periods (Copper: more than one million tons, Cobalt: more than one hundred thousand tons). There is therefore a strong demand for copper and cobalt, resulting in a production of metals without planning and at the pace of metal prices on the global market, on the London Metal Exchange (LME). This poses a threat of rapid depletion of deposits that are non-renewable resources, especially since the benefits of mining are not yet being felt by the population. In addition, the mineral reserves of the DRC are still very poorly known. The sustainable development of the DRC, can only be achieved through the good control and **the correct management of the production of materials, as well as their consumption**. It will thus be necessary in the near future to proceed to **a correct evaluation or re-evaluation of our reserves**, but also to a recognition of new deposits. The new questions that arise are those of knowing what treatment methods are needed with the appearance of mixed and sulphides following the deepening of the deposits, especially since sulphides are not better suited to leaching. It should be noted that adapting a treatment scheme to a variable ore feed would be ideal, but not easy to achieve as it often requires additional financial costs.

Table 1: Evolution of copper and cobalt production in 6 months of 2019

Year 2019	COPPER	COBALT
Jan-19	90,580	10,765
Feb-19	109,302	8,080
Mar-19	104,330	6,439
Apr-19	111,855	8,683
May-19	135,977	10,555
Jun-19	120,228	9,333

4. Technologies or methods of valorization of copper and cobalt ores in Katanga

After the prospection stage conducted by the geologist, and confirmation of the presence of a deposit, mining is done either by open pit, underground or a combination of both (mixed mode). Open pit mining is done for shallow depth deposits, while underground mining is done for deep deposits. A technico-economic study is always carried out before choosing the mining method.

Figure 3, shows all the stages of metal production from prospection, mining and mineral processing to metallurgy. Mineralurgy includes mechanical preparation and concentration. Mechanical preparation uses crushing and grinding operations, coupled with separation and dimensional classification operations. Concentration consists of the separation between useful and non-useful minerals, the concentrate is enriched in useful minerals while the tailing is enriched in non-useful minerals. In mineralurgy, flotation is one of the most importantprocessing methods for large rock masses, which allows the separation of minerals from each other, by difference in their surface properties, in an aqueous solution and in the presence of air. Oxidized ores constitute the first category of recoverable minerals, of a deposit evolving at depth. They are secondary ores, resulting from the alteration of primary ores (sulphides), and have the advantage of being found at shallow depths. Flotation also has the advantage of evolving with the deposit at depth, from oxides to sulphides, through mixed ores. The cut-off grade of a given metal varies in time and space. For example, in some countries (Chile, Australia, Canada, United States, etc.) that are among the major copper producers, the cut-off grade of copper is less than 1%. This is due to their technological and economic levels. Following the evolution of time, Katanga has also acquired new techniques in terms of valorization. We are witnessing the treatment of what was once considered waste and sterile, commonly referred to in the Congolese Mining Code (Law N° 007/2002, 11 July 2002) as "artificial deposits". This is the case of the slag heap in Lubumbashi, exploited by the company STL, and the Musonoï slag heap, which should have been exploited previously by the company KMT.

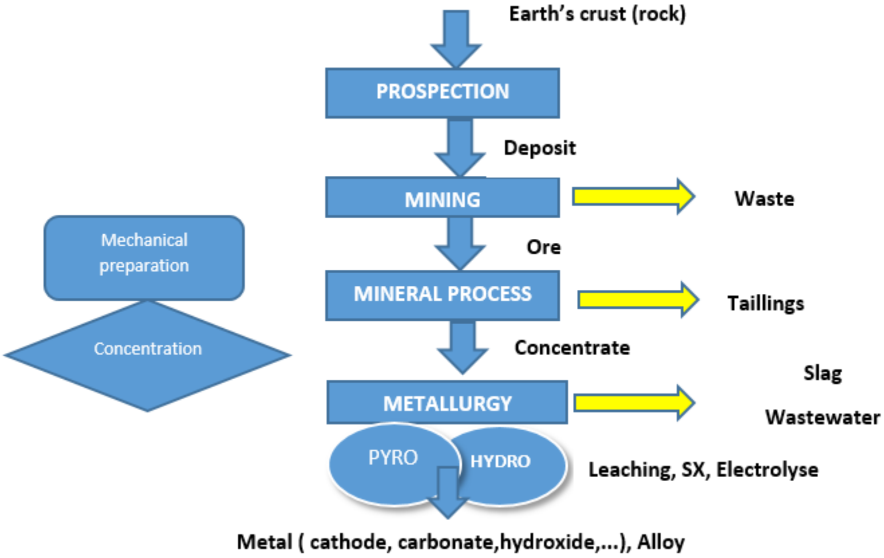

Figure 3: Steps in the production of a metal

For a very long time, leaching and flotation have always been the traditional methods of upgrading oxidized ores. Leaching is expensive compared to flotation, from an investment point of view (Lee K. et al., 2009). Flotation, although not totally the most advantageous, offers the possibility of processing large quantities of low-grade ores. This has been favoured by the depletion of many rich deposits, and the mandatory use of poor oxidized deposits, but also by the availability of tailings from old concentrators. Flotation also has the advantage of evolving with the deposit at depth, from oxides to sulphides, through mixed. In the copper-cobalt production chain, leaching is an important step that comes just after flotation, when the concentrates must be treated by hydrometallurgy.It is currently in vogue in Katanga, and is combined with solvent extraction and electrolysis. In the concentration of ores in Katanga, gravimetric and physicochemical methods have always been the most used. The gravimetric methods have the advantage of being non-polluting, because they use water as the only reagent. These techniques are currently combined with other methods, and are also used in the preconcentration stages. They are quite simple to use and relatively inexpensive, both in terms of investment and execution.

The treatment of very fine materials, does not work with classical gravimetric concentrators, such as jigs, spirals, shaking tables, etc. New gravimetric concentration devices have appeared on the market in recent years, capable of processing fine materials. These are the centrifugal gravimetric concentrators. Flotation on the other hand, is a physicochemical method, using many reagents. It favors the production of acid waste water, which is harmful to the environment. Currently, with the concept of "sustainable development", this is without fear, because there are many directives requiring companies to treat this waste water and to manage it well. In terms of metal recovery and treatment capacity, flotation has several advantages over gravimetric methods. Table 2 provides a summary of the methods used to recover ores, from raw ore to metal.

Table 2: Synthesis of some ore beneficiation methods

Processing Plant	Methods	Variantes	Production details (Reagents, grades, products)
NCK ou CMSK	Flotation	Combined	silicate de Na, dow/sasfroth, KAX, NaHS, acide citrique, mixture, sulfate NH4.
	Gravimetry	Shaking tables	Water
		Spirales	Water
KZC (GCM)	Flotation	Hydrometallurgy	Rinkalore 10, NaHS, G41, PNBX, Palm Oil
KTC (GCM)	Flotation	Hydrometallurgy	NaHS, PNBX, KAX, KEX, silicate de Na, gasoil, rinkalore, Unitol, tall oil, G41.
RUASHI	Flotation	Leaching-SX/EW	99%Cu Cathodes , 32-35% Co Hydroxydes
CHEMAF	Gravimetry	HMS, spirals	water, ferrosilicon, magnetite.
	Flotation	Leaching-SX/EW	Cu Cathodes
KAMBOVE	Flotation	Hydrometallurgy	NaHS, PNBX, KAX, Na silicate, lime, sasfroth, G41, rinkalore 10 et booster, tall oil, gasoil, separan.
KAMFUNDWA	Gravimetry	HMS, spirals	2%Cu Feed, 15% Cu concentrate

Government measures prohibiting the commercialization of raw minerals and concentrates in Katanga have encouraged the construction of many metallurgical plants alongside concentrators. This is why the majority of companies use hydrometallurgy for the production of copper and cobalt, without forgetting pyrometallurgy. In Katanga, many mining companies in the establishment or production phase are constantly adapting their production parameters from those of pre-existing companies. Still others, reproduce the parameters of others, without making laboratory tests, nor at the pilot scale. Several companies exploiting copper and cobalt on the copper arc of Katanga believe that everything is homogeneous in this arc. They are not concerned about the uniformity of production parameters (types of reagents, doses of reagents, treatment flow sheet, etc.).

We believe that, following the various heterogeneities (lithological, mineralogical, chemical) of the deposits, the production parameters will have to be adapted to the reality of each deposit. At the start-up of the plant, this generally does not pose a problem. In the evolution of the exploitation of the deposit, these companies find themselves confronted with the reality of its valorization, with serious consequences that paralyze production. This brings us back to the starting point, which is to master the behavior of the minerals in the laboratory and pilot plant, before moving to the industrial scale. In this framework, apart from the pilot flotation plant of the Department of Metallurgical Studies of Gécamines, a second pilot flotation plant in Katanga has been built at the laboratory of ore preparation of the Polytechnic Faculty. UNILU is in collaboration with the mining company CMSK, for this ongoing project. This pilot plant will allow the different companies to carry out not only laboratory but also pilot plant tests in Katanga. Flotation will continue to be used throughout the world for its multiple advantages (already listed), including adaptation to the evolution of the deposit at depth. It will always have a future, despite the fact that some companies are migrating towards direct leaching of all-purpose ores, but also despite the experimentation with bacterial leaching in some laboratories in Katanga. The results of bacterial leaching have yet to be proven on an industrial scale in Katanga, taking into account the variability of the ores, but also the technical and economic constraints of applying this new technology. In this context, the mining challenge is to study the best way to produce copper and cobalt concentrates at low cost, at acceptable grades and recovery rates. The search for optimal production parameters is therefore one of the major challenges to be met by the miner, mineralurgist or metallurgist.

5. Some illustrations of the technological contribution in the estimation of reserves, planning and quality control of ores and concentrates

5.1 In the mines

Mining, considered as a whole, is a succession of several distinct operations aimed at extracting useful substances buried in the ground and subsoil, indispensable in the daily life of man. The mining industry, characterized by high risk and high expenses, requires the mastery and knowledge of various technico-economic parameters involved in the process of extracting these natural resources.

Currently there are several means and techniques that allow to face the mining risk at each stage of the exploitation, among them we can mention the advent of computer technology in the mining sector. Indeed, over the last two decades, we have witnessed an increase in the use of computer hardware and software in the mining sector. These computer tools, compared to analytical and empirical methods, have some advantages such as the ease and precision in calculations that were once difficult or impossible or even tedious, the time saving in terms of the speed of data processing, the fineness of the results, the more or less exact reproducibility of the reality of the terrain, etc. In addition, their weaknesses lie mainly in the accuracy of the information used as input data and in the skill of the modeller or user (Losaladjome H., 2019).

Among these softwares, we can mention GEOVIA Surpac and GEOVIA MineSched which are products of the company Dassault Systèmes in its natural resources branch which recently bought the company from the GEMCOM firm. Geovia Surpac is the most widely used geology and mine planning software in the world, supporting open pit and underground mining operations and exploration projects. It is subdivided into several modules, the main ones being the following: creation of geological databases, solid (ore body) construction, resource estimation through block model construction, pit optimization, open pit and underground mine design, geostatistics, topography, drilling and mining. Figure 4 gives an illustration of the solid indicating the ore body of the East Karu deposit in Haut-Katanga Province.

Geovia MineSched is a software for advanced planning, reserve and production management of open pit and underground mines. This planning is carried out at three levels: short term (day to day), medium term (12 to 16 months ahead) and long term (year by year). For example, it manages the resources (shovels), storage backfill (ore and waste rock), and compliance with mill feed grade.

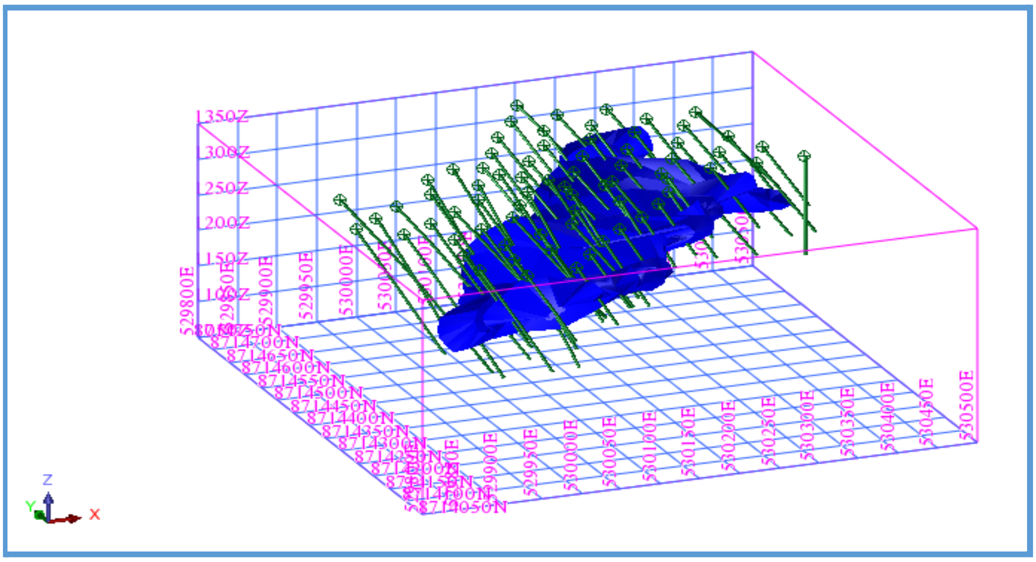

Figure 4: Superposition of the solid (ore body) of Karu-Est deposit with drillholes (Losaladjome H., 2019)

5.2 In fragmentation (Milling)

Determining the average size of mineral grains is very important to determine the degree of reduction of ores, in order to release the recoverable minerals. A software called "Image J.145" allows to analyze a series of microscopic images in order to determine the average grain size. It can calculate statistics of sector and pixel values of user-defined choices. It can measure distances and angles. It can create density histograms and line profile plots. Our doctoral research has been able to experiment this on Ruashi I ores from several lithological assays (SD, RSF, RSC, BOMZ, DSTRAT, RAT, MV, CMN). After having identified the recoverable minerals, their dimensions were determined, in order to see the possibility of their release during fragmentation.

After analysis of several microscopic images, followed by the measurement of their grains using the software "ImageJ.145s", the various recoverable minerals (malachite, heterogenite, bornite, chalcosine), have an average size of 205.880µm for 220 measurements carried out and 230.485µm for 125 measurements. This means that grinding at a d80 of 75µm, will be able to promote a sufficient release of recoverable minerals by flotation. Table 3 gives the type of raw file, which is generated when grain size measurements are made with this image processing software. Figure 5, illustrates how the large and small grain diameters were measured. This figure shows a BOMZ grain, showing purple to violet colors, translating the signs of transformation of a sulfide (presumably chalcopyrite) into bornite and chalcosine.

ISSN: 2319-7064
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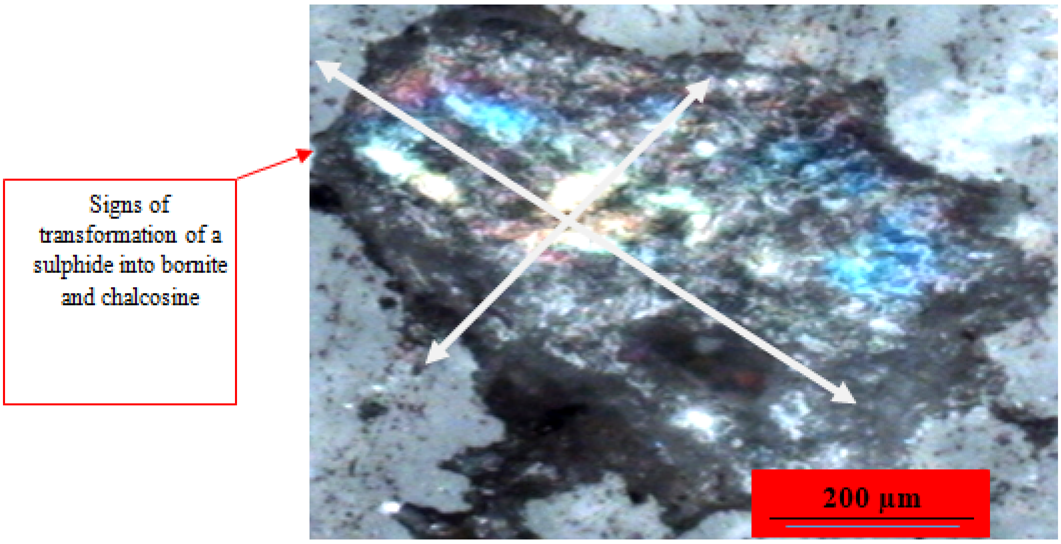

Figure 5: Microscopic view of some BOMZ minerals

Table 3: Extract of the file generated during the measurement of the average grain size

Observ.		Area	Mean	Min	Max	Angle	Length (1000.µm)
1	1	859 287	39 580	20 971	59 259	-67 724	679 499
60	35	197 684	23 058	16 610	83 333	-24 057	154 866
107	12	50 504	146 454	88 265	204 811	-26 565	39 328
161	6	487 677	50 999	23 751	175 055	-49 479	386 714
192	37	691 270	86 110	26 793	253 091	-32 672	549 212

5.3 In X-ray diffraction quality control

The products whose quality has been controlled come from flotation, a method of concentration already described in the previous paragraphs. The latter can also be done in a differential way. Differential flotation" consists in recovering the minerals separately. It is carried out either by depressing one with a reagent to float the other easily, or by first floating the more hydrophobic one, to float afterwards the more hydrophilic one. The latter is done after activation of its surface by another reagent. In another case, when the recoverable mineral is the most recovered at the discharge (not floated), and the floated product contains less, we will speak of "reverse flotation".

To illustrate the importance of mineralogical characterization, X-ray diffraction was used as a method for the structural characterization of Ruashi I copper-cobaltiferous ores. A sample is analyzed in the following way: an X-ray beam is sent to it, and a detector travels through a range of angles around the sample to measure the intensity of the diffracted X-rays. The result is a diffraction spectrum, where peaks of various intensities appear at specific angles. By comparing this spectrum with those of known crystalline phases, it is possible to find out which phases make up the measured spectrum, and thus the minerals contained in the analyzed sample. This technique also makes it possible to obtain a semi-quantitative mineralogical analysis of the sample from the spectra. In this case, standard phase spectra of known concentration are used. They are calibrated with respect to the corresponding mineral in the sample spectrum, in order to deduce by proportionality of peak intensity the concentration of the mineral in the sample. Table 4 gives the semi-quantitative X-ray diffraction analysis results obtained on different concentrates and flotation rejects of copper and cobalt ores from the different lithological settings of the Ruashi I deposit.

During mining, the boundary between the oxidized and sulphide part of a deposit is very difficult to determine. As a result, at a certain point in the evolution of the deposit at depth, it will be necessary to treat a feed composed of both copper and cobalt oxides and sulphides (mixed). Semi-quantitative analysis allows us to see the types of minerals contained in each flotation product. This allows us to know, the recoverable minerals that respond better to the process, but also those of the gangue minerals that are not depressed, and get dragged into the concentrate. It should also be noted that some recoverable minerals may be found in high proportion in the rejection, this situation would reflect an inefficiency of the process (even if losses are inevitable). Semi-quantitative analysis of the concentrates, rejects and crude ores from the lithological bedrock showed the depression of chalcopyrite under the sulphidation.

Figure 6 better illustrates this depression. On this figure, we can see that out of 100% of the chalcopyrite fed, 66% goes to reject and only 34% to concentrate. In fact, when the sulphidation is done totally on the ore, the sulphides are depressed (Lee K., et al., 2009) due to the lack of oxygen in the pulp, resulting in a drop in recovery yield. This analysis led us to adopt differential flotation, instead of continuing to do sulphidation flotation, mistakenly considering that the ore is oxidized.

Table 4: Semi-quantitative analysis of concentrates and rejects from lithological bases

Minéraux (%)	DSTRAT Concentrate	SD Concentrate	MV Concentrate	RSF Concentrate	RSC Concentrate	DSTRAT Taillings	RSC Taillings	RSF Taillings
Quartz	47,90	33,20	4,50	43,80	52,30	56,50	85,70	91,10
Hematite	1,60	0,90	0,50	1,50	0,50	0,30	0,40	0,50
Goethite	2,60	2,00	0,80	2,30	1,80	0,70	2,10	1,80
Calcite	0,00	0,00	0,00	0,00	0,00	0,00	0,40	0,00
Dolomite	30,30	1,60	0,40	2,90	0,00	40,40	0,90	0,20
Chlorite	5,10	1,70	30,10	7,30	1,00	0,80	0,00	3,10
Bornite	1,00	0,60	0,30	1,60	0,80	0,00	0,30	0,60
Chalcopyrite	3,40	0,00	0,30	0,00	0,10	0,10	0,90	0,20
Carrolite	0,60	0,00	0,10	0,70	0,00	0,10	0,00	0,10
Talc	0,80	3,50	47,60	0,00	1,60	0,00	0,00	1,00
Muscovite	0,00	42,80	3,80	0,00	37,10	0,00	8,10	0,00
Malachite	6,70	13,70	11,60	39,90	4,80	1,10	1,20	1,40
Total	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00

(Source : Kalenga J., 2012)

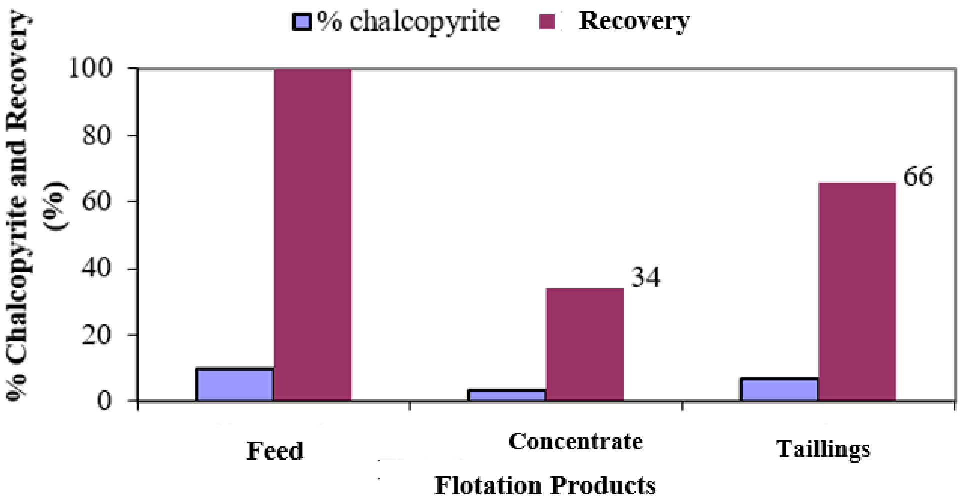

Figure 6: Percentage of chalcopyrite and its recovery in the different flotation products

For these reasons, we will perform differential flotation between sulphide minerals and oxidized minerals. The sulphides will be floated first, then the oxides after activation of their surface by NaHS. This will allow to apply the sulfidation only to the oxidized minerals, and will limit the amount of NaHS. This could optimize the amount of NaHS, as the amount that would otherwise be used unnecessarily for sulphide vacuuming would be saved.

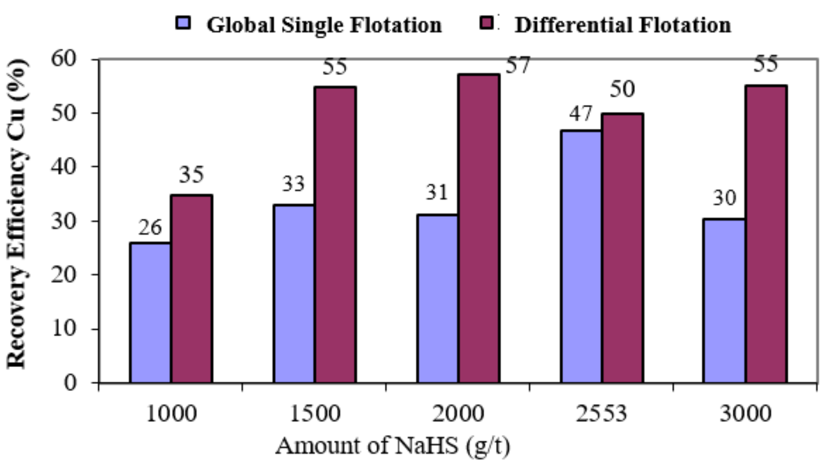

Figure 7: Comparison of copper recovery between global single flotation and differential flotation

Figure 7 shows the overall recovery of copper in different tests as a function of the amount of NaHS used. By observing the different results of the two flotations on the overall ore, it is clear that for the same total amount of

NaHS used, differential flotation recovered more copper than single flotation.

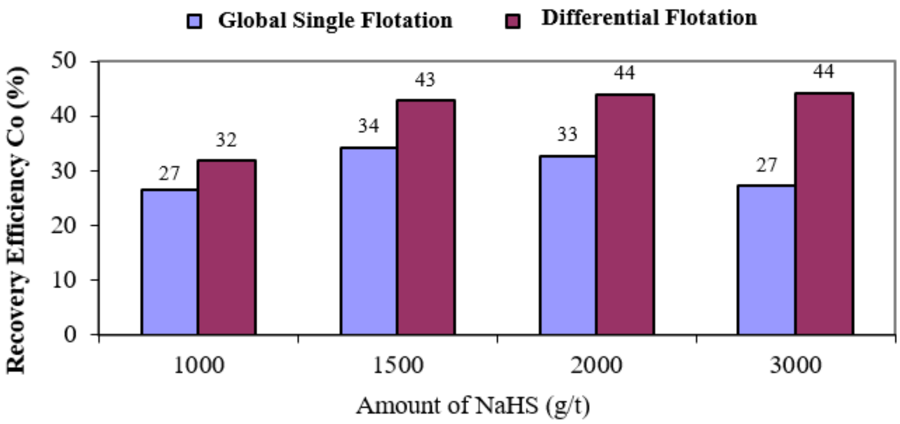

Figure 8: Comparison of cobalt recovery between global single flotation and differential flotation

At 2000 g/t NaHS, the difference in copper recovery between the 2 flotations is the largest, equal to 26%. For the overall cobalt recovery, as shown in figure 8, the differential flotation is even better compared to the single overall flotation. We can state that the optimization of the sulfidation is better when the oxidized copper-cobalt-bearing minerals are recovered separately from the sulfide minerals. For copper and cobalt, we note moreover that at 1500 g/t NaHS, the results are almost equal to those obtained at 3000 g/t NaHS. In other words, at 1500 g/t of NaHS, sulfidation can be optimized through differential flotation. This shows that with differential flotation, it was possible to reduce the sulfidation dose by half.

6. Conclusion and Outlook

In the preceding paragraphs, we have defined ore as any mineral substance that can be mined in an economically viable manner according to the extraction techniques available in time and space. For this, beyond the quality of the ore that must be extracted, quantity is also one of the most important factors when talking about a deposit. This is why the knowledge of mineral reserves is very important for any calculation of profitability. A wrong estimation of these reserves can lead to an abrupt shutdown of the company. We have shown that reserve estimation and planning software has come to the rescue of mines to estimate reserves from drill holes, give the shape of the deposit and even facilitate planning for its exploitation.

In addition to the valuation methods, ore characterization methods, which are very important for a good knowledge of the ores to be processed, must be associated. The evolution of the characterization methods allows to increase significantly the good knowledge of the ores before their valorization for a certain profitability of the mining exploitation. After having identified the recoverable minerals, one can determine their dimensions, in order to see the possibility of their release during fragmentation. Computer tools are also associated with characterization operations to manage grinding or flotation operations.

Currently many mining companies are facing the appearance of mixed minerals with the deepening of their deposits, which will certainly require a good characterization of the latter in order to adapt or find other methods of valorization. It is also within this framework that the Polytechnic Faculty of the University of Lubumbashi has equipped itself with a pilot flotation plant, necessary for the verification of flotation results after laboratory tests, before moving to industrial scale. In addition, several laboratories for materials characterization (materials mechanics, metallography, physical and analytical chemistry, environment) have been installed thanks to ADB funding.

Let us also mention a field of characterization in experimentation, known under the name of Applied Mineralogy or "Process Mineralogy", or more and more currently under the term "Geometallurgy". These are techniques that can allow us to sort the ores already at the mine level, so that we can only transport what is useful and eliminate the waste rock. These are quantitative techniques for characterizing ores, based on quantitative microscopy and digital imaging. Tools predicting the mineralurgical and environmental behavior of raw materials are developed, based on texture criteria (nature of the minerals, particle size, morphology, dispersion in the gangue, etc.). Sustainable development for the survival of future generations depends on good control and correct management of the production of materials, as well as their consumption in our daily lives. Economic growth, in the absence of the objective of human well-being, without renewal of the natural resources indispensable for the creation of wealth, and with the sole aim of short-term profit, is not currently sustainable. Sustainable mining must absolutely participate in social and community development (increased social actions), in the improvement of working conditions, hygiene and health (environmental protection), in the transformation of villages into new towns, and in the promotion of local labor (technology transfer). In addition, it should support the conversion of mining activities to commercial agriculture (food self-sufficiency), and the diversification of economic activities. Finally, good governance in the Republic in general, and in the mining sector in particular, must be the driving force for the sustainable development of the DRC.

In perspectives we suggest an in-depth characterization of the deposits by a combination of characterization methods, but also a combination of valorization methods. It can also be said that the use of FLUOSOLID reactors in Metallurgy is an important route for the transformation of sulphides into oxides as well as the continuous development of Geometallurgy (Kalenga J., 2009).

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