Concentration of Tantalum and Niobium

R.O. Burt

Tantalum Mining Corporation of Canada Ltd.,
P.O. Box 2000, Lac du Bonnet, Mb. Canada

CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>36</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>36</td>
</tr>
<tr>
<td>2. MINERALOGY AND ORE DEPOSITS</td>
<td>36</td>
</tr>
<tr>
<td>3. MINING</td>
<td>37</td>
</tr>
<tr>
<td>4. GRAVITY CONCENTRATION METHODS</td>
<td>37</td>
</tr>
<tr>
<td>5. FLOTATION</td>
<td>43</td>
</tr>
<tr>
<td>6. FUTURE PROSPECTS</td>
<td>46</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>47</td>
</tr>
</tbody>
</table>
ABSTRACT

The mineral processing of tantalum and niobium ores forms part of the chain which extracts ore from the ground and converts the contained metals into a useable state. This paper briefly examines the various tantalum and niobium minerals that are processed for the recovery of the contained values, and introduces the two major concentration routes: gravity concentration and flotation.

Some flowsheets of operating plants are provided, which typify these processes. The paper also comments on possible future processing routes that may, in time, become commercially employed.

1. INTRODUCTION

The production of metals is the result of the cooperative effort of various disciplines; mine; concentrator; smelter; refinery; fabricator. The manufacture of tantalum and niobium metal, compounds or finished products is little different. Raw ore from the mine has first to be processed to a concentrated mineral form, which, in its turn, must be converted into the metal or the oxide, which finally is fabricated into the finished article.

A typical tantalum bearing ore contains approximately 1 kg of tantalum in every tonne of ore: niobium ores of the order 6-30 kg of niobium per tonne. This is far too low a content for the metallurgist to be able to economically convert the minerals to metal without some form of concentration of the mineral into a smaller, much higher grade fraction. This mineral processing stage forms the subject of this paper.

2. MINERALOGY AND ORE DEPOSITS

Tantalum and niobium do not occur in the free state; they occur almost exclusively in complex oxide minerals, often in solid solution with a variety of other elements, such as tin, titanium, thorium and uranium. While close to fifty tantalum and niobium bearing minerals have currently bee identified /1/, only six tantalum and three niobium minerals are of economic significance (Table 1).

TABLE 1

<table>
<thead>
<tr>
<th>Important minerals of tantalum and niobium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tantalite</td>
</tr>
<tr>
<td>Microlite</td>
</tr>
<tr>
<td>Wodginite</td>
</tr>
<tr>
<td>Simpsonite</td>
</tr>
<tr>
<td>Stibiotantalite</td>
</tr>
<tr>
<td>Struverite</td>
</tr>
<tr>
<td>Columbite</td>
</tr>
<tr>
<td>Pyrochlore</td>
</tr>
<tr>
<td>Bartopryochlore</td>
</tr>
</tbody>
</table>

Tantalite and columbite are end members of an isomorphous series, as are microlite and pyrochlore.

Primary tantalum ore deposits are almost exclusively zoned pegamites, which are usually relatively small, and higher grade: the major such deposits, where mining is ongoing, are the Tanco pegmamate /2/, Manitoba, Canada and the Wodgina pegmamate /3/ in Western Australia. Another potentially significant pegmamate, in Wycoming, U.S.A., is of lower grade but higher tonnage /4/. In
the Soviet Union and in China, much of the tantalum produced is from apogranites, albitites and griesens /5/.

The majority of tantalum is, however, recovered as a co-product or by-product from tin mining, either in the mineral form, or as a by-product from the tin smelter. Such deposits are often much larger, and the tantalum lower grade. The Greenbushes pegmatite /6/ in Western Australia, the Mibra mine /7/ and Paranapanema’s Pitinga deposit /8/, both in Brazil are typical of co-product tantalum: tin mining, the latter also having a significant niobium content. By-product tantalum is recovered from many of the alluvial tin mines in Thailand /9/; some niobium by-product is also recovered from these operations.

By far the largest amount of niobium is produced as pyrochlore from carbonatite deposits, with approximately two thirds of the world’s production coming from the Araxa mine /10/ of Companhia Brasileira de Metalurgica e Mineracao (CBMM) in Brazil; here the sodium and calcium in the crystal lattice have been replaced by barium, to form bartopyochlore. The majority of the remainder comes from the Catalao mine /11/, also in Brazil, and Niobec’s St. Honore deposit /12/, Quebec, Canada.

Not only is the genesis of the two elements significantly different, so are the major mineral recovery processes. Tantalum is separated from its ores by gravity concentration; niobium, on the other hand is separated by flotation.

3. MINING

The methods employed for the mining of tantalum and niobium ores are little different to those used for the mining of the majority of other minerals, any differences that do exist being the result of the scale operations.

Mining of primary ores requires either underground, or open pit, mining. Tanco’s Bernic Lake tantalum mine and Niobec’s niobium mine are examples of the former, the Wodgina pegmatite is typical of the latter. Outcropping ores which have weathered to the point of kaolinization can be mined with front-end loaders, or by hydraulic mining. The weathered cap of the Greenbushes pegmatite is such an orebody, as is the Araxa mine of CBMM. The mining of alluvials can be accomplished by a variety of methods, the most common being dredging.

Mining of both primary weathered pegmatites and alluvials is also carried out on a very small scale in various parts of the world, with little mechanization. Individual output is small. Collectively these small operations make up an important sector of the tantalum mining scene; however their impact on overall niobium production is much less significant.

4. GRAVITY CONCENTRATION METHODS

Gravity concentration - the separation of two or more minerals as a result of differences in their specific gravity - is, next to hand picking, the oldest form of mineral processing, with archaeological evidence of its widespread use well over two thousand years ago. To this day, more minerals are processed by gravity concentration than any other process, including flotation. Nevertheless, its major application is currently in coal processing, and most metals are processed by flotation.
Tantalum is one of the exceptions. Apart from a short-lived attempt at tantalum flotation by Tanco in the early eighties /13/, gravity concentration has remained the only commercially applied process for tantalum concentration /14/, although some by-product columbite is also produced by gravity methods. This section will, therefore, primarily deal with tantalum processing.

Gravity concentration is most effective when separating liberated particles, thereby maximizing the differences in specific gravity. The overall size range of particles that can be treated by gravity concentration is larger than with any other process. The practical size range is 500 mm to 0.005 mm. However, no item of gravity concentration equipment can efficiently handle this whole size range, and different types of equipment have been developed to handle different size ranges. Fig. 1 shows the effective size range of some gravity concentration units.

Recovery of heavy minerals by an item of equipment will depend on many factors, including particle size, degree of liberation, particle shape, etc; efficiency decreases with decreasing particle size (Table 2) and increases with increasing liberation.

Primary ores require crushing and grinding to liberate the tantalum exacerbating, the fineness of many of the mineral assemblages, resulting in incomplete recovery - much of the complexity of a typical tantalum concentrator is related to the effort expended attempting to improve this recovery. Alluvial ores, on the other hand, are by their very nature completely or almost completely liberated and any ultrafine particles will have percolated out of the deposit - very high recoveries are, therefore common. Weathered deposits will be partially liberated; the extent of weathering determining the amount of crushing and grinding required prior to concentration.

For efficient gravity concentration, some form of feed preparation is essential. For rough concentration, or preconcentration of alluvials, this may simply involve rejection of oversize, and removal of ultrafines. However, for final concentration and concentration of finer sizes, more complex feed preparation of material into fairly small size ranges is required.

Screening is effective at coarser size (+0.5 mm), but is less effective at finer sizes; furthermore, except in low tonnage situations, fine screening becomes prohibitively expensive. Screening is therefore used mainly in grinding circuits, to minimize overbreak, and in simple sizing of coarser fractions.

Classification is more common in feed preparation circuits. For single size separations, hydrocyclones, sand cones and rake or spiral

<table>
<thead>
<tr>
<th>Type</th>
<th>Size Range</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>+1 mm</td>
<td>90-95%</td>
</tr>
<tr>
<td>Sands</td>
<td>-1+01mm</td>
<td>85-95%</td>
</tr>
<tr>
<td>Fine Sands</td>
<td>-0.1+-0.05mm</td>
<td>70-90%</td>
</tr>
<tr>
<td>Fines</td>
<td>-0.05+0.01mm</td>
<td>50-70%</td>
</tr>
<tr>
<td>Ultrafines</td>
<td>-0.01mm</td>
<td>5-30%</td>
</tr>
</tbody>
</table>
classifiers, are used. Such units are also used for
desliming - the rejection direct to waste of
untreatable material - and as preliminary sizers
prior to multiple sizing units such as hydroscizers.
These latter are ideal units for the separation of
long range feed for subsequent treatment on
shaking tables. Particles settle in a series of
chambers against an upcurrent of water, such
upcurrent decreasing in successive chambers; the
effect of a relative specific gravity of values and
waste is enhanced, improving subsequent
treatment.

Of the units shown in Fig. 1, jigs and sluices
are commonly used for primary concentration of
alluvials or weathered pegmatites, as these units
are capable of treating fairly long size range feeds.
Spirals, shaking tables, Bartles-Mozley's and
Crossbelts are commonly utilized for concentra-
tion of primary ores, and for clean-up or rougher
concentrates; these units treat smaller size range
feeds. Neither heavy medium separation (even
though it is the most efficient process available in
the coarser sizes) nor Reichert cones have found
favour in the tantalum industry. To date the new
range of centrifugal separators have not been
incorporated in tantalum concentrating circuits;
however, it is likely that in time they will be.

Concentrates produced in the gravity plant
may require final clean-up to separate the various
heavy mineral values from each other. This is
especially so where tantalum is a by-product in tin
concentration, such as in the South-East Asian
alluvials. Typical minerals that report to such
gravity concentrates, apart from the tantalum
minerals and cassiterite, can include, ilmenite;
magnetite; zircon; garnets; xenotime; rutile;
monazite; sulphide minerals; wolframite and
scheelite; and even some precious metals, as well
as some entrained lights, such as quartz /15/. The
majority of these various minerals are themselves
often of economic value; efficiency of separation is
therefore paramount, and throughput is generally

Fig. 1  Effective size range of gravity concentration equipment

STATIC
DYNAMIC
WATER ONLY
JIGGING
SLUICE BOX
REICHERT CONE
PINCHED SLUICE
SPIRAL
SHAKING TABLE
BARTLES-MOZLEY
CROSSBELT
PNEUMATIC JIG
AIR TABLE
CENTRIFUGAL

Heavy Medium
Stratification
Flowing
film
Shaking
Other

39
low. Clean-up can be carried out wet, dry, or a combination of both, using a variety of processes, which include sizing, further gravity concentration, sulphide flotation, magnetic electrostatic separation. This is carried out in the "tin shed", a shore based plant incorporating several of these stages: final separation of by-products, including tantalum minerals may be carried out in "among" plants, such as that shown in Fig. 2.

Over fifty percent of the tantalum produced is as a by-product from the tin smelting industry; tin, along with its by-products, is concentrated on dredges, or in smaller gravel pump plants, by gravity concentration followed by clean-up in tin sheds. The tin with associated tantalum and niobium is smelted by standard technology; the tantalum and niobium reports to the slag, from which they are recovered by hydrometallurgical methods beyond the scope of this paper /16/.

Typical concentrating plants

The following section considers only those plants where tantalum is the primary product, or is a co-product with tin; it does not consider plants which are essentially tin concentrators, where by-product tantalum or niobium is produced in the clean-up stage, or after smelting.

*Primary ore:* Alluvials and eluvials adjacent to the Wodgina orebody, in Western Australia have been mined since 1905; mining and processing of the main pegmatite commenced in 1990 with the commissioning of a 100,000 tpa concentrate late 1989 Fig. 3/17/.

Mine ore is crushed in a two stage plant and ground in closed circuit closed with DSM screens in a grate discharge ball mill to 0.5 mm. Screen undersize is treated on a four-stage spiral circuit, to produce a final 40% Ta₂O₅ concentrate; roughly 60% of the tantalum is recovered in this circuit.

1 Classifier  
2 Shaking Table  
3 Lanchute  
4 Drier  
5 High Intensity Magnetic Separator  
6 Induced Roll Separator  
7 Pneumatic Table

Fig. 2. Typical Amang plant, South-East Asia
Spiral circuit tailings are rescreened at 0.45 mm (the final liberation size of the tantalum), oversized returning to the ball mill. Undersize is cycloned at 75 μm in a stub-cyclone, sands being scavenged in a final bank of spirals. Cyclone overflow is treated on a bank of twelve Holman tables, with rougher concentrate being upgraded on a further table. Table middlings are also retabled. The table circuit accounts for a further 15% of the tantalum, resulting in an overall recovery approaching 75%. Apart from low intensity magnetic separation, to remove grinding iron, no further treatment of gravity concentrates is currently carried out.

The flowsheet at Tantalum Mining Corporation of Canada follows a similar philosophy, but with the more complex nature of the ore, and the longer life of the operation, the circuitry is more sophisticated. Fig. 4 /18/. The major differences are in the secondary circuits, after the spiral concentration stage.

Four spigot hydrosizers and cyclones are used to split the -250 μm ground product into a total of six size fractions. Hydrosizer spigots are treated on four banks of Concenco triple deck tables, cyclone underflow on Holman slime tables and cyclone overflow on Bartles-Mozley Separators. Rougher concentrates from each section are upgraded on tables or Crossbelt concentrators, with Table 3 showing a typical metallurgical balance.

**Kaolinized Ores:** The Greenbushes pegmatite is
TABLE 3
Typical metallurgical balance:
Tantalum Mining Corporation of Canada

<table>
<thead>
<tr>
<th>Product</th>
<th>Wt. tpd</th>
<th>%Ta₂O₆</th>
<th>Dist.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Concentrate</td>
<td>0.66</td>
<td>37.0</td>
<td>35.0</td>
</tr>
<tr>
<td>Sand concentrate</td>
<td>0.35</td>
<td>40.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Fine Concentrate</td>
<td>0.19</td>
<td>38.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Slime Concentrate</td>
<td>0.11</td>
<td>30.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Tailing</td>
<td>698.8</td>
<td>0.03</td>
<td>28.0</td>
</tr>
<tr>
<td>Feed</td>
<td>700</td>
<td>0.10</td>
<td>100.0</td>
</tr>
</tbody>
</table>

highly weathered, to the point of kaolinization; on the other hand, it contains a larger suite of heavy minerals than either of the primary tantalum plants. Consequently, whilst its primary treatment plant is relatively simple, its retreatment plant is much more complex /19/.
The primary, or clay plant Fig. 5 consists of degradation followed by two stages of jigging, with jig tailing fines being upgraded on spirals. Rougher concentrate is retreated in the Mineral Dressing plant, Fig. 6, as is rougher concentrate from a tailings reprocessing plant; it will also, eventually, treat rougher concentrates from the proposed hard-rock mine. The mineral dressing plant consists of both wet and dry sections; the former upgrading rough concentrates with gravity concentration and low intensity magnetic separation. The dry section utilizes air tables, magnetic and electrostatic separation to produce separate cassiterite (72% SnO₂), tantalite (42% Ta₂O₅) and stibiotantalite (25% Ta₂O₅) concentrates, and an ilmenite reject. Greenbushes is unique amongst tantalum producers in that it has its own on-site pyrometallurgical and hydrometallurgical plants to produce tin metal, tantalum and tantalum intermediates.

5. FLOTATION

Pyrochlore minerals are the major source of niobium; they are amenable to cationic flotation, using amines as collector.

Unlike sulphide flotation, oxide flotation is very susceptible to deleterious fractions in the ore.

- Feed
- 1 Trommel
- 2 Vibrating Screen
- 3 Autogenous Mill
- 4 Cyclone
- 5 Rougher Jig
- 6 Cleaner Jig
- 7 Spiral
- 8 2 mm Stationary Screen
- 9 Scavenger Spiral Circuit

Fig. 5 Greenbushes clay plant
The presence of slimes is a serious impediment, and their removal is, therefore, essential prior to commencement of flotation. Slimes removal used to result in significant losses, especially with weathered ores such as at Araxa, as much of the pyrochlore reports to the fine to ultrafine size range. The development of efficient, small diameter, cyclones, has permitted effective desliming as fine as 5 μm, thereby minimizing losses in the desliming stage. Likewise, excess magnetite is deleterious to flotation and its removal by magnetic separation is mandatory. Carbonates, which are present in primary ore, must also be removed, by a pre-flotation stage prior to pyrochlore flotation.

Flotation concentrates generally require further treatment, as their quality is unacceptable for succeeding processing to ferroniobium. Sulphide flotation followed by a hydrochloric acid leach is carried out by Niobec; a roast-leach at Araxa.

Typical concentrating plants:

The flowsheet of the Niobec orebody is typical of primary niobium processing. Fig. 7 /12/. Crushed ore, grading 0.66% Nb2O5, is ground in closed circuit with screens and a screw classifier to 95%-200 μm, flowed by desliming at 10 μm by banks of 250 mm and 100 mm cyclone in series.
Deslimed ore is subjected first to carbonate flotation followed by further desliming which also removes hard water emanating from the carbonate flotation stage; finally magnetite is removed by low intensity magnetic separation, prior to pyrochlore flotation. Approximately 40-45% of the feed weight is removed prior to pyrochlore flotation, with a loss of only 15-20% of the niobium.

Pyrochlore flotation upgrades the ore from 1.0-1.2% Nb₂O₅ to 40-45%; it consists of roughing followed by six stages of cleaning, with the pH being reduced in each bank, from 6.5 in the roughers to a pH of 2.8 in the sixth cleaner bank. Final flotation concentrates are further upgraded by two stages of sulphide flotation, using xanthates at a pH of 10.5, and an acid leach. Overall recovery at Niobec is 61-63%.

Ore grade at Araxa is approximately 3% Nb₂O₅, significantly higher than at Niobec. The flowsheet Fig. 8 has some significant differences, due to the different mineralogy of the associated minerals. There is no carbonate flotation at Araxa; however, the magnetic separation stage rejects 10-25% of the ore. Desliming is carried out at 5 μm using banks of 381, 100 and 25 mm cyclones in series. Flotation of the coarse fraction (the underflow from the 381 and 100 mm cyclones) consists of roughing followed by four stages of cleaning, at a pH of 2.5-3.5. Only two stages of cleaning are used in the
circuit floating the 25 mm cyclone underflow.

Filtered flotation concentrate is trucked to the leaching plant, where it is first calcined, at 800-900°C with CaCl\(_2\), followed by an acid leach with 5% HCl. The phosphorous, lead and sulphur content of the final product are significantly reduced, and calcium is substituted for barium in the crystal lattice.

These two flowsheets highlight the significant amount of desliming that is required to facilitate effective niobium flotation. This can be compared with the various tantalum flowsheets in the previous section, where little to no desliming takes place.

6. FUTURE PROSPECTS

This paper has outlined the processing of tantalum and niobium ores in existing plants using current state of the art technology. Some new prospects that have been examined require either a substantial increase in the price of the product to render them economic, or require the development of new technology to unlock the complex mineralogy.

In the former category are the Wyoming tantalum deposit, and the large, low grade deposit in Egypt, as well as the niobium-tantalum resources of Greenland /22/. However, it is the latter category that intrigue the adventurous mineral processor.

In Canada, the Thor Lake deposit was first studied for its tantalum potential, then for its rare earth potential, and latterly for its beryllium potential. The ultrafine nature of the tantalum defied existing technology, as well as such
potential processes as froth flotation, oil-phase extraction and high intensity magnetic separation.

In Australia, the Mount Weld carbonatite /23/ and the Toongl project /24/ are both complex rare earth-tantalum-niobium deposits with complex metallurgy. In both cases, the deposits are being primarily considered for their rare earth potential, with the low grade tantalum and niobium of secondary importance. However, with an "inferred" resource of 150 million tonnes of 0.034% of Ta$_2$O$_5$ and 273 million tonnes of 0.9% Nb$_2$O$_5$, the former deposit is vast. In both cases, however, current mineral processing technology is unsuitable for the concentration of the tantalum and niobium, and hydrometallurgical processing is being considered.

However, considering the relatively low cost concentration of tantalum by gravity methods, the ore reserves at the currently operating niobium plants, and the known but unexploited lower grade deposits that can be concentrated by current technology, commercial exploitation of low grade, complex resources requiring novel, and relatively costly processing, is unlikely in the near future, unless it can be subsidized by the value of the rare earths they contain.

REFERENCES


