Much ado about Tantalum. Again.

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Introduction.

Tantalum was first isolated as a discrete element in 1802, by Anders Ekeberg, who wrote *"This metal I call tantalum ... partly in allusion to its incapacity, when immersed in [many] acids, to absorb any and be saturated"* – a reference to Greek mythology, where Tantalus, as a punishment for several heinous acts, was condemned to stand in water, under a fruit tree, but never be able to reach the fruit nor drink the water.

Many within the industry would grin ruefully, and say “That fits”.

Compared to the ‘major’ metals, the tantalum industry is tiny: total world mine production rarely exceeds 2000 metric tonnes of contained Ta_2O_5 a year, which equates to an annual value, at today’s prices, of about US$300million. To put this in perspective that is less than 1% of the value of world’s copper output.

Copper is almost exclusively produced by several score of large industrial mines, often with captive smelters, with the resultant product being sold - either direct to manufacturers or to one of several bonded warehouses - at metal prices that are daily determined in a transparent manner on the London Metal Exchange. (L.M.E.) A mine can therefore produce at optimum rate, with an almost certainty that its product will be sold. Furthermore one ‘average’ mine more or less is unlikely to have anything but a minor impact on the market.

Tantalum, in the immortal words of that great thespian, Monty Python, is “something completely different”.

Tantalum is not traded on the L.M.E. - or any other exchange. Prices are set – either on long term contracts, or parcel by parcel - between miner or trader and processor, on a confidential basis. Most technical journals that take a stab at current prices would admit their figure is no more than a best guess, based upon ‘discussions’ with one or two industry watchers. Even the industry body, the Tantalum-Niobium International Study Center (T.I.C.) which collects, collates and publishes data on volumes of material as it passes through the supply chain, is by its mandate, and for anti-trust reasons, prohibited from collecting, publishing, or even discussing current and future prices.

Even at its most vibrant, there are only a relatively few industrial mines, at least of any size. Classically these sold their output to only a handful of chemical processors (colloquially often known as smelters). In addition, a not insignificant amount of material is won by artisanal means (but certainly only a fraction of that mythical '80%' quoted by some observers) – here the rough product passes through several hands that upgrade and blend small packages, prior to international traders selling these to the processors. None of these artisanal mines are, of themselves, of any significance, but as a whole they make up an important part of the market, in that they can come 'on stream' or shut down at a moment's notice – the miners coming from or moving on to a different product, whichever is the more profitable or available. More of this later.

Processors sell their product to a variety of customers who fabricate it into something else (for example, capacitors, bar, rod, etc.) which are then sold to manufacturers for integration into *their* products.

Market confidentiality, artisanal mining, convoluted supply chain. Add to this, that one of tantalum's major uses is in the electronics industries, and it is little surprise that a decade or so back some civil societies decided the tantalum used in cell phones would be the ideal target for their campaigns to alert the 1st world to the horrendous civil strife in central Africa. Right campaign, wrong target, as this paper will show.

The paper will also show that, while industrial mine production dropped dramatically after the 2008 recession, it is recovering, as old mines are restarting and new ones are close to coming on stream.

The future of the tantalum supply chain is secure.

Geological Background.

A detailed review of the geology of tantalum, and niobium, has recently been provided by Linnen, Trueman & Burt (2014), to which the interested reader is referred.

Neither tantalum nor niobium occurs in a free state, but in the form of complex oxides and other minerals. Whilst at least nineteen tantalum minerals had been recorded as early as 1982 (Foord 1982), many of them are only of mineralogical interest. Those that are found in economic quantities are shown in Table 1.

Tantalite-columbite and microlite are the most common minerals, being present to a greater or lesser extent in almost all tantalum orebodies. Tantalite is the tantalum rich end of the tantalite-columbite isomorphous series, where tantalum and niobium may substitute with each other. The common ratios between the two are from 3:1 to 1:3: hence the mineral commonly being referred to as tantalocolumbite or more often columbotantalite – which in Africa is colloquially shortened to 'coltan'. Unfortunately in many non-technical documents 'coltan' is incorrectly used to refer to all tantalum, be it in mineral or metal form.

TABLE 1
Tantalum minerals of economic interest.
The most important ones are in bold:

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

Microlite is the end member of the microlite-pyrochlore series, but there are very few cases of pyrochlore deposits with less than a 10:1 niobium:tantalum ratio, or indeed microlite with significant quantities of contained niobium. Microlite contains small amounts of naturally occurring radioactive minerals (NORM) resulting in concentrates containing microlite often being classified as ‘Class 7’ with consequent shipping restrictions.

Wodginite is less common, but was the primary tantalum mineral found in the original Wodgina deposit in Australia (from which it gained it name) and also at the Tanco mine in Canada. Struverite, a variation of rutile, is a low grade source of tantalum predominately associated with cassiterite (tin ore) in south-east Asia. The type location for simpsonite is the Tabba Tabba deposit in Australia, but it is occasionally found elsewhere.

A word of caution - when miners talk of ‘ore’ they refer to the material in the ground, which is different to processors who regard what a miner calls ‘concentrate’ as ‘ore’. An ore in the ground rarely contains more than 0.05% Ta_2O_5. While it is the miner’s job to get the ore to a concentration plant, it is the mineral processors job to turn it into a saleable product – generally regarded as of the order of 25-30% Ta_2O_5 or higher. (See Burt 2004, for examples of methodology).

Primary Deposits: All primary tantalum (and niobium) deposits are associated with igneous rocks, and can be grouped into three types, on the basis of the associated igneous rocks:

a) Alkaline to peralkaline granites (sometimes referred to as apogranites) and syenites,
b) Carbonatite-hosted deposits,
c) Peraluminous pegmatites and granites (referred to hereafter as pegmatites).

Alkaline granites: that is, rocks that are enriched in the alkali based minerals compared to aluminum, can contain economic quantities of the rare earth minerals, zircons, tin and, in the context of this paper niobium and tantalum. This is often in a 10:1 ratio, with the primary mineral being pyrochlore. They are often relatively large deposits (100-1,000 million tonnes), with fine mineralogy. Of this type, the Pitinga mine in Brazil would be a typical example of an operating mine. While primarily a tin mine, it also hosts one of the world's major resources of niobium and tantalum, the latter in the form of columbotantalite. Another, as yet unworked, significant deposit is Al Ghurayyah in northern Saudi Arabia.

Syenites are another form of alkali feldspathic rock, with dominant nepheline syenite (itself a valuable mineral used in glassmaking). They are often 'ring' formations (somewhat reminiscent of an onion skin), and generally highly complex. The Lovozero deposit in northern Russia is a prime example of an operating mine where tantalum, and niobium, are lesser albeit important by-products. Of potential interest are the Nechalacho deposit in Canada's Northwest Territories, and the Motzfeldt complex in southern Greenland.

Figure 1: The Lovozero metallurgical complex, northern Russia
(Picture courtesy of Lovozero GOK)

Carbonatites: these are igneous rocks containing in excess of 50% carbonate minerals. They are the major source of niobium – Araxa and Catalao mines in Brazil, and Niobec in Canada are all carbonatites. These are all pyrochlore mines with no tantalum of any significance. However, some other carbonatite deposits do contain potentially economic quantities of tantalum, along with various rare earth and industrial minerals – such as the Fir, Verity and Martinson deposits in Canada and the Mt Weld and Dubbo (zirconia) deposits in Australia.

Pegmatites are enriched in aluminum compared to the alkali based minerals (Černý 1989). Pegmatites have been, and continue to be, the most important source of tantalum mineralization – however, for clarity, only a very small fraction of pegmatites do contain tantalum. Simply put, 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 where tantaliferous pegmatites were intruded are in the Archaean (>2.5 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. The now closed Tanco mine, Manitoba, Canada would be typical of a complex, zoned, pegmatite (Černá et al, 1972); the Wodgina mine in Western Australia is an example of a simple, albite type pegmatite.

One sub-class of peraluminous granites is enriched in lithium and fluorine. While only hosting a relatively small proportion of tantalum resources, one - the Yichun deposit in China - is a significant producer of tantalum and lepidolite (a lithian mica).

Secondary deposits: 'blind' pegmatites – those that do not outcrop are extremely difficult to find. Even the Tanco pegmatite, the only significant blind pegmatite actually to be mined, was found by accident. The rest outcrop, at least partially, to surface or at least to the overlaying soil cover. Many of these are heavily weathered to the point of kaolinization, and have become 'soft-rock' deposits. Taken a stage further these weathered deposits spawn the alluvial deposits that are being mined in central Africa, (where columbotantalite is the predominant mineral, with lesser microlite) and elsewhere.

The grain size of the columbotantalite mined and recovered from the majority of these alluvial deposits suggests that they are spatially closely related to their primary source pegmatites; generally within 2 to 3 kilometres (Varlamoff 1969). Very little fine columbotantalite is recovered, especially when mined by artisanal means. This is at least partially related to the primitive concentration methods employed, but it is a reasonable assumption that there were very few fines in the alluvial deposits to begin with. This finer-grained columbotantalite and tin (either as primary fines within the original melt or coarser material that has been abraded down during weathering or transportation) would have been carried further downstream. It would thereafter be deposited on sandbars, potentially related to areas of reduced stream competency, or retained in suspension and finally washed out to sea.

How much tantalum *is* out there?

Mining and exploration companies, especially when going to the market for capital, have a duty to quantify their resource. Since the much publicised 'Bre-X' scandal of the 1990s, (see Francis 1997, for example) the industry and regulatory bodies have developed clear, concise, definitions and methodology that must be adhered to. Both the Australian developed JORC code (JORC 2004) and Canada's National Instrument

43-101 define resources and reserves, and how and what must be (and must NOT be reported, and when (OSC). Plainly put, the purpose of these Codes or Instruments is to ensure that misleading, erroneous or fraudulent information relating to mineral properties is not published and promoted to investors on the stock exchanges.

In simple terms a **resource** could be regarded as the 'geological' determination of a quantity of material in the ground in terms of tonnage and grade; a **reserve** is the 'economic' determination of this. Essentially, a reserve is only a reserve if it can be mined at a profit at the time of reporting. This means that a reserve at a market price of 'X' may well cease to be so if the market price decreases significantly, and vice versa (this is not just the case of putative mines, but also for existing ones). However, with a resource, the requirement is only that 'there are reasonable prospects for eventual economic extraction'; hence, within limits, a resource is essentially not price sensitive. Put another way – a 'reserve' is minable – a 'resource' potentially will be. Both of these categories are subdivided to show the certainty, or lack thereof, of the information.

In addition to these 'quantified' resources, some projects are at the relatively early stage of exploration, and do not meet any JORC or other standard - such deposits should be classed as an 'exploration target' only.

Obviously, a Company will only publish its own resource (and/or reserve) data, not anyone else's. However, this author did develop a 'global' resource estimate, not to the rigid JORC standards including deposits regarded as 'exploration targets with amounts appropriately discounted for uncertainty, as an attempt to give an overall indication of potential future supply (Burt 2010).

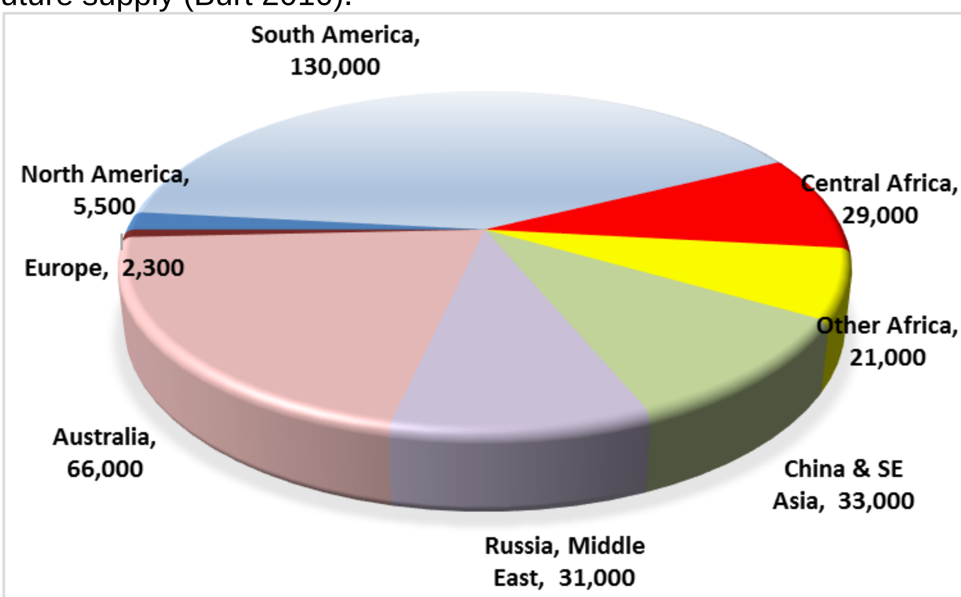

Figure 2: Estimated 'likely' resources in metric tonnesTa_2O_5 (after Burt 2010)

Of course, many deposits do not make it to a resource, and of those not all make it to a quantified reserve. And, as has become very clear over the last decade and a half, even companies that post reserve estimates often do not develop them – for a variety of reasons - into a mine.

What about central Africa? As early as 2002 we were told that:

> 'It is generally believed that 80% of the world's reserves are in Africa with the DRC accounting for 80% of the African reserves' (IPIS Jan 2002).

While that paper cited sources for other information, interestingly, it did not for this one - it is a bald statement, and where it may have originated is 'lost in the mists of time'. However, this figure (and the derivative – that 65% of the world's resources are in the DRC) took on its own momentum, morphing into ``DRC contains 80% of the world's entire coltan resources`` (Parkinson 2006, and others).

Figure 3: Typical pegmatite, mined artisanally, Rwanda

In actuality, there are almost no quantifiable reserves in the DRC. Figure 2 shows the whole central African region probably hosts about 29,000 metric tonnes Ta2O5, or 9% of the world's resources. Even this is based upon information some fifty years old. Not only has tantalum mining – along with the much more important tin mining –switched over the last forty years from industrial scale mining to artisanal exploitation, but essentially all mines are treating alluvial or easily mined soft rock deposits. Artisans do not carry out exploration to delineate future resources. In any event alluvial resource estimation is extremely difficult, even for experienced exploration geologists. Estimates of DRC resources that were available varied considerably with 50-60 million pounds being the favoured range, to which were added resources in other countries in 'central

Africa'. This included Rwanda, where a detailed inventory of that Country's tin mining industry was carried out by the BRGM with enough information for a reasonable estimate of its tantalum resources to be developed. (Guillou and Ziserman 1987).

Considering the general geology of the area, and its undoubted spawning of many pegmatites that have, through weathering, become exposed and therefore suitable for artisanal mining, almost certainly additional placer deposits will be found. For example, recent production in Rwanda would suggest that the BRGM report significantly underestimated tantalum resources. Furthermore, it is also eminently possible that a well-executed exploration programme in the region could discover one or more world-class pegmatites just below the overburden, or possibly even a 'blind' pegmatite 50-100 metres below the current surface.

Nevertheless, even if the 29,000 metric tonne figure is doubled, the 'likely resource' figure for the region it would still account for less than 20% of world resources. A long way from the 80% figure, claimed in the IPIS report.

So much for that urban myth…

Figure 4: a washing area at a typical artisanal mine, Katanga, DRC.
(Picture courtesy K. Hayes)

The supply picture.

Tantalum that reaches the processors for conversion to chemicals and metals originates not only from mining primary and alluvial deposits, but also from 'secondary sources' including tin slags, and recycling.

Higher grade tin slags (those with a Ta_2O_5 content in excess of about 3%) reach the processors directly. When the market is favourable, lower grade slags (say 1-3% Ta_2O_5) are converted, usually by pyrometallurgical processing, to a 'syncon' of a tantalum content suitable for standard chemical processing. Some reports suggest that these low grade slags are 'depleted'. This is just not so. It is simply that, when markets are low, syncon production generally slows or stops, as they *are* a high cost option. Many hundreds of thousands of tonnes of such slags remain, and will continue to be a viable source of tantalum units as and when the market requires.

Figure 5: A pile of tantalum rich tin slag, and its treatment.
(Pictures courtesy Malaysia Smelting Corporation)

In the early years of the tantalum industry tin slags was the primary source of tantalum – indeed even until the late 1980s more than half the tantalum units processed were from tin slags. It dropped rapidly to about 25% and then by the turn of the century to the range of 15-20%, at which level it has generally remained.

In tantalum terms recycling is primarily 'pre-consumer' that is, from within the upstream supply chain itself, rather than from end-users. The main source of this recycled material was from the electronics industry – capacitors, sputtering targets, etc. This would account for between 20-25% of processor feed being recycled scrap and other tantalum, a figure that hardly varied for at least twenty years.

However, this is changing. New separation technologies have allowed previous complex waste streams – that is where the tantalum units were lost to the supply chain - to be accessed. For example in the aerospace industry, rhenium was the captured element, but now the tungsten, tantalum, nickel, niobium etc. can all be accessed and recycling costs shared. Indeed, pre- and more recently post- consumer scrap recycling, (the so called ‘urban recycling’) has, according to some industry watchers, doubled in recent years.

Hence, primary sources – that is, from the mining and concentration of tantalum bearing ores – only accounted for approximately 60% of processor feedstock, and even this is now dropping with the increase in recycling.

It may be obvious but it is often overlooked that supply and demand (taken here as the processor’s requirements) can be – and have been – very different animals.

In the late 1990s demand – primarily related to the dot.com boom - increased rapidly, outstripping existing ‘industrial’ mine supply. Existing mines in Australia, Brazil, Canada, China, Ethiopia, Russia and elsewhere were running at full capacity, and although artisanal production around the world increased, an assertion in one recently published ‘meticulously researched’ book on the Congo that in 2000 (the height of the boom) 80% of the worlds tantalum came from the Congo - and the rest from just one mine in Australia (!) - is patently rubbish.

There was a flurry of exploration – from the Arctic circle to southern Africa - and those existing mines that could entered into a period of expansion, notably the two Australian mines owned by Sons of Gwalia (now GAM); Greenbushes and Wodgina. Their increased production neatly came on stream as the dot.com bubble burst early in the 2000’s; the market was unable to absorb this and supply outstripped demand for much of the next decade. Artisanal miners moved on to other more profitable minerals and exploration for new mines essentially ceased.

Figure 6; loading ore at Wodgina mine, Australia.

The Wodgina mine could indeed become a classical 'case history'. Originally a low-cost producer, its orebody was decreasing in grade, as anticipated in their mine plan. However, not anticipated was that the tantalum was becoming finer and hence more difficult to recover. Even if their operating costs per tonne of ore had remained constant this latter would have increased the cost per pound of the finished product. Unfortunately, labour and material costs were rising dramatically, due to the boom in the vastly larger local iron-ore mines, and Wodgina's production costs exceeded their potential income. The inevitable result was closure, by 2008. (It did reopen for a short period in 2011, but at the time of writing is still on care and maintenance). Greenbushes fared no better, closing its tantalum operations in 2007 – it is now one of the world's major lithium producers, and the tantalum mining side has not reopened, although its secondary plant continues to process low grade concentrates from other, small, West Australian operations.

The 2008 financial meltdown had other casualties, with the struggling Marropino mine in Mozambique closing in 2009, notwithstanding a very bullish report just a year earlier (Ruffini 2008). Since then, the Tanco mine has ceased tantalum production to concentrate on its profitable cesium orebody, and the Kenticha mine in Ethiopia was temporarily closed, as it came to grips with the handling of their concentrates, the radioactivity level of which had increased to Class 7 classification.

While the liquidation of the inventories built up in the 2002-8 period delayed the impact of these closures, demand was exceeding supply. Fortunately, some larger tantalum mines were surviving, including those in Brazil and China, as were several small-scale 'semi-industrial' operations, but, without doubt, industrial mine production declined dramatically in 2008.

Figure 7: the Yichun mine concentrator complex, China.
(Picture courtesy JiangXi Tungsten Industry Group Co., Ltd.).

Figure 8: MIBRA open pit, Brazil.
(Picture courtesy of AMG Mineracao, Brazil)

So, if industrial mines were closing, how to fill the gap?

While artisanal mining does occur in South America, south-east Asia, Nigeria and elsewhere, by far the largest potential output – and that most politically sensitive – is that from the Great Lakes region of Central Africa. Any discussion of this material must, therefore first discuss the geopolitical side.

The central African conundrum: From 1997 to 2003, the region was embroiled in what is known as 'Africa's World War'. The underlying reasons for this conflict are 'complex' and hotly disputed. While it is now accepted that the region's natural resource wealth was not the root cause of the violence, (see for example, Global Witness 2015), there is little doubt that the involvement of illegal forces in the mining, transportation and taxation of minerals from the war-torn eastern DRC did provide some of the funding needed to continue the war. However, 'there is no evidence that this [war] would have stopped if tantalum disappeared from the equation'. (Nest 2011)

Tantalum became the *cause celebre* for several activist groups, who saw the electronics industry as a soft target, even though tantalum was a minor contributor to rebel funding (approximately 5% of mineral revenues), while gold was by far the largest financial contributor, with tin the next largest contributor. And, that the amount of tantalum in a mobile phone was insignificant, even compared with tin, tungsten and gold – the other 'conflict minerals'.

In the end it was just another urban myth.

When hostilities flared up in 2006, old and new Civil Societies turned their attention again to the region – this time, however, while *'Blood on Your Mobile'* was the battle cry, is was not just tantalum in their sights, but all the 'conflict minerals'.

Early in the 2000's the T.I.C. advised its members that minerals sourced from central Africa should be obtained responsibly with the result that the majority of the processors disengaged, but the 2008 report by the United Nations Group of Experts challenged the tantalum and tin industries to act in a more determined manner.

<u>Industry led reactions.</u> The tantalum supply chain is complex and convoluted, but at its heart are the processors. There are many miners and suppliers of concentrates if one adds artisanal and industrial mines together and there are countless companies that use tantalum in one form or another in their products. But there are probably no more than a couple of dozen processors. Hence the supply chain neatly splits itself into 'upstream' and 'downstream' (of the processors). Another way of considering this might be that the former is the 'supply' side and latter is the 'demand' side.

Upstream reactions. For the upstream side of the supply chain devising programmes that ensured access to market was paramount. The tin industry was probably the most exposed of the '3Ts' minerals, and by mid-2009, they had introduced the due diligence programme known as the *ITRI Tin Supply Chain Initiative* (iTSCi). The tantalum industry became partners early 2010. By mid-2011 it had been activated in Rwanda and Kantanga province in the DRC. Maniema province was added a year later and both North and South Kivu mines as well as Burundi are now partners in the iTSCi programme (ITRI 2015a).

iTSCi is a full due diligence programme that uses the OECD Due Diligence Guidelines as its base document (see later). While sometimes referred to as a 'bag and tag' programme [all bags of concentrate are indeed tagged and recorded, with the tag following the material through the supply chain, allowing for appropriate transparency and provenance] it has the other two facets that make it OECD 'compliant'. One is regular, independent auditing of the programme, of countries, and of minesites. The other is risk management, which itself can be split into two. Minesite baseline assessments are carried out by iTSCi's in-region partner, Pact and their local partners prior to commencing iTSCi at that site. Incident reporting and mitigation are handled by local, regional, and provincial *Comite de Pilotage* depending upon the severity of the incident. None of this comes cheap, of course, and it has fallen to the miners to pay the necessary fees, not the buyers who are demanding that it be done. With the substantial drop in prices in 2015, the miners are finding this a heavy burden, and are calling for assistance from downstream, donors, and Governments who have, or plan to introduce, regulations on reporting of imports of 'conflict minerals', with an 'open letter' signed by representatives from the three countries already utilising iTSCi, as well as from the three managing partners of the programme including the T.I.C. (ITRI 2015b).

iTSCi is not without its difficulties. For example, the very wealth of data – there are in excess of ½ million data points generated per year, many of these using ‘pen and paper’ rather than an electronic system – has stressed the system, causing delays in reporting. However, five years after iTSCi was first introduced, no comparable programme has been successfully deployed. iTSCi is *the* accepted Due Diligence programme by both Upstream and Downstream. While not advocating a monopoly, having just one programme in an area does minimise any confusion and the potential of things slipping through the cracks especially in-region, where infrastructure and training remains fragile.

Two downstream-led projects for tantalum are in place in central Africa, both of them incorporating iTSCi. These are the AVX/Motorola Solutions led *‘Solutions for Hope’* and the KEMET led *‘Partnership for Social and Economic Sustainability’* programmes. Both are ‘closed pipe’, but slightly different in the detail   In the Solutions for Hope programme, the concentrates, once bagged and duly tagged, are sold direct to the downstream customer (AVX), who subsequently have the material toll processed by their chosen Processor. KEMET has a vertically integrated supply chain, with material flowing from their minesite to their capacitor powder plant in the US (KEMET 2015). This ‘closed pipe’ approach may indeed be the way of the future, at least for the larger producing artisanal mines or cooperatives, in that it simplifies the otherwise complex supply chain, which not only improves transparency, but also means more of the purchase price flows to the miners. In addition, both of these programmes include local infrastructure development, including schools and health centres – a must for any developing operation, whether a closed pipe system or indeed an industrial mine, in the region, as this creates a more socially responsible and sustainable situation (Persico 2012). International Traders will still have their place, helping smaller producers to get their product to international markets.

Downstream reactions. For the downstream side, the priority was ensuring that their feedstock was ‘conflict free’ – hence their approach was bound to be different to the upstream approach.   The electronics and telecommunications industries, through the Electronic Industry Citizenship Coalition and Global e-Sustainability Initiative (EICC/GeSI) developed the *‘Conflict Free Smelter Initiative’* (CFSI) which requires Processors to provide credible evidence of their conflict-free sourcing (Electronic Industry Citizenship Coalition, 2011). The Processors are subjected to an annual, independent validation audit using the EICC protocol developed specifically for that purpose. It is a vigorous, in-depth, and demanding regime involving open-book access in which follow-the-money assessments and physical stock checks provide a mass-balance of minerals and documentation to demonstrate that the chain of custody from mine to smelter is fully traced. (Millman 2015).

EICC/GeSI also developed a ‘Reporting Template’ that assists end users attempting to trace the links back to the Processor. (CFS 2012). It did not take long for Ford Motor Company, followed by others in the automotive and then the aeronautical industries to appreciate the efficacy of this programme, and to become partners in it.

The tantalum industry, with significant support from within the T.I.C. leadership, quickly embraced CFSI, accepting it as the new way of doing business, and most Processors are deemed CFS Compliant.

<u>Government and Inter-Governmental Agency reactions.</u> The OECD *'Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas'* (OECD 2011) and it's supplement for the '3T' <u>minerals</u> (cassiterite, columbotantalite and wolframite) was published early 2011, just over a year after multi-stakeholder discussions on such a Guidance began – a fine example of multi-stakeholder involvement when all parties, from Government to Civil Society to Industry, worked together toward a common <u>positive</u> goal – that of providing a framework where legitimate mineral exports could occur for central Africa, rather than putting so many roadblocks in the way that disengagement would be the only logical solution. It is worth noting the title of the Guidelines – they are non-specific, in that they relate to (any) minerals from (any) conflict-affected or high-risk area.

The International Conference of the Great Lakes Region (ICGLR) has developed their own *Regional Certification Mechanism,* which incorporates the OECD guidelines. It also requires mines to be certified 'conflict free' and as of the middle of 2015 the number of mines so certified exceeds 140. (Lezhnev 2015).

The Dodd-Frank Act (or more correctly, the massive U.S. Financial Stability Act) was promulgated in 2010: section 1502, relating to 'conflict minerals' came into force in 2012. (Dodd Frank 2012). This is very different to the above. It is law for all companies that are subject to reporting rules of the Securities and Exchange Commission, and is not a guideline. Furthermore, it is targeted, in that it specifies just four <u>metals</u> (tin, tantalum, tungsten and gold), and specific countries – The DRC and its adjoining countries. The EU is close to finalising its own regulations; while these will target the same four metals, they will apply to conflict regions – that is, not countries *per se*, but any conflict region worldwide, though how these will be defined could be 'interesting'.

Neither of these two regulations ban the purchase of conflict minerals from their target regions, just that they have to be declared, and there has to be the appropriate due diligence - the OECD guidelines being accepted as the appropriate due diligence. That said, a U.S. appeals court recently declared that the Securities and Exchange Commission cannot force public companies to declare whether their products may contain 'conflict minerals' because it violates their free speech, rather taking some of the teeth from Dodd-Frank – and presumably causing more confusion. Hardly surprisingly, some Civil Societies are challenging that ruling.

It is also ironic that the challenge to Dodd-Frank is coming from the US manufacturers, whom it was supposed to protect, while those that it truly impacted most – the miners and their families in Central Africa - have gone from seeing Dodd-Frank as 'another colonial imposition drafted without any consultation with the Governments in the region' to fully accepting the challenges that it brought, realising that it has, along with the in-region iTSCi programme, had a remarkably positive impact on the region. (PACT 2015).

Did all these measures have an impact on the market?

Industry and Government agencies have certainly put a myriad of measures in place, but in the end it is the consumer, or more accurately the consumer conscience that determines the overall efficacy of these measures. One obvious measure of their impact is the amount of ethically sourced material reaching the marketplace.

This paper can only speak for tantalum – here the impact has been massive, as the following figure highlights.

Even at the height of the 2000 tantalum 'bubble' exports from central Africa was less than 500 tonnes of contained Ta_2O_5, admittedly some of that coming from the DRC would now be called 'conflict mineral'. Once the bubble burst, and industrial mines had taken up the slack, output was rarely above 200 tonnes. The industry's policy was 'advisory', and while many Processors had disengaged, some hadn't, so up to 2008 a proportion of the output may have helped to finance the ongoing rebel activity. Since the passing of the Dodd-Frank Act, and since the roll-out of iTSCi, exports have dramatically increased, with close to 1,000 tonnes of contained Ta_2O_5 (of which more than half was from Rwanda) passing through the iTSCi and CFSI programmes in 2014.

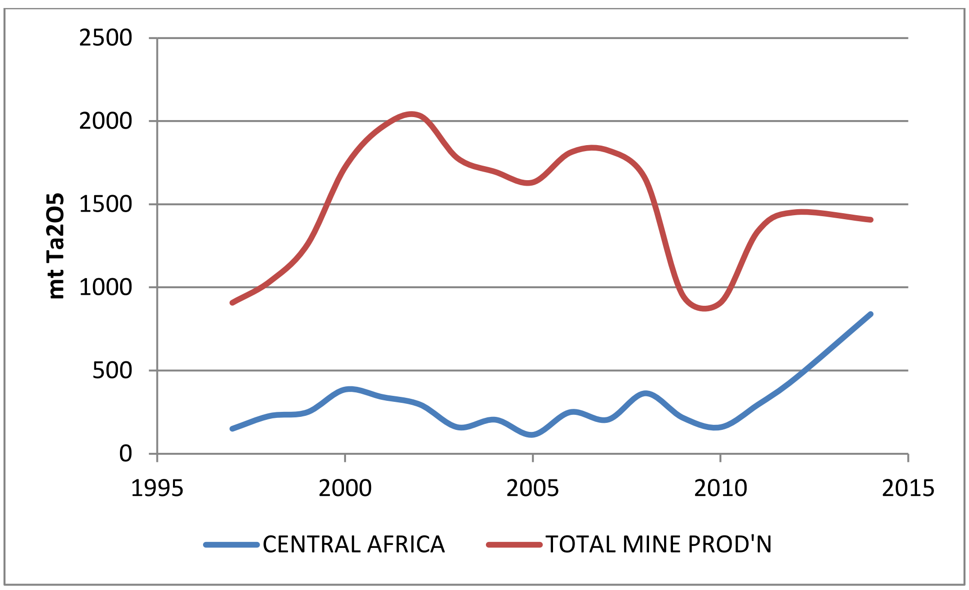

Figure 9: Mine output in metric tonnes Ta_2O_5. Blue line: reported Central African production. Red line: total world mine production. (Data generated by the author from various technical journals, company reports, government statistics and personal communication).

It is clear – and generally accepted by all stakeholders – that the various measures put in place by Governments and industry, with the enthusiastic support of many civil societies has effectively broken the link between mining and the funding of rebel groups, at least in the 3T sector. Furthermore, the programmes introduced by AVX and KEMET with their partners have demonstrated that socially responsible production of tantalum ores in the GLR is possible and practical, thereby assuring end users that they are using tantalum ethically sourced from Central Africa. In other words, by working together toward a common goal success has been assured.

For anyone left in doubt, a quote from PACT's Regional Director Yves Bawa (PACT 2015) says it all:

> As a Congolese citizen, I am incredibly proud of what is being achieved in my country and in those of our neighbors to build a responsible minerals sector in the region. As a development professional, I continue to be amazed at the rate at which we have achieved broad, impressive results in such a short time. As a brother, I remain deeply concerned for, and committed to, the welfare of the artisanal miners of the Great Lakes Region who still need so much support to earn a safer, more dignified living. As a father, I am working to build a better country for my children so they never have to face such hardship.

Quo Vadis?

2015 was a bad year for the mining industry. Markets were weak, prices were down, new projects were few and far between and exploration was at a forty year low. It is hardly surprising therefore, that tantalum is also suffering another one of its downturns, from mine to manufacturer. Rumours abound. There seems to be a 'Chicken Licken' atmosphere in the mining industry, and tantalum is not an exception. (Indeed, why should it be?) Everything from 'tantalum reserves are running out' to 'no-one wants the stuff anymore'.

Is this fair? Are tantalum resources 'running out'? Absolutely not! The 'likely resource estimate suggests there could be over 100 years of potential supply at current usage rates: there are very few minerals with THAT sort of resource base!

It is a fact of life that it is the lowest cost producers who survive when prices are low. Hence, artisanal mining – generally the lowest cost producers – will continue, and as more and more minesites are deemed conflict free, legitimate tantalum concentrates production will increase. Low-cost industrial mines that are producing have generally got reasonably healthy resources – this is doubly so for those where tantalum is not the main product, but a by-product of lesser or greater importance. Two major mines in Brazil (Pitinga and Mibra) – both of which have an economic tin content – have remained in production throughout the supply downturn, as has China's Yichun mine, which has an economic lithium product in addition to tantalum. Likewise, some tin smelters continue to produce tantalum bearing tin slags. Between these sources, tantalum supply appears to be reasonably in synch with demand.

Another uptick in tantalum price, or a return to a reasonably stable period of demand outstripping supply, could bring one or more of the recently closed mines back into production. Restarting even a mine on care-and-maintenance takes time and money and a Company is hardly likely to be willing to do this without a reasonably long term offtake agreement. This might not be simple, when the electronics industry – still the major user of tantalum - thinks in terms of months for the lifetime of some of their products, and new mines think in terms of years for start-up. The old Greenbushes mine – now a lithium producer - may just be one to buck the trend: its infrastructure is in place, supporting the lithium mine, and the tantalum secondary plant is operating. Both would simplify even a partial restart.

In addition, there are movements in several old ‘brownfield’ mines, especially in Africa. Zimbabwe hosts many small tantalum deposits that have produced in the past (for example, see Kuzvart 1994), and some are again being mined artisanally: however one in the south is on a semi-industrial scale. On the other side of the continent, the small but high grade deposits in Tantalite Valley, close to the southern borders of Namibia, may well be on the threshold of restarting. (Kennedy Ventures 2015).

In Mozambique, the new owners at the Morrua mine have started production, treating the old dumps in a semi-mobile 100 tph gravity plant, with concentrates being upgraded at the dry plant of their nearby sister Marropino mine, itself remaining on care-and-maintenance. Morrua (as well as Marropino) was, prior to Mozambican independence in the mid 1970’s, one of the world’s major tantalum mines, but its location close to the front line of the ensuing civil war resulted in its continued closure despite efforts by East German interests to reopen it in the 1980’s. Then in the 1995-8 period, a major player in the tantalum industry was looking seriously at reopening Morrua, but in the event, walked away from it, when Sons of Gwalia announced a substantial increase in reserves at both Greenbushes and Wodgina. Thirty years it took, but finally, with perseverance, it has reopened.

Australia, too, is seeing resurgence in tantalum mining, especially in Western Australia where, several small deposits that have been mined in the past are either close to, or have recently commenced production. These include Mt Cattlin and Bald Hill in the south, and the Tabba Tabba deposit in the Pilbara.

Figure10: The Tabba Tabba pit, Western Australia.
(Picture courtesy of Pilbara Minerals Ltd.)

Figure 11: Bald Hill's concentrator, Western Australia.
(picture courtesy Simone Suen)

Worldwide there are scores of small mineralized pegmatites – the author had indeed visited many of them – in North and South America, throughout Africa, Asia and Australia and even some in Europe. Some of them are large enough to warrant development on their own. In other cases packaging several nearby pegmatites together would improve the probability of their development. In these cases using an inexpensive semi-mobile primary plant that could be move from site to site, with a central upgrading plant for cleaning the rough concentrates, would be the answer. An advantage of this scenario would be that each 'package' would not cause a major shift in the supply:demand relationship, and consequent impact on prices.

What about all those 'mega-projects' that were touted during the 1999-2001 'boom'? While an exciting time for the explorationists and financiers, to date none have actually resulted in a mine. Many of these 'new' projects were little more than old projects that were dusted off while the price was high, to be put back on the shelf when prices returned to normal. Some were, undoubtedly, touted by 'financial miners' with little desire to actually develop the mine. However, others did have more promise, but with an over-supply there was, frankly, no place for them. The Junior Mining Companies that did hold on to them are now finding that host Governments will run out of patience, and they are losing their projects. In addition, there are several large, generally low-grade, tantalum deposits in the Former Soviet Union and China, but their status is unclear, as information is less easy to come by.

Given the right climate and the right developer, some of these may eventually come into production. It should be noted that, with current knowledge, none of this new breed of (significant) mines will be pegmatite based. Some will be apogranites, others carbonatites, and others syenites. Furthermore, most of these ‘megaprojects’ are not ‘tantalum’ projects *per-se*: they should more correctly be regarded as niobium projects (with a 10:1 niobium: tantalum content) or even niobium-REO-tantalum projects, with pyrochlore the major mineral present. This will require a switch to concentration by means of flotation, and away from gravity concentration, and will also require companies to break into a market where there is one major, very low cost producer – the former may be an easier ‘do’ than the latter.

And, finally, the world is a big place. Google Earth may give the impression that we know every square metre of the planet, but there are lots of places where geologists have as yet ‘feared to tread’ – and in truth, there are very few pegmatite geologists with the ability to find mineralized pegmatites, and even fewer to unearth those hidden ones.. It would indeed be foolish to presume that there is not even one more massive tantaliferous pegmatite out there.

After all, have you ever met a pessimistic geologist?

Acknowledgement

The author acknowledges all his colleagues in the tantalum and tin industries, and in various civil societies and Governments. Without their constructive comments over the years, his ability to write this paper would have been all the poorer. He thanks the various companies who happily gave permission to use photographs of their operations.

A shorter version of this paper is being prepared for publication in a forthcoming issue of Materials World (www.iom3.org/materials-world-magazine), the journal of the Institute of Materials, Minerals and Metals.

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