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The technical and economic viability of the re-activation of the Ollomont underground abandoned Cu-mine (Aosta valley – Italy)

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Copper and its alloys are nowadays used for many applications required to support energy transition and their market demand is growing. Due to a still limited re-cycling technology is likely that for the next years the request will be mainly covered by the traditional mining of geological deposits or from the reactivation of abandoned mines.
The costs of extraction and production of minerals through open-pit or underground extraction activity are given by the direct costs of cultivation (e.g. mining operations) and indirect costs which depend on the characteristics of the ore body, including transport, environmental costs for the reclamation and the security of infrastructures.
In this study, the authors developed the assessment of the technical feasibility and economic viability of the re-activation of the Ollomont underground abandoned Cu-mine (Aosta Valley – Italy). The field is located within a metallogenic province of the Western Alps well defined for the presence of Fe ± Cr, Ni-Co, Cu-Fe, Au, Mn, asbestos and talc. The Ollomont mine insists on banks of pyrite and chalcopyrite located in contact between Prasinites and Calcescists. The cultivation activities involved a mineralized strained layer of cupriferous pyrite. The analysis of the geological documentation allows estimating the reserves of exploitable ore still in place to about 20,000 tons at 0.9 ÷ 1% Cu.
Following parametric analysis on the present market current value the price of Ollomont's raw copper can be estimated 67 €/t while the total cost of re-starting of the mining activity can be estimated up to 135 €/t (including profits 10%). Therefore, the hypothesis of reopening turns out to be not sustainable at least in the short term and at the current values.
***Keywords**: underground mine, Cu mine, Ollomont, Aosta valley, Italy.*

1. Introduction

Abandoned mines are an abundant and widespread feature and is a problem that exists in several countries worldwide, occurring for the most varied reasons such as economic oscillations in the ore value, difficulties in complying with mineral and/or environmental legislations, and technical issues. It is estimated that about of 500,000 in the US, 50,000 in Australia, and 10,000 in Canada are the abandoned mines (Gutierrez 2020).

Making land usable again where mining once occurred requires the removal or minimization of such hazards. Whenever possible, the conversion of these sites and their mining wastes into valuable assets is sought.

However, abandoned mines are the source of multiple hazards, from collapsing of tunnels and shafts to contamination of soils, streams, and groundwater; in fact, a common characteristic to almost all cases is the environmental footprint that is left behind, which can cause strong environmental impacts in various ecosystem compartments such as surface and groundwater contamination, air pollution, soil degradation, as well as endangering the native fauna and flora (Perlatti *et al*., 2021; Bottero *et al*., 2020).

Inactive mine landscapes can be dramatically changed via waste disposal, polluted air, soil and water, and socioeconomic and/or cultural impacts. These impacts are not restricted to immediate mine areas but can extend well beyond to surrounding environments and communities. Recognizing this, in general the states and territories have established a series of programs to assess the risks posed by abandoned mines and to prioritize funding for their management.

These efforts have mainly been conducted independently, resulting in different reporting practices and classification schemes adopted between jurisdictions (Werner *et al*., 2020).

The Valle d'Aosta region (Western Alps, north-eastern Italy) has been an important mining and metallurgical center until the second half of the XX century, as testified by numerous mines and metallurgical sites (Toffolo *et al*., 2018). In some part of Aosta Valley there are a lots of copper mines, same of this are abandoned.

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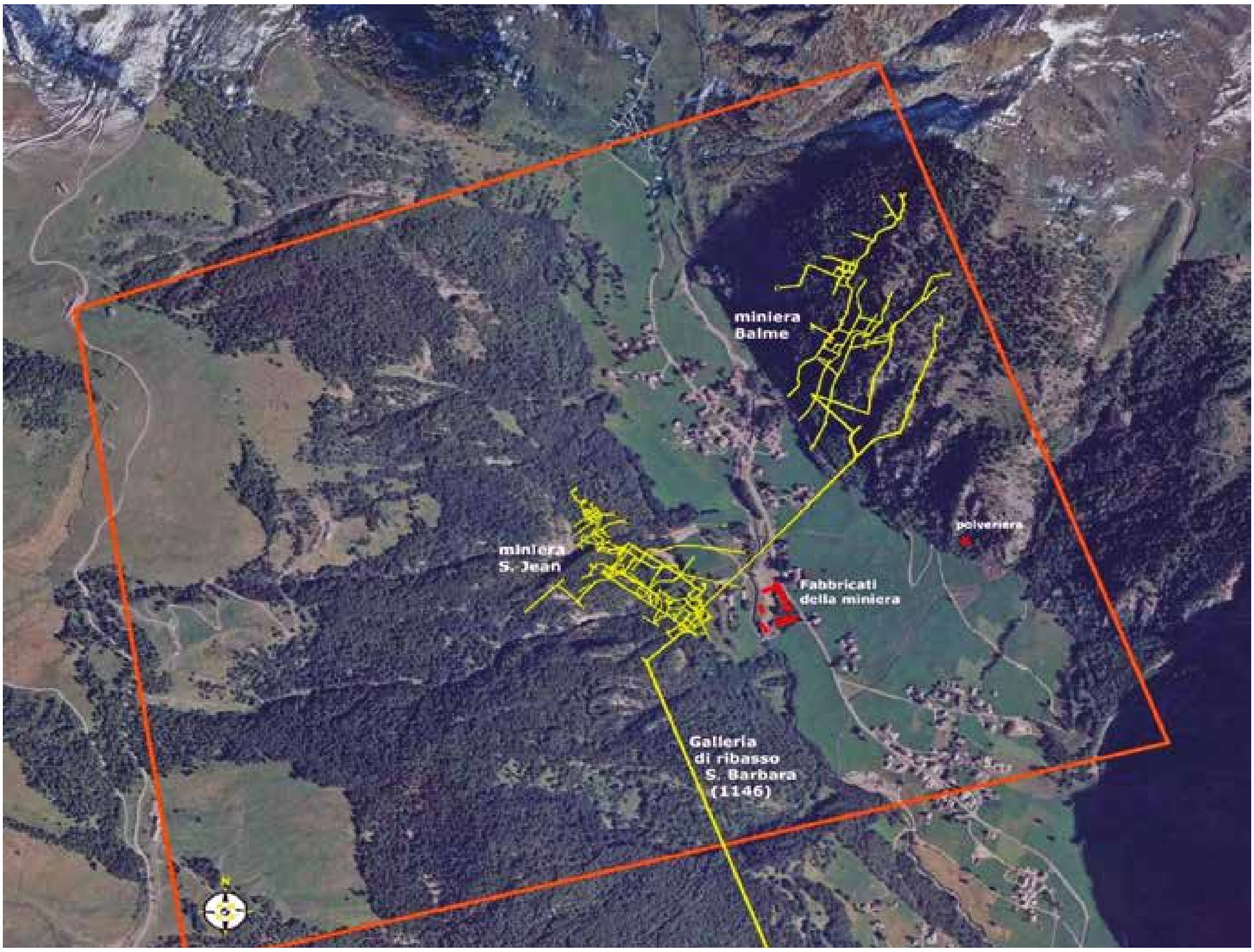

Fig. 1 – Location of Preslong mine (Saint Jean mine, Balme mine, Vaux mine o Vaud mine).

In the present work the research was focused on evaluating the cultivability in the hypothesis of a possible resumption of the mining concession in question considering the current and future technical-economic situation of the mining activity.

2. Methods

2.1. Study area description: the Preslong mine in Ollomont area

The Preslong mining complex is located within the territory of the Municipality of Ollomont, on the border with the Municipalities of Doues and Valpelline in the Aosta Valley. The mining works refer to a time span that includes about three centuries, involving three distinct sections: Saint Jean mine (San Giovanni), Balme mine, Vaux mine (o Vaud mine) (Fig. 1).

Historical background

According to Jean-Baptiste de Tillier, the mine was discovered in 1699 by Colonel De Tilllier in the territory under the jurisdiction of Count Carlo Filippo Perrone di San Martino (1653-1719), Baron of Quart. In reality, it is probable that this date corresponds only to an official deed of discovery of an already known deposit, perhaps even from the time of the Salassi (Engasser, 1909).

The vein seemed to have run out in 1720, but during 1728 year volumes and tenors were discovered in its upper portion, so than it was possible to proceed with the exploitation of the deposit (De Tiller, 1737).

In 1808, Argentier wealthy shopkeeper from Aosta, intervened inside the mine by building a large water wheel, to which a machine was connected for the extraction of infiltration water in the main tunnel. It also achieved the construction of a grinder for the beating of the mineral and a laundry. In 1818 Argentier ceased its activity, and the management of the entire mining area was taken over by Matteo Negri di Cuorgnè, director of the creditors' company of the bankrupt Argentier company (Turin State Archives, 1881). The new dealer left the business in 1831.

With the Royal Patent of 18 December 1849, the mine was granted to the family of General Barrane Ettore Perrone and his relatives (BRA 7). The following year, the Perrons rented the mine to Count Victor Seyssel d'Aix, who formed a partnership with Count Roberto De Cornelissen, Cavalier Giuseppe Zarnan, Cavalier Giuseppe Ponzio Vaglia and Filippo Oggero.

On April 22, 1901, the heirs of Count Perrone di San Martino ceded the mining area of Ollomont-Preslong to the lords Elzario Alda and Gaetano Favini. The latter then formed a partnership with the cav. Giuseppe Rotta, giving birth on 14 December 1903 to the Copper Mines Company of Ollomont G. Rotta & C. (CRIA, 1903). In 1905, 189 workers were employed and 150 tons of ore were extracted: pyrite with 45% sulfur containing a minimum of 4% to a maximum of 8% copper.

The workforce reached 400 units, afterwards, from 1909, it settled down on an average of 300 people. In 1915, after five years of important preparatory work that had involved a considerable commitment of capital, the Società Anonima Miniere di Ollomont decided to suspend the activity due to the impossibility of understanding whether the field was rich enough to maintain the colossal plants built.

On 26 July 1929, Società Anonima Minere e Fonderie di Valpelline was incorporated into the Cogne National Anonymous Company (CRIA, 1929). In 1937 the mine started again. Two years later, the production was implemented with a laundry section for the differential fluctuation of pyrite and chalcopyrite. In 1940 the other section was activated in parallel (Turin Mining District, 1950). The mine was exploited by the Cogne National Society for the entire period of the Second World War. In 1943 an extraction winch came into operation allowing the lower levels access. The exploitation continued until 1945 when the progressive exhaustion of the veins caused the interruption of the cultivation works, shortly after the mine was definitively closed (Valle d'Aosta Autonomous Region, 2018).

Preslong mine

The three m8ining sections were explored in different ways and at different times during the 18^{th}, 19^{th} and 20^{th} centuries. In accordance with the Turin Mining District 1920's documentation, the Ollomont mines were included in an area of 320 hectares. The original concession was subsequently supplemented approximately 575 hectares. This permit perimeter extended from the Ollomont village to the Valpelline village and perhaps it has been requested in order to drill an approximately three-kilometer drop tunnel (Ribasso di Frisonia) which would have reached the base of the deposit approximately 200 meters below the existing crops starting directly from Valpelline (Fig. 2).

The field is divided into three cultivation mines.

1. The Saint-Jean mine: the oldest and most important one, it is

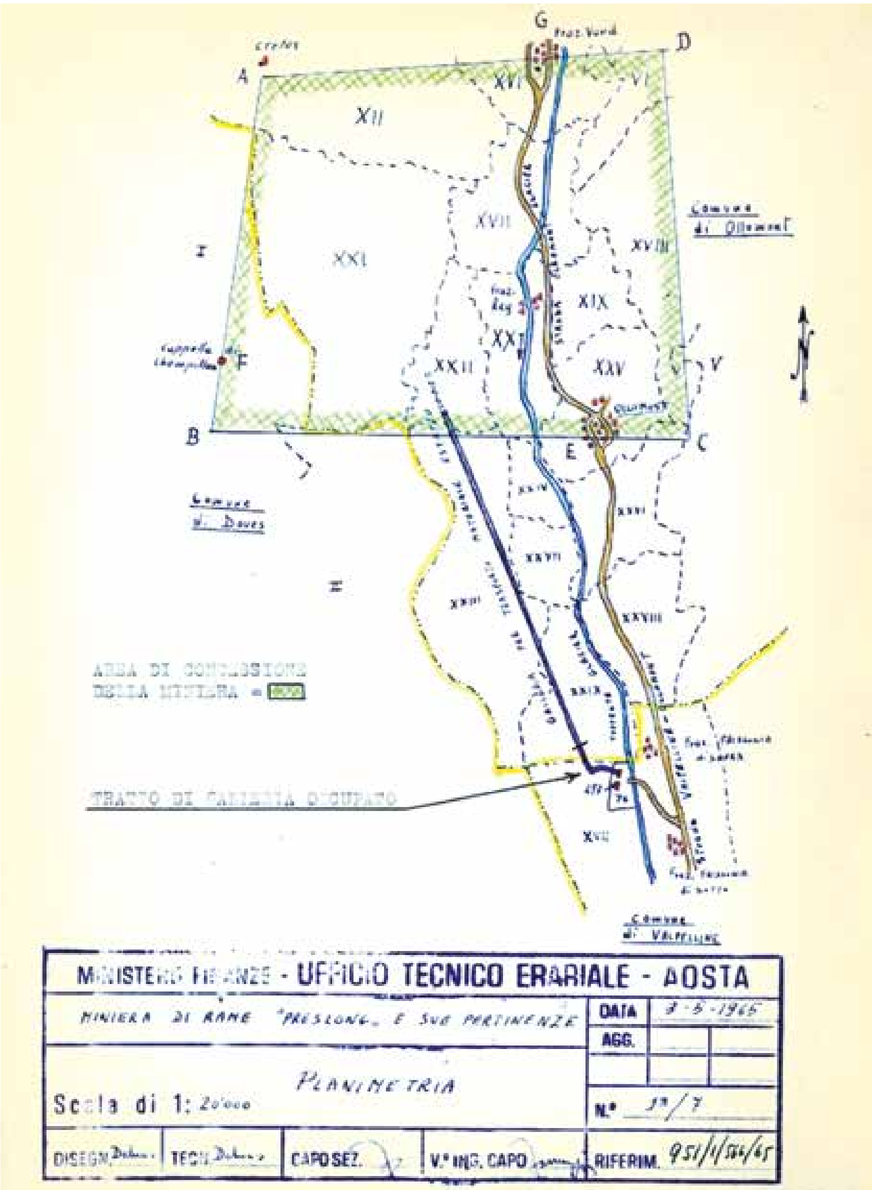

Fig. 2 – Scheme of a Preslong mine exploitation.

located on the orographic right side of the Buthier stream, near the village of Rey. The mine is developed on different levels (Fig. 3), the exploitation of the mine interests a range depth between 1026 and 1640 and is in communication with the mine of Balme. Following continuous flooding, the mine was permanently closed.

2. The Balme mine: this mine is located on the left orographic side of the stream, at an altitude of 1,400 m. The mine appears to be organized in different levels of tunnels. the exploitation of the mine involved a depth between 1147 and 1514 m. Also in this case, following the renunciation of the concession by the National Cogne Society, the entrances of the mine were locked.
3. The Vaud mine: 600 meters further north of the Balme mine there is the Vaud mine that is located on the left orographic side of the stream at an altitude of 1,570 meters. Due to repeated collapses, the entrance to the Vaud mine currently is no longer accessible. The impossibility of carrying out inspections inside the mine makes it impossible for any type of assessment of the conditions of the mine underground part.

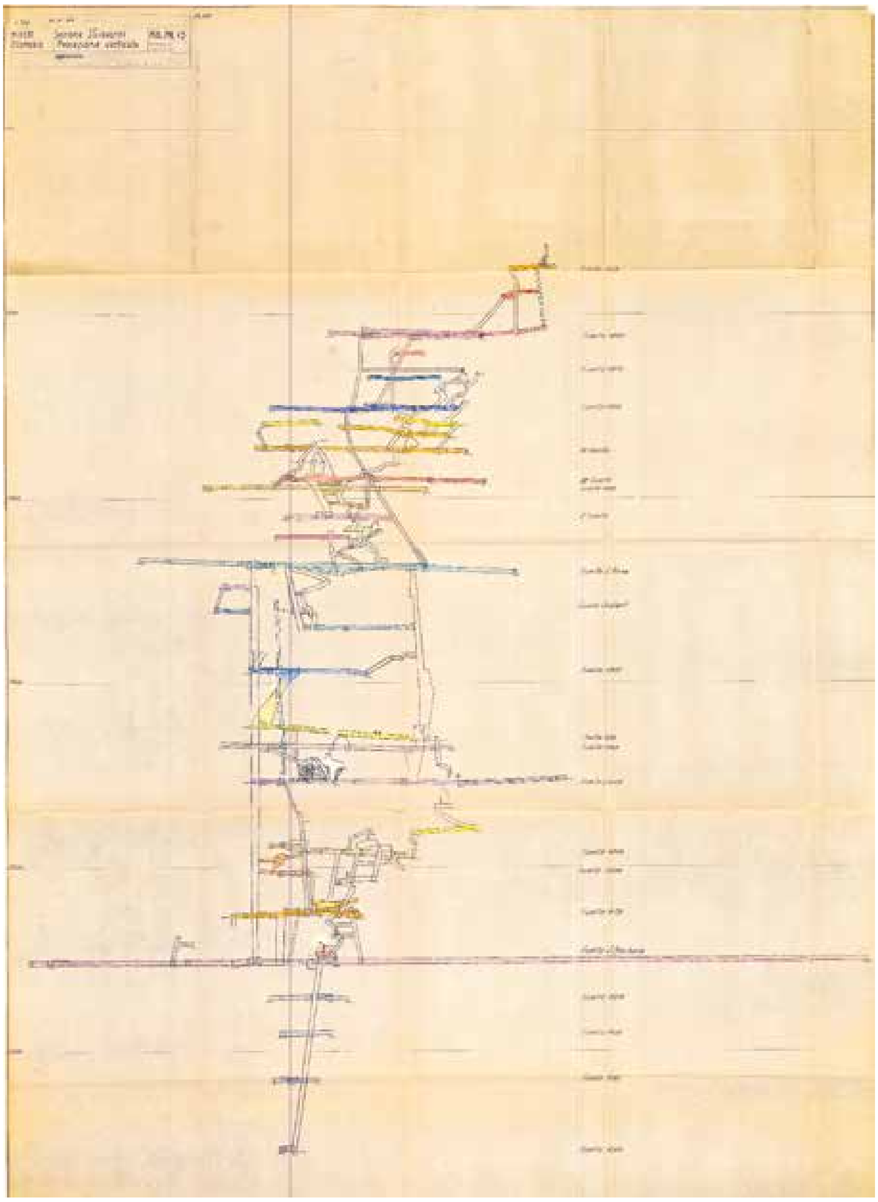

Fig. 3 – Vertical section of Saint-Jean mine (1940 year).

2.2. Preslong geological setting

The mining site is located in the metamorphic setting of the Western Alps, in particular at the margin between the Austroalpine tectonic domain and the Pennidic domain (Fig. 4).

Analyzing the Geological Map of Italy, scale 1: 100,000 – Aosta Sheet No. 28, the deposit appears to be located within the Piedmontese Area of Calcescisti with Green Stones (Pennidic Domain). This tectonic unit includes fragments of oceanic crust and a sedimentary Mesozoic cover characterized by calcescists (the "Schistes Lustrés" of French literature). In Fig. 5 there is an extract of the map, with the relative legend of the lithologies emerging. Specifically, the sector is affected by the outcrop of Calcescisti and phyllites (cs), prasinites and amphibolites (ρ) and by the presence of Quaternary moraine deposits (mo) in the valley floor. Saint Jean and Balme mines, indicated by special symbols in the geological map, are located on the border with the Dente Blanche System (Austalpine Domain) which is represented by porphyroid granites belonging to the Arolla Series.

The mineralization

The field of study is located within a well-defined metallogenic province of the Western Alps characterized by the presence of Fe ± Cr, Ni-Co, Cu-Fe, Au, Mn, asbestos and talc (Piedmontese area of calcescists with green stones). The Ollomont mine insists on pyrite and chalcopyrite banks located in contact between prasinites and calcescists; deeper, there are layers

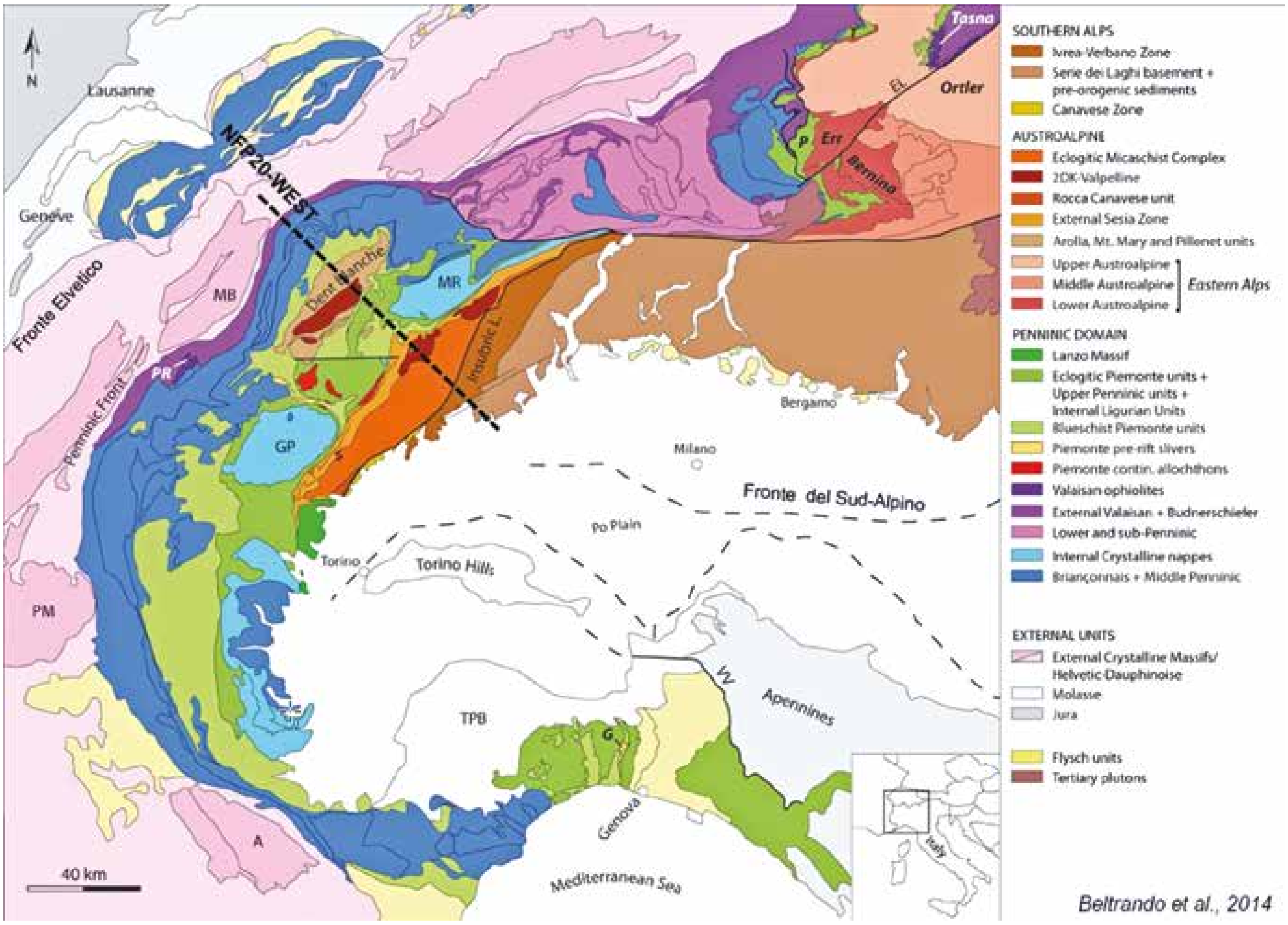

Fig. 4 – Tectonic Map of Alps. A: Argentera massif; G: Gazzo – Isoverde unit; GP: Gran Paradiso unit;MB: Mont Blancmassif; MR:Monte Rosa unit; P: Platta unit; PM: Pelvoux massif; PR: Punta Rossa unit; TPB: Tertiary Piemonte basin; VV: Villavernia – Varzi Line (Beltrando *et al.*, 2014).

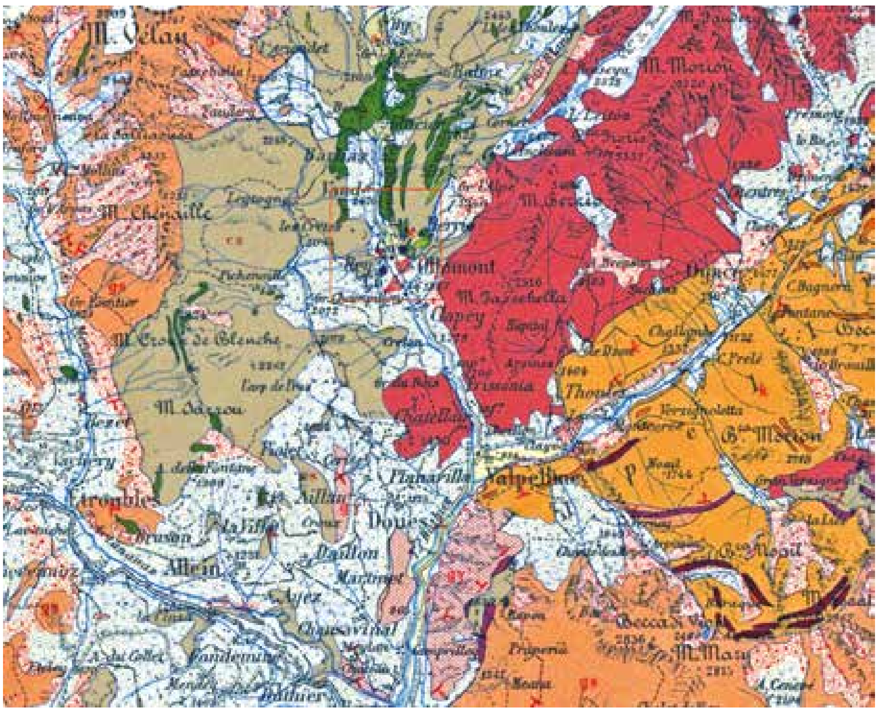

Fig. 5 – Extract of geological map at 1:100.000 scale – Aosta sheet No. 28. This extract not in scale (geologia VDA).

of serpentine interspersed with porphyroid granite.

From the past cultivation reports available, it appears that the field is housed in chloritic ovarditic iron garnet schists, inclined from West – South West of 40°. The power of the chalcopyrite mineralized layer is about 3 meters, with a percentage of copper ranging from 3% to 4.5% of the weight. The auriferous type chalcopyrite is accompanied by pyrite and hydrated copper carbonates. Locally, it was possible to find native gold in plates in the quartz present in the gangue. At the time of the declaration of renunciation by the National Society of Cogne in 1952, the field cultivated in the Saint Jean mine consisted of six seams and veins, affected by sub-horizontal faults, extended in the NE-SW direction on average of 100 m with immersion SE and of the average power in the lower levels of 0.7 m, ranging from zero to the peak of 1.5 meters.

2.3. The economic evaluation: the value of minerals trends, copper production and extraction cost at the international level

Currently, the trend of copper production is largely influenced by the two main world producers: Chile and Peru (ICSG, 2019a), which in the last years have been affected by many negative shocks related to economic supply.

As a consequence, it is clear that before undertaking investments and actions in the market of any mineral, it is necessary to know not only the market price and production levels but also the global geo-political scenarios of both the raw material market and the related political situations.

Figure 6 represents the trend of copper production in the decade 1995-2014. In particular, it underlines the considerable instability of the global copper market and its price, in fact, in the face of constant growth in production, the unpredictability of the sale and purchase price is observed. While on the one hand, the "selling price" factor is obviously one of the criteria that condition the cultivability of a mineral deposit, on the other hand, it is a parameter that has probably undergone the most abrupt fluctuations over time, also in relation to geopolitical crises and financial markets worldwide.

It's worth not neglecting that China is central in the world copper market, indeed, not only it represents one of the largest copper producers in the world, but also it is the largest importer. In fact, given the high demand, China is forced to turn outside to meet demand. This slowdown was also evident in copper sales prices, reaching an average annual value of less than USD 5,000/t in 2016. In recent years (2016-2020), the price of copper has seen a slight decrease, however not as critical as in 2016. This shows that China's current slowdown is less intense than that of the previous cycle.

Chile, Peru and China are the global key-players (Fig. 7) with percentages of global production in 2018 of 28.3% 11.8% and 7.9% respectively, while in Europe only Poland and Spain have noteworthy productions.

Figure 8 shows the extraction capacities of the world's largest copper mines. The order of magnitude of Copper capacity of these deposits reaches up to 100,000 tons (Ollmond Copper capacity is estimated at about 200 tons).

The cost of extracting and pro-

Fig. 6 – Graph showing the trend of copper production in the global market and the price fluctuation (ICMM, 2014).

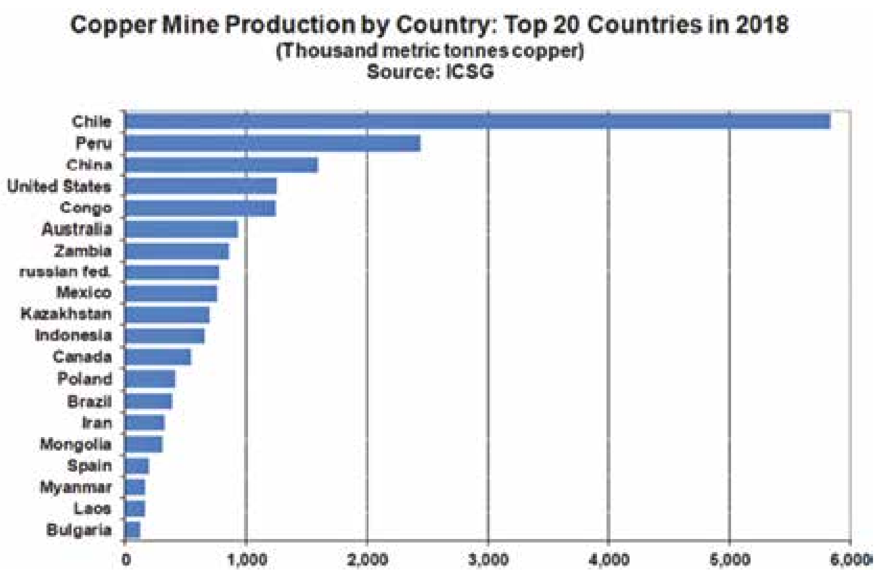

Fig. 7 – World copper production data (ICSG, 2019a).

Top 20 Copper Mines by Capacity (basis 2019)

Thousand metric tonnes copper

Source: ICSG Directory of Copper Mines and Plants – H1 2019 Edition

Rank	Mine	Country	Owner(s)	Source	Capacity
1	Escondida	Chile	BHP Billiton (57.5%), Rio Tinto Corp. (30%), Japan Escondida (12.5%)	Concs & SX-EW	1,400
2	Collahuasi	Chile	Anglo American (44%), Glencore plc (44%), Mitsui (8.4%), JX Holdings (3.6%)	Concs & SX-EW	570
3	Buenavista del Cobre (former Cananea)	Mexico	Grupo Mexico	Concs & SX-EW	525
4	Morenci	United States	Freeport-McMoRan Inc 72%, 28% affiliates of Sumitomo Corporation	Concs & SX-EW	520
5	Cerro Verde II (Sulphide)	Peru	Freeport-McMoRan Copper & Gold Inc. 54%, Compañia de Minas Buenaventura 19.58%, Sumitomo 21%	Concentrates	500
6	Antamina	Peru	BHP Billiton (33.75%), Teck (22.5%), Glencore plc (33.75%), Mitsubishi Corp. (10%)	Concentrates	450
7	Polar Division (Norilsk/ Talnakh Mills)	Russia	Norilsk Nickel	Concentrates	450
7	Las Bambas	Peru	MMG (62.5%), Guoxin International Investment Corporation Limited (22.5%), CITIC Metal Co., Ltd. (15%)	Concentrates	430
9	El Teniente	Chile	Codelco	Concs & SX-EW	422
10	Chuquicamata	Chile	Codelco	Concs & SX-EW	390
11	Los Bronces	Chile	Anglo American 50.1%, Mitsubishi Corp. 20.4%, Codelco 20%, Mitsui 9.5%	Concs & SX-EW	390
12	Los Pelambres	Chile	Antofagasta Plc (60%), Nippon Mining (25%), Mitsubishi Materials (15%)	Concentrates	370
13	Kansanshi	Zambia	First Quantum Minerals Ltd (80%), ZCCM (20%)	Concs & SX-EW	340
14	Radomiro Tomic	Chile	Codelco	Concs & SX-EW	330
15	Grasberg	Indonesia	PT Freeport Indonesia (PT Inalum and the provincial/regional government 51.2% and Freeport-McMoRan Inc 48.8%)	Concentrates	300
16	Kamoto	Congo	Katanga Mining Ltd (86.33% Glencore plc) 75%, Gecamines 25%	SX-EW	300
17	Bingham Canyon	United States	Kennecott	Concentrates	280
18	Toquepala	Peru	Southern Copper Corp (Grupo Mexico 88.9%, international investment community 11.1%)	Concs & SX-EW	265
18	Sentinel	Zambia	First Quantum Minerals Ltd	Concentrates	250
20	Olympic Dam	Australia	BHP Billiton	Concs & SX-EW	225

Fig. 8 – Copper mines and their capacity(ICSG, 2019a).

ducing any mineral in an open pit or in underground mining activity is given by the direct costs of cultivation concerning direct mining operations (which also considers the cost of labour and energy) to which various indirect costs must be added that depend on the geographical position of the field, including transport costs, environmental ones (which are particularly critical in areas with a high landscape value such as that in the case of study), restoration costs of sites and safety of infrastructures (Fig. 9).

The cost of extraction is highly related to the location of the reservoir, whether on the surface or underground; usually direct operations of open-pit cultivation are cheaper than those underground while environmental restoration costs tend to be higher for open pit mines rather than underground mines. The reference data for copper crops in the world are reported below (Fig. 9).

Open Pit Mine	
Country	**Average cost (USD/ton)**
Canada	3,70
Chile	7,20
Messico	2,95
Perù	8,26
Filippine	4,20
Stati Uniti	4,91
Jugoslavia	4,14
Altri	9,05
Total average cost: 5,80 USD/ton	

Underground Mine	
Country	**Average cost (USD/ton)**
Australia	26,00
Canada	30,94
Chile	7,95
Filippine	5,49
Stati Uniti	9,46
Zaire	28,66
Zambia	23,31
Altri	18,87
Total average cost: 16,32 USD/ton	

Fig. 9 – Average cost of copper extraction for day cultivation in open pit mine and underground mine (Porter and Patterson, 1992).

3. Results and discussion

3.1. The resources estimation

In order to define the current situation of the residual deposit was necessary to examine the bibliographic documentation due to the complete impossibility of direct access to the underground areas of the various mining sites. Without the possibility of acquiring new information with in-situ sampling, it has been taken into account the estimation already made by Eng. Tissi in 1952.

Taking into account the geology and deposition of the area, he assessed that the possible extraction ore availability was about 20,000 tons, with a tenor of Copper around 0.9 ÷ 1%. Therefore, the Outcome of copper weight value is equal to 200 tons.

As can be seen from the international evaluations of the mineral, the most important mines in the world have copper capacities 3-4 orders of magnitude higher than the Ollmont field. The real difficulty, in this case, is to set up a massive extraction with such a low copper content and reduced power.

Italy is not identified as a key country in the production of copper on an international scale, resulting in an importing country. For this reason, having to refine the analysis at very low production levels, the distribution of mines at a national level was analysed in order to better understand the potential of the Ollomont site in the context of Italian mining activities in this market, which, as it was mentioned before, is very uncertain and financially risky.

The known deposits in Italy that had led to the exploitation of mineral which copper was extracted as main product or as a by-product are the following (Ispra, 2006):

- Alta Val Sesia (Vercelli, Novara): gold, copper, iron and manganese
- Caporciano (Pistoia): copper
- Gares (Belluno): copper and iron
- Montecastelli (Pisa): copper
- Predoi (Bolzano): copper
- Sulcis-Iglesiente (Southern Sardinia): coal, lead, silver, zinc, iron, copper and barium.

ISPRA and ISTAT data indicate that these fields are no longer active or in a state of production due to the high cultivation cost (ISTAT, 2019). The relatively modest size of the number of mineralized masses requires a particularly expensive mining operation.

Unsurprisingly, the Ollomont mine/field is not even considered by these recent analyses, both for the negligible reserves and for the complexity of restarting cultivation in a thin strand type deposit.

it is interesting to recall a recent study related to the economic feasibility assessment of the project to open the new underground mine in Black Butte in the state of Montana (US) (Tetra Tech Wardrop, 2012). It is not irrelevant to underline that this site has reserves of over 12 Mt with an average copper tenor of around 3% (about $ 243/t). The richest portions of copper are lenses with powers of 28 m and 100 m. This is a situation in which it is possible to set up a massive type of cultivation, very different from what would be possible to do in the case of the reopening of the Ollomont mining site, which instead is characterized by strands of definitely more limited power. In a nutshell, this American mine is expected to have an average cost of extraction of the ore equal to 48 USD/t, therefore with revenues of around 195 $ for each ore ton processed. The total income of this potential mine activity can be roughly estimated at around 2 Billion dollars.

3.2. Extracting costs of the case study on the basis of current international parameters and techniques used nowadays

In relation to the aspects of mining cultivability of the deposit made up of reduced power veins, it is observed that modern extraction techniques include infrastructures with dimensions far greater than those that were present on the site since the mechanical means are currently much larger than those of the past. On the other hand, because of the long period of abandonment, these old infrastructures cannot be reused immediately but only after major renovation and rehabilitation of the support techniques based on modern technologies and safety requirements for personnel. Furthermore, the fact that many infrastructures are not accessible or have been flooded for a long time confirms and corroborates the aforementioned observation. With the prospective of a possible reopening, it must be considered that the entire infrastructure network would need to be rethought to make it compatible with the size of modern vehicles and with the use of supports and reinforcements of the rock. This could only result in a huge operation before the work starts.

Similar considerations should also be referred to the extraction and ventilation systems that should be redesigned for the renewal of cultivation. Moreover, the cultivation of low-power veins shouldn't be considered feasible for mineralization of medium-low specific value of the mineral since it would be necessary to achieve large volumes breakdown in order to reduce operating costs. This choice inevitably leads to the tenor decrease of the raw material as a consequence of the encasing rock abatement besides the vein, with inevitable economic repercussions. Eventually, the opening of new infrastructures would inevitably interfere with the existing mining voids and tunnels, creating interference and potential instability problems during excavation and operation.

Considering the aforementioned elements, it is extremely complex to come up with an analytical cost estimation since it would be necessary to draw up a detailed cultivation plan which, as evident, should include the complete reset of the mine. As already described, it is not possible to reuse the existing infrastructures and the tracing and access tunnels built in the past as they were partly flooded or collapsed and partly of dimensions no longer compatible with modern cultivation techniques. It was therefore decided to carry out evaluations conducted on a comparative basis:

- the cost of the mineral extracted if cultivated with a modern approach can be estimated at 45 €/t, increased by 10% due to the technical difficulties of the excavation on low-power veins, to reach therefore, in the case of study, a cost of 50 €/t.
- For the case under examination, it is worth considering an initial investment cost of the order of 15€/t since it is not possible to reuse the existing infrastructures. Due to the high quality of the surrounding landscape, for the Ollomont mine infrastructure should be located underground in order to minimize visual impacts on the environmental system. In this sense, it would be necessary to create caves and underground voids of sufficient size to house the infrastructures for the mining of the mineral; such interventions would further affect the initial investment cost.
- As far as indirect costs are considered, they are related to: transport, general charges (marketing, easements and extraordinary maintenance of local roads) and to the costs for the construction and arrangement of a possible tailings dump, which in the case in question could be very difficult to achieve due to the absence of suitable spaces and the high environmental impact connected. Grounding on similar cases it is possible to state that the totality of indirect costs covers about 70% of the cost of extraction, for a total value of 35 €/t.
- Further cost are related to the refining process of the raw material that is applied to recover a more concentrated material with 25-30% Cu content. These process costs can be increased by at least 30% due to the inadequacy of the already existing plants, which for such processes should be replaced or fully integrated. The process cost would therefore be around 16 €/t
- Different sources attribute a profit margin of similar activities equal to 20% of the selling price; reducing this margin to only 10-15%, it is traduced into a cost of 10 €/t
- In relation to the current economic data of the average prices relating to the raw ore, it turns out the average Copper price is about 6,665 €/t. In the case of the Ollomont mine, considering the Cu content equal to 1%, it should be reached proceeds of approximately € 67 for each rock ton processed.

In the light of the aforementioned consideration, the economic assessment of the Ollomont mine can be summarised in the following parameters:

- Overall extraction cost per ton = 126 €/t.
- Revenue per ton = 67 €/t.

Under these assumptions, the fair return on the risk capital invested does not seem to be guaranteed, making no-convenient the cultivability and the resumption of mining.

In any case, it should also be emphasized that this is an underestimated evaluation as environmental costs due to the negative impacts of the mining activity on the surrounding environmental system were not explicitly considered in the calculations.

4. Conclusion

This work presents the fundamental steps to analyse the possible reopening of a mining activity, proposing a guideline/scheme that allows the interpretation of any case study regardless of the quality and quantity of information available and regardless of the region, nation or geographical position where the concession is located.

The approach is independent of the choice of conducting the analysis on the basis of bibliographic data or on the basis of accurate data provided by survey campaigns.

This methodology allows the researcher/professional/company to choose the accuracy with which to guide the evaluation of the possible reopening, therefore simplifying at its discretion based on the information obtained and the relevance of the case.

In this case, the analysis was conducted exclusively on the basis of bibliographic information, which, inserted in the current context and in the proposed methodology, led to the final conclusion of the impossibility of restarting the mining activity.

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