NEW REQUIREMENTS AND OPPORTUNITIES FOR THE BRAZILIAN TANTALUM AND TIN INDUSTRY - AN APPROACH RELATED TO CONFLICT MINERALS *

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Abstract
Minerals containing Tantalum and Tin are considered conflict minerals, once the mining, transport or export of these ores have been related to financing of abuses to human rights or armed conflicts. In this scenario, corporate organizations and policy makers are constantly working on new regulations and requirements, in order to prevent companies from financing these issues. As consequence of these necessary efforts, the supply chain of tantalum and tin is already being affected and there may be a limitation of raw material availability for companies worldwide. Companies must adapt to new requirements while also looking for alternative materials such as secondary materials and/or byproducts of tantalum and tin the world and in Brazil, the necessary changes that Brazilian companies must go through considering this evolving scene and the possibilities for the metallurgical recovery of tantalum and tin from byproducts in Brazil. This recovery can help to enhance production levels, while not contributing to the financing of the described abuses.
Keywords: Supply chain risks; Conflict minerals; Tantalum and Tin; Tin slag.

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1 INTRODUCTION

Brazilian companies involved with minerals containing tantalum (Ta) and tin (Sn) will need to adjust to a new international scene regarding their supply chain. A much larger control over their material procurement and processing will be required and these changes can be acknowledged not only as a challenge, but also as a good window of opportunity to achieve a more social and environmentally sustainable supply chain.

A more responsible approach to the supply chains of resources used by our society is urgent [1,2]. This responsibility grows even more in relation to metals such as Ta and Sn, whose minerals are considered conflict minerals, alongside with gold and tungsten [3]. The trade of these minerals occur also in conflict affected and high risk areas (CAHRA's) and can be related to financing of armed groups, violation of human rights, money laundering and/or other abuses [3-7].

Among the conflict minerals listed by the European Commission, Ta and Sn minerals are particularly interesting for the Brazilian industry, due to their relevant reserves and production in the country [8,9]. Ta is a valuable metal used in important applications such as x-ray films, capacitors, lenses for digital cameras and cutting tools [8]. Sn is used for example in tinplate, solders, chemicals, copper alloys and in the automotive industry [10]. As can be seen, these metals are crucial for the industry and their uses are impacted by new technologies. Therefore, risks related to their supply chain could compromise the availability of raw material.

The supply chain of Ta and Sn can be threatened due to conflicts in areas where the minerals are originated. According to the 2018 Conflict Barometer from the Heidelberg Institute for International Conflict Research there are intense conflict areas present in the Democratic Republic of the Congo (DRC), Rwanda and Nigeria [11]. These African countries are relevant Sn concentrate producers. U.S. Geological Survey informs that the estimated mine production in these three countries accounted together for around 5.8% of the total world estimated production, with 17900 t in 2018. In the case of Ta the importance of these countries is crucial for the world supply. They were the main producers of tantalum concentrate in 2018 with a summed estimated production of 1360 t of tantalum content. For comparison, China had an estimated production of only 120 t, Brazil, 100 t and Australia, 90 t [12].

As a response to the problems related to the trade of minerals in CAHRA's, corporate organizations such as the Responsible Minerals Initiative (RMI) and ITRI Tin Supply Chain Initiative (iTSCi) have contributed for the identification, evaluation and mitigation of risks in the supply chain [13,14]. Regulations concerning the trade of conflict minerals were elaborated such as the Dodd-Frank Act from 2010 in the United States of America [15] and more recently the new Conflict Minerals Regulation developed by the European Commission, which is set to be valid from January 2021 and regulates the supply chain of conflict minerals exported to Europe [3,6]. Although these guidelines and regulations may differ from one another, they aim to avoid the procurement of raw material contributing to financing of armed conflicts and violation of human rights.

Since Brazil is one of the major producers of Ta and Sn, it is not out of this scope [8,9]. It will also face the challenges related to the supply chain of conflict minerals. Brazilian companies can also buy mineral concentrates from CAHRA's and/or that can be related to abuse of human rights and/or financing of armed conflicts. Besides, abuses could also happen in Brazil. According to the "OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas" (OECD Guidance) [4], the necessary control of the supply chain requires a rigid procedure when procuring raw material. If certain risks are identified, the relation with a supplier may be discontinued. As consequence, it enforces a lower availability of raw material containing Ta and Sn. This fact raises questions regarding possible alternatives for this supply limitation.

With the objective of identifying alternative raw materials that can be used for the production of Ta and Sn in Brazil, this article analyzed the primary production of these metals and typical byproducts of the tantalum and tin industry in the country. Then, based on literature, alternative routes for processing of these materials are proposed. Also, considering the recent developments regarding the problematic of conflict minerals, this work aimed to better understand it, as well as its impact on the Ta and Sn global supply chain and on Brazilian companies. The problematic of conflict minerals has not yet been explored enough in Brazil and studies related to the recovery of Ta and Sn from Brazilian byproducts are also scarce. Therefore, this work will contribute for the literature, as well as to build perspectives regarding the Brazilian Ta and Sn industry, which may be required to take further actions regarding the risks in its supply chain.

2 DEVELOPMENT

2.1 Ta and Sn as conflict minerals

Ta and Sn minerals are classified as conflict minerals, due to illegal activities related to their market [3-5,7,11]. The concept of conflict minerals, according to Vogel and Raeymaekers [16], was popularized two decades ago and was related to minerals from the DRC, which were financing the war. In that region, a conflict known as the "African World War" took place, being responsible for an estimated 5.4 million deaths [5]. In the DRC happened the Rwandan genocide in 1994 and shortly after erupted the first (1996-1997) and second (1998-2003) Congo Wars. Despite its official end in 2003, DRC kept facing continued fights in the eastern part due to ethnic violence and for the control of its natural resources [5,7].

Regarding those CAHRA's regions, Ta ores are present in soft alluvial deposits and semi-pegmatite. These ores require much lower investment and are easier to mine, allowing artisanal and small-scale mining (ASM) to be feasible in the region [17]. Alongside with Large Scale Mining (LSM), ASM are also exposed to abuses such as forced or compulsory labor at the mine, forms of child labor, torture, cruelty, among others. Also, ASM are more exposed to paying taxes or mineral shares to security forces or non-state armed groups alongside transport routes [4]. The international market has also contributed to this scene since it brought a growing interest on Ta and Sn, pushing the economic feasibility of their exploration on those countries [5,7].

In this context, supply chain risks management has been addressed by corporate organizations such as the RMI and iTSCi; Guidances have been developed, as for example, from the OECD; and legislations as the Dodd-Frank Act and the new European Legislation were elaborated. Although with some differentiation in terms of requirements, they help to prevent abuses throughout the supply chain and to guarantee the “chain of custody” of the material from upstream actors (for example, the mine) to downstream actors (such as a computer manufacturer). In other words, this new set of requirements, which is also often validated through audits, aims to secure that the Ta and Sn used by a given computer manufacturer did not contribute for the financing of armed groups and/or the violation of human rights at some point in the supply chain. [3,4,14,15,18]. As can be seen, the scope of the problematic, which once was focused in Africa, has widened considering that companies located worldwide can process Ta and Sn from CAHRA’s. Also, abuses can occur not only in countries such as the DRC but throughout the supply chain around the globe. Therefore, companies are being required to adapt to these changes.

Considering the OECD Guidance [4], which is used as reference for both iTSCi and RMI, companies are encouraged to stablish a 5 step mechanism for the procurement of conflict minerals. This is especially relevant when purchasing raw material from CAHRA’s. This mechanism is briefly shown in Figure 1.

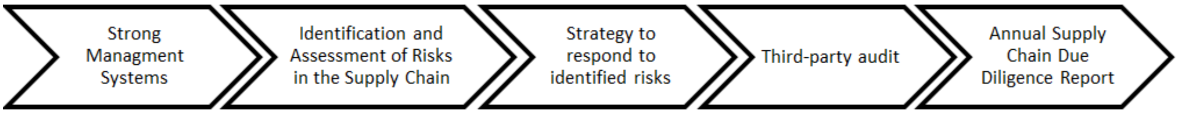

Figure 1 – 5 Step Procedure for Due Diligence [4].

For better understanding, the first step commits the company to adopt a supply chain policy forbidding it to buy material that can contribute to abuses. Also, it shall set rules regarding the Due Diligence process, including responsibilities for each step, internal structure, among others. Clear rules for contracts with suppliers regarding information about origin of material must also be set. Besides, the engagement with suppliers must also be strengthened, in which long term relationships should be favored, instead of spot sales. At last, a grievance mechanism that allows interest parties to make direct contact with the responsible for Due Diligence must be developed. The following steps are also very important and include a third-party audit to verify if these procedures are being correctly realized. In short, a key aspect of the 5-step procedure is to identify, assess and to mitigate risks in the supply chain. For example, when procuring cassiterite, the smelter may request an on-the-ground assessment. The on-the-ground assessment team could visit the mine and conduct an interview with an employee, aiming to identify if violations to human rights are taken place. Depending on the risk identified, such as in case of child labor, war crimes or inhuman treatment, companies are encouraged to immediately suspend or discontinue engagement with these suppliers [4]. Therefore, this necessary measure causes limitation of raw material availability.

2.2 Global supply chain of Ta and Sn

The TIC informs that only tantalite, microlite and wodginite are of economic importance for Ta, while Sn is primary obtained through cassiterite, which is the only mineral of relevant commercial significance [8,19].

The world’s reserves of Ta and Sn are not restricted to the African continent. Data from the U.S. Geological Survey 2019 [12] suggests that the global tin reserves are well spread, being the majority located in China, Indonesia and Brazil. As can be seen in Figure 2, the DRC has only the 9th reserve in the world. When considering mine production for tin concentrates, a similar pattern can be seen. However, nowadays China and Indonesia hold a larger share of the production, with 90000 and 83000 estimated tons respectively. For comparison, Brazil produced only 18000 t. No explanation has been found regarding this disparity between reserve and mine production for this country. In terms of mineral origin, which is a crucial aspect when considering conflict minerals, it is interesting to note that Nigeria and Rwanda have produced concentrates in their mines while their respective declared reserves were absent [12]. This lack of information may be related to the fact that Sn is mined through ASM in those countries, in which the resources are “rarely defined or reported”. Interestingly, the percentages for Burma (also known as Myanmar), regarding reserves and production also differ greatly from one another. This country has become the third largest tin producer in 2014 since it started to explore a new area near the border of China. This new reserve is not yet estimated, justifying the discrepancy between reserves and production as shown in Figure 2 [9].

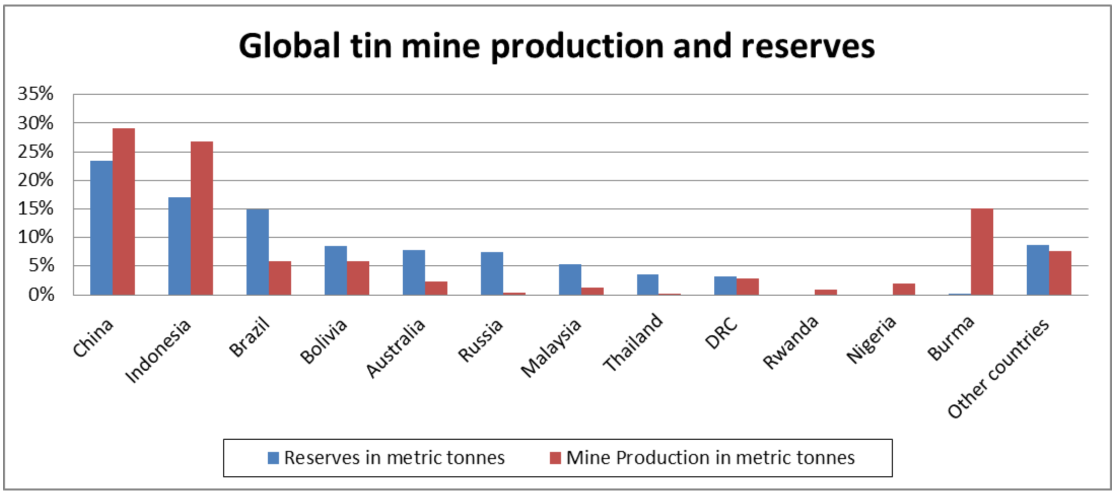

Figure 2 – Global tin reserves and estimated mine production in 2018. Adapted from [12].

In the case of Ta, the predominance of ASM in Africa combined with the situation of conflict previously described makes it even harder to get reliable data related to these minerals [8,17]. According to a report from U.S. Geological Survey [12], only Brazilian and Australian reserves of tantalum content were accounted in 2018. All other reserves were unfortunately not declared. The TIC developed a “Most Likely Resource Base”, which is shown in Figure 3. As can be seen, the low resource share contrast with its high production. This fact could be related to the lack of information and/or lower processing costs of soft alluvial deposits and semi-pegmatite deposits.

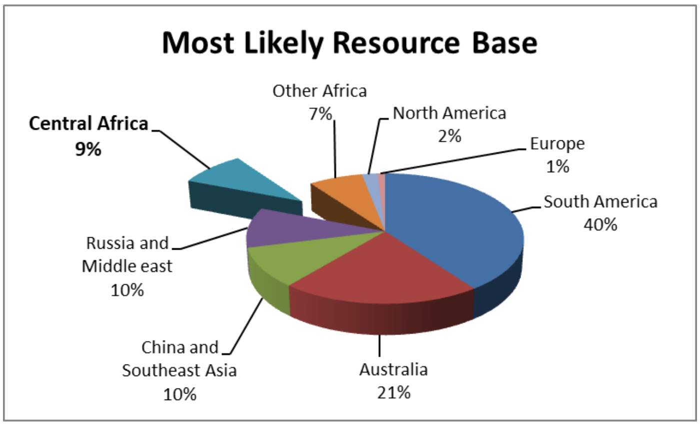

Figure 3 – Most Likely Resource Base [8].

Regarding tantalum mine production, the U.S. Geological Survey estimated that the DRC, Rwanda and Nigeria were the largest producers in 2018, with 710, 500 and 150 t of tantalum content respectively. These three countries represented over 75% of the declared world production [12]. Once again, it seems that illegal trading combined with the predominance of ASM accentuates the lack of reliable data about the mine exploration and trade. This situation is made clear once an estimative of the European consumption of tantalum found out that the continent consumption of the metal in a single year is higher than the reported global production of tantalum [17]. There is a misrepresentation of the origin of the material, particularly in the notoriously porous Congolese border to Rwanda, which could also hide abuses related to the trade of minerals [17,20,21]. Based on this fact and using data from U.S. Geological Survey and UN Comtrade Database, Mancheri [17] elaborated Figure 4. It shows the difference between the reported mine production for Africa and the estimated production, when considering that all the difference was produced in Africa.

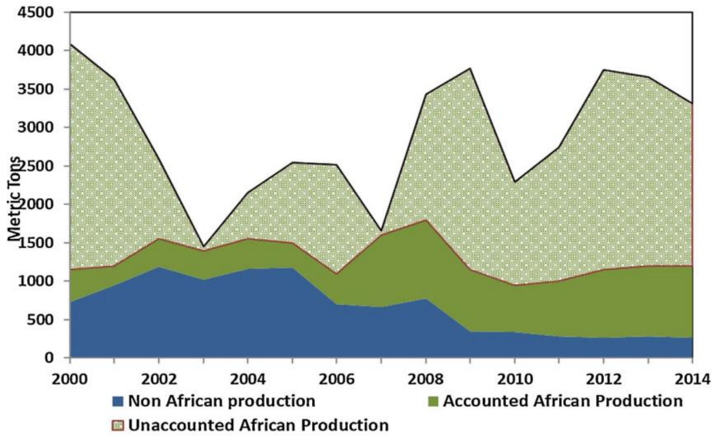

Figure 4 – Accounted and Unaccounted African Production [17].

Production of Ta and Sn do not rely only on primary materials, but also on secondary materials and on byproducts. When considering these byproducts, Brazilian, Malaysian and Thai tin slags can be used for Ta and Sn production [8, 22]. These slags have wide range of compositions, with Sn levels ranging from 0.1% to around 7% SnO_2 [22,23]. Furthermore, they may also contain tantalum oxide [23,24].

2.3 Supply chain and production of Ta and Sn in Brazil

According to the U. S. Geological Survey [12], Brazil has the third largest declared reserve of tin. Brazilian reserves are mainly located in the amazon region, specifically in the Mapuera mineral province and on the tin province of Rondônia, which are responsible for 59% and 29% of the Brazilian tin concentrate respectively [25]. Brazil had an estimated mine production of 18000 t of Sn content in 2018, representing 5.8% of the global production [12].

The technology for tin production from concentrates in Brazil relies on the reduction of SnO_2 from the mineral cassiterite to Sn in the metal phase using an EAF. A flowchart can be seen in Figure 5 [22,24,26]. Byproducts of tin production are slags, filter dust and Hardhead (FeSn), which are recirculated. Slags are generally not further recirculated after a certain number of batches, generating an end-slag [22,23].

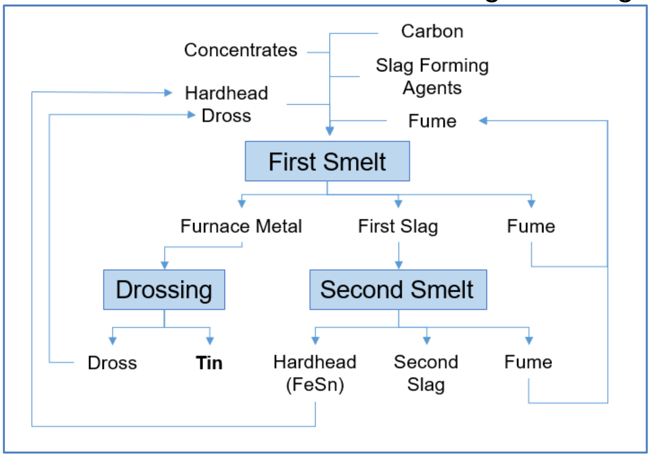

Figure 5 – Typical Cassiterite processing [27].

Updated data regarding tin production from smelters have not been found. However, data from 2015 helps to understand the overall scene. DNPM [25] estimated that Brazil produced 16531t of metallic tin in that year, representing around 4.8% of the world production, when considering total production of 354000t for the same year [28].

Also, according to DNPM [25], the tin produced in Brazil is either exported or internally consumed. In the year of 2015, which is the most updated data found, the USA were the main buyers of Brazilian tin products with 32% of the total of the exports and 36% of products such as non-alloyed tin, tin alloys and tin residues. Domestic use of tin is mainly for the steel industry for tin plates, in the solder industry, chemical industry and for pewter alloys and bronze.

Regarding tantalum, the largest Brazilian reserve is located in Presidente Figueiredo, with a potential of 35000t of Ta_2O_5. There are also some occurrences at the Pegmatitic Province of Borborema (Paraíba, Rio Grande do Norte and Ceará states) and in the states of Bahia, Roraima, Amapá, Minas Gerais and Goiás [25]. According to the TIC [8], a tantaline mine located in Nazareno (MG), is considered the "single largest operating tantalum mine" in the world. However, Brazil had an estimated production of 100t in 2018, representing only 5.6% of the global supply [12]. Brazil processes tantalum concentrate but also exports primary material [25].

2.4 Supply chain risks in Brazil and impact for Brazilian companies

Regarding the problematic of conflict minerals, it is important to analyze the risks presented in the country. The Heidelberg Conflict Barometer [11], which is a valuable tool for the identification of risks worldwide, has pointed out threats to human rights in Brazil, such as the limited war between drug trafficking organizations and security forces and the demarcation of indigenous territories. However, it did not identify evidences that such risks could compromise the supply chain of Ta and Sn. On the order hand, risks of violation to human rights regarding minerals are not uncommon in Brazil, which can be better exemplified by former gold ASM in Serra Pelada [31]. Also, the Amazon Geo-Referenced Socio-Environmental Information Network, which is a consortium of civil organizations in South America, develop a tool named *Minería Ilegal*, which identified many illegal ASM in the state of Rondônia. These are mainly related to gold and diamond, but some are also related to cassiterite [32]. These illegal activities constitute risks according to the OECD Guidance, since they are not paying the necessary taxes. Besides, it is safe to assume that they also cause environmental issues.

As can be seen, it is clear that Brazilian companies will be required to adapt to the procedures and laws considering risks, proving not only the origin of their material, but also guarantying that the procurement does not contribute for the violation of human rights and financing of armed groups. Considering that Brazilian companies may also import concentrate from other countries and that both Ta and Sn are exported to the USA and/or Europe, either in its primary or manufactured form, it seem unlikely that companies will not have to face changes in order to maintain their business.

Actually, Brazil is already engaged in the matter since it has contributed during the elaboration of the OECD Guidance [4]. Considering this Guidance, which is used as reference for audits, Brazilian companies shall also structure Due Diligence procedures with the 5 mentioned steps, in the same form as companies abroad.

2.5 Opportunities for Brazilian Companies

The problematic of conflict minerals has been affecting the tantalum and tin supply chain, including in Brazil. However, based on data from the Heildeberg Conflict Barometer [11], from USGS [12] and from DNPM [25], it seems that operations related to mining, beneficiation, transport and export of materials separate Brazil from high risk areas such as the DRC. Although the Barometer has identified some risks, they could not be related to conflict minerals. Also, even though there are illegal ASM in Brazil, these do not represent the majority of production of Ta and Sn, which are performed by LSM. This fact can be inferred from the report from DNPM [25]. In this sense, considering companies in Brazil that mine or procure material from legalized mines, they are in advantage over competitors, such as those located in some regions in Central Africa. Therefore, by adopting the requirements and following international regulations, they have a growing opportunity to gain market for their products. Besides, in order to expand this offer of “conflict-free” material, there are possibilities for the further recovery of Ta and Sn in Brazil, considering secondary materials and byproducts. As an example, Figure 5 shows the flowchart for the production of tin from cassiterite where all byproducts are recirculated, with the exception of the end-slag.

Garcia [24] stated that there are 600000t of slags in a Brazilian smelter with Sn content varying from 0.1% up to 3%. Considering an average of 1.5%, there is a potential for the recovery of 9000t of Sn, which is certainly a relevant potential. The literature does not inform stocks from other smelters, making it impossible to estimate the national potential recovery of Sn from slags. The author also shows high contents of SiO_2 (up to 37.4%) and ZrO_2 (up to 16.7%). Slags with high ZrO_2 contents may pose a problem in regards to its pyrometallurgical processing. As can be seen in Figure 6, adapted from Kwon [33], it cannot be guaranteed that a slag with this composition is completely fluid. Firstly, because the average tapping temperature of a typical furnace can be lower than the required. Also, data from a given smelter is difficult to analyze because the tapping temperature is usually not reported and because the sampling method is also not very well defined. As shown by Clemente *et al* [22] and exemplified in Figure 6, the sampling method has a significant influence over the analysis regarding tin slags. As consequence, these slags may have a high apparent viscosity at working temperatures, causing metallic phase to be trapped in the slag.

Clemente *et al* [22] also developed a slag model for the further processing of slags with low content of Sn and high ZrO_2. Therefore, smelters could apply this model for further slag reprocessing, in order to enhance their recovery. Through the controlled addition of fluxes, it could be possible to reach fluid phase, allowing the already reduced metallic phase to separate from the slag.

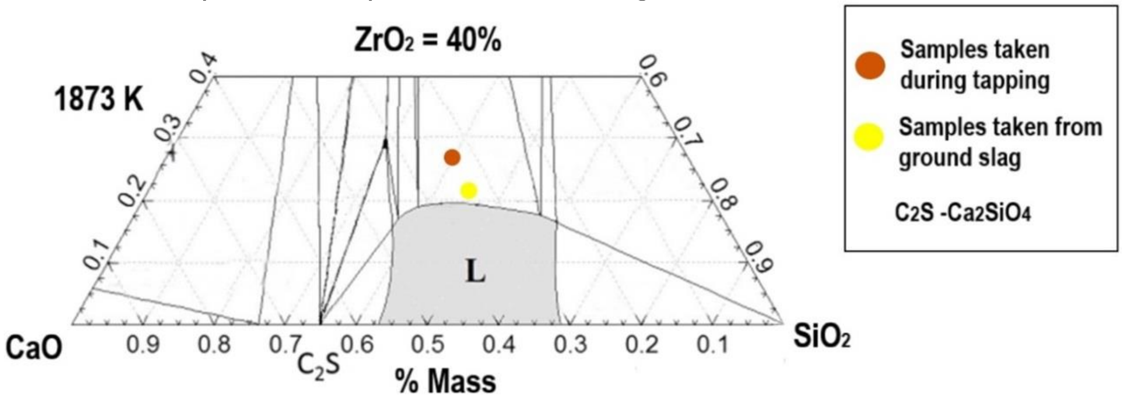

Figure 6 – Isothermal ZrO_2-CaO-SiO_2 phase diagram at 1873 K. Adapted from Kwon [33]

Regarding tantalum, Bose & Gupta [29] report that a relevant method to process tantalum concentrates is solvent extraction. In short, this method also allows separating niobium from tantalum, which happens to occur together in concentrates such as in columbite or tantalite. It uses methyl isobutyl ketone (MIBK) and tributyl phosphate (TBL), which are organic solvents, and an aqueous solution, containing Ta and Nb, in contact with an acid solution. This solution uses Hydrofluoric and sulfuric acids (HF-H_2SO_4). The concentrate is first dissolved in concentrated HF, in which compounds such as H_2TaF_7 and H_2NbF_7 are formed. Then, in contact with MIBK and TBP, an organic and an aqueous phase can be separated. This aqueous phase contains impurities such as Fe, Si, Mn and Cl. Therefore, Nb and Ta are concentrated in the organic phase. This phase is contacted with a diluted solution of HF-H_2SO_4, by which Nb is removed in another aqueous solution, while tantalum is further enriched in the organic phase. At this point, a re-extraction of aqueous solution with this fresh organic solvent and organic with dilute acid takes place, further enriching the organic phase with tantalum, while also producing an aqueous phase rich in Nb. Then, the organic phase is stripped using water (adjusting the PH) in order to generate a solution of fluotantalum acid. In this phase, tantalum can be precipitated by using ammonia (generating Ta_2O_5 as product) or by the addition of KF or KCl (generating potassium tantalum fluoride). Caliari *et al* [30] reports a process used by a Brazilian company with only minor differences, such as the usage of only MIBK. Besides, it also describes that Ta_2O_5 is obtained in hydroxide form, which must be dried and calcined. Brazil exports manufactured products of tantalum, including Ta_2O_5 produced by the described process.

Thus, technology for recovering Ta from slags, employing acid or basic digestion followed by liquor purification processes such as IX, SX and selective precipitation should be pursued. The potential for Ta recovery would be sizable. Although in low levels, slags studied by Garcia [24] also contain Ta_2O_5 (up to 1.62%) and the TIC [8] informs that tin slags can be used as raw material for the production of tantalum. However, an updated minimum input content of Ta_2O_5 for the solvent extraction used in Brazil has not been found in the literature. Also, no data has been found regarding this process recovery for low grade tin slags. It can be inferred that costs depends on acid and solvent costs, as well as on the price of tantalum products, among other factors. Further studies should be conducted in order to model the minimum Ta_2O_5 input considering Brazilian slags. Another important factor is that, overall, the price for tantalum ores and products is rather inconstant and depend on many factors such as political decisions and raw material availability, which are highlighted in Figure 7. More recently, the USGS [12] informed that the average monthly price per kilogram of Ta_2O_5 varied from US$ 193 in January 2018 up to US$ 224 in September of the same year. Any study regarding minimum input content and cost threshold should take this fact into consideration.

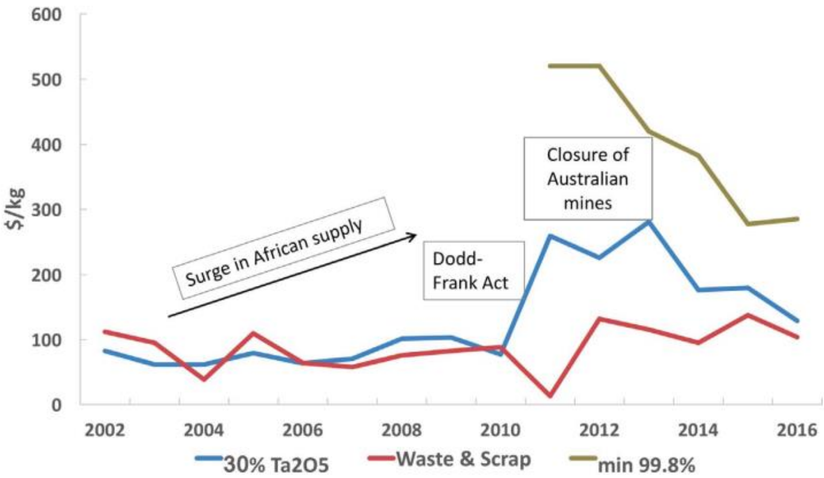

Figure 6 – Price fluctuation of Tantalum ore, secondary material and products over the years [17].

3 CONCLUSION

This work analyzed the problematic of conflict minerals, the supply chain for Ta and Sn and its risks, the impact of the ongoing changes for companies and metallurgical opportunities for Brazilian companies considering this scene.

As mentioned, violation of human rights and financing of armed forces can be associated with the extraction, transport and/or export of the so called conflict minerals, in which minerals containing Ta and Sn are included. Organizations and policy makers are taking measures in order to prevent these abuses alongside the supply chain and Brazil, which is a relevant producer for both minerals, is not out of this scope.

Brazil produces 5.8% of the Sn global concentrate and 5.6% of the Ta global concentrate. Data regarding mine production and reserves seem inconsistent for both metals. It is true that ASM contribute for the lack of reliable information in some countries. However, further studies should elucidate some aspects, such as the lower Brazilian production levels when compared with its high reserves.

Risks such as illegal ASM have been identified in the country. Also, Brazilian companies could buy material from CAHRA's that could have contributed to those abuses. Therefore, these companies shall comply with certain requirements in order to guarantee the origin of their materials and to identify, address and mitigate risks considering procurement, mining and/or processing of their material. Also, exporting companies shall comply with specific legislations such as the Dodd-Frank Act and the new European Conflict Mineral Regulation. The OECD Guidance recommends that a 5 steps procedure be implemented.

These new requirements also represent an opportunity for Brazil, since it is possible to mine or procure "conflict-free" material from legal sources in the country. Companies can also seize opportunities such as the recovery of Ta and Sn from tin slags. By the correct addition of fluxes by using a slag model, Sn can be further obtained. Regarding Ta, it is known that tin slags can be used for this recovery, which will depend on the recovery, costs and price of tantalum in the market.

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