Tantalum Market and Resources: An Overview

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INTRODUCTION

This paper highlights the world tantalum market, identifies classical tantalum-bearing deposit types that represent major tantalum resources and provides examples of each type. A global approach is required to put potential unconventional tantalum resources, such as some of the British Columbia carbonatites, into proper context.

Recent interest in tantalum is due to increases in spot prices for tantalum raw materials which during 2000 reached US$145 to 175/lb of contained Ta_2O_5 (Platt's Metals Week) and as much as US$ 350 /lb which was the bid rate for the Oct 2000 Davis Langdon Australia (DLA) Tender. As a result, exploration companies targeted a variety of pegmatites, specialty granites, alkaline complexes and carbonatites as possible sources of tantalum.

All these lithologies are enriched in tantalum, relative to the earth's crust, and with the exception of carbonatites are known to host deposits where tantalum is being recovered, at least as a by-product. Carbonatites are well known for associated niobium, REE, phosphate, vermiculite, fluorite, zirconium, uranium, thorium, titanium, copper and iron mineralization (Richardson and Birkett, 1996a; Birkett and Simandl, 1999); several carbonatite-hosted deposits contain relatively high tantalum concentrations.

British Columbia has favorable geological settings for tantalum exploration and is known for a large number of carbonatites and alkaline complexes. It also has a number specialty granite intrusions and pegmatite occurrences (Pell, 1994; Pell and Hora 1990). Tantalum-related mineral occurrences are documented in the BC MINFILE <www.em.gov.bc.ca/Mining/Geolsurv/Minfile>.

TANTALUM USE

Tantalum has a wide variety of uses (Perron, 1995; Cunningham, 2000). It is a hard, but ductile metal, resistant to acid corrosion, with a high melting point (2996 to 3015 ºC depending on source of information), and high density (16.654 g/cm^3). It is a good conductor of electricity and heat. In recent years over 60% of tantalum raw materials went into production of tantalum oxide powders, which are used mainly in manufacturing of electronic components such as capacitors. Tantalum, together with cobalt, nickel and iron, are key ingredients for superalloys used in space/aviation structures and engine components and marine propulsion systems. Because of its high melting point and its corrosion resistance, tantalum alloys are also used in manufacturing of heat exchangers, evaporators, condensers, pumps and liners for reactors and holding tanks for the chemical industry. Tantalum is inert with respect to the human body and is therefore used in hip and knee replacement systems and in the manufacture of a variety of surgical instruments and appliances. Tantalum carbide is used in cutting and drilling tools and wear-resistant parts

TANTALUM MARKET

According to the Tantalum-Niobium International Study Center, world tantalum product shipments for 1998, 1999 and 2000 totaled 3.259, 3.827 and 4.927 million pounds of contained tantalum respectively (Mosheim, 2001). This represents an increase in production of more than 50% in two years. There are no published prices for tantalum metal or intermediate chemicals. Significant proportions of the processor's requirements are met through long term contracts, however, estimated tantalite concentrate spot prices are listed in Platt's Metals Week. Prices, which include cost, insurance and freight to nearest US port, are listed per pound of contained Ta_2O_5. Dealer quotes 60% combined Ta_2O_5 and Nb_2O_5 content.

Year-end average prices of concentrate, per pound of contained Ta_2O_5, between 1959 and 2001 are shown in Figure 1. The trend is relatively steady and upward, but it has a few sharp spikes, notably in 1979-1980, 1988 and most recently in 2000. In November and December 2000, the spot prices for tantalite concentrate, per pound of contained tantalum pentoxide reached from US$ 145-175/lb. The stellar rise in the spot price of tantalite concentrates in late 2000 was largely due to an increase in a demand in a relatively restricted market. Prices have since moved downward and are currently in the US $ 40-50/lb range (Platts Metals Week, November 28, 2001).

There are regulations on the transport of radioactive materials. These regulations depend somewhat on the country or region concerned. There are tantalum/niobium minerals which can not be moved out of their country of extraction because of their levels of radioactivity. The normal limits quoted are 0.1% U_3O_8 and 0.1% ThO_2 (Wickens, J. A. 2001; personal communication).

Australia accounts for most of the Ta_2O_5 concentrate production. Other significant columbite-tantalite producing countries are Brazil, Canada, China, Ethiopia, Nigeria and Democratic Republic of the Congo. Several other African

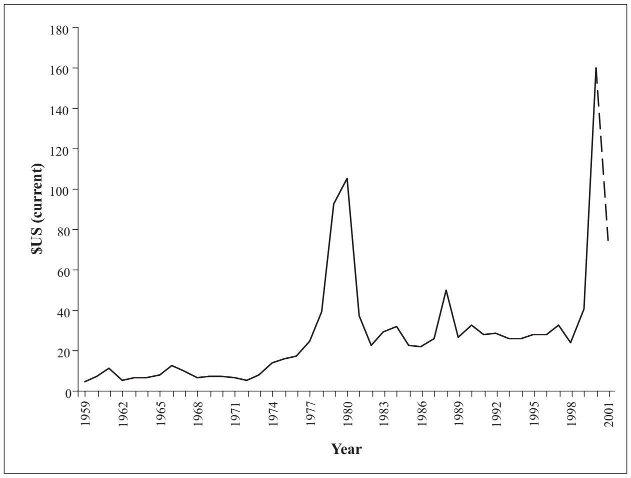

Figure 1: Year-end average tantalum concentrate price per pound of contained Ta_2O_5. The prices are corrected to 2000 US dollars. The price for 2000 is an estimate and the price for 2001 is a projection. Modified from Cunningham (2000).

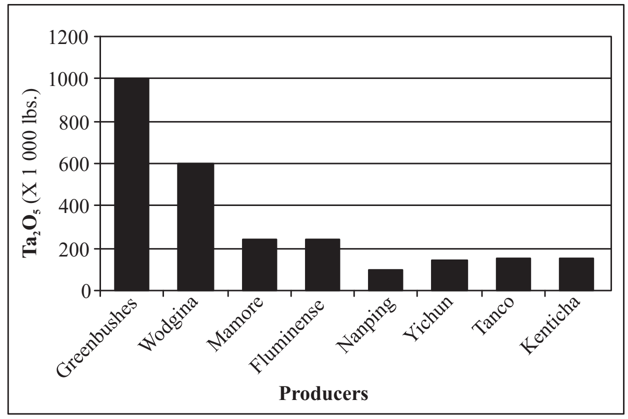

Figure 2. Major Ta_2O_5 concentrate producing mines (source: Sons of Gwalia Ltd.). Greenbushes, Wodgina operations (both in expansion phase) and Tanco are pegmatite-hosted deposits; Nanjing and Yichun and Mamore (Pitinga) are granite related; Kenticha rare metal field, in Ethiopia, contains both granites and pegmatites, in 2001 the production from this locality was greatly reduced because of the legal dispute. Companhia Industrial Fluminense is a unit of Metallurg Inc. It extracts and concentrates Ta and Nb containing ores from Nazareno mine. Concentrates along with other raw materials, are processed into metal oxides at the Sao Joao del Rei plant.

countries, such as Rwanda, Uganda, Zimbabwe, Namibia and Mozambique, also produce concentrates, but no reliable statistics from Africa are available. Ta-bearing slags, legacy of past tin mining in Thailand and Malaysia, were once a major source of tantalum. They are being rapidly depleted and currently supply less than 15% of the world's annual tantalum raw materials. The US Government holds substantial quantities of tantalum-bearing materials, such as tantalum carbide, capacitor grade powder, vacuum-grade metal ingots and ore concentrates in its National Defense Stockpile. Portions of this stockpile were disposed of in 2000 and additional sales were approved for disposal in 2001 (Cunningham, 2001a). Recycling is also an important element of the market (Cunningham, 2001b).

FUTURE MARKET EXPECTATIONS

Tantalum is not entirely irreplaceable; if tantalum prices remain high or shortages persist, then tantalum substitutes will become popular. Ta-based capacitors may have significant advantages over competing products, but in specific segments of the capacitor range they are interchangeable with aluminum, ceramic and niobium varieties. In the past, niobium-based capacitors were considered unstable at current operating temperatures and had substantially higher leakage of current then tantalum-based equivalents.

Recent high tantalum prices prompted. NEC Corp to announce (Press release of July 10, 2001), that it is in position to produce niobium-based capacitors. According to NEC, innovative manufacturing procedures appear to have overcome the stability problem and reduced the current leakage to acceptable level. Vishay Intertechnology Inc. and several European companies are expected to follow with similar products. On the other hand, there are a number of industry players, such as Kemet, that believe that the substitution of Ta_2O_5 by Nb_2O_5 will be limited at current price levels of raw materials.

Niobium is far more abundant and lower priced than tantalum. For example, in November 2000, when the price of tantalite concentrate peaked, the prices for columbite concentrate containing over 65% of combined Nb_2O_5 and Ta_2O_5 was set at US$4.80 to 5.30/lb and steel-making grade ferro-niobium was in range of US$ 6.75-7.00 (Cunningham, 2001c).

It is unlikely that Nb-based capacitors will replace to any large extent the Ta variety; however, the combination of costs of raw materials and technical performance will determine the degree of substitution. If Nb-based capacitors are widely accepted by the electronic industry as a viable substitute for Ta-based ones, the prices of Ta_2O_5-bearing concentrates are likely to further decrease. However, it is possible that the price of the tantalum concentrates will stabilize near pre-2000 year level in the near future.

The likelihood of future Ta_2O_5 shortages is being reduced not only by substitution, but also by production capacity increases of traditional Ta_2O_5 concentrate suppliers and by new exploration and development efforts. For example, Cabot Performance Materials (CPM), a major processor of tantalum, has long-term contracts with Sons of Gwalia Ltd. (SG) currently the world's largest Ta_2O_5 producer. In 2000, SG's combined output from Greenbushes and Wodgina mines was 1.307 million lbs of contained Ta_2O_5 (Figure 2). The A$ 100 million expansion of both mining operations is underway to reach a total capacity of 2.4 million lbs of contained Ta_2O_5 per year (Mosheim, 2001).

CPM plans to double its production capacity of tantalum and niobium products. The expansion started by immediate improvements to an existing electron beam furnace and the purchasse of a 3rd 2400kW electron beam furnace (Anonymous 2001b). The company has also invested in Angus & Ross to explore a deposit within the Motzfeld Centre, South Greenland.

Furthermore, Kemet Corporation, a capacitor producer, invested in the Dalgaranga project in Western Australia (Anonymous, 2001a). The close ties that are currently being developed between miners and downstream users through equity acquisitions and long term contracts may ultimately play an important role in determining which deposits will be developed in the future. At this stage, even major Canadian mining companies are getting a limited exposure to tantalum. This year, SG purchased PacMin Mining Corp. from Teck Cominco Ltd. for cash and shares. The transaction resulted in Teck Cominco holding a 12% stake in SG (Anonymous, 2001c). Placer Dome has ties with Avalon Resources, a company that controls the Separation Rapid pegmatite deposit in Ontario.

WORLD TANTALUM RESOURCES

The Ta content of average upper crust is estimated at 2.1 ppm; average granitic rock contains about 2.3 ppm Ta. Diorite (1.5 ppm), gabbro and basalt (0.9 ppm) and peridotite (<1ppm) have even lower tantalum content (Wedepohl, 1970, Table 73-E-4). Rocks that contain economically significant tantalum concentrations are: pegmatites, specialty granites, alkaline complexes and hyperalkaline rocks, and carbonatites. The only production of tantalum has been from pegmatites and specialty granites. Since the year 2000 rise in tantalite concentrate prices, a number of alkaline complexes and carbonatite occurrences became potential Ta/Nb exploration targets. In some deposits tantalum-bearing concentrate is the main product, but in many cases it is only a byproduct or possible byproduct.

Pegmatite deposits, or their overlying regolith, supply over 70% of world Ta_2O_5 concentrate. The Tanco mine in Manitoba had pre-production reserves of 1.9 million tonnes of 0.216% Ta_2O_5, 6.6 million tonnes of 2.76% Li_2O, 0.3 million tonnes at 23.3 % Cs_2O and 0.8 million tonnes of 0.2% BeO in hard rock (Crouse *et. al*., 1984).

Located in Western Australia, the Greenbushes and Wodgina operations are two of the better-known, world-class deposits with 160 million tonnes grading 0.0214% Ta_2O_5 (with Sn, Li_2O and kaolin as byproducts) and 30 million tonnes at 0.047% Ta_2O_5 respectively. These deposits currently supply the lion's share of the world Ta_2O_5 market (Figure 2).

Significant tantalum resources are contained in **specialty granites**, such as the Beavoir mine in France, which is currently exploited for kaolin and lithium. This deposit is reported to contain a million tonnes of Li at a grade of 1.5% Li_2O, 150 000 tonnes of Sn at a grade of 0.1% Sn, and 20 000 tonnes of Ta at a grade of 0.01% Ta in the upper 300 metres of the host granite (Cuney *et al*.1992). The Orlovka orebody in Russia is another example. A past producer, it had initial resources of 500 tonnes of Ta_2O_5, and 10 000 tonnes of Nb_2O_5, with an average Ta_2O_5 content of 0.013 % (Beskin *et al*., 1994). Yichun and Nanping mines, located in China (Yin *et. all*, 1995 and Mosheim, 2001) are important producers that probably belong to this category (Figure 2). Pitinga mine (Sn, Nb and Ta) orebodies and related placers in Brazil, and Kougarokon deposit on Seaward peninsula in Alaska, which is reported to contain tin and tantalum mineralization, may also belong to this category.

Alkaline Complexes and hyperalkaline rocks host significant tantalum resources (Richardson, D.G. and Birkett, T. 1996b). For example, the "Zone Lake" of the well known Thor Lake property, Northwest Territories has a resource of 64 million tonnes grading 0.04% Ta_2O_5, 0.57% Nb_2O_5, 1.99% REE oxides and 4.73% zirconium (Richardson, D.G. and Birkett, T. 1996b). The Strange Lake deposit located on the Quebec and Labrador border is reported to have a resource of 52 million tonnes grading 3.25% ZrO_2, 0.56% Nb_2O_5, 0.66% Y_2O_3, 0.12% BeO and 1.30% REE oxides (Venkatswaran, 1983). Miller (1988) describes a higher-grade zone with significant Ta_2O_5 content in pegmatite-aplite lenses associated with a roof of a small intrusion within this complex, but no grades and tonnage estimates are given. Within the Motztzfelt Centre, South Greenland, locality 4 has an estimated resource of 38 million tonnes grading 250 ppm Ta_2O_5 or 26 million tonnes grading 350 ppm Ta_2O_5 (Angus & Ross PLC, 2001). The Brockman deposit, located in Western Australia, contains a resource of 4.29 million tonnes grading 1.04% ZrO_2, 0.116% Y_2O_3, 0.44% Nb_2O_5, 0.027% Ta_2O_5, 0.035 % HfO_2, 0.011% Ga and 0.09% REE oxides in tuff (Chalmers, 1990). Unfortunately, the ore minerals are extremely fine grained, most are less than 10 microns in diameter.

Currently, there is no Ta-concentrate production from **carbonatite-related deposits**, although in some cases, tantalum may be recovered by refiners as a niobium byproduct from tantalum-bearing niobium ferroalloy. Two carbonatite-related mineralized zones in Crevier-Lagorce townships, Quebec have a drill-indicated resource of 15.2 million tonnes grading 0.189% Nb_2O_5 and 0.02% Ta_2O_5 (Societé Quebecoise d'Exploration Minière, Annual Report 1981-82). The regolith of the Mount Weld carbonatite in Australia contains resources of 250 million tons grading 18% P_2O_3, 270 million tonnes grading 0.9% Nb_2O_5 and 145 million tonnes grading 0.034% Ta_2O_5 (Duncan and Willett, 1990). The Verity and Fir deposits in the Blue River area of British Columbia, are two more examples that are currently being diamond drilled. Recently, the inferred resource of the Verity-Paradise Carbonatite Complex was reported at 3.06 million tonnes containing 0.0196% Ta_2O_5, 0.0646% Nb_2O_5 and 3.20% P_2O_5 (Commerce Resources Corp. news release, July 25, 2001). Martison Carbonatite, Ontario, containing a resource of 113 million tonnes averaging 21.4 % P_2O_5 is also reported to contain a zone with significant concentrations of Nb_2O_5 and Ta_2O_5.

TABLE 1
TANTALUM/NIOBIUM MINERALS OF ECONOMIC SIGNIFICANCE

Mineral	General formula	%Ta_2O_5	%Nb_2O_5	Density g/cm^3
Microlite	$Ca_2(Ta,Nb)_2O_6(OH,F)_7$	67-70	5-10	6.4
Tantalite	$(Fe,Mn)(Nb,Ta)_2O_6$	42-84	2-40	7.9
Columbite-tantalite	$(Fe,Mn)(Nb,Ta)_2O_6$	20-50	25-60	
Columbite	$(Fe,Mn)(Nb,Ta)_2O_6$	1-40	40-75	5.2
Wodginite	$Mn_4(Sn>Ta,Ti,Fe)_4(Ta>Nb)_8O_{32}$	45-56	3-15	7.1-7.4
Strüverite	$(Ti,Ta,Nb,Fe)_2O_6$	12-13	12-13	5.4
Euxenite	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$	2-12	22-30	4.3-5.9
Samarskite	$(Fe,Ca,U,Y,Ce)_2(Nb, Ta)_2O_6$	15-30	40-55	5.2-5.7
Pyrochlore	$(Ca,Na)_2(Nb,Ta,Ti)_2O_6(OH,F)$	<2*	50-70	4.2-4.6

Tantalum minerals of economic significance, their chemical formula, typical Ta_2O_5.and Nb_2O_5 contents and density. Density of minerals is one of the key factors in the selection of processing method required to produce a marketable concentrate. *The Ta content of pyrochlore, given here, is representative of niobium ores. In some deposits, such as Fir and Verity, British Columbia, pyrochlores have much higher Ta content.

ORE DRESSING - TRADITIONAL TA ORE MINERALS VERSUS PYROCHLORE SUBGROUP:

Tantalum is commonly present in a variety of rock-forming minerals, including iron and iron titanium silicates and oxides. The average tantalum content and the average Nb/Ta ratio reported by Wedepohl (1970) for selected rock-forming minerals is indicated in parentheses: biotite (10.1 ppm Ta; Nb/Ta = 11.3), muscovite (14.2 ppm Ta; Nb/Ta = 5.6), pyroxene (6.5 ppm Ta; Nb/Ta = 6.5), hornblende (7.2 ppm Ta; Nb/Ta = 9.8), titanite (330 ppm Ta; Nb/Ta = 11.5), titanomagnetite (100 ppm Ta; Nb/Ta = 6.8), ilmenite (250 ppm Ta; Nb/Ta = 6.4), perovskite (447 ppm Ta; Nb/Ta = 11.3), and zircon (38 ppm Ta; Nb/Ta = 1.0).

The main, economically important, tantalum ore minerals are tantalite columbotantalite (columbite-tantalite group), columbite, wodginite, microlite (Ta-rich mineral of the pyrochlore group) and strüverite. The chemical formula, typical compositional range and the density of these tantalum ore minerals and of pyrochlore are given in Table 1. Simpsonite (($Al_4Ta_3O_{13}$ (OH)) and stibiotantalite ($SbTaO_4$) are less important tantalum-bearing ore minerals. Columbite-tantalite minerals are the most widespread of Ta-Nb minerals, in some occurrences they are replaced by fersmite or microlite. Pyrochlore group minerals are commonly divided into three subgroups: a) pyrochlore (Nb+Ta>2Ti and Nb>Ta), b) microlite (Nb+Ta > 2Ti and Ta > Nb or Ta = Nb) and c) betafite **(**2Ti > Nb+Ta or 2Ti = Nb+Ta**)**. These subgroups may be further subdivided (Hoggarth, 1977), but this is outside the scope of this paper.

Minerals of the pyrochlore subgroup are commonly considered as niobium ores. In unusual circumstances, pyrochlore subgroup minerals may contain high, potentially economic concentrations of tantalum.

There are also other minerals, mostly oxides, that contain much higher tantalum concentrations than rock forming minerals, but they are not as widespread as the minerals listed in Table 1. In specific cases, these minerals may contribute significantly to the tantalum content of the ores and are considered as ore minerals. On the other hand, some of these minerals, especially those that are secondary in nature, may adversely affect the recovery of primary ore minerals during processing.

Pegmatites are currently the main source of Ta_2O_5 concentrates. Pegmatites generally have a significantly higher Ta/Nb ratio than carbonatites. Columbotantalite, wodginite, microlite and strüverite are dense (table 1); consequently Ta-bearing concentrates from pegmatites are produced mainly by relatively simple gravity separation methods, although flotation and magnetic separation may be used as secondary methods. Good descriptions of tantalum ore concentration processes are provided by Burt (1979,1988) and Flemming *et al*. (1982)._Tantalum concentrates usually grade 25% Ta_2O_5 or higher with Ta:Nb ratio greater than unity. The very best concentrates reach 65% Ta_2O_5 with <5% Nb_2O_5, while typical Central African material can go as low as 25%Ta_2O_5 and 40% Nb_2O_5.

Ta_2O_5 may be recovered as a byproduct of Nb_2O_5 production from columbite concentrates, if Ta_2O_5 content exceeds 3% (David Henderson, personal communication, 2001). Concentrates with Ta/Nb ratios around 1/10 or higher are commonly purchased by concentrate-processors for Nb_2O_5 and Ta_2O_5 recovery. In most cases, columbite-tantalite concentrate can be transformed into Nb_2O_5 and Ta_2O_5 products using solvent extraction, prior to conversion to pure metals, oxides, ferroalloys or other high purity tantalum and niobium products.

This is not always the case. At the Pitinga tin mine in western Brazil, cassiterite concentrate is the main product, however cassiterite-columbite middlings that are recovered as part of the process are converted into ferro-niobium-tantalum alloy assaying 50% Nb and 5%Ta. Both niobium and tantalum are recovered from this alloy by subsequent processing.

Carbonatites are the most important source of Nb_2O_5 and in general have a lower Ta/Nb ratio than pegmatites. The regolith that in many cases overlies carbonatite protore may grade over 2.5% Nb_2O_5, while hard rock carbonatites rarely exceed 0.6% Nb_2O_5. The most common ore minerals in carbonatites are of the pyrochlore subgroup and niobium-rich members of columbite-tantalite suite (Table 1). The recovery of minerals of the pyrochlore subgroup from carbonatites commonly necessitates flotation or consists of a combination of physical processing and flotation. A well documented example of such a beneficiation process is the Niobec plant in Quebec (Biss, 1982). Pyrochlore concentrates (55 to 65% Nb_2O_5) are converted directly on site, typically by aluminothermic reduction, to ferroniobium. Villeneuve and Dénommé (1997) summarized the process. Little or no pyrochlore concentrate is sold on the open market. There is no routine recovery of Ta_2O_5 from pyrochlore concentrate, which typically contains 800-2000ppm Ta_2O_5 (David Henderson, personal communication, 2001), although in some exceptional cases it may contain 2 to 5% Ta_2O_5. In such circumstances, tantalum recovery from pyrochlore concentrates may be justified.

Depending on the Ta/Nb ratio of concentrate, solvent extraction could probably be used prior to conversion to ferroalloys and other high purity niobium and tantalum products. If Ta/Nb ratio of a concentrate is low, it may be advantageous to produce a niobium-tantalum alloy as described above for the Pitinga tin mine.

DISCUSSION

The stellar rise in the spot price of tantalite concentrates experienced in late 2000 was largely due to an increase in a demand in relatively restricted market. Since the end of 2000, there has been a significant increase in the production of Ta_2O_5 from conventional sources and strong efforts to recover Ta as a byproduct are also being made. Rapid technological advances are starting to permit substitution of tantalum by other materials even in the field of capacitors. The spot price of Ta_2O_5 has not yet stabilized and in the short term prices are on their way down. It is unlikely that the prices of November and December 2000, will be reached again in the foreseeable future. In short term growth in Ta_2O_5 may be affected by economic slowdown, but in medium and long-term tantalum consumption is expected to continue to grow.

Conservative prices for Ta_2O_5 concentrates should be used in conceptual and pre-feasibility studies. Furthermore, discovery and development of a single large and high-grade tantalum deposit could dramatically change the market situation for years to come.

There are no established guidelines or rules of thumb, as far as evaluation of carbonatite-hosted deposits as a potential primary source of Ta_2O_5-bearing concentrate. Published grade and tonnage data from pegmatite-hosted deposits, as those listed in the previous section, could possibly be used as a starting point but not as a yardstick. The carbonatite deposits under consideration as a potential Ta_2O_5 source, should compare favourably with the more traditional resources in terms of grades, tonnage, mining and processing costs. In general, if Ta_2O_5 is to be recovered from pyrochlore-rich ores, flotation is likely to be needed to produce concentrate and capital costs may be higher.

If the Ta/Nb ore minerals have a high U_3O_8 and ThO_2 content, or high levels of other environmentally problematic impurities, disposal of tailings and/or slags could be a potential problem and cross border transportation of the concentrate may also be a problem.

Key parameters for developing a carbonatite-hosted tantalum mine are: favourable permitting conditions, acceptable environmental constraints, favourable market conditions, infrastructure requirements, open pit mineable reserves in tens of million tonnes, simple mineralogy, and ability to supply concentrates with Ta:Nb ratio of at least around 1:10 .

SUMMARY

Tantalum demand has grown at a rapid pace over the last few years, however, the market base for this commodity is relatively small. Recent expansions of operations supplying Ta_2O_5 concentrate and heavier reliance on long-term contracts between tantalite concentrate suppliers and processors greatly diminished the significance of variations in Ta spot prices. As more and more Ta_2O_5 is sold under contract, the swings in spot prices are expected to be wider but in reality their impact will be less important because of the small amount of product affected.

If a shortage or a prolonged rise in tantalum prices occurs, some of the new tantalum exploration projects will be developed. However, it is likely that substitution of tantalum by cheaper materials, where possible, will also occur in the electronics and other industries.

Future tantalum and niobium markets are the most important factors that will determine the potential of carbonatites and other unconventional resources as a source of tantalum.

It is conceivable, that under favourable market conditions, carbonatites (or alkaline complexes) with favorable grades and high Ta/Nb ratios may supply concentrates or ferroniobium from which tantalum could be economically recovered as a byproduct of niobium. These unconventional deposits will have to compete for part of the tantalum market with pegmatite and specialty granite-hosted resources that require relatively simple processing, and are proven to be viable operations even at the pre-2000 tantalum prices.

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