Recovery of Tungsten, Niobium and Tantalum occurring as by-products in mining and processing waste streams

(TARANTULA)

D2.2 Directory of W, Nb and Ta occurrences in current and former mines in the EU

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ABBREVIATIONS AND ACRONYMS

BRGM	Bureau of Recherches Gèologiques et Minières
GIS	Geographic Information System
GKR	Global Knowledge Representation
ICP	Inductively Coupled Plasma
IT	Information Technology
LIPS	Laser-Induced Plasma Spectroscopy
NICT	National Institute of Information and Communication Technology
OECD	Organization for Economic Co-operation and Development
REE	Rare Earth Elements
SLO	Social License to Operate
SME	Small and Medium Enterprise
WGS	World Geodetic System
XRF	X-Ray Fluorescence

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EXECUTIVE SUMMARY

Refractory metals are essential to achieve the energy transition. However, they are almost exclusively imported when there is strong geological potential in Europe. The rational exploitation of this potential is therefore a necessity for European industries, the crisis linked to COVID-19 having painfully recalled it.

Europe's new 2023 recommendations to produce on its territory 10% of the metals necessary for the energy transition and refine 40% of its needs are the results of this awareness.

Going back to the past to identify these potential tungsten resources is easy. Indeed, by the end of the First World War, a significant research effort had been undertaken for this metal and very many companies qualified today as SMEs had undertaken its exploitation.

Finding tungsten today involves first identifying known deposits and occurrences in order to determine their potential in the light of the latest knowledge acquired in metallogeny and mineral processing. The dumps and tailings to be reprocessed will therefore be primarily those of these former tungsten mines.

Niobium and Tantalum have only had real industrial applications for a few years, and for a long time the needs were met by the extraction of an ore generally concentrated in placers, columbo-tantalite. Thus, there are very few known old underground mines of Nb-Ta in Europe. If we exclude the Nordic countries, where geology favours the presence of alkaline complexes and therefore the discovery of specific Nb-Ta deposits, the search for potential resources goes through the recognition of deposits already exploited for other substances, but containing various proportions of Nb-Ta not valued by the ore treatment then used.

Thus, country by Country, we are establishing an exhaustive inventory of old mines and more recent discoveries for tungsten, but also for tin, titanium and Rare Earths whose deposits occasionally contain economic concentrations of Niobium and / or in Tantalum.

This study details the models of deposits concerned and the mineralogical guides described in deliverable D2.3 which make it possible to select among them those whose potential could be the most interesting.

The results are provided, together with the present report, in the form of Excel tables and Google Earth (.kmz) files in the Appendices.

Information relating to past mining research work is generally very heterogeneous and scattered. If finding this information relating to an identified target is often possible, using it as a criterion to make target selection is particularly difficult and constitutes an obstacle to the development of mining activity.

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To get around this difficulty, E-Mines will provide an interactive map readable under Google Earth. This map will present the user with the necessary links to directly access the source of the information that will be broadcast in the tooltips. The mining targets will be prioritized by a score that can be interpreted in terms of probability of success in the event of resumption of their exploration.

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1. INTRODUCTION

Europe has been the subject of intense mining activity since the 19th century, and today we can identify around 4,000 sites having known a form of exploitation or exploration of these metals.

The twentieth century saw the almost systematic closure of all the mines concerning them. These metals, essential to the rise of high technology and the energy transition are now imported, mainly from China.

In addition, awareness of environmental problems has been accompanied by extreme distrust among the public with regard to mining, which is considered to be eminently polluting and a remnant of days gone by. The ignorance of this activity reinforces this feeling and it must be taken into account that almost all the remaining mines having closed in the 1980s, there is today in our territories no witness of this activity under the age of 40 years.

If today we can regret the inconsistency of certain radical positions (these critical metals being essential to the advent of an eco-responsible society but we do not want to extract them from the ground), the fact remains that a reflection must be carried out on how to obtain them while minimizing the environmental impact to achieve them.

In addition, the repeatedly repeated discourse on new technologies and the strict application of environmental regulations is struggling to receive public acceptance, which cannot refer to recent examples of this activity in our territories.

Recycling provides a partial answer to the problem of supply; however, it mainly applies to the final products of the industry, and the recovery of waste from the old mining activity has hardly been addressed.

The experience of public meetings which accompanied the demand for mining titles in France in the period 2011 - 2016, shows that a large part of public opinion would not be unfavourable to the resumption of extraction on an old site, if prior restoration of previous pollution was carried out. Indeed, a society capable of restoring an environment contaminated by an old exploitation is therefore, by definition, capable of extracting the ore without contaminating its environment if it wishes to do so. Thus, at the territorial level, the social acceptability of a mining activity would seem to be closely linked to the ability to reprocess old mine wastes.

TARANTULA intends to draw up an exhaustive inventory of the sites which can be the subject of a reprocessing of mining discharges from former operations within the framework of a virtuous activity allowing:

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- The recovery of metals essential to our industries and today "wasted".
- Environmental restoration of formerly polluted sites.
- The dissemination of a positive image of the extraction of these metals

The historical data of former operations do not reflect their current mining potential, the economic and technological parameters having changed very drastically since their closure.

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2. TASKS DESCRIPTION AND RESULTS

This report explains the different stages of the method used to identify and prioritize refractory metal resources in Europe.

The first step is to establish which models of deposits are likely to supply these metals. Indeed, it should be noted that Nb and Ta can be contained in deposits exploited for other substances, but also that all the deposits containing these substances are not likely to contain Nb or Ta; this probability depends very largely on the metallogenic model.

The second step is to analyse the state of the resource, proven or simply assumed, from the stage of progress of the work which concerned it. This work can vary from simple geological prospecting to mining. In each case, we will examine the secondary resources (dumps, tailings, stocks, etc.) which could be valorised. A classification and prioritization of all mineral occurrences or deposits constitutes this second step.

The third step is concerned with the economics of the treatment to be applied. The refractory metals contained in the deposit or the mine tailings can represent too low an economic stake to justify processing or reprocessing. It is therefore important to anticipate what other resources could be jointly valued in order to make the economy possible.

The fourth step is to anticipate the environmental impact of the reopening of an old mine or the recycling of dumps. For this, it will be necessary to look for the contaminants in the minerals present in the ore or the gangue. For this, we integrate into the study the results of the mineralogical syntheses obtained in Task 2.2

The fifth step consisted in bringing together within a single IT structure, the GKR, a maximum of deposits and occurrences likely to be of interest for refractory metals. Thus, around 4,000 targets out of more than 68,000 have been previously listed. However, the corresponding files, coming from a wide variety of sources, have been checked, updated, harmonized and ranked.

The sixth step was to produce an interactive cartographic document to allow the user to immediately access all the information concerning the indicated resource by merging the detailed results of Task 2.1 and Task 2.2. The choice was made for a Google Earth representation usable by the widest audience.

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2.1 GEOLOGY OF THE W, NB, AND TA DEPOSITS

Tungsten, tin, niobium and tantalum are closely associated in the deposits. An excellent synthesis of their geology is summarized in the book "Geology of Mineral Resources" whose definitions we will summarize here (Annex p.37).

The metallogenic (gitological) model is an essential element in anticipating the mining potential of a deposit. Indeed, this model can make it possible, to a certain extent, to anticipate the size of the deposits, the nature of their content, the probable type of exploitation and the environmental problems associated with their exploration and later their exploitation.

The main difficulty in establishing them comes from the frequent confusion with the type of deposit which associates metal content with a mineral body morphology. Thus, the types of deposit can be identical, but belong to different models and therefore present different mining potentials (Table 1).

TABLE 1. Refractory metal deposits

Métallogenic model	Type of deposit	Main ore	Valuable
Granite pegmatites	Pegmatite	Sn, Nb, Ta, Li, Be	
W-Sn Cupolas	Quartz vein W (Vein Field) Quartz vein Sn-W (Vein Field) Greisen Breccia Pipes Stokscheider pegmatite	W W, Sn Sn, W, Nb, Ta, Li W, Sn, Nb, Ta Sn, W	Au Au, Nb, Ta
Skarns W	Skarns Mantos	W W	Au, Ag, Cu, Mo Au, Ag, Cu, Mo
Carbonatites	Stratiform	REE, Nb, Ta	
Nepheline syenites	Magmatic intrusion	REE, Nb, Ta	
Peralkaline granites	Magmatic intrusion	REE, Nb, Ta, U	Sn, Zr, Be, Pb, Zn
Peralkaline pegmatites	Pegmatites	REE, Nb, Ta, U	
Placers Sn-Ti	Placer	S, Ti	Nb, Ta

The analysis retained in the GKR and transcribed in the tooltips of the Google Earth document will therefore detail the following parameters[1]:

- **Size of the deposit.** The size of the deposit cannot be deduced from that of any possible exploitation to which it may have been subject. Indeed, depending on their

[1] A parameter of reliability of the interpretation will be attached to each assessment.

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history it is possible to have had a small or very small mine on a large deposit or a larger mine on a small deposit.

- **Morphology.** The morphology of a deposit does not reflect its composition but only its geometry. It is sometimes the only descriptive parameter found in the bibliography to describe an occurrence. This parameter can provide information on the usability of a deposit.
- **Type of deposit.** The type of deposit does not make it possible to refer to a model and therefore to predict certain characteristics such as the possible sizes or compositions of the deposits described. On the other hand, they provide useful information on the exploitability and the acid mine drainage (AMD) which would be associated with its exploitation.
- **Metallogenic model.** the metallogenic model can be considered as the genotype of the deposit. Once identified in its context, it makes it possible to anticipate the potential size of the deposits, its composition, the metals likely to be contained and valorised.
  Knowledge of the model associated with that of the type of deposit makes it possible to identify the interest of an occurrence from the most upstream stages of mining exploration.

These 4 parameters, weighted by their reliability, are involved in the automatic calculation of the score of each occurrence or deposit carried out by the GKR to establish the ranking of metalliferous sites.

2.2 STATE OF THE RESOURCE

In Europe, mining exploration operations for metals were mainly carried out between the 1960s and the 1980s. From the beginning of the 1980s, it was accepted that the supply of metals to the industry was ensured by the international market; mainly with the emergence of large mining countries: Canada, Australia, South Africa... China specialized in the production of what were called "small metals" at the time. It flooded the market with now strategic metals such as refractory metals and antimony. The resulting dumping heralded the closure of all European operations involving them, with very rare exceptions such as the tungsten Mittersill mine in Austria.

From the 1980s to the 2000s, only gold was of interest to mining exploration companies. He focused the majority of the exploration effort; other metals being neglected.

Thus, the information we have today is mainly buried in archives more than 40 years old. These documents, interpreted on the basis of the knowledge of the time in metallogeny, are often scattered and difficult to access. Their digitization is often partial and is mainly reduced to tiff-type images accessible on the geological survey sites which put them online.

The work undertaken here consists of reinterpreting them and allowing easy access to their content.

Fewer than ten refractory metals projects are in operation or ready to be in operation in Europe. However, at least 3,500 metalliferous sites have been recorded throughout our history. All new projects like Barruecopardo were carried out on old mining works from the beginning of the twentieth century. The challenge is therefore to identify new ones.

Since the initial number of potential targets was very high, it was important to use a system to rank them in order of potential interest. Certainly, the UNFC classification is a good criterion when it comes to examining targets under development (evaluation of resources/reserves, feasibility ...); However, it turns out to be poorly suited to judging the interest of very upstream projects for which all quantifiable resource data is lacking.

We have therefore established a score, rated out of 100, which allows us to understand the probability of success in the context of programming a mining research project.

2.3 RECOVERY OF METALS FROM REFRACTORY METAL DEPOSITS

Some tungsten deposits may contain gold in appreciable quantities. When they were mined around the middle of the twentieth century, the value of gold was less than $300/oz; today it is $2,000/oz. Very often, this metal was not included in the calculation of the economy of the deposit. Thus, the Anglade (or Salau) mine in the French Pyrenees in Ariège, which was the largest tungsten mine in Europe during its exploitation up to 1986, has never valorised the gold content (3 g/t on average). Today, this gold would represent a value comparable to that of the tungsten content.

2.3.1 NEED FOR FULL RECOVERY OF METALS

The ore mined by the miner generally does not only contain refractory metals; its gangue is likely to contain useful substances, which an adapted line of treatment would be able to develop. The full recovery of minerals is therefore probably an inevitable development in European mining. The reasons are many:

- Europe, which imports almost all of its high-tech metals, cannot afford to waste the resources it absolutely needs.
- Far from penalizing the economy of a project, a full recovery of the ore can on the contrary improve it.
- Full recovery can drastically reduce the environmental impact of mining wastes.

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- The gangues of treatment residues, cleaned of their metallic content, could sometimes find industrial applications.
- The social acceptability of a mining project in Europe can no longer be obtained if the stakeholders of the territory involved believe that future exploitation can be considered as a waste of non-renewable resources, even a looting of heritage; resources that would otherwise contaminate the environment.

Although not systematic, there is therefore a close relationship between recoverable metals and contaminants.

Gangues have only very rarely been systematically and comprehensively analysed by mining operations, focused on the elements directly involved in their production system. The recovery of metals was rather the business of the foundries, which could (or could not!) pay them to the miner in the formula for the sale of concentrates. The metals remaining in the gangue actually escaped this recovery.

2.3.2 MINERALOGICAL APPROACH TO THE RECOVERABLE METALS

It was not until the early 1980s that the analytical technique by ICP gave access to a multi-elemental analysis of rocks and ores. Imperfect at the start of its application, it is now mature and allows the overall composition of an ore to be obtained at an acceptable price. Likewise, recent developments in LIPS and XRF techniques have brought great flexibility for the rapid detection of recoverable metals in rocks.

These techniques do not exist during the carrying out of the old mining works and the exploitation of the old mines, the overall composition of the ores and their gangues remained very little known. This is all the more accentuated since the majority of metals sought today were of no interest at the time.

In addition, the international community of mineralogists which includes several tens of thousands of amateurs, often enlightened, has found with NICTs the means necessary to share their passion with professionals of distribution on the Internet. Online databases, such as the excellent Mindat.org[2], provide often very comprehensive mineralogical descriptions of former mine sites, favourite targets for mineral collectors.

The identification of the geological models of the occurrences and deposits corresponding to the old mining works and the old mines, supplemented by a fine analysis of the mineralogical

[2] https://www.mindat.org/

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composition of the rocks and ores contained, is a fundamental step to estimate the actualized potential of these targets.

The comparison between the refractory metal ores already exploited and the metal content which could be recoverable today therefore sheds new light on this former mining activity. The refractory metal deposits could therefore also contain the metals presented below, the valuation of which should be studied.

The metals listed below (Table 2) must meet with sufficient frequency and be able to reach a significant proportion in the overall composition of the ore to be able to be valued. In our approach in D2.3 we will therefore focus mainly on ore minerals and potential ore minerals.

It is also important to note that a mineral capable of providing a recoverable metal may also contain contaminants which would create environmental problems if they were not recovered. The details of all these possibilities are stored in the GKR System. The potential and hazard assessments specific to each occurrence will be based on this information.

Thus, the mineralogical study of indices is an essential background task for the estimation of exploitable potentials in refractory metals.

TABLE 2. Potentially recoverable metals in the W, Nb, and Ta deposits

Metal	Tungsten deposit	Niobium-Tantalum deposit
Tungsten	*****	*
Nb - Ta	**	*****
Gold	***	
Silver	*	
Tin	****	
Molybdenum	**	*
Lithium	*	***
REE	*	****
Uranium	*	**
Copper	**	
Zinc	**	

The Google Earth tooltip which summarizes the main economic and metallogenic data of each occurrence / deposit will contain the list of minerals susceptible to direct valorisation or that of mining waste.

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2.4 EUROPEAN RESOURCES OF REFRACTORY METALS

The European Critical Raw Materials Act (March 2023) identifies a list of critical raw materials (REE, Li, Co, In, Ge) and a list of strategic raw materials (W, Nb, Sb, Mg, Ga) crucial for technologies for the green and digital transition, as well as for defense and space. It also sets benchmarks for domestic capacities along the strategic raw material supply chain to be reached by 2030: 10% of the EU's annual needs for extraction; 40% for processing and 15% for recycling. No more than 65% of EU's annual needs of each strategic raw material at any relevant stage of processing should come from a single third country.

Tungsten, like tin, niobium, tantalum and gold is sometimes exploited in conflict zones and in particular in the Democratic Republic of Congo by armed groups. This source of income has led the United Nations, the OECD, the United States government and the European Union to various initiatives aimed at drying up this source of funding.

United Nations calls for production and export statistics, OECD released "Due diligence guide for responsible supply chains for conflict and high-risk minerals" in the United States, the "Dodd-Frank Wall Street reform and consumer protection act" aims to control the origin of raw materials. European regulations were published in the Official Journal of the EU on May 17, 2017, to take effect on January 1, 2021 and only concerns large companies that import minimum tonnage.

2.4.1 HARMONIZATION OF DATABASES

Europe has experienced centuries of mining activity, but it is only recently that the criticality of refractory metals has become evident.

The geological services of the countries have established mining inventories listing the known deposits and indices in their respective territories. In total, more than 68,000 records were identified and stored in a data integration system, the GKR.

The exploitation of this large amount of information, however, requires an extensive harmonization phase. Indeed, if harmonization exists today in part on significant deposits, it remains very approximate in terms of occurrences, which are however the potential source of new discoveries.

The work carried out during this project enabled:

2.4.1.1 INDEXING BY ONTOLOGIES

Indexing by ontologies of the terms used in all the files collected in the public databases. The information collected can thus be manipulated without the limitations linked to the language of their original entry and by using semantic clusters allowing queries based on terms not used by the authors of the files. Thus, the same search using the same criteria can be applied to all 68,000 selected files.

2.4.1.2 HARMONIZATION OF VOCABULARY

The use of a vocabulary common to all the records of deposit and occurrences is necessary (Table 3). It should be noted that there is a blurring between the terms used to describe the mining activity and the geological objects which concern it. The GKR will use the vocabulary above for geology and mining operations.

TABLE 3. Relation between Geology and Mining operation

GEOLOGY		Mining Operation
Province	Scale = 100 km. A mineralized province generally corresponds to a geological formation enclosing numerous mineral deposits that can be grouped into districts	Reconnaissance
District	Scale = 10 km. A mineralized district generally corresponds to a geological event generating numerous mineral deposits that can be grouped into fields.	Prospecting
Vein field	Scale =1-10 km. Grouping of deposits generally associated with the same mineralizing phenomenon. Can give rise to many operation sometimes grouped under the name of a single mine.	General exploration
Mineral deposit	A significant concentration, sometimes large, of ore or industrial minerals. The level of knowledge does not make it possible to define whether the economic conditions are favourable for exploitation in the short or medium term	Old mine Exploration
Ore deposit	A mineral concentration that is economically exploitable under the conditions existing at the start of the operation.	Mine (active/dormant) Detailed exploration
Ore body	Part of a deposit that can be exploited selectively. The ore bodies of the same deposit may have different morphologies.	Mining
Occurrence	A visible indication that mineralization exists, whether in the form of an outcrop or a mineralized boulder.	Old mining works Outcrop

2.4.1.3 SELECTION OF POTENTIAL RESOURCES IN W, NB AND TA

We have made a selection, country by country, of the targets used to assess their potential in refractory metals. Initially, 4,000 potential metalliferous sites were retained out of the 68,000 records present in the GKR system. The following tasks were carried out for all countries:

- elimination of duplicates;

- additions of records from new public sources;
- updating the vocabulary used;
- reinterpretation of metallogenic models;
- checking/correcting geographic coordinates;
- harmonization of records from heterogeneous descriptions;
- integration of mineralogical data from Task 2.2;
- ranking of metalliferous sites.

In this work, we integrated the analysis of Greenland (Denmark) and maintained the United Kingdom, independently of Brexit which occurred during the completion of the project. It is important to note that the number of metalliferous sites selected for each country does not depend solely on its surface area and geology. This number also reflects the effort made in twentieth century mining exploration and in the public dissemination of data.

The Table 4 summarises the achievement of the deliverables of WP2, country by country.

TABLE 4. Analysis of refractory metal potentials

Countries	Sites selection	Tungten	Niobium - Tantalum
Austria	Checked sites: 1,288 First selection: 60 **Kept: 54**	** skarns	
Czech Republic	Checked sites: 484 First selection: 51 **Kept: 64**	**	* Pegmatites
Denmark Greenland	Checked sites: 221 First selection: 7 **Kept: 92**		**** Alkaline Complexes
Finland	Checked sites: 482 First selection: 35 **Kept: 58**		*** Alkaline Complexes
France	Checked sites: 46,296 First selection: 1660 **Kept: 1000**	**** skarns	** Pegmatites
Germany	Checked sites: 1162 First selection: 73 **Kept: 102**	** Veins Greisen	* Pegmatites
Greece	Checked sites: 509 First selection: 4 **Kept: 10**	** Veins Greisen	
Hungary	Checked sites: 417 First selection: 1 **Kept: 5**	* Veins Greisen	
Ireland	Checked sites: 224 First selection: 6	* Veins	

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	Kept: 10	Greisen	
Italy	Checked sites: 977 First selection: 47 **Kept: 94**	** Veins Greisen	
Netherlands	Checked sites: 76 First selection: 2 **Kept: 0**		
Poland	Checked sites: 453 First selection: 9 **Kept: 23**	* Veins Greisen	
Portugal	Checked sites: 2,629 First selection: 802 **Kept: 778**	*** Veins Greisen	** Pegmatites
Romania	Checked sites: 459 First selection: 17 **Kept: 13**	* Veins Greisen	
Slovakia	Checked sites: 280 First selection: 21 **Kept: 20**	** Veins Greisen	* Pegmatites
Spain	Checked sites: 11,149 First selection: 990 **Kept: 876**	*** Veins Greisen	** Pegmatites
Sweden	Checked sites: 710 First selection: 48 **Kept: 81**		*** Alkaline Complexes
United Kingdom	Checked sites: 1,227 First selection: 164 **Kept: 356**	** Veins Greisen	

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2.4.1.4 ELIMINATION OF DUPLICATES

These duplicates come either from errors in the published databases, or from an incorrect use of the terms described in Table 3. The correction of these entries, subsequently imposes a search and the elimination of the duplicates caused according to the criteria specified in Table 5

TABLE 5. Main types of duplicates

Nature of the duplicate	Symptom	Remediation
True double	• Match the same target • Same name or not • Coordinates may be different	• Merge records • Fix coordinates
Homonymy	Another target with the same name already exists • Could be near the other one • Could exploit another commodity	• Keep the record • Establish hierarchy with the mine inside the GKR • Check/Fix coordinates
Confusion between mine and deposit	• could have the same name • could have the same coordinates	• Merge records • Fix coordinates
Several mines operating the same deposit	• could create false duplicate with other mines in the same Vein field • Possible confusion with “true” duplicate	• Keep the record • Modify the name if needed • Establish hierarchy with the mine inside the GKR • Check/Fix coordinates
Confusion between deposit and district having the same name	A mine and/or a deposit has the same name as a district in the same region	• Keep the record • Change the name of the district by adding “District” after the name.
Confusion between occurrence and deposit or mine	A record for the occurrence was made before the construction of the mine	• If the occurrence corresponds exactly to the mine site: merging records for the benefit of the mine. • If the occurrence is distant from the mine or deposit: Keep the record by changing the name.

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2.4.2 ORE AND DEPOSITS

2.4.2.1 TUNGSTEN

Seventy-seven minerals can incorporate tungsten into their crystal lattice, but only two of them are exploited and will be considered as ore minerals:

- **Scheelite** ($CaWO_4$) which represents 70% of the world's tungsten reserves.
- **Wolframite** $(Fe,Mn)WO_4$, a continuous solid solution between ferberite ($FeWO_4$), and hübnerite ($MnWO_4$), which represents the remaining 30% of the world's tungsten reserves.

As explained in Annex 4.1, tin, molybdenum, niobium and / or tantalum are often associated with tungsten in ores.

The tungsten ores are dense and brittle, the scheelite also being fluorescent under ultraviolet radiation. Only scheelite can be concentrated by flotation; wolframite, paramagnetic, being mainly concentrated by magnetic methods.

Grinding must be done with care to avoid the formation of too much fine particles due to the brittleness of the ore. A first concentration uses gravimetric methods (dense medium, spirals, shaking tables, centrifugation, ...) followed, depending on the nature of the ore in a flotation or magnetic separation.

The content of merchant ore is between 60 and 75% of WO_3.

In 2020, world mining production amounted to 84,000 t, of which 69,000 t produced by China and 2,430 t produced by the European Union (Austria, Portugal, Spain).

- **In Austria**, a scheelite ore is mined underground and concentrated by flotation in **Mittersill**, in the province of Salzburg, by the company Wolfram Bergbau und Hütten, controlled since 2009 by the Swedish group Sandvik.
- **In Portugal**, the **Panasqueira** underground mine is operated by Beralt Tin and Wolfram, a subsidiary of the Canadian company Almonty Industries which bought it in January 2016 from the Japanese group Sojitz Corp. Ferberite ore, found in quartz veins, contains cassiterite, chalcopyrite and silver. The deposit has been mined since 1896. Between 1947 and 2014, 31 million t of ore produced 111,123 t of tungsten concentrate, 5,383 t of 72% tin Sn concentrate and 31,702 t of copper concentrate containing 28% Cu.

  This deposit currently offers the largest stockpile of dumps and tailings relating to W, Sn in Europe.

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- **In Spain, in the province of Salamanca**, the open-pit scheelite mine at **Los Santos** is operated by Almonty Industries. In 2016, the extraction of 519,803 t of ore containing 0.35% WO3, with a recovery rate of 60.2% produced 931 t of WO3. Proven and probable reserves are 3.582 million t of ore containing 0.23% of WO3. In the same province, the **Barruecopardo** open pit mine shows proven and probable reserves of 8.69 million t of ore containing 0.30% of WO3. The planned production is 2000 t/year.

  In Extremadura, the **La Parrilla** open-pit tungsten-tin mine, owned by the company W Resources, has proven and probable reserves of 30 Mt of ore containing 0.1% WO3 and 116 ppm Sn.

- **In the United Kingdom**, the Drakelands open pit wolframite mine opened in 2015 by Wolf Minerals, produced 1,123 t of WO3 in concentrates and 194 t of tin in 2016. Reserves are 32.2 million t ore containing 0.17% WO3 and 0.03% Sn. In 2018, the mine was closed.
- **In France**, there is no longer any mining, but during the 20th century, 13 deposits were exploited with a total production of 25,771 t of WO3. The most important were those of Salau (09), with 12,415 t, Puy les Vignes (87), with 3,970 t, Echassières (03), with 3,900 t, Leucamp (15), with 1,700 t, Enguialès (12), with 1,300 t. The Salau mine (09), in operation between 1971 and 1986, was operated by the Société Minière d'Anglade (SMA).

  The resources estimated by the BRGM amount to 83,122 t of WO3; the main ones being located at Fumade (81), with 14,300 t, Coat-an-Noz (22), with 11,000 t, Montredon-Luitré (35), with 1,500 t.

  A new estimate of the resources of the Salau deposit was undertaken by the E-Mines Company from 2015. Studies conclude that there is a very significant mining potential on this site which can exceed 50,000 tonnes of high-grade WO_3 (> 0.6% WO_3). The failure of the Apollo company in France and the questioning of the validity of the mining title that preceded it suspended the exploration work on this project.

Europe consumes around 17,000 tonnes of tungsten per year and could therefore meet around 25% of its needs.

However, a distinction must be made between the production of mines (concentrate) and that of a usable form of the metal (mainly APT). In fact, with rare exceptions such as the Mittersill mine which has a plant for the manufacture of APT, the concentrates are exported for refining outside the borders of Europe. Mining production alone therefore proves incapable of limiting EU dependence and it will remain under Chinese dependence until a sufficient refining unit is installed; for this, new mines will have to be put into operation.

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2.4.2.2 TIN

Tin has been known since Antiquity since it is used in bronze, the first alloy produced which characterizes a prehistoric era.

Cassiterite (SnO_2) is practically the only mineral actually mined. Primary deposits are closely associated with those of W (see Annex p.40) and their ore represents 60% of world production; 90% of them are mined underground and 10% open pit.

The rest of the production comes from alluvial deposits (placers), formed after physical and chemical alteration of the primary rocks, transport and storage.

Cassiterite can fix up to 4% tantalum in substitution in its crystal structure; deposits from Thailand, Malaysia, Indonesia and Brazil are of this type.

During metallurgical operations to reduce the ore, tantalum is found in the slag. This source represents around 67,000 tonnes / year of Ta, or around 10% of world consumption.

2.4.2.3 NIOBIUM AND TANTALUM

Tantalum is often associated with niobium in its deposits, the two elements having similar chemical properties. However, there are niobium mines in which tantalum is not recovered and vice versa tantalum mines in which niobium is not exploited.

The main ore minerals are oxides with:

- The family of pyrochlores, whose composition varies between that of the pyrochlore proper $(Na, Ca)_2Nb_2O_6(OH, F)$ and that of the microlite $(Na,Ca)_2Ta_2O_6(OH,F)$. Pyrochlore, mainly exploited in Brazil and Canada, is the main source of niobium, with more than 99% of the world total. The rest comes from columbite in Central Africa and slag from the processing of tin ores, in Malaysia and Thailand.

  World reserves were more than 9.1 million t of niobium contained in 2018, divided between Brazil and Canada.

  The niobium concentrates sold, in the form of pyrochlore, have a content of 54% to 60% of Nb_2O_5.

- The family of columbo-tantalites, called coltan in Central Africa and whose exploitation is often artisanal and in the Democratic Republic of Congo, carried out by armed groups. Columbo-tantalite forms a solid solution between the columbite group $(Fe,Mn)Nb_2O_6$ and the tantalite group $(Fe,Mn)Ta_2O_6$ (Figure 1). Tantalite now accounts for 60% of world tantalum production.

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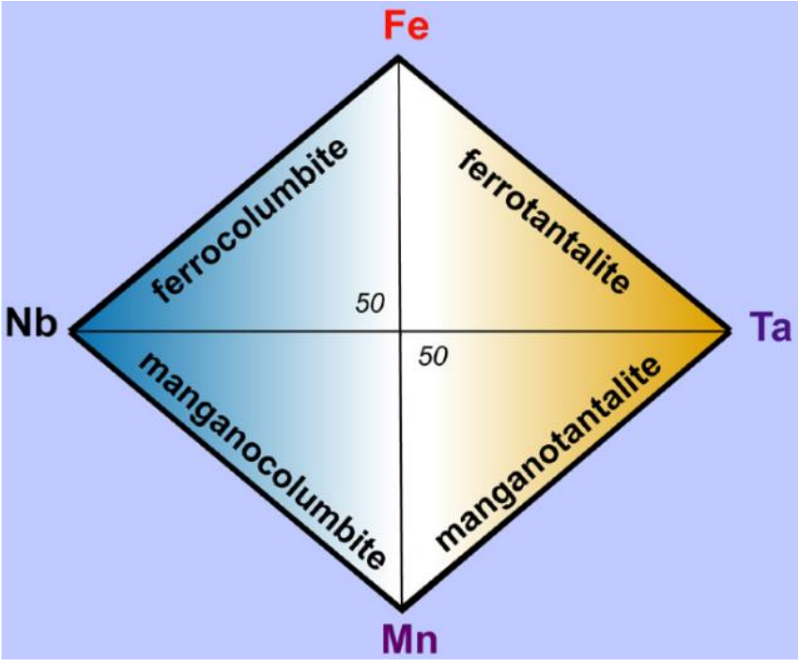

Figure 1: Compositions of minerals in the columbite and tantalite groups

- Wodginite: $(Ta,Nb,Sn,Mn,Fe)_4O_8$.

The contents of the niobium and tantalum ores are expressed respectively in Nb_2O_5 and Ta_2O_5; The Nb_2O_5 contents are between 0.6% in Canada and 2.5% in Brazil, for the Araxá (bariopyrochlore) deposit.

Niobium and tantalum are often found in tin and titanium ores, replacing tin in cassiterite and titanium in rutile and ilmenite. In cassiterite, tantalum can replace up to 4% of tin; this source represented in 2014 around 15% of world production.

Depending on the nature of the deposits (see Annex p.49), niobium and tantalum will also be associated with rare earths or lithium.

The minerals often contain radioactive uranium and thorium. When the radioactivity of marketed products reaches 10 Bq / g, this must be declared and precautions taken. This radioactivity corresponds to a content of 0.13% of ThO_2 and 0.048% of U_3O_8.

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2.4.3 EVALUATE EUROPEAN POTENTIALS IN W, NB AND TA: METHOD

The approach we will develop here is to examine the production potential of these critical and strategic metals based on existing information on their deposits and their exploitation.

From the gathering of metals to the exploitation of giant hyper-mechanized mines managed by artificial intelligence, the mining industry has evolved considerably, far from the images often conveyed by the media little interested in the question. In our approach, we will therefore distinguish mining activity by period, each of which reflects technological advances and specific economic needs.

2.4.3.1 HISTORICAL WORKS

We will classify in this group the mining works from the Roman era to the mid-nineteenth century. These are generally small works, although some exploitations have been maintained for centuries and have therefore been able to reach significant sizes over their lifespan. The metals exploited were few: iron, gold, silver, copper, lead, tin, antimony.

The exploitation, not mechanized, was interested in rather rich ores which can be extracted by hand and susceptible to recovery by known metallurgy.

Today, these exploitations will be considered as occurrences to be re-examined in the light of current knowledge because the deposits involved could turn out to be deposits that are still (almost) intact.

Due to the sorting which was carried out directly on the cutting face by the miner, these operations have in fact produced very few waste dumps and treatment residues capable of recovery. However, an environmental impact will be associated with them and its importance will depend on the importance of the works and the mineralogy of the ore.

2.4.3.2 OLD MINING WORKS

We will classify in this group the exploitations and the mining researches before 1950. The mining techniques are mechanized, but the powers involved remain low and impose rather modest returns.

In this way, production will focus on rich minerals and the extraction of dumps will be reduced to a minimum.

The tungsten mines, which experienced strong development with the discovery of the qualities of W, often developed on small geological structures such as veins and pegmatites associated with granite domes, will often be developed by small companies, which we could qualify of SMEs today. Generally, these operations will only extract a few hundred tonnes of

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metal, sometimes less. The high grades required for the ore and the low production therefore imply volumes of dumps and rejects of modest size. In general, they will not have sufficient volume to justify today an in-situ recovery.

On the other hand, the selection criteria which prevailed at the time of the decision to bring into operation could indicate the existence of potentially exploitable deposits.

It is more than likely that strong social pressure will impose environmental restoration of these former mine tailings before any exploration / exploitation of the deposit. Their recycling will probably be an obligation to obtain the social operating permit (SLO).

ENVIRONMENTAL IMPACT OF OLD MINING WORKS

During this period, the extraction of tungsten and tin, then considered as "small metals", fell under the SME. The "heavy" mining industry then only concerned coal and iron in Europe. We are therefore witnessing a multitude of small operations, often artisanal, especially located in Southern Europe (Variscan basement). Rock mining mainly targeted veins outcropping with tungsten (quartz - wolframite) and / or tin (quartz-cassiterite), easily recognizable in areas with low vegetation cover. The grouping of these veins in mineralized fields (see Annex p.40) has led to a multiplicity of small works distributed over small areas which can generate relatively diffuse pollution of the environment.

The dispersion of these piles of dumps is therefore an essential element in controlling the quality of surface water. Their density on reduced surfaces is in theory likely to have a greater impact than that which would be caused by a single pile having the same volume of rejections.

A simple pile of dumps of 50 x 20 m of surface and a thickness of 3 m (that is to say approximately 7500 tons), which we will qualify as “small”, even “very small” compared to the dumps of the current mines, and which would contain approximately 1% of arsenopyrite (which is little for the majority of mineralization) is still likely to release 35 tonnes of arsenic.

It should also be noted that environmental precautions, which are now absolutely essential, were not a concern. Generally, the waste was left in the open air without any form of protection.

Fortunately, the W-Sn mineralization are mainly composed of oxides and the ores and their gangues are little subject to major phenomena of sulfuric acid production by weathering (AMD); the arsenopyrite crystals, included in quartz, are not easily damaged and the arsenic will not be widely diffused in the end.

During the same period, numerous small alluvial mines for tin and titanium also developed in the context of granite domes. As these operations do not meet sulphides by definition, their current environmental impact can be considered as completely negligible.

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2.4.3.3 OLD MINES

The 1990s saw the closure of almost all metal mines in Europe. This closure had already reached tungsten mines in the 1980s, following dumping of Chinese tungsten; China remains by far the largest producer with 85% of world production.

The period 1950 - 2000 saw the advent of the modern mine. The evolution of equipment and technologies was continuous and it continues this trend today with an increasingly present digital activity.

As the technologies used allow for the effect of scale, mining operations have seen their size increase exponentially, limited only by their geology. It is largely this race for gigantism that has fuelled a phenomenon of rejection of this activity in European public opinion and exacerbated the NIMBY effect.

New techniques allowing the exploitation of lower and lower grades, the volumes of dumps and treatment discharges underwent a considerable increase in volume.

It was this period that initiated the opening of open pits, always larger and presenting stripping rates that can reach or exceed 10: 10 tonnes of “waste rock” removed for the extraction of a ton of ore, itself often containing less than 1% of the exploited substance.

During this same period, the valued metals saw the number increase very significantly. From under 15 at its inception, it is today almost all of the metals listed in the periodic table of the elements that today find use, mainly in the high-tech industries. The dumps and treatment waste from these old mines, especially those that had activity at the start of the period, are therefore likely to contain appreciable quantities of these critical substances.

In the context of an imposed circular economy, knowledge of this potential is therefore essential. Its estimation is a complex operation, because the new metals sought (including Nb and Ta) were not a priori analysed at the time of the feasibility, then of the exploitation of these mines. As the management of the dumps does not foresee their existence, the enriched parts of these dumps can be masked by recoveries of products from other totally sterile sectors of the mine. In addition, in many cases, mine tailings undergo significant transformations by the action of meteoric weathering, in particular during acid mine drainage (transformation of sulphides into sulfuric acid) and their surface part does not lend themselves to a representative sample.

Assessing the potential of these stocks therefore represents a cumbersome operation, the more important the greater the volume concerned. The purpose of this work is to provide guides allowing a first approach to select releases that are interesting enough to justify such estimation work.

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ENVIRONMENTAL IMPACT OF OLD MINES

This is where the problem lies!

The effective taking into account of the preservation of the natural environment is a recent operation, which we will rather relate to the 21st century. Discards from old mines are often stored by applying (sometimes not!) protective measures which today are deemed to be largely insufficient.

Underground mines, especially the older ones, generated less waste due to the high selectivity applied during extraction. These dumps generally contain a lot of “poor ore” according to current criteria and correspond above all to the rocks containing mineralization disseminated in the vicinity of the “rich” ores which were only exploited. For example, in the last years preceding its closure in 1986, the Salau tungsten mine in France practiced a cut-off grade (grade below which mineralization is no longer considered as an ore) of 0.9% WO3, which today corresponds to 3 times the average grade of a working mine.

Thus, it will be considered that the oldest mines are likely to provide waste presenting the best potential in terms of content, but that their volume will often be relatively small. Of course, these remarks remain general and the estimate made on a case-by-case basis.

The Salau mine, which closed in 1986, still left a stockpile of at least 900,000 t of dumps and tailings in the open air. Although the recovery rate of tungsten (82%) may still appear excellent today, due to the initial richness of the ore these tailing contain more than 0.3% of WO3; this grade now corresponds to the operating grades of many tungsten mines.

From the point of view of the composition of the ore, we will distinguish the ores made up of wolframite (and / or cassiterite) quartz, almost devoid of sulphides, scheelite skarns which in some cases, as in Salau, can contain significant quantities of iron sulphides. In both cases, the risks of chemical contamination of surface water are relatively reduced compared to mines of base metals such as copper, lead or zinc. Indeed, the wolframite ores, containing almost no sulphides, will only present very weak acid mine drainage, while the sulfuric acid released by the sulphide ores contained in the skarns will be neutralized by the carbonates which compose them.

2.4.3.4 DORMANT MINES

They will be cited here for the record. These are mines which have ceased to operate but retain infrastructure maintenance with the possibility of resumption of activity. In the context of our study, only the Drakeland mine can be classified in this category.

The study of mine releases can be an important element in planning a reopening. However, in the case of mines such as Drakeland, which were opened very recently and closed

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immediately, the resumption of discharges can in no case be a decisive criterion given the low volume produced.

2.4.3.5 ACTIVE TUNGSTEN MINES

These mines are few in Europe and they can be classified into two categories:

- Mines already having a long period of activity
    - Panasqueira (Portugal)
    - Mittersill (Austria)
    - Kaolins de Beauvoir, a subsidiary of Imerys, produces 55 t / year of tin-tantalum-niobum concentrates in Echassières (03), by-products of a kaolin operation. The content of the concentrates is approximately 10% of Ta2O5.
- Recently opened mines
- These mines are opening or have recently opened under new environmental regulations. The reprocessing of dumps and old residues is part of their exploitation strategy:
    - Barruecopardo (Spain, old existing mining works)
    - Los Santos (Spain, old existing mining works)
    - La Parrilla (Spain, old existing mining works)

2.4.3.6 THE MINES OF THE FUTURE

By definition, one would think that there would not be any problems with the recovery of waste for these future mines since their exploitation remains to come. The main objective would therefore be the full recovery of the metallic content of their ores with maximum recovery. The new technologies, tested and developed within the framework of the TARANTULA project, fit well into this approach.

However, the following observations should also be taken into account:

- 75% of the mines were explored by 2 to 5 companies before their discovery. In Europe, this research work, including non-mechanized artisanal operations, will be classified as old work.
- There are no longer any “virgin” areas of exploration in Europe.
- The highest likelihood of discovering a new mine is to assess the potential for occurrences, the vast majority of which corresponds to former mining work. Current examples are the recently opened mines in Spain of Barruecopardo and Los Santos, or in the process of opening of La Parrilla.

Under these conditions, the new mine will have to be concerned with the fate of the old mining wastes which could result from previous operations or works.

From the exploration stage, this need is likely to be imposed by the neighbouring communities.

This prerequisite is requested by the stakeholders of the territory affected by the project to study the feasibility of a new exploitation of the Salau deposit. Because of the volume and the content represented by the tailings, the TARANTULA project is particularly interested in the techniques which would allow the valuation of this type of stock.

2.4.4 SPECIFICITY OF EUROPEAN METALLOGENIC FIELDS

This specificity appears in the Table 4

All of the exploited European tin-tungsten deposits are linked to felsic magmatism, in the form of granite domes and scheelite skarns. In Europe, this type of mineralization is specific to the Variscan domain, which is at the origin of the historical development of metallurgy.

Deposits associated with metallogenic models from this geology can also contain niobium-tantalum resources, mainly in pegmatites or greisens. It should be noted, however, that their mining potential remains modest compared to that of models derived from hyperalkaline magmatism, such as carbonatites. The large deposits of these metals will rather be the prerogative of the Proterozoic basement which dominates the geology of Sweden, Greenland and Finland.

The need for niobium and tantalum has emerged with the high-tech industry. These metals were therefore not the target of historical productions focused on tin (since prehistoric times) or tungsten (early 20th century). In the absence of analyses, the Nb-Ta potential of the Variscan domain deposits will therefore have to be understood from a systematic mineralogical study of the metalliferous sites.

2.4.5 POTENTIAL IN REFRACTORY METALS FROM EUROPEAN COUNTRIES

The mining potential and / or reprocessing of wastes is estimated country by country using the same evaluation criteria with a view to harmonizing data on a European scale. For this we have established for each of them:

- A list as exhaustive as possible of all known occurrences, mineral deposits and ore deposits for these metals. The data sources have been filtered to eliminate as much as possible the duplicates and errors that appeared during their integration. The geographic coordinates have been corrected, where possible, using Google Earth

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which today offers ground accuracy that did not exist when the source data was created.

- Exploration works, historical works, old mining works have been grouped in the occurrence rank. The size of the deposits mined in the traditional way for tin and tungsten do not allow today to anticipate the existence of a deposit without the resumption of exploration work.
- Old mines or positive exploration work will be classified as deposits. For the most part, these mines closed after Chinese dumping in the 1980s and the deposits, then exploited with much higher cut-off grades than today, are very likely not to be exhausted.
- Study of the ore and gangue parageneses (Task 2.2) to determine:
    - Recoverable metals
    - Potential contaminants (heavy metals, arsenic, radioactivity, etc.)

Occurrences and deposits are examined according to the metals contained, the potential for recoverable metals, but also in relation to the environmental hazard which would be attached to the reopening of old works or the reprocessing of wastes.

The document provided is intended as a guide for institutions wishing to promote the enhancement of their mining heritage. The information provided may allow a prior assessment of the economic and environmental risk incurred.

For each country, the results are provided in the form of an electronic annex which includes:

- A database in Excel format presenting the main characteristics of the indices and deposits (georeferenced WGS 84).
- A .kmz file (Google Earth) which allows users who do not have a G.I.S. to easily access a very precise geographic location of all the referenced sites.

  It will be recalled that the opening of such files requires the download of the free application "Google Earth" to the user's computer. Internet access is required. Once this prerequisite is executed, the opening of a .kmz file is automatic by a simple double-click on its icon. Different .kmz files can be integrated into the same consultation session.

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3. CONCLUSIONS

A new approach for estimating Europe's mining potential in tungsten, niobium and tantalum has been finalized in WP2.

All of the exploration and exploitation work for these metals has been analysed and mapped in a single document with the precision that online mapping programs such as Google Earth allow today.

The integration of geological and economic data (Task 2.1) with mineralogical data of ores and gangues (Task 2.2) provides a common platform for all stakeholders in mining activity.

- States thus have a single document which exhaustively summarizes the current state of knowledge on the presence of these metals in their subsoil.
- Mining companies or companies specializing in the recycling of mining waste have the decision-making elements for the development of these metals.
- The administrations concerned have access to the potential environmental impact of an extractive anticipated activity by an analysis of the hazards intrinsically linked to an action on the mapped metalliferous sites.
- Civil society has clear and exhaustive public information, easy to consult, the sources of which are communicated and accessible directly via internet links.

The first conclusions concern the European geological potential in W, Nb – Ta. ***Europe has sufficient resources in its subsoil in W, Nb and Ta to sustainably supply its needs in the coming decades.*** However, there is great heterogeneity in the knowledge levels of member states, and it will be necessary to undertake ambitious evaluations programs to achieve this. The document provided in the appendix to this work is certainly an important starting point for the implementation of these programs.

Tungsten resources are limited to the Variscan geological domain which concerns the majority of countries with the exception of Denmark (Greenland), Finland and Sweden whose Precambrian base is not very favourable for this metal.

Tungsten skarn deposits are probably the most important deposits in size and richness of their ore. Important deposits belonging to this model exist in France (Pic de la Fourque - Salau, Coat an Noz, Fumade...); their discovery is the result of the major exploration program carried out by BRGM between the 1960s and 1980s. The discovery of other deposits of this type cannot be ruled out in Spain and Portugal.

Deposits such as veins, stockworks or greisen are by far those which present the greatest number of occurrences. Although more modest in size, they often contain in their matrix highly valuable metals today (gold, niobium, tantalum, lithium, REE), which was not the case when they were historically exploited in an artisanal manner. The score assigned by the GKR to each of the occurrences listed in the interactive map makes it possible to select the most interesting among these thousands of sites.

The large (sometimes giant) deposits of **niobium and tantalum** are linked to models of alkaline magmatism which characterize the basement of Greenland, Finland and Sweden. It is therefore normal that world-class projects are in the pre-operational phase today in these countries (Sokli, Finland; Illimaussaq, Greenland; …) These deposits systematically contain rare earths, but they can also contain tungsten and other metals.

Pegmatites and greisens can form deposits of sufficient size to authorize exploitation. Targets of smaller size than those previously indicated can therefore be sought in these deposit models. A significant potential for these metals therefore exists in the Variscan basement. The score of each occurrence makes it possible to prioritize the interest of the occurrences associated with these models.

- Excel folders provide a table of the deposits and occurrences that are the subject of this study (Europe_W-Nb-Ta_v2.xls).
- .kmz files (Google Earth) which will allow precise location of each of the occurrences in the interactive map. The main information relating to these occurrences will be summarized in 3 balloons attached to the coordinates of the points.

As it was mentioned in the Executive Summary, this information (Excel and .kmz files) is available in the Appendices. The standards of these two types of files make possible to envisage the integration of information in any computer system: database or GIS. In addition, these files are also directly usable by any user, their universality allowing wide dissemination.

The interactive map of mining potential and associated hazards is selected by the EU Innovation Radar.

This type of approach, limited in WP2 to tungsten, niobium and tantalum, could be extended to all metals in the energy transition.

The inclusion of all metals in this standard would also allow good localization of potential sources of contamination by heavy metals. These contaminations, often observed in environmental approaches, are generally classified today under the term diffuse contamination linked to geology.

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4. ANNEXES

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4.1 GEOLOGY OF THE W, SN, NB, AND TA DEPOSITS[3]

4.1.1 RARE-METAL GRANITE PEGMATITE

Pegmatite is a coarse-grained silicated igneous rock that forms at the end of volatile-rich (H_20, $C0_2$, F, Cl, B) magma crystallization. It occurs most commonly in association with felsic magmatism, and more rarely with mafic magmatism, whereupon the term pegmatoid is used. In this report we shall only consider the former, commonly referred to as granite pegmatite

Pegmatite is composed mainly of quartz, feldspar (microcline and albite in its cleavelandite facies) and mica, with many accessory minerals commonly of economic value. The main accessory minerals are beryl (Be), cassiterite (Sn), molybdenite (Mo), spodumene, petalite, lepidolite and amblygonite (Li), columbite, pyrochlore and tantalite (Nb, Ta), pollucite (Cs), as well as various uranium, thorium and Rare-Earth (allanite, monazite...) minerals, and several phosphates. These metals occupy a prominent place in the field of advanced technologies, be it the metallurgy of light metals (Be, Li, lighter than water), resistant metals (tantalum, unalterable and radiation opaque) or the energy sector (niobium superconductors, lithium batteries). Thus, pegmatite assumes an economic importance for these metals, as well as for caesium, rubidium and gallium.

However, although beryllium was once extracted from pegmatite which provided very large beryl crystals (7 metres weighing 18 tonnes from Albany, Maine, United States, and a crystal record of 18 metres long and weighing 470 tonnes from Malakialina, Madagascar), this metal is now mainly provided by the bertrandite of the Spor Mountain volcanic deposit. Pegmatite is also worked for its main components, i.e. feldspar for ceramics, mica for insulation and quartz for its piezo-electric characteristics. Finally, pegmatite may contain several kinds of gemstone, especially the valuable varieties of beryl (blue-green aquamarine, pink morganite, yellow heliodor, and more rarely emerald), topaz and tourmaline.

In Europe, the ceramic industry has required the exploitation of many pegmatites. Numerous quarries, often of modest size, bear witness to this activity. These sites have focused the attention of amateur and / or professional mineralogists whose publications are a source of valuable data for their reinterpretation in terms of potential resources in Nb-Ta or Li.

[3] Geology of Mineral Resources, by Michel Jebrak & Eric Marcoux. Geological Association of Canada, c/o Departement of Earth Sciences, Room ER4063, Alexander Murray Building, Memorial University of Newfoundland, St. John's, NL A1B 3X5 CANADA

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There are four main types of felsic pegmatite according to its depth of formation:

- abyssal pegmatite (> 11 km) comprising mobilizates and anatectic leucosomes hosted by sillimanite and kyanite schist in amphibolite- or granulite-facies rock, and rich in Ca, Ba, Sr, Mg, Fe, although generally of no economic interest;
- deep muscovite pegmatite (7 to 11 km) conformable to the foliation, rarely mineralized, but which can produce feldspar and muscovite. It was once considered as resulting from a high-pressure metamorphism, hosted by almandine garnet and kyanite schist; it can contain concentrations of Th, U, Nb, Ta, Zr or Ti;
- medium-depth, low-pressure, rare-element pegmatite (3.5 to 7 km) with rare earths and a lithophile element mineralization (Li, Rb, Cs, Be, Ta, Sn...), hosted by cordierite-andalusite schist and associated with allochthonous granite. Grades are commonly quite low, of the order of 0.02% Ta_20_5, 0.05% BeO and Li_2O;
- miarolitic gem pegmatite associated with epizonal to subvolcanic domes (1.5 to 3.5 km) in weakly metamorphosed areas; it contains pure quartz for piezo-electric use, locally precious beryl, topaz and, in places, optical-quality fluorite.

The deposits are almost all related to medium-depth rare-element pegmatite that geochemistry enables one to split into two groups; the one with Nb, Y and F (NYF, or rare-earth pegmatite) with alkaline affinities, and the second with Li, Cs and Ta (LCT) associated with Type S intrusions.

The morphology of the pegmatite bodies depends on many factors: the depth of installation, the structural context, and the competence of the surrounding. In Europe, they form small veins (often less than a hundred meters).

Pegmatite emplacement is controlled by fracture zones and generally results from hydraulic fracturing. Pegmatite is commonly more abundant in competent country rock cut by major faults that can be marked by sedimentary breaks or grabens. Deep pegmatite can occupy saddle zones, conformable with the country rock, tension cracks or pressure shadows.

At the regional level, pegmatite commonly shows a zoning with increasingly differentiated facies away from the pluton (Figure 2)INTRODUCTION. The zoning is better defined in the vertical sense rather than horizontally. Thus, a general sequence drawn up from the centre outwards gives associations with;

- (2) plagioclase – microcline;
- (3) microcline – albite;
- (4) lithium-rubidium mineralization;

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• (5) albite-spodumene, sometimes mineralized in Be, Ta, Sn;

• (6) beryl quartz, cassiterite and wolframite.

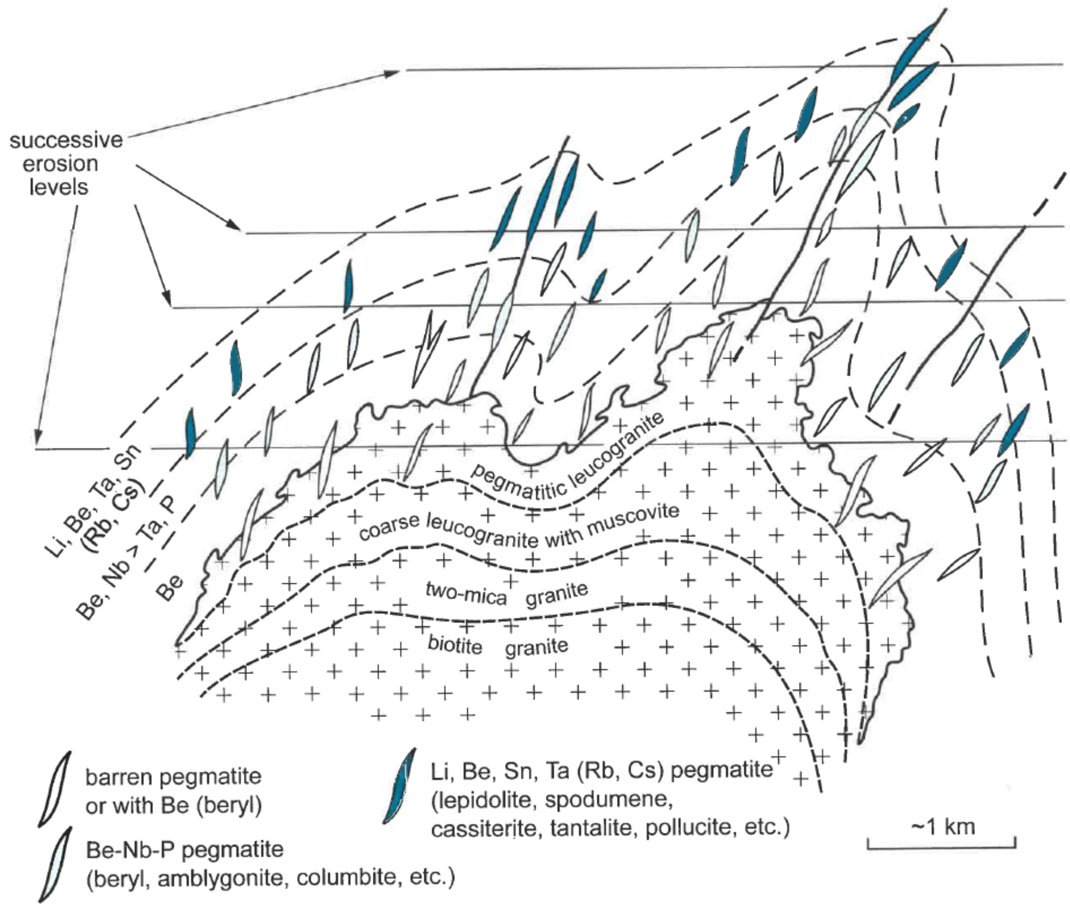

Figure 2: Idealized perigranitic zoning of pegmatite veins around a granite (veins not to scale). Note the concentric arrangement of the pegmatite veins around the irregular roof of the batholith and the strong influence of the level of erosion on the composition of the outcropping veins (from Cerny et al., 20054).

At the local level, one uses zoning, paragenetic criteria, mineral typomorphism: thus, blue apatite indicates Be, Nb-Ta mineralization; green columnar spodumene is restricted to lithium pegmatite; tourmaline is black in the barren areas (schorl), blue-green in the areas albitized with Sn-Nb-Ta (indicolite variety of elbaite), and pink (rubellite variety of elbaite) in pegmatite with Li, Cs, Rb. Other elements, such as Li, Be, Sn in muscovite and caesium in potassium feldspar, can provide indications on the metal potential.

[4] Cerny P. et Ercy T.S. , 2005. The classification of granite pegmatites revisited. Canadian Mineralogist 43:2005-2026

4.1.2 TIN AND TUNGSTEN PORPHYRIES AND CUPOLAS

Tin and tungsten porphyries and cupolas are found at the top of late- to post-orogenic plutons emplaced at a shallow depth (2-4 km, sometimes more). They are the trace of fossil hydrothermal systems centred on late, highly fractionated, granite intrusions (**Figure 3**). They occur in three types of geodynamic context:

- Zones of continent-continent hypercollision where they are associated with highly differentiated late-orogenic S-type two-mica leucogranite with a marked crustal character rich in hydroxyl minerals (muscovite) and enriched in lithophile elements such as Nb, Ta, Li, Be, P, F.

  The size of the cupolas varies from 1-5 Mt at 1% Sn to 15-80 Mt at 0.2-0.3% Sn, and an association with wolframite-bearing quartz veins (0.3 to 1.5% WO) is common.

  The Erzgebirge Altenberg (Germany) and Cinovec-Zinnwald (Czech Republic) deposits of Central Europe (known since Agricola, 1556), the historical deposits of Cornwall (England), and the Panasqueira (Portugal) and Montbelleux (Armorican Massif France) deposits are classic examples of this type of mineralization.

  In France, very large potential reserves of Li, Sn,Ta (and possibly Be) also exist in the Beauvoir-Echassieres albite-lepidolite-topaz granite cupola of the French Massif Central (Cuney and Autran, 1987[5]).

- Zones of continental collision producing crusta! overthickening with tin porphyries. The mineralization comes from very shallow subvolcanic peraluminous intrusions (Sillitoe et al., 1975) containing numerous tin minerals (dominant cassiterite, stannite, mawsonite, cylindrite...), quartz, pyrite and marcasite, etc. Such deposits are known in the Andes, mainly in Bolivia (Oruro, Llallagua, Cerro Rico de Potosi, and Chorolque), commonly at the site of inner continental arcs. Their very large size (100 to 1000 Mt at 0.2% Sn) makes them veritable tin porphyries.

  Absent in Europe, we will not describe them more precisely in this work and we will refer to the work of M. Jebrak and E. Marcoux.

- Continental rifts with annular anorogenic Sn-W-Be-Zn-bearing alkaline granite, locally with a rapakivi texture, found particularly in the Proterozoic of Brazil (Rondonia and Itu) and the Mesozoic of Nigeria (Younger granite). They have produced more than 0.5 Mt of tin in Amazonia. The granite is highly fractionated, rich in fluorine, and

[5] Cuney, M et Autran, A., 1987. Le forage scientifique d'Echassières (Allier). Une clé pour la compréhension des mécanismes magmatiques et hydrothermaux associés aux granites à métaux rares. Géologie de la France 2-3 :1-35.

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peraluminous with alkali feldspar, riebeckite, hastingsite, biotite, topaz, muscovite and zinnwaldite. The style of mineralization varies from stockworks, rarely skarns, to cupolas with greisen.

Also absent in Europe, we refer to the work of M. Jebrak and E. Marcoux.

GEOLOGY OF THE CUPOLAS

Mineralized cupolas form the apex of complex intrusion systems, in places porphyritic at the top of large batholiths of peraluminous felsic granitoid and locally of quartz gabbro (Indonesia). The intrusions are multiphase, with enrichment in incompatible elements in the youngest and smallest intrusions originating from fractions of a solidifying magma chamber.

The country rock is commonly sedimentary and weakly metamorphosed.

The upper contact of the intrusions is commonly marked by a stockscheider (German word meaning separation between two granitic units) or unidirectional solidification textures (UST), a few metres thick. This is indicated by arcuate and feathery pegmatitic feldspar, and quartz growing from the roof of the pluton.

The mineralization is associated with zones of tourmaline-rich aplite and topaz granite. The morphologies are varied: stockworks, simple and narrow veins (a few ten of centimetres thick), narrow vein systems, breccias, chimneys (Puy-les-Vignes, France; Correas), disseminations in greisens, skarn-replacement with sulphides.

The morphology depends on local conditions of permeability and the ratio between the fluid pressure Pf generated by the magma and the lithostatic pressure Pl (**Figure 3**):

- A low Pl allows the formation of thick veins. The vein fields can have varied structures: parallel, two directional, vertical or horizontal, divergent above an apex (Enguiales, France), sub-horizontal (Panasqueira, Portugal). They can extend vertically over hundreds of metres and horizontally for more than a kilometre.
- A high Pl and Pf balance one another, giving rise to extended fracturing with laminate veins and stockworks.
- A very high Pf in depth or in an area of low permeability near the surface, leads to an explosive rupture with the formation of hydraulic breccia and pipes.
- A high Pl and a low Pf result in the trapping of fluids in the intergranular space of the magma crystals, which can give rise to marginal pegmatite, few veins and a disseminated mineralization associated with an extended prisonisation (Montebras, France; Lagares, Portugal).

These varied morphologies are due to the passage of a radial or concentric tectonism at the top of an active intrusion for the earliest deposits, and to a regional stress-related tectonism for the later deposits.

The observed alterations can include early potassic alteration with dominant muscovite (greisen), or boron alteration with black tourmaline taken up by albite, sericite and clays.

Greisen is a metasomatic rock with dominant muscovite and quartz, locally with zinnwaldite, lepidolite, beryl and lithium phlogopite, which marks a potassium and lithium metasomatism at the top of the system. It corresponds to an alteration of potassium feldspar or plagioclase to muscovite at a pressure of the order of 1 to 2 Kbar and a temperature ranging from 500 to 600 °C. These alteration suites can be taken up by the percolation of meteoric water, a superposition that causes the formation of kaolinite, the raw material of the China clay of Cornwall and Brittany.

Zoning at cupola scale is commonly very marked with:

- tin-tungsten at the core, then
- tungsten-bismuth, and finally
- copper commonly preceding lead-zinc (Figure 3).

Other minerals are less common: argentiferous sulfosalts, stibnite, molybdenite, gold.
Finally, it is rare that the tin and tungsten are equivalent in terms of their economic volumes in a deposit; one often finds deposits of tin or tungsten, but rarely mixed deposits.

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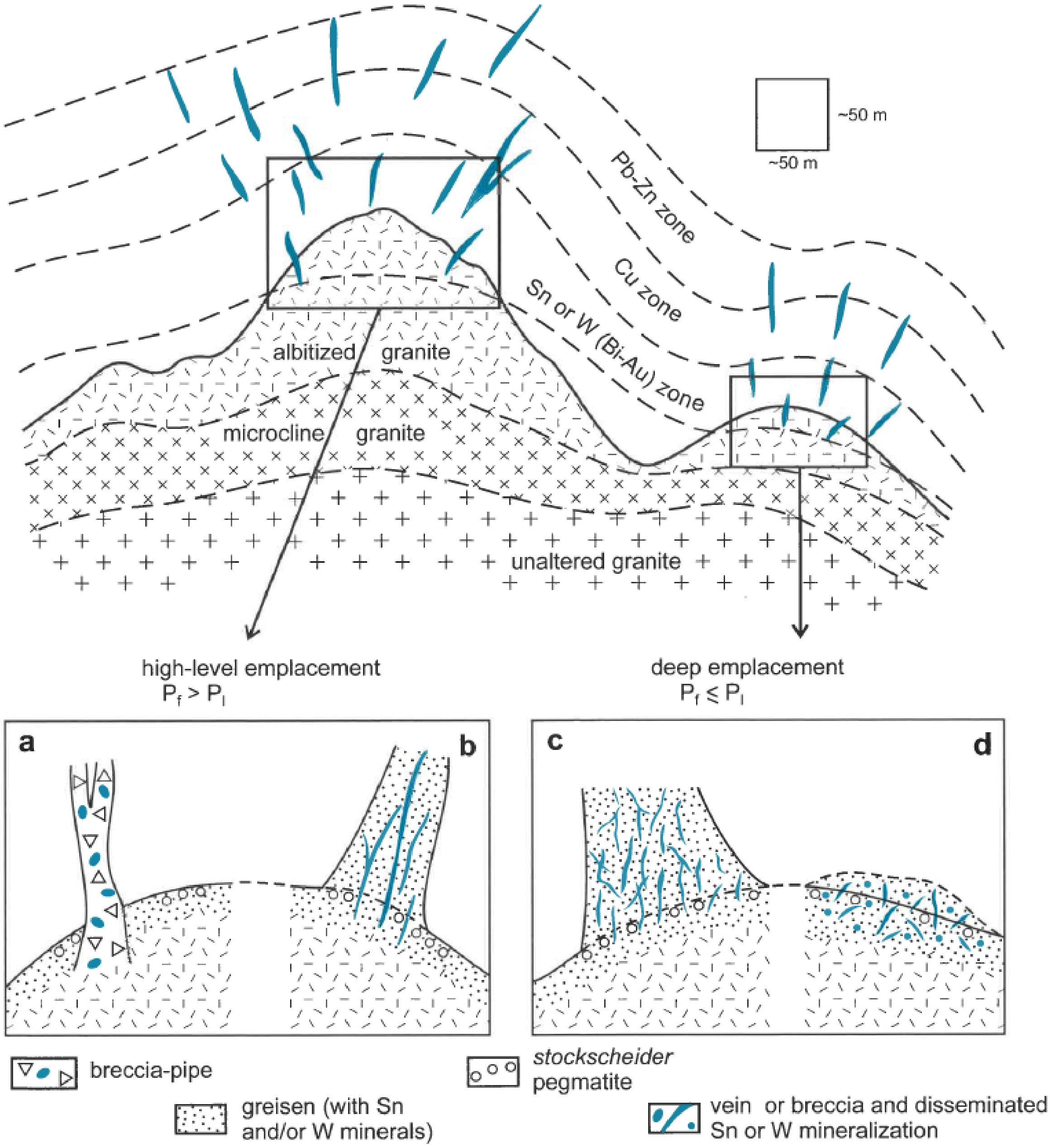

Figure 3: W-Sn cupolas. Top: idealized cross-section of a W-Sn granite cupola showing zoning of the mineralized veins. Bottom: morphology of the mineralization as a function of the ratio between fluid pressure (Pf) and lithostatic pressure (Pl). **a**) Pf >> Pl (very high fluid overpressure) causes explosions with the formation of breccia conduits and pipes; **b)** Pf > Pl causes the formation of fissures giving thick veins; **c)** Pf = Pl (balanced pressures) causes fissuring in the structure and the formation of stockworks and complex veins; **d)** Pf < Pl (high lithostatic pressure) maintains the fluids within the cupola, giving rise to intense greisenization and disseminated W-Sn mineralization.

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4.1.3 SKARNS AND SKARNOIDS

Contact metamorphism is accompanied by metasomatic or replacement processes in the vicinity of an intrusion, belonging to two main types: skarns and mantos. The skarns are in the immediate vicinity of the intrusion, while the mantos (Spanish word meaning cover, alluding to its frequently stratiform appearance) can be located up to several kilometres from the intrusion.

Metasomatosis, also called allochemical metamorphism, consists of a slow transfer of elements (Si, Al, Fe, Mn ...) by fluids impregnated in rocks which causes mineral transformations which can lead to deposits. These displacements are carried out thanks to hydrothermal circulations in porous environment, without open fracture. Fluid circulation and adjoining metasomatic transformations are then controlled by the lithology of the surrounding, both by its porosity and permeability, and by its ability to react with fluids.

The deposits developed by these metasomatic processes meet in a metamorphic environment. Skarns, mantos, and distal gold replacements of the Carlin type in particular are linked to contact metamorphism, or thermometamorphism. The action of high temperature magmatic fluids is manifested by the arrival of volatile elements (fluorine, chlorine, boron) and metals of magmatic origin (tungsten, molybdenum, and copper, gold ...). These deposits are related to the placement of plutons in sedimentary rocks and often associated with differentiated tin-tungsten granite domes.

Skarns are among the most widespread types of deposits on the planet and they constitute important deposits of tungsten, lead-zinc, copper or gold, but tin is also mined in the form of malayaite ($CaSnSiO_5$) or cassiterite, beryllium in the form of beryl, boron in the form of datolite and danburite, iron in the form of magnetite, or molybdenite and wollastonite.

The vast majority of skarns develop in contact with or near a magmatic intrusion. They result from diffusion phenomena generally at high temperature associated with granitic to dioritic intrusions of orogenic belts. The composition and texture of the protolite will largely control that of the resulting skarn, which explains the great variety of facies of these deposits.

The majority of authors propose a pragmatic classification based on the dominant economic metal. The characteristics of the different skarns are summarized below:

- iron skarns;
- copper skarns;
- zinciferous skarns;
- tungsten skarns which appear in depth, within vast metamorphic halos with skarnoids and corneas, in connection with calc-alkaline plutons dependent on vast batholiths;

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- tin skarns which are formed in connection with very siliceous granites, following a partial fusion of the continental crust; their strong fluorine activity develops an original retrograde alteration of the greisen type which sees the crystallization of topaz, fluorite, tourmaline, muscovite and quartz;
- the rarer molybdenum skarns (Azegour, Morocco; Little Boulder Creek, Idaho) and sometimes grouped with tungsten skarns which they come close to by the paragenesis rich in scheelite, but differ in their association with leucocratic granites.
- Boron skarns.

GEOLOGICAL CONTEXT

Skarns are commonly associated with small intrusions (a few km^2) containing host-rock pendants and having a sharp contact with a slightly tectonized carbonate host rock (**Figure 4**). Locally, the granite can be located above the carbonates. A distinction is made between exoskarn, which corresponds to mineralization replacing the host in contact with or in the immediate vicinity of the intrusion, and endoskarn, to replace the intrusion; the latter is rarer and less mineralized. A strong diffusion of calcium in the intrusive is marked by the disappearance of the feldspar and a replacement by an assembly with clinopyroxene, plagioclase, titanite and quartz.

MORPHOLOGY

The morphology of the skarns is a consequence of the depth of installation of the intrusions. The halo of thermometamorphism is less extensive and of lower intensity in copper skarns linked to porphyry intrusions placed at relatively shallow depth, than in ***batholites placed more deeply and commonly associated with tungsten skarns***. However, the extent of superficial skarns may be greater in the event of high fracturing intensity.

The morphology is a function of the respective importance of stratigraphic and structural controls, as well as the shape of the pluton. The skarns consist of very irregular mono-mineral beds, generally concordant but often locally discordant on the bedding (Figure 4).

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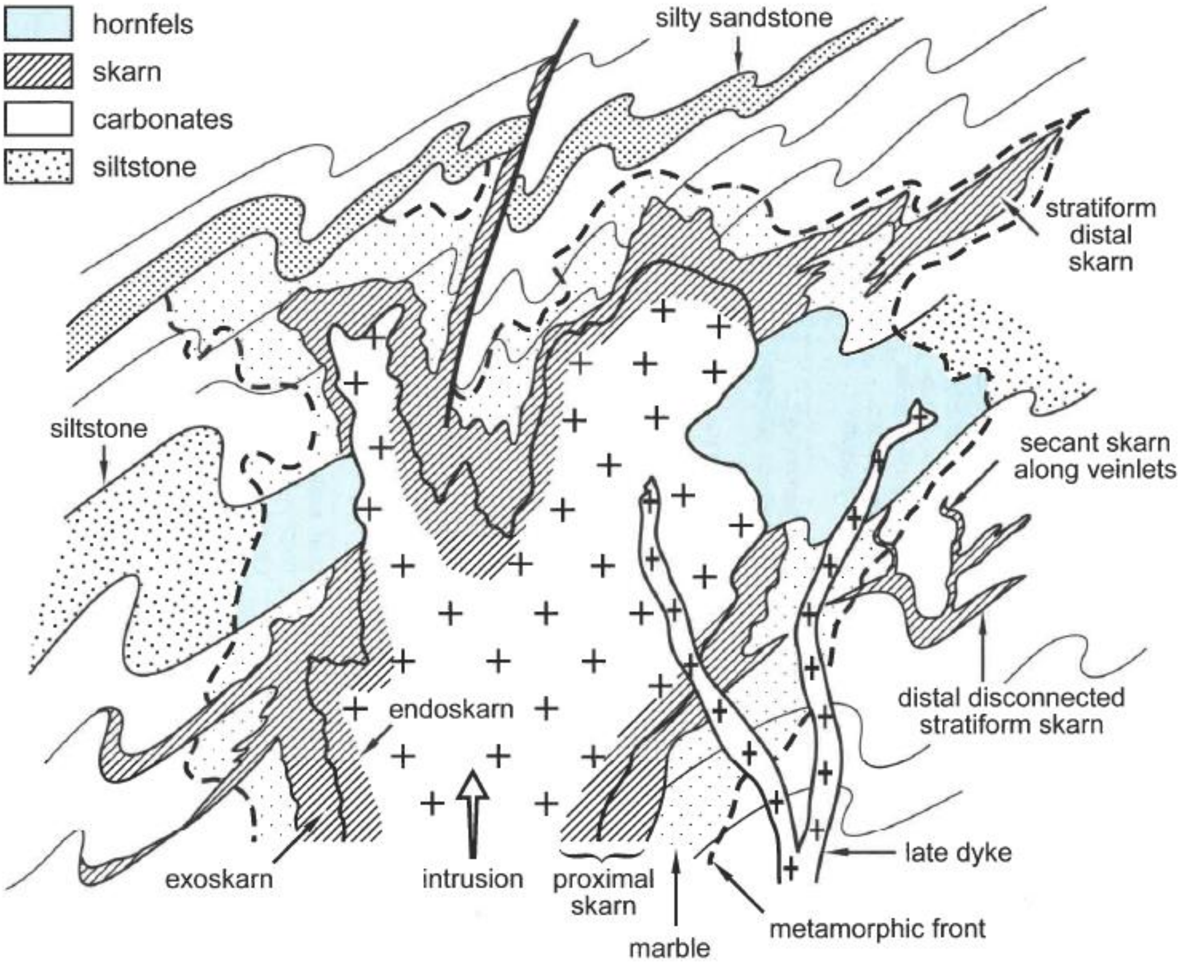

Figure 4: Idealized contact metamorphic aureole around an intrusion. Skarns are developed in the carbonate layers of the country rock and can spread quite far from the intrusion if there is fluid diffusion. Disconnected distal. Skarns are equivalent to the mantos. Hornfels occurs in the silico-aluminous levels.

FORMATION

Skarns show a clear zoning, in places with a greisen or a tourmalinization of the intrusion, commonly manifested at the initial stage and termed prograde (Figure 5).

The mineralogy of the metasomatic reaction zones, dominated by calcium silicates, is however highly variable; it depends on the lithological nature of the intrusion and the country rock, as well as on the temperature and degree of oxidation of the solutions.

This mineralogy evolves during the second stage of skarn formation, termed retrograde, with the appearance of hydrated minerals and sulphides. The changes do not generally significantly upset the zoning.

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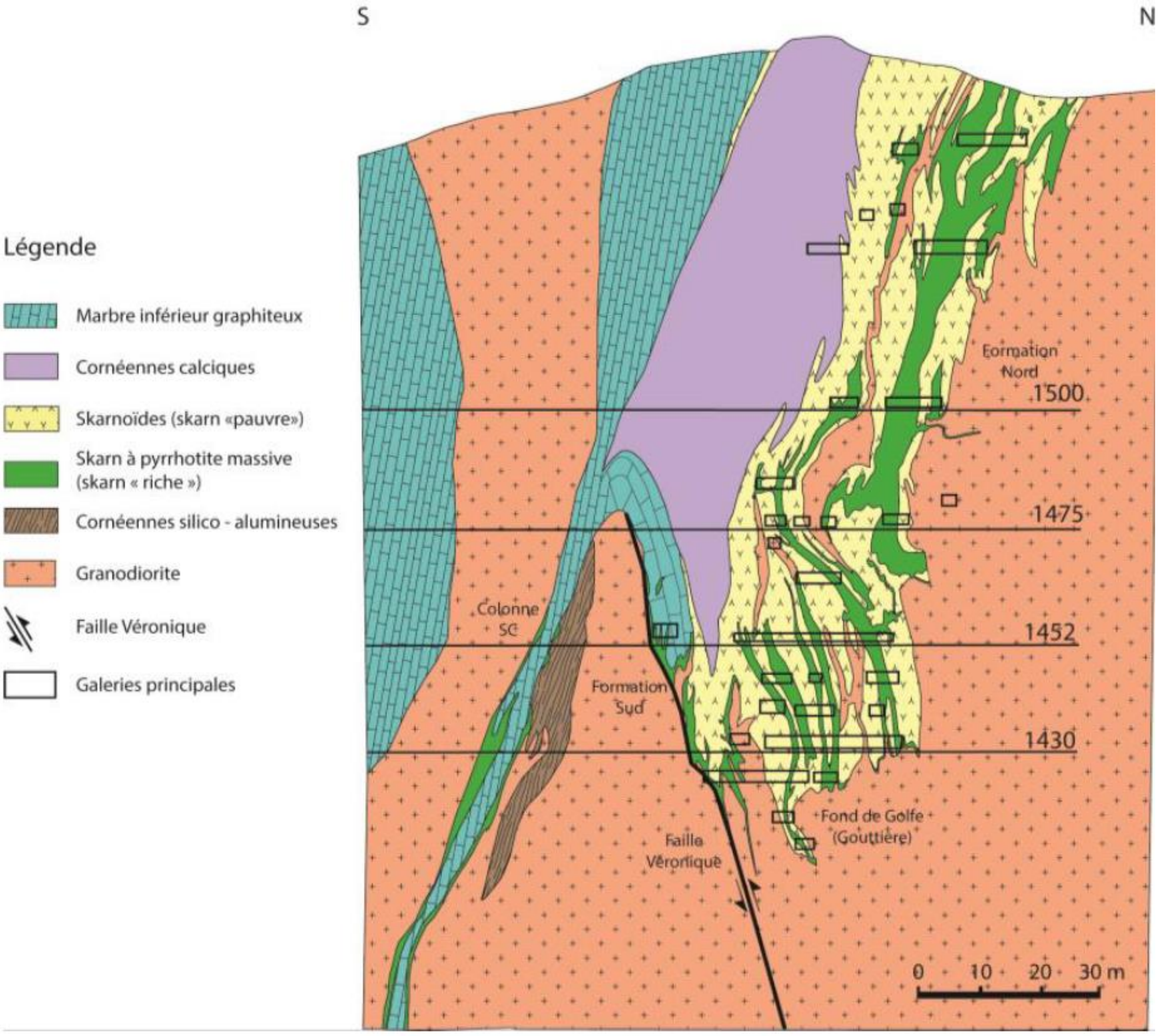

Figure 5: N-S section in the upper part of the Salau mine (France)

The deposits show a multiphase emplacement with three major stages that, in general, widely overlap:

- **A thermometamorphic** stage corresponding to the emplacement of the intrusion and the dehydration of the country rock with expulsion of the fluids. It is an isochemical process that transforms limestone to marble.
- **A prograde metasomatic stage** corresponding to an early metasomatism with the introduction of iron, manganese and aluminium at high temperature (600 to 500 "C) by the magmatic fluids released from the pluton. Typical anhydrous metamorphic silicates appear at this stage through reaction with the country rock: pyroxene (diopside-hedenbergite), garnet (andradite-grossular), clinozoisite, titanite, wollastonite, vesuvianite, as well as calcite and biotite. It is a diffusion process where element transfers are limited.

- In the case of tungsten skarns, fine deposits of disseminated low-grade scheelite (0.01% $W0_3$) may appear as of this episode. The episode is poor in copper and sulphides. Endoskarns form through the input of calcium from the country rock.
- **A retrograde hydrothermal** stage with the system being invaded by lower temperature fluids (450 - 300 °C). This fluid influx causes partial hydrolysis of the prograde-stage minerals and intrusive rock, leading to the appearance of many hydrated minerals, including amphiboles (actinolite, hornblende and tremolite), epidote, talc, chlorites, possibly sericite and montmorillonite clays, in addition to quartz and calcite.
- It is also the essential stage of sulphide deposition where the ore can be enriched to a mineable grade.

Stockworks and episodes of brecciation may accompany the emplacement of the sulphides.

The final paragenesis of the skarns therefore consists of preserved prograde minerals and later retrograde minerals. One thus finds hornblende-pyroxene skarns with, depending on their metal specificity, pyrrhotite, pyrite, chalcopyrite, or magnetite, possibly cubanite and scheelite, associated with actinolite and chlorite, and garnet-wollastonite skarns with sulphides (bornite, chalcopyrite, sphalerite, galena, tennantite) associated with dominant epidote. Lead-zinc sulphides can form veins, chimneys or peripheral layers (mantos).

Nature of the mineralization is closely associated with that of the magma and tin-tungsten deposits are linked with ilmenite granite.

4.1.4 DEPOSITS ASSOCIATED WITH ALKALINE PLUTONISM

Alkaline magmatism is rare since it represents only 5% of igneous rock, but it involves nearly 50% of the rock names, which gives an idea of the complexity of the assemblages distinguished by petrologists. The associated granite belongs to the A-type granite family: A as in Alkaline, but also as in Abnormal, Anorogenic and Aluminous.

In this work, we will quickly summarize the main characteristics of these deposits, which many responsible for the main productions of Nb, Ta known, however are limited in Europe to a few deposits in the Scandinavian shield and Greenland.

The alkaline series includes many rock types ranging from ultramafic to felsic; the most widely accepted definition corresponds to rock containing feldspathoids and/or pyroxenes and alkaline amphiboles. Peralkaline rock is characterized by an agpaitic ([Na + K]/ Al) index greater than 1.

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Alkaline magmatism can occur in two extensional geotectonic contexts that allow direct passage to the surface without contamination; one at rift level and the other behind subduction zones.

It is especially abundant at the continental or oceanic rift level, associated in particular with hot spots caused by mantle plumes. The recent volcanism of the French Massif Central is an example.

The alkaline magmatism also appears behind the subduction zones, both in continental and oceanic context. The alkaline magmas can appear very far from the subduction zone, in connection with a deep rupture of the subducted plate.

Alkaline magmatism frequently presents an enrichment in incompatible elements such as zirconium, niobium, uranium, yttrium, and rare earths. It is thus at the origin of a large number of mineralisation which appear at different structural levels, and even sometimes in the vicinity of the surface in the form of a diatreme. We can recognize several types of mineralization at Nb-Ta:

- mineralization associated with lamprophyres and carbonatites (Nb-Ta, rare earths; exceptionally Fe, Sr, Ti, Mo, Ta, U, Cu, Zn, vermiculite and platinoids);
- the mineralization associated with the nepheline and carbonatite syenite massifs: these are mainly very refractory minerals such as zircon, high-tech metal minerals (niobium-tantalum, rare earths, thorium-uranium), or apatite (mainly fluorapatite) usable in the phosphate industry;
- hydrothermalism associated with granites and pegmatites from more advanced alkaline systems is also responsible for various mineralization. The alkaline pegmatites produced iron, rare metals (Ba, F, Ce, rare earths, Y, Zr, Nb), and the differentiated granites from the annular complexes of Nb, Ta and Sn;

4.1.4.1 RARE EARTH, NIOBIUM AND TANTALUM CARBONATITES

Around 500 carbonatites are currently known worldwide (including 34% in Africa), and around 25 deposits are active. We can distinguish two sub-groups:

- primary carbonatites which produce rare earths, niobium-tantalum (pyrochlore, columbite). Carbonatites of this type are in use at Mountain Pass (California, United States), St Honoré (Quebec), and Araxa (Brazil). The latter is particularly rich with a 3% Nb_2O_5 ore. Bayan Obo (Inner Mongolia, China) or Palabora (South Africa) are also associated with this type;
- hydrothermalized carbonatites, used for fluorite, result from a reaction between magma and groundwater, such as the Amba Dongar (India) and Okorusu (Namibia) deposits.

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Carbonatite bodies are often located in fault zones or at the heart of alkaline complexes with dominant nepheline syenites: they therefore generally occupy volcanic devices of the diatreme-maar type, and sometimes form veins. Their surface appearance is roughly circular to elliptical, but their general morphology is that of pipes or dykes. They frequently contain pyrochlore, columbite, tantalite, bastnaesite, apatite and alkaline feldspar.

The mineralization generally occupies a crescent at the periphery of the pipes and can constitute powerful tabular bodies of 50 m. The carbonatites are often surrounded by a halo of alteration, or fenitization, which obscures the contacts and can extend up to 4 km around the intrusion. Fenitization is a desilicification accompanied by the development of alkaline minerals (aegirine, riebeckite), and alkaline feldspar (microcline). The composition of the fenites also depends on the nature of the host rocks. The zoning of the alterations shows a potassium metasomatism at the top, and more sodic alterations in depth. Fluorite appears late and replaces carbonates.

A tropical supergene alteration can play an important role, allowing a residual enrichment. This type is well known in Araxa (Brazil), where the primary niobium mineralization becomes a loose and enriched ore, exploitable in the quarry in its altered surface part, making this deposit the first world producer of niobium.

4.1.4.2 ALKALINE COMPLEXES

Differentiated alkaline magmatism is represented by plutons, often zoned, called alkaline complexes, set up in an anorogenic context. There are two main types, quite commonly associated within a complex:

- nepheline syenites with zirconium and niobium, respectively in the form of zircon and pyrochlore, or with sodalite, rich in rare earths, uranium and thorium. They frequently contain deposits of rare metals (Zr, Nb, Ta, Y, Be, rare earths), such as Arendal in Norway or Ilimaussaq in Greenland.
- hyperalcaline granites and their pegmatites, of variable nature. The term "hyperalcalin" indicates a (Na + K) / Al ratio greater than 1.

These complexes are locally mined for Zr, Nb, Ta, Sn, sometimes uranium, and even gold, linked to late alkaline intrusions from the Archean greenstone belts.

NEPHELINE SYENITES

Nepheline syenites are usually small intrusive massifs, frequently circular in appearance, and often intersected by late carbonatite dykes. The nepheline syenites of Ilimaussaq (Greenland), also show a fenitization (hydrothermal alteration inducing a desilicification of the rock) associated with the concentrations of zirconium, yttrium and rare earths.

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These are highly undersaturated, granular magmatic rocks made up of alkaline feldspars (usually perthitic microcline and albite) constituting nearly 70% of the rock, feldspathoids (nepheline, more rarely sodalite, analcime or haüyne) 20%, biotite, amphibole and alkaline pyroxenes (riebeckite and aegirine respectively), and an impressive procession of accessory minerals including zircon, titanite, fluorine, pyrochlore, corundum, bastnaesite, l apatite, etc.

They may exceptionally contain large quantities of phosphate in the form of apatite ("urtite" from Khibiny, Russia). Magmatic phosphates represent 14% of world production.

PERALKALINE GRANITES

These granites can be aligned along large crustal structures in extension (1600 km in Nigeria) and seem in connection with the horsts of the Precambrian basement. The massifs are in the form of annular complexes or massive bodies with a felsic heart and a more mafic margin. The magmatic sequence extends from alkaline gabbro to riebeckite-biotite granites with an albite granite border.

The peralkaline granites with rare elements are characterized by a very low phosphorus content, a large abundance of fluorine, rare earths, yttrium, zirconium and niobium, as well as high contents of thorium, tin, beryllium, rubidium and uranium. The paragenesis is mainly with albite, riebeckite, zircon, aegirine, arfvedsonite, and niobium minerals (columbite, tantalite).

Economically, in addition to tin, exploited as cassiterite almost exclusively in alluviums and eluvions, peralkaline granites also produced Pb, Zn, U, Nb, Th and rare earths.

Alkaline mineralization forms at the magmatic stage and are often reconcentrated at the hydrothermal stage in the associated pegmatites.

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4.2 THE W AND NB-TA DEPOSITS OF THE VARISCAN BASEMENT

As Nb-Ta deposits are not the subject of historical research, the location of favourable pegmatites and greisens is guided by the search for associated W-Sn domes.

4.2.1 THE VARISCAN OROGENY

The Variscan chain constitutes the backbone of Europe, extending from the Bohemian massif in the east to Iberia and Morocco in the west. It represents a segment of a cordillera which extended over approximately 10,000 km in the Upper Carboniferous. Witnesses of this extent are found from Texas in the West, to the Polish Sudetenland in the East, via the Appalachians, Central America and the Mauritanides of West Africa.

Its current architecture results from the collision between the Avalonia microcontinent and the northern margin of Gondwana (Figure 6)

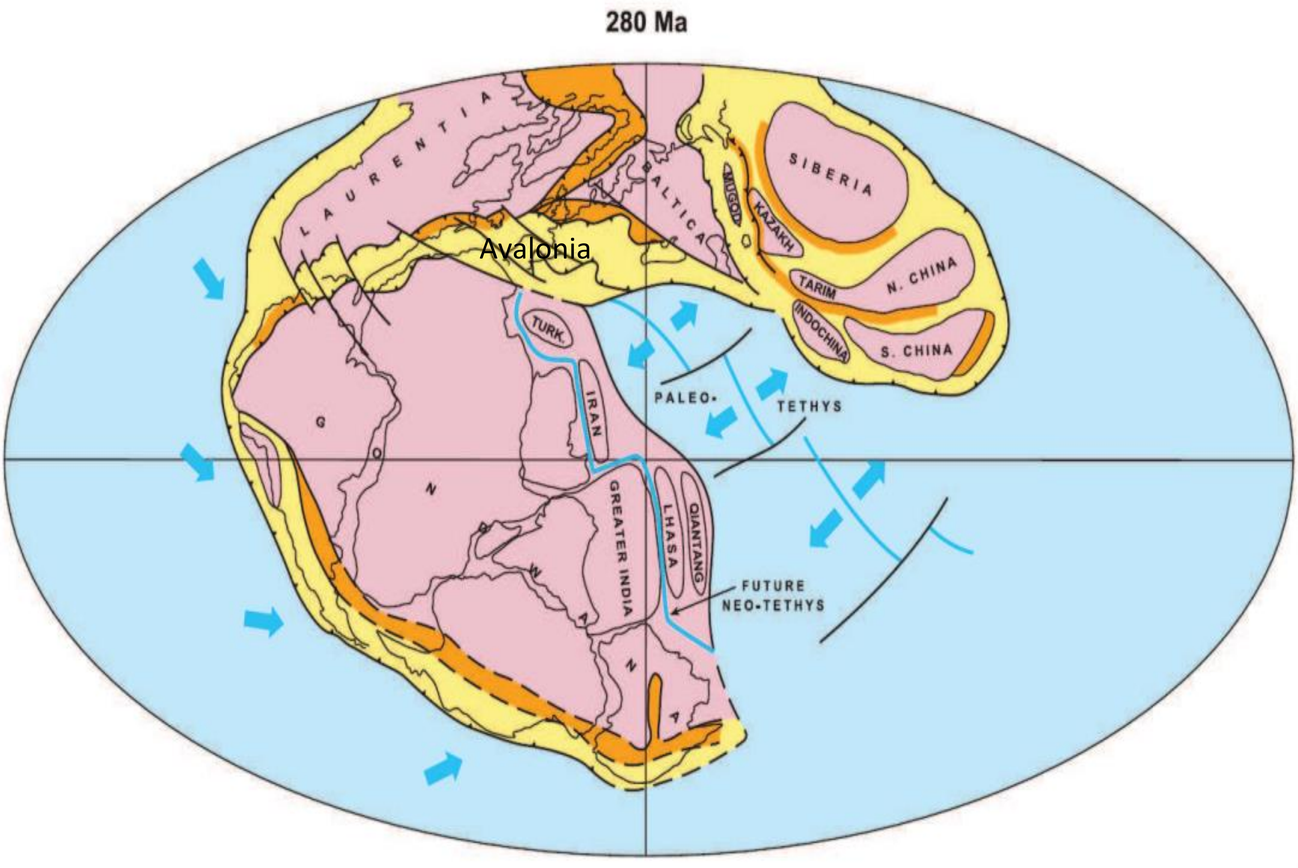

Figure 6 : Permian assembly of the main continents forming Pangea and showing the extension of the Paleozoic chains. 400 – 250 Ma in yellow; 450 – 400 Ma in orange.

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This orogeny begins in the Upper Devonian and results from the accommodation of two oceanic subductions towards the south under Gondwana. They affect internal areas. The history of this mountain range continues in the Upper Carboniferous with the accretion of the different continental blocks which is manifested by the closure of the oceans to the north, leading to the continental collision between the MGCH (Mid-German Crystalline High) and the Armorican plate already attached to the Gondwanan continent to the south.

This collision leads to the stacking of crustal sheets responsible for:

- thickening of the crust in its internal areas;
- a Barrovian type HT/MP metamorphism with partial melting of the crust, and
- a significant magmatism from 340 Ma to 290 Ma.

The Variscan chain therefore follows the opening and closing of several oceanic domains which make it possible to divide it into several major lithotectonic zones (figure 8), from north to south: the Rhenohercynian zone, the Saxothuringian zone, the Cadomian zone and the Moldanubian zone. For the Bohemian massif, the Teplá-Barrandian zone, possible equivalent of the Cadomian zone, is also described.

During the Devonian, between 420 and 360 Ma, convergence was marked by the subduction and closure of several oceanic domains. The continental collision occurs around 360 Ma, manifesting itself by a crustal thickening marked by a stacking of layers, a metamorphism of HT/LP and an exhumation of the subducted units of HP/BT today dispersed in the internal zones of the chain.

Between 360 Ma and 290 Ma, the dynamics of the West-European chain changed profoundly. This is manifested in particular by a late to post-orogenic extension and an extensive partial melting which affects the foreland and the internal zones of this orogeny. In the internal parts, the partial melting process reaches its peak and leads to the formation of migmatitic domes exhumed by crustal detachments. This episode of partial melting strongly affects areas located towards the foreland of the orogen.

This partial melting is associated with intense magmatism both in the internal and external zones of the chain (figure 7). It materializes through the installation of crustal fusion products (peraluminous granites) initially and then hybrid or mantle magmas (calc-alkaline granitoids).

This regional thermal event is synchronous with a reorganization of the Variscan chain with the activation of major fault systems.

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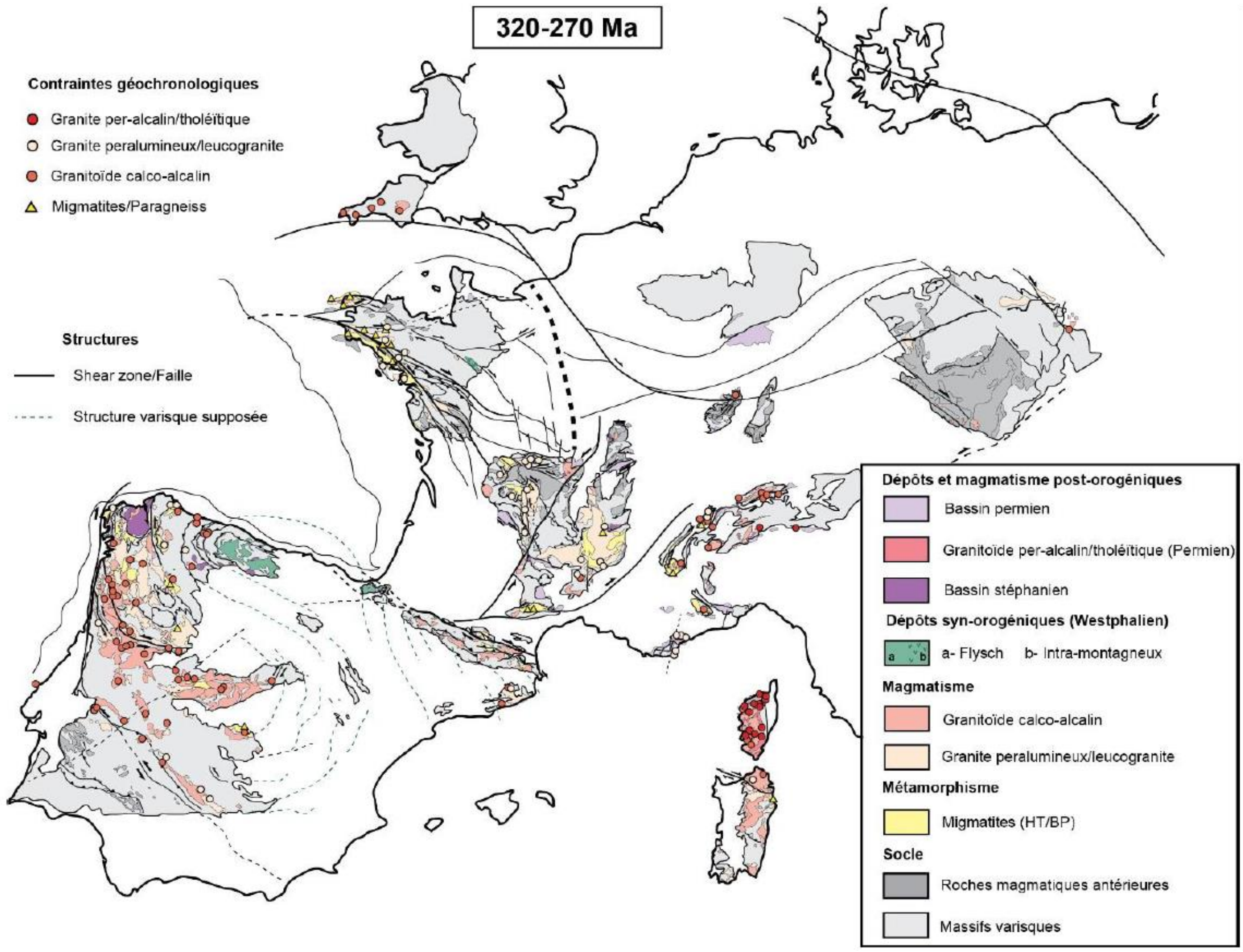

Figure 7 : Map of the West European Variscan chain (Cochelin, 2016)

Major normal faults and crustal strikes then favored the large-scale partitioning of the post-orogenic extension (305-260 Ma) and gave a fragmented appearance to the West-European Variscan chain after its dismantling.

4.2.2 DISTRIBUTION OF THE MAIN RESOURCES IN W, NB, TA OF THE VARISCAN DOMAIN

The tin and tungsten deposits of the West-European Variscan chain are distributed over a vast area of 1300 km from North to South and 1500 km from East to West. They are varied in nature and are represented essentially in the form of 3 main type deposits:

- veins and stockworks;
- rare metal pegmatites or granites;
- skarns.

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They are distributed in most of the Variscan massifs: Bohemian Massif (BM), Harz, Black Forest, Vosges, Central Massif (FMC), Armorican Massif (AM), Cornwall (C), Pyrenees and the north-west of the Iberian Peninsula (figure 8).

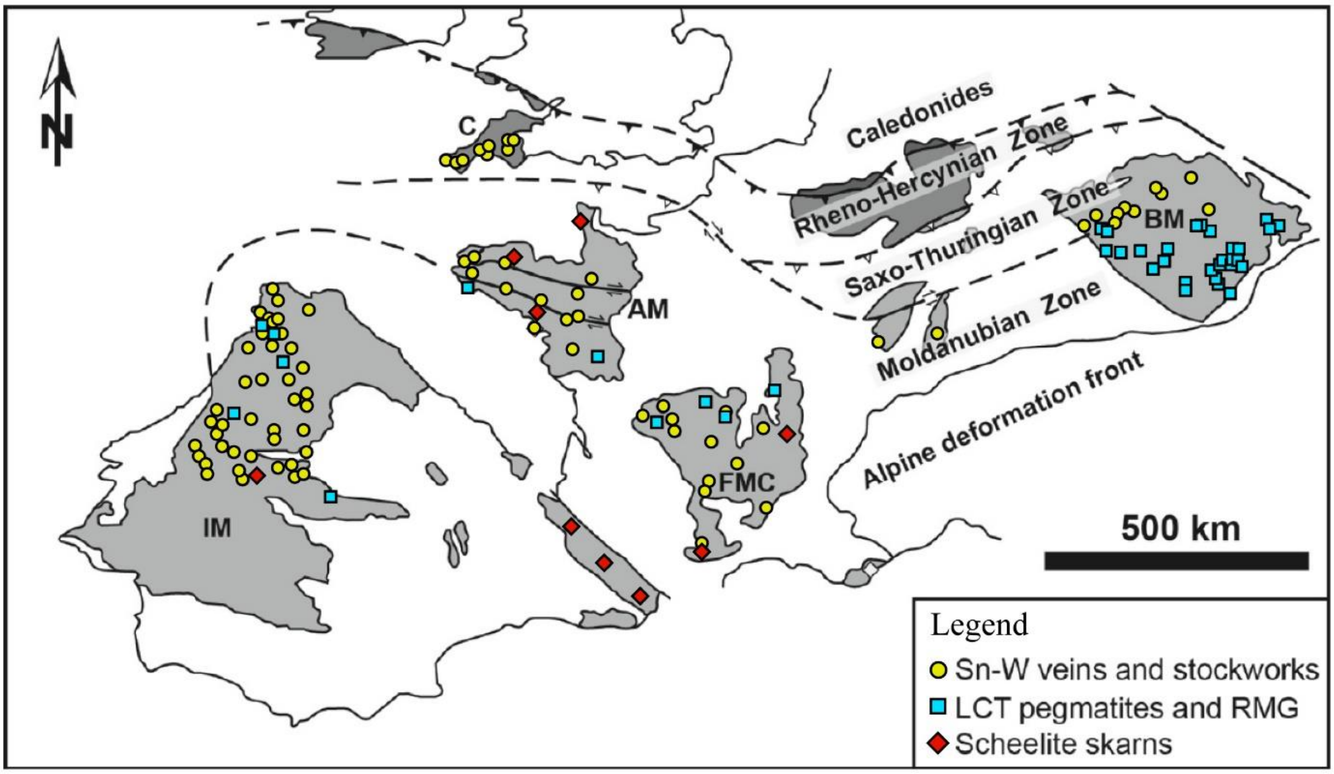

Figure 8 : Distribution of tungsten deposits in the Varisque chain (modified after Harlaux, 2016). LCT = Lithium-Cesium-Tantalum pegmatites; RMG = Rare Metal Granite

The distribution of tin and tungsten in orogenic belts would be controlled on a large scale by the superposition of processes in the passive and active margins.

The expression of tin and tungsten in these different types of deposits appears in almost all periods from the Precambrian to the Liassic. The climax of their genesis is linked to late-Variscan granitic intrusions.

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4.3 HARMONIZATION OF VOCABULARY

4.3.1 REMINDERS ON MINING DEFINITIONS

Between **exploration** and **exploitation**, the terms are similar, but they hide deep distinctions which then lead to misunderstandings linked to this confusion on the part of readers, even those who are already well informed. We will try to provide here some details on the use of the most common terms in mining vocabulary.

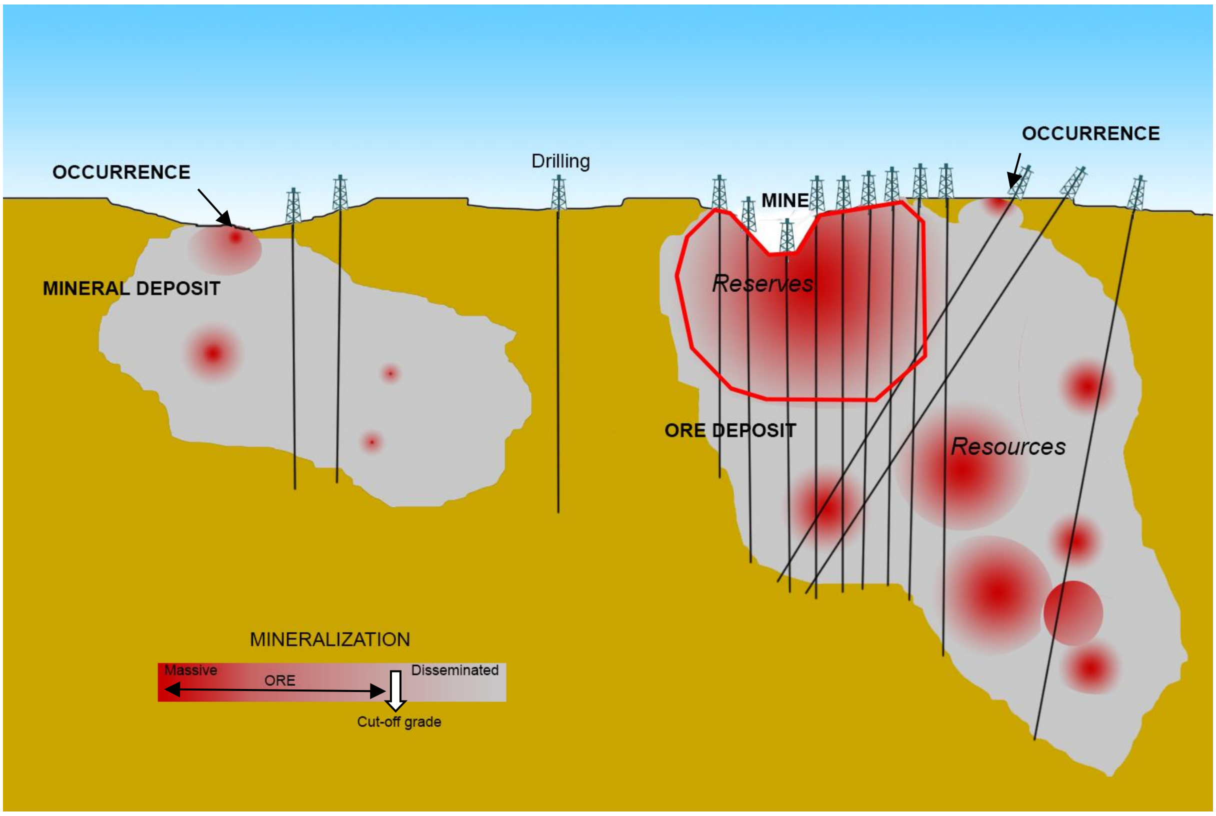

Figure 9: illustration of the main terms used in mining geology

4.3.1.1 ORE

An excellent definition is given in the work of Michel Jebrak and Eric Marcoux "Geology of mineral resources"[6]

"An ore is a mineral or rock from which one or more elements can be profitably extracted". However, this concise definition is ambiguous.

[6] Michel Jebrak & Eric Marcoux "Geology of mineral resources" published by Géologie Québec ISBN: 978-2-551-23737-1. Government of Quebec 2008.

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Indeed, for the mineralogist, the ore is the mineral which contains the element to be recovered: galena (PbS) for lead, chalcopyrite (CuFeS2) for copper, etc., it is the ore in the strict sense.

For the miner, on the other hand, ore designates the mass of material brought down in the mine as a whole, and not the only recoverable mineral: it is ore in the broad sense. Sandstone impregnated with hematite is thus an iron ore, and galena quartz is a lead ore, although the proportion of “real” ores, hematite and galena, is at most a few tens of percent.

In the case of gold, the ore is often a sulfide-gold quartz, in which the strict ore, native gold, represents only a few grams per ton. This broader meaning is very close to the definition in the Larousse dictionary (“rock containing useful minerals in a notable proportion”), and has no connotation of exploitation. This notion of ore joins those of deposit and grade, which have an essential economic dimension.

After extracting the ore, obtaining a marketable product requires a series of complex operations known as mineral processing. This begins with more or less extensive crushing and grinding, and continues with physical and/or chemical operations such as flotation or cyanidation intended to separate the economic mineral from the others. The marketable product is usually a concentrate in which the economic mineral(s) are highly enriched relative to the starting ore. The concentrate then undergoes a chemical operation, often a fusion, which provides the desired element(s): a solid (copper, gold, lead, etc.), a liquid (mercury) or a gas (fluorine, bromine, etc.). »

4.3.1.2 MINERALIZATION

Mineralization is a rock containing exploitable minerals (ore in the mineralogist's sense), but these may be present in too small a proportion to reach the economic threshold. In fact, mineralization can be a rich ore as well as an ore that is too poor or not large enough to be exploited, and which then loses its strict name of ore.

Within deposits, the “border” between ore (rich mineralization) and poor mineralization is mainly defined by the content of the metal exploited. This content, called “cut-off grade”, marks the difference between the rocks which will be sent to the processing units (the ores) and the rocks which will be rejected on the waste rock because they have too low an economic value.

This cut-off grade is therefore not a geological parameter, it is a purely economic parameter. The cut-off value will vary with the market. A mine can therefore find itself at a standstill if the price of metals is too low and its exploitability requires a cut-off grade that is too high.

Very often, the higher the cut-off grade, the more complex the ore morphology becomes and more difficult to exploit. At the same time, maintaining exploitation in these conditions results in selective exploitation of the richest parts of a deposit, which will have the direct consequence of drastically reducing the life of the mine if prices were to rise subsequently.

4.3.1.3 MINE

The deposit is studied by the geologist, the mine by the miner! Everyone will have their own perception.

The mine is the industrial operation corresponding to extraction. There is no direct relationship between the size of the mine and that of the deposit; this relationship is a function of a political and economic choice.

You may want a small mine on a large deposit if you want to prioritize the lifespan of the operation or limit the initial investment, or not impact a market, or any other reason...

We may also want a large mine on a small deposit, if the technical conditions allow it and if, on the contrary, we want to “complete” the deposit as quickly as possible for fear (for example) of a political or social risk deemed too high.

The lifespan of the mine is established on its **reserves**, that is to say the volume of ore whose tonnages and contents have been determined with certainty and which meets all the economic and technical criteria of its exploitability (from extraction to processing and marketing). In general, these reserves guarantee the lifespan for at least the next 10 years and a responsible operation will have to invest in the necessary surveys to maintain them at this level if it is deemed acceptable.

The calculation of reserves therefore depends on the policy of the mining company, and not necessarily on the intrinsic qualities of the deposit. In periods of economic difficulty, the investment necessary to maintain reserves will often be sacrificed, and reserves will decline rapidly as production increases. This does not necessarily mean that the deposit is depleting quickly.

On the contrary, if the company plans to sell its mine or raise funds on the stock market, it will tend to invest in increasing its reserves in order to reassure potential investors about the future of the company.

4.3.1.4 THE ORE DEPOSIT

This is the volume of ore defined by geology. It is estimated by its ore **resources**. At this stage, we will only consider the economic criteria of the ore; considerations on all the exploitability parameters will not yet be taken into account. ***The reserves therefore result from a more in-depth study of part of the resources.***

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In the CIM classification (2000) adopted by standard 43-101 of the Toronto Stock Exchange, a mineral resource is a concentration of natural, solid, inorganic or fossilized material in the crust whose shape, quantity and content, or quality could allow economic extraction. There are three categories of resources: measured, indicated or inferred:

- **measured mineral resources** are those which are of intrinsic economic interest, and whose tonnage, density, shape, physical characteristics, quality, content and continuity are known with a high degree of certainty;
- **indicated mineral resources** are also of intrinsic economic interest, but their characteristics are known with a lower degree of certainty than measured mineral resources; the reliability is however higher than for inferred mineral resources;
- **inferred (or supposed) mineral resources** are those which are of intrinsic economic interest, but with a limited degree of certainty, and a low level of confidence. They are only hopes which have only a low probability of becoming measured resources.

4.3.1.5 THE MINERAL DEPOSIT

This is the volume of rock mineralized in metals which does not necessarily yet present an intrinsic economy. The work of the exploration geologist generally consists of discovering a mineral deposit and then evaluating it to see if it can constitute an ore deposit. At this stage, we will not be able to talk about resources, but depending on the precise characteristics of these deposits, an experienced mining geologist will generally be able to identify known models of mineralization and predict the probability that this will have to evolve into an ore deposit.

These studies are carried out using evidence of mineralized rocks discovered in outcrops or by geological exploration drillings. These evidences of mineralization, the economics of which remain unknown, are called **occurrences**.

The occurrences may therefore be the surface manifestation of a deposit not yet discovered. Depending on the metallogenic models, the density of its occurrences on a given surface and the geometry of the alignments can anticipate the size of the mineral deposit. Their precise mapping is therefore an essential element of the mining potential map.

In this work, we therefore endeavored to exhaustively list all the occurrences described during public prospecting campaigns. Their number therefore corresponds to the effort made for this task and is not necessarily a reflection of the importance of the mining potential.

In all cases, the information thus synthesized remains a major decision-making element for setting the exploration strategy of a state, an institution or a private company.

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So, to summarize the history of a mine, we can say that a mine begins with the discovery of one or more **occurrences**, which make it possible to identify a **mineral deposit**, which will evolve following development work towards an **ore deposit**, in which **reserves** will be defined if **resources** are deemed sufficient.

It is only at the end of this long process that the opening of a mine will be scheduled.

In general, less than 1% of “serious” occurrences evolve into a mine.

In the study of the European mining potential in W, Nb - Ta, we will consider old historical small mining works as occurrences; we will therefore take the a priori that they do not provide sufficient information to define an ore deposit or a mineral deposit without additional studies.

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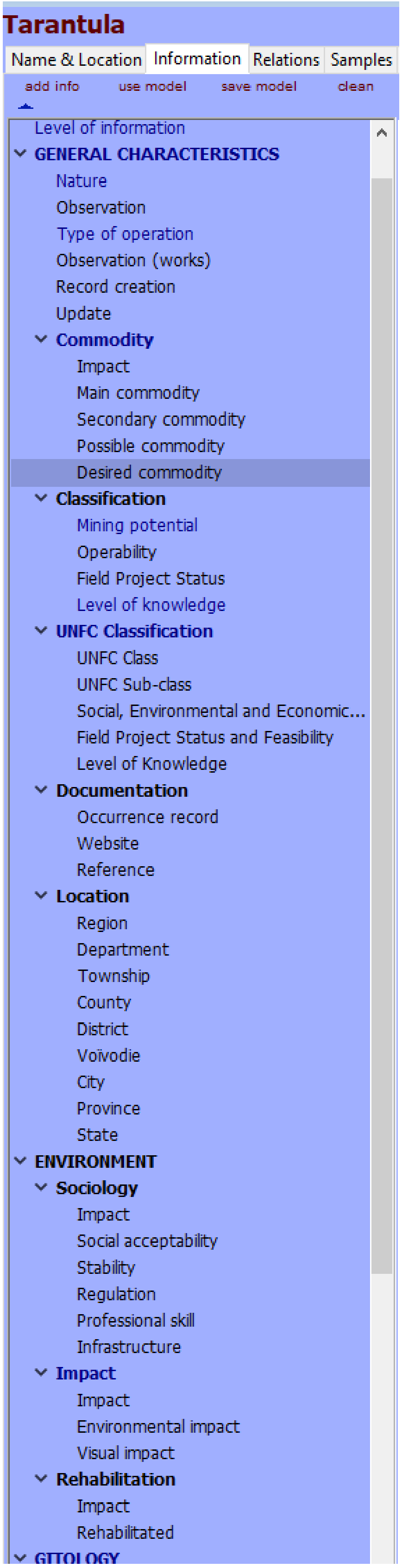
4.3.2 PARAMETERS OF THE GKR METALLIFEROUS SITES



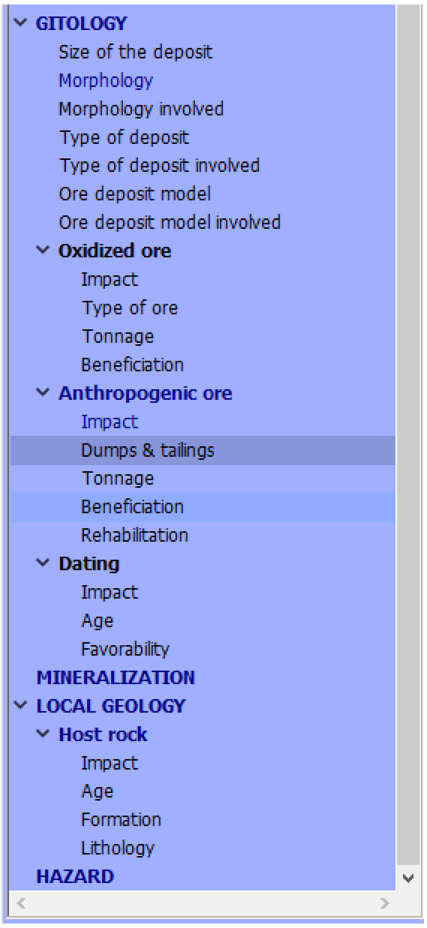


Figure 10. main labels in the GKR

As the GKR is a generic information system (Figure 10), each record can use different labels, and the number of items entered in a file is not limited.

To carry out our study and establish comparisons between the deposits and the occurrences of refractory metals in Europe, it is however essential that each record has a minimum of common criteria with all the other records. We will only detail here these main labels, a GKR sheet can contain several dozen more. Each label can be repeated several times if multiple entries are required, the GKR then having the necessary instructions to prioritize the various options.

The labels (i.e. "Main commodity") are classified hierarchically under chapters (i.e. "Commodity"). In turn,

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each chapter depends on a section (i.e.,"GENERAL CHARACTERISTICS"). A label can, however, be directly classified in a section.

Each label is a complex object which has indexed values, numerical values, semi-quantitative values and two parameters “reliability” and “interest” reflecting the reliability of the information provided and the importance of its impact on the score of the chapter or of section if no chapter is designated.

In turn, each chapter has the two parameters "reliability" and "interest" which weight its impact on the score to be assigned to the section.

The operation is repeated at the level of each section, until a final score is obtained for the metalliferous site.

Nature

The values entered in "Nature" will include at least one of the values listed in chapter 2.4.1.2; it can then be more detailed by additional indications, for example an occurrence can be supplemented by the value "outcrop".

Type of operation

To be able to estimate a mining potential, it is essential to clearly distinguish the nature of the mineralization (occurrence, mineral deposit, ore deposit...) and the activity associated with it (mine, mining work, ...). A giant deposit may not be exploited and a giant mine may be completely depleted. Mining potential must therefore take these two situations into account.

Mine: the term is quite blur, and it is often used for very different operations. It will often be confused with "exploitation", the meaning of which is more restrictive. In the GKR we will consider that the mine is the industrial operation which carries out the exploitation of a mining site. Depending on its size, a parallel will be drawn with the nature of the mineralization.

We should avoid any legal reference to the mining regime defined by the countries (notion of mine and quarry in France for example). The technique used for exploitation will be explained in an "exploitation" label.

Modern mine in operation: the parallel is established with the notion of ore deposit. However, it should be noted that a giant deposit can be exploited by several mines belonging to different companies. On the mine site, there may be several operations that would be interested in different mineral bodies. The most classic example is that of the surface part of the deposit exploited in a quarry while the deep part is exploited by a well located at a distance from the quarry.

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Former medium / large mine: we will always refer to the notion of mineral deposit. Note that the closure of the mine does not mean that the deposit is depleted. In addition, there will necessarily be associated tailings which could be examined in the light of new economic and / or technical parameters.

Artisanal mine: we will associate it by default with the notion of occurrence; the geologist’s opinion may, however, extend this notion to that of mineral deposit depending on the number and quality of other evidences that would be found in its immediate environment.

Exploitation: Large deposits are often exploited by the same mining company from several sites close to each other. The concept of mine will refer to all of its sites which will generally centralize the processing of ores on only one of them.

For example, the Panasqueira mine (Portugal) does not correspond to a single site, but it brings together several exploited sites which will be defined as operations:

- Panasqueira and Barroca Grande
- Corga Seca, Alvoroso, Veia Branca and Giestal
- Lomba da Cevada
- Ledges and Seladinho
- Fonte das Lameiras
- Vale das Freiras and Vale da Ermida
- Cabeço do Pião

Each operation, if significant, is the subject of a specific record, hierarchically linked to that of the mine which corresponds to it. In many cases, this operation will have its own name, separate from that of the mine. This peculiarity is the cause of numerous duplicates within the databases because the operations will be difficult to distinguish from the mines (separate coordinates, distinct names, different mining techniques, commodities exploited close but not necessarily identical in the event of zoning in the deposits …). Comprehensive work to establish the mining potential of a region should therefore ensure that this distinction is made. If necessary, we will create for each farm whose name is not known, a record bearing the name of the mine (Mine) which contains it followed by an index (Mine # 1, Mine # 2 ...)

In the case of giant deposits, the discussion could relate to the parallel to be established between the notion of mine and that of ore deposit. In some cases, the parallel would rather be to establish with the notion of mineralized field.

The values entered in "Type of operation" will include at least one of the values listed in chapter 2.4.1.2 ; it can then be more detailed by additional indications or use of ontologies, for example "quarry" will be understood as a mine or a mining works according to its size.

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Mining Works: mining or exploration work will be systematically linked to the notion of Occurrence. Depending on their nature, they will have a different weight in the definition of mineral deposit or ore deposit that they can induce in a mining expertise. We can distinguish (non-exhaustive list)

- Very small artisanal exploitations (recent or old)
- Small exploration works (recent or old)
- Outcrops, drillings or trenches
- Boulders
- Geochemical or geophysical anomalies

Main commodity

Commodity having defined the notion of deposit and mine. The extraction is managed by the exploitation of these commodities.

Secondary commodity

Commodity enhanced by the formula for selling merchant concentrates containing the main commodities. Are often considered as an operating bonus but do not define the selection of the ore.

Possible commodity

Commodities not valued by mining, but which could participate in the economy of the deposit if new recovery technologies could be implemented. In the old mines, could correspond to metals not exploited or sought during the period of life of these old mines. Niobium and Tantalum are examples of these commodities.

Desired commodity

Research work, generally a drilling for a given substance, may have been undertaken without success. This negative information does not represent an occurrence, but it carries important information by indicating to the user the uselessness of searching for mining potential in the indicated sector.

Morphology

This is the geometry of the deposit detailed at the level of the mineralized bodies. We will distinguish veins, layers, clusters... Several morphologies can coexist within the same deposit or deposit. In the event of operation, they will define the method of operation. However, the morphology alone is insufficient to characterize the deposit.

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The same deposit can have several morphologies. We will first list the dominant morphology; the other morphologies will be listed under a compound label with the addition of "involved"

Type of deposit

The type of deposit provides important precision in relation to the morphology. In general, it will correspond to the association of a morphology with a mineralized content, for example: a vein of fluorite, a layer of sulphides, a copper stockwork...

In many cases, the type of deposit is confused with the metallogenic model. However, it does not provide information on the genesis of the deposit, and therefore on the fundamental characteristics of the ore or the criteria that would allow its efficient exploration/exploitation and/or the environmental impact of it. Several types of deposits can coexist within the same deposit and be generated by the same metallogenic model.

We will use the same rule as that used for morphologies. We will first list the dominant type which will have an impact on the importance of the DMA phenomenon. Other types will be listed under a compound label with the addition of "involved".

Metallogenic model

The metallogenic model explains the genesis of the deposit. The deposits belonging to the same model have very similar characteristics, which makes it possible to anticipate their mining potential and the environmental constraints which could be induced by their exploitation (themselves deductible from paragenesis of the gangue and the ore). Knowledge of this model is an essential parameter to guide the exploration and later the development of a deposit. Knowledge of the model is also an important element in anticipating the environmental hazards associated with their exploitation or even their exploration.

We will use the same rule as that used for “type of deposit”. We will first list the dominant model which will have an impact on the importance of the DMA phenomenon. Other models will be listed under a compound label with the addition of "involved".

Label “impact”

Some chapters do not directly participate in the score of the established metalliferous site. They can, however, influence the final score by providing a "bonus", such as a large volume of recoverable tailings or, on the contrary, a "penalty" linked to the absence of infrastructure or deplorable social acceptability.

This "impact" label is associated with the chapters: "sociology", "Impact", "Rehabilitation", "Oxidized ore", Anthropogenic ore", "Dating" and "Host rock".

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It defines the influence of the chapter: neutral, importance of the bonus (the score of which is calculated according to the other labels of the chapter) or on the contrary that of the penalty.

Score

This label without chapter and without section is not entered by the system user. It is established automatically with the entry of hierarchical labels. Between 0 and 100, the score reflects the probability of success that exploration on the metal site could achieve. It is obvious that 0 does not mean that nothing will be found, any more than 100 can guarantee the success of the operation and the certainty of having a mine. This is an assessment established from the information available, an assessment which is intended to be independent of the subjectivity of the consultant or the author of the sheet.

Level of information

Ideally, a score should be established with as many labels as possible to define it. The “Level of information” label provides information on the relative proportion of the filling rate of a metallogenic site sheet. It differs from the Level of knowledge, which can be very high even if the site registration is extremely incomplete. Indeed, we can, for example, consider that an operating mine has a high level of knowledge, even if the corresponding file is poorly completed.

This label is important for prioritizing metalliferous sites by weighting the decision according to its level. Strictly speaking, the hierarchy between metalliferous sites must be based on comparable levels of information: for identical types of operation, a high score with a high level of information is of more interest than a high score. with a low level of information.

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4.4 INTERACTIVE MAP

Nearly 4,000 metal sites with mining potential for tungsten, niobium and tantalum were identified in task 2.1.

For each site, a geological and economic synthesis was carried out (task 2.1) and a detailed analysis of the minerals contained in each of them (Task 2.2).

All of the information collected was summarized in the form of 3 separate sheets generated by the GKR system. These files can be examined in the tooltips opened by Google Earth when their specific icon is clicked.

Some occurrences having been very poorly informed, not all sites systematically broadcast the 3 tooltips, but we can nevertheless consider that at least 10,000 pages of information are brought to the attention of the user of this map.

Google Earth software support was chosen due to the following advantages:

- intuitive software, free and usable by a very wide audience, not necessarily an audience of specialists;
- very high precision of 3D images which allow the visualization of old mining works when they are not covered by vegetation. The imagery provided is sufficient in the majority of cases to approximately estimate the importance of mining waste.
- the visualization of metalliferous sites can be carried out at all scales, from the broadest to the most detailed and clear information can be attached to icons.
- all information is provided in a compact file (.kmz) which is very easily distributed and very easy to use.

A score was assigned by the GKR system to each metal site sheet. This score reflects the potential interest of a site. The higher it is, the higher the chances of success of a mining exploration. We will agree, however, that the reliability of this score will of course depend on the quality of the work carried out on the site as well as that of the retailer's report.

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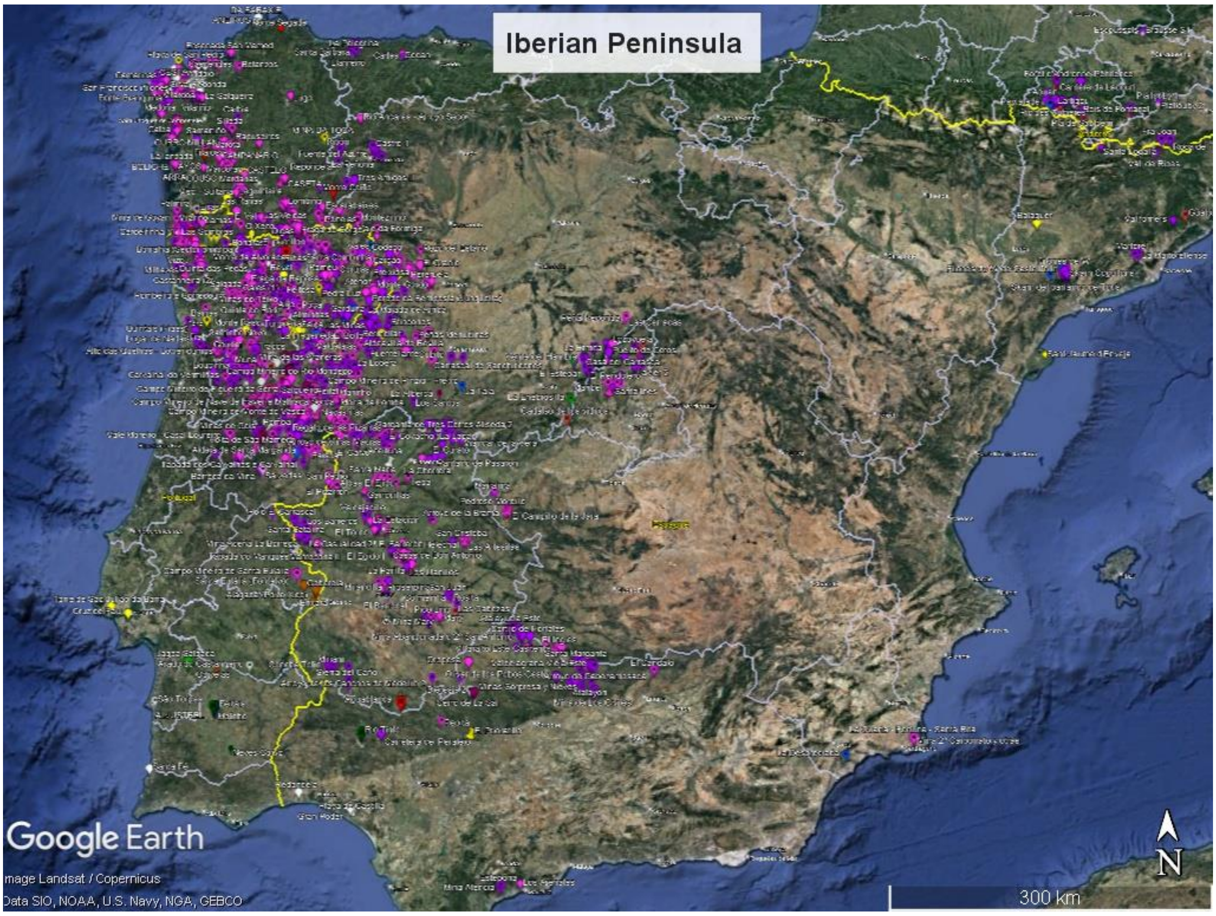

Figure 11 : visualization of 1,650 metalliferous sites for W - Nb - Ta in the Iberian Peninsula.

4.4.1 DEPOSITS AND OCCURRENCES

The metalliferous sites shown on the map are the result of an important compilation of documents established during the 20th century. The topographical surveys of the sites were carried out when the current GPS systems were not yet imagined. These surveys used the topographic funds available: maps of the General Staff for the oldest, geological map at 1/80,000, geological map at 1/50,000, topographic maps at 1/20,000 scale or 1/25,000 scale (from the IGN in the years corresponding to the Mining Inventory of France).

The accuracy of these surveys, adapted to the cartographic needs of the time, remains somewhat approximate when reporting them on a Google Earth document.

The position indicated on the map can therefore be marred by an error of several tens or even hundreds of meters; it must be considered systematically, especially if the site in question is in the undergrowth and hidden by vegetation.

For this reason, the position of a site indicated on this document will not be used to identify the properties actually impacted by the hazards. When the direct view of works is not possible or when the area occupied by them is considerable, field checks are essential to ensure the exact position of the hazard and the area concerned.

This relative inaccuracy does not affect the diagnosis that can be established on the position of deposits. Indeed, their size is most often greater than the positioning error of the point that represents them.

Figure 12: Close-up view of the Barruecopardo deposit and nearby occurrences

For the old mines, exploited industrially in the second half of the 20th century, the position indicated will essentially correspond to that of the main entrance to the works. It should also be taken into account that some deposits were mined from many galleries or many shafts opening to the surface. The point indicated then corresponds to only one of these works.

This position does not in any way imply the size of the deposit or that of the underground workings. An overview of the latter being specified by the size of the icon and in the headings appearing in the bubble of the metalliferous sites. The user will be reminded that a deposit can develop in all directions over several hundred meters, or even over several kilometers. The size of the mining works does not necessarily reflect the size of the deposit. Thus, a former "small mine" may have been developed on a large deposit which under current conditions would be likely to allow the development of a new mine of equivalent or greater size.

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Since the mining was carried out from numerous structures emerging at the surface, the dumps and tailings could have been dispersed over numerous neighboring sites which will not be systematically identified in this work. Thus, the hazard attached to the metalliferous site may cover a much larger area than the single point indicated on the map. The preliminary assessment of the hazard provided here can in no way replace a risk study, which therefore remains essential in the case of major mining works or widely dispersed over a large area.

For old mining works, which are generally older and exploited in an artisanal way, the position of the site will gain in precision following the reduction in size of the works. The exploited mines, very rich and small (according to our current criteria), are located by their main entrance, often indicated by the mining waste that accompany it.

In open field, these mining remains are often identifiable on Google Earth maps and corrections to the original coordinates have been made. However, these corrections cannot be systematic and they will tend to favor the position of the old discharges (position of the hazard) compared to that of the main entrance to the works (position of the deposit).

For occurrences and drillings, the precision is that reported by the authors of the reports. By definition, no trace will be visible on the map and no correction of the coordinates indicated in the documentation will be made.

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Icons for « sites »

The sites that may present a mining potential are displayed by icons whose color is different for each of the substances listed in the sub-folders of the “Places” window. These icons have slightly different sizes depending on the nature of the site concerned: small for the indices and more or less large depending on the size of the mining work carried out.

Moreover, a distinction is also visible depending on the nature of its work; we will distinguish the following icons whose color indicates the nature of the main commodity:

Occurrence: 

Drilling: 

Former mining work: 

Former mine: 

Active mine or quarry: 

Reliability of the information deployed in the "site" balloons

Colored bullets can be attached to the information communicated in the balloons. They reflect the reliability of the information.

- **Good reliability:** the information communicated can be considered as reliable.
- **Medium reliability:** the information provided is indicative of the state of knowledge at the time of the studies.
- **Low reliability:** The information communicated is in no way guaranteed. However, they remain the most plausible hypotheses.
- **Very low reliability:** unreliable hypotheses requiring additional study.

Intensity or size attached to information

A gauge with 3 graduations can complete information, such as the size of a deposit or that of mining works. We can express 4 possibilities :

- — — —: Negligible or very low size/intensity.
- — — —: Weak size/intensity.
- — — —: Medium size/intensity.
- — — —: Big or strong size/intensity.

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4.4.2 HAZARD

The notion of hazard used here corresponds to technological hazard; it should not be confused with that of risk.

The reader can refer to the Wikipedia definition:

"A technological hazard is the probability that a dangerous phenomenon, of at least a large part of technical anthropogenic origin (ground movements induced by human activities, emissions or explosion of mine gas, radiation, waste dump fires, dike instability tailings, flooding, etc.), threatens or affects a given area by producing effects of a defined physical or chemical intensity. It is therefore the estimate of the realization of this process. The evaluation of the hazard (intensity, frequency) in a given place does not depend in any way on the possible damage (victims, destruction of infrastructures, natural elements) nor on the possible economic consequences".

The hazards indicated on this map can be combined on the same site. Their impact on the environment can be potentiated in a "cocktail" effect and the final impact will prove to be greater than that of the sum of each hazard taken individually.

The hazard estimate will be made for each site, for example for old mining works.

These old mining works are often of modest size (galleries of a few hundred meters) and therefore they most often generate low-intensity hazards. However, these old workings often come together in swarms, several "old mines" are located in a small space of a few km². In these sectors, the final impact of an anthropogenic hazard will have to take into account the accumulation of the hazards attached to each of the sites.

Icons used

To display these icons, check the “Hazards” folder in the substance folder.

Potential hazard: This type of hazard will be attached to occurrences that have not been the subject of known work. Its intensity corresponds to that which could be induced by the mining works which would be carried out. In the absence of this work, it can be estimated that the site has reached an equilibrium profile and that it does not represent a significant source of contamination.

Hazard identified: Technical hazard associated with mining activity.

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