A DIAGNOSTIC ASSESSMENT OF OPERATIONAL, ENVIRONMENTAL AND SAFETY PROCEDURES IN THE ONSHORE CASSITERITE ARTISANAL MINING SECTOR IN INDONESIA

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Mining Engineering)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

October 2018

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A diagnostic assessment of operational, environmental and safety procedures in the onshore cassiterite artisanal mining in Indonesia

submitted by Fabricio Peixoto Maia in partial fulfillment of the requirements for

the degree of Master of Applied Science

in Mining Engineering

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Abstract

Cassiterite (SnO_2) is the main ore-mineral of tin, with tin constituting 78.8% and oxygen 21.2%. It is mostly mined in secondary deposits. Tin is one of the components in electronics like computers and smart phones, solder to produce welding wire and is also part of steel plates, which is commonly used in cars and of cans. Considering the world annual production of approximately 280,000 tonnes of tin, resources should sustain production for another 30 years. Approximately 97% of the world's metallic tin comes from emerging and developing countries and around 25% of cassiterite around the globe is mined by artisanal miners, who use rudimentary techniques, resulting in frequent accidents and occupational hazards that generate health problems for operators and neighbors. The second largest producer of cassiterite in the world, the production of Indonesian artisanal miners constitutes about 40% of the global tin market. Indonesia's export of tin in 2016 totaled almost 64,000 tonnes. Approximately 60% of cassiterite concentrate production in Indonesia, in 2017, came from artisanal miners in two islands, Bangka and Belitung, in 10,000 mining sites in total (Bangka 8,000 and Belitung 2,000), with more than 50,000 artisanal cassiterite miners (Bangka 40,000 and Belitung 10,000 miners), plus dependents. An individual artisanal miner making approximately US $176 per month. In comparison, the minimum wage in Indonesia is US$ 198/month. Tin recovery was estimated in 12% (metallurgical recovery), whereas the concentrate mass yield was calculated in 0.004% (mass recovery). Cassiterite is mined and processed by artisanal miners in Indonesia using simple techniques consisting of hoses, pumps and poorly constructed sluices boxes. Sixty miners died in Indonesia artisanal cassiterite mining per year, mostly buried in tin alluvial mines or trapped underwater during dredging offshore mining activities. The most common occupational risks are the risk of block sliding, falling and wall collapse. In order to improve organization, formalization, capacity building and, the passing of laws and standards to regulate the sector, important steps should be pursued. Moreover, a stronger and more effective government interference in inspection and training, and willingness of the stakeholders for implementing improvements are imperative.

Lay Summary

Tin is one of the components needed for different types of electronics, including computers, smart phones, and is also used in cars and cans. Cassiterite is the main ore of tin. The majority of cassiterite is mined by artisanal miners around the world, who use rudimentary techniques, which result in frequent accidents and occupational hazards that generate health problems for operators and neighbors.

Indonesia is the second largest producer of cassiterite in the world. Approximately 90% of Sn production in Indonesia occurs on the two islands of Bangka and Belitung and is mostly produced by artisanal miners. Although rudimentary mining practices have been common place for decades, they need to be improved.

This thesis aims to describe the safety, environmental and operational issues in Indonesia's artisanal cassiterite mining sector and offer insights into how this sector can be improved, providing more potential for sustainability for the artisanal miners.

Preface

This dissertation is the original, unpublished, and independent work by the author, Fabricio Peixoto Maia.

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List of Abbreviations and Acronyms

AETI: Association of Indonesian Tin Exporters – (Asosiasi Eksportir Timah Indonesia)

AGM: artisanal small-scale miners / mining of gold

APRI: Association of Indonesia Small Scale Miners – (Asosiasi Penambang Rakyat Indonesia)

DNPM: Brazilian Agency of Mineral Production (Departamento Nacional de Produção Mineral)

ESDM: Ministry of energy, mining and mineral resources

ICP-OES: Inductively coupled plasma atomic emission spectroscopy

IUP: Mining Business License – (Izin Usaha Pertambangan)

OHS: Occupational Health and Safety

Reserves: according to USGS definition, reserves are part of the reserve base which could be economically produced. The term reserves need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials; thus, terms such as “extractable reserves” and “recoverable reserves” are redundant.

Reserve base: according to USGS definition, reserve base is part of an identified resource that meets specified minimum criteria related to current mining (e.g.: grade, quality and depth). The reserve base is the (measured plus indicated) resource.

Riffle: small barriers made of metal or wood in a sluice box

TCLP: Toxicity Characteristic Leaching Procedure

WASH: Water, sanitation and hygiene

WPR: People’s Mining Area – (Wilayah Pertambangan Rakyat)

Acknowledgements

I would like to offer my thanks to my wife, my kids, my mother, my father (in memoriam) and my two sisters. My whole family, including my helpful mother-in-law for their constant support. Many times, all of them made sacrifices, so I could pursue my dream.

To Dr. Marcello Veiga, my eternal gratitude. This important step in my life would not have been possible without his support, enthusiasm, friendship, patience and so many occasions that he pushed me to achieve the goals. I am very proud of being Dr. Veiga's student.

To Dr. Bruce Marshall, my sincere gratefulness for his friendship, partnership and support not only my student life, but also personal life.

I will never forget helpful people as Samuel Spiegel, Ruby Stocklin-Weinberg, Adriana Gonçalves, Prof. Toninho Peres, Leslie Nichols, Jabin Sufianto, Nickolaus Hariojati, Mariel Plummer, Felipe Cota, Gercino Junior, Karina Bianchini, Lucenir Piovesan, Eduardo Patrocinio, Edson Carlos, Alexandre Petolchckny, CIRDI and PACT

Many other friends, whose direction, advice, support, and contributions have proved invaluable along the way. My apologies if I missed someone.

Dedication

I dedicate this thesis to my family and the artisanal miners in Indonesia, who struggle to survive but still enjoy life with simplicity and happiness.

To them all, my wishes of peace and love.

1. Introduction

1.1. Statement of the problem

Indonesia is the world's second largest producer of cassiterite (SnO_2) behind China. According to the United States Geological Survey (2018), of 4.8 million tonnes of tin reserves (resources measured plus indicated), China has 23% of the known world tin reserves followed by Indonesia at 17%. USGS estimates indicate the major uses for tin in 2017 were: chemicals, 20%; tinplate, 18%; solder, 17%; alloys, 10%; bronze and tinning, 10%; and other, 25%. In Indonesia, tin production mainly occurs on the two islands of Bangka and Belitung, locally called "Babel". According to the Association of Indonesian Tin Exporters (AETI), Indonesia shipped approximately 64,000 tonnes of tin in 2016. PT Timah, the largest mining company in Babel, produced around 24,000 tonnes of Sn ingots. AETI estimates that the remaining 40,000 tonnes of total national Sn production comes from the artisanal miners. According to USGS, Indonesia produced 55,000 tonnes of metallic tin in 2017. However, AETI noticed that the total tin shipments for 2017 was 22% higher than in 2016, jumping to 78,190 tonnes. Of this, 69,300 tonnes came from Bangka and approximately 9,000 tonnes from Belitung (Jabin, 2017 pers. comm.).

Artisanal mines are generally described as formal or informal mining operations with predominantly rudimentary forms of exploration, extraction, processing, and transportation of ore. Conventional mines employ more sophisticated mining and processing techniques. Artisanal mining operations can include men, women and children either working on an individual basis or working in family groups (Hinton et al., 2003). Worldwide, the large majority of cassiterite is mined and processed by artisanal miners using rudimentary, or artisanal, techniques (ITA, 2018) in very low grade tin which can varies from 0.2 to 1 kg/m^3 or 0.007 to 0.037% Sn respectively with specific gravity approximately 2.7 t/m^3.

Although artisanal miners in Indonesia are legally only allowed to operate in areas designated by the provincial government (WPR – People's Mining Area) or concessions of mining companies (IUP - Mining Business License), most miners work illegally in both areas, as well as on other sites which are not officially designated WPR or IUP. Furthermore, these artisanal operations are typically found to employ poor safety, operational and environmental protocols, which put the workers at risk and pose significant adverse environmental impacts.

1.2. Justification of the Thesis

In Indonesia, mining companies produce less than 40% of refined tin, and therefore, more than 60% of it comes from artisanal miners located mainly on the islands of Bangka and Belitung (Jabin, 2017 pers. comm.). They predominantly use rudimentary exploration, extraction, processing, and transportation practices to explore alluvial and offshore Sn deposits in generally unsafe conditions (ITRI Babel, 2018).

For the last of 15 years, artisanal miners have also been mining underground deposits, excavating deep tunnels in precarious conditions which involve a high risk of subsidence. A preliminary assessment (Stocklin-Weinberg et al., 2017) has determined that artisanal cassiterite mining causes many labor accidents, significant environmental impacts, high occupational risks, and chronic health problems for the miners and communities adjacent to the mine sites. However, a more detailed assessment of mining activities in Indonesia needs to be conducted.

This thesis aims to describe the safety, environmental and operational issues related to Indonesia’s artisanal tin mining sector, applying theory, benchmarking and fieldwork in order to recommend practical improvements. In addition, an overall assessment of Indonesian mining companies and their practices, and an analysis of corporate perspectives related to safety, operational and environmental standards was also conducted.

1.3. Research Questions

The primary aim of this study is to describe the operational, environmental and safety procedures of artisanal tin mining in Bangka and Belitung in Indonesia and provide recommendations for improvements to ensure greater sustainability of this sector. To this end, the following research questions were asked:

1. How is cassiterite (SnO_2) mined and processed by artisanal miners in Indonesia?

2. What are the most common occupational risks during the extraction and beneficiation of cassiterite? How can they be prevented?

3. What kinds of technical improvements could be proposed for implementation on the management level of artisanal mining to achieve higher recovery, while at the same time improving occupational safety and reducing the occurrence of environmental impacts?

1.4. Objectives

The following objectives were part of an integrated field assessment of artisanal mining of cassiterite in Indonesia:

- Provide an overview of global cassiterite artisanal mining and mineral processing operations;
- Describe the mining and processing methods of artisanal miners in Bangka and Belitung in Indonesia;
- Assess operational details, safety risks and environmental impacts related to artisanal mining of cassiterite in Bangka and Belitung in Indonesia;
- Propose recommendations to improve operational efficiency in terms of mining techniques and mineral processing and reduce both safety and environmental impacts for the artisanal mining sector in Indonesia.

1.5. Applied Research Contribution

Efforts to understand and improve the operating conditions of artisanal mining of cassiterite continue to pose challenges for researchers and policy makers worldwide. Although the global price of tin has generally been low for the last 18 months, hovering around US $21,000/t (London Metal Exchange, 2018), cassiterite mining activities in Bangka and Belitung have been increasing. This can be attributed to the fact that it is more profitable than farming, fishing or tourism activities, and it is a way for the miners to earn money quickly. Because of this increase, there are concerns over the long-term sustainability of the practice. Furthermore, hazardous worksite conditions, low mineral recovery, lack of awareness for preventing accidents, and poor health and environmental standards all contribute to problems in the sector (Hodal, 2012). In general, due to culturally-accepted practices and behaviors, there is a lack of investment, training, environmental standards, safety procedures, regulatory compliance (Stocklin-Weinberg et al., 2017). The results of the assessment conducted in this study could help artisanal miners, their bosses, the authorities, processing center owners, mining companies, and the authorities find ways to improve the artisanal mining sector. Additionally, that is the first time an assessment has been conducted in Indonesia for cassiterite artisanal mining sector.

1.6. Academic Contribution of Research

There is significant concern regarding the poor practices currently in the artisanal cassiterite mining sector in Indonesia, including the use of rudimentary techniques, lack of procedures to prevent accidents, and environmental contamination due to unregulated waste and tailings disposal (Agus et al., 2017). The global overview, the assessment in the Indonesia artisanal mining sector of cassiterite, and the improvements suggested in this thesis will be useful for both practical and academic applications. That is the first time an assessment has been conducted in Indonesia for cassiterite artisanal mining sector. This research reveals the working conditions of Indonesian artisanal miners and suggests procedures to improve the safety and environmental impacts.

2. Literature Review

2.1. Artisanal Mining Practices

Veiga et al. (2014) defined artisanal mining in terms of the rudimentary technologies applied as opposed to the size of the operation. He emphasized that artisanal mining is very labour intensive and provides an essential livelihood (directly or indirectly) for many members of a community. Because they are rudimentary, artisanal mining practices do not meet industry standards, environmental protection standards or safety procedures. According to Veiga (1997), a person who works as an artisanal miner aims to feed his or her family and pay the bills, with the dream of possibly making it rich.

Worldwide, artisanal mining covers a range of more than 30 mineral substances in 80 different countries, and directly employed approximately 100 million people globally in 2013 with this number increasing annually (World Bank, 2013). Globally, artisanal mining can benefit a rural community by providing more income than agriculture, fishing and forestry (Siegel and Veiga, 2009) but it has been associated with political conflicts and poverty, as well as child labor and gender discrimination. Marginalized, artisanal miners have historically received less government support than other local livelihoods (Veiga, 2016).

Even though this sector is still an important economic activity in many developing countries, serving as an important source of income, especially in rural areas where job opportunities are often scarce (Hinton et al., 2003), there are significant risks associated with it. Lack of knowledge, adequate techniques, formalization, law compliance, and many other factors often cause workplace accidents (Rupprecht S M, 2015). Impacts on the environment, including the discharge of untreated effluent to streams and rivers, often results in enormous environmental footprints and environmental degradation (Wiriosudarmo, 2009). Finally, rudimentary mining and processing methods often result in low mineral recovery.

Due to economic constraints for most artisanal miners, the use of machinery is normally minimal, resulting in increased occupational risks (Hodal, 2012). In addition, there is a lack of local, provincial and federal authorities to enforce regulatory compliance in the artisanal mining sector, which is spread out over a vast area in many developing countries. Furthermore, there is often a lack of technical knowledge and capital investment to improve the labour conditions and quality of life of the miners (Rupprecht S M, 2015).

Gold is the preferred mineral extracted by artisanal miners, representing 16 million workers or approximately 50% of the whole contingent of these miners worldwide (Seccatore et al., 2014). Considering both onshore and offshore operations, gems, silver, tin and other metals are not as popular as gold (USGS, 2009).

2.2. Cassiterite Artisanal Mining Practices Globally

The total metallic tin produced in 2017 was approximately 280,000 (ITA, 2018). According to the United States Geological Survey (USGS Mineral Summary, 2018), the main global tin producers are (in thousands of tonnes): China (100); Indonesia (50); and Myanmar (50), which represented almost 70% of total worldwide production in 2017.

The top three biggest mineral reserves are located in (in thousands of tonnes) China (1,100), Indonesia (800) and Brazil (700), which together correspond to 55% of global tin reserves (USGS, 2017).

Developing countries are responsible to approximately 97% of the world's primary refined tin (ITA, 2018). According this source, considering the annual production of 280,000 tonnes of tin, the demand for tin will be met for the next 18 years. Global known resources should sustain the current rate of production for 30 years (Sainsbury, 1969).

Cassiterite mining sites can be found in about 35 countries around the world (USGS, 2017) and most deposits are formed by placers, which are easily mined by artisanal miners (Stocklin-Weinberg et al., 2017). Artisanal cassiterite mining directly supports approximately 200,000 people worldwide, and indirectly supports up to ten times that number (Romia, 2017 pers. comm.). Globally, artisanal cassiterite miners account for the production of nearly 25% of the annual global production of 280,000 tonnes of metallic tin per year which means 70,000 tonnes of metallic tin per year (Fritz et al., 2014).

Mining and beneficiation methods of tin ore vary depending the nature of the ore deposits. Cardarelli (2018) and Lima (2009) compared hard rocks mined by underground and open pit conventional techniques related to alluvial deposits. They pointed out that with underground and open pit methods, comminution is mandatory in order to liberate the mineral of interest. On the other hand, alluvial cassiterite deposits can be extracted by using dredges, hydraulic monitors or even machinery to remove *in-situ* ore and then processed using gravity methods (sluice boxes, jigs, shaking tables, spirals, etc.). Gravity methods are the only processes used for beneficiation, as flotation for cassiterite is not often used (Cardarelli, 2018).

Even though Cardarelli (2018) suggested flotation for cassiterite is not common, Warhurst (1999) described the Bolivian industrial experience with flotation process for fines and low-grade cassiterite. However, he noticed that they had no technical background in flotation, and moreover, they had been mining old tailings areas, which made it a simple and low-cost process. According to Kossoff et al. (2014), old cassiterite tailings areas are often useful for reworking by artisanal miners, as the tailings are viable enough to generate at least some income for an individual or a group of artisanal miners (Nurtjahya et al., 2009).

According to the International Tin Association (ITA, 2018), the production of Indonesian artisanal miners constitutes about 40% of the global tin market. This could be significantly higher, since Chinese and Indonesian smelters end up purchasing cassiterite concentrate from the artisanal miners in Indonesia (Davis and Wulandari, 2008). This is not officially reported as artisanal miners tin bars production, however, but as the smelters' production, as confirmed by personal communication with the manager of PT Tommy Utama, the second largest Indonesian smelter.

2.3. Cassiterite Production in China

China is the world's largest cassiterite mining country with 100,000 tonnes of metallic Sn from SnO_2 produced in 2017. This represents around 34.5% of the world's production. Reserves are also estimated to be around 1.1 million tonnes of Sn (USGS, 2018).

Most cassiterite in China is mined in the southern part of the country, where predominantly primary ores are mined, but alluvial deposits are also exploited. The tin deposits extend from southeastern Yunnan in the west (an area known as the Nanling Mountains) to the coastal areas in the east. Strong tectono-magmatism made the Nanling Mountains the most important tin-producing region in China. The cassiterite deposits are basically skarns, that is, calcium-silicate rich rocks developed by contact metamorphism in which the intrusion of hydrothermal fluids changed the chemical composition of the host rock forming other minerals (metasomatism). They occur together with sulphides in contact zones between granite and limestone. The contact metamorphism favored high concentrations of other elements in addition to tin, such as copper, lead, zinc, tungsten, molybdenum, bismuth, beryllium, indium, silver, arsenic, sulphur and fluorine. The Gejiu mining area in the Nanling Mountains is representative of this mineralization (Xin and Zhitai, 1988). Other elements are also associate with the tin mineralization, such as Ag, W, S, As, Bi, Mo, Be, Au, and Rare Earth Elements. The Gejiu polymetallic ore reserve is still attractive, with 3 million tonnes of Sn (ore grade of 1% Sn) as well as large reserves of copper and lead minerals (Cheng et al., 2016).

Gejiu is a town in the Honghe Prefecture (Figure 1) in Yunnan Province and has 136,00 inhabitants. The town was created by the tin mines in the area, which have the largest tin reserves in China. For over 100 years, the town's economy has been very dependent on the mining industry. The discovery of tin started a boom that attracted thousands of miners to the area. At the beginning, the tin mines were operated using artisanal methods and it is only recently, since the 1950s, that they have been operated on an industrial scale. However, during the 1990s, the reserves declined, and the mining companies started to lay off miners. By 2008, according to sources from the

Chinese Government, about 90% of the tin reserves were depleted. Today, there are tens of thousands of unemployed miners that have turned to illegal artisanal mining to earn a living. Mine site accidents, crime and prostitution are rampant (Scally, 2013) (Figure 2). Furthermore, the abandoned mines now mined by artisanal miners have increased pollution in the region, which was observed by the concentration of heavy metal in local water sources (Cheng et al., 2016).

Figure 1. Gejiu town in the Yunnan Province
(Sources: Cheng et al., 2016)

Figure 2. Gejiu minintown
(Source: Scally, 2013)

The Yunnan Tin Company Group Limited (YTG), established in 1883 and operating in the Gejiu region, is still the world largest tin producer, with an output of 76,000 tonnes of refined Sn in 2016 and 74,500 tonnes in 2017 (International Mining, 2017). With the reduction in local mining production, the company also imports cassiterite from other countries and, on April 20th, 2017, received permission from the Chinese Government to buy tin concentrate from abroad without paying tax, as long as the refined tin was exported (ITA, 2017). Beyond production of metallic tin for different industries such as jewelry, float glass, and galvanized steel, the YTG also produces Sn-Pb for solder, stannous chloride, arsenic compounds and precious metals (e.g. Au, Ag, Pt, Pd). The company also produces platinum catalysts and metallic copper, lead, zinc, antimony, nickel, arsenic indium, bismuth, rhodium, and osmium. (YTG, 2018). In September 2017, the CEO of the YTG complained that the refined tin production of China will be affected by a shortage of tin concentrates as well as by the higher costs of implementing measure to comply with stricter environmental regulations (International Mining, 2017). The Chinese environmental inspectors have been vigilant and closing tin mines and smelters all over the country; in Yunnan alone, four smelters were shut down indefinitely (Burt and Lian, 2016).

Myanmar has been the main exporter of tin concentrates to China, representing almost 99% of the Chinese imports of the mineral concentrate in 2017. Also in 2017, the Chinese imports of tin concentrates, approximately 295,421 tonnes, decreased 37.7% from previous year, but the Chinese refined tin exports, 2,181 tonnes, increased 196.5% from 2016 (Metal Bulletin, 2018; SMM, 2018). Most of tin imported and produced by China are incorporated in electronics produced in the country.

The information about artisanal mining activities in China is very limited for a number of reasons. First, the country does not want to recognize the presence of “illegal or informal” workers. Secondly, together, the rudimentary conditions of the artisanal and conventional mines generate the largest number of mining accidents in the world every year. Finally, the Chinese Government and researchers do not publicize the data. Gunson and Veiga (2004) estimated that about 6 million people in China work in deadly conditions in artisanal coal, gold, mercury, gemstones, iron, tin, dimension stones, sand, and other mines. In terms of cassiterite, Gunson and Jian (2001) estimated that 44.5% of production comes from artisanal operations. The information about the practices of Chinese artisanal miners is normally kept secret, as the Chinese Government is constantly trying to shut down their operations. In 2006, the number of artisanal tin miners in China was estimated around 32,000, based on different local sources (Lei and Ginson, 2016). In 2018, the International Tin Association (ITA, 2018) recognized that almost 97% of the world's tin comes from emerging and developing countries and around 40% of it from artisanal miners. But it is important to note that ITA does not consider the production of tin minerals by Chinese artisanal miners in their estimates.

China cannot improve the conditions for artisanal miners if the Chinese Government does not recognize this type of mining activities in the country. It seems that the Chinese government admits the existence of artisanal miners but the term artisanal brings strong connotation of illegality or unregulated business to the Chinese culture (Ferchen, 2012).

2.4. Cassiterite Production in Myanmar

Myanmar is the second largest country in Southeast Asia with a population of 52 million people and one of the poorest countries in the region (Gardiner et al., 2015). In terms of economic climate for foreign investors, Myanmar was ranked in 131st in 2016. In 2015, it placed 140th in the World Economic Forum (WEF) Global Competitiveness report (Gardiner and Sykes, 2016). In the same report in 2017-2018, Myanmar did not rank (WEF, 2017).

The Myanmar Centre for Responsible Business (MCRB, 2018) listed a total of 1,454 licensed mines in the country as of January 31, 2018. These licensed mines extract all types of minerals and 54.5% of the operations were classified as small-mines, but the MCRB does not distinguish whether they operate artisanal fashion or not. Mining occurs in two main regions: the Wa Division in the western part of the country and Dawei in the south. The mining sector constitutes 6% of the GDP, 24% of the Government revenues and 38% of the exports, however jade and gemstones (e.g. ruby) represent the major part of the mineral production. Figure 3 shows an overview of Myanmar location as well as the Wa Division and Dawei mining region.

Figure 3. Wa Division and Dawei mining region

Main cassiterite mining regions in Myanmar (Sources: Base map: http://myanmar.travel/map-2/ and Wa Division: Peel and Anderson, 2016)

Burmese and Chinese artisanal miners have been extracting cassiterite since 1599 and at the beginning of the 20th century, under the British colonization, the mining industry in this region was modernized (Gardiner, et al., 2015). The rise of Myanmar as a tin producer started in 2009. In 2017, together with Indonesia, Myanmar was the second largest cassiterite producer in the world with an estimated production of 50,000 tonnes of Sn in SnO_2. The country has reserves estimated at 113,000 tonnes of tin in cassiterite (USGS Mineral Summary, 2018). By 2014, cassiterite production increased 4,900% from 2009 levels and most cassiterite concentrates have been exported to China, where, in 2014, 97% of the Chinese cassiterite imports were from Myanmar (Gardiner et al., 2015). The ITRI (2016) reported that Myanmar increased its tin exports from only 1,000 tonnes in 2009 to 45,000 tonnes of tin contained in ore in 2015. This increase is due to production at the Man Maw mines located in the Wa Division, in the northeastern part of the country at the border with China. In 2016, it was estimated that this mining region accounted for 95% of the country's cassiterite production. The cassiterite production has been conducted by both artisanal miners and large mechanized operations in open pits and underground mines. High grade ores with between 7 to 10% Sn had been reported as common in Wa Division mines. Recently the average mining grades have declined to 2-3% Sn (International Mining, 2016) or even lower (Gardiner and Sykes, 2015). The concentrates from Man Maw mining area currently exported to China have approximately 23% Sn (or around 30% of cassiterite, considering that the pure cassiterite has 78.8% Sn) which is better than the grades of 13% Sn in concentrates imported in 2016 (USGS Mineral Summary, 2018).

The cassiterite deposits in Myanmar belong to a Tin Belt that consists of a granitoid province that covers 1.12 million km^2 of southeast Asia encompassing China, Myanmar, Malaysia, Thailand and Indonesia (Stratfor Worldview, 2013). The belt of granite in the Malaysian Peninsula extends to the north from Phuket in the peninsular region of Thailand to the central region of Myanmar (Gardiner et al., 2015). These authors stated that the magmatic belts in Myanmar has strong similarities with the Central Andes. The Southeast Asian Tin Belt is the largest tin reserve in the world, and was evaluated as having 9.6 million tonnes of tin content in 1995 (Schwartz et al., 1995) (Figure 4).

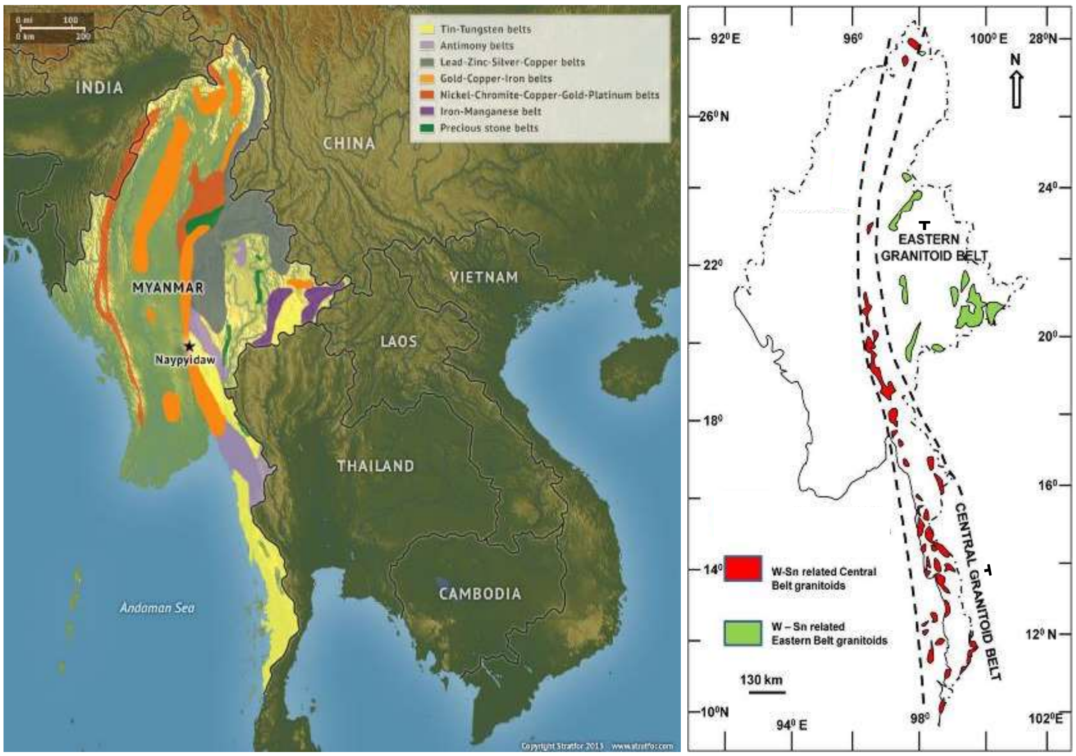

Figure 4. Myanmar mineral belts
(Source: Stratfor Worldview, 2013)

Tin mineralization in Myanmar occurs in the south and northeastern part of the country and has historically been mined in the Dawei region at the border with Thailand on the Malaysian Peninsula (Gardiner and Sykes, 2015). In this region, there are more than 50 mining sites where primary and secondary (alluvial and eluvial) deposits have been mined by both large, conventional companies as well as by artisanal miners. In November 2015, the Myanmar Ministry of Mines licensed approximately 2,500 mining operations, most of them small, locally-owned operations using rudimentary techniques (Oxford Business Group, 2016). The official number of artisanal miners in Myanmar is not known and Smith (2007) expressed his frustration saying that the access to information in the country is the main hurdle to generate solutions for the environmental problems caused by mining. Hilson and Maconachie (2017), estimated that 14,000 artisanal miners are currently operating in Myanmar extracting gold, tin, jade and gemstones. The activities of the artisanal tin miners in the country are not well reported, nor the extraction and processing methods they use. Very few documents mention how the artisanal tin miners operate. However, even though the actions of the artisanal gold miners (AGM) are rarely reported, Osawa and Hatsukawa (2015) revealed for the first time the mercury contamination of the AGM operations spread all over the country. Myanmar mining practices are generally recognized as rudimentary, using a high level of artisanal techniques with little attention paid to pollution, environmental and occupational safety. In November 2015, two major landslides occurred in the jade mines in the Kachin State of Myanmar, killing more than 100 people (Gardiner and Sykes, 2016).

The experts have predicted that tin mining production in Myanmar will decline beginning in 2018. However, Liedtke (2018) states that Myanmar will remain the fastest growing major tin ore producer and, despite the country’s weak economic performance in the previous five years, cassiterite production has kept growing, increasing 5.3% in 2018 compared to the previous year.

The recent political instability of Myanmar has triggered a series of press articles about the fate of the tin produced in the authoritarian country. Lee and Schectman (2016) questioned the ethical role of more than 500 companies, including the manufacturers of smartphones, jewelries and many Chinese suppliers for indirectly supporting the human-rights violations in Myanmar. In 1989, authorities in the historically contentious Wa region signed a ceasefire with Myanmar, which was renewed in 2011. The mines run by the United Wa State Army (UWSA), an armed ethnic party that have self-governed the Wa Division near the Chinese border since 1989, have been repeatedly accused of involvement in narcotics trafficking since 2003. The Wa Division became recognized by the central Myanmar Government as an independent State in August 2010. The International Tin Association (ITA Myanmar, 2018) reacted to the allegations of human-rights violations by explaining that cassiterite production from Wa self-administered Division has been respecting the international multi-stakeholder agreement of the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High Risk Areas (DDG). The ITA (2018) and the Chinese company YTC (importing tin from Wa Division) stated that they “are already actively working in alignment with the recommendations of the DDG to understand and implement improvements in practices relating to sourcing from Wa as necessary.” The cassiterite production from the Wa Division represented 10% of the world supply in 2015 (Peel and Sanderson, 2016). These authors reinforced that tin mining is an uncontrolled activity in Myanmar conducted by armed groups that has sponsoring wars and generating environmental destruction and tax evasion.

The allegations of negative environmental impacts do not point exclusively to artisanal miners. The Thai-owned company Myanmar Pongpipat Ltd (MPC) formally operating the Heinda mine, in Dawei, one of the oldest tin mines in the country, has also been target of human rights violations and environmental degradation. The mine produces up to 1 to 2 tonnes/day of tin content in cassiterite with hydraulic monitors and exports the concentrates to Thailand. In reaction to the Heinda mine, ethnically discriminated groups, local villagers, artisanal miners, and scientists started to mobilize to protest the mine (EJOLT, 2018).

The proliferation of artisanal tin mines in Myanmar seems to have had a positive reaction from the Government in terms of creating policies that consider the presence of these miners and the need for formalization. The Government started a large process of consultation with different stakeholders to accommodate subsistence miners. The Sector Wide Impact Assessment of the mining sector (SWIA) recently recommended that the Government be more transparent and consultative when developing the National Mineral Resources Policy. They also recommended that the development of the policy should involve different types of stakeholders and cover all types of minerals (MCRB, 2018).

Since 2016, the new Myanmar Government has limited the process of licensing new mines and renewing existing mineral titles. The Government measures reduced the issuance of licenses by 6% between October 2016 and March 2017, and an additional 3% between March 2017 and January 2018 (MCRB Summary, 2018). This has affected the artisanal mining sector. Informal and artisanal miners have continued operating illegally throughout the country. Due to high levels of corruption and poor levels of government inspection and enforcement, large-scale mechanized operations are also operating in artisanal mining areas without a license (MCRB Summary, 2018), where the tools and machinery are supposed to be restricted. Artisanal mining in Myanmar is also characterized as subsistence mining which is conducted in an informal way. The regulatory framework of 2015 (Valentins Resources, 2016) attempted to bring basis for the formalization of the artisanal mining sector defining the type of deposits that can be mined, the types of tools and equipment that are allowed to be used and other issues. A license for subsistence mining can be obtained locally. Conflicts between artisanal and large-scale mining are common in the country, as they usually compete for the same mining areas. The subsistence mining permits last for one year and they are defined based on the area of the mineral title (MCRB Summary, 2018):

- < 1 acre for gold and other valuable metals (only 1 plot per household)
- < 3 acres for other metallic minerals
- < 5 acres for industrial raw minerals or stones.

Law amendments of December 2015 were consolidated in February 2018 by the new Ministry of Natural Resources and Environmental Conservation. The New Mine Rules, as it is locally known, extended the maximum production permit period for large scale producers to 50 years, allowing joint ventures between foreign and local investors in small and medium scale mining projects. The production level of these projects can be increased to reach a larger scale, but new permits must be requested. The New Mine Rules have also different attributes for the level of production of a project, but all levels demand an environmental permit (Harwood, 2018).

Figure 5 depicts pictures of artisanal mining of cassiterite in Myanmar.

Figure 5. Artisanal Cassiterite Mines in Myanmar
(Source: Gardiner and Skyes, 2015)

2.5. Cassiterite Production in Brazil

Brazil is the largest country in South America with an area of 8.516 million square kilometers and near 207.7 million habitants (2016), which makes it the fifth largest nation in the world (National Geographic, 2018). In terms of economic climate for foreign investors, Brazil was rated in 81st in 2016, placing out from the 75th in the 2015 by the World Economic Forum (WEF) Global Competitiveness report (Schwab, 2018). In the 2017-2018 WEF report of Global Competitiveness, Brazil moved up one place, to 80th position (WEF, 2017). After China, Indonesia and Myanmar, Brazil was the fourth largest cassiterite producer in the world, with an estimated production of 25,500 tonnes of tin content in cassiterite in 2017. According to USGS (2018), in 2017, Brazil produced approximately 25,000 tonnes of Sn ingots, which was the same production level as the previous year. The country has reserves estimated in 700,000 tonnes of tin in cassiterite, which represents 14.6% of the world reserves of tin (USGS Mineral Summary, 2018). The cassiterite concentrate production reported by the Brazilian Government in 2016 was of 27,344 tonnes of tin content in cassiterite (DNPM, 2017).

The large majority of the cassiterite deposits in Brazil are located in the Amazon region (Figure 6), where, in 2014, the State of Rondonia (deposits of Bom Futuro, Santa Bárbara, Massangana and Cachoeirinha) was responsible for 47% of the national production and the State of Amazon, 50% (Villela, 2015).

According to Barrera (2017), Minsur, the Peruvian company was among the biggest Brazilian producers of Sn, with mine production of 6,864 tonnes and refined tin output of 5,873 tonnes in 2016. Minsur’s operation in Brazil is located in the Amazon region. White Solder was the second-largest refined tin producer, with 2,731 tonnes in 2016. Other smaller productions have been estimated as 3,000 tonnes.

Figure 6. Brazil map: regions, tin deposits
and most important producers (Source: derived by DNPM, 2017)

In the late 20th century, Brazilian tin production increased 1,365% (1970 to 1980) and 665% (1980 to 1989), which turned the country an important global tin producer (Rodrigues, 1997). The primary Brazilian cassiterite deposits, particular those in Rondonia, are associated with griesens (skarn alteration of granite). The greisen fluids, as a result of the magmatic differentiation of granites, are rich in gas, water and economic valuable elements such as Li, Be, B, F, P, Sn, Ta, Nb and Rare Earth Elements (Dias et al., 2013). The large majority of the Brazilian cassiterite mines operate on weathered ores, either alluvial or colluvial deposits. All cassiterite production in Brazil is from open pits or placers. In 2008, the cassiterite production was mainly conducted by organized companies such as Minsur in the Amazon State (former Paranapanema Group), which is the largest Brazilian tin producer, and ERSA (CSN Group) in the Rondonia State, together representing approximately 67% of the production. Coopersanta and a series of artisanal mining cooperatives produced the remain 33% of the cassiterite in Brazil (Lima, 2009).

The discovery of the Pitinga deposit (Taboca Mine) in the Amazon State in 1983 increased the national cassiterite production 52% in the first and second years of operation, reaching 20,000 tonnes of metallic tin. In 1985, thanks to Pitinga, the Brazilian production reached 26,000 tonnes of Sn. In 2016, the Taboca Mine produced 13,000 tonnes of tin content in cassiterite or 47.5% of total Brazilian Sn production and the rest was produced by the mining cooperatives (DNPM, 2017).

Two main deposits are known in the Rondonia State: Bom Futuro and Santa Bárbara (Porsani et al., 2004). Cassiterite was discovered in the Rondonia State in 1952 and since then the deposits have been exploited by artisanal miners. From 1959 to 1984, tin from Rondonia contributed 78.5% of the total Brazilian tin production, but in 1985 the international price of the metal plummeted, and most mines were phased out. In 1987, boosted by the discovery of the Bom Futuro deposit, discovered by farmers as part of a government project to open roads to agricultural areas, production restarted. This is considered the largest Brazilian reserve of cassiterite, as well as one of the largest in the world, representing 7% of the global tin reserves. From 1988 to 1990, approximately 30,000 artisanal miners (“garimpeiros”) rushed to the region and changed the economy of the region, which had previously been completely based on agriculture (Lopes, 2017). The artisanal mine site of Bom Futuro became a great social and environmental problem for the country, and in 1994, more than 40 deaths were reported at the mines, caused by landslides and subsidence of shafts and drifts. Due to their small size, about seven hundred children were used as cheap labor to enter the tight mine shafts (Carvalho, 1997). Founded in 1989, the Coopersanta Cooperative of Artisanal Miners of Santa Cruz started to establish an organized structure with modern methods of mining and processing and by the end of the 1990s, the organization of artisanal miners in the Bom Futuro deposit had increased.

In 2017, the Canadian company Meridian Mining signed an agreement with Coopersanta to re-process 130 million tonnes of tailings from Bom Futuro as well as to explore new cassiterite deposits in the region. The first test plant, with capacity of processing 50 tph, was established in 2015 (Meridian Mining, 2018; The Globe and Mail, 2017).

Another important Brazilian tin producer is ERSA, a subsidiary of the largest Brazilian steelmaker CSN. In order to supply its own steelmaking process, which is one of the five largest in the world, refined tin is produced by ERSA and transported approximately 2,500 km to Rio de Janeiro. Figure 7 illustrates ERSA final products, produced in Ariquemes, Rondonia state.

Figure 7. Sn ingots – ERSA

Artisanal cassiterite miners that are organized into cooperatives operate other mines in Rondonia state and are responsible for more than 50% of Brazilian production (DNPM, 2017). Cooperatives in Brazil may be considered a successful example of formalization and organization, where miners share their profits at the end. The largest cooperative in the state of Rondonia is COOMIGA (Mining Cooperative of Artisanal Miners from Ariquemes), which is structured to produce around 100 tonnes of cassiterite concentrate per month (Teixeira, 2009).

Brazilian cooperatives operate mid-size equipment as excavators (e.g. PC 200, from Komatsu) in their mining operations (Figure 8). Trommels are used for sizing or scalping; jigs (Figure 9) and shaking tables are used for concentrating cassiterite (Ferreira, 2016 pers. comm.; Wordpress, 2011). Excavators open a pit, where artisanal miners use water from the local rivers to operate a setup of pumps that redirect the slurry to the plant. Once at the plant, the slurry may then be scalped or sized by trommels or pumped directly to the jigs, where gravity processes concentrate the SnO_2 (Wordpress, 2011). In some cases, fines may be separated by shaking tables afterwards (Ferreira, 2016 pers. comm.).

Figure 8. Excavator mining cassiterite
(Source: Wordpress, 2011)

Figure 9. Jigs installed in Bom Futuro mine site
(Source: Wordpress, 2011)

According to Lima (2009), when miners work with weathered tin ore, which is most cases, Brazilian cooperatives use excavators, dredges and hydraulic monitors to extract the material. This is then either dumped into small trucks or pumped to the processing plant, where gravity concentrators and magnetic separators produce a concentrate with 60% to 92% of cassiterite, which stoichiometrically corresponds to 60% to 72% tin. Tailings are discharged in old pits with no spillways and the water is reused (Figure 10).

Figure 10. Artisanal mining Brazilian tailings dams
(Source: Wordpress, 2011)

2.6. Mining sector in Indonesia

2.6.1. Current Indonesian Mining Scenario

The mining industry in Indonesia is one of the main contributors to Indonesian development, contributing 14% to the total Indonesia exports and is 4.7% of gross domestic product (GDP). However, it plays a much more important role in the resource-rich area’s economy (Rosyida et al., 2018). Government revenue, exports, employment and the development of remote areas are considered the main benefits created by mining companies, who are typically the principal employers in rural regions of the country (Aspinall, 2001). Although the contribution of mining to the GDP decreased from 6.14% in 2011 to 4.70% in 2017, which was mainly due to a downturn in global commodity prices, this sector continues to grow and has continued to assert dominance in regional economies, including in Papua, Central Sulawesi, East Kalimantan, Bangka and Belitung (PWC, 2018).

The historical data of the mining industry's contribution to the GDP is shown in Figure 11 and the internal market share of the mining sector as a percentage of total Indonesian exports is shown in Figure 12.

Figure 11. Historical data of mining industry contribution of Indonesia GDP (Source: PWC, 2018)

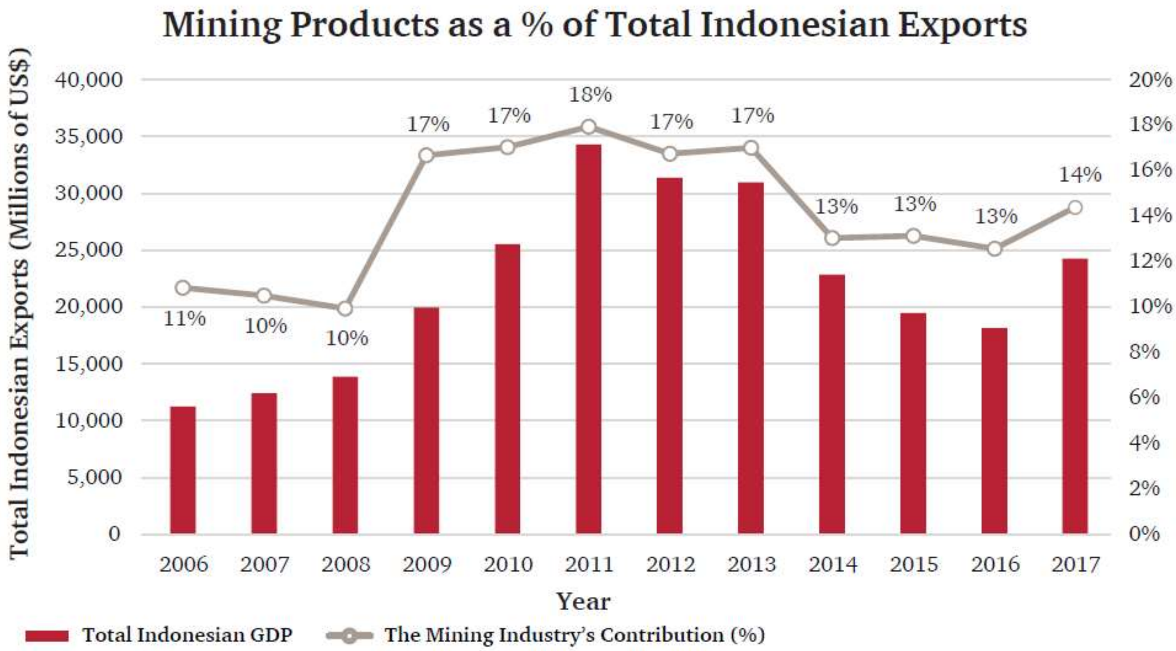

Figure 12. Internal market share of the mining sector
(Source: PWC, 2018)

Approximately 250,000 artisanal miners are currently extracting gold, tin and diamonds all over Indonesia (Pact, 2018). According to International Tin Association, approximately 50,000 of the cassiterite artisanal miners, plus dependents, are in Bangka and Belitung, including both offshore and onshore activities.

The artisanal tin mining sector in Indonesia contributed approximately 80% of the total national tin production in 2001 (Aspinall, 2001; USGS, 2002). In 2017 Indonesia produced about 78,100 tonnes of refined tin (ITRI Prod, 2018), of which more than 60% came from artisanal miners (Jabin, 2017 pers. comm.).

2.6.2. Historical Aspects of Cassiterite Mining in Indonesia

Indonesia is one of the largest country in the world with an area of about 1.9 million square kilometres. It is surrounded by water and has a population of approximately 260 million people (World Bank, 2018). The entire country consists of more than 17,000 islands, as many as half of which are pristine and exhibit a rare native beauty, with many of them still unnamed (The Embassy of USA of Indonesia, 2018). Others, like Sumatra and Java are very populated, with Java being the most populous island with over 130 million people, of which 9 million live in Jakarta, the national capital (Indonesian Ministry of Tourism, 2017).

There is an impressive variety of 200 cultural and language groups across the Indonesian islands, where Javanese culture predominates. The native language is a form of Malay, Bahay Indonesia or Indonesian (National Geographic Expeditions, 2018). Indonesia is known for its rich cultural diversity, where ancient temples, different sorts of music and rhythms, literature, poetry, food, rituals and ways of life can vary regionally, the result of thousands of years of influence due to trade with China, India and the rest of the world (Hays, 2015). The country has the largest Islamic population in the world and approximately 90% of Indonesians consider themselves Muslim (Malasia Digest, 2018). However, Indonesia is not an Islamic state and has a long history of religious tolerance. Although the country is considered a democratic country, it has often been mentioned in the global media for its corruption, political violence and terrorism (Vickers, 2013).

Beginning in 1602, Indonesia was colonized and occupied by the Dutch for approximately 350 years, who named the territory the Dutch East Indies. The first Dutch expedition to the region arrived in 1595 in order to access spices from Asia (Reid and Alilunas-Rodgers, 2001). Promptly, they started commercializing tobacco, cloves, cinnamon, tea, coffee, sugar, rubber and peppers. They established the Dutch East India Company to anchor the monopoly (Encyclopedia Britannica, 2018). Although most of the islands were dominated by the Dutch, many of them remained independent, creating conflicts for the Dutch military forces and then, prior to World War II, Indonesia was invaded by the Japanese, which dismantled the Dutch colonial state and economy (Maddison, 1989). Following the Japanese surrender in August 1945, independence for the territory finally was declared (Global Security Org., 2017). Sukarno, who had been a prominent leader of the Indonesian independence movement during the latter stages of the Dutch colonial period, assumed the Presidency of the country, guiding an authoritarian democracy from 1949 to 1966 (Pringle, 2010). He was then deposed by the army under Suharto, who governed from 1967 to 1998 (Hanna, 2015).

Although the Dutch occupied Indonesia for more than three centuries, there are no reliable documents regarding Dutch attempts to produce diamonds, gold or tin on a large scale (Doyle, 1994). Tin, gold and coal mining did not expand significantly until Suharto opened the sector to international investment in the 1970s, which prompted a period of massive growth through the 1980s (Global Security Org., 2017). Due to a severe economic crisis and plagued by numerous corruption scandals, Suharto's leadership had lost support by the early 1990s, resulting in defeat in 1998 (Ignatius, 2007; Miguel et al., 2005).

Although the Dutch began exploiting cassiterite from alluvial deposits on Belitung Island around 1850, the existence of small-scale mining has been documented from as far back as 1668 (Agus et al., 2017), when the Dutch proceeded to exploit known reserves using both, local and Chinese laborers (Suryadinata et al., 2003). The first large-scale cassiterite mine was developed by Dutch-owned Billiton (now BHP Billiton) in 1860 exploiting tin reserves on Billiton (Belitung). Interestingly, the current name for BHP Billiton came from Belitung's name, which was formerly called Billiton (Blainey, 2010) .

The company was known in England as Billiton Tin Company and many Chinese workers came to the region to mine, which increased Belitung's population to approximately 42,000 habitants by 1910, of which 12,000 were Chinese (Reid and Alilunas-Rodgers, 2001). The company thrived for many decades and just before World War I, 80 mines employed approximately 7,500 men. However, by the late 1950s the boom was over and Billiton decided to expand into other mineral markets, leaving cassiterite behind (Blainey, 2010).

Three Dutch companies also mined cassiterite during the colonial era (Doyle, 1994). In 1953, during Sukarno's tenure, the companies were nationalized before being amalgamated into one state-owned company called PN Tambang Timah in 1968 (TBK, 2017). In 1976, PN Tambang Timah changed its status to become a public company under the name of PT Timah, which is fully owned by the Government of the Republic of

Indonesia (Kurniawan, 2005). Currently, PT Timah is the largest Indonesian tin mining company and the most important tin smelter in Belitung (TBK, 2017).

In order to attract and retain its labor force during the tin boom of the 1980s, PT Timah built a complete village to house its laborers in Belitung, including sports and health facilities (Nickolaus Hariojati, 2017 pers. comm.). Although most of the buildings are now abandoned, some of them are still occupied by former employees who bought their houses from the company and are currently low-income village residents (Kurniawan, 2005) working as artisanal miners of cassiterite as a livelihood or at other small business in Belitung. In order to develop tourism in the region, the provincial government refurbished several other buildings and transformed them in museums and guest houses, preserving the rich mining history for future generations (TBK, 2017).

Figure 13 depicts former PT Timah village abandoned, while Figure 14 shows refurbished buildings to encourage tourism in the region.

Figure 13. PT Timah’s former village in current condition

Figure 14. PT Timah's former village refurbished
to tourism industry

2.6.3. Current Cassiterite Production in Indonesia

It has been estimated that Indonesia has approximately 250,000 artisanal miners extracting gold, tin and diamonds (Pact, 2018). Bangka and Belitung host approximately 50,000 artisanal cassiterite miners, including both, offshore and onshore activities. It is estimated that 10,000 mining sites are responsible for providing a livelihood for them. Bangka hosts 8,000 mining sites while 2,000 is located in Belitung (ITA, 2018). In 2017 Indonesia produced approximately 55,000 tonnes of refined tin (USGS, 2017), of which more than 60% (Jabin, 2017 pers. comm.) came from artisanal miners located on the islands of Bangka and Belitung (ITRI Babel, 2018).

Old mining practices that were developed 200 years ago (Vickers, 2013) are currently applied for alluvial mining operations in Bangka and Belitung. Miners simply follow their instincts when exploring for deposits and implement rudimentary mining practices to obtain the cassiterite concentrate (Stocklin-Weinberg et al., 2017). Although the owners of cassiterite artisanal mining operations are aware of the importance of identifying and evaluating geological information, they do not invest time and money conducting surveys and field assessments.

As in many other parts of the world where artisanal mining activities have occurred continuously for many years, alluvial landscapes in the Bangka and Belitung are severely impacted by these practices, being marred by old excavation areas and untreated tailings (Jenkins and YakoVleva, 2004). Although a few reclamation efforts have been attempted by some mining companies, they have not culminated in substantial positive results, and, moreover, poor excavation and digging of precarious mine shafts over the years has led to accelerated erosion and increased risk for workers (Walle and Jennings, 2001). With little regard for slope stability and other safety concerns, many accidents and fatalities occur each year due to mudslides and collapsing banks or tunnels (Crispin, 2002). Additionally, the practice of washing the material with hydraulic monitors, in conjunction with haphazard excavation techniques, eventually led to banks collapsing into the artificial lake created by the artisanal operations in this region (Stocklin-Weinberg et al., 2017).

There is substantial uncertainty regarding statistics reporting accidents and fatalities, caused by lack of safety management. It is believed that dozens of people die every year (Hodal, 2012; Jabin, 2017 pers. comm.). According to Friends of Earth International (FOEI, 2012), an international non-governmental organization, as many as sixty miners died in Indonesia artisanal cassiterite mining per year, mostly buried in tin alluvial mines or trapped underwater during dredging offshore mining activities.

Operators in Indonesia are often exposed to other hazardous working conditions, including exposure to solar insolation, effects of overexertion and dehydration, lack of necessary sanitation facilities, injuries to hands and fingers, and ergonomics risks related to frequent attempts to fix malfunctioning pumps and hoses, which generally operate in less than ideal condition (Bissie, 2016). In addition, other injuries (Hodal, 2012) and fatalities are caused by lack of training (Stocklin-Weinberg et al., 2017;

Worstall, 2013) and a lack of personal protective equipment (PPE) and collective protective equipment (CPE).

Old cassiterite tailings ponds are often suitable for reworking by artisanal miners (Kossoff et al., 2014). Mining companies, especially those that mine alluvial deposits, leave behind an economically-workable percentage of tin in the tailings ponds, which is viable enough to generate at least some income for an individual or a group of artisanal miners (Nurtjahya et al., 2009). In average, the grade of the ore is about 0.02% of tin, which is lower than most of cassiterite alluvial ore bodies worldwide which ranges 0.04 to 1% of tin.

PT Timah is the largest Indonesian tin mining company and run the most important tin smelter in Belitung (TBK, 2017). Artisanal miners currently produce more tin than PT Timah in Bangka and Belitung region. Both illegal and legal artisanal miners are linked to PT Timah and other smelters (Davis and Wulandari, 2008) through business relationships, since the company's policy allows locals to mine cassiterite and sell their final concentrate through collectors to the smelters. (Aspinall, 2001).

Artisanal miners around the rest of the country use rudimentary dredges and rafts that are equipped with a steel-made sharp tip in offshore operations. This tip is poorly attached to a PVC tube and is sent down to the bottom of the river to suction the ore upstream (Davis and Wulandari, 2008). Onshore, artisanal miners work submerged in dirty water, because they commonly mine through a water driver which detaches the friable sedimentary rocks, then suction the ore upstream to the sluice box or traps, either to prevent blockage against the pump suction or to simply pan (Stocklin-Weinberg et al., 2017).

Processing is comprised of homemade sluice boxes, panning, shaking tables, jigs and sometimes, for competent rocks, crushing and grinding to liberate the precious particle. Pans, sluices box or traps equipped with riffles or barriers to improve concentration of the desired metal are operated to extract cassiterite concentrate (McCarter, 1982). The same principle was referred by Veiga et al. (2005) and Veiga and Hinton, (2002) when they detailed that artisanal gold miners use carpet to trap gold particles.

Women traditionally participate in all levels of artisanal mining. Most involved in the mining process pan tailings from the sluice boxes (Pact, 2017). However, several women are bosses, owning processing equipment and managing miners (Aspinall, 2001). The role of women in artisanal mining changes day by day (Hodal, 2012).

3. Methodology

3.1. Fieldwork Overview and Objectives

Operational, environmental and safety practices associated with artisanal mining of cassiterite in Bangka and Belitung were investigated during a field trip to Belitung Island, the east of the province, in July and August 2017. The objectives of the fieldwork conducted for this study were to: 1) observe mining and processing methods of artisanal miners; 2) obtain information about types of equipment, mineral recovery, earnings, use of personal protective equipment (PPE), number and characteristics of the most common accidents tailings discharge and reclamation methods. 3) find out if the level of radioactivity in the mining sites is relevant; 4) record opinions and perceptions from local artisanal miners regarding safety, environmental and operational procedures; and 5) determine the nature of relationships among miners and all stakeholders as mining bosses, collectors, smelters, community, government and other.

Firstly, local guides introduced the reason of the fieldwork and verbal authorization was obtained, and then informal conversations on mining sites were conducted amongst artisanal miners and notes written on pocket book after their authorization.

3.2. Belitung Overview

The Bangka and Belitung or “Babel” Island, located off the southeastern coasts of Sumatra, was initially colonized by the Dutch who rules from 1595 to 1942 (Vickers, 2013). The province is made up of two main islands, Bangka and Belitung, as well as a few smaller ones. The capital is Pangkal Pinang, which is the economic center of the province and seat of the Bangka and Belitung Provincial Government (Ministry of Tourism, 2017). Other relevant cities in the province are: Sungailiat, Tanjungpandan and Manggar. Ethnically, culturally, and linguistically diverse, Babel has an important role within Indonesia culture and history, including during World War II, as it was target by the Japanese invaders who recognized it as a valuable source of tin production (Suryadinata et al., 2003). The map of Indonesia is shown in Figure **15**. Map showing all of Indonesia and Banka-Belitung Province, with the Bangka Belitung Islands highlighted.

Figure 15. Map showing all of Indonesia and Banka-Belitung Province (Source: Indonesian Ministry of Tourism, 2017)

Belitung (or East Belitung) island is located on the east coast of Sumatra, in the Java sea. It covers an area of approximately 4,800 km^2 and had a population of 271,868 in 2014. Its main town, Tanjungpandan, has approximately 120.000 habitants (Indonesia Tourism, 2018). Farming, fishing, tourism and mining are the most important economic activities for the island, and it is specifically known for its production of pepper and palm oil, popular tourist beaches and its tin production (Indonesia Commerce, 2017).

3.3. Study Area

The Belitung geology consists of a biotite granite suite and a quartz syenite suite (Lehmann and Harmanto, 1990). Approximately 210 million years ago, an enormous metamorphic folding and thrusting occurred (Westerveld, 1936). Two and half million years ago, a transgression-regression and chemical weathering reigned, whereby, Banka-Belitung Islands experienced several eustatic sea-level changes and marine sedimentation that enhanced the formation of tin deposits (Ko and Centre, 1986). Tin deposits are geographically well-positioned in a long, boot-shaped belt of tin stretches from Myanmar all the way down through Thailand, Malaysia, Singapore and Indonesia, with Belitung and its sister island Bangka comprising its toe (Thomas, 2012). The geological formation is composed of granite as well as sedimentary hard banks of sandstone. For a large part of the granite, the sediments constitute an important aspect of Babel geology. Although cassiterite deposits in Belitung might be from a few different source of granite, such as Sn-greissen, cassiterite-quartz veins and sandstones sediments (Lehmann and Harmanto, 1990; Stocklin-Weinberg et al., 2017), the ore mostly occurs as secondary deposits (alluvial) and comes in very fine grains due to hydrothermal processes (Taylor, 2014).

Belitung was a very important tin mining region until the end of 1980s, hosting huge industrial-scale private and public tin mining companies (Kurniawan, 2005). After this boom period came to the end, unconventional artisanal miners proliferated. Currently, only a few conventional mining companies are still operating in this region, although at much reduced production levels than in the past. As a consequence of this, artisanal tin miners obtain their livelihood by exploring former mining sites, either legally or illegally.

The provincial government designated certain areas where artisanal miners can work legally, which are called WPR, that may be translated from Indonesian as People's Mining Sites. These areas used to be conventional mining areas occupied by Indonesian and foreign companies. In addition, artisanal miners can operate in designated areas called IUP, which from Indonesian means Private Mining Sites. At these sites, the artisanal miners need a contract with the mineral title's owners to have a license to operate and sell their production to the owners (Stocklin-Weinberg et al., 2017).

Figure 16 shows the location of the main cassiterite mining sites, which are mainly located close to Manggar and Gantung. The footprint of the artisanal mining activities is visibly identified in the satellite image.

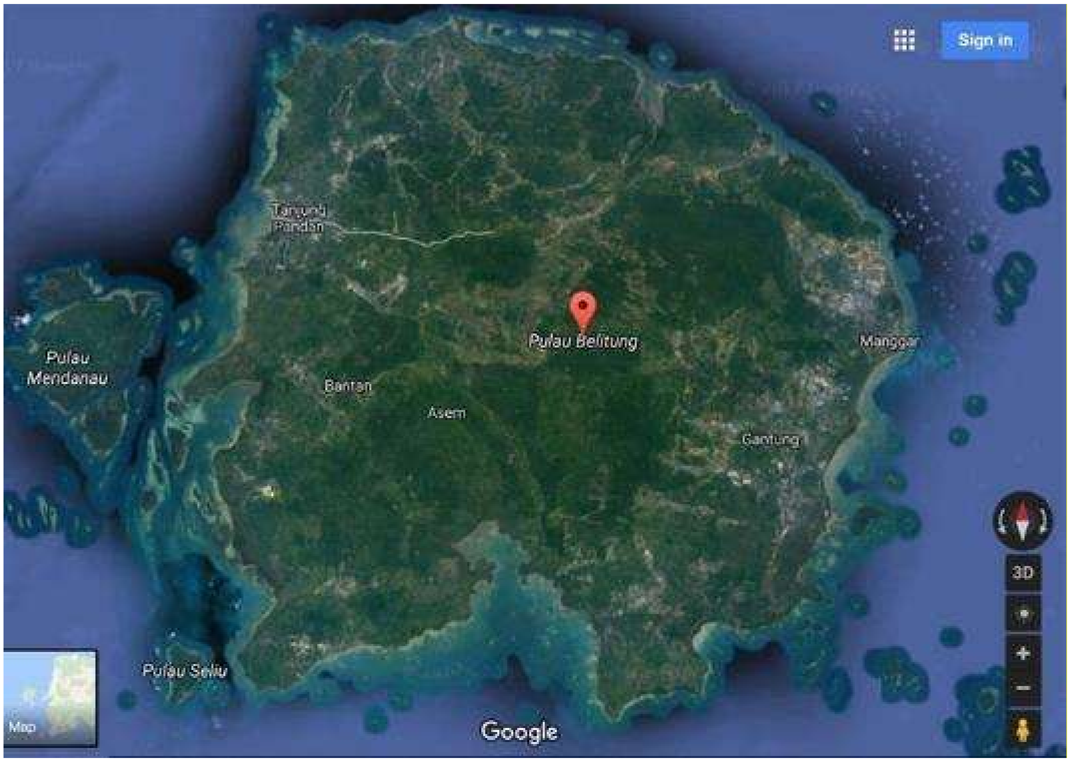

Figure 16. Satellite image showing locations and cassiterite mining on Belitung (Source: Google Earth, 2018)

The field activities were conducted at the mining sites of Belitung Island, that belongs to the Bangka-Belitung Province, where there are many sites in both Mining Business License (IUP) and People's Mining Areas (WPR) where alluvial artisanal mining of cassiterite occur, both legally and illegally.

A map of the artisanal mining sites visited in Belitung is shown in Figure 17. A short description of each site and the fieldwork conducted in Belitung at each site is included as follows:

Figure 17. Satellite image showing locations of mine sites visited
(Source: Google Earth, 2018)

1. Sukamandi: artisanal mining sites were visited as well as personal observations and communication with artisanal miners and a mining boss *in loco.* Sukamandi village is in the Manggar sub-district, East Belitung District, in Bangka Belitung Island. Considered the most important mining location in Belitung, Sukamandi hosts around 9,000 people who depend on artisanal mining activities for their livelihood (Jabin, 2017 pers. comm.).

2. Kelapa Kampit: illegal underground mining sites were visited. Kelapa Kampit is the name of the region and the District. This region has a long tradition of artisanal mining and is important to the history of Belitung Island. Currently, Ministry of Tourism has been investing to attract people who enjoy outdoor activities, such as hiking, camping as well as encouraging tourist to see how the locals earn their living using traditional mining activities and visiting the former BHP open pit (TripAdvisor, 2018).

3. Mengkubang: PT Timah mining site was visited. Located in Damar sub-district, Mengkubang has approximately 3,200 habitants, most of them mining for livelihood in IUP areas belonging to PT Timah.
4. Gantung: PT Tommy Utama, an Indonesian smelter was visited. Due to the installation of PT Timah's port, Gantung became one of the most important city in Belitung. Known for being a floodplain during the rainy season, this region is more renown for its plantations (rubber, palm oil and pepper) than for being a mining area. Additionally, there is a designated industrial zone where PT Tommy Utama is located.
5. Tanjungpandan and Mangar: two meetings were conducted with a representative Association Artisanal Miners (APRI) and with the representative of Belitung Village Association respectively. As mentioned before, Tanjungpandan is the most important city on the Island, with more than 100,000 habitants. In addition, it is the capital of Belitung. Locally known as the "City of Coffeshops", Mangar was the centre of Dutch colonial era. The tradition of coffee-drinking was common among historic tin miners, who used to drink the beverage during the breaks and after their working day.

3.4. Stakeholders

Due to scarcity of literature of artisanal mining of cassiterite in Indonesia, fieldwork for the development of this study was considered indispensable. In order to meet the main objective of this thesis, the fieldwork aimed to investigate how the locals produce cassiterite concentrate, as well as outlining operational, environmental and safety procedures.

The information regarding operation and safety procedures came from informal meetings, personal observations and consultations with artisanal miners and other stakeholders in the sector, including:

1) Miners: the artisanal miners encountered in the field were very kind and open, providing information about techniques, production, risks exposure and their relationship with the bosses and collectors.
2) Mining Boss: a mining boss was met at her house and hosted a visit to one of her mine sites afterwards. The boss was very friendly and shared relevant information for this study. She operated as a boss and collector at the same time, clearly demonstrating that several levels of collectors do exist in the chain of tin.
3) Processing Centers: Processing centers are small and rudimentary installations that charge artisanal miners to upgrade their cassiterite concentrate. Two processing centers were visited in two different locations. How they operate, techniques and equipment applied, tailings discharge and its room in the tin chain were assessed.
4) Smelters and Collectors: the smelters are the companies that reduce the SnO_2 to Sn in electric furnaces, and collectors (cassiterite buyers), were also visited.
5) Representatives of Associations: several meetings occurred *in loco* with representatives of artisanal miners' associations, as well as with the president of Association of Indonesian Tin Exporters (AETI).

3.5. Sampling and Analysis

The risk of pollution caused by heavy metals and organics was also investigated. Previous fieldwork conducted by PACT (2017) and UBC has collected water, ore and tailings samples that were analyzed in Indonesia labs by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-OES) to provide a list of elements of interest present in the samples.

Field X-Ray Fluorescence semi-quantitative analyses were used to assess some contaminants of concern. Solids samples were analysed by a Niton XL 3T XRF portable X-ray fluorescence (XRF) spectrometer with selected channels. X-rays responded with certain characteristic for each type of mineral that was analyzed. This semi-quantitative procedure was useful to determine the concentration range of the elements of interest. The available channels of this equipment were: Zr (zirconium), Sr (strontium), U (uranium), Rb (Rubidium), Th (Thorium), Pb (Lead), Au (Gold), Se (Selenium), As

(Arsenic), Hg (Mercury), Zn (Zinc), W (Tungsten), Cu (Copper), Ni (Nickel), Fe (Iron), Mn (Manganese), Cr (Chromium), V (Vanadium), Ti (Titanium), Sc (Scandium), Ca (Calcium) and K (Potassium).

The Toxicity Characteristic Leaching Procedure (TCLP) (US EPA, 2018) analysis is an indirect method to assess the bioavailability of metals from a substrate when the element reacts with an organic substance, such as acetic acid, that was used as a proxy in this specific case. The lower the concentration of the metal in the TCLP solution, the lower the bioavailability should be. The results are presented in Chapter 4.

Some of the samples were brought to UBC in Vancouver, and the mineralogy was investigated by X-ray diffraction to reveal the crystalline minerals in the samples through XRD Cu tube and interpretation by Rigaku software.

The most important results were selected, assessed and presented in Chapter 4.

Analyzed samples were collected in Bangka and Belitung and consisted of:

1. Cassiterite concentrate (Mapur - Bangka)

2. Sluice box tailings (Mapur - Bangka)

3. Dry-tabling tailings from the collectors Mangkubang (Belitung)

4. Selected iron oxide concretions from WPR Sukamandi (Belitung)

Maps illustrating the collection areas are shown in Figure 18, Figure 19 and Figure 20.

Figure 18. Location of Concentrate and Sluice Box Tailings samples Mapur – Bangka (Source: PACT, 2017)

Figure 19. Location of Iron Oxide samples - Sukamandi - Belitung (Source: PACT, 2017)

Figure 20. Location of Dry Tabling samples – Mangkubang - Belitung
(Source: PACT, 2017)

3.6. Radioactivity Measurements

Some of the main concerns of tin mining and the smelting process are thorium (^{232}Th) and uranium (^{238}U) emission levels, as both elements can be concentrated in granite and alkaline magnetic rocks normally followed by other elements like Rare Earth (Gilmore and Jackson, 1982). Additionally, cassiterite orebody aggregates accessory minerals like tantalite, zirconium, monazite, xenotime and thorite. Even though Belitung deposits are rich in monazite, minerals such as columbite and tantalite are not abundant (Harjanto et al., 2013).

Cassiterite mining sites expose uranium – thorium elements that can easily disperse to surface soil within low range (Arogunjo et al., 2009). Conversely, the specific activity of ^{232}Th and ^{238}U is enhanced in the slag during the smelting process and, in large quantities, the slag storage can be a very relevant radiation hazard due to time of exposure elevating dose rates (Sumaryanto, 2014). A Geiger app was installed in a smart phone, and variations in concentration between different types of tailings and concentrate were observed and is discussed further, as well as standards parameters to express the dose radiation in an individual.

Figure 21 shows an example of one of the radioactive measurement that were read in a tailing sample.

Figure 21. Radioactivity level measurement in tailings samples

It's important to notice that there are many parameters to express the dose of radiation received by an individual. The most accepted by the International System of Units (SI) is the Sievert (Sv) (Canadian Center of Occupational Health and Safety, 2018) and the dose rate is commonly expressed in mSv/h (miliSievert per hour) or mSv/a (miliSievert per annum). MicroSievert/h (μSv/h) or 0.001 mSv/h is usually the unit used by Geiger counters that detect ionization radiation.

The world background of ionization radiation in the air is 1.26 mSv/a or 0.00014 mSv/h and in USA the level is 2.26 mSv/a or 0.00026 mSv/h (or 0.26 μSv/h) (Background Radiation, 2018).

The International Commission on Radiological Protection recommends for occupational exposure, the radiation dose limit of 50 mSv per annum with a maximum of 100 mSv/a in a consecutive five-year period, and for public exposure an average of 1 mSv/a (0.001 Sv/a), not including medical and occupational exposures (IRCP, 2007).

4. Results

This chapter presents results found from the field, including: a description of the chain of tin, site-specific observations, environmental contamination, and safety aspects surrounding heavy metals, organics and water. Fieldwork, observations, tables and pictures are used to support the results, described in the following sections.

4.1. The Dynamics of the Operation

Indonesia's tin production in the artisanal mining sector is composed of different steps. First, artisanal miners extract cassiterite ore at alluvial or underground artisanal mining sites in either WPR or IUP areas. The ore is then delivered either to processing center or a boss. Processing centers charges for the service of upgrading and produce a concentrate from the tailings artisanal miners left behind. The bosses sell the concentrate which has been produced by a group of three to five miners to the collector. The concentrate is then sold to a smelter, which end up exporting the metallic tin. The following subsections discuss the chain of tin in further detail.

4.1.1. WPR and IUP Artisanal Mining

WPRs (People's Mining Areas) are areas indicated by the provincial government to be mined by artisanal miners based on potential mineral deposits, but they must be approved by the National Planning Agency, the Ministry of Home Affairs and the Ministry of Energy, Mining and Mineral Resources (ESDM). In general, WPRs typically consists of old tailings disposal areas left over from past mining activities or abandoned low grade deposits.

In comparison, an IUP (Mining Business License) is a private area owned by the mining companies that allow artisanal miners to work legally under permits granted by those companies, which then purchase their production afterwards.

The provincial government has zoned part of the East Belitung as a mining area and PT Timah, which is the largest Indonesian public tin mining and smelter (Bell, 2017), has 60% of these mining titles. Most of these titles are part of PT Timah's IUP area and the remaining 40% is divided between a WPR area and other mining companies' sites. In general terms, the difference between a WPR and an IUP area is just the process of obtaining permits to mine. While miners in a WPR area must submit a request to provincial government authorities, IUP miners need to work with private or public companies to obtain the necessary license to operate.

In principle, artisanal miners should operate only in designated areas with permits, in reality, most of those operating in WPR areas do so illegally. In comparison, for artisanal miners whom operate in IUP areas, most of them have their own license, and therefore, are considered legal operations.

All other areas that artisanal miners work without permits, including underground operations, are considered illegal mine sites. For example, in Sukamandi, one of the sites visited for this study, where underground tin miners usually follow the ore vein until they reach a maximum depth of 100 meters, they work without legal permits. They then take their ore to processing centers that offer services of comminution and concentration. Figure 22 shows the camp of an operation to mine in IUP area.

Figure 22. Camp of an IUP Operation.
In an IUP area it is required to display the permit

Table 1provides further information about both WPR and IUP areas.

Table 1. A comparison between WPR and IUP according safety, environmental, operational, deposits, inspections and legal parameters

	SAFETY	ENVIRONMENTAL	OPERATION	ORE DEPOSIT	INSPECTION	LEGAL OR ILLEGAL
WPR	In theory, is less safe than IUP, since no one is present to support, inspect or improve the mining site. There is a lack of PPE, infrastructure, procedures, standards or training programs.	Lack of environmental management	Set-up of water (pumped from the local river) and slurry pumps, pipes and hoses, buckets and homemade sluice boxes. Controlled by *mine bosses* or groups of artisanal miners.	Predominantely, WPR are old tailings discharge areas with very low grade of tin (around 0.04%).	Authorities and regulatory agencies rarely inspect the artisanal miners	Both legal and illegal miners operate in WPR area. Vast areas with no inspection by authorities.
IUP	In theory, the mining site should be supervised by the mining company (the owner of the area). Instead, there is no commitement to providing PPE, infrastructure, procedures, standards nor training. Barely any inspector are present to critique artisanal miners and order changes in their operation.	Mining companies' contribution to land reclamation remains very low	Set-up of water (pumped from the local river) and slurry pumps, pipes and hoses, buckets and homemade sluice boxes. Mostly controlled by *mine bosses*.	Old tailings discharge areas and alluvial deposits, both with very low grade of tin (around 0.04%)	Artisanal miners must keep the permit visible in the field available for mining company inspector to check it.	Legal; very few illegal miners work in IUP area.

Operating in either a WPR or an IUP area, artisanal mining of cassiterite operations normally consist of two cast-iron diesel pumps, mostly made in China. Typically, pumps have 27 Hp, 2,200 rpm of speed and weigh 220 kg each. These pumps draw water to the hydraulic monitors through hoses of approximately 40 meters in length and PVC pipes of 4 – 6 inches in diameter. A miner operates the hidraulic monitor close to the pit wall and removes the ore, which forms a pulp in a small pool at the bottom of the pit. A second pump delivers the slurry with 15 - 25% of solids (w/w) to the sluice box placed on the border of a man-made lake. The area is rich in gravel, weathered cobble and pebbles of magnetite, hematite and other iron oxides. On the pump suction, a second miner works full-time in wet conditions to unclog the pump when it is filled up with large stones. The third miner is usually responsible for the pumps, pipes, water supply, sluice boxes and maintenance.

The sluice boxes are typically primitive and made of wood. Although the normal operational angle of a sluice box is approximately 15 ^{o}, (Wills and Finch, 2015) Indonesia's cassiterite artisanal miners operate in a lower angle of 5 ^{o} in order to increase recovery. On the other hand, this method decreases the SnO_2 grade of the concentrate. The large mass of sand (quartz) accumulated on the equipment acts as a trap for the cassiterite grains, which have higher specific gravity (s.g. = 7) than the quartz (s.g. = 2.7). Other heavy minerals, such as magnetite (s.g. = 5.2), hematite (s.g. = 5.2), monazite (s.g. = 4.6 – 5.7) and zirconite (s.g. = 4.6) are also retained in the concentrate. There is no standardized size of sluice box. However, they are generally 3 m long and 0.8 – 1 m wide (Figure 23). As the sluice boxes do not have any riffles to reduce the increasing water velocity down the length of the box, they work essentially like gutters, with low residence time, culminating in great losses of fine cassiterite particles.

Figure 23. Different kinds of sluice boxes

The sluice box feed rate is approximately 20,000 kg/h. The artisanal miners operate during day light only, and when the concentration process stops, after 2 days of operation, the cassiterite concentrate is cleaned by an operator and all of the grey material is stacked at the top of the sluice box for further rudimentary gravity concentration process using shovels, jet water hoses and hand-shaking. Cleaning (Figure 24) consists of the operators washing the material with a hose and pulling the dark minerals (cassiterite, hematite and magnetite) to the top of the sluice box. Washing of sluice boxes take approximately 1 to 2 hours. Their rudimentary processing methods incur huge losses, resulting in low recovery. In addition, lack of quality control is typical in this process.

Although, miners are confident that they know how to operate the equipment, no standard operational procedures or maintenance plan are observed. Miners will operate machines until they breakdown. At this point, the machines are poorly repaired by the miners themselves and returned to service in questionable condition (with dust throughout the equipment, spillage of critical fluids and lack of lubrication are some examples of what was observed). Ultimately, this affects productivity, creating huge losses and inefficiency (that was confirmed by personal communication with the miners).

Some miners, including women and children, pan the tailings from the sluice boxes (Figure 25). It is quite common to see locals waiting near the discharge point of the sluice boxes to collect the tailings for panning in a small improvised plastic sluice boxes (Figure 26).

Figure 24. Miners washing the concentrate in a WPR area

Figure 25. Women collecting sluice box tailings
(Source: PACT, 2017)

Figure 26. Primitive plastic sluice box

In order to achieve around 70% of SnO_2, the slurry is concentrated by gravity methods, either onsite by themselves using sluice boxes or at processing centers, when they are not able to upgrade running only sluice boxes. Many independent artisanal miners take their panned concentrate to their own houses, where they dry the concentrate and then bring it to a processing center in order to increase the grade on a dry shaking table, before selling it to a collector. Artisanal operations are usually conducted under the leadership of a mine manager, or “boss”, as they are known locally. Miners working under a boss simply take the material to their boss and suffer the penalties of a low grade, rather than taking it to a processing center in order to avoid additional costs.

Mining bosses (Figure 27) are the owners of the equipment and supply water, slurry pumps, fuel, sluice boxes, pipes or hoses, and other types of equipment. Artisanal miners of cassiterite typically come from poor backgrounds, with little education and who follow the orders of the bosses.

Figure 27. Sluice box operation at PT Timah's Site
The boss can be seen wearing a conical blue hat

In Belitung, there are at least seven bosses working in IUP and WPR areas. Each boss has one to three sets of pumps, sluice boxes, pipes and hoses. Most bosses have an additional source of revenue, which normally comes from farming (e.g. palm oil) or construction.

One boss from the Sukamandi region who was consulted during the fieldwork (Figure 28) demonstrated a good level of knowledge about mining and processing steps. When questioned about the size and operation of her sluice box, and whether it might be better to incorporate roughers, cleaners and scavengers, or work with a jig, centrifuge or spirals concentrators, she promptly answered that she was aware of these types of gravity concentrators. However, she felt that it was not worth the investment due to uncertainty about size and location of ore body, previous losses due to floods, and her preoccupation with another business that she and her husband were running concurrently, which they considered more important than mining. This type of boss would not be willing to invest in equipment and new processing methods based on the uncertainty about increased earnings. However, the boss said she was glad to be working in the mining sector and generating a profit through her operation, as she and her husband were able to sustain a good standard of living.

Figure 28. Meeting with the boss in her house located in Sukamandi Village.

Generally, local miners work together in small groups of three or five relatives or friends and split the profits after the ore is processed. Under the rules of the boss, the earnings are divided into three parts, where a third belongs to the miners, a third goes to the boss and the last third covers the operational costs, like fuel, maintenance, hoses, water and sometimes even the food that was fed to the miners.

However, very often, the artisanal miners do not have a boss and therefore split the costs and profits equally among members. Collectors then buy the cassiterite concentrate from the bosses, which is priced based on the density of the material. Often, a boss is also a collector, buying concentrate from other artisanal operations as well. Although collectors could deliver the concentrate directly to the smelters, there are normally two or three levels of collectors involved, where the last collector delivers the material to the smelter to produce metallic tin. In some cases, the processing centers also function as tailings reprocessing centre, where they can reprocess the tailings left behind by the artisanal miners and then resell them to another collector. PT Timah provides a collection center in Sukamandi Village to buy concentrates from WPR and IUP areas, where private security guards ensure the local order (Figure 29).

Figure 29. PT Timah’s Collection Centre

The following flowsheet (Figure 30) illustrates the chain of tin. It starts with artisanal miners delivering their cassiterite concentrate to the bosses or to a processing center to upgrade it till 70% of Sn. The collectors then bring the concentrate to the smelters. Although the smelters own mining areas, the majority of cassiterite concentrate that is smelted in their electrical furnaces comes from artisanal miners. They end up operating as “fake” mining.

Monazite may be also extracted by the processing center and collectors export it.

It is relevant to notice that collectors are the ones that the most take advantages of artisanal mining sector in Indonesia (“sharks”).

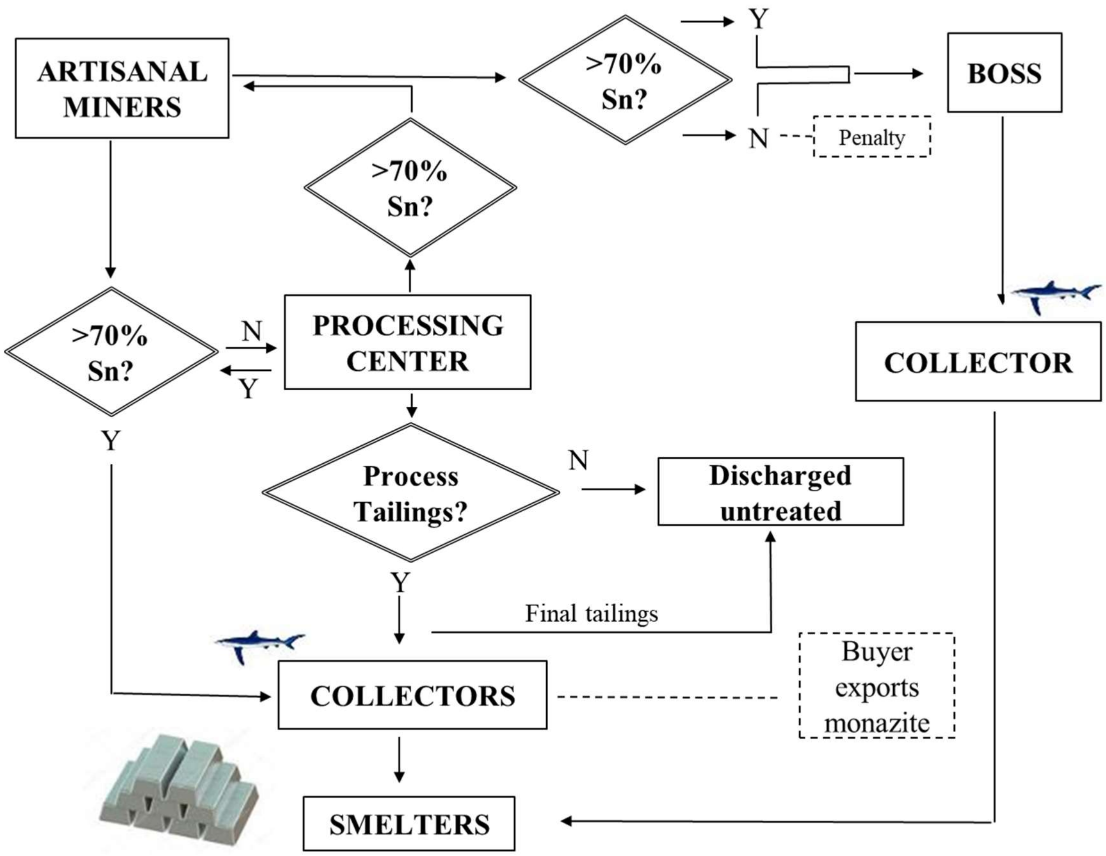

Figure 30. Tin chain: mining to smelting

In Indonesia, mining and processing are based on rudimentary technologies and labour-intensive processes, without the implementation of necessary industry standards, environmental protection and safety procedures. On the other hand, at the other end of the chain, the smelting process is modern and well-structured operation.

4.1.2. Cassiterite Concentrate and its Trade

According to Association of Indonesian Tin Exporters (AETI) (Jabin, 2017 pers. comm.), alluvial tin grades may, on average, vary from 0.2 to 1 kg/m^3 or 0.007 to 0.037% Sn respectively with specific gravity approximately 2.7 t/m^3. This is considered very low grade, since pure cassiterite (SnO_2), has 78.8% of the element Sn.

Typically, a group of local miners produce on average 15 kg of concentrate every two days. On a “good” production day, it is possible to reach about 20 kg (Figure 31). When the concentrate grade is 70% tin or higher, the selling price it is US$ 10/kg, which is measured by density standardized scale. Gross monthly income of an operation is approximately Rp 22,000,000 or US $1,580, according to dollar exchange rates from Reuters (2018). This is normally divided as detailed above, resulting in an individual miner making approximately US $176 per month. In comparison, the minimum wage in Indonesia is US$ 198/month (Indonesia Investments, 2018).

Figure 31. Final sluice box concentrate
ready to be packed after being washed

Although the global tin price has been generally low for the last 18 months or so, holding steadily at approximately to US $21,000/t (London Metal Exchange, 2018), cassiterite mining activities in Bangka and Belitung have been increasing. This is due to the fact that, even though artisanal miners do not earn much money, it is still more profitable than farming, fishing or tourism activities. In addition, they can earn money quickly.

Once the miners have collected the cassiterite concentrate, they take directly to the boss, but can also take it to processing centres to upgrade . Frequently observed along the roads, processing centers are commercial spots with comminution and concentration equipment such as shanking tables, crushers and mills. The processing centers are generally family-structured businesses that charge depending on the type of services offered to the miners. For example, grinding costs approximately US $0.11/kg of material processed while the price doubles per kg if a shaking table is required, which always is the case.

On average, processing centers process approximately 100 kg of ore/day from different miners, making around US $484/month. The tailings are usually then reprocessed by the processing center owners. It is interesting to notice that the poorest part of these tailings (low SnO_2 grade), which are rich in monazite (rare earth phosphate), are either dumped into the rivers or sold to other collectors who sell to Asian buyers, mainly Chinese, buyers who pay US $100/tonne for material rich in rare earth elements (REE) and US $40/tonne for the material with lower grades of REE.

In order to avoid discharge tailings in slurry, dry shaking tables are operated by processing centers located in urban areas. Figure 32 shows a processing center with a dry shaking table in Sukamandi Village.

Figure 32. Processing center with a dry shaking table

4.2. Field Observations

Fieldwork provided interesting observations and results at each of the mining sites visited within the study area as detailed below.

4.2.1. Sukamandi

Sukamandi is one of the most important mining location in Belitung, where approximately 9,000 people depend on artisanal mining operations for their livelihood (Jabin, 2017 pers. comm.). Most of the island's WPRs and IUPs are located in Sukamandi, where WPR is specifically designated for the local artisanal miners to mine legally and IUP is private areas owned by the mining companies.

Mining and processing rudimentary practices are used for all over the mine sites, where sets of pumping and sluice boxes suck and concentrate cassiterite with high safety risks and low mineral recovery. Under wet conditions and working in the slurry, operators wash the material against the mine face, using intuition and practical knowledge, which, together with the wet conditions, leads to an increased risk of slippering and falling rock.

Figure 33 and Figure 34 respectively show artisanal miners working in Sukamandi's WPR and IUP areas, while different types of sluices boxes can be observed in Figure 35.

Figure 33. Artisanal miners extracting cassiterite in a WPR area

Figure 34. Artisanal miners extracting cassiterite in an IUP area.

Figure 35. Different set ups of sluices boxes
used in artisanal mining of cassiterite in Indonesia

4.2.2. Kelapa Kampit

Another important tin mining site is Kelapa Kampit, which has been occurring since 1908, with underground activities starting in 1915. The last owner of the old underground mining site was the Australian company BHP, which carried out open pit and underground operations from 1971 to 1985. The pit in the mountain is 700 m deep and its has become the target of artisanal miners digging rudimentary shafts. In recent years, the provincial government has started a tourism project aimed at highlighting the mining history of the region for both cultural and educational purposes. They have put up informative posters outlining the mining history of the site, as seen in Figure 36.

Figure 36. Sign at Kelapa Kampit outlining the history of the site

Even though the provincial government is involved in this site, illegal underground mining at Kelapa Kampit appears to continue unabated. It was observed that there were more than 20 shafts in primary rock, which likely employ as many as 100 illegal miners underground.

The miners use very rudimentary wooden stakes to both support the walls of the shafts and help the miners climb out of the cave. They follow orebody veins sometimes 50 meters long, with different miners taking turns in the shafts to extract waste rock and ore and bring it to the surface (Figure 37).

In general, it appeared that no safety precautions whatsoever were being taken to protect the lives of the miners from subsidence, tunnel collapse and other risks.

Once extracted, the underground miners take their primary ores to a processing center for manual crushing, where 2-3-inch pieces are fed to rod mills that grind the ore for 15 to 40 minutes, depending on the ore hardness. Typically, the material is reduced to a size less than 0.2 mm before being processed on a wet shaking table (Figure 38).

Figure 37. Illegal underground mining: primary rock extraction following the vein.

Figure 38. Processing center equipped with bar mills and wet shaking table

Tin mining companies at Kelapa Kampit clearly prefer buying concentrate from artisanal miners than mining their own, resulting in little investment to improve operations at mine sites. In order to avoid penalties and confrontation with official government agencies, it appears that many tin producers keep “fake” mining site, where they pretend to be mining. A mining company called MCM was observed In Kelapa Kampit and although we were not allowed to visit their smelting installations, a “fake” mining area was inspected, where no activity appeared to be occurring (Figure 39). Figure 40 shows the MCM smelting facilities and the company employees’ houses.

Figure 39. MCM “fake mining” site

Figure 40. Smelting facilities and employees houses

4.2.3. Mengkubang

Another mining site is Mengkubang, which is a village located in Damar sub-district in Belitung, where PT Timah has been mining a typical alluvial deposit since January 2017, producing 40 - 50 kg/day of cassiterite concentrate using pumps, sluice boxes, pipes and hoses (Figure 41) and sluice boxes working in parallel (Figure 42).

Figure 41. PT Timah operational and safety practices are very similar in both WPR and IUP

Figure 42. PT Timah's mining installations with two sluice boxes working in parallel

The labor force at the mine site is composed of 12 miners who work from Monday to Friday, from 07:30 a.m. to 04:30 p.m., earning an unreported salary. Most of the workers are based in Mangar and daily transportation to and from the mining site is provided by PT Timah, as well as food, drinking water and restrooms.

The concentrate produced at PT Timah's Mengkubang site is taken to the port located in Gantung, and then shipped to Bangka, where smelting facilities have been installed (Figure 43).

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Figure 43. PT Timah's port in Gantung
from where it ships product to Bangka.

Considering PT Timah's tin production level, this mining site could also be a "fake" mining site. The amount of concentrate produced is not enough to supply its smelting facilities located in Bangka, so they need to supplement their own concentrate with concentrate purchased from artisanaql miners.

4.2.4. Gantung – Smelter

Differently to the previous mining sites, Gantung hosts Tommy Utama, a 100% Indonesian-owned mining company, which is another important smelter in Indonesia.

Although Tommy Utama has a mechanized mining operation with trucks and hydraulic excavators, according to the operation manager of the smelter, the company's mining methods are similar to those used in artisanal mining, which implies that miners work in wet conditions, with poor safety, health and environmental management, and have low mineral recovery. Similarly, to PT Timah's Mengkubang site, it was clearly observed that Tommy Utama blatantly promoted the purchase of cassiterite concentrate from artisanal mining operations through IUP and WPR areas to supplement their own ore and concentrate to feed their smelting process.

It has been observed how they are connected and more importantly, how Tommy Utama and other smelters, including PT Timah, operate as "fake" mining companies, since they prioritize purchasing material from the artisanal miners through the collectors, instead of mining their own ore.

Figure 44 illustrates diverse samples of Utama production while Figure 45 shows the site's production flowsheet.

Figure 44. Samples of Tommy Utama Tin production

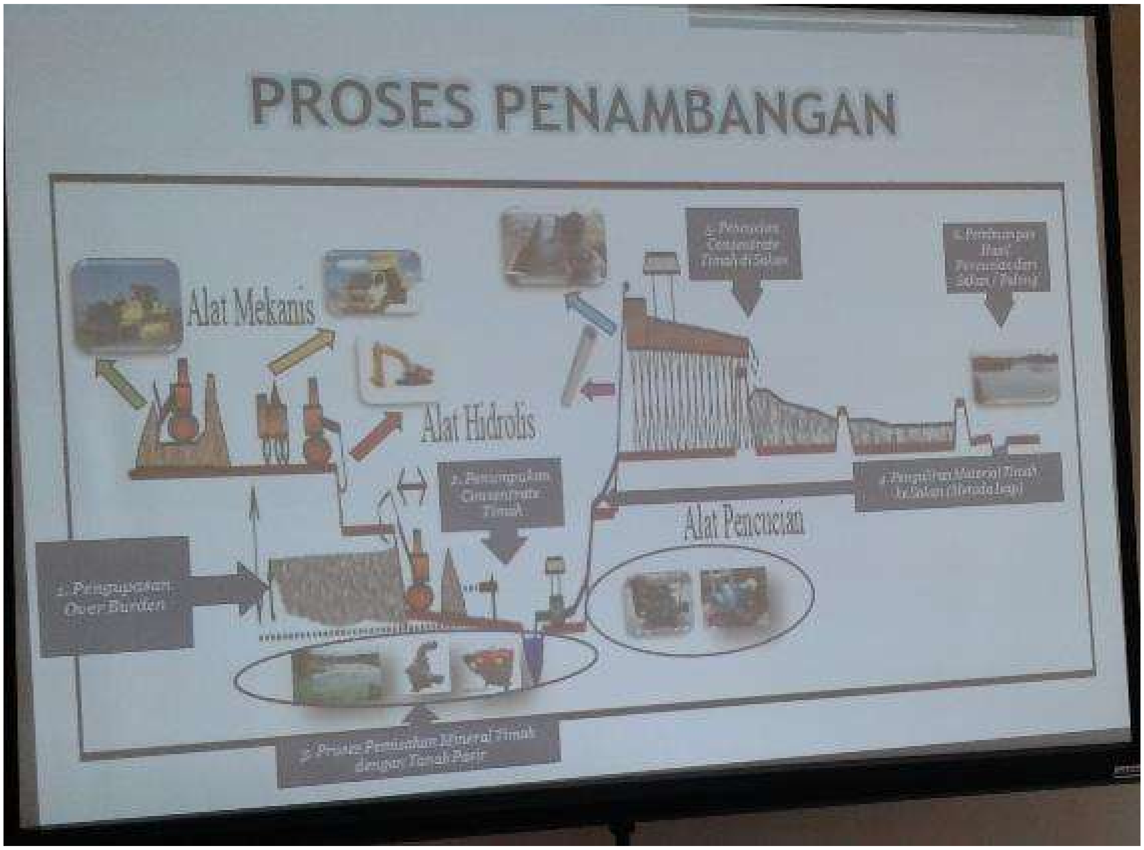

Figure 45. Tommy Utama flowsheet

4.2.5. Tanjungpandan and Mangar – Meetings

In Tanjungpandan, a meeting was arranged with a representative from the Association of Indonesian Miners (APRI). APRI was founded at the beginning of 2017 by artisanal miners, with the purpose of providing support to fellow miners who, clearly, have historically suffered from a lack of organization and partnership. Moreover, there seems to be strong distrust among themselves. Although the association members appear to be motivated, committed and engaged, they still do not have much influence on other miners nor do they have a deep knowledge on how the artisanal mining sector operates in Indonesia.

In Mangar, during a meeting with the president of Belitung Village Association, the president stressed that artisanal mining operations in the area has increased relatively to farming and fishing, as it is a fast way of earning money. Overall, unconventional mining continues to provide a viable livelihood for those who continue to mine.

4.3. Environmental Aspects

The following sections include descriptions of the results regarding environmental aspects, including relevant environmental footprints, tailings discharging, heavy metals, organics and water contamination.

4.3.1. Footprint and Tailings Discharging

The environmental footprint of cassiterite artisanal mining and the environmental impact of discharging to the local rivers as well as the deforestation is impressively high.

Based on Belitung artisanal cassiterite concentrate production of approximately 9,000 tonnes of Sn ingots per year and calculating backwards with mass recovery of 0.004% discharged into the environment can be estimated at over 18 million tonnes per year.

Tailings are discharged through natural drainage downstream, with no dams nor any other controls, from miners as well as from processing centers and mining companies, whose reclamation processes are not normally very robust and encouraged by lack of inspections from regulatory agencies.

An overview of PT Timah’s IUP in the early stages of a reclamation process is highlighted in Figure 46. Figure 47 shows the final tailings from one of the processing centers visited and a PT Timah mining site being discharged to the river.


Figure 46. IUP area undergoing reclamation


Figure 47. Tailings being discharged to the environment.
Left: Tailings from a processing center. Right: Tailings from a PT Timah mine

4.3.2. Heavy Metals and Organics

The impact of and risks associated with pollution caused by heavy metals and organics was also investigated.

Beginning in 2017, PACT, an non-profit international development organization, in collaboration with the University of British Columbia (UBC) conducted a study of many aspects of artisanal cassiterite mining in Bangka and Belitung. Samples were collected and analysed to determine their environmental impact. The results are detailed below:

1) X-ray diffraction (XRD): the PACT (2017) study revealed crystalline minerals in the samples. REE bearing minerals, such as monazite (Ce, La, Nd, Th), and xenotime (YPO_4), were identified as trace minerals by XRD of the samples.

The high grades of Fe in some samples indicate the presence of iron oxide minerals such as amorphous and crystalline hydrous ferric oxides like limonite and goethite (identified by XRD), which have properties to adsorb heavy metals such as As, Cd, Cu, Pb, Th, U, Zn and Rare Earths Elements. Presence of magnetite (Fe_3O_4) was characterized in the field in some iron-rich samples using a hand-held magnet but was not detected in the XRD analyses.

X-Ray Diffraction results are presented in the Table 2.

Table 2. X-ray Diffraction (mineralogy)
(Source: PACT, 2017)

Samples	Minerals	Formula	Amount
Cassiterite Concentrate	cassiterite	SnO_2	Predominant
	quartz	SiO_2	Minor
	hematite	Fe_2O_3	Minor
	goethite	FeooH	Minor
Tailings	quartz	SiO_2	Predominant
Dry Table Tailing	orthoclase	$K(AlSi_3O_8)$	Predominant
	quartz	SiO_2	Predominant
	cassiterite	SnO_2	Minor
	goethite	FeOOH	Minor
	zirconite	$ZrSiO_4$	Minor
	monazite	$(Ce, La, Nd, Th, Y)PO_4$	Trace
	xenotime	YPO_4	Trace
Selected iron oxides	goethite	FeO(OH)	Predominant
	hematite	Fe_2O_3	Predominant
	quartz	SiO_2	Minor
	illite	$K_{0.6\text{-}0.85}Al_2(Si,Al)_4O_{10}(OH)_2$	Minor
	kaolinite	$Al_2Si_2O_5(OH)_4$	Minor
	gibbsite	$Al(OH)_3$	Trace

2) *Toxicity Characteristic Leaching Procedure – TCLP:* TCLP the one of the most important methods for determining hazardous samples. The lower the concentration of the metal in the TCLP solution, the lower the bioavailability should be.

TLCP was used by PACT (2017) on selected solid samples collected in Bangka and Belitung mining sites. Concentrations are expressed in mg/L (or ppm) of the element in the acetic acid solution (Table 3).

Table 3.TLCP results of the elements in solution (mg/L or ppm)

(Source: PACT, 2017)

Element / # of the Samples	51	54	57	71	73	77	78	79	80	85
Arsenic	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.19	<0.02	<0.02
Lead	0.18	<0.02	<0.02	<0.02	0.03	0.03	0.04	<0.02	<0.02	<0.02
Tin	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Titanium	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Copper	<0.02	<0.02	<0.02	0.04	<0.02	0.10	0.29	9.66	0.08	<0.02
Zinc	0.35	0.37	0.42	0.29	0.34	0.29	0.27	0.49	0.36	0.31
Phosphorous	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Note: detection limits = As, Pb, Ti, Cu and Zn is 0.02 mg/L; Sn is 0.2 mg/L and P is 1 mg/L.

As reference, the US Code of Federal Regulations (CFR) outlines the maximum concentration for a TCLP of 40 contaminants (EHSO, 2016). If the element in the TCLP solution is above this maximum concentration, the waste might be considered as having characteristics of hazardous waste.

CFR includes only As and Pb with maximum concentrations in the TCLP solution of 0.5 mg/L for both elements. Neither As nor Pb showed levels above this maximum guideline.

For those elements that are not included in the TCLP guidelines, such as Cu and Zn, the Soluble Threshold Limit Concentration (STLC), which is a leaching test using 0.2 M of sodium nitrate for 48 h, provides results very similar to the TCLP (Labmicro, 2018). Therefore, the concentrations of Cu and Zn for the STLC guidelines are Cu 25 mg/L and Zn 250 mg/L. No sample showed results close to these guidelines, indicating that the possibility of mobility and consequent bioavailability of these metals from the tailings is remote. However, this result is an indirect information on bioavailability and must be handled carefully.

Sample 79, which is a brown-reddish clay with evident presence of hydrous ferric oxides, presented the highest concentration of soluble As of 0.19 mg/L (ppm). The residue of this sample was then analysed and 3,320 ppm of As was identified, indicating that even with this high concentration, the As is not easily soluble (mobile). The arsenic mineral was not identified in the XRD, therefore it is likely that the arsenic is adsorbed on the hydrous ferric oxides, as the XRF analysis indicated high concentration of iron in this sample.

Sample 51 introduced highly soluble Pb in the TCLP test, with a concentration of 0.18 mg/L (ppm) of soluble Pb and residue of 12 ppm Pb. The levels of lead in the samples are quite low and no lead mineral was identified. Similarly, the high levels of iron, around 0.14%, indicated by the XRF analysis, suggest that iron was strongly adsorbing Pb, which does not make it mobile within the acetic acid.

The Indonesian lab could not analyse uranium and thorium using TCLP. However, using phosphorous as a proxy and knowing that these elements would be associated with P in the monazite structure, it is reasonable to suggest that these radioactive elements would not be mobile from the samples and would not be bioavailable. This issue will be discussed further.

From the previous PACT (2017) fieldwork, solid samples were also analysed by X-ray fluorescence (XRF) for a full analysis of the heavy metals and Rare Earth Elements (REE) present. These results are summarised in Table 5.

Table 4. Chemical analyses of heavy metals and REE of 4 samples
(Source: PACT, 2017)

SAMPLE / ELEMENTS	U	Th	Pb	P	Fe	Sn	Ce	Sm	Yb	Nd	Pr	La
	ppm	%	%	%	%	%	%	ppm	ppm	ppm	ppm	%
Cassiterite Concentrate	8.19	0.266	1.115	0.58	6.41	>20	1.1	3.58	2.25	17.2	4.67	0.54
Sluice Box Tailings	33.8	0.025	0.007	0.06	1.42	0.577	0.11	72	36.6	395	116.5	0.05
Dry Tabling Tailings	91.4	0.035	0.012	0.13	16.35	3.29	0.15	115.5	139.5	551	170	0.06
Iron Ore Oxide	-	0.005	0.026	0.11	44.1	0.094	0.01	-	-	-	-	0.01

in blue = Rare Earth Elements

Some observations can be obtained by the combination of the mineralogy by XRD and the chemical analyses by XRF.

1) *Cassiterite Concentrate:*

The high grade of Fe confirms that the concentration process is bringing hematite, goethite and very likely amorphous hydrous ferric oxides (HFOs) to the concentrate.

The grade of P = 0.58% is attributed to the presence of monazite and loparite, which is confirmed by the high grades of La (0.54%) in the monazite and Ce (1.1%) in the loparite. The presence of uranium is low but the concentration of thorium is significant and, together with other heavy REE, justifies the level of radioactivity of this sample (0.0006 mSv/h) analyzed by a Geiger and the (Government of Canada, 2018; Periodic table, 2018), which is 3 times higher than the other samples. The grade of Pb = 1.115% may be related to Th and U decay or it can be adsorbed on the HFOs.

2) *Sluice Box Tailings*

Because this sample was collected close to a sluice box, the grade of Sn is quite high, 0.577%, as a confirmation of the low-recovery rudimentary processes used by the artisanal miners. The presence of P, Ce, La, Sm and other REE again indicates the existence of monazite and small amounts of xenotime indicate by 0.035% of Y. Zirconite is also another possible trace mineral indicate by the grade of 0.542% Zr in this sample.

3) *Dry Table Tailings*

The results of the rudimentary processes applied by the collectors to cleaning the cassiterite concentrate in a dry shaking table are now evident. The tailings have 3.29% Sn (4.18% SnO_2) and this is the main reason why third parties buy these tailings to separate this residual cassiterite in a wet table to sell back to the collectors.

4) *WPR Iron Ore Oxides:*

The grade of Fe = 44.1% confirms the mineralogical analysis performed by XRD, where hematite and goethite were the main iron minerals identified. Amorphous HFO do not diffract x-rays but its presence is very likely. The high grade of As is a confirmation of the adsorption of this and other heavy metals on the ferric oxides. The mobility of the metals once they are adsorbed is not high, but this depends on many factors such as presence of soluble organic matter in the water, or even organic pollutants. It is very interesting to notice how the ferric oxides “clean” the waters by adsorbing heavy metals.

4.3.3. Water Samples

The water samples were analyzed by ICP-OES without filtration. The sample “Ogah camp” refers to the non-drinkable water collected which is provided to the miners for bathing in a mining operation located in Bangka. The sample “Collector” refers to the water used in the processing center in which one collector was processing the cassiterite concentrates, bought from the miners, using a dry table. Because there were no particles in suspension, the water samples were not filtered prior to analysis, which generally increases the measured concentrations of heavy metals.

Arsenic (As)

Although none of the sample presented total As concentrations above the MMER standard of 500 µg/L, the Ogah camp sample had levels above both the Health Canada drinking water guideline (10 µg/L) and the CCME threshold for the Protection of Aquatic Life (5 µg/L). Arsenic is toxic to both plants and animals, although inorganic arsenic species are generally more toxic than organic forms to living organisms, including humans and other animals (Ferrante et al., 2013). A wide range of arsenic toxicity has been determined which depends on speciation, with arsenite (As III), for example, usually being more toxic than arsenate (As V) compounds (Sharma and Sohn, 2009).

Lead (Pb)

None of the water samples presented Pb concentrations above the MMER standard of 200 µg/L, but again, the Ogah sample had levels above both Health Canada and CCME. Although exposure to lead through water is generally low in comparison to exposure through air or food, lead toxicity in solution can be a concern due to the risk of potential bioaccumulation in aquatic biota.

Copper (Cu)

Ogah camp sample exceeded the CCME copper threshold of 3.5 µg/L. According to Agency for Toxic Substances and Disease (ATSDR, 2004), in lakes and rivers, copper concentrations normally range from 0.5 to 1,000 µg/L, with an average concentration of

10 µg/L. Copper usually occurs as a single ion, Cu^{2+}, in solution, but when the water contains organic matter, the organic complex is more stable and less toxic. Single ions of copper are easily strongly adsorbed onto the surface of hydrous ferric oxides (Veiga et al., 1991).

Zinc (Zn)

Although none of the water samples exceeded the Health Canada drinking water guideline for zinc of 5000 µg/L, the highest concentration (4,380 µg/L) in the Collector sample was almost 9 times the MMER mining standard for discharge of effluents (500 µg/L) and 146 times over the CCME threshold for the Protection of Aquatic Life (30 µg/L).

Zinc toxicity has both acute and chronic forms and can lead to reduced immune function in organisms. Zinc in solution, like copper, occurs mainly as simple ions (Zn^{2+}), which are easily transported and adsorbed on hydrous ferric oxides or clay minerals. In the latter, the adsorption is usually weak and reversible when the aquatic conditions change (Livingstone, 2015). Considering that only one tenth of zinc is carried in solution (Tarras-Wahlberg et al., 2001), one would expect to find much lower concentrations in solution in surface waters than in sediment.

Phosphorous (P)

Only the Collector water sample registered a P concentration above the detection limit of 1000 µg/L, showing a phosphorous level of 65,000 µg/L, which indicates high loading, likely due to influx of sewage effluent, as this water was collected beside the camp of one collector's processing centers. There are no guidelines for phosphorous in mining effluents.

Tin (Sn)

Although there are no guidelines for tin levels in superficial waters, it does not appear to be a concern with the results presented, since these concentrations were low for both. It is important to note that tin binds to soils and to sediments in water and is generally regarded as being relatively immobile in the environment (Hosseini et al., 2013).

Table 5 shows the heavy metals concentrations in the water from these two specific places in Bangka and Belitung.

Table 5. Heavy Metals Concentrations in Water Samples
(Source: PACT, 2017)

HEAVY METAL	MMER (μg/L)	Health Canada (μg/L)	CCME (μg/L)	SAMPLES (μg/L)	
				Ogah camp	Collector
As	500	10	5	28	2
Pb	200	10	Equation = ~2.5	17	<5
Cu	300	≤ 1000	Equation = ~3.5	17	<5
Zn	500	≤ 5000	30	70	4,380
P	n/a	n/a	n/a	<1000	65,000
Sn	n/a	n/a	n/a	6	12

Note: threshold guidelines: the MMER (Canadian Metal Mining Effluent Regulations) (Maximum Authorized Monthly Mean Concentration) (2016); the Health Canada Drinking Water Guidelines (2014); and the CCME (Canadian Council of Ministers of the Environment) Freshwater Quality Guidelines for the Protection of Aquatic Life (2006). Samples with concentrations above any of the guidelines are marked in red.

4.3.4. Radioactivity Results

The results of radioactivity analyses of the Indonesian samples conducted in the lab with a Geiger counter provided low results in terms of dose rates. The Canadian guidelines for workers constantly working in radioactive places is 20 mSv/a or 0.0023 mSv/h and incidental exposure of the public is 1 mSv/a or 0.0001 mSv/h. The average annual radiation dose to Canadians from different sources like (inhalation of Radon, cosmic rays, soils, medical diagnosis rays, food sources, etc.) is 2.62 mSv/a (0.0003 mSv/h) (Health Canada, 2013).

These results are consistent with the radioactivity measured in these samples since monazite might be the only radioactive mineral in the materials.

The levels of radiation analyzed in the Indonesian samples (Table 6) are usually below 0.0006 mSv/h which is considered low but there two factors must be considered:

a) The analyses of radioactivity on samples in the lab are usually lower than what is observed in the field. So new in situ analyses must be conducted;

b) According to the UBC Radiation Protection Dept., despite the low radioactivity, the health situation can be harmful for one inhaling material with 0.0005 mSv/h.

Therefore, the risk of inhalation of powder of cassiterite concentrates and tailings from the dry table with monazite and xenotime is the main point to be stressed. Those employees of the collector’s processing centers in urban areas conducting dry concentration of cassiterite in a shaking table are definitely exposed to harmful dust.

Table 6. Radioactivity of four samples from Bangka and Belitung
(Source: PACT, 2017)

SAMPLE	DOSE RATE (mSv/h)
Cassiterite Concentrate	0.0006
Sluice Box Tailings	0.0002
Dry Tabling Tailings	0.0002
Iron Ore Oxide	0.0002

The values measured from the Geiger App installed in the smart phone indicated very low levels, also lower than 0.0006 mSv/h.

4.4. Safety Aspects

Rupprecht (2015) emphasized that safety and health issues in artisanal mining are often neglected by government agencies, private companies and NGOs due to the nature of the business, which is broadly a subsistence occupation and intrinsically associated with poverty. This is also strongly observed in artisanal mining of cassiterite in Indonesia.

Miners operate the hydraulic monitor with no standard procedures, strategies or technical knowledge. They work based on their experience and copying techniques used by their neighbors. They run the monitors very close to the pit walls (less than 2 m), which is a significant safety risk. The walls of alluvial material in WPR and IUP area are very steep and landslides often occur. When a miner was asked why he was not wearing boots, he promptly answered that boots might hinder him when running away from a landslide that may occur.

In theory, in WPR area, safety and health concerns are not as strong as in IUP areas due to lack of inspection, support, infrastructure, procedures or improvements from mining companies. However, as observed in the field, even though IUP is a mining company area and should be under mining company supervision, they barely develop safety recommendations. When representatives of the IUP's owner come, demands are listed, and artisanal miners must implement improvements by themselves with no financial support from the owners. Moreover, mining companies do not provide PPE, safety procedures or training. At the mining site, no one was observed wearing PPE, including goggles, boots, earplugs, respirators, gloves, coveralls or protection against sun.

Infrastructure available in the field is very precarious for human beings and for the equipment as well. The operator who is in charge of unclogging pumps work in wet condition full-time (Figure 48).

Figure 48. Artisanal miner operating in wet conditions

Due to rudimentary work conditions, pumps and accessories are clearly risky for whom needs to operate and maintain the apparatus installed (Figure 49 and Figure 50)

Figure 49. Artisanal miners working hard during corrective maintenance

Figure 50. Pumps and accessories with no isolation

In order to support their team of artisanal miners, which usually number between 3-5 individuals, bosses either own or rent excavators in order to better access the mine-face. The lack of training and knowledge of the mining site, as well as lack of wearing PPEs, creates a risky environment for the operator of the excavator and other miners (Figure 51).

It is interesting to note that a group of miners in WPR area declared: “We do not need any kind of safety improvement. We are very glad and blessed to have this job. Happy enough”.

Even at PT Timah’s mining site, rudimentary conditions were observed, including techniques and equipment similar to those used by artisanal miners. This turns the mining site an operation as risky as an IUP or WPR site. Although PT Timah’s employees wore safety helmets, miners working in wet conditions were clearly observed and evidence of the risk of block sliding, risk of falling and wall collapse were obvious (Figure 52).

Figure 51. Excavator operating under unsafe conditions

Figure 52. PT Timah's mining site
similar to artisanal mining unsafe conditions

The risks of heat stroke and dehydration and poor water, sanitation and hygiene (WASH) practices were the biggest occupational health safety (OHS) risks observed at Belitung. The mining lake is used to pump water into the mine, but also by miners to bathe, urinate, defecate, and at the same time, to cook and wash pots, pans, cooking utensils and plates (Figurer 53).

In addition, there were no reports of problems with drug or alcohol abuse, neither off site nor related to artisanal miners coming to work intoxicated, although smoking cigarettes while mining and on breaks was very common.

Figure 53. Mining lake used by the miners for bathing

Illegal underground artisanal miners use very rudimentary wooden stakes to support the walls and also to climb the cave and leave afterwards (Figure 54). Increased risk of landslide, the risk of falling from upper level, lack of oxygen and ergonomic factors are three of many hazards discovered during this study.

In summary, safety is a very important issue in cassiterite artisanal mining sector, as sixty miners died in Indonesia artisanal cassiterite mining per year, mostly buried in tin alluvial mines or trapped underwater during dredging offshore mining activities.

Figure 54. Underground illegal artisanal mining
using rudimentary wooden stakes to
support the walls and assist climbing

5. Discussion

The results of the main three pillars of this thesis (operational, environmental and safety issues) presented in Chapter 4 will be now be discussed. Pictures, tables and fieldwork observations are used to support the discussions.

5.1. Operational Issues

The details of the operations of the mining sites visited during the fieldwork, as well as the role of each character of the chain of tin, including purchasing and sales of the concentrate, are discussed below.

5.1.1. Mining

In order to optimize costs, increase operational efficiency and develop a safe mining site, knowledge about the nature of the ore body is important to have before any operations can begin. Hustrulid and Kuchta (1998) emphasized that exploration information, which includes the size, composition, shape and grade of a mineral deposit, is vital and necessary to determine the viability of the reserve as a financial asset. These two authors roughly divided mining operations in four stages: prospecting, exploration (where size, shape, position, characteristics and value of the deposit are measured and determined), development stage (where detailed geological information is determined to facilitate planning and design of the mine), and actual mining of the deposit within a planned design.

According to Stocklin-Weinberg et al. (2017), in the case of alluvial mining operations in Babel, none of the above-mentioned steps are followed. Artisanal miners simply follow their instincts when exploring for deposits and implement rudimentary mining practices to obtain the ore. Additionally, Vickers (2013) highlighted the fact that Indonesian artisanal miners have been using the same rudimentary practices for more than 200 years.

It was observed that although the owners of artisanal mining operations (known as “bosses”) are aware of the importance of identifying and evaluating geological information, they will not invest time and money conducting surveys and field assessments. They do not believe it will bring in enough money, compared to what they currently earn, or increase productivity.

From the point of view of big companies, like PT Timah and PT Tommy Utama, which were visited during the fieldwork, they end up prioritizing purchases of cassiterite concentrate from the artisanal miners through the collectors, instead of investing in their own mine site.

Rupprecht (2015) discussed methods of surface mining of artisanal miners and highlights the very popular practice of undercutting steep pit benches aiming to follow mineralized veins in artisanal gold mining, which creates instability and unsafe conditions (Figure 55). Furthermore, as artisanal miners are mainly focused on the richest part of the ore body, they end up prematurely “closing” the mine and losing a decent part of the mineral of interest. The same practice was observed in artisanal mining of cassiterite in Brazil, where most of the cassiterite was left behind due to the restricted shape of the open pit (Figure 56).

Figure 55. Examples of benching in Central Africa
(Source: Rupprecht S M, 2015)

Figure 56. Examples of benching in Brazil

The shape of the mine, including the design of the slopes (bench height and width) is assessed based on diverse techniques including: knowledge of the geology, waste and orebody properties, size of the equipment and others. Bench slope as well as the overall slope are defined by the geo-technical conditions (CSIRO, 2013).

Ricardo and Catalani (1990) emphasized the importance of using mechanized operations over manual efforts. Even though dozers or excavators may increase the initial investment cost, the higher cost of the operation is worth the price, as greater amounts of material may be mined in a shorter time.

Lima (2009) illustrates that for weathered ore, dozers and very rarely explosives were observed in the cassiterite artisanal mining sector in Brazil. Although the concepts of benching in an open pit is not applied to extend the safety or life of the mine, the majority of Brazilian cooperatives mechanized their operations to increase productivity.

In contrast, artisanal miners mining alluvial cassiterite in Indonesia mostly operate hydraulic monitors, with no concerns about sustainability or safety. It was observed that artisanal miners do not use benches, instead excavating the alluvial material with hydraulic monitors or, on occasion, using excavators or bulldozers to better liberate the *in-situ* material (Figure 57).

Figure 57. Excavator rented by boss to support artisanal miners

Stocklin-Weinberg et al. (2017) emphasized the lack of knowledge as an important reason for the use of unprofitable mining techniques in the Indonesian artisanal mining sector. Additionally, lack of technical support that should be provided by the stakeholders, such as the government, private companies and the bosses, is considered another factor in their use of their chosen techniques. It is important to note that when asked to an operator of excavator rented by the boss if he had been trained before, he responded in the negative and added that, within his ten years of experience, he had three tipping accidents in WPR and IPU areas.

In order to implement changes in Indonesian artisanal mining methods, a massive education process is needed, mainly to convince the bosses that new techniques might increase productivity (Stocklin-Weinberg et al., 2017).

While Indonesian artisanal miners operate without a solid knowledge base, using the hydraulic monitors anywhere they "feel" the presence of tin ore (Figure 58), there are two other techniques of mining alluvial cassiterite ore, which could be perfectly applied to Indonesian tin sector:

1) *Sequential basins*: due to scarcity of water to operate hydraulic monitors, some artisanal mining of alluvial cassiterite confine operation into sequential basins

and therefore, reuse the water in the process. Excavators open a basin where artisanal miners operate the hydraulic monitors. Set ups of pumps bring the slurry to the plant upstream. Tailings are discharged in the last cave mined, which is now transformed in tailings dam as well as a source of water process. In summary, this practice potentially increases productivity and poses significant less adverse environmental impacts. However, artisanal miners would still work in wet conditions. Figure 59 illustrates the upstream and downstream basins and highlights tailings disposal and the non-potable water that will be reused in the downstream basin in a typical Brazilian cassiterite mine site.

2) *Load and haulage method feeding a bin*: the haulage material feeds one or more silos, which have pumps in the bottom. The *ROM* (run of mine) is washed by a water driver which is then manually run by an operator and pumped to the beneficiation plant or wash plant to be processed. Additionally, on the top of this silo, hydraulic monitors with some chairs and cover (sun protection) may be installed, ensuring better working conditions to the operators and removing the hazardous wet conditions that currently existing in this sector (Figure 60 and Figure 61).

Figure 58. Indonesia artisanal miners mining tailings

Figure 59. Water reuse, tailings disposal into basins
in a typical alluvial cassiterite mine site

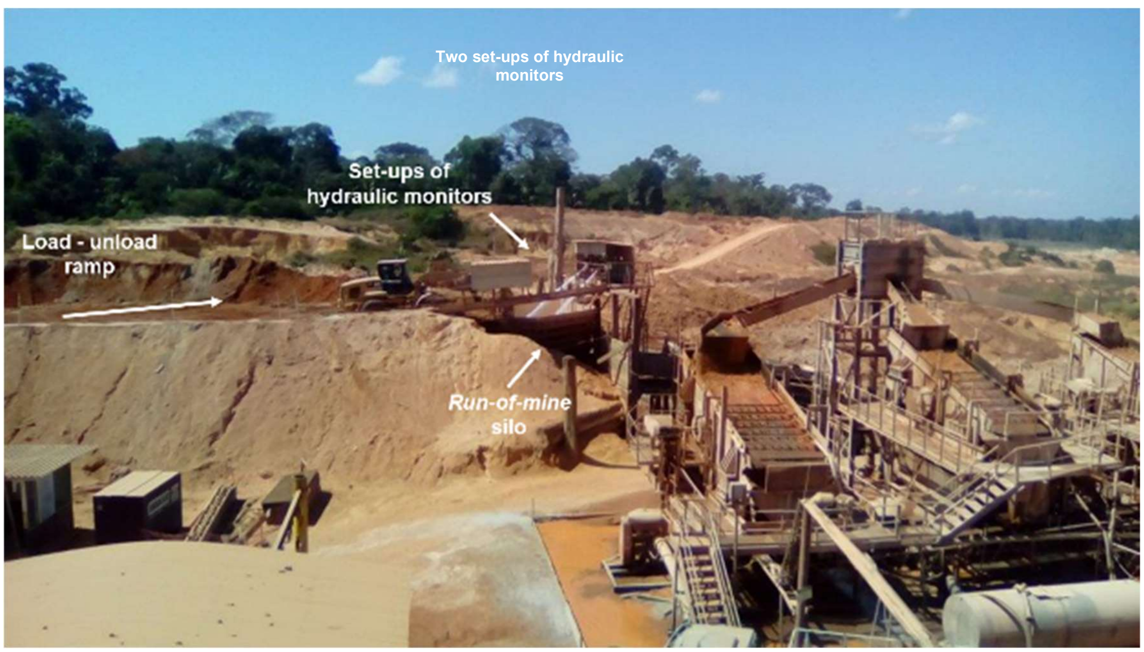

Figure 60. Operation in Brazilian alluvial cassiterite mining site
load ramp, hydraulic monitors and ROM silo installed

Figure 61. Water jet operation

Mining companies commonly operate alluvial cassiterite mines as conventional open pits, consisting of benches and walls, using either equipment and trucks for loading and hauling the material up to the plant or dredging it directly to the wash plant. Frequently, miners run both mine equipment and dredges at the same time.

Stocklin-Weinberg et al. (2017) showed a Brazilian cassiterite mine that use 32° as overall slope angle and 45 ° for each bench (Figure 62). The mine also features internal roads with central barriers and enough room to operate to avoid collisions. Signaling is also a good idea to avoid accidents within the mine. These features would be the “state of art” for artisanal mining in Indonesia. Many other steps must be implemented before achieving this level of organization, including work as cooperatives. However, at the current rate of development, this which seems to be very far off.

Figure 62.Alluvial cassiterite mine in Amazon region
(Source: Stocklin-Weinberg et al., 2017)

5.1.2. Processing

Indonesian artisanal mining sector concentrates its cassiterite using very rudimentary gravity techniques. The most popular one is by using a homemade sluice box, followed by panning, shaking tables, and sometimes, for competent rocks, crushing and grinding, to liberate the ore-mineral particles before exposing the concentrate to a wet or dry shaking table, which is done at the processing centers or by the collectors.

These observations agree with Cardarelli (2018), who states that for colluvial and alluvial tin ore, after pumping the dense gravel, the slurry goes to sluice boxes (denominated *palongs* in eastern Asia). Then, dense cassiterite plus other heavy metals showed up in zirconite, monazite, xenotime or hematite, settle out by gravity, mixed with quartz and other gangues minerals, as kaolinite, goethite or orthoclase.

For the next sections of this chapter, it is important to notice that size distribution is estimated in 50% below 1.5mm (d50 = 1.5 mm). Figure 63 shows a sample of cassiterite concentrate taken from a sluice box.

Figure 63. Sample of final cassiterite concentrate
which is the artisanal miners' final product

5.1.2.1 – Gravity Methods Concepts

According to Wills and Finch (2015), gravity concentration methods essentially segregate the mineral of interest by using the difference in specific gravity and other forces applied within the gravity concentrator.

When immersed in a fluid, particles are influenced by specific gravity, shape and size, where large particles are more affected than smaller ones. In addition, flatter particles tend to float and report to the tailings (Veiga, 2014; Wills and Finch, 2015).

Gupta and Yan (2006) supported this part of the theory, stating that, on average, the efficiency of a gravity concentrator increases with particle size and moreover, rocks must be suitably coarse to move according with Newton's law. Control of the feed size distribution is required to obtain higher efficiency.

5.1.2.2 – Sluice Box

The most popular gravity separation equipment used in artisanal mining in Indonesia, sluice boxes have been used since the 16th century, and are mentioned by Agricola in his famous work *De Re Metallica* (1556). According to Luz et al. (2010), operators mostly run sluice boxes for alluvial deposits of gold and cassiterite. These boxes are commonly made from wood and have barriers (riffles) installed to hold dense particles and release lighter ones. McCarter (1982) pointed out that transverse angle riffles are the most common. The slurry must be periodically cleaned, and the concentrate may need to be recleaned in a second stage. Figure **64** illustrates a right-angle riffle installed (Silva, 1986).

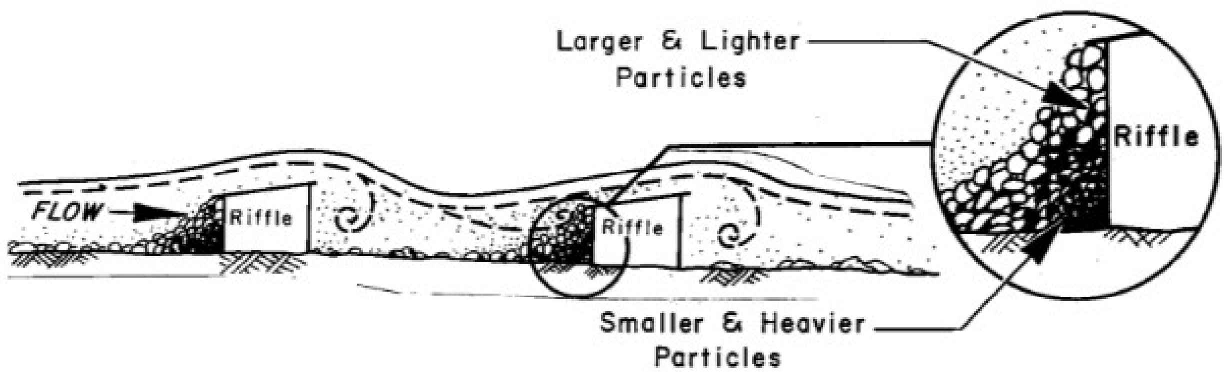

Figure 64.Schematic sluice box with riffles on detail
(Source: Silva, 1986)

Both Veiga et al. (2005) and Veiga and Hinton (2002) detailed that artisanal gold miners use carpet and riffles to trap heavy particles in their sluice boxes. Unlike what Veiga and Hinton (2002) described for gold and as observed in the fieldwork, Indonesia artisanal miners of cassiterite do not use anything to trap the particles (e.g. riffles or carpets) except for a square area installed at the top of the equipment called dump box (Figure 65). The sluice boxes used by Indonesian miners end up working essentially like gutters, with low residence time and culminating in high losses of the fine cassiterite particles.

Figure 65. Rudimentary sluice boxes without riffles
and a dump box located at its head

Pinched sluice boxes change the velocity of the particles along its length and the use of splitters is suggested by Wills and Finch (2015) at the discharge point (Figure 66) as way to collect the particles that were stratified by the descending flow. This may increase mineral recovery and suggests that a next step, such as a cleaner stage with a smaller sluice box, would be required. In contrast, King (1966) pointed out that it is not possible to adjust the sluice's splitter configuration to meet variations in the feed rate, due to difficulties with visual control.

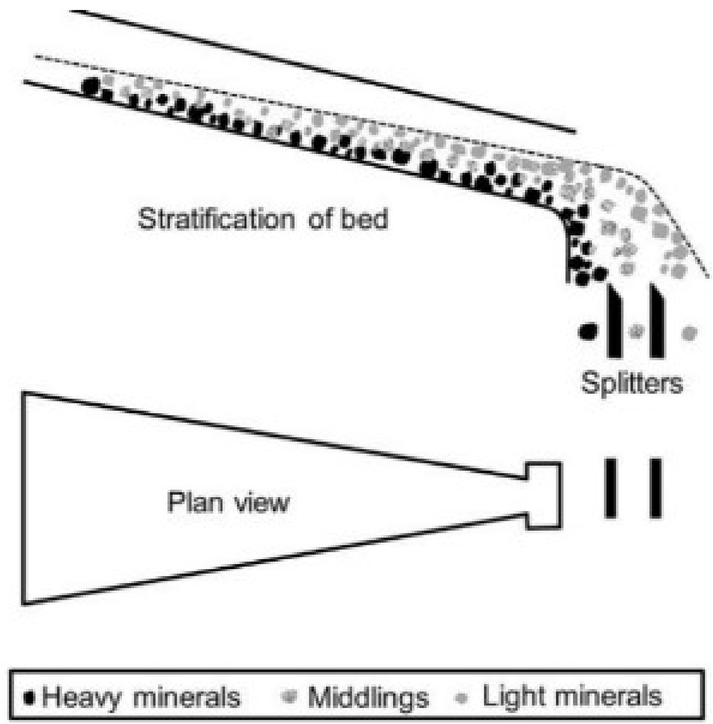

Figure 66. Sluice box with splitters installed
(Source: Wills, 2015)

According to McCarter (1982), studies have been done to determine influence of the shape in gold particles less than 1 mm. Even though this is smaller than the particles in Indonesian artisanal mining cassiterite operations and due to scarcity of literature regarding cassiterite grains, assumptions may be made about sluice box variables using the behaviour of gold particles, which are described below:

1) Shape and weight of the particles: if the particles of interest are coarse and round, concentration is more effective. For grains which are light and flat, the recovery decreases.
2) Specific gravity: sediment transport in water is an intense field of study, where specific gravity is one of the most important variables. The rate of fall of the particles is strongly affected by specific gravity.
3) Velocity of the water: a continuous and slow flow of water may create different layers within diverse particles. Increasing the water speed results in the

appearance of eddies, which produces a turbulent flow, and small particles will be held in suspension. The higher the flow velocity, the bigger the size of the particles that can be held in suspension and may cause losses in mineral recovery, with fines being transported directly into the tailings. On the other hand, lower velocity can not transport large rocks and they would need to be removed by hand afterwards. Additionally, particles should be captured by the grain beds created between riffles – when they do exist – almost in a semi-fluid state. If the water velocity is too low, the grains settled down and become compacted. Then, the particles of interest end up going to the main stream of the sluice boxes and carried out into the tailings.

4) Cleaning: although sluice boxes are robust and presents low mechanical downtime, stoppages are imperative to clean it. The more often the concentrate is removed from the channel, the more efficient the recovery. The way the slurry is scoured is another important variable. Turbulence at the moment of cleaning may result in losses to the tailings.
5) Feed rate, pulp density and instability in the feed rate (Sivamohan and Forssberg, 1985).

Recommendations for Indonesian artisanal cassiterite miners:

1) Riffles: although the creation of turbulence hinders fines to be captured, most of the authors and papers consulted referred to the riffles as an important feature of a sluice box that aids recovery. In order to install these barriers and increase mineral recovery, very simple modifications are required on the Indonesian sluice boxes.
2) Splitters: pinched sluice boxes with splitters installed is recommended. A minimum change in the current equipment is required. In addition, sumps should be implemented downstream to collect heavy and middlings.
3) Rougher, cleaner and scavenger stages: in order to increase mineral recovery, an improvement in the processing is imperative. Installation of zig-zag sluice boxes with rougher, cleaner and scavenger concepts are strongly recommended

for the Indonesian cassiterite artisanal mining sector. Bosses (in WPR or IUP areas) and mining companies (in IUP areas) are encouraged to invest in setting up different size sluice boxes or even shaking tables, after first sluicing stage. The discharge of the first stage of sluicing, also known as rougher, would feed the cleaner, which is considered the second stage and where the concentrate is produced. Tailings from the cleaner stage would feed the scavenger, where final tailings would be discharged to tailings dam. Product of this third stage will return to the rougher stage.

5.1.2.3 – Jig

According to Abols and Grady (2006), gravity concentration using a jig concentrator has been used in conventional mining for more than 100 years. Stratification is created by pulsating a fluid up through the bed particles. This repetition of motion allows particles to repeatedly mix and consolidate, influenced by gravity, and then concentrating the heavier particle of interest (Gupta and Yan, 2006). The pulsation is caused by a piston that pumps the fluid, usually water. This creates a flow that propels the lighter particles upwards, fluidizing the particles. Then, heavy particles sink to a layer of grinding media, normally steel-casted balls, known as ragging. The ragging screen is responsible for classifying the heavy and light particles, where heavy particles pass through it, sinking and being transferred to the bottom of the jig. The lighter fines particles report to the overflow, where the tailings are discharged.

Wills and Finch (2015) said that better performance of jigs may be achieved from coarse material (e.g. 3 – 10mm) and greater specific gravity (SG) range in minerals presented in the feed (e.g. fluorite 3.2, from quartz 2.7). Priester et al. (1993) showed that jigs have been used by artisanal miners in a manual system to create pulsating effect on a bed of minerals to concentrate gold specks at the bottom of the jig, being very sensitive to the size ranges of the particles and usually are effective to separate particles of gold coarser than 100 Mesh (0.15 mm). The range defined by Priester et al. (1993) is significantly lower than Wills and Finch (2015).

Presence of fine sand and slime may hinder good classification; therefore, fines and slime content should be controlled in a jig circuit to create optimum bed conditions (Wills and Finch, 2015). Fines can interfere in the gravity separation, particularly for slime content.

If the range of grain size is narrow, finer grain sizes can be separated. Jigs accept large amounts of ore and can process up to 1,000 tonnes or ore/h (Wills and Finch, 2015). Pulp density is usually 10–30% solids.

A jig 8 x12 feet with capacity of processing rate of 70,000 kg/h and a motor with 40 HP costs between US $4,000 to 5,000. It can be provided by a solar panel with a cost of US $2,000 in average, in developing countries, which, ultimately, may be not affordable.

As an ideal alternative to Indonesian artisanal mining sector, local industry could manufacture small jigs 4 x 6 feet with capacity of processing rate of 30,000 kg/h with 10 to 30% of solids and a motor with 25 HP which ultimately would cost approximately US $2,000.

The main problems with jigs are:

- They need large amounts of water.
- Power supply
- They are not good for fine particles.
- Flattened particles may be floated and be lost with light particles.
- Operation requires skill from the operators.

A cross section of typical jig is shown in the Figure 67.

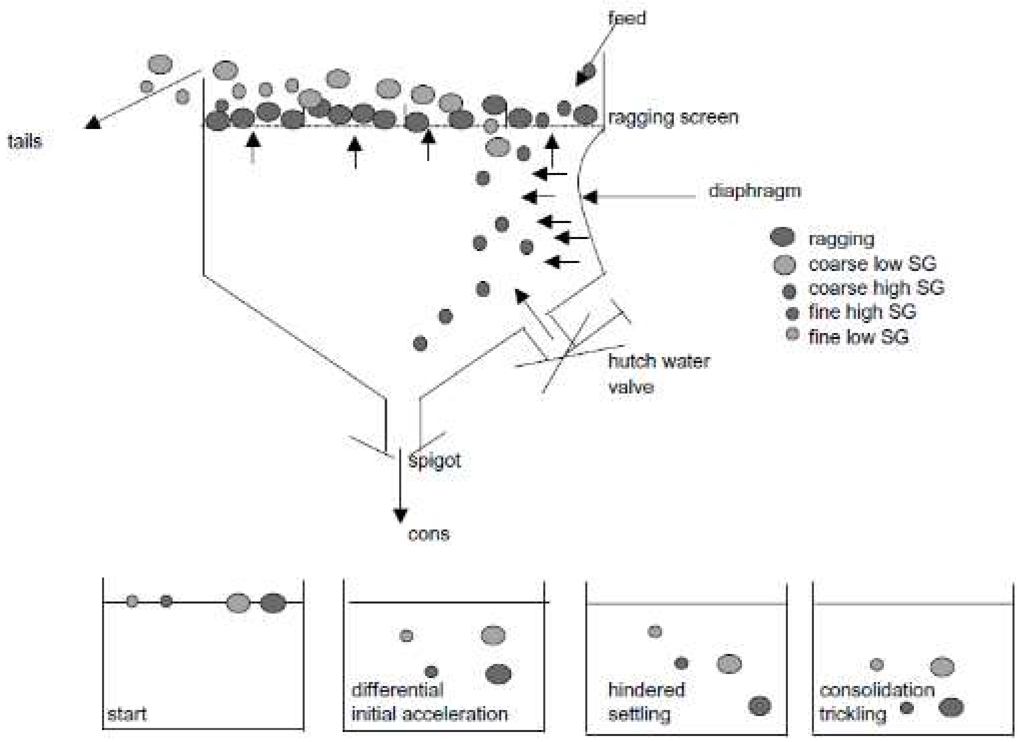

Figure 67. Cross section of a typical jig
(Source: Falconer, 2003)

Recommendations:

Due to power supply and other problems related to the operation of jigs, they are not recommended to the Indonesian cassiterite artisanal mining sector. Besides, artisanal miners operate mostly in fines, mainly because they run old tailings deposits, which implies a fine size distribution. According to Wills and Finch (2015), jigs required a coarse size distribution (e.g. 3 to 10 mm), which makes the use of jigs inappropriate for artisanal cassiterite mining.

5.1.2.3 – Spiral Concentrator

Spiral concentrators can be applied to concentrate a variety of mineral of interest including ilmenite, rutile, zircon, monazite and have recently been used to recover fines of coal (Wills and Finch, 2015), as well as cassiterite.

Spirals should not be mistaken for a spiral classifier, which classifies particles by different of sizes, while the spiral separation mechanism consists of using gravity to differentiate particles by their densities. Supported by a central column, a spiral concentrator consists of one or more helical profiled troughs where the material is fed from the top to bottom and the slurry is stratified by differences in density (Metso Minerals, 2015).

Sivamohan and Forssberg (1985) noted that for plants with low capacities, spiral concentrators may operate efficiently and with low capital cost. On the other hand, they pointed out the pumping system with distributors and other accessories as being quite complicated for artisanal miners, who are not provided with a maintenance structure, any spares parts or technical knowledge, hindering the use of spiral concentrators. Although spirals may achieve a greater concentration of the mineral of interest due to the possibility of visually adjusting the splitters, fewer light heavies are captured, decreasing recovery. King (1966) mentioned that there is a trend towards replacing spirals with sluicing to recover those light heavies. Because of these characteristics, spirals have mostly been used for recleaning.

As an alternative to Indonesian artisanal mining sector, one single line of 3 to 5 units of 40 HP pumps, pumping the slurry to 8 to 4” hydrocyclones and spirals could be installed. The total cost of installation would be approximately US $25,000.

The main problems with spirals concentrators are:

- Capital cost of pumping and distribution system
- Operational cost, maintenance, spare parts and technical knowledge to deal with the accessories required
- High maintenance demand, mainly for the peripheral equipment, such as pumps, valves and hoses
- Training, skills plus discipline to regulate the circuit, when required

A range of accessories such as hoses, distributors and sumps can be observed in Figure 68, which depicts a low capacity plant operating with spirals in Brazil.

Figure 68. Spiral Concentrators
installed in Brazilian mine site

Recommendations:

Even though the high capital cost and the complexity of peripheral equipment to operate and maintain, Indonesian cassiterite artisanal miners are encouraged to install spirals. Besides, the sector basically operates with fines associated with former tailings areas, which implies spirals should be reliable to upgrade mineral recovery.

5.1.2.4 – Centrifuges

Centrifugal separators or simply centrifuges are designed to increase the settling rate of heavies contained within fine particles based on centrifugal acceleration instead of gravitational force (Gupta and Yan, 2006).

The centrifuge's mechanism is explained by Veiga et al. (2006) and Honaker (1998), who agreed with Gupta and Yan (2006), explained the system of trapping the heavy particles. This system consists of a vertical rotation bowl with a series of concentric rings. They emphasized that a centrifugal force, which is higher than the gravitational force (G), is internally applied on the slurry ore particles. This force may be 60, in the case of a Knelson concentrator, to 300 times higher than G, in the case of a Falcon concentrator.

The slurry is fed through the concentrating cone through a stationary tube, which is then driven outward to the cone wall by the centrifugal acceleration. Heavier particles within slurry stream migrate to the cone wall, filling each ring in the spinning chamber, creating the concentrating bed, which is transferred to the bottom through a controlled valve. The lighter particles or tailings products tend to move to the top of the slurry with the water (Falconer, 2003; Veiga et al., 2006).

Gupta and Yan (2006) highlighted the pioneering Knelson Concentrator which was applied for the first time to separate gold around 1980, and currently is also applied for other heavy mineral recovery in many different mine sites. Knelson (1992) supports Gupta and Yan (2006) and noticed that both the Knelson and Falcon concentrators are the most globally used centrifugal concentrators, which is agreed by Abols and Grady (2006).

Falconer (2003) listed the advantages and disadvantages of centrifugal concentration, as described below:

Advantages:

- Able to treat particles in size down to 15 – 20 microns
- Relatively simple mechanically and robust
- High level of upgrading
- Relatively high capacity
- Relatively low operator attention

Disadvantages

- Needs clean water
- Power supply
- Not simple to operate
- Susceptible to clay minerals interference
- Narrow size fractions are better to prevent blinding*

* Note: in order to classify, disaggregate clay particles, as well as clean (organic matter) cassiterite alluvial ore that comes from the mining (ROM), Brazilian cassiterite artisanal mining sector operates with a trommel as the first equipment of the processing plant (Figure 69).

Figure 69. Trommel used in Brazilian artisanal mining local-manufactured

Due to scarcity of literature regarding the use of centrifugal separators to concentrate cassiterite and given artisanal cassiterite mining's similarity to artisanal gold mining, it is reasonable to apply conclusions drawn from studies of artisanal gold mining to the artisanal cassiterite mining industry. According to Veiga et al. (2006), a variety of other types of centrifuges, especially those that are cheaper, simpler, and made of rubber, operate at different artisanal gold mining sites around the world (Figure 70). Those machines can work for 8 hours with nominal capacity of 24 tonnes/h of feed rate gold ore.

Figure 70. Centrifuges operating in artisanal mining
operations in Brazil (left) and Zimbabwe (right) (Source: Veiga et al., 2006)

As an example, the main specifications of centrifuges used by artisanal miners in Zimbabwe are:

- Diameter of the bowl: 0.78 m
- Operation: unfluidized centrifuge, ribbed cone
- Cone Material: butyl rubber
- Operating Speed: 102 rpm
- Feed Capacity: up to 3 tonnes/h in slurry at 30% solids
- Feed Size: -4mm max
- Shipping Weight: 130kg
- Extent of Mechanization: partially mechanized; batch discharge of concentrates
- Mode of Operation: batch; discharging from bottom
- Drive Bevel gear and V-Belt
- Installed Power: 0.7 kW
- Price: approximately US$ 2,000

It is interesting to notice that Falcon Concentrators, the company that produces the eponymous machine, has developed a small centrifuge called the “Icon” that is aimed at artisanal miners. The Icon operates using the same principles of concentration as the big centrifuges. Working in batches, the price of one Icon is around US $5,000 and the feed throughput capacity is 1 to 2 tonnes/h (*Icon 150*). The maximum slurry load size is

2 mm, with 30% solids. The production capacity is 3 to 6 kg of concentrate of gold per hour, depending how often the concentrate is discharged. In field tests the concentrate was discharged every 20 min. The Icon operates with an electric motor of 2 HP. This centrifuge uses 30 L water/min and the speed is controllable generating G from 60 to 180 (1100 rpm). As an option for a greater capacity, Icon 350 is also an interesting alternative.

Recommendations:

Processing centers are encouraged to install centrifuges to increase mineral recovery. In order to recover heavy from fines, they should be installed as primary concentration, after milling plus screening (trommel).

5.1.2.5 – Shaking Table

Falconer (2003) listed shaking tables as another type of gravity separation equipment that has been used for many decades with minimal changes. Over the years, design changes have consisted of adding a multi-deck to the table and restricted it to three levels. In addition, the capacity of a shaking table is relative to the extent of floor area.

Abols and Grady (2006) and Falconer (2003) stated that due to their low capacities, which is less than 2 tonnes/h, shaking tables are ideally used as cleaners downstream, after centrifugal concentrators, jigs or spirals. In contrast, Wills and Finch (2015) argued that shaking tables were not restricted to cleaning stages, and mentioned that shaking tables were used primarily for the concentration of minerals of tin, iron, tungsten, tantalum, mica, barium, titanium, zirconium. They were not as common in gold, silver, thorium, uranium, and others. Additionally, Wills and Finch (2015) authors pointed out that shaking tables are now being used in e-waste recycling, which is electronic scrap recycling to recover precious metals.

According to Abols and Grady (2006), for both conventional or artisanal mining sector, the use of shaking tables can achieve high gold recoveries. However, this process is affected by operator skill, ore mineralogy, table set-up and degree of liberation. In addition to this, he suggested that the angle of inclination of the table surface, length and frequency of table stoke, as well as splitter position can all be adjusted to improve concentrate yield.

The slurry is fed at the top corner of the equipment and layers are created according to particle density and size. This segregation process results from the motion of the table, which is asymmetrical, being slow in the forward direction and rapid in the reverse direction (Gupta and Yan, 2006). Riffles are responsible for providing retention time, and then fine heavies are concentrated to the uppermost side of the table and lower density, coarse material reports to the lower part of the table, being discharged as tailings (Lopes, 2013).

Gupta and Yan (2006) and Wills and Finch (2015) agreed that the middling stream, which is also produced, can be recycled back to the grinding circuit for further liberation (Figure 71).

Figure 71. A typical shaking table producing cassiterite concentrate in Brazil

Normally, table decks are made of wood and lined with rubber or plastics. Gupta and Yan (2006) noted that modern tables use either rubber riffles fixed to a rubber covered deck or the entire deck is molded with fiberglass. Wills and Finch (2015) highlighted that although decks made from fibreglass are more expensive, they have a longer life-time.

As suggestion, a cost-benefit analysis should be performed in order to decide between a fibreglass or a wooden table.

According to Wills and Finch (2015), feed particles and concentration criteria are important variables to define the capacity of a table, which can be designed to process up to 2 tonnes/h of 1.5 mm sand material. In terms of fine sands, this capacity drops to 1 ton/h. The author of this thesis agrees with this statement and considers this specification suitable for artisanal mining sector.

Falconer (2003) mentioned feed rate and feed percentage of solids (by weight) as relevant variables, which were supported by Wills and Finch (2015) and Gupta and Yan (2006). However, in terms of percentage of solids, Falconer (2003) suggested the slurry of a typical shaking table should consist of 40% solids (by weight). This was contradicted by the other others, who stated that a shaking table could operate effectively with a slurry with 25% solids (by weight). This last proposition is supported by the author of this thesis.

It is very common artisanal gold mining sector operates with maximum 2,000 kg per hour of feed rate to upgrade existing concentrates.

The effect of variables on shaking table performance is described in Table 7.

Table 7. Effects of variables on table performance
(Source: Gupta and Yan, 2006)

Variable	value	Effect
Deck shape	diagonal	increased capacity increased grade lower middling flow finer size separation
Riffling	partial deck	cleaning duty treats unsized feed
	full deck	roughing duty treats sized feed
Feed rate	2 t/h 0.5 t/h 15 t/h	for 1.5 mm sand for -150 µm slimes for up to 15 mm coal

Falconer (2003) listed the advantages and disadvantages of a shaking table, as described below:

Advantages:

- Possibility of achieving high selectivity with high upgrading ratio, if operated in a correct way
- Visual adjustable

Disadvantages

- Low capacity and large floor area is required to increase capacity
- Not efficient for primary concentration
- Requires skills, discipline and technical knowledge to inspect and adjust often
- Feed should be sized

Recommendations:

Indonesia cassiterite artisanal mining sector currently runs shaking tables to upgrade the concentrate from sluice boxes, in case of secondary deposits. In the processing centers, in the case of hard rocks, shaking tables are fed with the product of grinding (bar milling) with no screening before it. In order to increase mineral recovery, improvements are imperative; processing centers are encouraged to keep operating shaking tables, ideally after screening with a trommel and running the concentrate through centrifuges, before using a shaking table.

In order to avoid contamination by inhaling material, the use of dry shaking table is strongly non-recommended and has to be extinguished.

5.1.2.6 – Flotation

Gupta and Yan (2006) stated that flotation started commercially in 1905, when complex, small and low-grade ores required specific methods to be concentrated. Wills and Finch (2015) agreed with these two authors and noticed that flotation is the most flexible processing method and it is currently undergoing expansion within mining industry.

Angadi et al. (2015) defined flotation as being a separation and concentration method which is based on physico-chemical particles properties, where many factors play a relevant role in this process, such as (a) electro-chemical, solubility and other physical properties of the mineral surfaces, (b) the physico-chemical characteristics of the slurry, such as pH, dissolved ions, bubbles and percentage of solids and hydrodynamic factors, and (c) physical and electro-chemical properties of reagents such as collectors, frothers and depressors.

Supporting Angadi et al. (2015), Gupta and Yan (2006) stated the concept of hydrophilicity (affinity for water) and hydrophobicity (repelled from water), as well as equilibrium established between three phases, solid, liquid and water, as important flotation variables (Figure 72). When the concentration of any chemical reagent is higher at the surface of a liquid or solid phase than it is in the bulk, this liquid or solid is referred as adsorbed by this reagent. Therefore, adsorption of reagents onto the mineral surface is very relevant and must be achieved selectively. Only the mineral of interest surface becomes hydrophobic, while the rest of minerals surfaces turn into hydrophilic (Bulatovic, 2007).

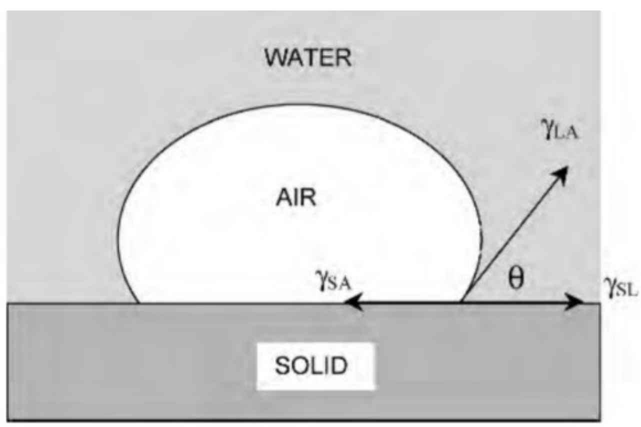

Figure 72. Three phase contacts between solid, liquid and air (Source: Gupta and Yan, 2006)

According to Wills and Finch (2015), the first cassiterite flotation process on an industrial scale ran in 1938. Flotation was developed primarily to process sulphides of copper, lead, and zinc, and was later expanded to gold, platinum, nickel, hematite, cassiterite, malachite, phosphates, and others. Ultimately, it has proven very important to recover fines of coal.

The more depleted of high grade and coarse grains a deposit is, the lower the capability of gravity methods to obtain cassiterite concentrate and the higher the demand for flotation.

Lepetic (1980) considered gravity separation methods inefficient on grains less than 50 microns and had no reasonable final results on grains below about 20 microns. Kuys (1986) agreed with Lepetic (1980) and argued that cassiterite grains below 20 to 40 microns are considered non-recoverable by gravity concentrators. Since tin ores deposits have a variety of other minerals in fine portions, this process may not be economically viable.

Conversely, Michaud (2015) considers a range of 2 to 100 microns as the best size distribution for cassiterite flotation. He mentioned that top size depends on the liberation degree of the metal and particles coarser than 100 microns are difficult to float, while grains less than 2 microns are difficult to float due to selectivity.

According to Senior et al. (1989), a typical range of pH 4-6 may be considered a typical range to float cassiterite. Ives (1984) is more conservative and claims that it is important to keep pH at lower level, such as 4.5.

Carboxylic acids derivatives (e.g. oleic acid tall oil), sulfosuccinamates, phosphonic acid derivates (e.g. styrene) and arsenic acid derivatives are the most commons collectors for SnO_2 flotation (Michaud, 2015). It is known that sodium silicates, sodium fluoride and sodium silico fluoride are the most commonly depressants and dispersants. In several plants, sulfuric acid plays a dual-role as a pH regulator and a depressor for silicate minerals (Wills and Finch, 2015). Lepetic (1980) observed that frothers such as methyl isobutyl carbinol (MIBC), Dowfroth 250, or Aerofroth 250 are industrially used to float cassiterite.

Kuys (1986) listed the advantages and disadvantages, as described below:

Advantages:

- Good recovery of cassiterite within medium grade range particles
- Circuit is easier to control than gravity separators

- Higher throughput than gravity devices
- Low maintenance and labour costs
- High recovery in the rougher process (>90% Sn)
- Wide range of reagents can be used

Disadvantages

- Size range limited to 2-20 microns into final concentrates
- Grade of cassiterite concentrate rarely exceed 25% Sn and magnetic devices or leaching is needed to upgrade it
- Strongly affected by slimes, which consume reagents and downgrade the concentrate
- Rigid desliming process is required
- Prior removal of sulphides is always required before floating oxides
- Due to reagents costs, flotation faces higher operation costs than gravity
- Recovery dramatically decrease during cleaning stage
- Soluble ions in slurry (e.g. Fe^{+3}, Ca^{+}, Cu^{+}) can create further problems

Wills and Finch (2015) agreed with many disadvantages described by Kuys (1986) when they mentioned that a variety of companies are currently considering using a gravity-based system due to the high costs of flotation reagents. The simplicity of gravity processes plus lower capital and operational costs inspire company to invest in gravity process expansion.

Recommendations:

Although Veiga (2014) stated that small-scale flotation increases in many artisanal gold mine sites, such as in Brazil, Chile and Ecuador, cassiterite flotation is not considered a reality for Indonesian artisanal mining sector of tin ore. The complexity of the process and elevated costs that are associated with lack of organization, formalization, financial and technical resources, turns flotation into an inefficient alternative to concentrate fines of cassiterite.

<u>5.1.2.7 – Concentration Devices versus Particle Size Range</u>

Concentration properties connected to particle size handling are different for each type of equipment considered above. Angadi et al. (2015) summarized the working size for each device discussed (Figure 73).

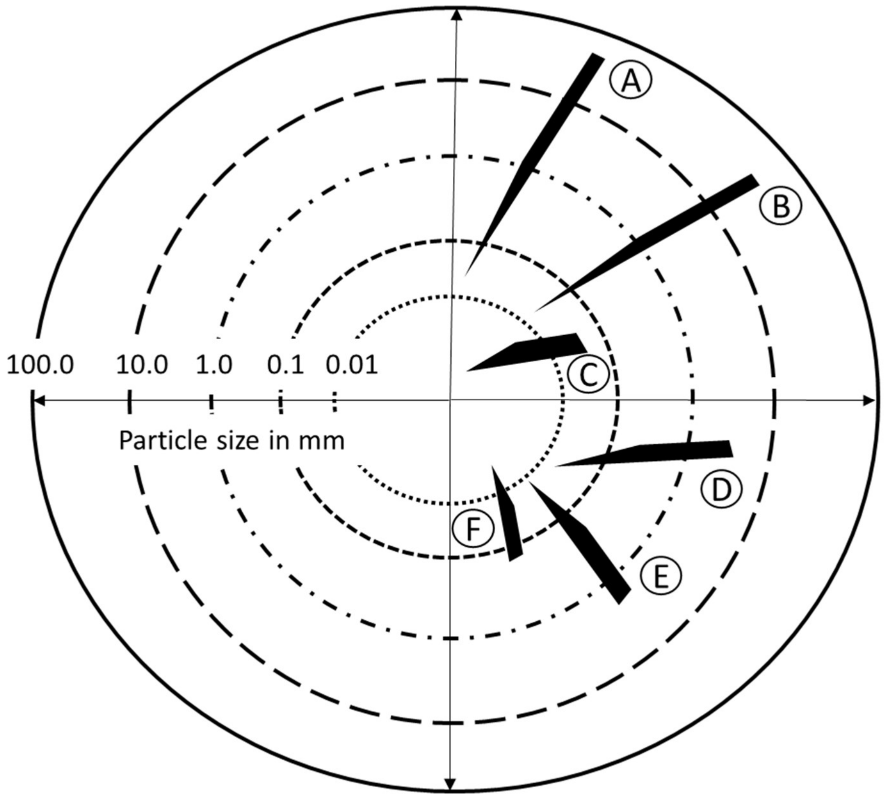

Figure 73. Concentration Device x Particle Size
A = Jig, B = Sluice, C = Centrifuges, D = Spiral, E = Shaking table, F = Flotation
(Source: Angadi et al., 2015)

5.1.3. Estimated Recovery

Low recovery is one of the most significant characteristics of artisanal mining of cassiterite in Indonesia. This section aims to estimate both the mass and metallurgical recovery of alluvial mining, which is the majority of cassiterite artisanal mine sites in Indonesia. Improvements are suggested.

<u>Calculations and Assumptions</u>:

During the fieldwork stage of this thesis, it was observed that a group of artisanal miners produce on average 15 kg of concentrate every two days when they discharge and clean the sluice box. Work hours may be assumed being 10 hours per day, as they operate only during sunlight.

Due to scarcity of literature in case of artisanal mining of cassiterite, it is reasonable to compare it with the artisanal gold mining sector. According to Veiga (2018), 10 to 20% slurry density (or percentage of solids in the slurry) is mostly used by artisanal miners through gravity concentrators. In order for the particles of gold to become trapped in the gravity equipment (e.g. sluice box), Veiga (2018) noticed that the thickness of the flow cannot be higher than 3 cm, which is enough to allow the gold particle to sink in the flow. He illustrated how to assess the pulp density of a sluice box through a top-cut 2-liter plastic bottle if a scale is available in the field to take measurements (Figure 74).

Figure 74. Method to calculate the pulp density of the pulp flow in a sluice box
(Source: Veiga 2018)

In this method, a regular, clear plastic bottle is used to collect the slurry at the discharge of the sluice box. The bottle is completely filled with the slurry. Ten marks are made along the bottle at equal intervals, indicating percent of the volume of the bottle. The bottle and slurry is then left to settle. After a certain time, a reading of the percentage of volume of solids settled in the bottle is taken, according to the numbers of bottle marks. The second step is to covert the % volume of solids into % mass of solids.

Three formulas are applied to achieve % mass of solids:

$$(1) \quad \%Mass_{solids} = \frac{mass_{solids}}{mass_{solids} + mass_{water}} * 100$$

$$(2) \quad density_{solids} = \frac{mass_{solids}}{volume_{solids}}$$

Then, combining equation (1) and (2):

$$\%Solids = \frac{(density_{solids} * volume_{solids})}{(density_{solids} * volume_{solids}) + (density_{water} * volume_{water})} \times 100$$

N.B.: the density of the solids may be assumed to be 2.7, which is the specific gravity of silicates. The density of water can be assumed to be 1.

A typical artisanal pump has 27 Hp, 2,200 rpm of speed and weighs 220 kg each (Figure 75) Figure 75. Typical artisanal mining pump

. A simulator was used to obtain the amount of material fed into the sluice box, which is around 20 t/h (Table 8).

Figure 75. Typical artisanal mining pump

Table 8. Sluice box feed flowrate pumped by 27Hp of power

SLURRY PUMPING CALCULATION						
Ds=	Specific Gravity	(t/m^3)	Dsu=	Pipe suction diameter	(Pol)	
n =	Eficiency	(t/h)	C=	Pipe coeficient		(mm)
Cw=	% sol weight	(%)	K=	Experimental coeficient		
Dt=	Discharging pipe diameter	(m)	Ps=	Discharging pressure at the end	(Bar)	(m/s)
D50=	Particle size (average)	(mm)	L=	Pipe length	(m)	(m/s)
Fl=	Friction Factor		Le=	Equivalent pipe length	(m)	(m)

INPUTS AND OUTPUTS												
Ds=	2.70	(t/m^3)				Dsu=	0.152	(m)				
Ms=	19.94	(t/h)				C=	140.00			Zs=	0.50	(m)
Cw=	23.00	(%)				K=	1.00			H_0=	4.00	(m)
Dt=	0.102	(m)	DN=	4.0	(pol) s/revs	Ps=	2.00	(kg/cm^2)	1.9718			
D_{50}=	1.50	(mm)				L=	200.00	(m)				
Fl=	1.272					Le=	10.00	(m)		Power	27.00	Hp

According to Association of Indonesian Tin Exporters (AETI) (Jabin, 2017 pers. comm.), the alluvial ore in Bangka has grades ranging from 0.2 to 1 kg/m^3 or 0.0074 to 0.037% Sn respectively. Therefore, an average value was considered: 0.022%

The assumptions are briefly described below:

(a) $Cassiterite\ Concentrate\ Production$: $15 kg\ every\ 2\ days$
(b) $Work\ hours$: $10\ \ h/day\ (sunlight)$
(c) $Sluice\ box\ feed\ flowrate$: $20{,}000\ kg/h$
(d) $Content\ of\ Sn\ in\ the\ cassiterite\ concentrate$: 70%
(e) $Sn\ production$: $10.5\ kg\ every\ 2\ days\quad [a \times d]$
(f) $Ore\ grade$: $0.022\%\ of\ Sn$

Mass and Metallurgical Recovery are then calculated based on the formulas below:

$$(g)\quad \%\ Mass\ Recovery\ per\ Day = \frac{Concentrate\ mass\ (kg)}{Feed\ mass\ per\ day (kg)} \times 100$$

$$(g)\quad \%\ Mass\ Recovery\ per\ Day = \frac{a}{b \times 2c} \times 100$$

$$Metallurgical\ Recover\ (\%) = \%\ Mass\ Recovery\ \times \frac{\%Sn\ in\ concentrate}{\%Sn\ in\ feed}$$

$$\%\ Metallurgical\ Recover = g \times \frac{d}{f}$$

The results of the calculations are described below:

Metallurgical Recovery = 12.0% and Mass Recovery = 0.004%

<u>Further Comments</u>:

A very low mass recovery had been expected, but the metallurgical recovery could be improved. Artisanal gold miners have been operating using similar processes and equipment in other countries and are able to achieve metallurgical recovery of 10 to 20%. Indonesian artisanal cassiterite miners are strongly encouraged to implement simple and cheap improvements, such as installation of riffles, splitters and perhaps a second stage of sluicing, to improve recovery of Sn substantially.

5.2. Environmental Issues

Currently, environmental impacts of artisanal mining in Bangka and Belitung communities have become a source of immense concern to the local government and globally, as the tourism sector has become effected. An enormous environmental footprint, tailings discharge to the local rivers, as well as deforestation are the three most important issues.

Increasingly, international media, social media, and non-governmental organizations around the world are focused on spreading news and revealing the reality of artisanal mining in Indonesia. According to Friends of Earth International (FOEI, 2012), an international non-governmental organization, tin mining has severely impacted Bangka's forest and coral reefs, with more than 60% of them have being already damaged. They noticed that water supply is also affected by mining activities, as fifteen rivers were contaminated by tailings. Shop Ethical (2018), an online ethical consumer guide, noted that due to the cassiterite mining industry, approximately 10% of Indonesia's forests have been destroyed over the last 13 years and there is the very real threat that if mining continues at the current rate, half of Bangka and Belitung will become arid land.

One has to be careful with statements coming from sources like those cited above. These articles are aimed to commercialize news, and they occasionally exaggerate and make the situation seem overly dramatic.

For the reputable *The Guardian* newspaper (Hodal, 2012), both conventional and artisanal mining have produced massive changes to the environment of Bangka and Belitung. On the other hand, the newspaper pointed out some successful initiatives aiming to reduce the environmental footprint, particularly a protest that resulted in permits for seabed mining being revoked over concerns that such activities may further harm the coral reefs. The article mentioned that tailings ponds are favorable to mosquitos, which could spread diseases like dengue fever and malaria. However, aware of this problem, the provincial government is looking for solutions together with the federal government. This article is a good example of journalism, which reports the real news, but also investigates the issues, putting pressure on those responsible to find solutions.

The biggest smartphone companies are now on the target of the protesters. Samsung and Apple are some of the electronics producers that have been pushed to decrease negative social, human and environmental impacts and improve the frequency of labour accidents caused by artisanal mining. In an effort to try to educate costumers in reducing the consumption of tin, Shop Ethical (Shop Ethical, 2018) emphasized that five smartphones contains almost the same amount of tin as an entire car may contain. Additionally, Friends of the Earth created a campaign called Make It Better (FOE, 2012), which was based on requiring European companies to report the human, social, environmental impacts of their products. They are required account how much water, land and raw materials were used in manufacturing them.

Kent (2014) emphasized that traceability is vital to identify where a product comes from and encourages consumers to be aware of the impacts to the rivers, wildlife habitats, and deforestation (Figure 76). He cited the positive actions the Indonesian palm industry has taken over the years and invites the chain of tin and its stakeholders to do the same. Compared to palm industry, the fragmentation of the chain is one of the hardest challenge to overcome to ultimately deliver tin responsibly and sustainably.

Another important concern is the presence of carcinogenic minerals in cassiterite deposits such as REE, which includes minerals such as monazite that are radiotoxic due to alpha radiation from thorium and uranium.

When the land surrounded by mining sites is used for agriculture and the water collected in the tailings dams is used for irrigation or as drinking water, it may increase the risk of human exposure to radioactivity (Jibiri, 2001). In addition to this, artisanal mining sites are an open area where locals have free access, and occasionally tailings have being used as raw building materials (Ademola and Farai, 2006).

Katsnelson et al. (2009) studied the toxicity of monazite in the monazite sand mining sector. He mentioned that there are no experimental studies concluding detrimental effects of monazite, but experiments conducted by South African authors in the 1950s demonstrated the possibility of pneumoconiosis when powder of monazite is inhaled. Additionally, impacts of thorium in monazite-rich sands were evaluated in Kerala, India, and its carcinogenic effects were not statistically proved (Nair et al., 2009).

Figure 76. Tailing being discharged in Bangka artisanal mining site (Source: Kent, 2014)

Stocklin-Weinberg et al. (2017) noticed that it is hard to make conclusions about the effects of this contamination among artisanal miners, since the lack of management, monitoring system and knowledge plus negative habits in Indonesia, like high levels of cigarette consumption among miners, might hinder this assessment. This statement was confirmed during the fieldwork stage of this thesis, when smoking habits were observed.

The Indonesian lab did not analyse uranium and thorium using in the TCLP solutions. However, it is reasonable to suggest that these radioactive elements would not be mobile enough from the samples to become bioavailable, because of the absence of association with phosphorous minerals. Except for the cassiterite concentrate sample, all of them presented low levels of uranium-thorium. Although uranium was low, thorium was higher than the other samples, but it can be adsorbed on the HFOs.

In 2015, Syarbaini and Dadong (2015) conducted a baseline assessment of the concentration of radionuclides and calculated the external exposure to the public in Bangka and Belitung. The annual effective dose of 1.17 mSVy-1 from thorium concentration was found which is slightly higher than 1mSvy, the recommended value for public exposure according to The International Commission on Radiological Protection (ICRP, 2007). ICRP recommended for occupational exposure, the radiation dose limit of 50 mSv per annum with a maximum of 100 mSv/a in a consecutive five-year period. These thresholds demonstrate that levels of radiation in cassiterite mining site are very low.

Studies of annual effective dose from natural radioactive elements through ingestion of foodstuffs in tin mining area of Nigeria was conducted by Jibiri et al. (2007). The area studied was a former tin mining area and the researchers investigated bioavailability and bioaccumulation of radionuclides in food crops and the dose ingested by the locals. Although the estimated ingestion dose and external dose on the land near the mining site were identified as being high, they were not considered high enough to produce detrimental effects in humans (Jibiri et al., 2007).

Contaminants were also identified by activity concentrations of uranium (^{238}U) and thorium (^{232}Th) in soils and mineral sands from another Nigerian tin mining region, where local foodstuffs and water samples were collected (Arogunjo et al., 2009). Compared to United Nation Scientific Committee on the Effects of Atomic Radiations (UNSCEAR) reference values (United Nations, 2000), elevated activity concentrations of ^{238}U and ^{232}Th were identified in several foods, which may be attributed to mining activities in the surrounding area. However, final exposure dose rates do not exceed few Microsievert (μSv) per year, therefore below the critical levels of toxicity.

Low levels of bioavailable uranium and thorium originating from a mining site was demonstrated by Arogunjo et al. (2009), who collected samples 25 km and 500 km away from the mining site. The values measured farther away from the mining site remained within the normal variability range (United Nations, 2000).

In terms of Indonesian artisanal mining sector, the main concern is regarding workers who constantly working in radioactive places. Comparatively to Canadian guidelines (Health Canada, 2013), the results of radioactivity analyses of the Indonesian samples conducted in the lab with a Geiger counter provided low results in terms of dose rates.

Canadian guidelines:

- For workers daily exposed is 20 mSv/a or 0.0023 mSv/h
- For incidental exposure of the public is 1 mSv/a or 0.0001 mSv/h.
- The average annual radiation dose to Canadians from different sources like (inhalation of Radon, cosmic rays, soils, medical diagnosis rays, food sources, etc.) is 2.62 mSv/a (0.0003 mSv/h) (Health Canada, 2013).

All the levels of radiation analyzed in the Indonesian samples were below 0.0006 mSv/h (equal for the concentrate) which is considered low.

According to the UBC Radiation Protection Dept., despite the low radioactivity, the health situation can be harmful for one inhaling material with 0.0005 mSv/h. That must be considered to the employees of the collector's processing centers in urban areas conducting dry concentration of cassiterite in a shaking table are definitely exposed to harmful dust.

It is important to note that the levels of radioactivity increase closer to tin smelting and refining processing plants. Indonesia smelters have no radioactivity controls and slags are stored and commercialized in China (Jabin, 2017 pers. comm.). Although the smelting process was not covered in this thesis, it is very likely that occupational exposure of radiation levels is higher than the acceptable limits of 50 mSv per annum, with a maximum of 100 mSv/a in a consecutive five-year period (ICRP, 2007) in this part of production chain.

Figure 77 shows a personal dosimeter, which is an instrument used to measure the dosage rate that an operator is exposed, used in a Brazilian smelter. On average, it costs only US $3.00. It is an important personal safety device to measure exposure to radiation. It is critical to implement a minimum level of safety management to deal with the results of radiation levels measured by the personal dosimeter, such as: disposing slags correctly, use of PPEs and CPEs, and training for the employees of the smelting area.

Figure 77. Personal dosimeter

Recommendations:

The use of *sequential basins* as an effective mining method is strongly recommended to decrease discharge of tailings to the local rivers.

The elements discussed in the section *5.1.2 – Processing* may help improve mineral recovery, which ultimately results in lower impacts to the environment.

Training is also imperative to make artisanal miners aware of the detrimental impacts that their livelihood can have on their health and the environment.

Furthermore, some degree of mining site infrastructure should be provided by either bosses, private company or local government. This is important in order to make artisanal miners aware about the effects to themselves and the environment. Currently, this barely exists.

5.3. Safety Issues

As described above, uncertainties regarding the number of accidents and fatalities do not clarify how outrageous artisanal mining of cassiterite is in terms of occupational safety in Indonesia. According to personal communication with Jabin (2017), the president of Association of Indonesian Tin Exporters (AETI), dozens of people die each year. Friends of Earth (FOEI, 2012) supported this statement, mentioning that sixty miners died per annum, mostly buried in cassiterite alluvial mines or trapped underwater during dredging and offshore mining activities. This NGO noticed that Bangka police estimates that in 2011, an average of one miner a week died in an accident.

Similarly to environmental issues, many well-respected and international channels of media, including websites, television and news agencies, such as Bloomberg and *The Guardian*, are increasingly covering the precarious work conditions of artisanal mining of cassiterite in Indonesia (Hodal, 2012; Simpson, 2012).

The most frequent causes of accidents in artisanal mining activities are highwall collapses, falls into unprotected pits, falls from benches, and sliding of material and equipment. Lack of knowledge and training are also a substantial reason as well as obsolete and poorly maintained equipment (Stocklin-Weinberg et al., 2017). This is supported by Walle and Jennings (2001) who noted that normally, miners using hydraulic monitors concentrate the water jet in particular pockets of cassiterite and this creates holes on the shaft wall, causing more instability of the mine face.

Recommendations:

Safer methods such as Sequential Basins, Load and haulage method feeding a bin and, at the end of the section, open pit conventional method (which is more suitable for bigger operators than artisanal) were suggested to improve safety. Unfortunately, any change in mining methods should be preceded with an intensive education process to convince bosses that safer methods can also potentially result in more productivity.

Consumers can also play a role. They do not need to update their smartphones twice a year, nor have two or three tablets at home. Instead, educating consumptions habits might be a good way of pressuring governments, suppliers and private companies to improve work conditions in artisanal mining of cassiterite around the world.

A minimum level of safety management should be implemented in WPR and IUP areas. In order to provide support to the artisanal miners, respectively, bosses and mining companies should gather and hire at least one technician to train and give advice to miners, which would ultimately prevent accidents in those areas. In addition, is considered imperative to provide PPEs to the miners in WPR and IUP areas. It is important to remember that it does not make sense to produce ore, earn money and injury or kill people at the same time.

5.4. Further Comments

Gonçalves (2016) stated that the Ecuadorian artisanal gold mining sector, together with local government representatives, has been studying the possibility of creating cooperatives as a way to protect artisanal miners. Brazil has been using a similar model for gold and cassiterite artisanal mining sector for many years, and it seems to work very well in terms of organization, formalization, tailings contained, low level of accidents.

In contrast, Indonesian artisanal cassiterite mining sector apparently do not improve anything for several reasons:

1) The mining "bosses", who are also in most cases the "collectors", have enough money from mining, as well as other source of income, which does not encourage them to invest further in mining
2) Artisanal mining in Indonesia is still quite profitable compared to farming, fishing or tourism activities, and miners can earn money quickly. The artisanal miners seem to be very satisfied and "thankful" for making money as it is
3) Encouraged by poor inspection from regulatory agencies and, sometimes, high levels of corruption, big companies end up working as "fake" mining companies, buying cassiterite concentrate from the artisanal miners through the collectors, no matter where and how they mine it.
4) Electronic industries, that should boost the sector, does not contribute effectively to implement improvements. Instead, they advertise list that claim to be their sustainable suppliers (Figure 78).

Metal	Smelter Name	Country	Third Party Audit Status	Risk Readiness Assessment Status
Tin	PT Tommy Utama	Indonesia	Compliant	Completed
Tin	PT Timah (Persero) Tbk Kundur	Indonesia	Compliant	Completed
Tin	PT Timah (Persero) Tbk Mentok	Indonesia	Compliant	Completed

For More Information

For more information about Apple's Supplier Responsibility program, visit www.apple.com/supplier-responsibility.

Apple Supplier Responsibility | 2017 Smelter and Refiner List

Figure 78. Apple Supplier List
(Source: Smelter and Refiner List, 2017 - www.apple.com/supplier-responsability)

The approach of improving artisanal mining sector in Indonesia must have multiple facets. Social, environmental, safety and operational considerations have to be developed together, otherwise negative aspects might be generated with the promise of earning greater profits. For example, improvements in operational variables to increase profits may attract new artisanal miners to the sector, which may end up having negative social or environmental impacts.

An interesting question to be answered is: what would happen to the women and children that currently pan tailings downstream from the sluice boxes if improvements that increase mineral recovery and reduce tailings were implemented?

6. Conclusions

This research was focused on Indonesian artisanal cassiterite mining sector in Bangka and Belitung and was undertaken to describe the mining and processing methods, assess operational details, safety risks and environmental impacts and finally, propose recommendations to improve operational efficiency and reduce both safety and environmental impacts.

The following findings were derived from this thesis:

- Indonesia has approximately 250,000 artisanal miners of many different types of minerals, of which around 20% mine cassiterite from offshore and onshore alluvial deposits in Bangka and Belitung. Bangka hosts 8,000 mining sites with estimated 40,000 artisanal miners. Belitung hosts 2,000 mining sites with 10,000 artisanal miners.
- From 78,200 tonnes of refined tin produced in Indonesia in 2017, more than 60% came from artisanal miners from mines across Indonesia.
- While offshore and onshore mining in Bangka accounted for 69,300 tonnes of refined tin, Belitung artisanal mining produced around 9,000 tonnes in 2017 from onshore alluvial deposits.
- As an attempt to formalize and support artisanal miners, specific areas were created by the government to allow artisanal miners operate legally. However, neither WPR (public area) nor IUP (private area owned by mining companies) properly work as their intended purpose due to many different reasons, including: lack of engagement of the main stakeholders, such as government and private companies; lack of inspection by regulatory agencies; lack of organization of artisanal miners and lack of interest of bosses and collectors.
- WPR areas: artisanal miners operate both legally and illegally, but most of the work is illegal. In these areas, miners are either controlled by a boss or work independently in groups of three to five.

- IUP areas: artisanal miners who operate in IUP areas have their own license, and therefore are considered legal. They are controlled by a boss and are rarely found in autonomous groups.
- Sukamandi is one of the most important mining region in Belitung, where approximately 9,000 people depend on artisanal mining operations for their livelihood and where most of mining sites are located.
- Artisanal mining of cassiterite in Indonesia is the most significant local sector, followed by farming (palm oil), fishing and tourism. This is due to several reasons including poor inspection from regulatory agencies and the ability for miners to make money quickly.
- Local government, in the case of a WPR area and private companies, in the example of an IUP area, should provide technical knowledge, infrastructure, training, safety procedures and environmental standards. However, the artisanal miners are marginalized by them instead.
- Due to lack of organization and strong informality, cassiterite artisanal mining sector in Bangka and Belitung does not have enough power to develop.
- Brazil's cooperatives of artisanal miners are good example for the Indonesians to follow, since formalization and their organization are able to provide a minimum level of infrastructure. As part of their structure and respecting some rules, a representative is nominated and therefore, negotiating power and motivation to work is increased.
- Under the rules of the boss, the earnings of cassiterite artisanal production are divided into three parts, where a third belongs to a group of three to five miners, a third goes to the boss and the last third covers the operating costs, like fuel, maintenance, hoses, water and sometimes even the food that is fed to the miners. If there is no boss, costs and profits are divided equally among the miners.
- Typically, a group of local miners produce on average 15 kg of cassiterite concentrate with grades of 65% to 70% tin every two days. On a "good production day", it is possible to produce about 20 kg.

- When the concentrate grade is 70% tin or higher, the selling price it is US $10/kg, which is measured by density on a standardized scale.
- Gross monthly income of an operation is approximately Rp 22,000,000 or US $1,580 per month. This results in an individual artisanal miner making approximately US $176 per month. In comparison, the minimum wage in Indonesia is US$ 198/month.
- The processing centers are generally family-structured businesses that charge depending on the type of services offered to the miners. For example, grinding costs approximately US $0.11/kg of material processed while the price doubles per kg if a shaking table is required, which always is the case.
- On average, processing centers process approximately 100 kg of ore/day from different miners, making around US $484/month. The tailings are usually then reprocessed by the processing centre owners.
- Many artisanal miners dry their panned concentrate in their own houses and then bring it to a processing center to increase the grade on a dry shaking table, before selling it to a collector. Artisanal miners working under a boss simply take the concentrate to their boss.
- Collectors buy the cassiterite concentrate from the boss. Frequently, a boss is also a collector and sometimes there may be two or three levels of collectors involved, where the last individual collector sells the material to the smelter. In some cases, the processing centers also function as collectors, reprocessing tailings the artisanal miners left behind, which they then resell to another collector.
- Tin mining companies, including PT Timah (fully owned by the government of Indonesia and the largest Indonesian tin mining and smelter), clearly prefer buying concentrate from artisanal miners than mining their own, resulting in little investment to improve operations at mine sites.
- In order to avoid penalties and confrontation with official government agencies, it appears that many metallic tin producers keep “fake” mining site, where they pretend to be mining.

- Mining operations owned by smelters are very similar to artisanal operations located in WPR or IUP areas, where rudimentary techniques, lack of operational, environmental and safety standards are predominant.
- Based on the calculation and Belitung field measures, the tin recovery was estimated in 12% (metallurgical recovery), whereas the concentrate mass yield was calculated in 0.004% (mass recovery).
- A very low mass recovery was expected using the artisanal methods observed, mainly because of the sluice box, designed with five degrees of slope, which is very simple and ultimately work essentially like gutters, with low residence time, culminating in great losses of fine cassiterite particles.
- Discharges of Tailings:
    - Based on Belitung artisanal cassiterite concentrate production of approximately 9,000 tonnes of Sn ingots and due to mass recovery achieving only 0.004%, the mass of tailings released into the environment may be estimated as over 18 million tonnes per year discharged into the local rivers and waterways.
    - Tailings are discharged through natural drainage downstream, with no dams nor any other controls, from miners, processing centers and mining companies, which, encouraged by lack of inspection from regulatory agencies and sometimes corruption, are not committed to containing the tailings.
- Environmental footprint: due to the preferred mining method, which basically consists of water (which is pumped from local rivers) to detach the ore, lack of tailings dam to contain the slurry and lack of commitment to reclamation, artisanal mining of cassiterite are characterized by an enormous footprint in both, WPR and IUP areas.
- Heavy metals contamination: even though the ore is naturally slightly radioactive, mainly due to occurrence of monazite, and therefore ^{238}U an ^{232}Th may occur.
- Pollution: bad maintenance conditions of the set-up of pumps provides exposure of fumes to the artisanal miners when working close to the pump exhaust pipe.

- The most common occupational risks during the extraction and beneficiation of cassiterite are the risk of block sliding, risk of falling and wall collapse.
- It is believed that more than 60 people die per year in onshore and offshore artisanal mining activities in Bangka and Belitung. Mostly died buried in tin alluvial mines or trapped underwater during dredging of offshore mining sites.
- Artisanal miners work to close to the sidewall, detaching the ore with hydraulic monitors with no adequate techniques, which increase the risk of subsidence.
- Illegal underground artisanal miners are exposed to increased subsidence risk due to lack of proper techniques, training, adequate tools and PPEs.
- Many artisanal miners work detaching the ore on average 10 hours per day, in wet conditions, sunk into a small pit created by using of hydraulic monitors.
- When contracted by mine bosses to support their artisanal miners, lack of training exposes the excavator operators to frequent rolling machine accidents. It was noticed that one single excavator operator experienced three accidents within a ten-year interval.
- Risks of heat stroke and dehydration as well as poor water, sanitation and hygiene (WASH) practices were the biggest occupational heath and safety (OHS) risks observed Belitung. This includes children and women working panning the discharge of the sluice boxes.
- In order to reprocess the artisanal miners' tailings and make money with monazite presented in the tailings, some processing centers purchase tailings from other collectors, locally known by "tailing byers".
- During non-scheduled maintenance of pumps set-ups, artisanal miners are at risk of accidents involving hands, fingers and eyes. This condition is enhanced by the lack of training and lack of PPEs, such as boots, gloves and protective goggles.
- The largest electronics companies are the most important clients of the Indonesian tin market. They purchase tin for soldering and, ultimately should be engaged with investment in improvements in the artisanal mining sector. Instead,

they make profits and increasing demand pushes the sector towards more artisanal methods.

- Indonesian artisanal miners of cassiterite have no inclination to associate and develop better standards of safety, for several reasons:
  - The mining "bosses", who are also in the most of cases "collectors", have enough money as well as other sources of earnings, and do not invest in better practices.
  - Artisanal mining in Indonesia is still quite profitable compared to farming, fishing or tourism activities, and it is a way to make money fast. The artisanal miners seem to be very satisfied and "thankful" for making money as it is, and do not demand anything more.
- The methods that Indonesia's artisanal miners used to extract alluvial deposits present opportunities to implement improvements, such as: a) sequential basins, b) load and haulage method feeding a bin or, c) open pit conventional method (which is more suitable for bigger operators than artisanal).
- Implementation of one of these mining methods, replacing the current methods, would decrease detrimental environmental effects as well as provide safer operation and increased profits.
- Gravity concentrators also presented an opportunity to improve processing, using better designed sluices, spirals, centrifuges or jigs.
- The approach of improving artisanal mining sector in Indonesia must be multi-faceted. Social, environmental, safety and operational factors have to be developed together, otherwise negative aspects might be generated with the promise of earning greater profits.
- If the provincial or federal governments lead the process of changing the current scenario, the chances to improve conditions become real. The beginning of the changes is linked to enforcement of existing laws. Indonesia artisanal mining regulations do exist; however, impunity and lack of inspection prevails in the sector.

- Any changes or technical improvements will need to be the result of a long-term strategy. It is important to engage stakeholders such as government, public and private companies, regulatory agencies, final clients and communities in the process.
- In summary, in order to develop and improve all aspects of this sector, organization, formalization, capacity building and, finally, the passing of laws and standards to regulate the industry and its practices are the most important steps that should be pursued. Moreover, a stronger and more effective government interference in inspection and training, as well as willingness of the stakeholders for implementing improvements are imperative.

7. Opportunity for Future Research

Artisanal mining of cassiterite in Indonesia offers many opportunities for further academic and other research. Based on the observations obtained from the study present, further research is needed in the following areas:

- It is important to conduct a water, metallurgical and mass balance of at least three different groups of artisanal miners, WPR and IUP areas, and potentially, show in numbers, the margin of profits that could result if the above recommendations are implemented.
- In order to conduct a “pilot study”, a partnership with a mine boss or a group of artisanal miners may be investigated. Improvements could be implemented, and the gains measured after a period of time. It could be sponsored by Chinese or Indonesian equipment manufacturers.
- Ultimately, profits from this assessment would be divided among stakeholders, mainly between mine bosses and mining companies, which own WPR and IUP areas. That would convince them of the monetary worth of improvements.
- Another interesting approach might be investigating the process of producing monazite and REE as by-product of cassiterite.

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