

# QUANTITATIVE CHARACTERIZATION OF THE REE MINERALS BY QEMSCAN FROM THE NECHALACHO HEAVY RARE EARTH DEPOSIT, THOR LAKE PROJECT, NWT, CANADA

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## ABSTRACT

The Nechalacho rare metal deposit is located in NWT, Canada. Avalon Rare Metals Inc. is now evaluating processing techniques for recovery of REE to be used in the industry. QEMSCAN® analysis coupled with whole rock, REE, Zr and Nb, and electron microprobe analyses were utilized to identify and quantify the mineralogy of the deposit, and define the REE distribution among minerals. QEMSCAN® mineralogy was performed on fifty intact drill samples using EXPLORIMIN™ that provided textural information for the mineralization; crushed samples were used to determine the variability of the ore and define REE domains, and composite samples to determine the liberation and association of the REE minerals. The sample matrix predominantly consists of biotite, feldspars, quartz, muscovite/clays, minor chlorite and amphibole, magnetite and hematite and carbonates. REE include in decreasing order of abundance allanite (3.6%), monazite (1.5%), synchysite (0.9%), columbite (0.9%), fergusonite (0.6%), bastnaesite (0.4%), and zircon (11.0%). The majority of the HREE are carried by fergusonite and zircon, and the LREE by monazite, allanite, synchysite and bastnaesite. QEMSCAN® mineralogical data is extremely valuable in assessing the mineralogy of the ore. The data have been implemented in defining the mineralogy of the ore body, support metallurgical testwork, predict recoveries and grades, and finally calculate reserves of the deposit.

## INTRODUCTION

Avalon is in the unique position of owning and developing one of the world's largest rare earth deposits in the Northwest Territories of Canada.

The term Rare Earth Elements (REE) is used to describe the 15 lanthanide elements or metals and, more recently, the metals yttrium and scandium, which display similar physical and chemical properties. REE are not particularly rare and have a similar abundance in the earth's crust to nickel, tin or tungsten. Unlike these better known metals however, the rare earths have little tendency to become concentrated into commercial ore deposits. When they do become concentrated, deposits of REEs usually display enrichment in one of two groups. The most commonly occurring deposits of REEs contain a sub-group of elements referred to as the "light rare earth elements" (LREEs), which include lanthanum, cerium, praseodymium, neodymium, and samarium. Less commonly, deposits of REEs contain the much more valuable sub-group of elements referred to as the "heavy rare earth elements" (HREEs), which include europium, gadolinium, terbium,

dysprosium, holmium, erbium, thulium, yttrium and lutetium. Yttrium and scandium most commonly occur in association with this second HREE sub-group. Generally, LREEs are produced from the mineral bastnaesite, and the HREEs have been produced from the minerals xenotime and monazite. LREEs continue to be produced from bastnaesite, however in the 1980s, China started production of HREEs from unique laterite clay deposits. China now produces approximately 95% of the world's rare earths.

## APPLICATIONS OF REE

The growing demand for REE is due to their unique physical and chemical properties, which make them indispensable in many highly technical, 'green' and novel applications. The supply of the LREE lanthanum to samarium is adequate at present but many of the HREE, europium to lutetium, are in short supply and with growing demand have seen rapid price increases. Table 1 illustrates the current and demand driven applications of REE (Avalon Rare Metals Inc).

## QUANTITATIVE APPLIED MINERALOGY

Quantitative automated mineralogy is increasingly being applied to ore deposits. It helps to understand and improve mineralogical parameters for textural characterization of the ore and the host rocks from various geological environments. Automated mineralogy provides data to improve the understanding of field relationships of various rock units in a deposit, distribution of ore and gangue minerals, define geological domains based on mineral abundances, and liberation and association of ore. Liberation studies are used to streamline metallurgical beneficiation programs and help to optimize metallurgical processes for mining operations. These all fall into the area of geometallurgical research that aims at defining and examining mineral characterization for potential process development impacts (e.g., Gunning et al., 2009).

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## SCOPE OF THE STUDY

Different analyses are aimed at the characterization of the rocks and the REE. Intact drill core samples were examined to define the textural features of REE and gangue minerals and an ore variability study was carried out to determine and speciate the REE minerals in the deposit. More detailed studies aimed to determine the liberation and association characteristics of REE minerals. Mineralogical analyses coupled with electron microprobe analyses (EMPA) were used to calculate the elemental distribution of light and heavy REE. These all fall into the area of geometallurgical research that aims to define and examine mineral characterization for potential process development impacts.

## GEOLOGICAL SETTING

The Aphebian Blatchford Lake Complex, intrudes Archean Yellowknife Supergroup metasedimentary rocks and comprises of early ultrabasic and basic rocks through to leucoferrodiorite, quartz syenite and granite, finally to a peralkaline granite and a late syenite (Figure 1) (Davidson 1982, Pedersen et al., 2007). There appears to be

successive intrusive centres including an early western centre that is truncated by a larger second centre consisting of the Grace Lake Granite and the Thor Lake Syenite. Nepheline syenite underlies Thor Lake Syenite and was recognised in drilling of the Lake Zone mineralization. The Lake Zone is indicated on this map as the small oval pink area in the northwest of the red coloured Thor Lake syenite. The last intrusive event is believed to be the nepheline syenite, intruded into Grace Lake Granite and the Thor Lake Syenite. Davidson (1982) has shown that the Grace Lake and Thor Lake intrusions are essentially consanguineous but did not recognize the nepheline syenite. Recent studies have indicated that the mineralization is hosted in metasomatized and hydrothermally altered nepheline syenite underlying the Thor Lake syenite (NI 43-101 Report, Nechalacho Deposit, August 2010). Recent geochronological studies of the intrusive complexes from both the east and west sides of the deposit indicate that age relationships are comparable.

RARE EARTHS	APPLICATION	DEMAND DRIVERS
Nd, Pr, Sm, Tb, Dy	Magnets	Computer hard drives, consumer electronics, voice coil motors, hybrid vehicle electric motors, wind turbines, cordless power tools, Magnetic Resonance Imaging, and maglev trains
La, Ce, Pr, Nd	LaNiMH Batteries	Hybrid vehicle batteries, hydrogen absorption alloys for re-chargeable batteries
Eu, Y, Tb, La, Ce	Phosphors	LCDs, PDPs, LEDs, energy efficient fluorescent lamps
La, Ce, Pr, Nd	Fluid Cracking Catalysts	Catalysts petroleum production - greater consumption by 'heavy' oils and tar sands
Ce, La, Nd	Polishing Powders	Mechano-chemical polishing powders for TVs, computer monitors, mirrors and (in nano-particulate form) silicon chips
Ce, La, Nd	Auto Catalysts	Tighter NO <sub>x</sub> and SO <sub>2</sub> standards - platinum is recycled, but for rare earths it is not economic
Ce, La, Nd	Glass Additive	Cerium cuts down transmission of UV light, La increases glass refractive index for digital camera lens
Er, Y, Tb, Eu	Fibre Optics	Signal amplification

Table 1: REE Applications

## DEPOSIT GEOLOGY AND MINERALIZATION

The Nechalacho deposit is an unusual rare earth element (REE) deposit for its exceptionally high HREE (Eu through Lu and Y) content. The Nechalacho REE mineralization is hosted in a tabular hydrothermal alteration zone, exposed over an area in excess of one km<sup>2</sup> and averaging about 100-200m in thickness (Figure 2). This east-west section shows a typical view of this tabular deposit. The light grey is the upper part that is dominated by light rare earths and where the heavy rare earths are about 5 to 10% of the rare earth content. Within this light rare earth zone there are higher grade bands that may grade typically between 1 and 4% total rare earths. At the base of this light rare earth zone, there is a distinct Basal Zone with 1.5 to 2.5% total rare earths in 2m drill samples, and enriched in heavy rare earths to the level where the heavy rare earths are 20 to 30% of the total rare earth content. The Nechalacho deposit is characterized by near-complete replacement of the primary mineral assemblage including K-feldspar, plagioclase, biotite and amphibole, by chlorite, magnetite, biotite, zircon, bastnaesite, monazite, allanite and fergusonite. Where the rare earth grades are higher, the presence of visible high grade zircon is striking. Current work by Avalon Rare Metals Inc. is focused on drilling for indicated resources and metallurgical testwork leading to a pre-feasibility economic analysis due in late 2010.

**MINERALOGICAL PREPARATION FOR QEMSCAN™**

The current mineralogical study was initiated to quantify the amount of REE-bearing minerals, in intact drill core and in composite samples using the QEMSCAN™ technology – an automated mineralogical instrument. QEMSCAN™ is an acronym for Quantitative Evaluation of Materials by Scanning Electron Microscopy (e.g., Benedictus et al. 2008; Hoal et al., 2009 and references therein). This automated, quantitative mineralogy system is based on an EVO 430 SEM equipped with an EDS X-ray facility. If the minerals or constituent phases within the sample are chemically distinct, QEMSCAN™ is capable of reliably discriminating and quantifying phases, and is capable of providing volume and mass data, as well as liberation, grain-size and association characteristics. The data was processed with iDiscover™ software (version 4.2).

Intact drill core samples (N=30) were analyzed with the EXPLMIN™ method to determine rock-types and provide textural characterization of samples. Composite reject samples (greater than 50) from drill cores were stage crushed to 106 µm and analyzed to determine the ore variability. Approximately 25 composite samples were staged crushed to K80 -150 µm, screened and fractions were then combined to four size fractions (-600/+150µm, -150/+75 µm, -75/+25 µm and -25/+3 µm) for a more detailed mineralogical determination for the purpose of metallurgical beneficiation. Assays including whole rock analyses by XRF for major elements, Zr, Nb, and REE (+Y, U, Th) analyses were also carried out for the various samples and products.

The Bulk Mineral Analysis, or BMA, and the Particle Mineral Analysis, or PMA were used for the analyses. A BMA is performed by the linear intercept method, in which the electron beam is rastered at a pre-defined point spacing (nominally 3 micrometers, but variable with particle size) along several lines per field, and covering the entire polished section at any given magnification. A PMA is a two-dimensional mapping analysis aimed at resolving liberation and locking characteristics of a generic set of particles. A pre-defined number of

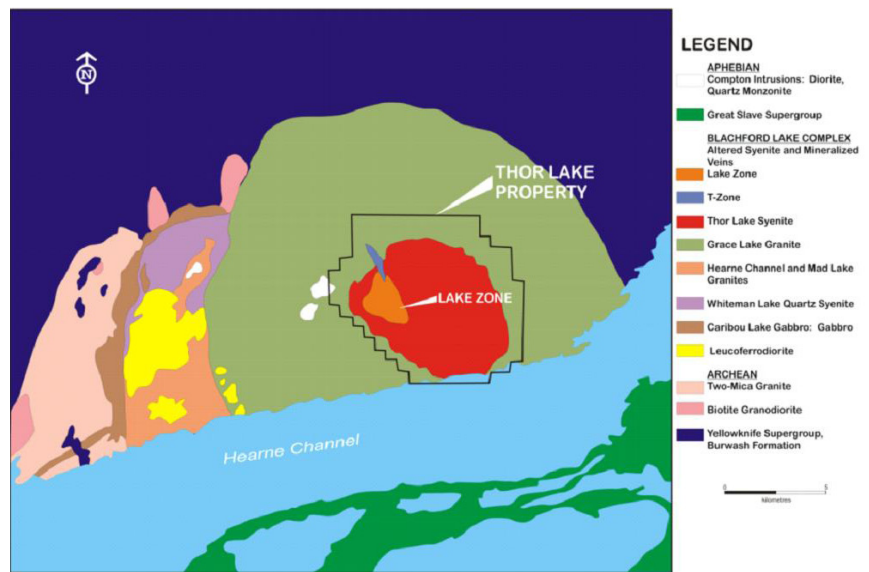


Figure 1: Location of the Lake Zone REE property

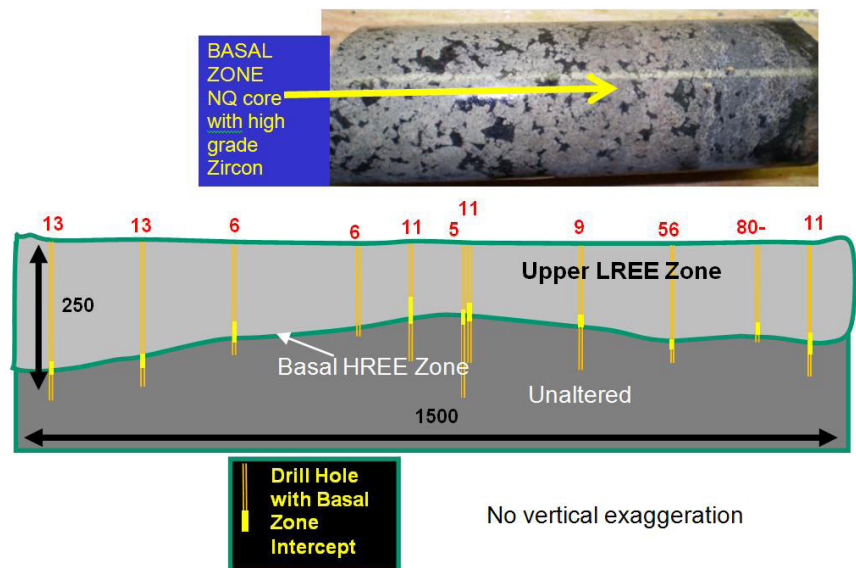


Figure 2: Schematic view of the Basal Zone

particles are mapped at a point spacing selected in order to spatially resolve and describe mineral textures and associations.

Graphite-impregnated polished sections (PS) were prepared from representative riffled sub-samples. For the EXPLMIN™ studies, a PS was made from each sample. For the variability study one PS was made from each sample while another was randomly made to check the variability of the analysis. For the composite samples two PS were made from the two coarse fractions and one from each of the fine fractions to increase statistical representation of the minerals.

All of the polished sections were submitted for analysis using QEMSCAN™ technology. The analyses are based on X-ray chemistry of minerals. Chemical assays are compared to the QEMSCAN™ calculated assays for data validation purposes. Liberation and association classes were defined as the following; barren is a particle that has 0% of mineral A, free is a particle that has > 95% of the surface area of mineral A, a binary particle of mineral A and mineral B is a particle that has > 95% of the surface area of mineral A and mineral B, and complex any combination of the particles.

**EXPLOMIN™ RESULTS**

This part of the study aims at characterization of the rock types, distribution of REE minerals, alteration and overall textural features of the rocks associated with mineralization.

The samples consist mainly of silicate gangue minerals that include biotite, plagioclase, quartz, K-feldspar, Fe-oxides and less muscovite/clays, chlorite, carbonates, amphibole, and trace amounts of other minerals (Table 2). REE minerals include mainly zircon (ZrSiO<sub>4</sub>) (11.1%), and altered zircon (2.2%), allanite [(Ca,Y)<sub>2</sub>(Al,Fe)<sub>3</sub>Si<sub>3</sub>O<sub>12</sub>(OH)] (2.7%), monazite [(LREE,Y,Th)PO<sub>4</sub>] (0.6%), columbite(Fe) (FeNb<sub>2</sub>O<sub>6</sub>) (0.4%), synchysite [Ca(REE)(CO<sub>3</sub>)<sub>2</sub>F] (0.3%), fergusonite [(REE,Y)NbO<sub>4</sub>] (0.2%), bastnaesite [REE(CO<sub>3</sub>)F] (0.2%).

Zircon and allanite were detected more consistently and in higher abundance than the other REE phases. Biotite and plagioclase were also detected consistently in most samples. Zircon forms locally massive bands (up to 63% in the Basal Zone) in both the upper zones and the Basal Zone. Bastnaesite, synchysite and columbite occur in trace amounts to minor amounts but are significant REE carriers. REE mineralization is not strongly correlated with silicate alteration minerals. This might indicate different mineralization events that precipitated the present minerals.

A representative back scattered electron microscope image (Figure 3) illustrates the complexity of the ore. It shows fergusonite and zircon among various silicates, carbonates and Fe-oxides. The EXPLOMIN™ analysis maps the entire section in which images are then processed and converted to digital images using pseudo colours. These are very powerful because they provide unperturbed textural features (Figure 4). The images can be used to characterize the samples and extract valuable information of the mineralization. Figure 4A illustrates the entire polished section with a detailed mineral list. The image illustrates three mineralogical domains including quartz-K-feldspar-(biotite)-zircon-monazite (Domain 1), plagioclase-allanite (Domain 2) and a biotite-K-feldspar vein (Domain 3). The image has been processed (Figure 4B) to illustrate

primary, secondary minerals, zircon and REE minerals, and only the REE minerals (Figure 4C).

**ORE VARIABILITY – DEFINING GEOLOGICAL DOMAINS**

This portion of the study was primarily focussed at “mineralogically” resolving the zones of elevated REE grades and distinguishing between the domains between concentrated LREE and HREE.

The ranges and average values of the minerals are presented in Table 3. The host rocks are dominated by quartz, followed by biotite, muscovite/clays, plagioclase, Fe-Oxides, K-feldspars, chlorite, and carbonates. Zircon averages 4.3%. REE minerals include monazite (0.7%), allanite (~0.6%), synchysite (~0.3%), columbite (Fe) 0.3%, fergusonite <0.1%, bastnaesite 0.1%.

The data from the modal analysis of the reject samples has been used to determine the variability of the ore in conjunction with geochemical analyses. QEMSCAN™ calculated assay vs. chemical assay reconciliation from the reject samples is given in Figure 5. Correlation is considered very good with R=0.97. Note that the calculated assays from the QEMSCAN are based on the mineral mass and average composition of minerals and electron microprobe analysis (EMPA - which is not discussed in detail in this paper). Therefore, reconciliation will not be perfect and variations are expected.

MINERAL MASS %	MIN	MAX	AVE
Columbite (Fe)	0.0	1.9	0.4
Fergusonite	0.0	1.4	0.2
Bastnaesite	0.0	1.3	0.2
Synchysite	0.0	2.9	0.3
Monazite	0.0	3.3	0.6
Allanite	0.0	18.2	2.7
Other REE	0.0	0.0	0.0
Zircon	0.0	56.2	11.1
Altered Zircon	0.0	16.0	2.2
Apatite	0.0	0.9	0.1
Quartz	0.2	45.0	10.5
Feldspars	0.0	56.2	9.8
Biotite	0.2	56.9	28.5
Muscovite/ Clays	0.0	15.2	2.8
Other Mafic Minerals	0.1	10.2	2.1
Carbonates	0.0	14.0	1.6
Fe-Oxides	0.0	32.3	9.9
Other	0.0	1.2	0.1

Table 2: Minimum, maximum and average mineral mass % from the EXPLOMIN analysis

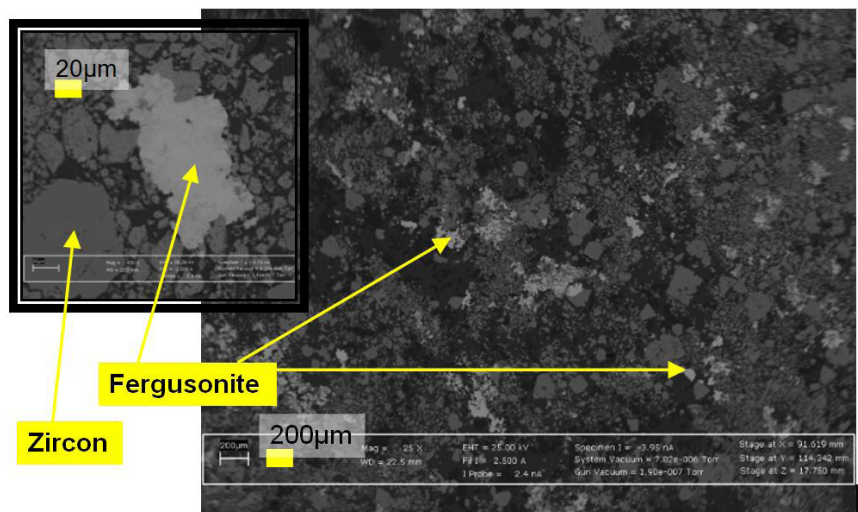


Figure 3: Back scattered image from an intact sample

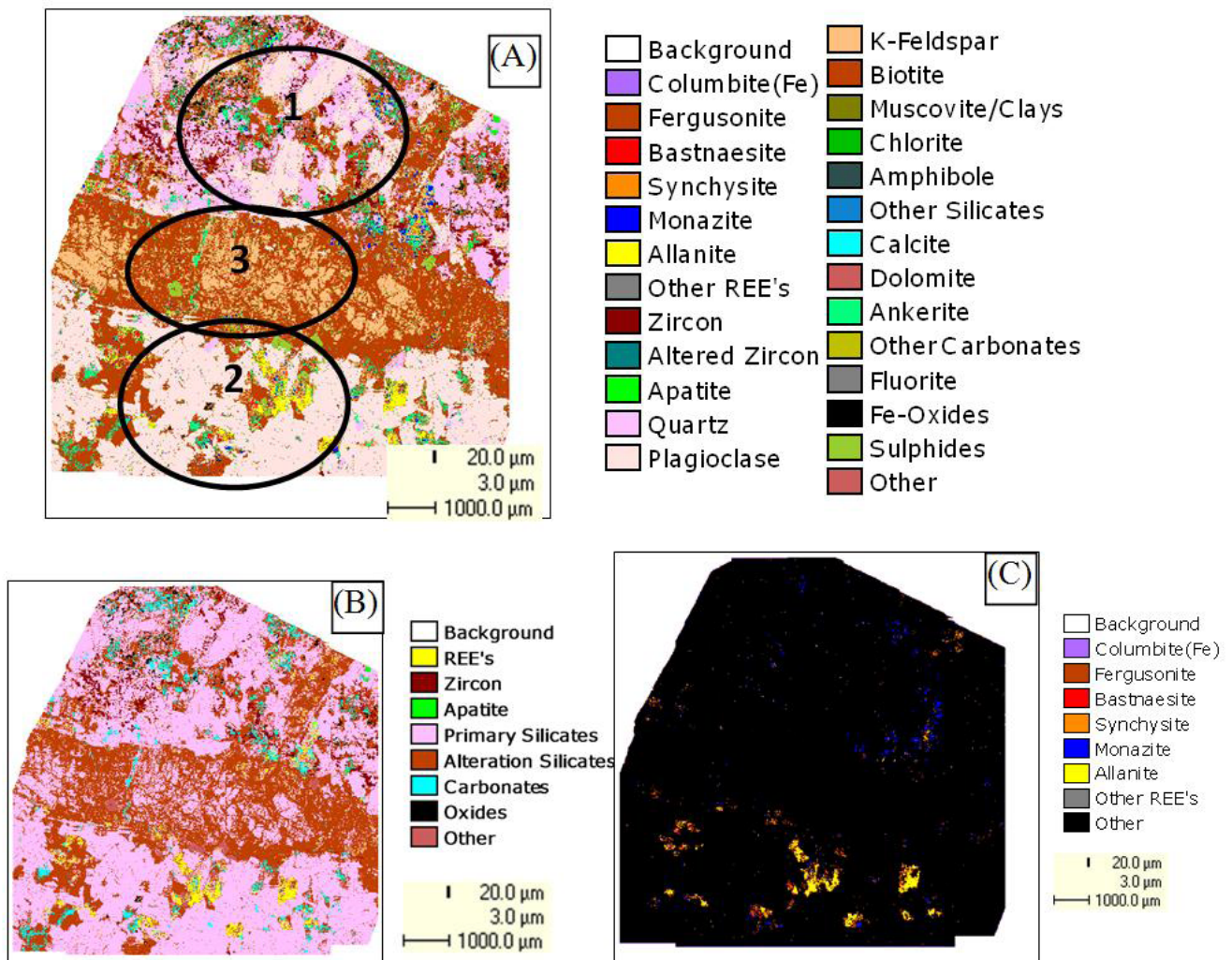


Figure 4: Mineral maps of an entire section showing (a) detailed list of minerals, (b) short list, and (c) only REE list

By comparing the chemical analysis and the mineral distributions, the zones of enriched LREE and HREE a mineralogical distinction was demonstrated. Zones of enriched HREE have higher abundances of fergusonite (Ce,La,Y) NbO<sub>4</sub>. Fergusonite was a target mineral because it carries significant HREE. The analysis showed high and low grade fergusonite ore types that have been defined using a combination of both mineralogy and geochemistry (Figure 6).

**COMPOSITE SAMPLES**

This segment of the study illustrates a more detailed technique to provide important information on the liberation/ association of REE minerals. This is highly critical because it sets criteria for initial target grind sizes for liberation. This type of study can also determine mineral associations among REE minerals and with various gangue phases

and can be used to predict grade vs. recovery. It can also be used to predict concentrate quality with regard to deleterious elements.

Twenty three composite samples were analysed separately to help determine the not just the mineralogical variance, but also to determine of the variability of the liberation vs. grain size within the deposit.

**MODAL MINERALOGY**

For the twenty three samples, the minimum, maximum and the average values for the major mineral components and the REE minerals were tabulated and presented in Table 4. The samples consist of feldspars, muscovite/clays, quartz, biotite, chlorite, amphibole, Fe-oxides and carbonates. The total REE mineral grade ranges from 4.1% to 32.8% and ave. 7.9% and zircon from 0.4% to 23.9% and ave. 11.0%.

MINERAL MASS %	MIN	MAX	AVE
Columbite (Fe)	0.0	0.8	0.3
Fergusonite	0.0	0.4	0.0
Bastnaesite	0.0	0.5	0.1
Synchysite	0.0	1.3	0.2
Monazite	0.0	4.2	0.7
Allanite	0.0	3.7	0.6
Other REE	0.0	0.1	0.0
Zircon	0.2	14.1	4.3
Quartz	10.2	41.4	24.5
Feldspars	0.1	38.5	9.1
Biotite	3.6	42.1	22.8
Muscovite/ Clays	1.7	32.2	13.8
Other Mafic Minerals	0.3	8.7	2.2
Carbonates	0.2	9.8	3.2
Fe-Oxides	0.2	19.5	6.1
Other	0.2	2.4	0.8

Table 3: Minimum, maximum and average mineral mass % from variability samples

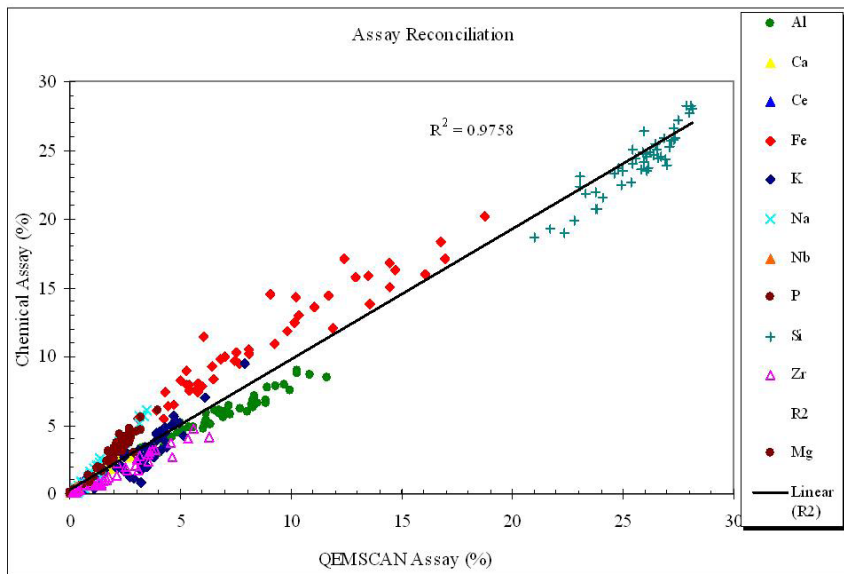


Figure 5: QEMSCAN™ calculated assay vs. chemical assay reconciliation

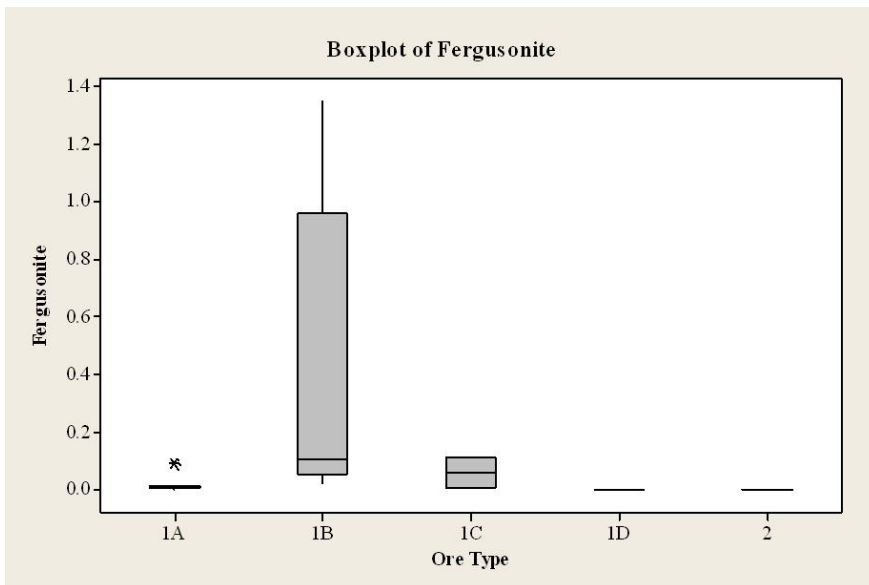


Figure 6: Graph shows the distribution of fergusonite that defines ore type 1B

**LIBERATION AND ASSOCIATION OF REE MINERALS AND ZIRCON**

Liberation and association of the REE minerals, especially for bastnaesite, fergusonite and synchysite are based on relatively low (<0.2%) contents in some of the samples, and thus relatively a small population of particles have been measured. Therefore, caution is advised because liberation and association values might vary.

Each of these samples was crushed to 80% passing ~150 µm (100 mesh) to determine mineralogical parameters on a size by size fraction. The liberation and association analysis shows that liberation of bastnaesite averages 10.1% and forms complex (ternary and

quaternary particles) middling particles (63%), followed by middling particles with alkaline (feldspars and quartz) and mafic silicates (~19%). Synchysite liberation averages 24%, and the main association is complex middling particles (44%), followed by middling particles with alkaline and mafic silicates (14%). Allanite liberation averages 38%; the main association is complex middling particles (19%), followed by middling particles with mafic silicates (17%), and alkaline and mafic silicates (14%). Fergusonite liberation averages 15% and the main association is complex middling particles (33%), followed by middling particles with zircon (24.5%), and alkaline/mafic silicates/zircon

MINERAL MASS %	MIN	MAX	AVE
Columbite	0.2	1.5	0.9
Fergusonite	0.0	2.2	0.6
Bastnaesite	0.0	2.0	0.4
Synchysite	0.0	6.6	0.9
Monazite	0.3	4.0	1.5
Allanite	0.1	20.4	3.6
Other REE	0.0	0.0	0.0
Zircon	0.4	23.9	11.0
Quartz	3.6	25.2	13.9
Feldspars	0.1	44.0	14.2
Biotite	12.1	54.7	28.9
Muscovite/Clays	0.8	15.5	5.5
Other Mafic Minerals	1.3	8.2	4.0
Carbonates	0.5	10.3	3.7
Fe-Oxides	0.2	19.4	10.3
Other	0.2	1.4	0.6

Table 4: Minimum, maximum and average mineral mass % from the composites

(14%), and columbite (5.2%). Monazite liberation averages 50%, and the main association is complex middling particles (20%), followed by middling particles with mafic silicates (8%), alkaline/mafic silicates/zircon (8%) and alkaline and mafic silicates (6.5%). Columbite liberation averages 18%, and the main association is complex middling particles (30%), followed by middling particles with alkaline/mafic silicates/zircon (13.5%), mafic silicates (12%) and alkaline/mafic silicates (11%), and zircon (5%). Zircon liberation averages 54%; the main association is middling particles with mafic silicates (17.5%), followed by complex middling particles (10%), alkaline and mafic silicates (9%). It should be noted that these values are better represented for high grade material and for mineral mass greater than 2-3%.

Figure 7 illustrates a typical graph generated for a composite sample that shows zircon liberation and association characteristics. The graph shows that the overall liberation of zircon in the sample is about 57% (related to the mass in each size fraction) but increases with decreasing particle size from ~27% to ~85%. Liberation increases by ~11%

from the +25 to -25 µm fractions.

This must be taken into consideration when targeting grind sizes to maximize liberation of any phase.

A liberation analysis size by size class can also be calculated (Figure 8) that shows a more constrained distribution of liberation and can help to target coarse middling particles to liberate the mineral.

An image grid and particle maps showing the liberation and association of zircon is shown in Figure 9. The particles provide a visual presentation of the occurrence of the minerals. Specific categories can be further extracted middling particles be classified to complex, moderately and simple that provide a degree of difficulty to liberate zircon from the gangue minerals.

The overall liberation and association data indicate that flotation of the ore will be at approximately 38 microns (NI 43-101 Report).

**ELECTRON MICROPROBE ANALYSES (EPMA)**

EPMA were done with a JXA JEOL-8900L electron microprobe at the Department of Earth and Planetary Sciences, McGill University, Montreal. Analyzing conditions were: Accelerated Voltage at 20 kV, Beam Current at 30 nA, Beam Size at 10 µm, and Correction Method was ZAF. Approximately 300 analyses were done from bastnaesite, synchysite, fergusonite, allanite, monazite, zircon and columbite. Representative electron microprobe analyses of REE minerals and zircon in Table 5.

**REE DISTRIBUTION**

The distribution of the REE (Table 6) is calculated based on the mineral mass within a sample and average chemical composition established from the EMPA. It should be noted that the composition of the REE minerals and zircon might vary across the deposit. Therefore, caution is advised as local and varied REE contents and mineral abundance can alter these results. Figure 10 illustrates that fergusonite and zircon carry most of the HREE, whereas monazite, allanite, synchysite, bastnaesite carry most of the LREE (Figure 10).

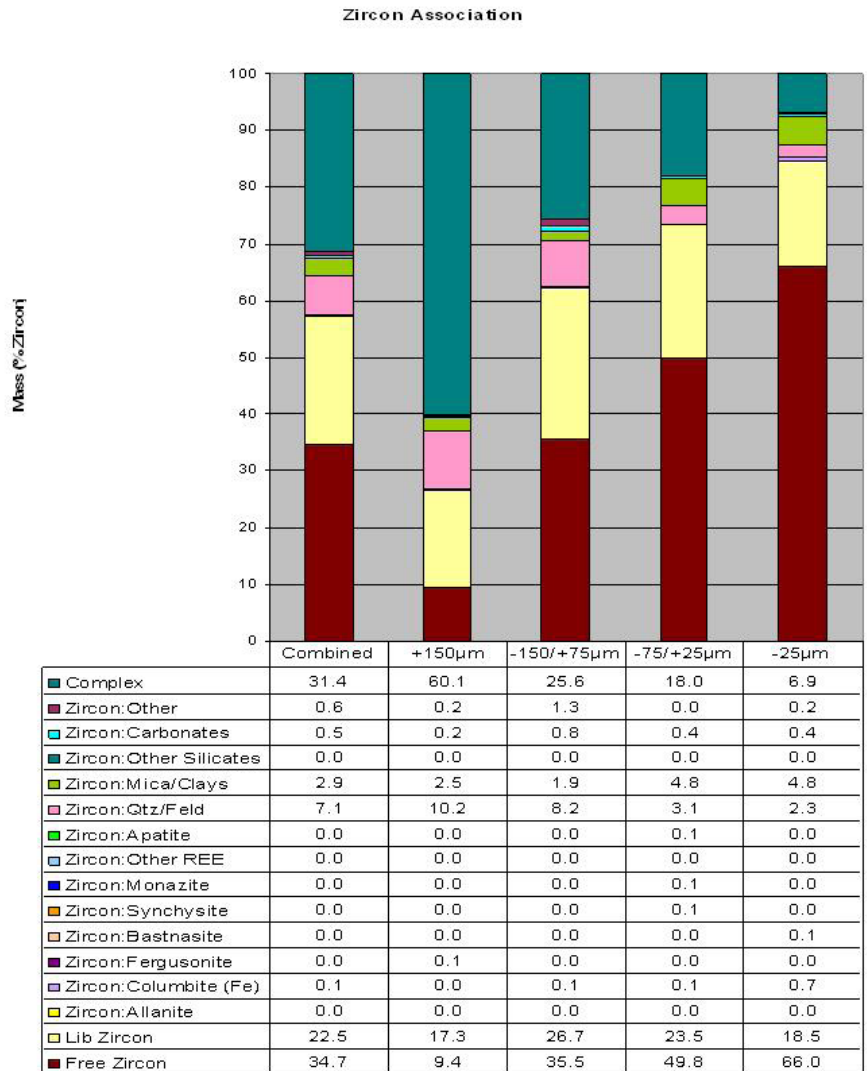


Figure 7: Typical liberation and association of zircon in a single composite

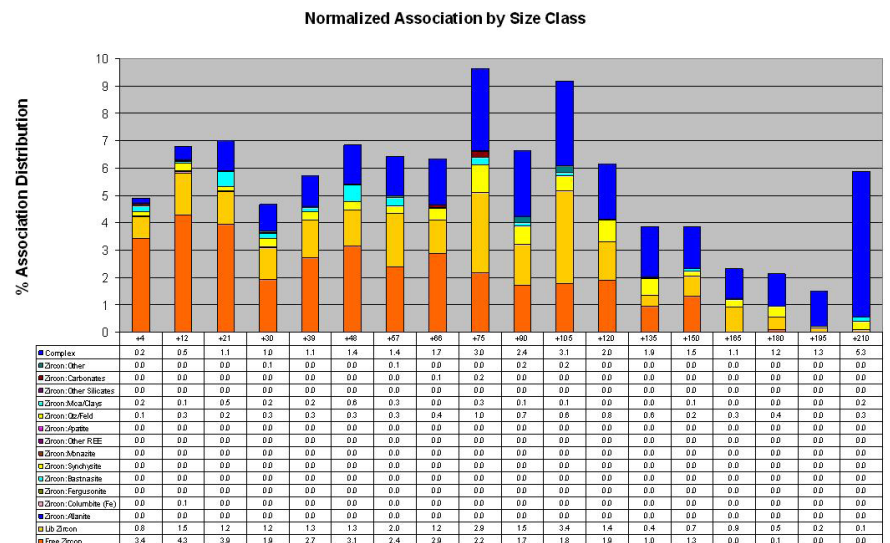


Figure 8: Size by size liberation of zircon

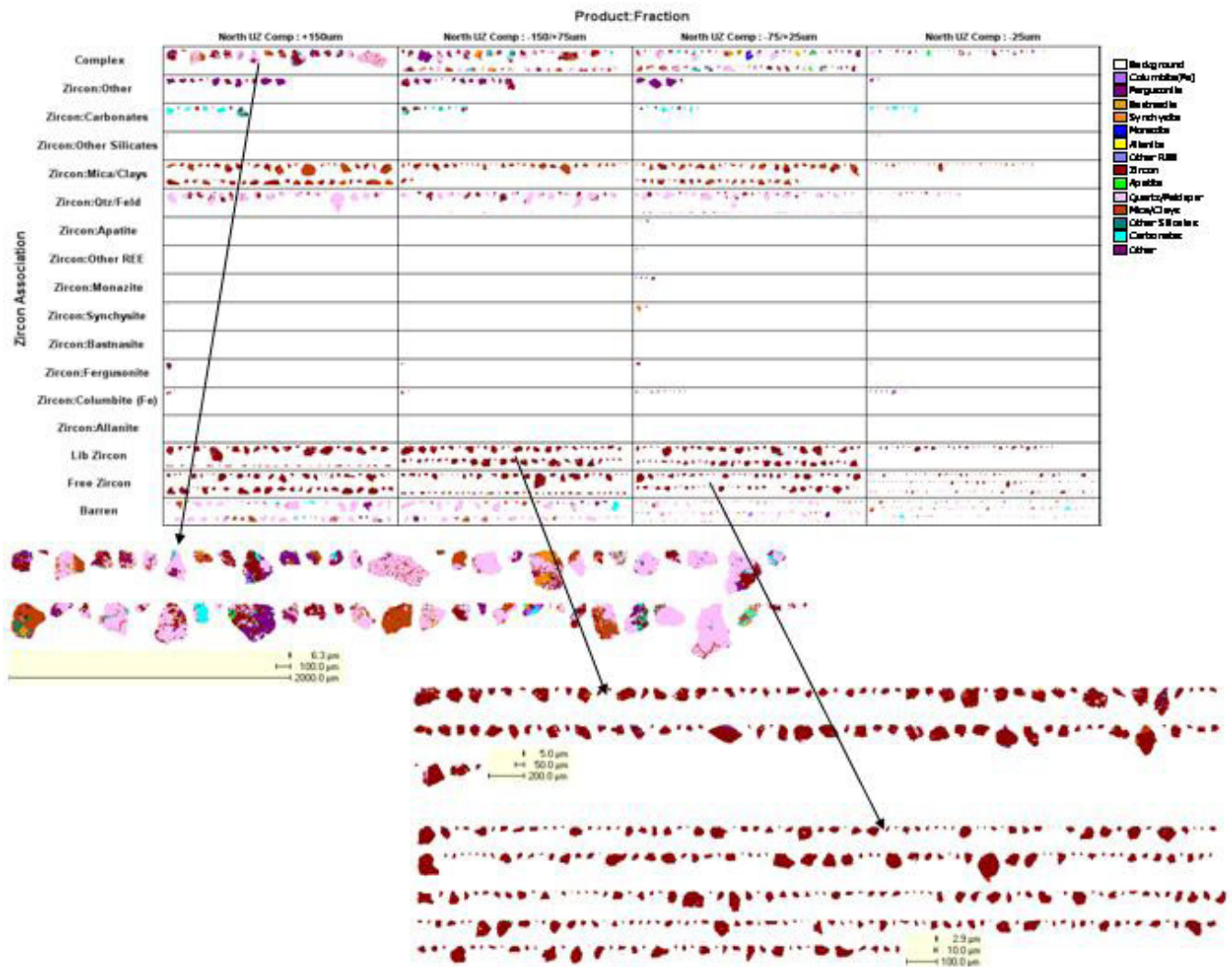


Figure 9: Image grid of liberation and association of zircon

Bastnaesite, synchysite, allanite and monazite account for ~97% of the total La in the sample, 96% of Ce, 89% of Nd, and 99% of Pr. They also account for 55% of the Sm, whereas zircon and fergusonite for ~23% and 22%, respectively. Fergusonite (48%) and zircon (30%) account for most of the gadolinium (Gd), whereas the LREE group ~22%. Tb is carried exclusively by fergusonite, but additional analyses are needed to determine to better determine Tb due to its very low contents in the analyzed minerals. Most of the Dy is carried by fergusonite, followed by zircon (21%) and LREE minerals (~14%). Er is accounted mainly by fergusonite (44%) and zircon (48%). Fergusonite (46%) and zircon (45%) account for most of the Y. Composite samples for metallurgical test work can be chosen based on the distribution of REE carriers and REE distribution in each individual sample.

Defining zones with high HREE/LREE ratios can lead to the delineation of geological domains based on these parameters.

**MINERALOGICAL AND GEOLOGICAL IMPLICATIONS**

The textural and variability analyses indicate that the main silicates are feldspars, mafic phases, and a variety of alteration minerals. REE minerals and zircon occur as intergrowths with each other, disseminated and in clusters among the primary and secondary minerals in the samples. The rocks can be texturally classified and data can be used for drill core logging purposes. REE minerals display variable chemical composition and EMPA is necessary to define chemical variations and determine elements of interest. The LREE are carried by monazite, allanite, bastnaesite

and synchysite as shown above, whereas most of the HREE by zircon and fergusonite. Therefore, defining high and low grade domains or zones of these minerals is critical. Although REE minerals vary across drill holes, domains can be defined with low and high grade REE minerals as shown in the case of fergusonite.

The mirror images of REE distribution between zircon and REE minerals is intriguing and indicates a genetic relation (Figure 11). It is possible that zircon was a primary cumulate phase in the deposit and carried most of the REE. Alteration of zircon might have released REE that were hydrothermally transported and deposited as REE minerals (allanite, bastnaesite etc.). Additional studies must be carried out to better determine such theories.



NAME	ALLAN-1	ALLAN-2	MON-1	MON-2	BASTN-1	BASTN-2	SYNC-1	SYNC-2	COL-1	COL-2	FERG-1	FERG-2	ZIRC-1	ZIRC-2*
La2O3	6.61	5.60	15.56	15.68	16.81	15.93	11.86	9.98	nd	nd	0.03	0.00	0.03	3.68
Eu2O3	0.07	0.21	0.09	0.25	0.33	0.18	0.13	0.22	nd	nd	0.70	0.83		
Ce2O3	13.00	15.42	32.84	33.96	37.25	41.38	25.27	24.96	0.00	0.00	0.58	0.50	0.00	8.58
Gd2O3	0.13	0.03	0.36	0.73	0.31	0.25	0.22	0.35	nd	nd	6.92	8.25	0.11	0.32
Y2O3	0.05	0.04	0.00	0.15	0.11	0.08	0.14	0.21	0.19	0.15	24.72	25.07	1.66	0.51
Pr2O3	1.65	1.81	4.27	4.02	4.34	4.72	3.53	3.53	nd	nd	0.39	0.23	0.05	n/a
Sm2O3	0.26	0.03	0.97	1.39	1.14	0.80	0.65	1.06	0.01	0.01	2.44	2.94	0.01	0.65
Nd2O3	4.55	3.86	14.82	13.42	14.65	13.53	10.15	11.16	nd	nd	3.25	2.75	0.04	3.47
Dy2O3	nd	nd	0.02	0.08	0.16	0.07	0.01	0.02	nd	nd	6.33	5.70	0.16	0.00
Er2O3	nd	nd	nd	nd	nd	nd	nd	nd	0.14	0.19	2.61	2.05	0.08	0.04
Yb2O3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.68	0.62	0.23	0.13
Ta2O5	nd	nd	nd	nd	nd	nd	nd	nd	1.33	0.71	1.65	1.87	0.05	0.09
Nb2O5	nd	nd	nd	nd	nd	nd	nd	nd	72.62	74.57	47.89	47.56	0.00	0.00
ZrO2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	62.98	43.09
HfO2	nd	nd	nd	nd	nd	nd	nd	nd	0.07	0.00	0.32	0.33	1.16	1.03
UO2	nd	nd	nd	nd	nd	nd	nd	nd	0.03	0.07	0.06	0.10	0.00	0.00
ThO2	0.00	0.00	0.72	0.87	nd	nd	nd	nd	0.00	0.05	0.14	0.16	0.05	0.00
SiO2	31.34	31.63	nd	nd	nd	nd	nd	nd	0.02	0.01	nd	nd	31.94	22.60
FeO	13.70	14.45	0.28	0.06	0.06	0.04	0.09	0.28	19.55	18.35	0.10	0.00	0.34	1.22
Al2O3	16.07	16.22	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.04	0.01
CaO	8.61	8.66	0.09	0.36	0.15	0.29	18.83	19.07	0.05	0.02	0.07	0.18	0.03	9.78
MgO	0.17	0.20	nd	nd	nd	nd	nd	nd	0.17	0.22	nd	nd	0.02	0.01
MnO	1.08	0.43	nd	nd	nd	nd	nd	nd	1.74	3.45	nd	nd	0.01	n/a
TiO2	0.03	n/a	nd	nd	nd	nd	nd	nd	3.07	1.80	0.10	0.02	0.00	0.01
P2O5	nd	nd	30.17	28.89	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Na2O	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.09	0.04	nd	nd
SnO2	nd	nd	nd	nd	nd	nd	nd	nd	0.26	0.15	nd	nd	nd	nd
CO2	n/a	n/a	n/a	n/a	20.73*	19.59*	24.279*	24.538*	n/a	n/a	n/a	n/a	n/a	n/a
Cl	nd	nd	0.02	n/a	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
F	0.00	n/a	0.47	0.52	6.79	5.40	8.37	7.96	nd	nd	nd	nd	nd	nd
TOTAL	97.37	98.60	100.19	100.37	100.00	100.00	100.00	100.00	95.73	97.63	99.08	99.20	98.99	95.21

Table 5: Representative electron microprobe analyses of REE minerals and zircon

Note: n/d = not detected; n/a = not applicable or analyzed

ELEMENTAL MASS %	LA	CE	ND	PR	SM	GD	TB	DY	ER	Y
Columbite	0	0.0	0.0	0.0	0.64	0.0	0.0	0.0	7.8	2.1
Fergusonite	0.0	0.3	3.6	1.4	21.62	47.9	100.0	65.8	44.4	46.4
Bastnaesite	9.3	9.0	8.6	9.0	4.91	3.9	0.0	1.0	0.0	0.4
Synchysite	16.9	17.2	16.4	18.2	11.06	11.5	0.0	4.0	0.0	2.6
Monazite	37.8	38.4	38.3	39.8	28.99	0.0	0.0	8.5	0.0	2.8
Allanite	32.7	31.4	25.8	31.5	10.24	6.5	0.0	0.0	0.0	0.5
Other REM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Zircon	3.2	3.6	7.3	0.0	22.54	30.2	0.0	20.7	47.8	45.2
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 6: Normalized REE distribution per mineral for the composites

**METALLURGICAL APPLICATIONS**

Liberation and association indicate that most of the REE minerals would be very well liberated below 38 µm. Since the LREE and HREE are carried by specific minerals it is important that the association between zircon and fergusonite and with the LREE carriers is defined. Zircon and fergusonite generally show a weak association with the LREE carriers, but display a moderate association with each other. The HREE carriers must be separately concentrated and processed together to maximize the HREE recovery. The distinction of the REE carriers is critical in the metallurgical recovery of the HREE and LREE. Therefore, predictions can be made with regards to recovery and potential impurities in a concentrate.

**CONCLUSIONS**

The results show that QEMSCAN™ can determine mineralogical parameters of single or composite samples (mineral abundance, liberation, association, elemental distribution). The data can be used to determine the variability of ore zones, defined mineralogical domains, i.e., low and high grade ore zones, and predict the composition of concentrates. Thus, the data combined geochemical and geological information, can lead to ore delineation, resource estimation and definition of geological domains characterized by specific mineralogical and metallurgical parameters. These analyses belong to the emerging discipline of geometallurgy (e.g., Williams and Richardson, 2004) that is becoming increasingly recognized as a discrete and high value activity towards a more effective integration of exploration, mine development and optimization. Automated and quantitative mineralogy constitutes an integral part of the geometallurgical framework. It provides data to help develop and predict geometallurgical parameters for geological and processing performance that reflect inherent geological variability.

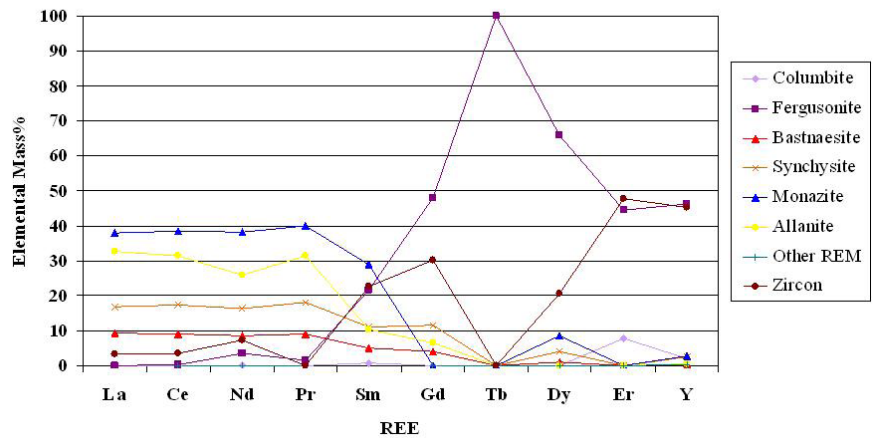


Figure 10: HREE and LREE distribution among the minerals

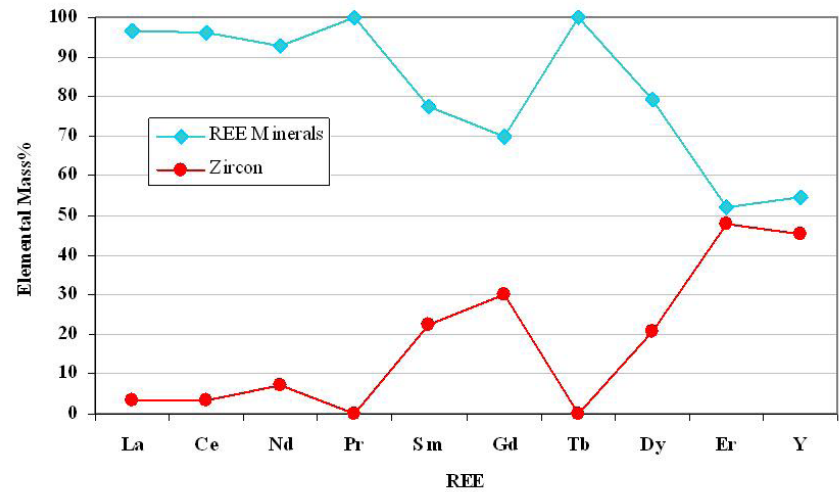


Figure 11: HREE and LREE distribution among the minerals

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