



## TITANIUM IN TAILINGS OF PORPHYRY DEPOSITS IN BRITISH COLUMBIA

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### INTRODUCTION

Rutile, ilmenite, and, to a lesser degree, sphene are the most common 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 aerospace industry. Recent studies on alternative sources of titanium in the United States (for example, Force, 1976; Force *et al.*, 1979; Llewellyn and Sullivan, 1980) suggest that porphyry deposits are potential hosts of titanium minerals as a by-product. To assess the titanium potential of similar deposits in British Columbia, a systematic examination of tailings from porphyry-type mines was initiated in the fall of 1982. Fourteen mines were chosen for an exploratory study that 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 results of titania analyses, mainly by an emission spectrographic method from 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 previously mentioned deposits; it is therefore listed separately as Group D. From the table, it is evident that calc-alkaline porphyry deposits (Groups A and C) are lower in titania than the alkaline deposits (Group B) while Equity Silver (Group D) contains the most titania among the four groups. Using an arbitrary cutoff value of 0.50 per cent  $\text{TiO}_2$ , selected samples from promising deposits in each group were examined in more detail, both analytically and mineralogically. The findings are summarized in the following.

#### CALC-ALKALINE SUITE PORPHYRY COPPER DEPOSITS

##### Bell Copper

Chemical analyses by atomic absorption spectroscopy indicate that titanium in the 10 samples from the deposit range from 0.39 to 0.73 per cent with an average of  $0.55 \pm 0.09$  per cent  $\text{TiO}_2$ . The major mineral

constituents of the most titanium-rich sample (0.73 per cent  $TiO_2$ ) are, in order of decreasing abundance, plagioclase, quartz, mica (biotite + muscovite  $\leq 10$  weight per cent), K-feldspar, chlorite with or without kaolinite, dolomite, siderite, pyrite, hematite, and calcite. Another sample with similar mineralogy but about half as much mica yielded 0.60 per cent  $TiO_2$ , 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 weight per cent chlorite, 10 weight per cent biotite, and 0.5 weight per cent magnetite, a mass balance calculation accounts for titania content of 0.5 per cent; therefore about 0.2 per cent of finely disseminated rutile is suspected to be present. This amount of rutile is, however, not readily recoverable.

TABLE 2  
TITANIA CONTENT OF COMMON TITANIUM-CONTAINING MINERALS  
(Data source: Deer, 1966)

Mineral Name	Formula	$TiO_2$ per cent
Rutile	$TiO_2$	100
Anatase (+ brookite)	$TiO_2$	100
Leucoxene*	$TiO_2$	100
Sphene (titanite)	$CaTiO(SiO_4)$	40.8
Ilmenite	$FeTiO_3$	52.65
Ulvospinel	$FeTiO_4$	35.7
Magnetite	$Fe_3O_4$	<1.5
Biotite	$K(Mg, Fe)_3(AlSi_3O_{10})(OH)_2$	<5
Hornblende	$(Na, Ca)_{2-3}(Mg, Fe, Al)_5Si_6(Si, Al)_2O_{22}(OH)_2$	0.03-7.12, generally <2**
Clinopyroxene	$(Ca, Na)(Mg, Fe, Al)(Si, Al)_2O_6$	0.04-1.18, generally <0.8**
Chlorite	$(Mg, Al, Fe)_{12}[(Si, Al)_8O_{20}](OH)_{16}$	0.00-0.88, generally <0.35**

NOTES:

\*Leucoxene is normally finely crystalline rutile (Deer, 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 titanium dioxide (Kerr, 1959, p. 196). In this report, the first definition is adopted.

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

A sub-sample was taken and the 80 to 100 mesh portion used for further testing. This sub-sample has a size distribution of 54.2 per cent >80 mesh, 9.9 per cent 80 to 100 mesh, and 35.8 per cent <100 mesh; 1.15 weight per cent of the sub-sample has a specific gravity exceeding 3.3.

This heavy fraction consists mainly of pyrite with lesser hematite and minor amounts of magnetite, siderite, dolomite, mica, K-feldspar, and quartz. No rutile was detected. Although K-feldspar might have masked its strongest reflection peak in the diffractogram, the detection of 0.73 per cent  $\text{TiO}_2$  in the light fraction (S.G.  $<3.3$ ) argues against any significant concentration of titania in the heavy fraction. Incidentally, the minus 100 mesh portion of the sub-sample is characterized by 0.79 per cent  $\text{TiO}_2$ , indicating that rutile, if present, is slightly enriched in the finest portion. Unfortunately, surface tension problems encountered in mineral separation involving heavy liquids and lack of facility for alternative methods of separation available in the laboratory prevented detailed analyses of the fine fraction.

### **Granisle**

Atomic absorption analysis of the eight tailing samples gave a range of 0.44 to 0.88 per cent and a mean of  $0.69 \pm 0.14$  per cent  $\text{TiO}_2$ . The major mineral components are quartz, plagioclase, and biotite; minor to accessory phases identified include muscovite, K-feldspar, chlorite, calcite, magnetite, pyrite, gypsum, apatite, and hematite. The 80 to 100 mesh size fraction of a sample with 0.75 per cent  $\text{TiO}_2$  was separated into two portions using heavy liquids. The heavy portion (S.G.  $>3.3$ ), which makes up only 1.8 per cent of the sub-sample, contains a small amount of marcasite, chalcopyrite, and molybdenite in addition to the minerals mentioned previously. The titania content of this heavy portion is 1.26 per cent, considerably higher than the 0.73 per cent of the light portion (S.G.  $<3.3$ ). Whereas rutile has not been positively identified in either, the mineralogy of various sub-samples and a mass balance calculation similar to that done for Bell Copper suggest that the original sample might contain up to 0.4 per cent free rutile. The biotite is, again, likely to be slightly titaniferous.

### **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 with or without pyrophyllite, amphibole, and rutile. The size distribution and titania contents of a composite sample are listed in Table 3. A heavy liquid separation of the 80 to 100-mesh size fraction of a larger composite sample yielded 0.82 weight per cent of material with S.G. exceeding 3.3. Minerals identified from this heavy fraction are pyrite, magnetite, and minor amounts of quartz, chlorite, chalcopyrite, molybdenite, mica, plagioclase, and rutile. The predominating light fraction (S.G.  $<3.3$ ) still contains 0.65 per cent  $\text{TiO}_2$ . It is estimated that the original sample might contain 0.45 per cent rutile.

**TABLE 3**  
**DISTRIBUTION OF TiO<sub>2</sub> IN VARIOUS SIZE-FRACTIONS (WEIGHT % IN BRACKETS) OF TAILINGS FROM SELECTED PORPHYRY DEPOSITS**

Deposit Name	Bulk Sample	Titanium Analyses (%)		
		>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)

#### ALKALINE SUITE PORPHYRY DEPOSITS

##### Afton

Analyses of eight tailing samples by atomic absorption spectroscopy show a range of 0.60 to 0.75 per cent TiO<sub>2</sub> and an arithmetic mean of 0.70±0.05 per cent titania. The tailings consist of plagioclase, quartz, K-feldspar, calcite, chlorite, hematite, magnetite, mica (illite and minor amounts of biotite and muscovite), ankerite, native copper, chalcocite with or without epidote, clinopyroxene, and apatite. In addition, sphene occurs 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 give the following data on titania content: magnetite 0.03 to 3.37 per cent; biotite, 5.37 to 6.83 per cent; clinopyroxene, 0.35 per cent; hornblende, 2.65 to 3.10 per cent; chlorite, 0.04 to 0.23 per cent; and epidote, 0.01 to 0.02 per cent. 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 these minerals and sphene. Free rutile is estimated to be approximately 0.1 per cent.

##### Granby

The two samples collected outside of Princeton from the old Granby mines' operation yielded 0.57 and 0.69 per cent TiO<sub>2</sub> 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, and pyrite with or without ilmenite. The heavy fraction from the 80 to 100 mesh fraction of a subsample contains 1.2 weight per cent of the sample. This heavy mineral separate contains 5.97 per cent TiO<sub>2</sub> and consists of clinopyroxene, magnetite, sphene (5 to 8

per cent), pyrite, and minor amounts of ilmenite (about 2 per cent), chalcopyrite, rutile (about 2 per cent), chlorite, plagioclase, quartz, biotite, hornblende, and epidote and rare K-feldspar. Titanium minerals readily account for the titania content of the bulk sample. However, the relatively high concentration of titania in the heavy separate accounts for only about 10 per cent of the total titania content of the size fraction analysed. The rest is probably incorporated in very fine-grained titanium minerals that are associated closely with lighter grains that escaped separation.

### **Newmont**

Since tailings from the Ingerbelle orebody are significantly higher in titania than those from the Copper Mountain orebody, only selected Ingerbelle samples were investigated in more detail. Mineralogically, the prominent components are plagioclase, augite, chlorite, biotite with or without minor muscovite, calcite, prehnite, gypsum, quartz, K-feldspar, magnetite, and pyrite with uncommon epidote, sphene, and ilmenite. The size distribution of a sample with 0.73 per cent  $TiO_2$ , together with the titania content of the various fractions, is listed in Table 3. 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 from the 60 to 80 mesh fraction with S.G. greater than 3.3 separated from a sample with 0.59 per cent  $TiO_2$  is void of detectable rutile, ilmenite, and sphene. The titania in the sample probably occurs in biotite, magnetite, and possibly augite. As at Afton, rutile does not seem to occur in recoverable amounts.

## **PORPHYRY MOLYBDENUM DEPOSITS**

### **Kitsault**

Minerals determined in the four samples of the deposit include quartz, K-feldspar, plagioclase, mica (muscovite>>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 per cent  $TiO_2$  are shown in Table 3. The heavy portion of the 60 to 100 mesh fraction of a composite sample with 0.63 per cent  $TiO_2$  yielded 0.9 weight per cent of material. This heavy separate consists mainly of pyrite, some quartz and K-feldspar, and minor amounts of molybdenite and pyrrhotite with or without chalcopyrite. The light portion (S.G. <3.3) contains 0.57 per cent  $TiO_2$  and consists of quartz, K-feldspar, plagioclase, lesser amounts of mica (mainly muscovite), calcite, chlorite, and trace amounts of pyrite and dolomite. Since no prominent titanium host minerals have been detected, it is suggested that  $TiO_2$  in the composite sample occurs mainly as minute, finely dispersed grains of rutile. Unfortunately the reflection peaks of rutile are masked by those of K-feldspar in X-ray diffractograms so this conclusion cannot be confirmed.

## OTHER DEPOSITS

### Equity Silver

A sample of the Main zone final tailings from the pilot plant was reanalysed by X-ray fluorescence (XRF) and atomic absorption methods which gave 1.25 and 1.20 per cent  $\text{TiO}_2$  respectively. The titania contents of various size fractions according to XRF analyses are shown in Table 3. Minerals identified from individual fractions include quartz, muscovite with some illite, plagioclase, chlorite, dolomite, calcite with or without chalcopryrite, magnetite, K-feldspar, and minor amounts of rutile and sphene, as well as pyrite, arsenopyrite, and galena. Magnetite is absent in a composite sample made up of three samples from the flotation tailings of the Southern Tail zone. The heavy portion of the 60 to 100 mesh fraction of this composite consists mainly of pyrite with small amounts of arsenopyrite and quartz. The light portion makes up 97.5 weight per cent of the size fraction and contains 0.99 per cent  $\text{TiO}_2$ . Its mineralogical composition is characterized by quartz, muscovite with some illite, plagioclase, and trace amounts of pyrite, arsenopyrite, rutile, chlorite, and kaolinite. Although 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 the contained titania.

## DISCUSSION AND CONCLUSION

Limited by the facilities available and the sensitivities of the instruments used, some of the data presented above are semi-quantitative in nature. For example, in the mineralogical analyses, minerals present in amounts less than 2 per cent generally could not be identified positively. Pre-concentration techniques (for example, by panning or heavy liquid separation) can aid detection of minerals. However, where interference in X-ray diffraction patterns occurs, mineral abundances must be assessed from indirect evidence. In the present case, estimation of rutile occurring together with K-feldspar is particularly difficult. Nonetheless, the apparent consistency of data within each group allows valid comments to be made on the form and abundance of titaniferous minerals in the tailings and on the feasibility of recovering these minerals as a viable by-product.

Alkaline porphyry deposits contain more titania than calc-alkaline suite deposits. In these alkalic 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 calc-alkaline category appear to have more than half of their titania content in rutile (which should easily be confirmed by electron microprobe analysis). Among the remaining calc-alkaline deposits, which have less than 0.50 per cent titania, rutile has been reported in Bethlehem, Highmont, Brenda, and Boss Mountain (Drummond and Godwin, 1976).

From examination of tailings from the eight deposits described above, it is evident that calc-alkaline suite samples have higher ratios of pyrite/magnetite and muscovite/biotite than those of the alkali suite. 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. In contrast, rutile in porphyry copper deposits of the southwestern United States is prominent in propylitic and argillic zones (Creasey, 1966) and less commonly in the potassic zone (Force, 1976).

More assessment is needed to evaluate the feasibility of recovering the titanium minerals. Table 3 shows the titania content of various size fractions of tailing samples from four of the deposits (one from each group) where rutile appears to be the dominating titaniferous 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. Heavy liquid mineral separation performed on the 60 to 100 mesh fraction of most samples failed to significantly concentrate titanium minerals. These observations suggest that efficient recovery of titanium minerals from the tailings requires an optimum grain size of less than 250 mesh. Thus for many tailings regrinding may be required and only deposits with relatively high titania content and the right titanium ore mineralogy warrant further study. In the group of deposits examined, only Equity Silver apparently meets these requirements.

After experimenting with several beneficiation methods on a sample of porphyry copper mill tailings containing 0.75 per cent  $TiO_2$ , Llewellyn and Sullivan (1980) concluded that 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 this deposit.

In conclusion, whereas calc-alkaline porphyry deposits generally contain less titania than alkaline suite deposits, they constitute a better potential source of by-product titanium because they contain rutile. Among the 14 deposits investigated in this study, a transitional porphyry system deposit (Cyr, et al., 1984), Equity Silver, shows the highest titania content (about 1 per cent) and a significant amount of rutile. Flotation testing of more finely ground samples is a further necessary step in assessment of the feasibility of recovering rutile from this deposit.

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