

Quantitative Analysis of Ilmenite Magnetic Fractions.

Two granular samples of ilmenite magnetic fractions were submitted for quantitative X-ray diffraction and chemical analysis. The issue with these samples was to determine their veracity as ilmenite ore fractions and to provide an elementary indication as to the ore's quality.

The two samples consisted of lustrous, coarse grains. Sample 1, the magnetic fraction purported to be magnetite, appeared as well-developed opaque, black octahedra under an optical microscope. Sample 2 was a mixture of opaque, lustrous blocky and hexagonal crystals, and blocky transparent green-yellow crystals. These samples were ground with a mortar and pestle, and diffraction data were collected for quantitative Rietveld analysis from these powders. Preliminary qualitative analyses indicated a number of major phases present as:

Sample 1 (Magnetic Fraction 1):

- magnetite
- ilmenite
- rutile
- quartz
- zircon (trace)

Sample 2 (Magnetic Fraction 2):

- ilmenite
- hematite
- enstatite
- pseudobrookite
- zircon
- riebeckite
- magnetite (trace)
- rutile
- quartz (trace)
- garnet

This assemblage is typical of Eastern Asian ilmenites, (e.g. Yi et al. (1997), *Journal of the Geological Society of China*, vol. 40(4), pp. 709 – 722) with key indicator minerals such as pseudobrookite (Fe₂TiO₅) and the associated pyroxenes. Ilmenite in these present assemblages is not phase-pure, with exsolution hematite and hem-ilmenite. As a result, the phase labelled “ilmenite” is very iron-rich. Magnetite in these assemblages also typically bears titanium in solid solution, and indeed in the present case, is actually a titano-magnetite.

Quantitative phase analysis was carried out based on the named minerals, with further refinement subsequently including the major minerals’ crystallographic cell dimensions. The cell dimensions could be used to estimate the iron content of a mineral.

The mineralogies of the samples were refined to the following values (Table 1), and the analytical data are presented graphically in the attached Rietveld plots (Appendix A). Table 2 gives the chemical analyses of these samples.

Table 1: Quantitative X-ray Diffractometric mineralogical analyses of Ilmenite Magnetic Fractions 1 & 2.

Mineral	Sample 1 wt %	Sample 2 wt %
Ilmenite	7.4	39.7
Hematite	0.0	13.4
Pseudobrookite	0.0	4.6
Rutile	0.6	2.0
Magnetite	91.2	0.1
Quartz	0.7	0.0
Zircon	0.0	1.0
Enstatite	0.0	37.5
Riebeckite	0.0	0.5
Garnet [†]	0.0	1.2

† It is not possible to determine the type of garnet from diffraction data alone.

Table 2: Chemical analyses of Ilmenite Magnetic Fractions 1 & 2.

Element	LOR* %	Sample 1 wt %	Sample 2 wt %
TiO ₂	0.1	13.7	24.2
Fe (total, elemental)	0.01	57.00	35.40
Al ₂ O ₃	0.01	2.83	1.81
Cr ₂ O ₃	0.01	0.06	0.12
MgO	0.01	2.11	6.84
P ₂ O ₅	0.01	0.08	0.12
SiO ₂	0.01	0.72	15.05
ZrO ₂	0.01	0.01	0.21

* Limit of Resolution.

Major elements are reconciled between the minerals as shown in Tables 3 and 4. The discrepancies between TiO₂, Fe, MgO, and Al₂O₃ are due to multiple solid solution, especially within the enstatite phase. For instance, where The enstatite structures used in the present analyses actually model a poorly defined Mg-Fe silicate mineral of the pyroxene group, with a composition which can span from diopside (CaMgSi₂O₆) through orthoferrisilite (MgFeSi₂O₆), to enstatite proper (Mg₂Si₂O₆).

These major elements, as well as minor elements such as Cr₂O₃ are also able to fully substitute into ilmenite-hematite and magnetite crystal lattices.

Traces of P₂O₅, however, indicate the presence of trace monazite or xenotime (rare-earth phosphate minerals), but in quantities too small to be reliably analysed by X-ray diffraction.

As part of the reconciliation, the TiO₂ content of a mineral in the ilmenite-hematite solid solution series can be determined from its crystallographic unit cell parameters:

Unit cell dimensions for ideal ilmenite FeTiO₃ (52.7 % TiO₂) are $a = 5.088 \text{ \AA}$, $c = 14.093 \text{ \AA}$, which decrease with increasing Fe content to those of ideal hematite Fe₂O₃ (0 % TiO₂) - $a = 5.035 \text{ \AA}$, $c = 13.748 \text{ \AA}$.

The hem-ilmenite in Sample 1 has cell dimensions of $a = 5.032 \text{ \AA}$, $c = 13.879 \text{ \AA}$, which suggest an average TiO_2 content of 9.5 %. The hem-ilmenite in Sample 2 has cell dimensions of $a = 5.086 \text{ \AA}$, $c = 14.001 \text{ \AA}$, which suggest an average TiO_2 content of 43.8 %. Exsolution hematite in Sample 2 also shows evidence of Ti substitution, with slightly dilated unit cell dimensions of $a = 5.040 \text{ \AA}$, $c = 13.757 \text{ \AA}$, suggesting a TiO_2 content of 3.0 %.

Magnetite shows similar unit cell dilation with Ti substitution, going from $a = 8.396 \text{ \AA}$ for pure, ideal Fe_3O_4 to $a = 8.423 \text{ \AA}$ for titanomagnetite $\text{Fe}_{2.75}\text{Ti}_{0.25}\text{O}_4$. The magnetite in Sample 1 is Ti-substituted, since $a = 8.411 \text{ \AA}$, ideally corresponding to a TiO_2 content of 3.5 %. Since the magnetite in Sample 2 is of such low abundance, reliable cell dimensions and composition could not be estimated. It should be noted here that Mg, Al, and Cr substitution which is possible in magnetites will also affect the observed cell dimensions, but the crystallographic data is lacking here to make an informed judgement on the extent of this substitution.

Table 3: Elemental reconciliation between mineral phases for Sample 1.

Sample 1	Wt %	TiO₂	Fe(tot)	Al₂O₃	MgO	SiO₂
Ilmenite	7.4	0.7	4.8			
Hematite						
Pseudobrookite						
Rutile	0.6	0.6				
Magnetite	91.2	3.2	63.5			
Quartz	0.7					0.7
Zircon	0.1					0.1
Enstatite						
Riebeckite						
Sum (calc)		4.4	68.3	-	-	0.8
Sum (obs)		13.7	57.0	2.83	2.11	0.72

Table 4: Elemental reconciliation between mineral phases for Sample 2.

Sample 2	Wt %	TiO₂	Fe(tot)	Al₂O₃	MgO	SiO₂
Ilmenite	39.7	17.4	16.8			
Hematite	13.4	0.4	9.1			
Pseudobrookite	4.6	1.5	2.1			
Rutile	2.0	2.0				
Magnetite	0.1	0.0	0.1			
Quartz	0.0					
Zircon	1.0					
Enstatite	37.5		6.7	1.0	14.5	14.4
Riebeckite	0.5		0.1		0.0	0.3
Garnet	1.2		0.0	0.3	0.4	0.5
Sum (calc)		21.4	34.9	1.3	14.9	15.5
Sum (obs)		24.2	35.4	1.81	6.84	15.05

As it stands, the present ilmenite is of relatively low grade for titanium ore, compared to Western Australian ores, which contain between 55 % and 70 % TiO₂. Unlike the Western Australian ilmenites which are strongly weathered, the TiO₂ from these present highly crystalline minerals is relatively difficult to extract.

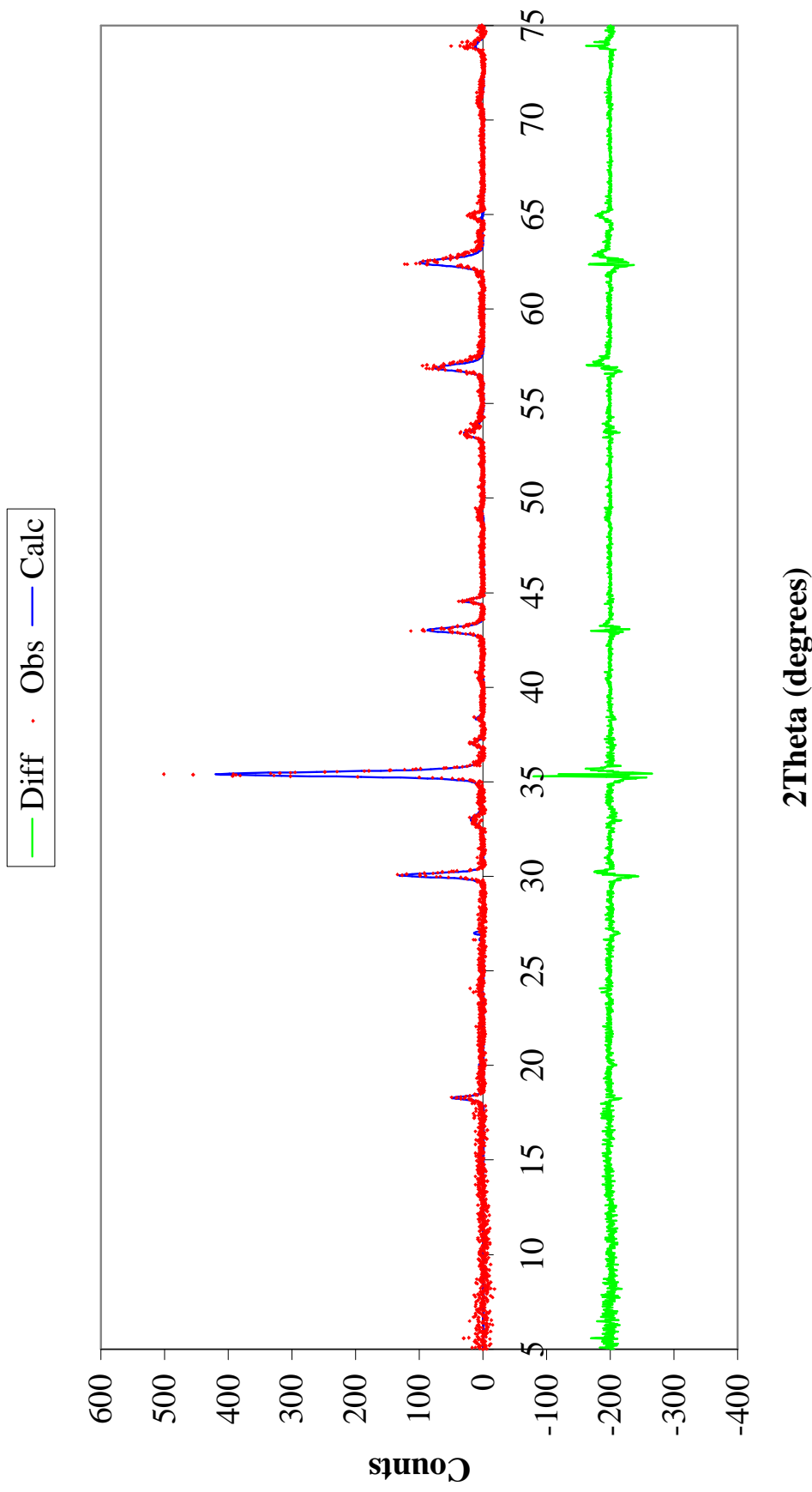
A subsequent density separation may upgrade the ore to remove the pyroxene-enstatite component effectively (compare the density of ilmenite = 4.78 g/cm³ to that of enstatite = 3.96 g/cm³). However, the easily accessible TiO₂ content of the ilmenite is at best 42 %, while the TiO₂ content of the pseudobrookite is extracted with difficulty.

The present ilmenite is better suited for dense aggregate or dense fill in specialty concretes, as abrasive medium, or as slag/flux for welding rods. This last application accounts for approximately 1/3 of ilmenite consumption, the remainder, higher-grade ore (54 % minimum TiO₂) going to TiO₂ production for pigments and metal production.

An excellent review of titanium mineral trade and applications can be found at:

<http://minerals.er.usgs.gov/minerals/pubs/commodity/titanium/>.

Ilmenite Magnetic Fraction 1 Rietveld plot



Ilmenite Magnetic Fraction 2 Rietveld Plot

