

*Island Copper  
included in study.*

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TITANIUM IN TAILINGS OF PORPHYRY DEPOSITS IN BRITISH COLUMBIA

( A report on laboratory investigations by Y.T. John Kwong )

Introduction

Rutile, ilmenite and, to a lesser degree, sphene are the most important ore minerals of titanium. Among these minerals, rutile is the preferred raw material for manufacturing titanium dioxide pigment and is practically essential for making titanium metal, which is heavily used in the aero-space industry. Recent studies on alternative sources of titanium in the United States of America (e.g. Force, 1976, Force et al., 1979 and Llewellyn and Sullivan, 1980) suggest that porphyry deposits are potential hosts of titanium minerals as a byproduct. To assess the titanium potential of similar deposits in British Columbia, a systematic examination of tailings from porphyry copper/molybdenum mines was initiated in the fall of 1982. Fourteen mines were chosen for the exploratory study. It involved chemical determination of titania for the whole sample suite, mineralogical study of selected high-titanium samples by x-ray diffraction and limited work on mineral separation and recovery. The main purposes of the study are to identify deposits of potential interest and to suggest areas and methods of further study where appropriate.

Result and Interpretation

Table 1 lists the cursory titania analyses, mainly by an emission spectrographic method, of three main groups of porphyry deposits, namely (A) calc-alkaline suite porphyry copper deposits, (B) alkaline suite porphyry copper deposits and (C) porphyry molybdenum deposits (calc-alkaline). The Equity Silver deposit shows a different style of mineralization compared to the above deposits and is therefore listed separately in Group D. From the table, it is evident that the calc-alkaline suite porphyry deposits (Groups

Table 1. Titania content of tailings from selected porphyry deposits in B.C.

Number	Deposit Name	Number of Samples	Titania Analyses (%)		
			Range	Mean	Standard Deviation
<b>A. Calc-alkaline suite porphyry copper deposits</b>					
1	Bell	10	0.34 - 0.64	0.49	0.08
2	Bethlehem	2	0.35 - 0.43	0.39	0.06
3	Brenda	7	0.30 - 0.43	0.38	0.06
4	Gibraltar	5	0.43 - 0.43	0.43	0.00
5	Granisle	8	0.40 - 0.78	0.56	0.13
6	Highmont	7	0.30 - 0.43	0.31	0.05
7	Island Copper	6	0.49 - 0.87	0.57	0.15
8	Lornex	12	0.30 - 0.43	0.35	0.05
Group		8		0.435	0.096
<b>B. Alkaline suite porphyry deposits</b>					
9	Afton	8	0.54 - 0.68	0.62	0.05
10	Granby (Copper Mtn.)	2	0.51 - 0.61	0.56	0.08
11	Newmont	9	0.33 - 0.97	0.67	0.21
	(i) Ingerbelle	6	0.52 - 0.97	0.77	0.15
	(ii) Copper Mtn.	3	0.33 - 0.53	0.44	0.10
Group		3		0.617	0.055
<b>C. Porphyry molybdenite deposits</b>					
12	Boss Mountain	2	0.35 - 0.43	0.39	0.06
13	Kitsault	4	0.49 - 0.57	0.56	0.04
Group		2		0.475	0.120
<b>D. Others</b>					
14	Equity Silver	4	0.81 - 0.97	0.84	0.08

A and C) are lower in titania in comparison with the alkaline suite deposits (Group B) while the Equity Silver deposit (Group D) contains most titania among the four groups. Using an arbitrary cutoff value of 0.50%  $TiO_2$ , selected samples from promising deposits in each group were examined in further details, both analytically and mineralogically. The findings are briefly summarized as follows:

#### A. Calc-alkaline suite porphyry copper deposits

(1) Bell Copper :- Refined chemical analyses by atomic absorption spectroscopy indicate that the ten samples from the deposit range in titania from 0.39 to 0.73% with an average of  $0.55 \pm 0.09\%$   $TiO_2$ . The major mineral constituents of the most Ti-rich sample (0.73%  $TiO_2$ ) are, in order of decreasing abundance, plagioclase, quartz, mica (biotite + muscovite  $\leq 10$  wt. %), K-feldspar, chlorite + kaolinite, dolomite, siderite, pyrite, hematite and calcite. Another sample with similar mineralogy but about half as much mica yielded 0.60%  $TiO_2$ , indicating that the biotite is probably titaniferous. However, using the upper limits of titania content of various minerals listed in Table 2 and assuming that the first sample contains 2 wt. % chlorite, 10 wt.% biotite and 0.5 wt.% magnetite, a mass balance calculation yields a total titania of  $\leq 0.52\%$ . Therefore,  $\geq 0.21\%$  of finely disseminated rutile is suspected to be present in the sample. This amount of rutile is, however, not readily recoverable. The 80-100 mesh portion of a subsample (with a size distribution of 54.2%  $> 80$  mesh, 9.9% 80-100 mesh and 35.8%  $< 100$  mesh) contains 1.15% of grains with a specific gravity (S.G.) of  $> 3.3$ . This heavy fraction consists mainly of pyrite with a subordinate amount of hematite and minor amounts of magnetite, siderite, dolomite, mica, K-feldspar and quartz. The presence of K-feldspar might have masked the strongest reflection peak of rutile in the diffractogram. However, the detection of 0.73%  $TiO_2$  in the light fraction (S.G.  $\leq 3.3$ ) argues against any significant concentration of titania in the heavy fraction. Incidentally, the  $< 100$  mesh portion of the subsample is

Table 2. Titania content of common titanium-containing minerals.  
(Data source: Deer et al., 1966)

Mineral Name	Formula	% TiO <sub>2</sub>
Rutile	TiO <sub>2</sub>	100
Anatase (+ Brookite)	TiO <sub>2</sub>	100
Leucoxene*	≈ TiO <sub>2</sub>	≈ 100
Sphene (Titanite)	CaTiO(SiO <sub>4</sub> )	40.8
Ilmenite	FeTiO <sub>3</sub>	52.65
Ulvospinel	FeTiO <sub>4</sub>	35.7
Magnetite	Fe <sub>3</sub> O <sub>4</sub>	< 1.5
Biotite	K(Mg,Fe) <sub>3</sub> (AlSi <sub>3</sub> O <sub>10</sub> )(OH) <sub>2</sub>	< 5
Hornblende	(Na,Ca) <sub>2-3</sub> (Mg,Fe,Al) <sub>5</sub> Si <sub>6</sub> (Si,Al) <sub>2</sub> - O <sub>22</sub> (OH) <sub>2</sub>	0.03 - 7.12, generally < 2**
Clinopyroxene	(Ca,Na)(Mg,Fe,Al)(Si,Al) <sub>2</sub> O <sub>6</sub>	0.04 - 1.18, generally < 0.8**
Chlorite	(Mg,Al,Fe) <sub>12</sub> [(Si,Al) <sub>8</sub> O <sub>20</sub> ](OH) <sub>16</sub>	0.0 - 0.88, generally < 0.35**

Notes:

\* Leucoxene is normally finely crystalline rutile (Deer et al., 1966). However, the same term has been loosely used elsewhere to include a mixture consisting mostly of rutile and partly of anatase or sphene (Glossary of Geology, American Geological Institute) and amorphous hydrous titanium dioxide (Kerr, 1959, p.196). In this report, the first definition is adopted.

\*\* Value used in the mass balance calculations unless otherwise stated.

characterized by 0.79%  $TiO_2$ , indicating that rutile, if present, is slightly enriched in the finest portion. This material, however, has not been further examined due to surface tension problems encountered in mineral separation involving heavy liquids and limited facility available in the laboratory for alternative methods of separation.

(ii) Granisle:- Improved analysis of the eight tailing samples gives a range of 0.44-0.88% and a mean of  $0.69 \pm 0.14\%$   $TiO_2$ . The major mineral components are quartz, plagioclase and biotite, and minor to accessory phases identified include muscovite, K-feldspar, chlorite, calcite, magnetite, pyrite, gypsum, apatite  $\dagger$  hematite. The 80-100 mesh size fraction of a sample with 0.75%  $TiO_2$  was separated into two portions. The heavy portion (S.G.  $> 3.3$ ) makes up only 1.8% of the subsample and shows a small amount of marcasite, chalcopyrite and molybdenite in addition to the minerals mentioned above. The titania content of this heavy portion is 1.26%, which is conceivably larger than the 0.73% of the light portion (S.G.  $\leq 3.3$ ). Whereas rutile has not been positively identified in either of the portions, the mineralogy of various subsamples and a mass balance calculation similar to that done for the Bell Copper suggest that the original sample might contain up to 0.4% free rutile. The biotite is, again, likely to be at least slightly titaniferous.

(iii) Island Copper:- The mineral components of the six samples from the deposit include quartz, plagioclase, chlorite, calcite, muscovite and minor amounts of pyrite, magnetite, laumontite  $\dagger$  pyrophyllite  $\dagger$  amphibole  $\dagger$  rutile. The size distribution and titania contents of a composite sample are listed in Table 3. A heavy liquid separation of the the 80-100 size fraction of a larger composite sample yielded only 0.82% of material with S.G.  $> 3.3$ . Minerals identified from this heavy fraction include pyrite, magnetite and minor amounts of quartz, chlorite, chalcopyrite, molybdenite, mica, plagioclase and rutile. The predominating light

Table 3. Distribution of  $TiO_2$  in various size-fractions (weight % in brackets) of tailings from selected porphyry deposits.

Deposit Name	Titania Analyses (%)			
	Bulk Sample	>100 mesh	100-250 mesh	<250 mesh
A. Island Copper	0.64	0.61(18.4)	0.62(27.5)	0.67(54.1)
B. Ingerbelle	0.73	0.66(25.2)	0.68(31.4)	0.81(43.4)
C. Kitsault	0.67	0.61(34.7)	0.62(29.0)	0.75(36.3)
D. Equity Silver	1.25	1.22(16.4)	1.25(39.1)	1.27(44.5)

fraction (S.G.  $\leq$  3.3) still contains 0.62%  $TiO_2$ . It is estimated that the original sample could contain 0.45% rutile and the balance of titania rests mainly with magnetite, chlorite and mica.

#### B. Alkaline suite porphyry deposits

(i) Afton:- Accurate analyses by atomic absorption spectroscopy show that the eight tailing samples have a range of 0.60-0.75%  $TiO_2$  and an arithmetic mean of  $0.70 \pm 0.05\%$  titania. The tailing mineralogy include plagioclase, quartz, K-feldspar, calcite, chlorite, hematite, magnetite, mica (illite + minor biotite and muscovite), ankerite  $\pm$  epidote, native copper, chalcocite  $\pm$  hornblende  $\pm$  clinopyroxene  $\pm$  apatite. In addition, sphene has been observed in many thin sections cut from specimens collected from the deposit and its vicinity. Electron microprobe analyses on magnetite (Cann, 1979) and silicate minerals (Kwong, 1980, unpublished data) from the deposit render the following data on titania content: magnetite, 0.03-3.37%; biotite, 5.37-6.83%; clinopyroxene, 0.35%; hornblende, 2.65-3.10%; chlorite, 0.04-0.23% and epidote, 0.01-0.02%. Based on these data and mineralogical analyses of various size and gravity fractions of a composite sample, it is concluded that the bulk of titania in the tailings is locked up in sphene and the minerals just listed. Free rutile is estimated to be  $\leq 0.12\%$ .

(ii) Granby:- <sup>(Cann, 1979)</sup> The two samples collected were re-analysed and yielded 0.57 and 0.69%  $TiO_2$ , respectively. The sample with higher titania was found to consist of plagioclase, K-feldspar, biotite, quartz, clinopyroxene, chlorite, calcite and minor amounts of hornblende, magnetite, pyrite  $\pm$  ilmenite. The 80-100 mesh fraction of a subsample contains 1.2% of grains with S.G.  $>$  3.3. This heavy mineral separate contains 5.97%  $TiO_2$  and consists of clinopyroxene, magnetite, sphene (5-8%), pyrite and minor amounts of ilmenite ( $\leq 2\%$ ), chalcopyrite, rutile ( $\leq 2\%$ ), chlorite, plagioclase, quartz, biotite, hornblende, epidote  $\pm$  K-feldspar. Thus the titanium ore minerals readily account for the titania

content of the bulk sample without recursing to the silicate minerals. However, it must be pointed out that the relatively high concentration of titania in the heavy separate only accounts for about 10% of the total titania content of the size fraction analyzed. The rest is probably incorporated in very fine-grained titanium minerals closely associated with lighter grains that escaped separation.

(iii) Newmont:- Since tailings from the Ingerbelle orebody are significantly higher in titania than those from the Copper Mountain orebody, only selected samples from the former were investigated in more detail. Mineralogically, the prominent components are plagioclase, augite, chlorite, biotite  $\pm$  minor muscovite, calcite, prehnite, gypsum, quartz, K-feldspar, magnetite, pyrite  $\pm$  epidote  $\pm$  sphene  $\pm$  ilmenite. The size distribution of a sample with 0.73%  $TiO_2$  is listed in Table 3 together with the titania content of the various fractions. Among the six samples examined, variation in titania content appears to depend on the abundance and/or presence of sphene, ilmenite, magnetite, biotite and, to a lesser degree, augite. Material with S.G.  $> 3.3$  separated from the 60-80 mesh fraction of a sample with 0.59%  $TiO_2$  is void of detectable rutile, ilmenite or sphene. The titania in the sample probably rests with biotite, magnetite and possibly augite. As with the case of Afton, rutile, if present at all, does not seem to occur in any significant amount worth recovering.

### C. Porphyry molybdenum deposits

(i) Kitsault:- Minerals detected from the four samples of the deposit include quartz, K-feldspar, plagioclase, mica (muscovite  $\gg$  biotite), chlorite, calcite, dolomite and trace amounts of amphibole, apatite and molybdenite. The titania contents of various size fractions of a sample with 0.67%  $TiO_2$  are shown in Table 3. The 60-100 mesh fraction of a composite sample with 0.63%  $TiO_2$  yielded 0.9% of material with S.G.  $> 3.3$ . This heavy separate consists mainly of pyrite, some quartz and K-feldspar, and minor amounts of molybdenite, pyrrhotite  $\pm$

chalcopyrite. The light portion (S.G.  $\leq$  3.3) is characterized by 0.57%  $TiO_2$  and consists of quartz, K-feldspar, plagioclase and lesser amounts of mica (mainly muscovite), calcite, chlorite and trace pyrite  $\pm$  dolomite. Since no prominent titanium host minerals have been detected in either portions, it is suggested that  $TiO_2$  in the composite sample occurs mainly as finely dispersed minute grains of rutile, the reflection peaks of which are masked by those of K-feldspar in the x-ray diffractograms.

#### D. Others

(i) Equity Silver:- A sample of the Main zone final tailings from the pilot plant was re-analyzed by x-ray fluorescence and atomic absorption methods which gave 1.25% and 1.20%  $TiO_2$ , respectively. The titania contents of various size fractions according to XRF analyses are shown in Table 3. Minerals identified from the sample include quartz, muscovite  $\pm$  minor illite, plagioclase, chlorite, dolomite, calcite  $\pm$  chalcopyrite, magnetite, K-feldspar  $\pm$  rutile  $\pm$  sphene as well as pyrite, arsenopyrite and galena. Magnetite is absent in the composite sample made up of three samples from the flotation tailings of the Southern Tail zone. The heavy portion (S.G.  $>$  3.3) of the 60-100 mesh fraction of this composite sample consists mainly of pyrite with small amounts of arsenopyrite and quartz. The light portion (S.G.  $\leq$  3.3) makes up 97.5% of the size fraction and contains 0.99%  $TiO_2$ . Its mineralogical composition is characterized by quartz, muscovite  $\pm$  minor illite, plagioclase and trace amounts of pyrite, arsenopyrite, rutile and chlorite  $\pm$  kaolinite. Whereas minor amounts of titania may be locked up in magnetite and chlorite in the Main zone tailings, rutile is believed to account for the greater proportion of titania contained in the tailings of the deposit.

### Discussion and Conclusion

Limited by the facilities available and the sensitivities of the instruments used, some of the data presented above are at best semi-quantitative in nature. For example, in the mineralogical analyses, minerals present in < 2% generally could not be positively identified. Though pre-concentration techniques (e.g. by panning, heavy liquid separation, etc.) could enhance detection of minerals in doubt, where interference occurs, mineral abundances have to <sup>be</sup> assessed from indirect evidence. In the present case, this is particularly true with the estimation of rutile occurring together with K-feldspar. Nonetheless, the apparent consistency of data within each group allows valid comments to be made on the form and abundance of Ti-containing minerals in the tailings and on the feasibility of recovering these minerals as a viable byproduct in addition to the mined ore.

(1) Form and abundance of Ti-containing minerals:- It has already been pointed out above that alkaline porphyry deposits contain more titania than calc-alkaline suite deposits. In the former deposits, however, most titania is incorporated in silicates like biotite and hornblende and in less desirable titanium minerals like sphene and ilmenite. In contrast, most of the deposits in the latter category studied in detail appear to have more than half of their titania manifested as rutile (which should easily be confirmed by electron microprobe analysis). Among the rest of calc-alkaline deposits with less than 0.50% of titania, rutile has been reported in Bethlehem, Highmont, Brenda and Boss Mountain (Drummond and Godwin, 1976). From the detailed examination of tailings of the eight deposits described above, it becomes evident that the calc-alkaline suite samples differ significantly from those of the alkali suite in having higher ratios of pyrite/magnetite and muscovite/biotite. This observation, together with the differences in titanium mineralogy, supports the contention that rutile in these deposits derives mainly from the sulfidation of mafic minerals during

hydrothermal alteration (Force, 1976). It also suggests that rutile is enriched in the phyllic alteration zone. This contention is especially applicable to the Equity Silver deposit where the tailing mineralogy reflects pervasive quartz-sericite alteration. In contrast, rutile in porphyry copper deposits of the southwestern United States of America is prominent in propylitic and argillic zones (Creasey, 1966) and less commonly in the potassic zone (Force, 1976).

(ii) Feasibility of recovery:- Table 3 shows the titania content of various size fractions of tailing samples from four deposits (one from each group) where rutile appears to be the dominating titanium-containing species. Whereas in each of these cases, the differences in titania are well within experimental error, the finer-grained fractions are consistently higher in titania. Besides, heavy liquid mineral separation performed on the 60-100 mesh fraction of most samples failed to concentrate titanium minerals to any significant extent. These observations suggest that for efficient recovery of titanium ore minerals from the tailings of these deposits, the optimum grain size is less than 250 mesh. For many tailings, regrinding may be required. Since additional expense is likely to be involved, only deposits with relatively high titania content and the right titanium ore mineralogy warrant further study. In this respect, Equity Silver appears to be the only candidate that may meet these requirements. After Experimenting with several beneficiation methods on a sample of porphyry copper mill tailings containing 0.75%  $TiO_2$ , Llewellyn and Sullivan (1980) concluded that rutile flotation was the most promising technique for rutile beneficiation. Similar experiments with tailings of the Equity Silver deposit appear to be a logical step in assessing the feasibility of rutile recovery from the Canadian deposits.

In conclusion, whereas calc-alkaline porphyry deposits generally contain less titania than alkaline suite deposits, they constitute a better source of byproduct titanium by virtue of their rutile content. Among the fourteen deposits

investigated in this study, Equity Silver shows the highest titania content (about 1%) and the greater portion of which is manifested as rutile. Tailings from this deposit are suitable for rutile beneficiation studies provided the required fine-grinding (to release the rutile) does not pose difficulties in the relevant procedures.

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