PARISITE FLOTATION FROM CARBONATITE REE-ORE

*R. Gerhard Merker[1], Thomas Heinig[2], Adam Balinski[2], P. Quang Van [3], Robert Moeckel[2]

*[1] Merker Mineral Processing (MMP)
Oertenroeder Strasse 21, 35329 Gemuenden (Felda) / Germany,
merker@merker-mineral-processing.de

[2] Helmholtz Institute Freiberg for Resource Technology (HIF),
Freiberg / Germany

[3]Hanoi University of Mining and Geology (HUMG), Dept. of Environm. Engineering,
Hanoi City / Vietnam.

ABSTRACT

Rare earth bearing fluoro-carbonates (REFK) are one of the most important sources of rare earth elements (REE) globally, with bastnaesite being the most studied mineral of this group in terms of flotation.

However, in contrast, the REFK mineral parisite has virtually no special reference in the literature with respect to its flotation behavior.

A carbonatite REFK-ore from Vietnam that contains mainly parisite and associated Ba-Sr-minerals was investigated by Helmholtz institute Freiberg Germany (HIF).

The Authors present information herein regarding the deposit material used, and the results of the beneficiation test program undertaken, as well as finally propose a multi-stage processing technique comprising the following essential process steps:

- Crushing and sensor-based pre-sorting,
- Milling, sizing and de-sliming,
- Conditioning and cold rougher REE-flotation,
- Re-grind and hot cleaner REE-flotation.

With a bench-scale flotation test program, REFK mineral concentrates of 40 % TREO could be produced at a high recovery.

Thereby, a clear sequence of REFK-floatability (recovery and selectivity) could be shown; in this case according to the order bastnaesite, parisite, and synchisite which is inversely proportional to the Ca-content of the single REFK obviously.

The work represents an interesting advancement in this field, as differences in the floatability between individual REFK could be proven and documented by SEM-based image analysis (MLA – mineral liberation analyzer).

KEYWORDS

1. INTRODUCTION

It is widely viewed that the Rare Earth Elements (REE) are a group of elements of the periodic table of elements (PSE) comprised of the 15 lanthanides and yttrium, although scandium is occasionally included.

They are high-tech-metals of great economic importance and dynamically growing demand, especially with respect to the permanent magnet industry.

Over the last couple of years, the REE-market and its perception has shifted, and refocused on those REE where demand is considered to have the most sustainable growth, as well as constrained supply, over the near through long-term. These rare earths include Nd, Pr, and to a lesser extent Tb and Dy, collectively known as the Magnet Feed REEs (MFREE). (Merker & Smith 2018)

When it comes to the beneficiation of the REE ores, each and every REE-occurrence features special characteristics in terms of mineralogy and genesis that considerably influence any separation of the REE-minerals from barren gangue minerals prior to the chemical dissolution and stage-wise chemical extraction of the single REE. This is particularly true to carbonatitic REE-ores as the dominant global source of REEs. (Merker & Smith 2018)

The main REE-bearing minerals of carbonatites are usually REE-fluoro-carbonates (collectively REFK) besides REE-phosphates like monazite.

The next table (**Table 1**) shows selected data of the three REFK that occur in REE-carbonatites with bastnaesite being the most studied mineral of this group in terms of flotation as it is the most common mineral of these deposits.
Parisite and Synchisite on the other hand are usually of minor abundance in carbonatite ores of that type. Special references in the literature as to the flotation of parisite are not known to the authors.

Table 1: *Selection of REFK mineral data (Merker & Smith 2018)*

Mineral source	Simplified formula	Assay + REO content	True density	Mohs hardness
Bastnaesite	$(Ce, La, ..) [CO_3] F$	36-56% Ce_2O_3, ard. 19% La_2O_3, ++LREE	4.5 - 5.2	4 - 4.5
Synchisite	$Ca (Ce, La, ..) [(CO_3)_2] F$	similar Bastnaesite	3.9 - 4.15	4.5
Parisite	$Ca (Ce, La, ..)_2 [(CO_3)_3] F_2$	53- 61% REO, similar Bastnaesite	4.3	4.5

China has been playing a dominating role in global rare earth mine production for many years based on carbonatite ores mainly. However, REE-carbonatites have been known from the late 1960s on at least to occur beyond the southern border of China in Vietnam too.
Due geological structures in Vietnam were object to joint exploration and mineral beneficiation work of German and Vietnamese geologists and processing engineers throughout the 1980s for instance (Merker G., et al. 1991).

The Helmholtz Institute Freiberg (HIF) started new investigations into Vietnamese REE-deposits in co-operation with Vietnamese partners in 2016. This work was financially supported by grants of the German Ministry of Research and Education (BMBF, CLIENT Vietnam Project NamXe).

The headline of this project study was "Mineralogical characterization and sustainable mineral processing strategy for the REE-deposit Nam Xe".
Main targets of the mineral processing were defined as follows:
- The separation of REE-mineral concentrates of plus 30 % TREO grade (total rare earth oxides) with a maximized recovery level,
- Proposal of a mineral processing concept on a "best available technology level" (BAT).

Merker Mineral Processing (MMP) was contracted by HIF for consulting support in terms of the mineral processing part of the project.

A part of the beneficiation test results is presented in this paper with focus on flotation.

Geo-metallurgical aspects of the results of this project will be published elsewhere (Moeckel, R. et. al. 2019).

2. MATERIALS AND METHODS

2.1. Head ore

The deposit is divided into a northern and a southern part. The northern part consists of a lateritic ore body of up to 40m thickness, however was not part of this flotation study. The Nam Xe South deposit consist of more than 20 known carbonatitic veins within an andesitic host rock.

All assaying and processing work described hereafter was done on drill core samples from the Nam Xe South deposit that derived from exploration carried out by the Vietnamese partners.

The next picture (**Figure 1**) shows a part of the drill cores containing carbonatite ore veins and host rock.

Figure 1: Drill cores NamXe South, host rock NG (grey) and Red ore ROE (reddish)

From the drill cores, the following four different rock types were manually pre-sorted by HIF from mineralogical points of view, and delivered to the UVR-FIA GmbH Freiberg (UVR) laboratories where all processing was done monitored by MMP:

- Red ore (ROE),
- Yellow ore (GE),
- Surface ore (OFE, similar to ROE),
- Barren host rock (NG).

Prior to any processing work, the drill cores of the single rock types were stage-wise crushed, and split to representative sub-samples. A comprehensive mineralogical and chemical characterization was carried out on these head ore sub-samples by HIF subsequently.

2.2. Metallurgical Assaying

The metallurgical assaying of head ore samples and processing products comprised the X-ray fluorescence analysis (XRF PANalytical Axios) as routine procedure to detect the four light REE Ce+La+Nd+Pr (LREE) as proxy of the total REE, as well as selected gangue components like Ba, Sr, S, Ca, Fe, F, Pb, Nb, and Si).

In the course of the processing test program, the XRF-procedure was re-calibrated twice on internal standard processing product samples against ICP-MS-data from ALS Geochemistry Loughrea.
This measure was necessary to adjust the XRF procedure to the increasingly diverging mineral matrices of concentrates and tails caused by the separation processes used. The distribution of the single REE was object of these ICP-MS analyses too.

All mineralogical characterization was conducted with HIF by MLA (Mineral Liberation Analysis). The applied evaluation software was MLA-Suite 3.1.4 of FEI using a customized EDX-Spectra data set for carbonatites with REE fluoro-carbonates.

2.2. Mineral processing test work

Model blends of the rock types OFE and NG in a ratio of 50/50 and 20/80 respectively were used for upgrading tests by flotation, magnetic separation, sensor-based-separation (SBS) etc. to mimic a thinning of the vein ore by host rock in a future mining operation.

In this paper, the results of flotation tests will be described and evaluated exclusively.

All mechanical pre-treatment such as milling, screening, and sizing was carried-out at the laboratories and mineral processing test installations of UVR. SBS work was done with the company Tomra-Sorting GmbH Wedel/Germany.

For the flotation tests that are to be discussed in this paper, sub-sample batches of the 50/50 mix of a minus 3.15 mm grain size were prepared, and grinded by a dry screen-discharge ball mill to reach a fineness of minus 100 microns.

These grinding products initially were used without further sizing. In the course of the project, it turned out however that a two-stage de-sliming is favorable prior to any flotation.

This part de-sliming at a "cut-size" of about 6 microns was carried out batch-wise by a 30mm hydro-cyclone rig. The underflow of this procedure was subsequently dried and used as head sample for lab flotation tests.

A mechanically "upgraded" Denver flotation machine, with 65-mm-impeller and forced air supply, was used for all flotation work.

Flotation cell sizes between a quarter gallon (about 1 liter) and half a gallon (about 2.5 liter) were used; the 1-liter cell in the beginning for the rougher flotation, later on the 2.5-liter "rougher+scavenger" cell combined with a 1-liter cleaner flotation cell respectively for multi-stage operation.

If needed, a further re-grinding of the rougher flotation froth concentrates by a wet ball mill was applied to reach a better liberation prior to any cleaner stages.

Typically, any conditioning prior to rougher as well as cleaner flotation was carried out on a high solids level in an extra conditioning cell that was mounted on a heating plate. Thereby, the chance of optional working cold (ambient) or hot (at raised temperature of +50°C) was given.

Parameters like pH, temperature and partly the pulp potential were monitored by a set-up with suited detecting sensors.

Any timing of reagent dosage and conditioning was fixed on a personal experience basis with a general dosage order as follows:

1.   Activator REE,
2.   Depressant of gangue,
3.   pH-regulator, 1st shot,
4.   Collector(s), if more than one – the FA-type first,
5.   pH-regulator 2nd shot if needed,
6.   Frother.

After any flotation test, all flotation products were filtered by means of Buechner funnels with vacuum pump, dried at 105 °C, and weighed. A flocculant was added to the cell-product (tails) prior to the de-watering step.

Any chemical assaying was carried out on sub-samples after careful homogenization and grinding of the dried products.

As the given frame of money and time of this processing study was limited, the scope of influencing process parameters had to be condensed. More intensively investigated and varied to a certain extend respectively were the following ones:

- Particle size of head samples for rougher and cleaner flotation,
- pH-level of rougher and cleaner flotation,
- Dosage of collectors and depressants,
- Hydroxamate-type of used collectors,
- Temperature of rougher (and partly cleaner) flotation conditioning stage,
- Slime content of rougher flotation head,
- Solids content of rougher flotation pulp (21/26%),
- Impeller turnings (adjusted to varied grinding fineness).

For the same reason, the pool of flotation reagents (see **Table 2**) was reduced to a few proven products that promised a good chance of success. The array of used reagents is shown in the next table.

All reagents that may be sensitive to storage time and temperature were purchased shortly before the tests, and kept stored in a fridge.

Table 2: Flotation reagents used

Reagent	Type	Source	Remark
A 6494	8-10C-A-Hydroxamate, saponified	Cytec	Collector REE-min. etc.
C7510	Benzyl-hydroxamic ac.	Florrea	Collector REE-min. etc.
Attrac 922	Oleyl-sarcosine formulation	Akzo	Collector REE-min, carbonates, phosphates etc.
A70	MIBC	Cytec	Frother
F 549	Polyolefin glycol-Ether	Cytec	Frother
Soda ash	Na2CO3	?	Activator, pH-Regulator
Silico fluoride	Na2SiF6 techn.	Omnilab	Ion catcher, depressant
F 500	Ligno-sulfonate biopolymer	Pionera	Depressant, carbonates etc.
Caustic soda	NaOH	?	pH-Regulator
Hydrochloric acid	HCl	?	pH-Regulator
Cyfloc C573	Poly-quat.- amine formulation	Cytec	Flocculant

Caused by the limited reagent pool, there may remain a good potential of flotation process improvements by a more intensive screening of suited collectors and depressants.

3. RESULTS AND DISCUSSION

3.1. Head ore characteristic

As aforementioned, a 50/50 model blend of the ore type OFE with host rock NG was used as basic head material of the flotation tests.

The composition of the blend is shown in the next tables (**Table 3**+**Table 4**). The latter one reveals that parisite is the main REFK, accompanied by smaller amounts of bastnaesite and also synchisite amongst few other minor REE-minerals

Associated gangue minerals from the carbonatite veins are predominantly sulfates of Ba and Sr (as barite, celestine and barito-celestine), and carbonates of different composition.

From the host rock part mainly, various iron bearing silicates, feldspar, quartz, and phyllosilicates derived among others.

*Table 3:* Chemical characteristics (XRF data) of sort NG, and 50/50-mix,

Ore type / Sample	4LREO [1] %	TREYO [2] %	Al_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	Mn_3O_4 %	TiO_2 %	SiO_2 %	BaO %	Fe_2O_3 %	SrO %	SO3 %	F %
Host Rock NG	0,01	0,016	12,3	7,15	9,61	3,04	2,17	0,19	0,19	1,75	48,6	0,08	10,7	0,06	0,26	
Average 50/50 mix	7,4				14,4						25,3	8,9	12,0	8,2	6,9	0,66

Legend Table3: *1) 4LREO = oxides of La+Ce+Pr+Nd; 2) TREYO = Total oxides of REE+Y*

Table 4: Mineralogical characteristic of 50/50 mix NG+OFE, on MLA grouped

Mineral groups, %	NG+O
REE-minerals	
Parisite_Ca02-13	12,91
Synchysite_Ca_30	1,10
Bastnaesite	0,29
REFK total	**14,30**
Monazite+Allanite	0,80
Y+Nb-phases	0,18
REE-minerals total	15,28
Gangue	
Barite	5,57
BaSr+Sr-sulfates	18,19
Ankerite	11,63
Mg-Ca-Sr-carbonates	5,04
Fe-silicates	21,45
Feldspar+Quartz+Zircon	12,01
Phyllosilicates	7,62
Apatite+Fluorite	0,54
Sulfides	0,34
Th-bearing phases	0,01
Ti+Fe-Ti-oxides	1,66
Magnetite	0,67
unknown+low+No	0,00
Total	100,00

The distribution of REE-elements is displayed in **Figure 2** with the sought-after Magnet feed REE (MFREE) as a +18% component of the total REO pool (TREYO).
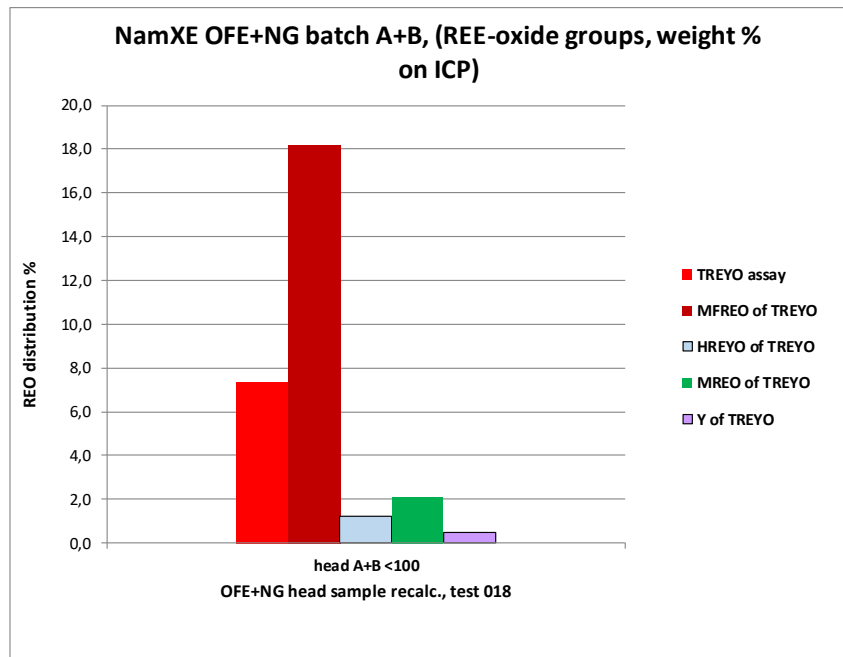
Figure 2: REO-groups proportion of total REO-content (TREYO) of flotation head ore

Legend Fig. 2: TREYO = Total oxides of REE+Y; MFREO = "Magnet feed REE oxides" of Nd+Pr+Tb+Dy; MREO = Middle REE-oxides of Sm+Eu+Gd; HREO = Heavy REE-oxides of Tb+Dy+Ho+Er+Tm+Yb+Lu+Y.

In the following **Figure 3**, selected MLA-results of the flotation head (OFE+NG) samples after a dry grind to an X95 particle size of minus 100 microns prior to the rougher flotation are shown.

It can be seen that for the REFK a pretty good surface liberation (+75%) can be reached up to the particle fraction +75 microns with a liberated proportion of + 50%.

However, other MLA-graphs revealed that with a grind like that, a remarkable remainder of lockings with Ba-Sr-sulfates above all would be unavoidable even in the fine particle fractions below 20 microns (bimodal locking distribution!).

In these fine fractions, mineral groups like REFK, Ba-Sr-sulfates and phyllosilicates were found to more or less get enriched simultaneously.
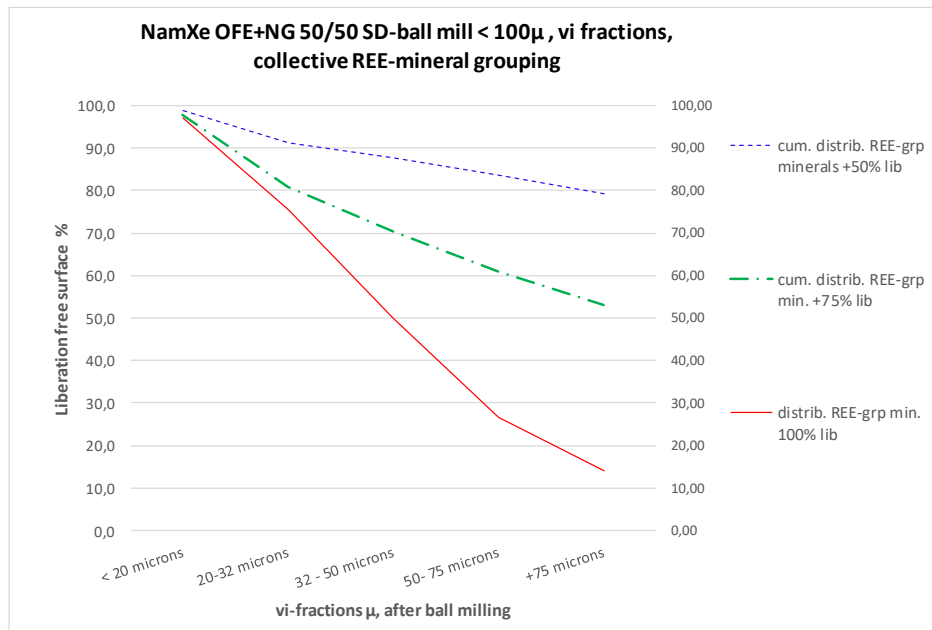
Figure 3: Liberation free surface, ore OFE+NG, +50 % classes cumulative

3.2. Flotation

From the multitude of findings and results, only essential ones will be shown and discussed in the following text.

The work of this study started with alkyl hydroxamates as REE-mineral collector, soda ash as activator, Na-Silico-fluoride as ion catcher, and lignosulphonate as gangue depressant.

In the course of the flotation test work, the following conditions were found to bring about a stable and successful flotation performance:

- Use of a collector combination with oleylsarcosin,
- Work at pH plus 10 in the rougher and minus 9.5 in the cleaner stages,
- Removal of primary slimes prior to the rougher flotation,
- Grinding particle size of minus 100 microns for rougher and minus 40 microns for cleaner flotation,
- Proper dosage order and amounts of reagents,
- Rougher flotation at ambient temperatures,
- followed by re-grinding of the rougher/scavenger froth concentrate,
- and a hot conditioning step with a likewise hot cleaner flotation.

The next table (**Table 5**) displays a chronological work flow scheme of the flotation process development as it was carried out.

Table 5: Work steps of flotation tests, simplified

Work step flotation	Result / comment
Fixing of needed liberation (MLA) and comminution,	Rock types + 50/50 mix, Start with grind size X95 100 microns
Selection of suitable reagents,	HXM + HXM/FA-combi, REE-activator, ion-catcher, gangue depressant, pH-regulator, dispersant
Calibration of procedures and XRF on 50/50 mix	(tools, analytics, test steps, head preparation, product treatment, work station set-up, etc.)
Fixing of tentative test conditions and parameters	(pH, hydrodynamics, conditioning, T, dosage, pulp solids, reagent concentration, etc.),
Start with moderate depressant dosage, ambient T, single collector HXM	Insufficient upgrading and recovery
Ramping up depressant dosage, + collector combi	up to frothing break down,
Shift to hot flotation,	30% TREO with rougher test 9, + 70% LREO recovery,
Re-calibration of XRF-analytics to expanded REO-range	on own calibration standards for higher conc. grades, on ICP
Current optimization of main parameters	(pH, dosage, T, PSD, de-sliming, etc.),
Start of multistage open cycles after 29 tests	(Rougher + scavenger + Cleaner stages), hot-hot-combi, + wet re-grind calibration
Introduction of de-sliming,	+ optimization of "cold" Rougher-flot. on hydro cyclone underflow
Combi of cold rougher flotation + "hot" cleaner after 36 tests,	39 % TREO Cleaner conc., 90% REO recovery rougher flot., with test 37
Optimization of multi-stage conditions + head ore preparation	Including cold-cold combi test, and finer re-grind < 35 microns
+40 % TREO (cleaner) and + 90 % recovery (rougher flot.), test No. 57	rougher + cleaner flot. = 6-fold upgrading, (cold-hot combi), basis of flow sheet concept

With application of a hot conditioning as early as in the rougher flotation, concentrates of about 30 % REO were accomplished shortly. However, direct cleaner tests on such rougher concentrates brought about no remarkable further REE-enrichment.

This problem of insufficient upgrading with the cleaner stages finally could be overcome by a combined process with a cold rougher followed by a hot cleaner flotation after re-grinding. By these measures, two pros were reached that should help lowering future process costs:

- Mass-reduction by extensive rejection of silicate gangue from the host rock part, aside from a first proportion of carbonates and sulfates prior to a costly hot conditioning step (see **Figure 5**),
- Further upgrading towards a 40 % REO grade in the cleaner stage after re-grinding to maximize the separation from the Ba-Sr-sulfates.

With the hot flotation, it turned out that a conditioning temperature of more than 75°C would not improve the flotation performance.
The role of temperature for this special case is currently under further investigation.

A rejection of primary slimes was found to play a key role for the subsequent REE-flotation. By proper de-sliming with hydro-cyclones after the 1st grinding stage prior to the

rougher flotation, REE-losses in the slime reject could be limited to a level of considerably less than 10 %.

Based on the initial lab flotation program with mainly rougher and scavenger flotation tests, a couple of open cycle multi-stage tests were carried out to maximize the final REE-concentrate grade.

The next picture (**Figure 4**) shows selected results as grade-recovery curves of LREO of four multi-stage tests.

All tests of this series were carried out on de-slimed feed blend of an X95 minus 100 microns particle size. Each test comprised a cold rougher plus scavenger REE-flotation followed by a water shift, and a wet regrind of the concentrate prior to a hot conditioning with cleaner flotation, and up to 3 cleaner scavenger stages.

With the regrinding, different particle sizes were reached with an X95 of minus 35 microns of test 37-05 as the most fine-grained cleaner input. In the cleaner flotation, differing reagent dosages and pH-levels were tested as well.

As can be seen in the graphs of **Figure 4**, three of these tests (37-01, 37-04, 37-05) exceeded the 35 % LREO-grade level with test 37-01 reaching even 40%.

From MLA-shots could be seen that the partly intimate locking between REFK and Ba-Sr-sulfates is a crucial problem that needs to be resolved with further test work to improve the final cleaner concentrate grade even more.
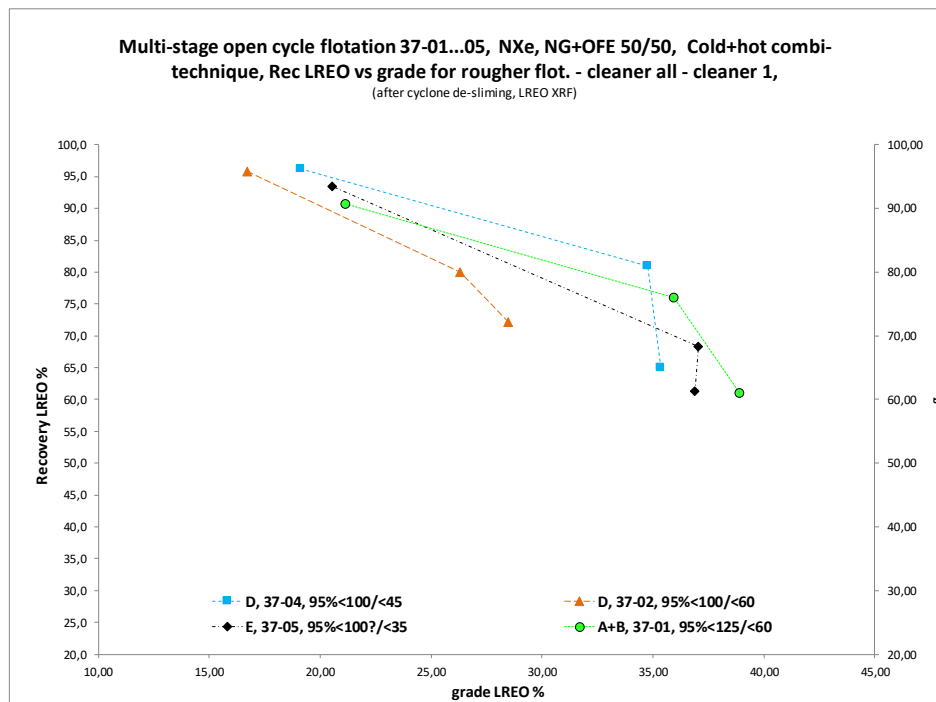

Figure 4: LREO grade-recovery curves of four multi-stage flotation tests

The next figure (**Figure 5**) displays the modal mineralogy of all products of the multi-stage flotation test 37-5.

The following trends can be seen here to have happened in the course of the process:

- Preferable deportment of silicates (green), carbonates (blue), and Fe-oxides (grey) in the scavenger tails (T-scav) of a low REFK-content,
- Enrichment of the REFK-group (red) together with Ba-Sr-sulfates (pink) in the rougher concentrates (C-Ro), and even better in the cleaner concentrates (C-Clean) totaling to nearly 70 % REFK-mineral grade,
- Paradoxical development of the REFK-grades in the cleaner stages with better figures at the end, (by faster flotation of fine grained lockings)
- Deportment of a part of the Ba-Sr-sulfates and carbonates in the middling T-clean which would be cycled back to the rougher conditioning stage in a closed cycle operation.
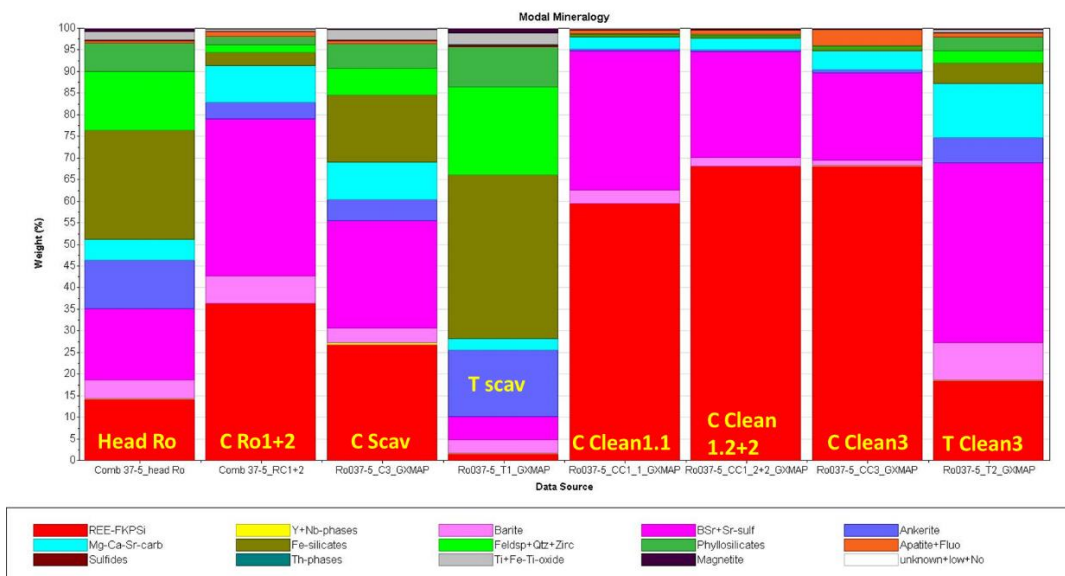
Figure 5: Modal mineralogy of flotation products, test 37-05 multi-stage

Another interesting, though actually paradoxical phenomenon was observed when looking into the virtual PSD-fractions of the first cleaner concentrates as it is shown in the next figure (**Figure 6**) about the test 37-05.

In contrast to a normal fraction-wise display of flotation results as it usually can be expected, the REE-mineral grade was hereby increasingly improved toward the coarser fractions with a maximum of 80% REFK in the +40 microns fraction.

These trends can be explained by a bimodal distribution of the REFK grain size with partly well liberated mineral particles in the coarse fractions, and a lot of intergrowing even in the finest fractions that are faster floating beyond that.
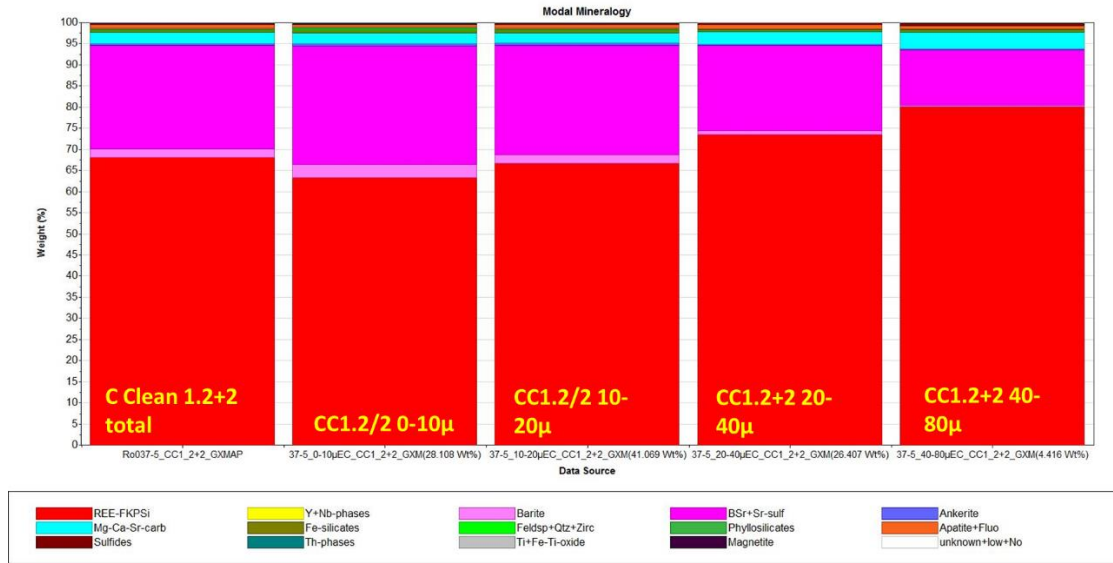
Figure 6: Modal mineralogy fraction-wise, cleaner products 37-05 multi-stage

When looking into the aforementioned flotation results on a more detailed mineral grouping of the REFK, even a mineral dependent trend of floatability could be disclosed.

In the following figures (**Figure 7**+**Figure 8**), this finding is illustrated by mineral recovery figures of the single REFK (bastnaesite, parisite, synchisite) in the froth concentrates of test 37-05.

It clearly can be seen that the three REFK responded differently to the used flotation scheme with a recovery of 94 % for bastnaesite, 90 % for parisite, and 89 % for synchisite. In the cleaner stages, these differences became even bigger.
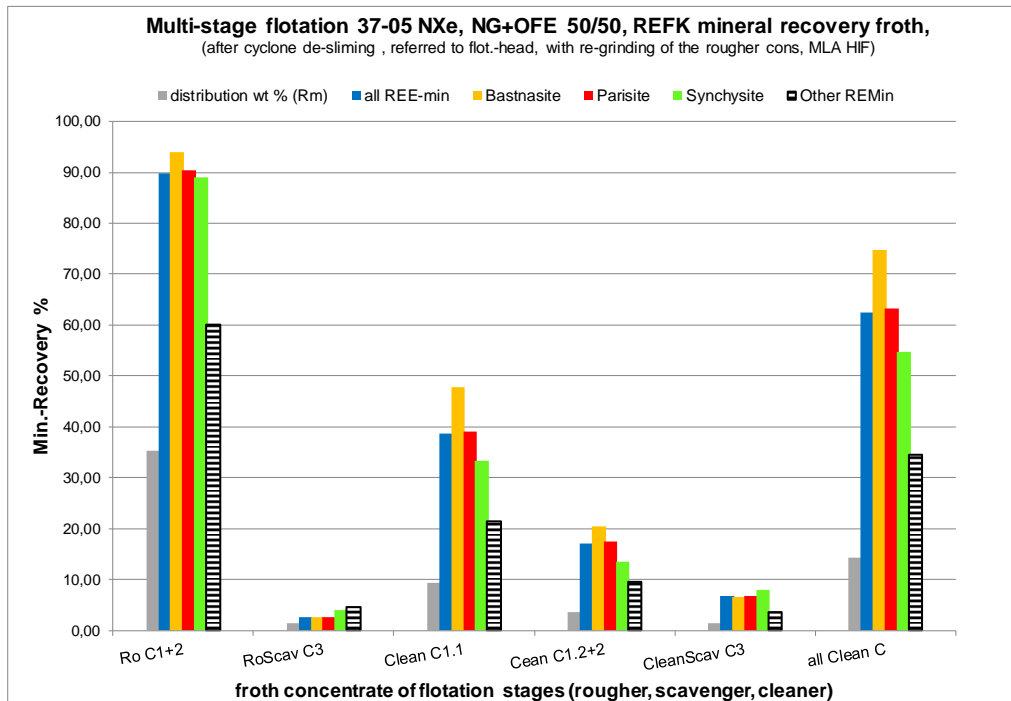
Figure 7: REFK mineral recovery in froth products, 37-05 multi-stage

The reason of this behavior likely can be explained by differences in terms of a competing absorption of flotation reagents on the Ca- and REE-lattice points of the REFK particle surface respectively.

Bastnaesite floats best in rougher (Ro) and cleaner (Clean) stages whereas synchisite floats best in the scavenger stages as illustrated in **Figure 8**. The "portion change" of this figure visualizes the shift of REFK-proportions in the course of flotation. Thereby, above all the synchisite (more than parisite) as the most Ca-bearing REFK shows a worse selectivity with higher deportment to the tails and middlings (scav) compared to bastnaesite.

Shifts of adsorption equilibria by stepwise dosage of reagents and purposed pH-manipulations in the course of the process may deliver an explanation of those contrasting trends.

Even if all these assumptions need further investigation to get confirmed, a clear sequence of REFK-floatability (recovery and selectivity) can be shown; in this case with the order bastnaesite, parisite, synchisite that is inversely proportional to the Ca-content of the single REFK obviously.
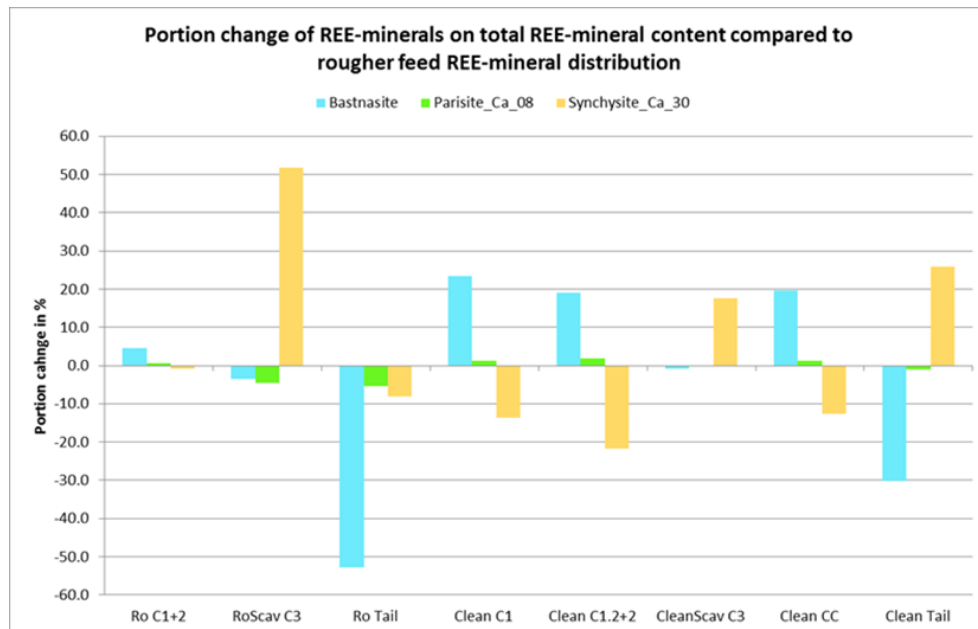

Figure 8: Shift of REFK proportions in the course of flotation, test 37-05

The mineral composition of a total cleaner froth concentrate with 63 % REE-minerals as produced by test 37-05 is exemplified in the next picture (**Figure 9**). Main impurity is Baryto-Celestine aside from minor baryte and carbonates.

An acid attack to the residual carbonates was tested with the result that a slight upgrading is doable if the leach conditions are not too harsh with a pH above 4. Similar to the flotation process, the Ca-bearing REFK would need a special approach to avoid REE-losses in the liquor.

Main target of a next investigation step is suggested to be the separation of the residual Ba-Sr-sulfates after an optimized liberation. This step holds good potential for a further remarkable improvement of the final mineral grade.
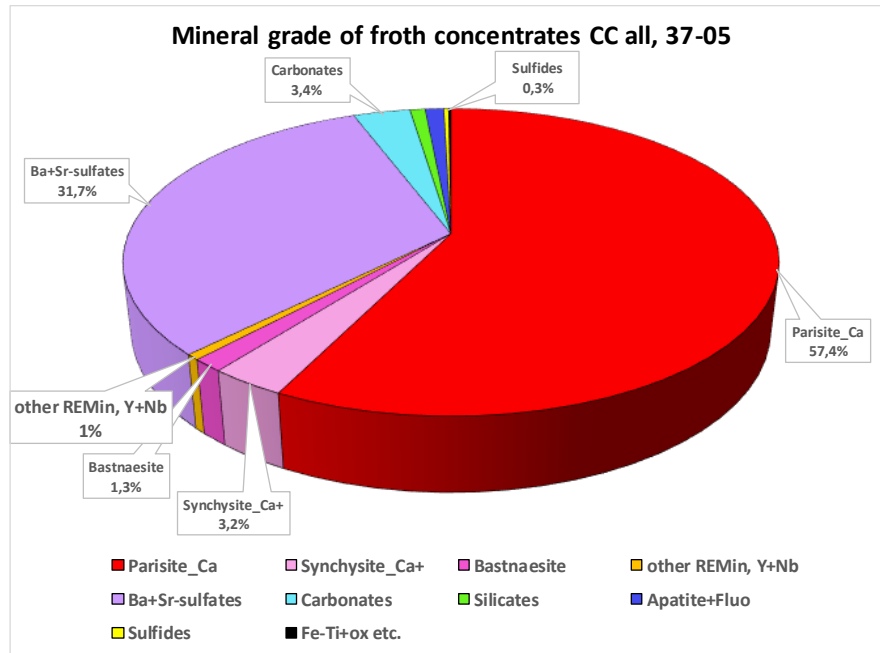
**Figure 9:** Mineral composition of a cleaner flotation froth concentrate, test 37-05

Based on the aforementioned flotation results, a processing concept for the Nam Xe South ore was developed that is shown in the next flow sheet (**Figure 10**).

This tentative draft contains the results of all mineral beneficiation tests on this ore comprising sensor-based pre-sorting (SBS), de-sliming, and a multi-stage flotation.

The SBS revealed a good potential on a "diluted" 20/80-blend of ore for a 10-30 mm screen fraction with a considerable REFK-upgrading ratio of +6, and very low REE-losses in the virtually "barren" tails (0.1 % LREO grade).

A first estimation is given with a total LREO-recovery of + 75 % and a final cleaner froth grade of minimum 40 % TREO.

The flow-sheet is suggested to get confirmation by pilot plant operation in the frame of a prefeasibility study.
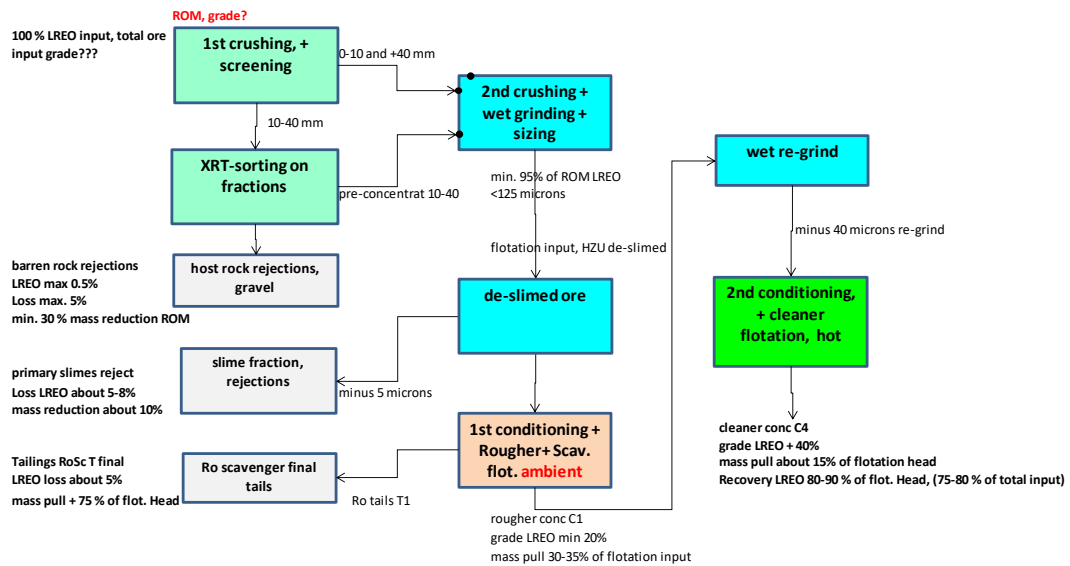
Figure 10: Conceptual processing flow sheet for the Nam Xe South ore

4. SUMMARY AND CONCLUSIONS

The parisite bearing carbonatite REFK-ore of Nam Xe South can be characterized by chances and challenges in terms of mineral beneficiation:

- Interesting ore grade with mainly Ca-bearing REFK like parisite,
- Partly close intergrowing of REFK with gangue minerals like Baryto-celestine above all,
- Bimodal locking and grain size distribution of REFK,
- Normal REE-distribution with a good deal of valuable MFREE,
- Detrimental primary mineral slimes,
- Slightly differing floatability of the contained REFK,
- Good amenability to a sensor-based pre-sorting (SBS),
- Differing acid leach behavior of the REFK.

With multistage lab flotation tests using mixed collectors of the hydroxamate and oleylsarcosin type, cleaner froth concentrates of up to 40 % TREO were reached with an REO-recovery of + 90 % in the rougher+scavenger stage and 70-80 % in the cleaner stage (calculated on flotation head) so far.

Thereby, a clear sequence of REFK-floatability (recovery and selectivity) could be proven; in this case according to the order bastnaesite, parisite, and synchisite which is inversely proportional to the Ca-content of the single REFK obviously.

Based on the available flotation results that were accomplished on mixed ore samples, and other results of the beneficiation test program undertaken, a multi-stage processing technique comprising the following essential steps is proposed:

- Crushing and sensor-based pre-sorting,
- Milling, sizing and de-sliming,
- Conditioning and cold rougher REE-flotation,
- Re-grind and hot cleaner REE-flotation.

The incomplete state of work and knowledge about the technique developed holds good potential for a remarkable improvement of the process performance by further investigations downstream through:

- Extended flotation reagent screening, particularly in terms of Sr-mineral depressing,
- Test of a combination of SBS with subsequent flotation,
- … Including confirmation of the doable mass reduction by SBS,
- Optimization of the REFK-liberation, particularly for the re-grinding,
- Test of separated coarse and fine particle flotation,
- Tests of "selective comminution" to minimize the slime formation,
- Upgrading tests by WHIMS on cleaner concentrates,
- Optimized carbonate leach on cleaner concentrates,
- Confirmation of the processing concept by closed circle flotation tests and/or pilot plant operation.

In terms of beneficiation response, the Nam Xe South carbonatite deposit can be defined as a promising potential source of rare earth minerals that can presumably reach the performance level of known and successfully running REE-projects.

5. ACKNOLEDGEMENTS

REFERENCES

Merker G., et al. (1991): A processing technology for heavily weathered rare earth ores ...,17th Int. Mineral Processing Congr., Dresden, 23-28 Sept. 1991, Preprints Vol. IV, pp. 321-330.

Möckel, R., Heinig, T., Cardenas V., A.F., Gutzmer, J., Merker, G., Van Phan Q.: Beneficiation of parisite-rich rare earth ore from the Nam Xe South deposit, Society for Geology applied to Mineral Deposits, Glasgow Conference, Aug. (2019),