BENEFICATION OF TERRISTRIAL RESOURCES FOR THE PRODUCTION OF LUNAR SIMULANT SEPARATES

By

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Workshop on the Lunar Applications
of Mining and Mineral Beneficiation

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Get Into It!

Introduction

Objectives:

Develop and characterize a mineral beneficiation process for the production of simulated lunar regolith using terrestrial resources.

Examine, select, and develop a process for the production of high quality calcium plagioclase and clinopyroxene separates using Stillwater Mine ores and mill byproducts.

Introduction

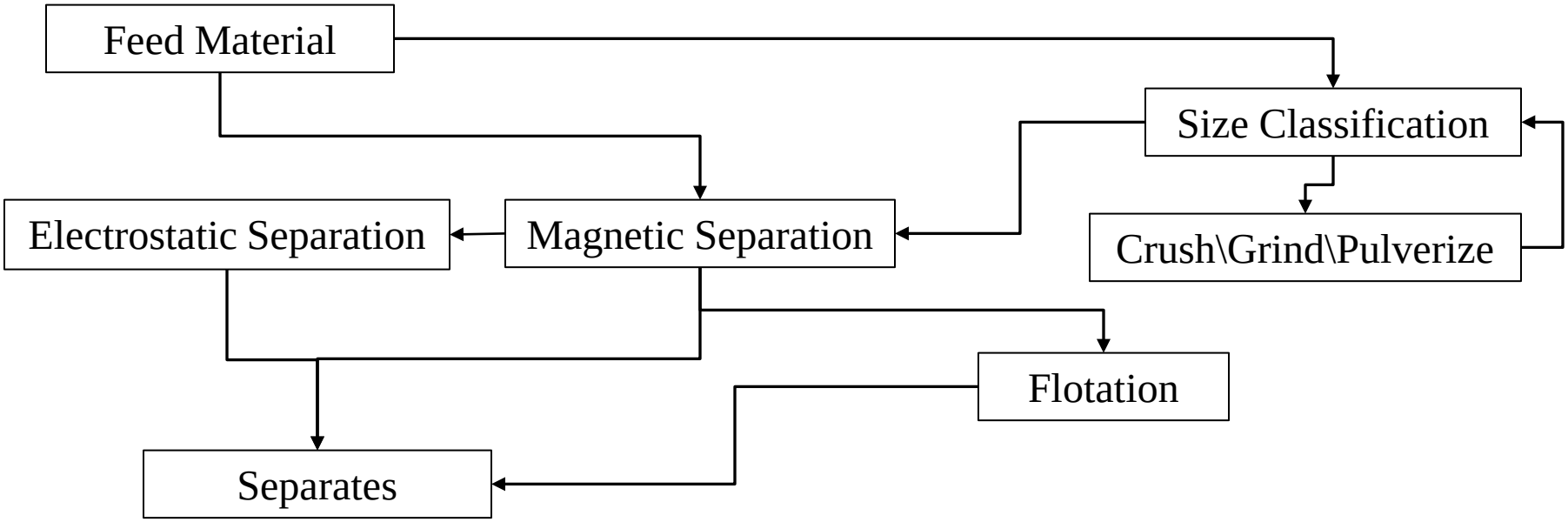
Feed Stock Materials

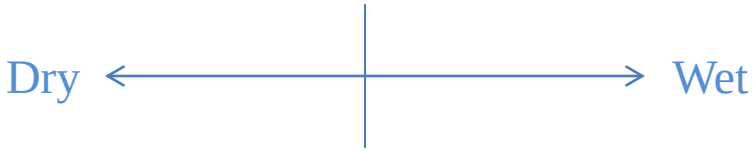
Slurried Stillwater Mill Tailings

"Road" Norite

Dried Stillwater Mill Sands from USGS

Experimental Approach





Introduction

Dry Magnetic Separation Equipment

Hand Magnet

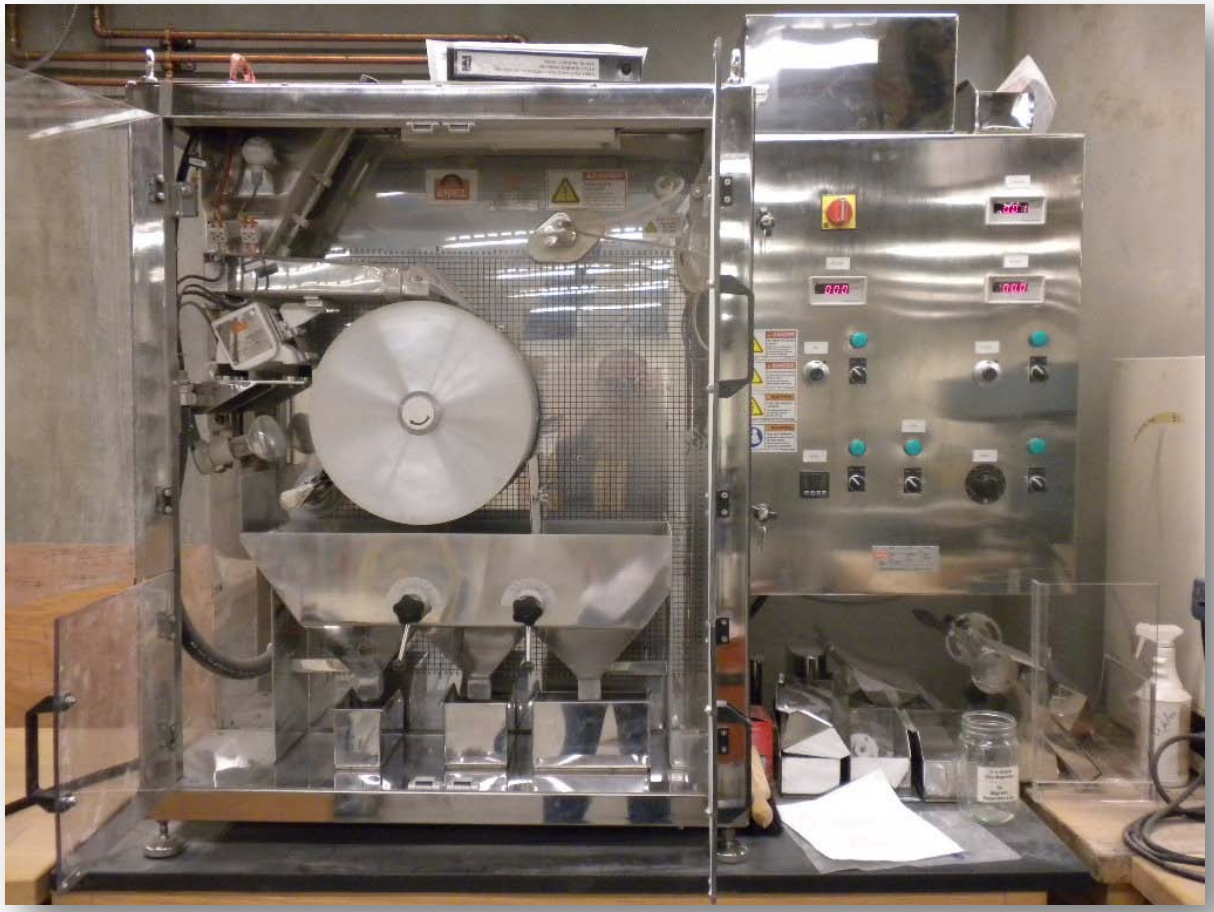
Multiple Element Dry Drum Separator

Rare Earth Magnetic Belt Separator

Introduction

Electrostatic Separation (ES) Equipment

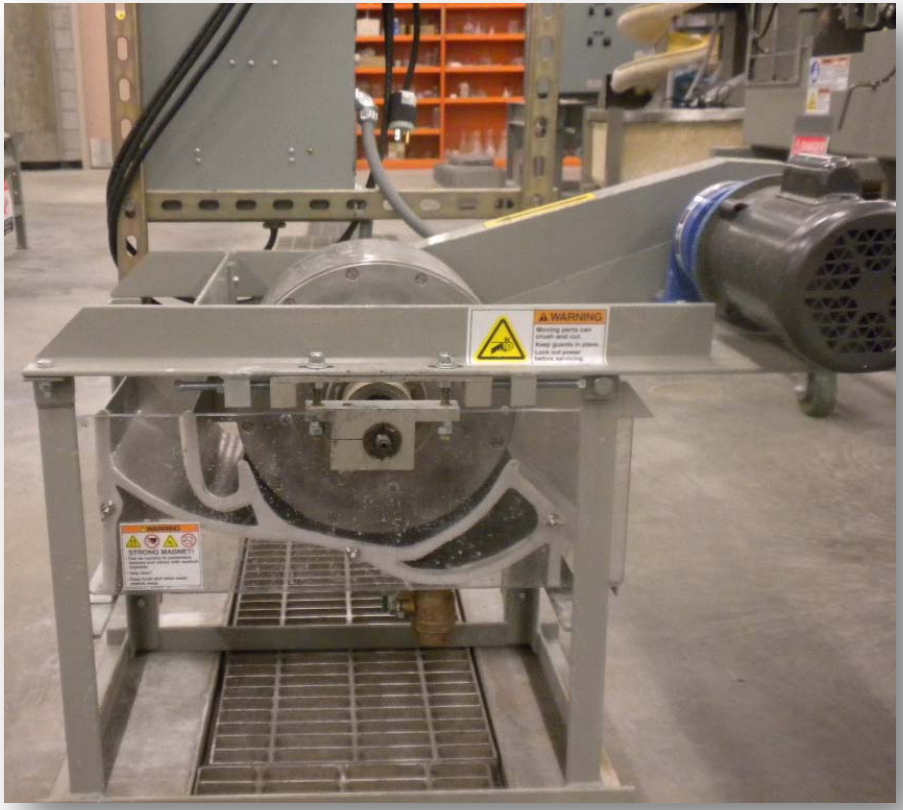
Electrostatic Separator



Introduction

Wet Magnetic Separation Equipment

Electromagnetic Wet Drum Separator



Wet High Intensity Magnetic Separator (WHIMS)

Introduction

Froth Flotation Separation Equipment

Froth Flotation Cell

Introduction

Analytical Equipment

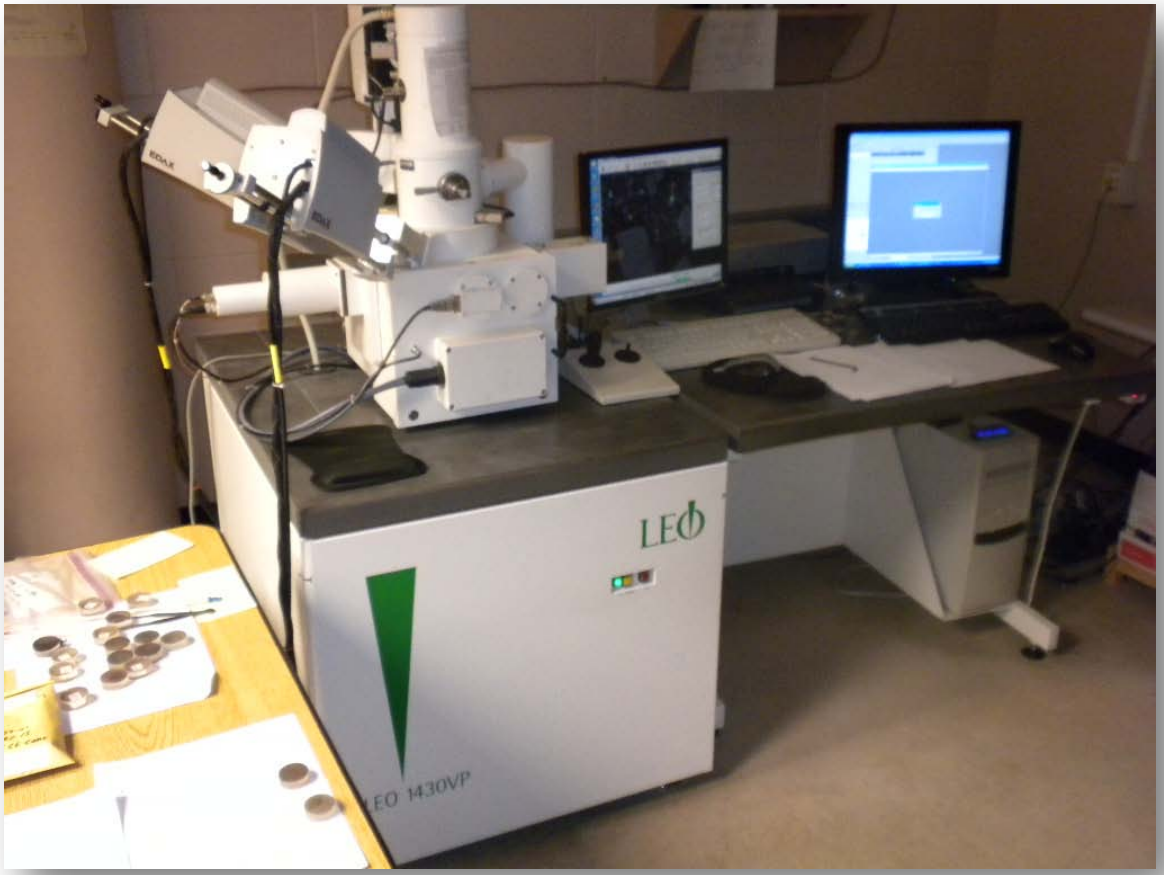
X-ray Diffraction (XRD)

X-ray Fluorescence (XRF)

Introduction

Analytical Equipment

Scanning Electron Microscope\Energy Dispersive X-ray Spectroscope\Mineral Liberation Analyzer



Results

"Road" Norite Rare Earth Belt Magnetic Separations (Dry)

Magnetic Separations at Various Size Fractions					
Particle Size (μm)	Weight (grams)	Paramagnetic (grams)	% Fraction	Nonmagnetic (grams)	% Fraction
<1000 / +600	564.0	380.0	67.4%	184.0	32.6%
<600 / +300	665.1	453.3	68.2%	210.8	31.7%
<300 / +150	429.9	274.8	63.9%	155.1	36.1%
<150 / +75	240.3	117.4	48.9%	122.9	51.1%
-75	Too Fine				

- Similar results as NASA/USGS Study[1] ~ 68% nonmagnetic material
- <150 μm particle sizes are not compatible with dry process techniques

[1] D. Stoeser and W. Benzel, XRD results for Eriez magnetic separates of the Stillwater Road Norite, NASA/USGS Simulant Development and Characterization Project Internal Project Report, November 30, 2009.

Results

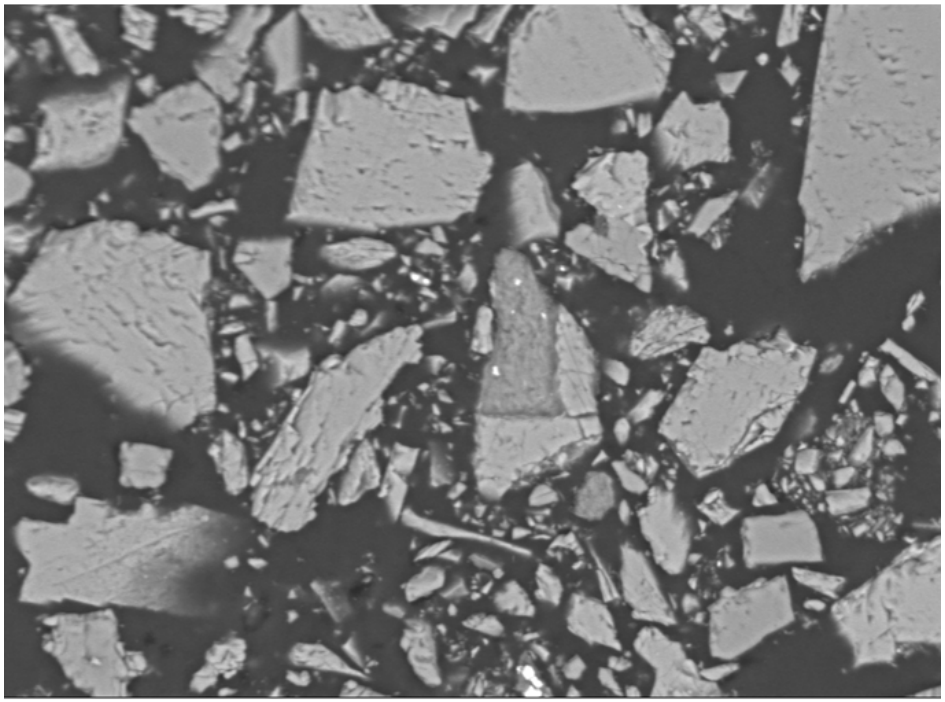
“Road” Norite Wet High-Intensity Magnetic Separation (WHIMS)

- “Road” Norite Ground to 70 % passing 45 µm
- Grinding introduces iron contamination
- Separations based on magnetic susceptibility possible

Sample Separations from WHIMS

Split	(grams)	%
NM-A	212.5	13.0
NM-B	615.9	37.7
PM-1	231.5	14.2
PM-2	116	7.1
PM-3	34.9	2.1
PM-4	11.4	0.7
PM-5	190.5	11.7
PM-6	221.1	13.5
Sum	1633.8	100.0

SEM Image

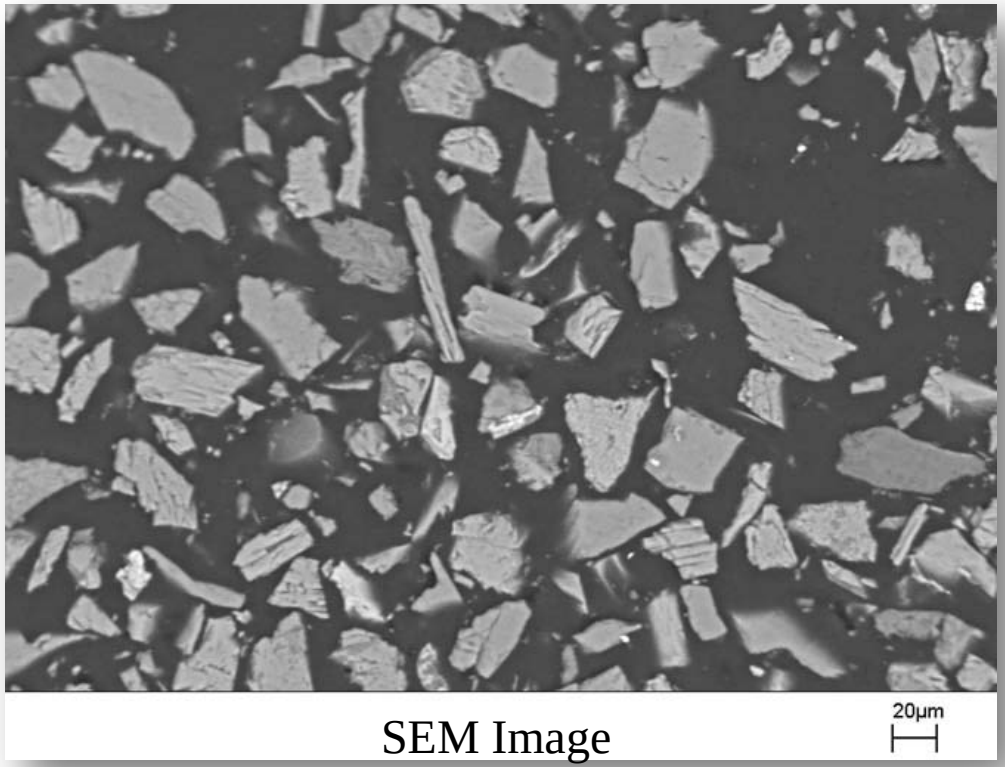


Results

Multiple Element Dry Drum Separations

- Nonmagnetic (plagioclase)\Paramagnetic (pyroxene) split performed

Dry Stillwater Mill Sands from USGS



SEM Image

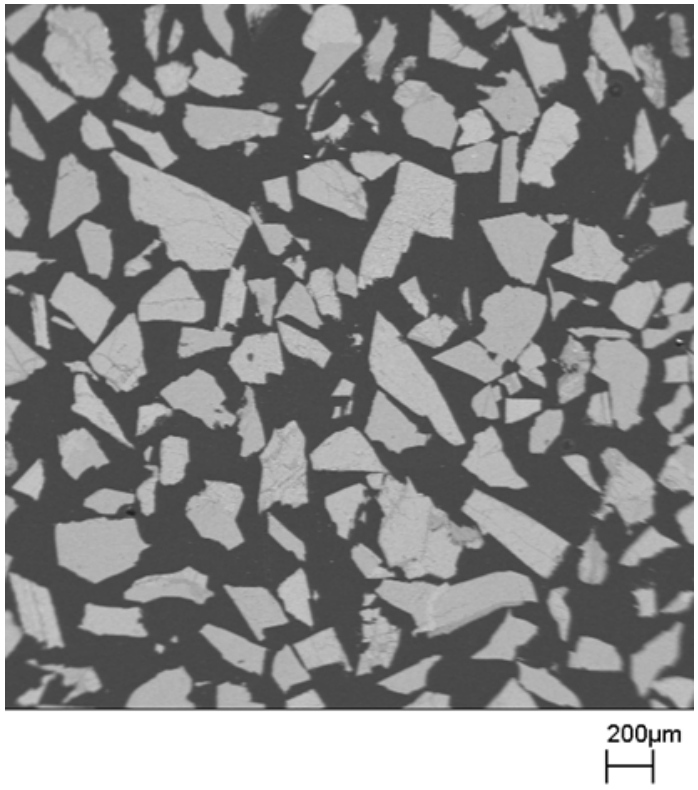
Sample Separations

Split	(grams)	%
1 (NM)	107.2	6.9
2 (NM)	826.2	53.3
3 (PM)	435.1	28.1
4 (PM)	83.5	5.4
5 (PM)	13.3	0.9
6 (PM)	3.6	0.2
7 (PM)	4.9	0.3
8 (PM)	5.4	0.3
9 (PM)	4.9	0.3
10(PM)	25.8	1.7
11(PM)	37.1	2.4
12(PM)	2.2	0.1
SUM	1549.2	100.0

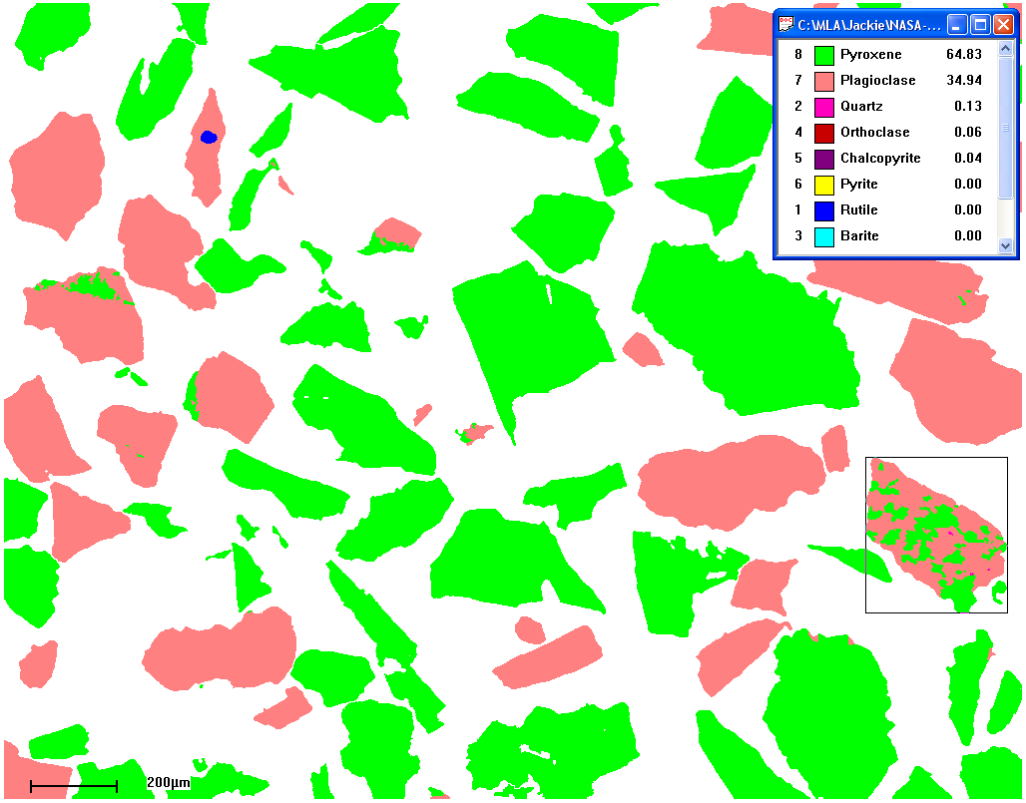
Results

Paramagnetic Material From "Road" Norite Rare Earth Belt Magnetic Separations (Dry) + Electrostatic Separation

SEM Image



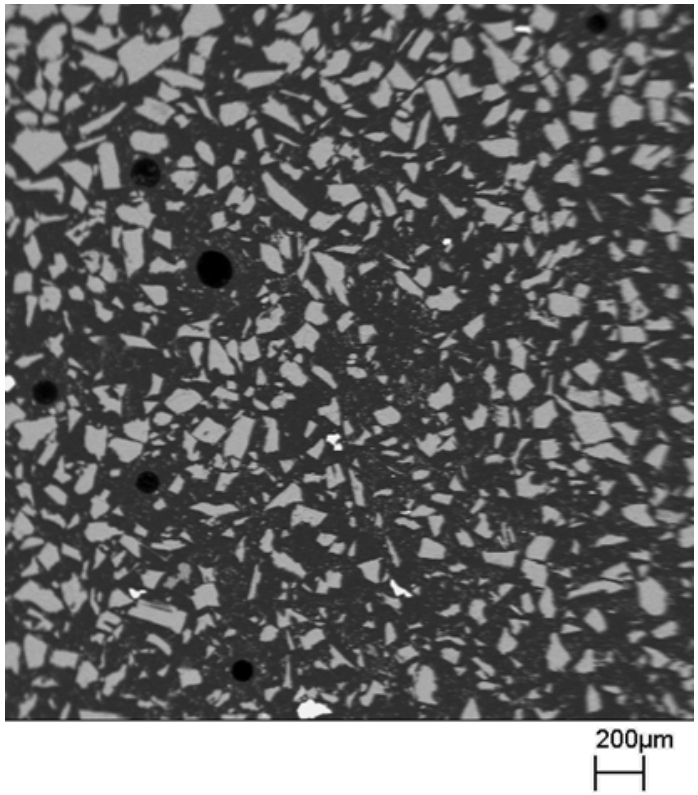
MLA Image



Results

Nonmagnetic Material From "Road" Norite Rare Earth Belt
Magnetic Separations (Dry) + Electrostatic Separation

SEM Image



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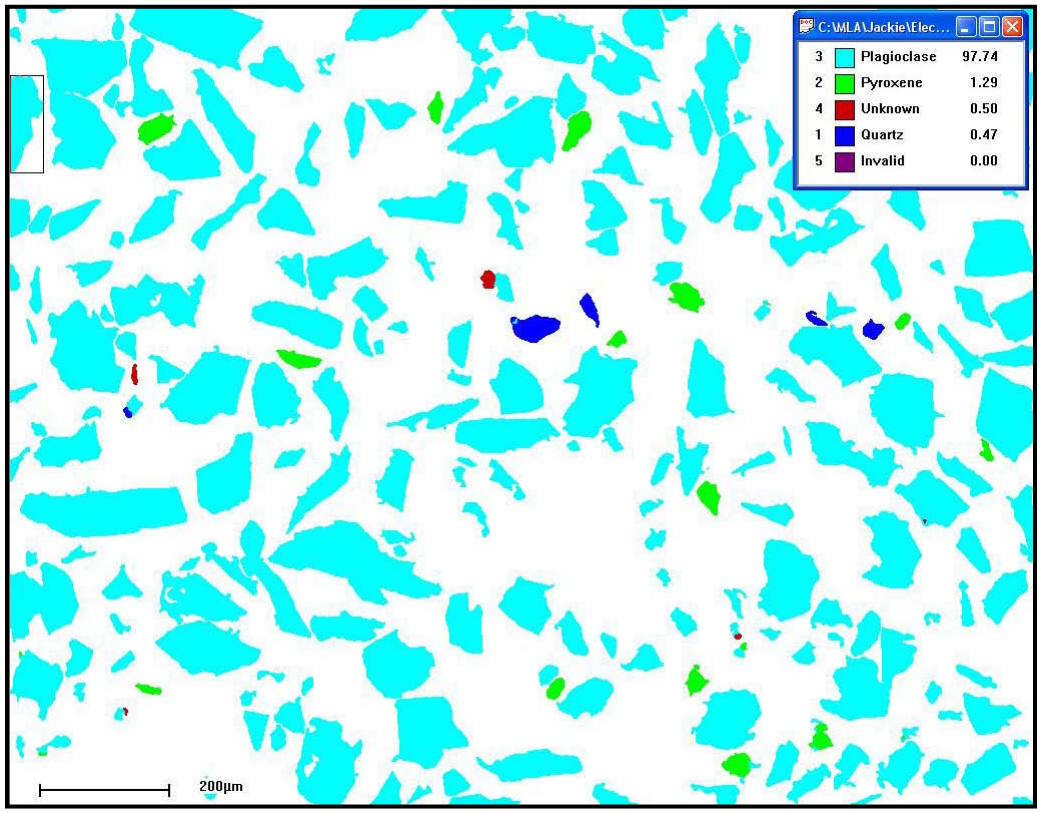
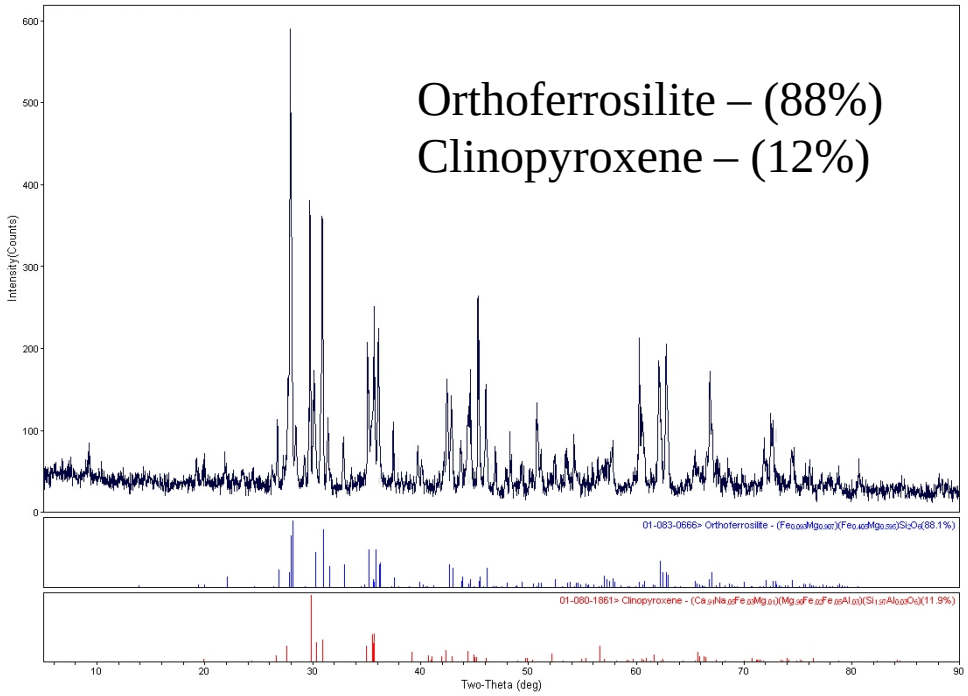


Results

Paramagnetic Material From "Road" Norite Rare Earth Belt Magnetic Separations (Dry) + Electrostatic Separation

- ES Not Effective with Particle Sizes < 150 μm
- No Significant Electrostatic Separation Observed



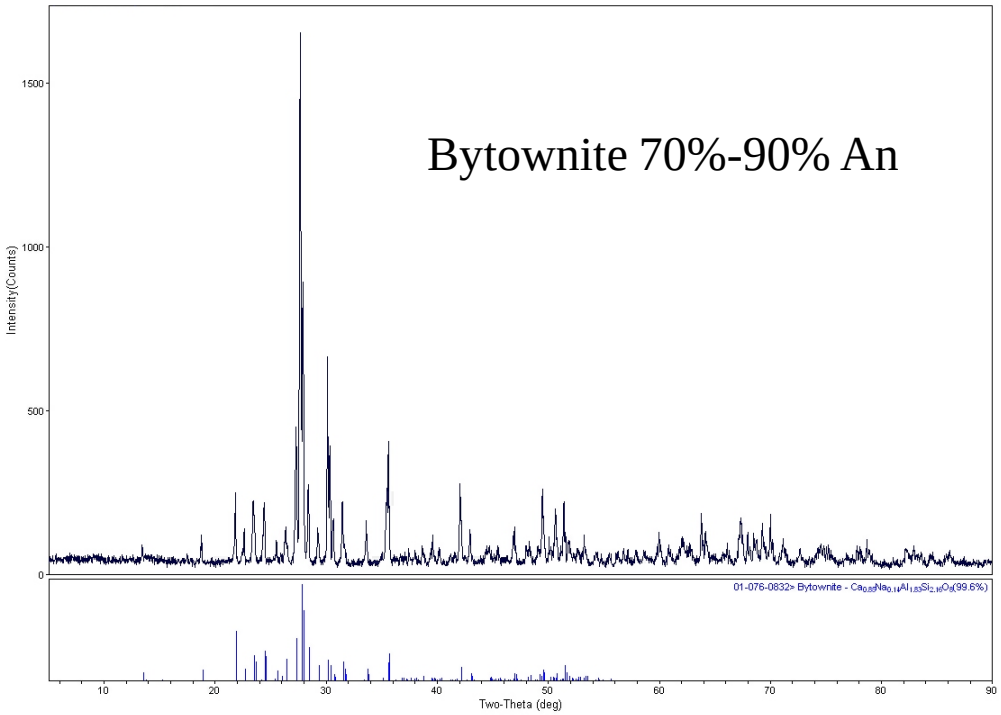
EDS Analysis (wt %)

O	36.31
Mg	10.42
Al	9.09
Si	29.23
Ca	7.49
Fe	7.46

Results

Diamagnetic Material From "Road" Norite Rare Earth Belt Magnetic Separations (Dry) + Electrostatic Separation

- ES Not Effective with Particle Sizes < 150 µm
- No Significant Electrostatic Separation Observed



EDS Analysis (wt %)

	600- 1000 µm	150-300 µm
O	36.00	51.77
Na	1.14	0.00
Al	20.04	16.55
Si	27.08	19.22
Ca	14.98	12.44
Fe	0.77	0.00

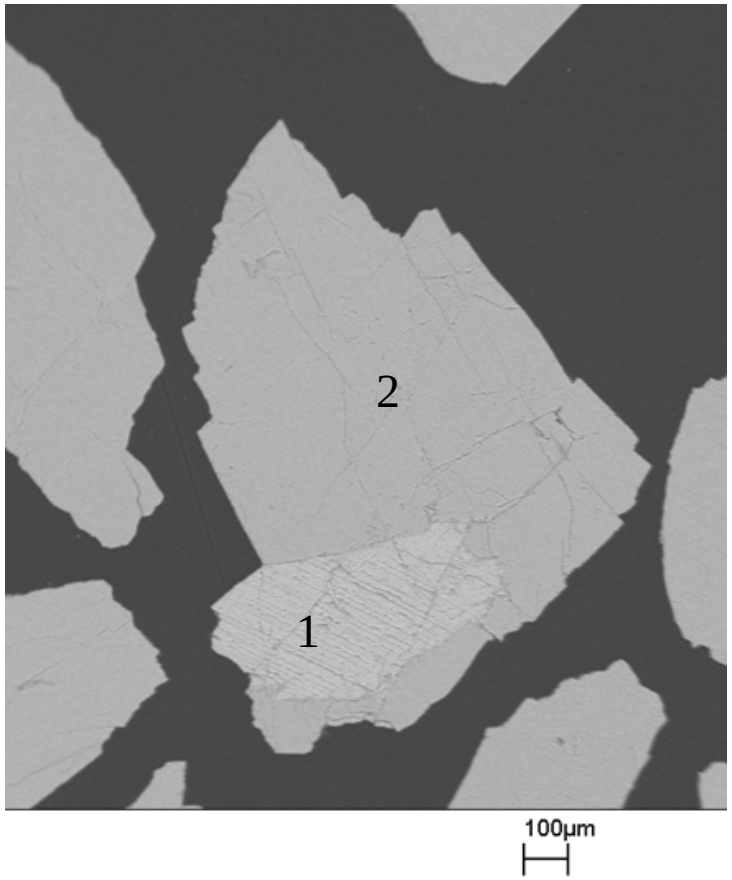
Results

Locked Particles - Nonmagnetic

- "Road" Norite Separated with Rare Earth Belt Magnetic Separator
- Particle Classified as Nonmagnetic

EDS Analysis

	wt%	
Element	Region 1	Region 2
O	36.00	32.34
Na	1.08	1.24
Mg	0.99	0.00
Al	19.07	21.14
Si	27.01	28.51
Ca	14.93	16.77
Fe	0.93	0.00



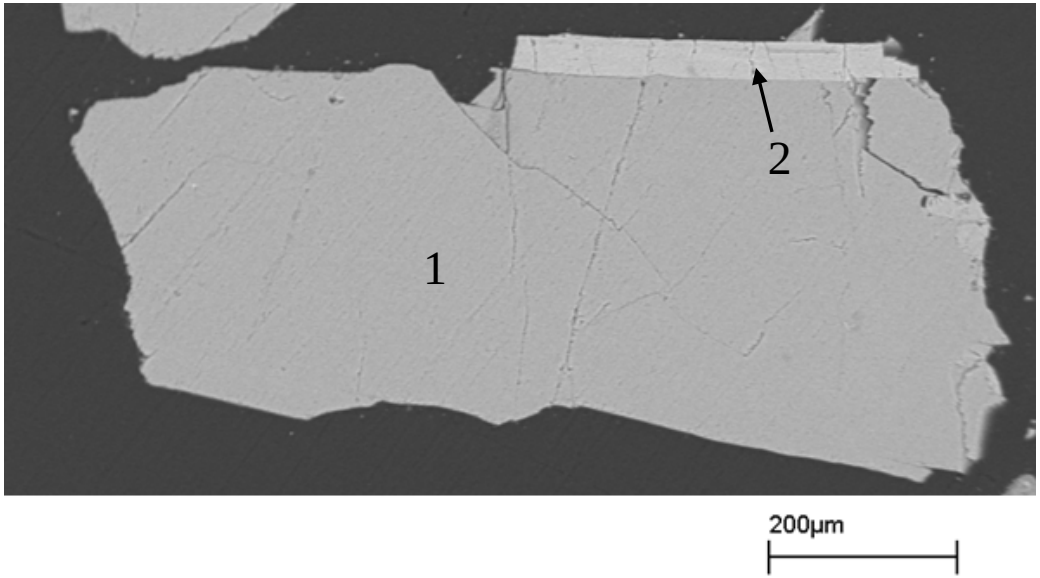
Results

Locked Particles - Paramagnetic

- "Road" Norite Separated with Rare Earth Belt Magnetic Separator
- Particle Classified as Paramagnetic

EDS Analysis

	wt%	
Element	Region 1	Region 2
O	29.75	33.11
Na	0.00	1.21
Al	16.14	21.15
Si	23.15	28.6
Ca	21.23	15.93
Fe	9.73	0.00

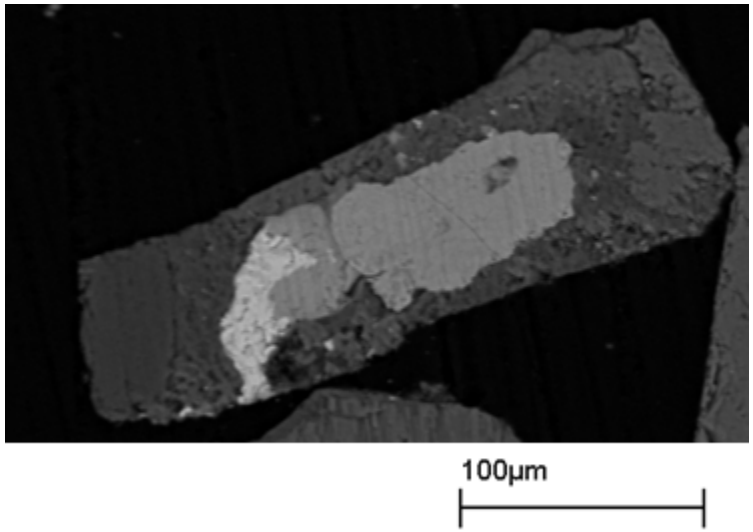


Results

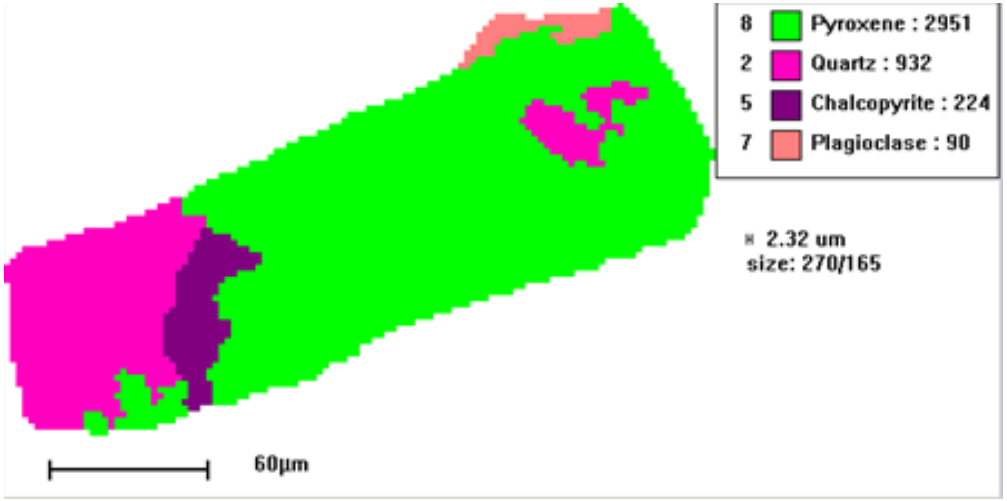
Locked Particles

- “Road” Norite Separated with Rare Earth Belt Magnetic Separator
- Particle Classified as Paramagnetic

SEM Image



MLA Image



Materials and Processes

"Road" Norite

- Rare Earth Magnetic Belt Separator*
- Electrostatic Separator
- Multiple Element Dry Drum Separator
- Wet High Intensity Magnetic Separator
- Froth Flotation

Slurried Stillwater Mill Tailings

- Wet Drum Electromagnet
- Wet High Intensity Magnetic Separator*
- Multiple Element Dry Drum Separator
- Froth Flotation

Dried Stillwater Mill Sands (from USGS)

- Rare Earth Magnetic Belt Separator
- Electrostatic Separator
- Multiple Element Dry Drum Separator

Flotation

Objectives:

1. Concentrate Calcium Minerals
2. Remove Hydrated Minerals

Process Steps:

1. Grind to liberate mineral particles,
2. Condition to achieve hydrophobic differences,
3. Float hydrophobic particles, and
4. Produce desired mineral concentrate.

Disscussion

Froth Flotation

"Road" Norite Slurry
Adjusted to pH 9.0
(80% Passing 325 mesh)

Discussion

Froth Flotation

“Road” Norite Slurry
Direct Flotation

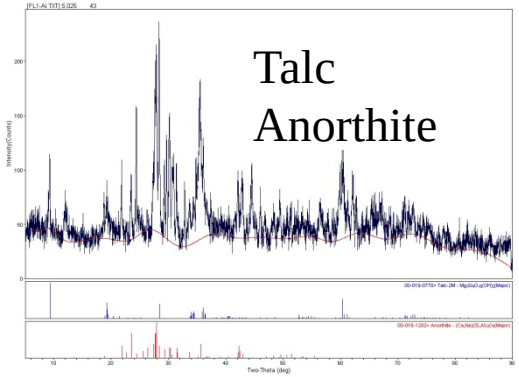
Discussion

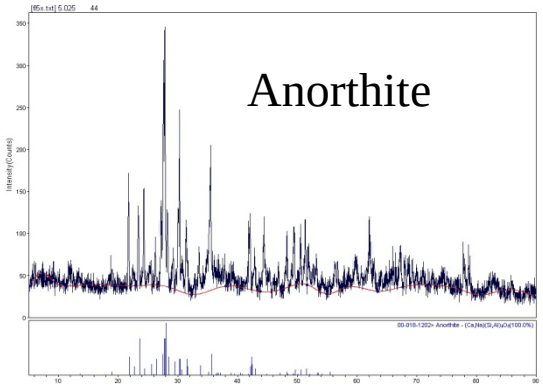
Froth Flotation

“Road” Norite Slurry
Reagent Flotation

Results

Froth Flotation of Mill Slurry from Stillwater Mill



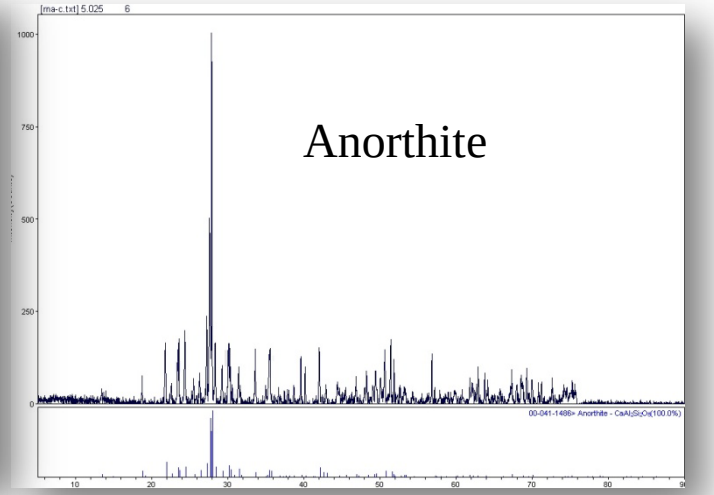


Reversing Talc Suppression					
	grams	Reagents	Time	Fraction	Particle Size (μm)
Feed	288.9			100.0%	80% -45
FL0	13.2	Only DF	5 mins	4.6%	
FL1	9.1	Peroxide, DF	20 mins	3.1%	
FL2	16.2	Peroxide, DF	40 mins	5.6%	
FL3	13.4	Peroxide, DF	48 hrs	4.6%	
FL4	58.0	FA, DF	10 mins	20.1%	
FL5	179.0			62.0%	

Results

Froth Flotation of "Road" Norite Nonmagnetic Material

Exploratory Test					
	grams	Reagents	pH	Fraction	Particle Size (μm)
Feed				100.0%	80% -45
C1	23.2	Only DF	9.0	19.1%	
C2	3.1	AERO 704, DF	9.0	2.6%	
C3	6.4	AERO 704, DF	9.0	5.3%	
T	88.5			73.0%	

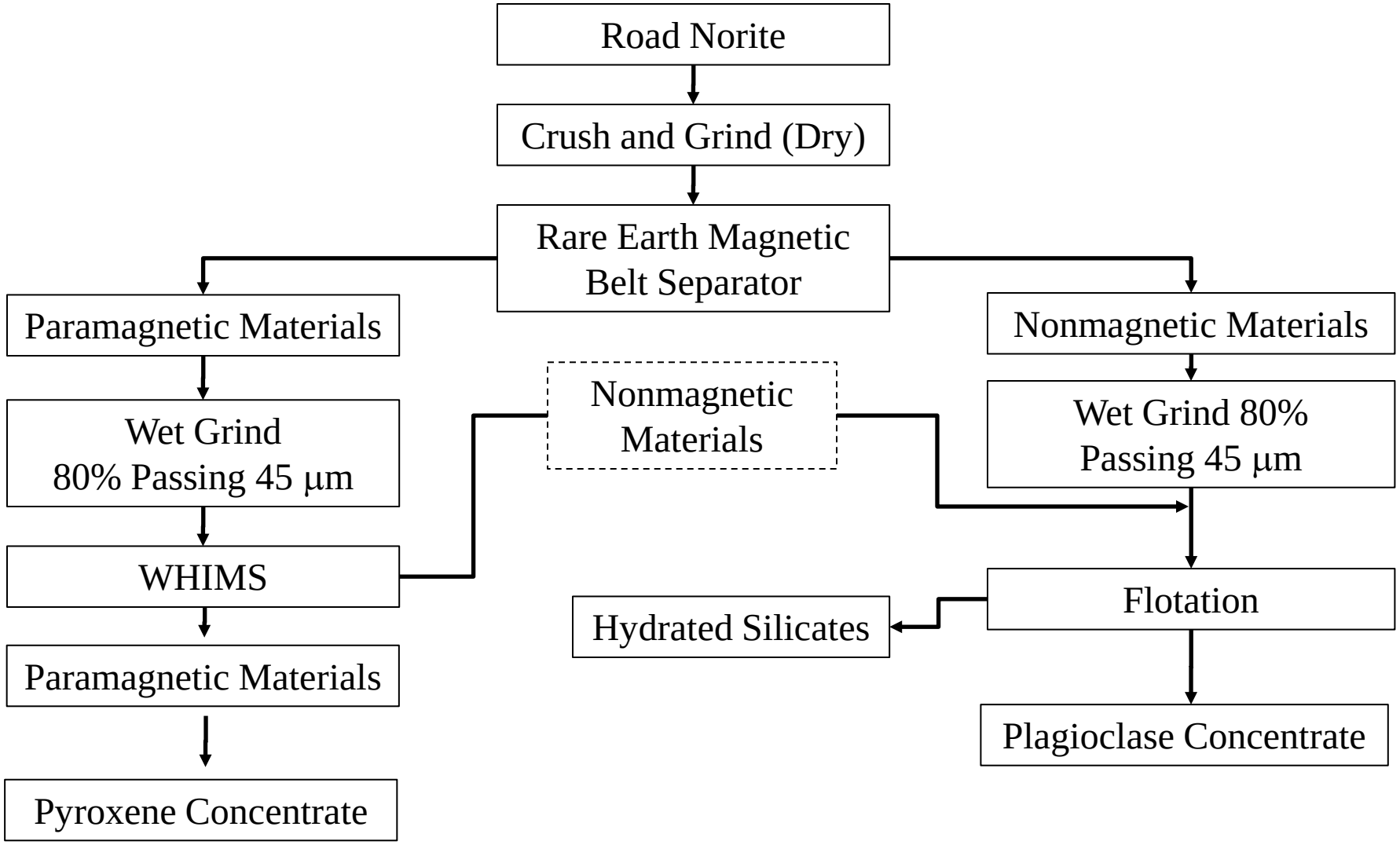


Results

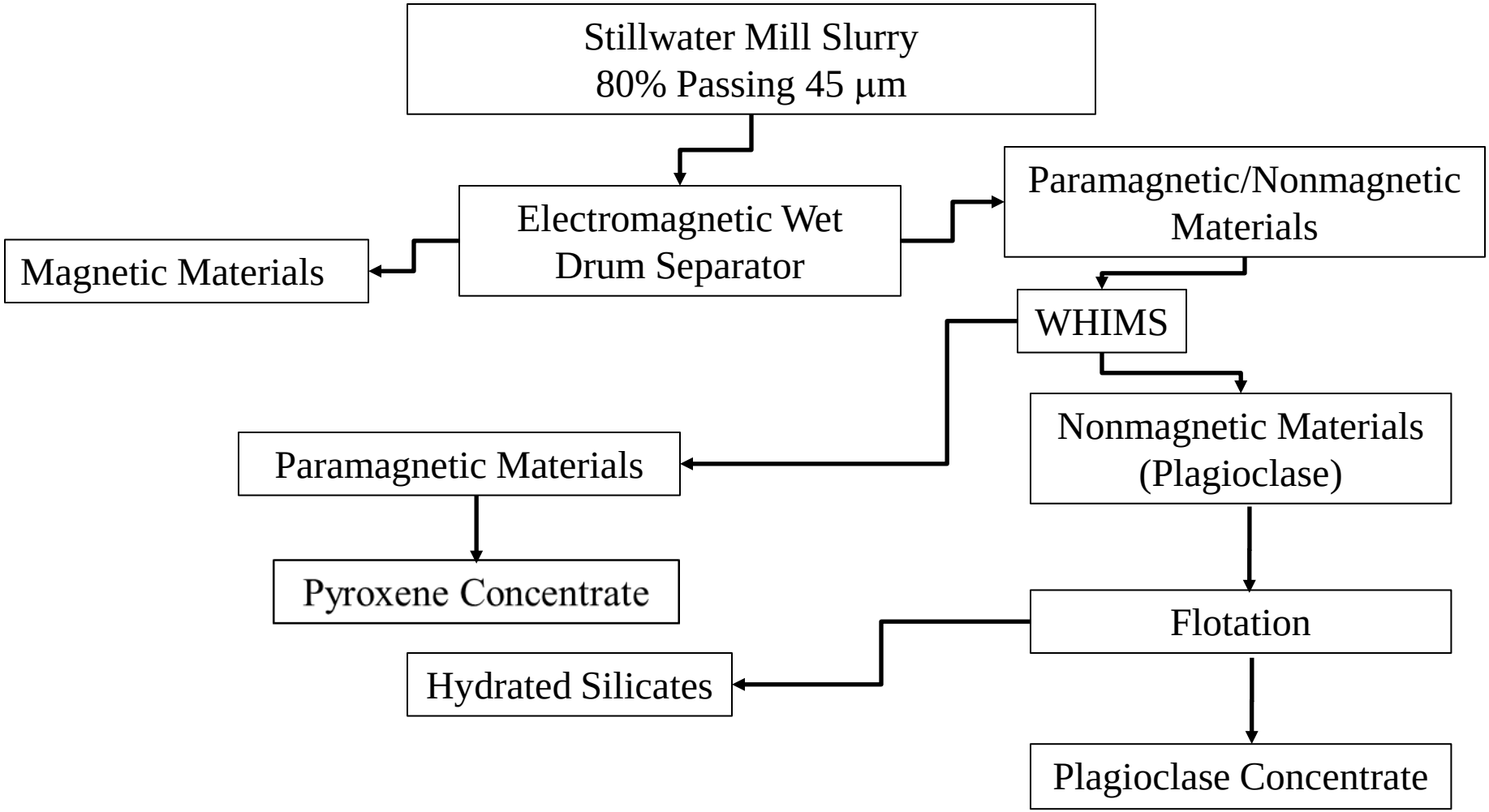
Froth Flotation of “Road” Norite Paramagnetic Material

Exploratory Test					
	grams	Reagents	pH	Fraction	Particle Size (μm)
Feed				100.0%	80% -45
C1	16.1	Only DF	9.0	13.3%	
C2	9.0	AERO 704, DF	9.0	7.4%	
C3	15.0	AERO 704, DF	9.0	12.4%	
T	80.9			66.9%	

Proposed Road Norite Process Flowsheet



Stillwater Mining Sands Process Flowsheet



Conclusion

Findings

Feedstock Dependent Process
Produced Plagioclase Concentrate > 70% An (Dry)
Produced Plagioclase Concentrate > 80% An (Wet)
Pyroxene Separation Observed (analytical refinement needed)
Hydrated Silicate Minerals Removed with Flotation
Locked Minerals Influence Magnetic Susceptibility of Particles

Further Work

Flotation Refinement for Hydrated Minerals
Investigate Flotation Calcium Enrichment
Wet Magnetic Optimization
Characterization of Products

Acknowledgements

Funding

This Project was funded by NASA Steckler Grant Number NNX10A0AC23A through Montana State University (MSU) Grant Number G250-10-1W2986

People

Dr. Douglas Rickman, Marshall Space Flight Center
Dr. Jennifer Edmunson, Marshall Space Flight Center
Dr. Steven Wilson, United States Geological Survey
Dr. Doug Stoeser, United States Geological Survey
Ms. Angela Des Jardins, Montana Space Grant Consortium (MSGC)
Larry Braunbeck, Stillwater Mining Company
Dr. Paul Miranda, CAMP, Montana Tech