BULLETIN N° 118
ISSN 1019-2026

TIC

TANTALUM-NIOBIUM INTERNATIONAL STUDY CENTER

PRESIDENT'S LETTER

The T.I.C. will hold its Forty-Fifth General Assembly in Philadelphia, Pennsylvania in the United States on Monday, October 11th 2004. The Technical Session looks to be as informative as ever, covering a wide range of topics of interest to members. We are very fortunate to have a representative from DLA/DNSC presenting a paper on tantalum sales from 1997 through the present. Mr William Serjak, T.I.C. Technical Promotion Officer, will present an update on the progress of the Transport Committee. On behalf of the entire Executive Committee of the T.I.C., I would like to commend the Transport Committee for the hard work and accomplishments to date. We will certainly recognize these individuals at the General Assembly.

I must again solicit the help of all member companies to submit abstracts for papers to be presented at the Symposium in 2005 to be held in Thailand. We must start preparations early in order to provide a Technical Programme of the caliber we have become accustomed to. The Symposium Technical Sessions will be divided into specific categories with a chairman whose responsibility is to fill the time slots with top quality papers within that subject category. Please help when asked.

I look forward to seeing you in Philadelphia. The Forty-Fifth General Assembly is shaping up to be another great meeting for all.

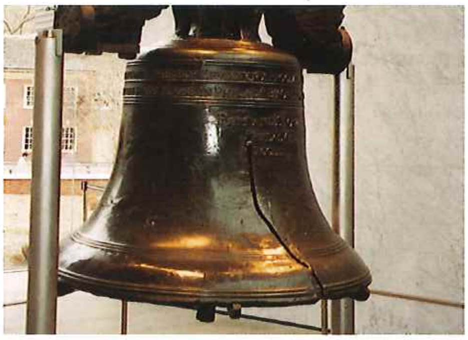
Dave Reynolds
President

CONTENTS

SYMPOSIUM IN 2005
In October 2005, in Thailand, the T.I.C. will hold its next international symposium on tantalum and niobium.
Please submit your proposals for papers to the secretariat as soon as possible. We look forward to hearing from you.

FORTY-FIFTH GENERAL ASSEMBLY

The General Assembly of the members of the T.I.C. will take place on October 11th 2004 as part of a meeting in Philadelphia, Pennsylvania, United States from October 10th to 12th. The conference sessions will be held at the Sheraton Society Hill Hotel, where delegates will also stay.



The registration desk will be open from 10a.m. to 5p.m. on Sunday October 10th, and on Sunday evening all delegates and guests, and accompanying persons, are invited by the T.I.C. to the welcome reception.

On Monday October 11th the General Assembly of the members, to conduct the business of the association, will open at 8.30a.m. After a short coffee break the technical session will begin, continuing until lunch at 12 noon. The technical programme will resume at 2p.m. and run until 5p.m., with a short break for tea. In the evening all participants are invited to the gala dinner.

On Tuesday October 12th there will be a plant tour of the facility of Reading Alloys at Robesonia – please see below the story of this company. We are grateful to Reading Alloys for the opportunity to visit this interesting plant, which has so recently celebrated its 50th anniversary.

We have also arranged sightseeing tours for those accompanying the delegates attending the technical meeting. On Monday the group will have a guided tour to discover the historical significance of Philadelphia, once the capital of the United States; and on Tuesday there will be an opportunity to see the delightful Longwood Gardens.

Invitations will be sent to the member company delegates by early July. Others who would like to take part in our meeting should let the Secretary General know as soon as possible.

www.tanb.org
e-mail to info@tanb.org

TECHNICAL PROGRAMME, PHILADELPHIA MEETING

The Defense National Stockpile Center's sales of tantalum and niobium from 1997 through the present
by the Administrator
United States National Stockpile Center
Review of the year, and a report on the work of the T.I.C. Transport Committee
by William A. Serjak, Technical Promotion Officer
Tantalum-Niobium International Study Center
Niobium for high-temperature applications
by Tadeu Carneiro, Vice President
Reference Metals Company, Inc
Tantalum powders for high voltage applications
by Leah F. Simkins, Michael J. Albarelli, Kathleen B. Doyle and Bonnie Cox
H.C. Starck
Challenges involving deposition of counter-electrode systems in high charge (≥100k CV/g) tantalum powders
by Eric Zediac, Chris Coker, John Moore
KEMET Electronics
Tantalum coated materials for surgical implants
by Bo Gillesberg
Danfoss A/S
Recent advances in tantalum mill products for physical vapour deposition
by Peter Jepson, Rich Malen and Prabhat Kumar
H.C. Starck
How far can we go with high CV tantalum capacitors?
by Yuri Pozdeev Freeman
Vishay Sprague
The usage of tantalum for physical vapour deposition applications
by Michael W. Morris
Cabot Supermetals
Some problems of yttrium-refined tantalum production
by S. Dobrussin, Y. Gulyaikin, G. Gyintsev, V. Shevlyakov
NAC Kazatomprom, Ulba Metallurgical Plant JSC

READING ALLOYS

Reading Alloys, Inc (RAI) was founded in January 1953 by Fred H. Perfect to produce what would become known as Master Alloys for the developing titanium and superalloy industries. Master Alloys are various metallic elements dissolved together to form compounds with sufficiently low melting points that they can be readily dissolved into other base metals such as iron, titanium, or nickel. Reading Alloys' first customer was the Carpenter Steel Co. of Reading, Pennsylvania, known today as Carpenter Technology.

Ferro-niobium was first produced in late 1953 along with ferro-titanium, and chromium metal. By 1955, aluminium alloys of vanadium and molybdenum were added to the product line to supply the titanium industry with the alloying elements necessary for the high temperature metal in the developing jet engine. Using the exothermic oxidation/reduction process known as the thermite reaction, Fred was able to produce these and a variety of other metal combinations using low cost raw materials. In 1957, the first water cooled copper thermite vessel was developed at RAI as well as many new products including aluminium/niobium. By 1958, a vacuum grade of nickel-niobium was introduced for use in superalloy production such as Inconel 718.

As owner, president, and technical director, Fred Perfect continued his pioneering metallurgical efforts at Reading Alloys until his death in 1992. Upon his passing, the management of Reading Alloys, Inc. moved to Mr Perfect's wife, Marjorie Perfect, who very capably directed and further expanded the company's operations. Under Marjorie's guidance, the company added two electron beam furnaces, a new automated hydriding operation to support developing high purity metal powder products, and broadened the technical staff. The Perfect family sold Reading Alloys in 1998 to KB Alloys who are producers of Master Alloys for the aluminium industry. This combination of resources has strengthened each company and accelerated new product developments that continue to broaden the technically demanding markets served by Reading Alloys.

The management and staff at Reading Alloys are looking forward to welcoming the T.I.C. members and guests to our facility in October. Located on the 200-acre former Perfect family farm in south-eastern Pennsylvania, you will be treated to a harmonious blend of industrial technology and beautiful countryside. The plant tour will focus on the processes and quality requirements for supplying metal into the rotating parts of jet engines, including the opportunity to view production thermite reactions performed in Reading Alloys' unique water cooled copper vessels. A quality and safety orientation will precede the tour and no cameras, pens or electronic devices will be permitted in the plant.

AVAILABILITY OF TANTALUM RAW MATERIALS INTO THE FUTURE

by David Paull, Sons of Gwalia. The views expressed in this article are those of the author and his company, and not necessarily those of the T.I.C.

The general consensus is that the tantalum market is improving, following two very poor years in 2001 and 2002. It is therefore an appropriate time to update the tantalum industry on the ability of raw material suppliers to meet this growing demand.

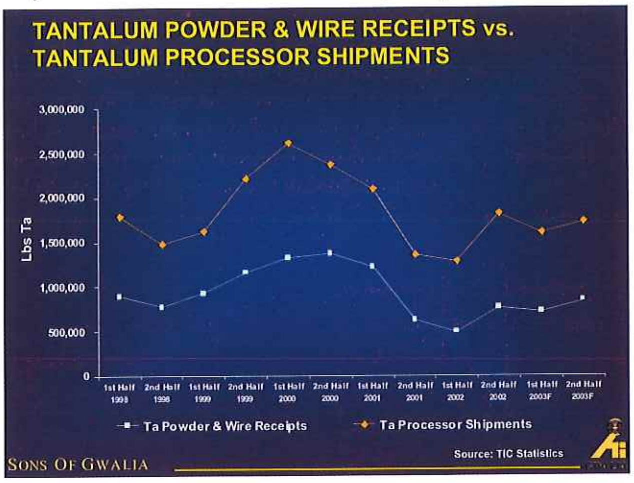
SPOT PRICE MOVEMENTS

The improving demand picture has impacted on the spot markets where a substantial overhang of tantalum concentrates, which were held over from the 2000 boom, have now been absorbed into the market. This has resulted in upward pressure on spot purchases, which has been evidenced by recent sales in the range US$32-$35 per lb (that is, per lb Ta_2O_5 contained). The spot price has risen over the past 12 months from a US$22-$25 per lb range. The market should not be overly concerned with this. Spot pricing of less than US$30 per lb reflects weak demand conditions and liquidation of stockpiles.

MARKET ESTIMATES FOR 2003 TO 2005

As the chart shows, the market has been in an upward movement in terms of demand since the first half of 2002. This graph shows Tantalum Processor Shipments as provided by the T.I.C., with statistics for the 2003 calendar year being estimates. We also have actual data to 2003 for Tantalum Powder and Wire Receipts by the largest tantalum capacitor manufacturers. As you can see, over the last 12 months, most of the recovery in the tantalum business has been driven by the electronics industry and its demand for tantalum powder in the construction of capacitors. This growth in the electronics industries' consumption of tantalum is anticipated to remain robust in 2004. In terms of predicting overall demand requirements for 2004, the most recent T.I.C. statistics show that the estimate for processor shipments in 2003 was 3.32Mlbs Ta, equivalent to 4.15Mlbs Ta_2O_5. This is an increase of approximately 7% over 2002. A similar increase would see the market grow to around 4.5Mlbs Ta_2O_5 in 2004 and to 4.8Mlbs Ta_2O_5 in 2005.

Given demand estimates at these levels, the industry is well placed to meet demand requirements. As 20-25% of raw material requirements are sourced from recycled products, the new raw material feed requirements for 2004 should be in the vicinity of 3.2-3.4Mlbs Ta_2O_5. These raw material feed requirements are sourced from a variety of operations, the key



provider of which is Sons of Gwalia Ltd ('SGW'). For the calendar year 2004, SGW has committed sales of 2.3Mlbs Ta_2O_5 or 65-70% of the world's raw material requirements. SGW's production capabilities and its near term production plans are therefore important for the industry as a whole to understand in order to have confidence in the supply side of the equation.

For calendar year 2004, SGW estimates that it will produce 2.2Mlbs Ta_2O_5 with the current inbuilt capacity able to produce between 2.5 and 2.75Mlbs Ta_2O_5, and it has the ability to increase this further to 3Mlbs Ta_2O_5 per annum at relatively short notice.

We continue to have exploration success at the Wodgina Mine and the life of this operation is intended to extend past the 20 year reserve life currently in place at existing production rates of more than 1.2Mlbs per annum.

At the Company's Greenbushes Mine, the operations continue to run at less than full capacity. A study will shortly be completed looking to restart the development of a significant underground mine at Greenbushes, which will produce in the order of 500 000lbs per annum. This, in addition to the Greenbushes open pit activities, would see 1.3-1.4Mlbs per annum produced when operating at full production capacity. The underground mine at Greenbushes could be expanded to further increase production from this operation once the mine has been established such that total production of 3Mlbs could be achieved. The Greenbushes operations currently have a reserve life of around 25 years at full production rates.

While SGW provides the core supply sources for the industry, there are other important sources, which are important contributors to the supply balance. These sources include:

(a) the US Defence Logistics Agency (USDLA), which currently has approximately 1.5Mlbs Ta_2O_5 of various categories available for access through its regular tender system. The USDLA has been offering 0.5Mlbs per annum regularly to the industry;
(b) the Kenticha Mine in Ethiopia, a regular contributor of 120-150 000lbs Ta_2O_5 per annum in concentrates, which also sells through an open tender basis from its current mining operations;
(c) the Paranapanema Tin Mine in Brazil, which produces 150-200 000lbs per annum of Ta_2O_5 as a by-product from tin mining operations;
(d) Metallurg's operations in Brazil, which contribute approximately 150-200 000lbs Ta_2O_5 to the supply equation;
(e) the Nanping and Yichun Mines in China, which together contribute approximately 200-250 000lbs Ta_2O_5 per annum.

These specific resources can contribute up to 1.3Mlbs Ta_2O_5, which, along with numerous small mining operations such as those located throughout Eastern Africa, combine to balance the supply equation.

In addition, Sons of Gwalia maintains a stockpile of concentrates of around 200 000lbs and is aware of other stockpiles (in addition to those held by the USDLA) which total around 500 000lbs Ta_2O_5. Combined with existing production capacities, these can adequately cover growth rates of triple the estimated 7% growth rate anticipated for 2004 and 2005.

SUMMARY

In summary, rising spot prices for tantalum are a healthy indicator that the industry is now returning into balance. The majority of tantalum is sold under long-term contracts, which are at prices significantly higher than spot but which have been consistent since 2000. Raw material prices, on a weighted basis, have therefore not increased substantially since the downturn in 2001 even given the recent recovery. The effects of the long-term contracts are to ensure the consistent delivery of pounds into the market at a predictable and sustainable price.

Meanwhile, development activity in the tantalum business has begun to re-emerge with projects being promoted in Egypt, Saudi Arabia and Mozambique. Over time, it is important that new projects are developed in order to ensure a robust supply equation for the industry longer term. SGW is taking a lead role in this and is preparing analyses of various expansion options at both of its mines in the event that continued growth in the tantalum industry warrants such expansions.

WITH PICK AND PAN – MINING AND PROCESSING OF OF TANTALUM ORES

Presented by Mr Richard Burt, President, GraviTa Inc, at the T.I.C. meeting in Lisbon, October 2003. This version has been slightly shortened.

A tantalum particle passes through many stages on its journey to become an integral part of a computer: some are low-tech, others high-tech, requiring complex processing and equipment in increasingly sterile conditions. But it all starts, literally, in a 'hole in the ground', with the winning and separation of the tantalum minerals from their host rocks.

This paper briefly reviews the major localities where tantalum is found, where it is mined, and the various minerals and ore types of both current and potential future importance. The paper will then focus on the mining and mineral processing technologies that are currently applied to the upgrading of the ore to a mineral concentrate suitable for the next stage in the supply chain – chemical processing. It will also discuss the 'next generation' mines, the different technologies that may be required to unlock their wealth, and some of the potential constraints to their development.

INTRODUCTION

The tantalum industry, in terms of the tonnage, is relatively small, compared to many other metals and minerals; nevertheless, the supply chain is complex. A tantalum atom passes through many stages from rock to high purity metal and oxide – from mine to mill to processor, through manufacturer to OEM and finally to the customer.

This paper will limit itself to just one relatively small part of the chain: the mining and mineral processing of tantalum ores. A little over two decades ago, the majority of tantalum produced was a by-product of the mining of tin ores: this is not the case today, and the mining and mineral processing of tantalum ores predominates.

The current world of tantalum

Tantalum, while it can be classified as a 'rare metal', is widespread, with mining taking place in four continents, and the potential for mines in all five, as shown in Figure 1.

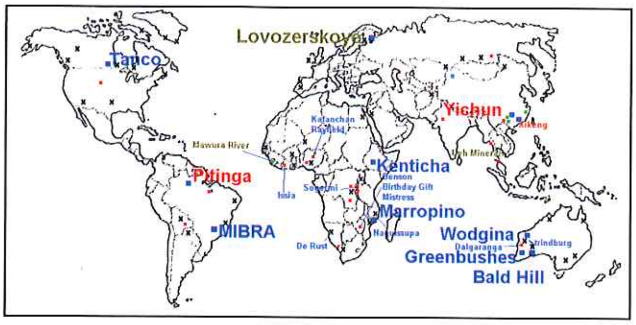


Figure 1: The current world of tantalum

Currently, approximately half of the world's production occurs in Australia – essentially at the two Sons of Gwalia mines, Greenbushes and Wodgina. Close to half of the rest is produced in the African continent, with the capability of two individual mines (Kenticha, Ethiopia, and Marropino, Mozambique) each exceeding 100 000 lbs per year – otherwise most of the production from Africa is from the smaller mines or results from artisanal production. Asia and South America each account for a little over 10%, both from organised mines and from artisanal production. Canada, once the largest tantalum producer, now accounts for less than 5%, all from the Tanco mine in Manitoba.

This wide range of locations results in different strategies for mining and processing. In the industrialised nations of the world, where labour costs are high and infrastructure is extensive, there is a general tendency to design larger plants and to incorporate capital intensive rather than labour intensive processes. Sophisticated equipment, the extensive use of instrumentation and control, as well as the inclusion of innovative equipment to improve performance are all acceptable. In comparison, in the developing world, with its lower labour costs and the social need to provide employment, the opposite is often the case. Simplicity of operation must outweigh sophistication; reliability must outweigh innovation[1].

THE ORES AND MINERALS OF TANTALUM

To alleviate any confusion, in the context of this paper, ore – defined as 'a mineral assemblage that can be mined and processed at a profit' – is the raw material of the mine, the final product of which is a 'concentrate'.

Orebodies are made up of different types of rock, themselves made up of different mineral assemblages. For example, quartz, a mineral, is a major constituent of granite, a rock. The most common rock formation that hosts the tantalum ores of today is pegmatite. A pegmatite is a coarse grained rock assemblage formed by intrusion of molten magma into voids or weaknesses deep (5-8km) in the Earth's crust. The two main periods when tantaliferous pegmatites were intruded are in the Achaean (>2 billion years ago) and the Proterozoic (500-1400 million years ago). Pegmatites are generally relatively small (1-100 million tonnes). They can be 'simple' or 'complex', with several discrete zones within the pegmatite, each zone containing significantly different mineral assemblages. For example, the Bernic Lake pegmatite mined by Tanco contains commercially discrete zones of tantalum ore, spodumene (an ore of lithium) and pollucite (cesium ore)[2] .

Rwandan pegmatite

Another type of rock mined for tantalum, but to a much lesser extent at present, is aplitic granite, also known as an apogranite. Generally much larger (100-1000 million tonnes), they are often lower grade, with finer mineralogy, than pegmatites. Typical examples would be the Pitinga mine in Brazil, and the Yichun mine in China.

Minerals are naturally occurring inorganic crystalline solids with narrowly defined chemical and physical properties: they are not chemical substances and do not behave in the orderly manner of chemicals. To exacerbate the situation, there is not just one tantalum mineral but many – no less than nineteen had been recorded as early as 1982[3] . The more important ones are shown in Table 1.

Tantalite-columbite	$(Mn>Fe)_4(Ta,Nb)_8O_{24}$
Microlite	$(Na,Ca)_2Ta_2O_6(O,OH,F)$
Wodginite	$Mn_4(Sn>Ta,Ti,Fe)_4(Ta>Nb)_8O_{32}$
Simpsonite	$Al_4Ta_3O_{13}(OH)$
Stibiotantalite	$SbTaO_4$
Euxenite	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$
Struverite	$(Ti,Ta,Nb<Fe)_2O_6$

Table 1: Commercially important tantalum ores

Considering the recent spate of publicity surrounding tantalum[4] , it might be surprising that 'coltan' does not appear on this list. However, the reason is simple – 'coltan' is not an official mineral name: it is a shortening of columbo-tantalite. This itself is just one part of the isomorphous mineralogical series stretching from pure tantalite – $(Mn>Fe)_4Ta_8O_{24}$ to pure columbite - $(Mn>Fe)_4Nb_8O$. Neither end of this series occurs in any quantity: where tantalum significantly outweighs niobium it is tantalite, and where niobium significantly outweighs tantalum it is columbite; where the Ta:Nb ratio approaches unity, one has columbo-tantalite, or 'coltan'. The major significance of the Ta:Nb ratio relates to grade of the final concentrate. As the tantalum and niobium are chemically combined within the crystal lattice, the ratio cannot be altered during processing. Consequently, as the Ta:Nb ratio decreases, so does the maximum theoretical grade of the final product.

While the tantalite-columbite series is the most widespread, microlite occurs in many orebodies. Microlite – the end mineral of the microlite-pyrochlore series – is generally finer in particle size, lighter and more friable; it is more difficult to process than tantalite-columbite. It also is more likely to contain inclusions of uranium or thorium. Wodginite, the other significantly important mineral, is found primarily at Wodgina (its type locality) and at Tanco. The other minerals are less common, although struverite and its sister mineral ilmenorutile are found in south-east Asia and in Sierra Leone.

In general, the tantalum content of an ore can range from as little as 100 grams per tonne to close to 1000 grams per tonne. The rest will be other 'heavy minerals' such as cassiterite, ilmenite, zircon, rutile, monazite, garnet, urananite or various sulphide and iron minerals, and the 'light minerals' such as quartz, feldspar, mica, apatite, spodumene, amphibole or tourmaline, some of which could form valuable by-products. It will be the art of the mineral processor to sort the tantalum and other valuable minerals from those that are truly 'waste'.

MINING

Before the processor can get to work, however, first the geologist has to find the ore, and the miner has to mine it. Obviously, one cannot find, let alone mine, orebodies that occur 5 km deep in the Earth's crust! Over the eons, most of the covering rock has been eroded away, to the point where the pegmatite either outcrops on the surface or is only buried by no more than 200 metres. Even then, discovering 'blind' pegmatites has proved to be a considerable challenge.

It is reasonable to assume that a lot of pegmatites have been eroded away either partially or completely. This is what results in the alluvials.

The miner's job is simple: all he has to do is to extract the rocks from the ground and provide the mineral processing plant only with those rocks that contain tantalum, and at a size which can be handled, while not 'over-breaking' the rock such that the tantalum is too fine to process. Also, to deposit the non-tantalum-bearing rocks that surrounded the pegmatite in a separate pile. All in a safe, cost effective and environmentally sustainable manner. Not so simple, after all!

There are different types of mines – alluvial mines, open pit mines, treating either soft or hard rock, and underground mines generally mining only hard rock (Table 2). Alluvial mining is generally the cheapest, per tonne of rock, whereas underground mining is the most expensive.

'Hard Rock': makes up the majority of the Earth's crust. Obviously it is 'hard' – it needs explosives to break it apart

'Soft rock': by the forces of weathering some of the minerals will have become very friable, and the rocks can be broken apart quite easily – often by pick and shovel

'Alluvials': occur when these soft rocks have been water borne and then the sand and gravel deposited in river valleys

Table 2: Hard, soft, alluvial – what's the difference?

The majority of 'industrially mined' tantalum is won from open pit mines. In open pit mining, varying amounts of barren rock (waste) have to be mined in order to mine the ore. The tonnage of waste rock that has to be mined to produce one tonne of ore is known as the stripping ratio – the higher the stripping ratio, the higher the cost of each tonne of ore delivered to the mill. Hard rock requires drilling and blasting; it is therefore unsafe – indeed often impossible – to have a pit with vertical sides. They must be angled to a greater or lesser extent, related to the inherent stability of the rock strata.

Where the orebody itself is vertical, then ore and waste mining can occur concurrently, although the stripping ratio will increase with pit depth. Where the ore is horizontal, then all the waste must be removed prior to mining of the ore.

Mining, by its very nature, tends to be a 'batch' process. The drilling phase is followed by the blasting phase which is itself followed by the load-and-haul phase, where broken rock is delivered by trucks sized to suit the mined tonnage, to the "run-of-mine" stockpile, or ROM. Ideally, the ROM will be large enough for the miner to place ores of different quality in different piles, allowing some blending to take place at this stage.

Soft rock open pit mining, such as practised in Rwanda, can be carried out with pick and shovel: in such cases the pit slope is much closer to vertical, as the 'country rock' generally has not weathered anywhere near as much as the pegmatite. Sometimes primary mineral processing is carried out within the pit itself, on other occasions it will be taken out of the pit for processing.

Artisanal mining is the ultimate for simplicity. In some cases, literally hundreds of locals descend upon an interesting outcrop, claim their square metre of dirt and start digging and processing with little more than a calabash, selling their meagre pickings to a more enterprising local, who will himself (or herself) on-sell to a larger trader, and so on up the line.

Underground mining generally requires that only ore need be mined; the mine is designed in such a way that the connecting tunnels are driven through the waste rock. In an underground mine, not only the walls have to be safe, but also the 'back' or roof.

MINERAL PROCESSING

The objective of the mineral processing stage is to separate the various constituents of the ore into two or more discrete fractions, one or more – the concentrate(s) – will contain as much of the tantalum minerals, with as few of the other minerals in the ore as possible. The proportion of tantalum in the ore that reports to the concentrate(s) is known as the *recovery*.

It has been previously noted that an ore will consist of tantalum minerals, other heavy minerals, and light minerals. Generally, mineral processing consists of two basic phases: primary concentration, where the heavy minerals including tantalum are separated from the light minerals, and secondary concentration, where the tantalum minerals are separated from the other heavy minerals.

Primary Processing
As opposed to the great majority of other metals, essentially all primary concentration of tantalum is effected by *gravity concentration.*

However, the first stage, at least in hard-rock mining, is the liberation of the tantalum minerals from the other minerals. In soft rock mining, nature has often carried out this phase, as the weathering process that produces the soft rock generally weathers the main ore minerals of feldspar and spodumene to friable, clay-like, material, leaving the tantalum, other heavy minerals, micas and quartz as fairly discrete individual particles.

Crushers, usually jaw or cone type, break the large rocks down to about 10mm and finer, with crushed material passing to a fine ore stockpile, or bin, which acts to smooth out the inevitable surges that occur in the crushing plant. Thereafter the plant will generally operate as a continuous, steady state, process. The second stage of liberation – grinding – is carried out in rod mills, or ball mills.

Liberation breaks the rocks into a size where the tantalum and the other minerals are essentially discrete. Complete liberation is not necessary; the aim is to achieve sufficient liberation to allow concentration. Furthermore, good mineral processing practice dictates that the valuable minerals should be recovered as soon as they are liberated, but also that a throw-away tailing should be made at as coarse a size as possible. The size at which these two requirements occur rarely coincides[5]. This leads to the first building block of gravity concentration circuits. A first liberation step may allow a first concentration step to produce a throw away tailing, and a low grade fraction containing most of the tantalum, that requires further liberation and concentration. The alternative approach allows the first concentration step to produce a final concentrate, and a fraction that requires further liberation and treatment. Both building blocks may be used within the same circuit. The ideal liberation phase will minimise the number of un-liberated coarse particles, while at the same time minimising 'overgrinding' and the production of unnecessary very fine particles. Neither crushing nor grinding units produce an efficiently ground product in one pass, and it is necessary to re-circulate the material through the mill several times, screening out the fine material at each pass.

The reason that the production of unnecessary fines is problematic is that gravity concentration, which effectively separates by mass, becomes increasingly less efficient as the particle size decreases below about 0.1mm (Figure 2).

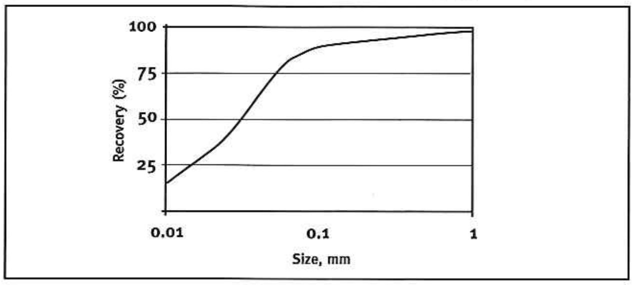


Figure 2: Typical recoverability of a liberated particle by size

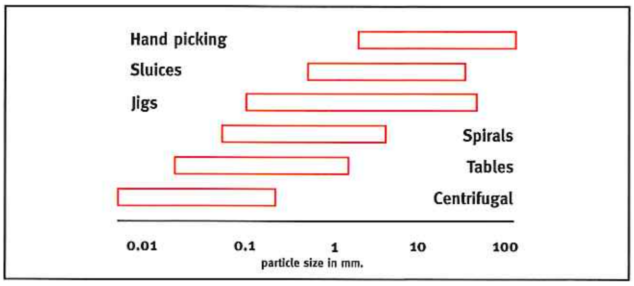


Figure 3: What equipment works at what size

While gravity concentration, as a process, is capable of separating liberated particles over a wider size range (500mm to 0.02mm) than just about any other process, no one item of equipment is effective over the whole size range (Figure 3). While some units can handle a fairly wide size range, others require a carefully sized material in order to operate effectively, both metallurgically and mechanically.

This leads to the next building block – series circuits, where a unit process can treat a longer size feed, and parallel, where careful feed preparation is required (Figure 4). In both cases, a simple concentrate and tailing is shown for clarity; however, most processes cannot make such a perfect separation, and there is nearly always a middling fraction, which is a combination of both concentrate and waste.

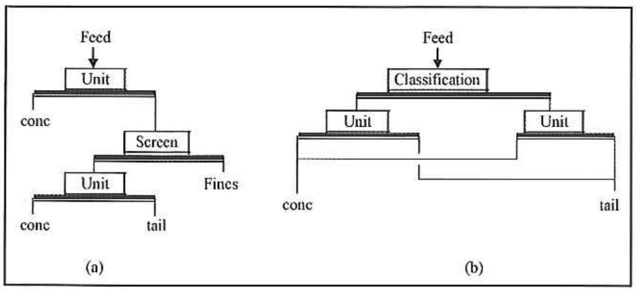


Figure 4: (a) Serial and (b) parallel circuit building block

Sluices are the unit of choice for the majority of artisans, in that these simple units can be fabricated by hand (or even hewn out of the rock itself, in which case it is called a ground sluice), and they need no power. Typically, material and water are fed to the top of the sluice; the tantalum settles out behind a series of cross bars, or riffles, designed to keep the lighter minerals in suspension and these, along with the water, flow down to the other end. In the case of ground sluices, the necessary agitation is achieved by the operator's careful shovelling. Sluices produce a low grade concentrate which requires digging out on occasions and treating on a second sluice.

Jigs are the other workhorse for the soft rock mine. The process is essentially the same: feed and water enter at one end of the unit, the heavy minerals settle out while the lights are kept in suspension – in this case by a vertically oscillating movement – and flow to the waste end.

Nigerian jig-table plant

Jigs have the advantage of being able to treat relatively long size range material, and serial circuits are common. When used in grinding circuits in hard rock operations, a rougher-cleaner arrangement could produce a final concentrate, with a tailing passing to further processing (Figure 5). This is the case at Wodgina. Alternatively, a rougher concentrate and final tailing can be produced, as at Greenbushes.

The mechanism of concentration of a jig results in a lower recovery of the middle size-range, and a refinement to the basic circuit would therefore include screening of the primary jig tailing, treating one or both of the screen products (Figure 5).

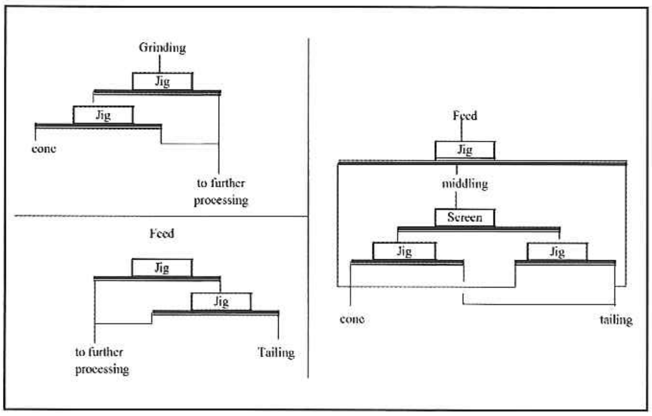


Figure 5: Typical jig circuits

Similar circuitry can be applied to soft rock ore treatment. In these cases all that may be required is the rejection of coarse, barren oversize and very fine clays, with two-stage jigging, to produce a concentrate for further upgrading, and a final tailing.

Spirals have, in recent years, become one of the most commonly used items of equipment. Inexpensive, with small footprint, relatively simple to operate, and reasonably 'tamper-proof' from inexpert helpers, they are ideal units especially for roughing and scavenging, although some circuits also use them for cleaning.

Requiring, ideally, a more closely sized feed than jigs, manufacturers offer different models designed to handle different sizes, and indeed types, of feed. Optimum plant operation therefore requires correct selection of the spiral model, and also that quantum changes in duty are not made after selection.

Simple spiral installations within the grinding circuit are used to recover liberated tantalum as coarse as possible (Figure 6a) – such is the circuit used at Tanco. Where spirals are the main concentration device, quite complex circuits can result: they are often designed and built as packages by the spiral manufacturer and will include all appropriate feed systems, internal pumps and plumbing. A typical circuit, Figure 6b, incorporates pre-sizing and potentially parallel circuits consisting of rougher, cleaner and re-cleaner spirals, with middling spirals. Scavenger spirals may well also be incorporated – such is the case at the newly constructed Marropino plant in Mozambique.

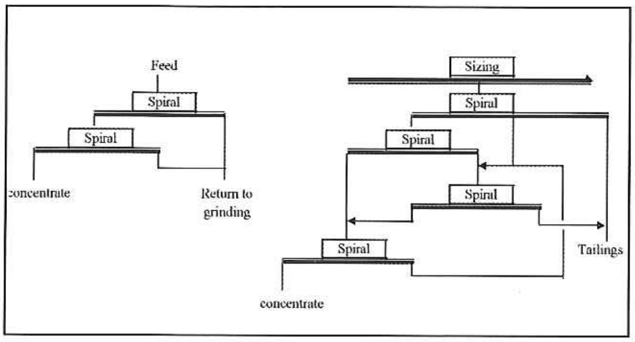


Figure 6: Spiral circuits (a) within the grinding plant (left)
(b) module of a complex all-spiral circuit (right)

Shaking tables are cumbersome, of low unit capacity and generally large footprint. However, in most cases they remain the ideal unit for cleaning mid-size range material, such as spiral concentrates. Less commonly, they can be used as the rougher unit as well. Tables require well sized feed, and hydraulic sizing – or classification – is preferable. When well operated they can, however, produce very great ratios of enrichment, albeit with some middling recirculation.

Very fine concentrating devices. Recovery of very fine particles in hard rock mining has always been a challenge (ultra-fine tantalum and its recovery is not generally an issue with soft rock mines), and has probably resulted in the development (and discarding) of more types of equipment than for any other size range. Currently favoured are the centrifugal devices, with the Falcon and Mozley MGS units being preferred for roughing/scavenging and for cleaning respectively. The other unit still in use is the Bartles CrossBelt Concentrator, as a cleaner unit.

Generally, all these units have a relatively low enrichment ratio (concentrate grade divided by feed grade) and units typically operate in series (Figure 7).

Non-gravity processes. While Tanco did operate a tantalum flotation plant in the early 1980's there are currently no operations where flotation, electrical separation, or other non-gravity circuits are in operation in the primary plants.

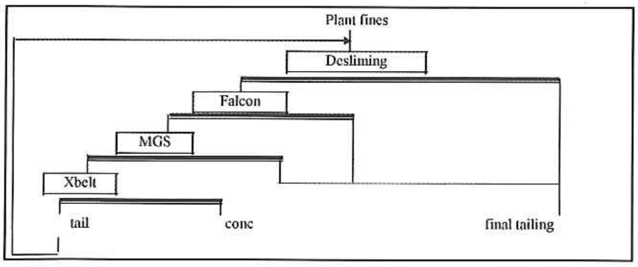


Figure 7: Typical ultrafines circuit incorporating centrifugal units

Putting it all together. One of the keys to efficient concentration is to choose the right equipment for each specific part of the circuit, and to plumb them together to provide optimum performance throughout the size range. Simple ore, such as alluvial ores, or even soft rock, require much simpler circuits than hard-rock mines, as indicated with the three circuits shown in Figures 8 and 9.

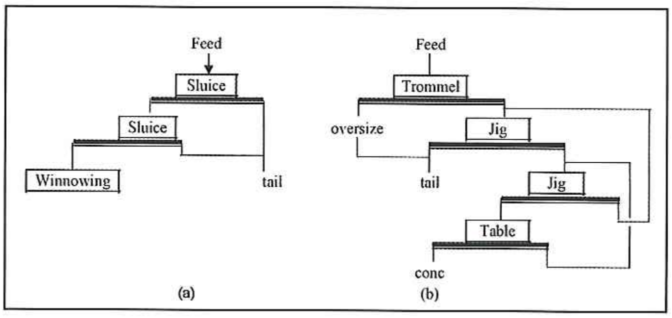


Figure 8: Simple soft rock flowsheets (a) artisanal producer in Rwanda.
(b) soft rock treatment plant, Nigeria

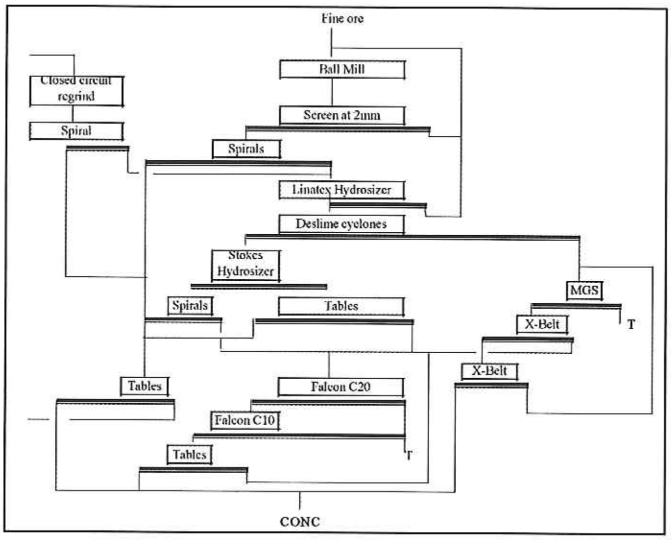


Figure 9: Tanco – a complex, hard rock processing plant

Secondary Processing

The primary plant will have separated the tantalum and other heavies from the light minerals. Secondary processing separates the heavies (and any remaining lights) from the tantalum. While the largest producers operate their own secondary plant or have a dedicated contractor, in most cases a dedicated secondary plant is not warranted: in these cases, the 'central processing plant' is the answer. Such plants may treat several very different primary concentrates with differing grades and mineralogy from several different mines; as such flexibility, not continuity is the key.

Whereas in the primary plant classification of feed prior to concentration may be regarded as a necessary nuisance, it is of paramount importance in secondary processing. Separating the incoming feed into five or more closely sized fractions, and treating each one separately, is not uncommon. Furthermore, the various units employed may individually run semi-continuously, but commonly material is transported from one unit to the next by 'mobile containment devices' (buckets!).

While further gravity concentration – either wet or dry – may be employed, probably the most common unit is the dry magnetic separator. Capable of producing several products from one machine, they can separate tantalite/wodginite (slightly magnetic) from microlite and cassiterite (non magnetic) and ilmenite and iron oxides (magnetic). Other processes used include 'reverse' flotation, to remove sulphides; one plant at least has developed a flotation process to effectively separate zircon from tantalite. Roasting, for antimony reduction, and even smelting to produce tin metal and tantalum-rich slag (glass), are occasionally used, although except in the very largest installations the latter will be done at a third party tin smelter. Putting all these unit processes together, complex 'circuits' can result.

OPERATING COST

This paper will not deal with any figures, real or estimated. However, as a guide, the following 'technical' factors play a major role in determining the cost of operation and cost of production:

- The type of mining – alluvial, soft rock, hard rock. The increasing hardness increases cost for drilling, blasting, crushing, grinding, need for power.
- Open pit mining is always much cheaper per tonne of rock moved than an underground mine.
- The mine strip ratio. The higher the ratio, the more tonnes of rock that need to be mined for each tonne treated, and hence the higher the cost.
- Mineralogy – the more complex the ore, including not only the tantalum mineralogy, but also the other minerals, the more complex the flowsheet, and potentially the lower the concentrate grade and overall recovery.
- Ore grade and recovery – these do not impact on the cost of operation in terms of cost per tonne processed, but they do have a major impact in the production cost in terms of cost per pound Ta_2O_5. Lower head grades and lower recoveries increase costs.

THE NEXT GENERATION OF MINES

Currently installed mining and processing capacity is sufficient for the near term. Making an assumption that at some time in the medium term demand will exceed current production capacity, additional tantalum production could occur by increasing the capacity of current plants, by an upsurge in artisanal production – although it is impossible to quantify the potential – or by bringing new production on line.

The recent market surge resulted in a substantial increase in interest within the exploration community, and there is a significant amount of tantalum that could be brought on stream, should the various market forces fall into place. Such new production could come from two very different types of source.

Several pegmatites have been discovered, in Australia, Brazil, Canada, Mozambique and elsewhere. Partially explored, many could potentially produce low cost tantalum, albeit generally at relatively low volumes, within a comparatively short time-frame. The same technologies described above would unlock their wealth, so markets, not technology, will determine the timing of such mining projects.

The other type of source could be the 'megaprojects'. Those in Australia, Brazil, Canada, Egypt, Greenland and Saudi Arabia have been well publicised in the last two to three years. They are all apogranites or carbonatites/syenites. As such they have in common: potentially very large volume; finer mineralogy; metallurgical complexity, and very low Ta:Nb ratios. Indeed, the majority are essentially niobium projects with small amounts of tantalum, with Ta:Nb ratios in the range of 1:10. In the apogranites tin, and sometimes feldspar, is also a potential by product: the carbonatite/syenites tend to have higher uranium and zircon.

Primary concentration of the apogranite type deposits will probably continue to incorporate gravity concentration to a great extent: with the carbonatite type deposits however, where the main mineral is tantaliferous pyrochlore, pyrochlore flotation will probably be the key. Pyrochlore flotation, with Araxá, Brazil, being by far the largest example, requires very careful desliming, and thereafter multiple stages of cleaning[6].

In all cases, secondary processing will be mandatory, while in several projects some chemical processing will also be required. In these cases, the product will not be tantalum minerals but some form of intermediate – a TaNb alloy, a tantalum oxide, or even a potassium fluotantalate.

The flowsheets for most 'megaprojects' remain conceptual; while they all incorporate technologies known to be effective for other elements, they will require significant pilot plant work to confirm their applicability to tantalum, and the specific orebodies. Hence, new technology, as well as markets, will be drivers for these projects.

It is also reasonable to presume that such mines will require significant capital to bring them on stream, plus higher operating costs. Unless there are significant 'credits' from by-products, this suggests that they would have to be regarded as the 'next generation' mines, meeting the next major leap in tantalum requirements, or as a result of sustained significant growth within the industry, rather than competing with currently operating mines for existing markets.

ACKNOWLEDGEMENTS

I should like to thank the various mining companies, as well as colleagues and friends, for all their help

References

1) Burt, R.O. (1999) Research, Innovation and Reality – the Second Richard Mozley Memorial Lecture. Proc 31st Annual Meeting of the Canadian Mineral Processors. Ottawa CIM pp136-148.
2) Hilliard, T (2003) TANCO – Endurance through adaptability. CIM Bulletin 96 (1070) April. pp43-46.
3) Foord, E.E. (1982) Minerals of tin, titanium niobium and tantalum in granitic pegmatites. Cerny, P Ed. Short Course in Granitic Pegmatites in Science and Industry Mineralogical Association of Canada, Winnipeg. pp187-238.
4) For the TIC response see 'Coltan' and the DRC TIC Bulletin No 106, June 2001.
5) Burt, R.O. (1984) Gravity Concentration Technology. Elsevier Science Publishers BV, Amsterdam. 607pp.
6) Paraiso, O. de Silva, and de Fuccio, R. (1982) Araxá Niobium Mine. Mining Magazine. Feb.
7) Correira Salles, J.J. (2000) Production of niobium and tantalum from the Pitinga hard rock tin mine. TIC Bulletin No 101 March 2000 pp4-6.

DLA/DNSC

On April 6th the DLA announced the following awards in March, under the Basic Ordering Agreement (BOA) system: 11 000 lbs capacitor grade tantalum metal and 20 000 lbs vacuum grade columbium (niobium) metal to H.C. Starck, Newton, MA and ABS Alloys, Mexborough, England, for approximately \$820 000. On April 15th the award of 150 000 lbs tantalum oxide to Sogem USA of Raleigh, NC for approximately \$5.1 million, under solicitation of offers, not BOA, was announced.

No awards were made in April or May under BOA. On June 3rd the DLA suspended sales of ten commodities until further legislative authority is granted, based on the 'results of the review of statutory revenue ceilings'. The commodities concerned included columbium concentrates, columbium ingot, tantalum concentrates, tantalum carbide powder and tantalum oxide.

SURVEY OF RESOURCES

The Department of Industry and Resources of Western Australia has recently published Mineral Resources Bulletin 22 of the Geological Survey of Western Australia: 'Tantalum in Western Australia'. Chapter 10, 'International tantalum resources – exploration and mining' is admirably thorough. This can be found at www.doir.wa.gov.au.