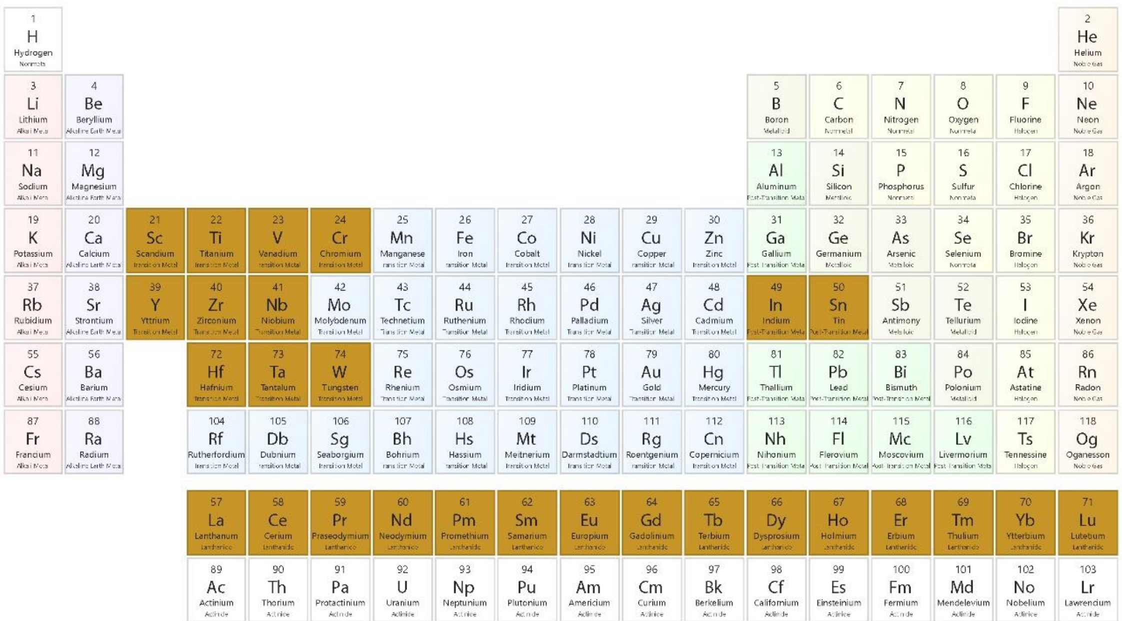
Economic heavy minerals on the continental shelf offshore of Virginia - new insights into the mineralogy, particle sizes, and critical element chemistry



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OPEN FILE REPORT 2019-03
July, 2019

Prepared under BOEM Cooperative Agreement M14AC00013
Award period: May 28, 2014 – May 16, 2019

DMME
Virginia Department of Mines Minerals and Energy

BOEM
Bureau of Ocean Energy Management

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DISCLAIMER

Funding for this project was provided by the U.S. Bureau of Ocean Energy Management under Cooperative Agreement M14AC00013 with additional funding contributions from the Virginia Department of Mines, Minerals and Energy. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Government. Mention of trade names and commercial products does not constitute their endorsement by the U.S. Government.

CITATION

Lassetter, W.L., and Blanchette, J.S., 2019, Economic heavy minerals on the continental shelf offshore of Virginia - new insights into the mineralogy, particle sizes, and critical element chemistry: Virginia Division of Geology and Mineral Resources Open-File Report 2019-03, 33 pp and Appendices.

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ABSTRACT

Since 2014, the Virginia Department of Mines, Minerals and Energy's Division of Geology and Mineral Resources (DGMR) and the U.S. Bureau of Ocean Energy Management (BOEM) have worked through a cooperative agreement to assess sand and economic heavy mineral resources on the continental shelf offshore of Virginia. Beach-quality sand deposits have been identified as potential resources for coastal remediation needs. Heavy minerals deposited with the sand include ilmenite ($FeTiO_3$), rutile (TiO_2), leucoxene (altered ilmenite), monazite $(Ce,La,Y,Th)(PO_4)$, chromite $(Fe,Mg)Cr_2O_4$, zircon $(Zr,Hf,U)(SiO_4)$, and others that occur in quantities ranging from trace amounts to over 10 weight percent. These minerals contain critical elemental commodities such as titanium, zirconium, chromium, and rare earth elements (REE) that have commercial value and are potentially recoverable as an integral part of beach restoration operations. Laboratory analysis of total heavy mineral (THM) concentrates from offshore samples has allowed for the quantification of the compositional variability of economic minerals, and the concentrations of the critical commodities they contain. The results also provide new information about grain size characteristics that, together with specific gravity and magnetic susceptibility, are important for the evaluation of recovery and separation methods.

A total of 63 marine sediment samples were analyzed for heavy minerals during 2016-19. The samples were gathered as part of the BOEM-sponsored Atlantic Sand Assessment Project (ASAP) and the Virginia Offshore Wind Technology Advancement Project (VOWTAP). Grain size analysis of the bulk samples provided mean ϕ values for the sediments, which averaged $\phi M = 2.45$, indicating predominantly fine grained sand textures that are suitable for beach nourishment. The preparation of the relatively large-volume samples for laboratory analysis included a pre-concentration procedure using a three-turn Humphrey spiral. Heavy liquid separation in the laboratory further refined the concentrates, producing a sink fraction containing minerals with specific gravity greater than about 3.2. For all samples, the THM content averaged 0.60 wt% (dry weight percent of the total sample), with individual samples ranging from 0.01 wt% up to 1.94 wt%. Modal mineralogical analysis showed ilmenite to be the predominant heavy mineral, averaging 23.5 wt% of THM, followed by rutile 8.7 wt%, and zircon 3.7 wt%. The sum of economic minerals in the concentrates averaged 40.5 wt% of THM.

Major-oxide and trace element geochemical analysis of the THM concentrates indicated significant enrichments in critical elemental commodities including Ti, Zr, REE, Cr, Hf, In, Nb, Sn, Ta, U, V, and W. The chondrite-normalized patterns of REE concentrations in particular provide valuable insight for further investigations of the geospatial distributions and transport processes of the minerals in the offshore environment.

INTRODUCTION

Following the devastating erosional impacts of Hurricane Sandy along the Atlantic coastline in 2012, the U.S. Bureau of Ocean Energy Management (BOEM) initiated cooperative agreements with 13 coastal states, including Virginia, to identify sand resources on the Outer Continental Shelf (OCS) suitable for beach nourishment and other coastal protection and restoration projects. In the initial cooperative agreement that extended from May 2014 to May 2016, the Department of Mines, Minerals and Energy's Division of Geology and Mineral Resources (DGMR) created an inventory of existing offshore geophysical surveys and geotechnical data from vibracore logs and seafloor grab samples, and a geodatabase containing analytical results for new samples characterizing sand and heavy mineral resources. The results are summarized in *Cooperative Agreement M14AC00013: Virginia Summary Report 2016 – Assessment of Offshore Sand Resources for Virginia Beachfront Restoration* (available on-line, https://www.boem.gov/Virginia-Projects/).

Virginia's State Cooperative Agreement was renewed for the period extending from August 2016 to May 2019 (M14AC00013 Modification 2) to conduct site-specific assessments of sand and heavy mineral resources using geologic data collected as part of the BOEM-sponsored Atlantic Sand Assessment Project (ASAP). From 2015 to 2017, BOEM contracted the Chicago Bridge and Ironworks Company (CB&I) to collect geophysical data and sediment cores in resource areas located in Federal waters 3 nautical miles (nm) to 8 nm off the Virginia coast (Figure 1). In the Wallops resource area, located offshore of Assateague and Wallops Island, reconnaissance scale geophysical surveys and 10 vibracores (including 2 twinned holes) were completed in an area encompassing about 245 square kilometers, km^2 (72 nm^2). In the Sandbridge area, located offshore of Sandbridge Beach and False Cape State Park, geophysical surveys and 5 vibracores (including 2 twinned holes) were completed in an area covering about 187 km^2 (54 nm^2). In the Delmarva area, offshore of the "Chincoteague Bight", 14 vibracores were completed in 2016-17 to evaluate sand deposits and heavy mineral occurrences. Heavy mineral resources were tested in the Smith Island area by 4 vibracores completed in 2017.

The ASAP offshore work provided a valuable opportunity to leverage sample collection activities for the evaluation of heavy minerals. For this report, heavy minerals are those generally characterized by specific gravity greater than about 3.2. Previous studies have recognized the potential economic value of marine sediment deposits containing heavy minerals such as ilmenite ($FeTiO_3$), rutile (TiO_2), zircon ($ZrSiO_4$), monazite ($CePO_4$), among others (Berquist and others, 1990; USBM, 1987). Since 1985, over 600 samples collected offshore of Virginia have been analyzed for total heavy minerals (THM) content, with the results indicating about 44 percent of the samples containing greater than 2.5 wt% THM (of the dry weight total sample), and 2 percent of the samples containing greater than 10 wt% THM (Berquist and Hobbs, 1986; Berquist and others, 1990; Luepke, 1990; Berquist and others, 2016; present report). These concentrations compare favorably with the known economic grades of onshore deposits mined by Iluka Resources LLC in Dinwiddie and Greenville Counties, Virginia. In the last full year of production in 2015, over 272 thousand short tons of titanium- and zirconium-enriched heavy mineral concentrates were produced from placer deposits in Pliocene-age beach sand. The estimated value was over $27 million (DMME, 2016). These ancient beach sand deposits may represent an onshore analog to similar deposits located offshore.

This report summarizes the results of analyses of recently acquired samples and provides new insights concerning the modal composition, geochemistry, and concentrations of critical commodities contained in heavy minerals offshore of Virginia. The future recovery of economically valuable heavy minerals as part of offshore sand mining operations for beach restoration could provide value-added benefits.

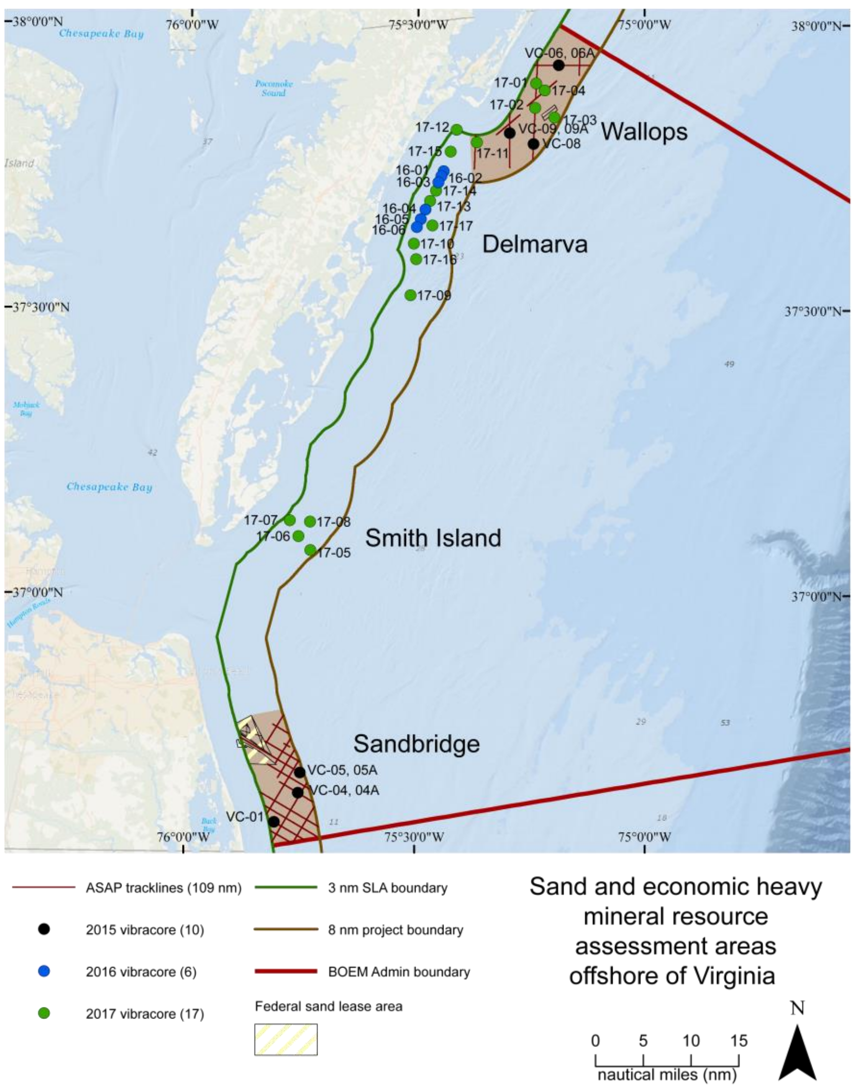

Figure 1. Marine mineral resource assessment areas evaluated as part of ASAP. Volumetric assessments of beach-quality sand were conducted in the brown-shaded areas at Wallops and Sandbridge.

PURPOSE AND RELEVANCE

A priority objective of the BOEM-Virginia State Cooperative is to assess occurrences of "value-added" heavy mineral resources that could provide positive economic offsets to the costs of sand dredging and beach restoration projects in Virginia. Economic heavy minerals include those containing critical mineral (elemental) commodities listed in U.S. Geological Survey Open-File 2018-1021 that are identified as "essential to the economic and national security of the United States" (Fortier and others, 2018). To date, nine economic minerals (or mineral groups) have been identified in heavy mineral concentrates from offshore Virginia (Table 1), including ilmenite, leucoxene, rutile, titanite, zircon, monazite, xenotime, apatite, and chromite. Minerals of the sillimanite group, garnet group, and staurolite potentially have non-critical economic value. Other heavy minerals that commonly occur in sample concentrates, but have little or no economic value include magnetite and other iron-oxides, pyrite, epidote, amphibole, pyroxene, among others.

Vibracore samples collected in 2015, 2016, and 2017 to support the ASAP sand resource assessments were leveraged for economic heavy minerals analysis. This report presents DGMR's findings in partial fulfilment of the work product deliverables for Cooperative Agreement M14AC00013. Recommendations from this assessment may assist BOEM's policy decisions if the demand for non-traditional marine mineral resources increases.

Table 1. Heavy minerals (sp.gr. >3.2) identified in marine sand deposits offshore of Virginia

Mineral name	Composition	[1]Specific gravity	[2]Critical mineral commodities	Non-critical economic value
Ilmenite	$FeTiO_3$	4.7	Ti	
Leucoxene	altered $FeTiO_3$	3.6 – 4.3	Ti	
Rutile	TiO_2	4.2 – 4.3	Ti	
Titanite	$CaTiO(SiO_4)$	3.3 – 3.6	Ti	
Zircon	$ZrSiO_4$	4.7	Zr, U, Hf, REE	Th, refractory
Monazite	$(Ce, La, Y, Th)PO_4$	4.6 – 5.4	REE, Y	Th
Xenotime	YPO_4	4.4 – 5.1	Y, REE, U	
Apatite	$Ca(PO_4)_3(F,OH)$	3.2	REE, U, Sr	fertilizer
Chromite	$(Fe, Mg)Cr_2O_4$	4.6	Cr	refractory
Sillimanite minerals	Al_2SiO_5	3.2 – 3.7		Al, refractory
Garnet group	$(Ca, Fe, Mg, Al)(SiO_4)_3$	3.4 – 4.6		abrasive sand
Staurolite	$Fe_2Al_9(Si, Al)_4O_{22}(OH)_2$	3.6		abrasive, cement
Magnetite / Hematite	Fe_2O_3 / Fe_3O_4	5.2 – 5.3		
Goethite	aFeO·OH	4.4		
Pyrite	FeS_2	5.0		
Epidote	$Ca_2(Al, Fe)_3(SiO_4)_3(OH)$	3.4		
Spinel	$MgAl_2O_4$	3.5 – 4.1		
Pyroxene	$(NaCa)(Mg,Fe,Al)(Al,Si)_2O_6$	3.5 – 3.7		
Amphibole	$Ca_2(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$	2.9 – 3.6		

[1] Sources: Van Gosen and others, 2014; Garner, 1978.
[2] Source: Fortier and others, 2018

METHODS AND ANALYSES

Acquisition of marine sediment samples

The findings presented in this report include results of analysis for 63 sediment samples collected in the offshore project area (Figure 2). Thirty-five of these samples were collected as part of the BOEM-sponsored ASAP vibracoring activities in 2015-17. Details concerning the vibracore locations, dates of collection, total depths, logs, etc. are provided in a separate deliverable report entitled: *BOEM Cooperative Agreement M14AC00013, Assessment of offshore sand resources for beach remediation in Virginia*.

In addition to the ASAP samples, 28 marine sediment samples received by DGMR in 2014 were analyzed. These seafloor grab and core samples were taken in 2013 in association with the Virginia Offshore Wind Technology Advancement Project (VOWTAP). As part of the VOWTAP geotechnical studies, Tetra Tech Inc. (Tetra Tech) conducted sediment sampling and geophysical surveys in the planned wind turbine demonstration area of the Wind Energy Area (WEA) and along the proposed cable route to Camp Pendleton, Virginia Beach. Tetra Tech provided DGMR with 69 grab samples and 90 bagged sample intervals from 17 vibracore locations. The results of grain size analyses and other geotechnical data are available in the final VOWTAP report (Tetra Tech, 2014).

Table 2 provides a complete list of the samples by field sample identification, the assigned DGMR rock repository number, the source, resource area, sample type, collection date, geographic coordinates, and laboratory report identification number.

Sample preparation

The ASAP vibracores were split by the contractor and sampled for grain size analysis by CB&I and the Delaware Geological Survey (DGS). The DGS also selected shell samples for amino acid racemization (AAR) dating. Lithologic logs for the ASAP cores were provided by CB&I and DGS. Lithologic logs for the VOWTAP vibracores were provided by Tetra Tech. After logging and sampling for grain size and AAR were completed, the ASAP core halves were transferred from the DGS facilities in Newark, DE to DGMR in Charlottesville, VA. Separate geologic examinations and sampling for heavy minerals analysis were performed by DGMR geoscientists at facilities located at the College of William and Mary in Williamsburg. The selection of core intervals for heavy minerals analysis was guided by visual estimates of the percent of opaque minerals. In some cases, the sample intervals for ASAP grain size analysis and heavy minerals analysis varied slightly, but this report generally utilizes the DGS logs and grain size data as the primary source for stratigraphic and lithologic characterizations.

The ASAP and Tetra Tech vibracore samples for heavy minerals were typically composites of five-foot sections; some intervals were less than five feet depending on the original recovered length of the core.

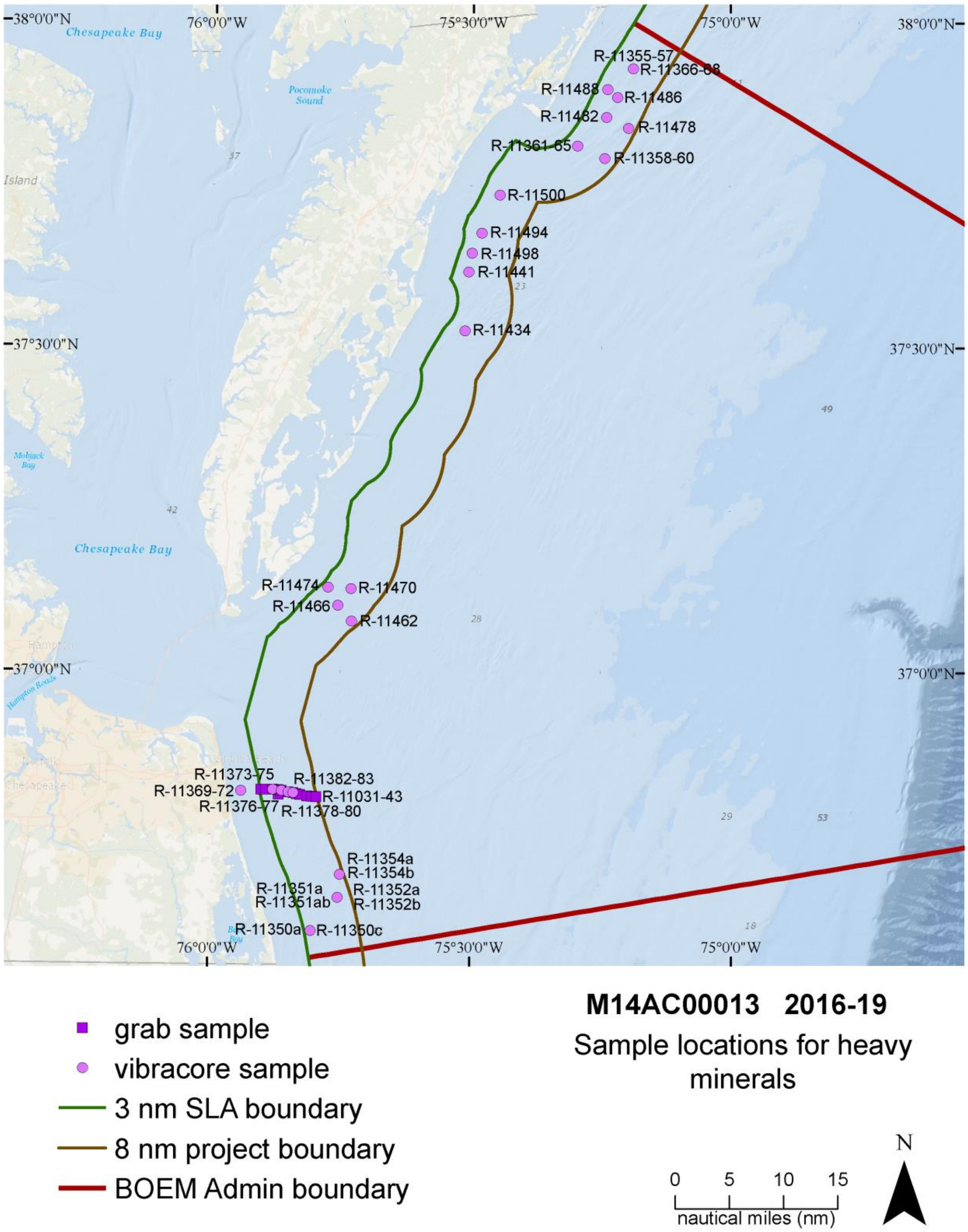

Figure 2. Locations of sediment samples analyzed for heavy minerals.

The Tetra Tech grab and vibracore samples were delivered to DGMR in large sealed Zip-lock bags and typically consisted of several kilograms of wet sediment. The samples were air dried in large plastic shallow tubs, a process that took about two weeks on average to remove all of the moisture. The dry weights of the bulk samples were recorded for later calculations of the dry-weight percent of total heavy minerals (THM). Each sample was then saturated in water for a minimum of eight hours to flocculate the fine sediment particles. This was followed by wet sieving through ASTM 10- and 230-mesh sieves. The plus 2-mm fraction retained on the 10-mesh screen was separated, air-dried, and the weight recorded as the "oversize" fraction for each sample. The fraction retained on the 230-mesh sieve, the "sand" fraction was air-dried in a large open-air plastic container, and the total dry weight recorded. The minus 0.062-mm fraction that passed the 230-mesh sieve was generally not significant and was discarded. The air-dry bulk sand fractions were prepared for heavy mineral separation using the three-turn Humphrey spiral apparatus.

Grain size statistics

Granularmetric reports were provided by CB&I for samples taken from the ASAP vibracores completed in 2015. The Delaware Geological Survey also completed grain size analyses for different sample intervals from the 2015 cores, as well as for samples from the ASAP vibracores taken in 2016 and 2017. Several samples selected by DGMR for heavy mineral analysis consisted of silty sediments; grain size analysis was not performed on these.

Grain size statistics were evaluated for the sand fraction particle distributions using the base two logarithmic phi (ϕ) scale. For those samples for which moment statistics were not provided, the mean sand grain size (ϕM) was calculated as the average of the ϕ size at 16%, 50%, and 84% taken from the arithmetic-scaled cumulative weight percent curve:

$$\phi M = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

Grain size statistics, water depths, sample depths below the sea floor (bsf), and ASTM classifications are summarized in Table 3.

Heavy mineral concentration using the three-turn Humphrey spiral

Heavy mineral concentrates were prepared from the bulk sand fractions by passing the entire sample through the three-turn Humphrey spiral. The sample was introduced into the top of the spiral under a steady, low pressure stream of water (Figure 3). The rate of sample input was somewhat subjective and grain-size dependent; samples that contained mainly fine particles were introduced at a slower rate than samples with coarser material. Water flowed through the spiral from two sources: from a hose at the top used to wash the sediment from the sample container into the top hopper, and from small jets located along the length of the spiral. The combined flow rate was maintained at about 1 gallon per minute and checked periodically to ensure consistency.

In operation, the sediment-water mixture flowed down the spiral and the heavy minerals (grains with specific gravity generally greater than about 2.9) were separated by gravity towards the inside of the spiral while the lighter materials (shell, quartz, phosphate, etc.) were carried in the water stream towards the outside of the stream. A splitter at the bottom of the spiral was adjusted in the water stream as needed to ensure the separation of the heavy minerals, which were collected in a separate container. The concentrate was washed into the top of the spiral again to eliminate as much quartz and lighter weight minerals as possible. The heavy mineral concentrates were air dried and the weights recorded. The light-density sand fractions were either discarded or archived for future reference.

Figure 3. Washing a large volume sediment sample into the top hopper of the three-turn Humphrey spiral for heavy mineral separation.

Laboratory analysis

For each spiraled sample concentrate, a minimum 100-g split was submitted to Activation Laboratories, Ltd. (ActLabs) located in Ancaster, Ontario, Canada for heavy minerals analysis. At the lab, the samples were further concentrated using heavy liquid separation methods that produced a heavy (sink) fraction with specific gravity generally greater than about 3.2. The lab provided the final dry weights of the sink and light (float) sediment fractions. The percent sinks reported by the lab was multiplied by the dry weight of the spiral concentrate to calculate the THM concentration as the dry weight percent of the total bulk sample:

$$\frac{\%Sinks * HMC_t}{Sample_b} = THM$$

where:
- HMC_t = dry weight of heavy mineral concentrate recovered by spiral, in g
- Sinks = heavy liquid separation sink fraction reported by lab, in g
- Float = heavy liquid separation float fraction reported by lab, in g
- %Sinks = calculated percent dry weight Sinks
- $Sample_b$ = dry weight of bulk sample, in g
- THM = total heavy minerals, as weight percent of total dry-weight sample

Mineral identifications were completed using the FEI FEG QEMSCAN scanning electron microscope Mineral Liberation Analysis (MLA) method. Two modes of measurement were used: BMA or line scan to produce modal mineralogy data, and particle mapping to determine grain size distributions. The laboratory reported the mass weight percent for up to 11 titanium-enriched minerals, 5 REE-enriched minerals, 6 oxide/hydroxide minerals, 12 silicates, and a variety of other minerals that occurred in low trace amounts or were unclassified.

Twenty-seven heavy mineral concentrate samples were also analyzed for major oxides and trace elements using the ActLabs 4LITHO RESEARCH whole rock analytical package. This package utilizes lithium metaborate/tetraborate fusion ICP for the whole rock analysis and ICP/MS analytical methods for trace elements including the rare earth elements (REE) at the lowest detection limits available. The analyses were performed on the “sink” fraction resulting from the heavy liquid separation performed at the lab.

Table 2. Marine sediment samples analyzed for economic heavy minerals.

Sample ID	DGMR Repository ID	Source	Area	[1]Type	Collection date	Longitude dec deg W NAD83	Latitude dec deg N NAD83	Lab Report
REF-002	R-11031	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/20/13	-75.86700	36.81215	A16-03579
GS-021	R-11032	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/19/13	-75.90069	36.81946	A16-03579
GS-022	R-11033	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/19/13	-75.89147	36.81952	A16-03579
GS-023	R-11034	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/19/13	-75.87816	36.81944	A16-03579
GS-024	R-11035	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/20/13	-75.86786	36.81905	A16-03579
GS-025	R-11036	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/20/13	-75.86131	36.81794	A16-03579
GS-026	R-11037	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/20/13	-75.84834	36.81544	A16-03579
GS-027	R-11038	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/19/13	-75.83873	36.81415	A16-03579
GS-028	R-11039	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/19/13	-75.83258	36.81293	A16-03579
GS-029	R-11040	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/19/13	-75.82635	36.81175	A16-03579
GS-030	R-11041	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/19/13	-75.81243	36.80933	A16-03579
GS-031	R-11042	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/19/13	-75.80282	36.80897	A16-03579
GS-032	R-11043	Tetra Tech VOWTAP	Sandbridge	grab, conc	6/19/13	-75.79487	36.80842	A16-03579
VC-01 1/3	R-11350a	BOEM-ASAP 2015	Sandbridge	core, conc	9/16/15	-75.80410	36.60230	A18-05577
VC-01 3/3	R-11350c	BOEM-ASAP 2015	Sandbridge	core, conc	9/16/15	-75.80410	36.60230	A18-05577
VC-04 1/3	R-11351a	BOEM-ASAP 2015	Sandbridge	core, conc	9/16/15	-75.75324	36.65378	A18-05577
VC-04 1/3	R-11351ab	BOEM-ASAP 2015	Sandbridge	core, bulk	9/16/15	-75.75324	36.65378	A18-05577
VC-04A 1/2	R-11352a	BOEM-ASAP 2015	Sandbridge	core, bulk	9/16/15	-75.75325	36.65378	A18-05577
VC-04A 2/2	R-11352b	BOEM-ASAP 2015	Sandbridge	core, bulk	9/16/15	-75.75325	36.65378	A18-05577
VC-05A 1/2	R-11354a	BOEM-ASAP 2015	Sandbridge	core, conc	9/16/15	-75.74899	36.68914	A18-05577
VC-05A 2/2	R-11354b	BOEM-ASAP 2015	Sandbridge	core, conc	9/16/15	-75.74899	36.68914	A18-05577
VC-06 1/3	R-11355	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.18973	37.93084	A17-11430
VC-06 2/3	R-11356	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.18973	37.93084	A17-11430
VC-06 3/3	R-11357	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.18973	37.93084	A17-11430

Sample ID	DGMR Repository ID	Source	Area	[1]Type	Collection date	Longitude dec deg W NAD83	Latitude dec deg N NAD83	Lab Report
VC-08 1/3	R-11358	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.24478	37.79299	A17-11430
VC-08 2/3	R-11359	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.24478	37.79299	A17-11430
VC-08 3/3	R-11360	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.24478	37.79299	A17-11430
VC-09 1/3	R-11361	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.29728	37.81161	A17-11430
VC-09 2/3	R-11362	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.29728	37.81161	A17-11430
VC-09 3/3	R-11363	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.29728	37.81161	A17-11430
VC-09A 1/2	R-11364	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.29730	37.81162	A17-11430
VC-09A 2/2	R-11365	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.29730	37.81162	A17-11430
VC-06A 1/3	R-11366	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.18983	37.93084	A17-11430
VC-06A 2/3	R-11367	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.18983	37.93084	A17-11430
VC-06A 3/3	R-11368	BOEM-ASAP 2015	Wallops	core, conc	9/17/15	-75.18983	37.93084	A17-11430
VC-001A 1/3	R-11369	Tetra Tech VA WEA	Sandbridge	core, conc	6/27/13	-75.93936	36.81728	A17-03131
VC-001A 2/3	R-11370	Tetra Tech VOWTAP	Sandbridge	core, conc	6/27/13	-75.93936	36.81728	A17-03131
VC-001A 3/3	R-11371	Tetra Tech VOWTAP	Sandbridge	core, conc	6/27/13	-75.93936	36.81728	A17-03131
VA-001A core tip	R-11372	Tetra Tech VOWTAP	Sandbridge	core, conc	6/27/13	-75.93936	36.81728	A17-11430
VC-002B 1/2	R-11373	Tetra Tech VOWTAP	Sandbridge	core, conc	6/22/13	-75.89520	36.81933	A17-03131
VC-002B 2/2	R-11374	Tetra Tech VOWTAP	Sandbridge	core, conc	6/22/13	-75.89520	36.81933	A17-03131
VA-002 core tip	R-11375	Tetra Tech VOWTAP	Sandbridge	core, conc	6/27/13	-75.89520	36.81933	A17-11430
VC-003 1/2	R-11376	Tetra Tech VOWTAP	Sandbridge	core, conc	6/22/13	-75.88418	36.81906	A17-03131
VC-003 2/2	R-11377	Tetra Tech VOWTAP	Sandbridge	core, conc	6/22/13	-75.88418	36.81906	A17-03131
VC-004 1/3	R-11378	Tetra Tech VOWTAP	Sandbridge	core, conc	6/27/13	-75.87606	36.81928	A17-03131
VC-004 2/3	R-11379	Tetra Tech VOWTAP	Sandbridge	core, conc	6/27/13	-75.87606	36.81928	A17-03131
VC-004 3/3	R-11380	Tetra Tech VOWTAP	Sandbridge	core, conc	6/27/13	-75.87606	36.81928	A17-03131
VC-005 2/3	R-11382	Tetra Tech VOWTAP	Sandbridge	core, conc	6/27/13	-75.86445	36.81847	A17-03131
VC-005 2/3 red	R-11382	Tetra Tech VOWTAP	Sandbridge	core, conc	6/27/13	-75.86445	36.81847	A17-03131
VC-005 3/3	R-11383	Tetra Tech VOWTAP	Sandbridge	core, conc	6/27/13	-75.86445	36.81847	A17-03131

Sample ID	DGMR Repository ID	Source	Area	[1]Type	Collection date	Longitude dec deg W NAD83	Latitude dec deg N NAD83	Lab Report
VA-2017-09 1/3	R-11434	BOEM-ASAP 2017	Delmarva	core, bulk	12/3/17	-75.51400	37.52700	A18-05577
VA-2017-10 1/3	R-11441	BOEM-ASAP 2017	Delmarva	core, bulk	12/3/17	-75.50779	37.61752	A18-05577
VA-2017-05 1/3	R-11462	BOEM-ASAP 2017	Smith Island	core, bulk	12/5/17	-75.72999	37.07900	A18-05577
VA-2017-06 1/3	R-11466	BOEM-ASAP 2017	Smith Island	core, bulk	12/5/17	-75.75600	37.10300	A18-05577
VA-2017-08 1/3	R-11470	BOEM-ASAP 2017	Smith Island	core, bulk	12/5/17	-75.73102	37.12901	A18-05577
VA-2017-07 1/3	R-11474	BOEM-ASAP 2017	Smith Island	core, bulk	12/5/17	-75.77499	37.13100	A18-05577
VA-2017-03 1/3	R-11478	BOEM-ASAP 2017	Wallops	core, bulk	12/4/17	-75.19899	37.83901	A18-05577
VA-2017-02 1/3	R-11482	BOEM-ASAP 2017	Wallops	core, bulk	12/4/17	-75.24102	37.85601	A18-05577
VA-2017-04 1/3	R-11486	BOEM-ASAP 2017	Wallops	core, bulk	12/4/17	-75.21997	37.88700	A18-05577
VA-2017-01 1/3	R-11488	BOEM-ASAP 2017	Wallops	core, bulk	12/4/17	-75.23902	37.89898	A18-05577
VA-2016-04 1/3	R-11494	BOEM-ASAP 2016	Delmarva	core, bulk	8/20/16	-75.48265	37.67709	A18-05577
VA-2016-06 1/3	R-11498	BOEM-ASAP 2016	Delmarva	core, bulk	8/20/16	-75.50089	37.64635	A18-05577
VA-2016-02 1/3	R-11500	BOEM-ASAP 2016	Delmarva	core, bulk	8/20/16	-75.44757	37.73616	A18-05577

[1] Type: grab is seafloor grab sample, core is vibracore, conc is spiral concentrate submitted to lab, bulk is bulk sample submitted to lab (not pre-concentrated).

Table 3. Grain size statistics for marine sediment samples analyzed for economic heavy minerals.

DGMR Repository ID	[1]Water depth m MLLW	Sample depth m [2]bsf	Gravel %	Sand %	[3]Mud %	ASTM D2487 classification	Sand fraction ϕ_M
R-11031	13.8	0.0	0.1	87.6	12.3	SM	2.72
R-11032	11.0	0.0	0.3	98.4	1.3	SP	1.75
R-11033	11.0	0.0	4.6	94.3	1.1	SP	0.66
R-11034	14.0	0.0	0.0	73.3	26.7	SM	3.53
R-11035	14.8	0.0	0.2	97.5	2.3	SP	1.89
R-11036	15.8	0.0	0.0	82.8	17.2	SM	3.41
R-11037	16.0	0.0	0.1	95.2	4.7	SP	1.98
R-11038	15.7	0.0	0.0	84.9	15.1	SM	3.28
R-11039	15.8	0.0	0.1	84.8	15.1	SM	3.27
R-11040	16.2	0.0	0.1	86.7	13.2	SM	3.06
R-11041	16.1	0.0	0.0	84.8	15.2	SM	3.24
R-11042	16.6	0.0	0.1	84.8	15.1	SM	3.33
R-11043	18.4	0.0	12.3	79.6	8.1	SP-SM	-0.23
R-11350a	14.0	0.0-1.5	1.4	98.6	0.1	SW	1.21
R-11350c	14.0	3.7-5.2	[4]nd	nd	nd	ML	nd
R-11351a	16.0	0.0-1.8	0.0	99.9	0.1	SP	1.51
R-11351ab	16.0	0.0-1.8	0.0	99.9	0.1	SP	1.51
R-11352a	16.0	4.3-5.2	0.2	98.7	1.2	SP	2.01
R-11352b	16.0	5.2-6.7	0.4	37.8	61.8	ML	3.61
R-11354a	14.0	3.4-4.9	0.0	98.7	1.3	SP	2.30
R-11354b	14.0	4.9-6.4	0.1	99.4	0.5	SP-SW	1.87
R-11355	16.7	0.0-1.5	0.9	99.0	0.2	SP	1.26
R-11356	16.7	1.5-3.0	0.2	99.4	0.5	SP	1.47
R-11357	16.7	3.0-4.6	0.0	80.5	19.5	SM	2.50
R-11358	18.4	0.0-1.5	0.4	99.0	0.6	SP-SW	1.47

DGMR Repository ID	[1]Water depth m MLLW	Sample depth m [2]bsf	Gravel %	Sand %	[3]Mud %	ASTM D2487 classification	Sand fraction ϕ_M
R-11359	18.4	1.5-3.0	0.1	97.5	2.4	SP-SM	2.86
R-11360	18.4	3.0-4.6	nd	nd	nd	ML	nd
R-11361	15.5	0.0-1.5	0.2	95.3	4.5	SP-SM	2.62
R-11362	15.5	1.5-3.0	0.1	98.4	1.5	SW	2.40
R-11363	15.5	3.0-4.6	0.0	93.5	6.5	SP-SM	2.84
R-11364	15.5	3.2-4.1	1.1	97.1	1.8	SP-SM	2.70
R-11365	15.5	4.1-5.6	0.0	97.8	2.2	SP-SM	2.64
R-11366	16.7	3.1-4.2	nd	nd	nd	ML	nd
R-11367	16.7	4.2-5.7	0.0	86.0	14.0	SC-ML	2.15
R-11368	16.7	5.7-7.2	0.2	97.4	2.4	SP	1.64
R-11369	8.1	0.0-0.9	0.1	85.6	14.3	SM	3.29
R-11370	8.1	0.9-1.8	0.1	86.2	13.7	SM	3.33
R-11371	8.1	1.8-2.4	0.1	85.6	14.3	SM	3.30
R-11372	8.1	2.4-2.4	0.1	85.6	14.3	SM	3.30
R-11373	9.7	0.0-0.9	6.0	93.6	0.4	SP-SM	1.31
R-11374	9.7	0.9-1.8	34.5	63.6	1.9	SP	-0.28
R-11375	9.7	1.8-1.8	nd	nd	nd	SM	nd
R-11376	12.6	0.0-0.9	0.2	90.9	8.9	SP-SM	2.76
R-11377	12.6	0.9-2.1	0.3	84.0	15.7	SM	3.32
R-11378	14.1	0.0-0.9	0.9	88.3	10.8	SP-SM	3.26
R-11379	14.1	0.9-1.5	0.0	68.8	31.2	SM	3.38
R-11380	14.1	1.5-2.6	0.2	80.4	19.4	SM	3.32
R-11382	15.1	0.9-1.5	0.0	80.7	19.3	SM	3.40
R-11382	15.1	1.5-1.6	25.3	73.4	1.3	SP	-0.07
R-11383	15.1	1.6-2.6	25.6	71.4	3.0	SP-SW	-0.13
R-11434	9.1	0.0-1.5	1.0	97.5	1.5	SP	2.08

DGMR Repository ID	[1]Water depth m MLLW	Sample depth m [2]bsf	Gravel %	Sand %	[3]Mud %	ASTM D2487 classification	Sand fraction ϕ_M
R-11441	11.1	0.0-1.5	0.4	66.6	33.0	SC-ML	3.94
R-11462	15.0	0.0-1.5	0.0	80.4	19.7	SM	3.63
R-11466	12.3	0.0-1.5	0.3	92.2	7.5	SP-SM	3.25
R-11470	13.1	0.0-1.5	0.0	85.8	14.2	SM	3.36
R-11474	11.3	0.0-1.5	0.0	88.0	12.0	SM	3.56
R-11478	20.8	0.0-1.5	1.4	86.7	11.9	SM	2.76
R-11482	17.5	0.0-1.5	0.2	95.7	4.1	SP-SM	2.78
R-11486	15.2	0.0-1.5	0.0	94.8	5.2	SP-SM	2.77
R-11488	17.4	0.0-1.5	nd	nd	nd	ML	nd
R-11494	15.7	0.0-1.5	0.1	95.8	3.9	SP-SM	2.15
R-11498	12.3	0.0-1.5	0.6	98.0	1.4	SP	1.98
R-11500	15.0	0.0-1.5	0.4	41.0	55.9	ML	3.86
Mean	14.4		2.1	87.4	10.5		2.45
Standard deviation	2.9		6.6	13.0	12.3		1.06
Median	15.1		0.1	88.2	7.0		2.74
Median abs dev.	1.3		0.1	8.6	6.5		0.66
Max	20.8		34.5	99.9	61.8		3.94
Min	8.1		0.0	37.8	0.1		-0.28
Count	63		58	58	58		58

[1] MLLW is mean lower low water National Tidal Datum Epoch from the U.S. National Oceanic and Atmospheric Administration (NOAA).
[2] bsf = below sea floor.
[3] mud fraction in the Tetra Tech samples are minus 200-mesh (0.075 mm), all others are minus 230-mesh (0.063 mm).
[4] nd = no data available.

RESULTS

Grain size statistics

The results of grain size analysis performed by CB&I, DGS, and Tetra Tech indicate the range of sediment textures in the samples selected for heavy minerals analysis (Table 3). For reference, Appendix A provides a comparison of grain size scales and sieve sizes for sediment classification. Overall, the sediments averaged 2.1% gravel, 87.4% sand, and 10.5% mud (silt+clay) fractions, and generally are classified as muddy sand to sand (Figure 4). It is noted that the sample grain size analyses received from Tetra Tech defined the "mud" fraction as sediment passing the 200-mesh sieve (ϕ=3.75, 0.07 mm) whereas all other samples delineated the "mud" fraction as sediment passing the 230-mesh sieve (ϕ=4, 0.06 mm). Although not greatly significant, the overall average percent mud is probably somewhat overstated and the overall average percent sand fraction understated. One of the criteria in sample selection was the co-occurrence of opaque minerals with potentially beach-quality sand. The mean ϕ value (ϕM) for 58 samples was 2.45, which confirmed the visual observation of predominantly fine- to very fine sand textures.

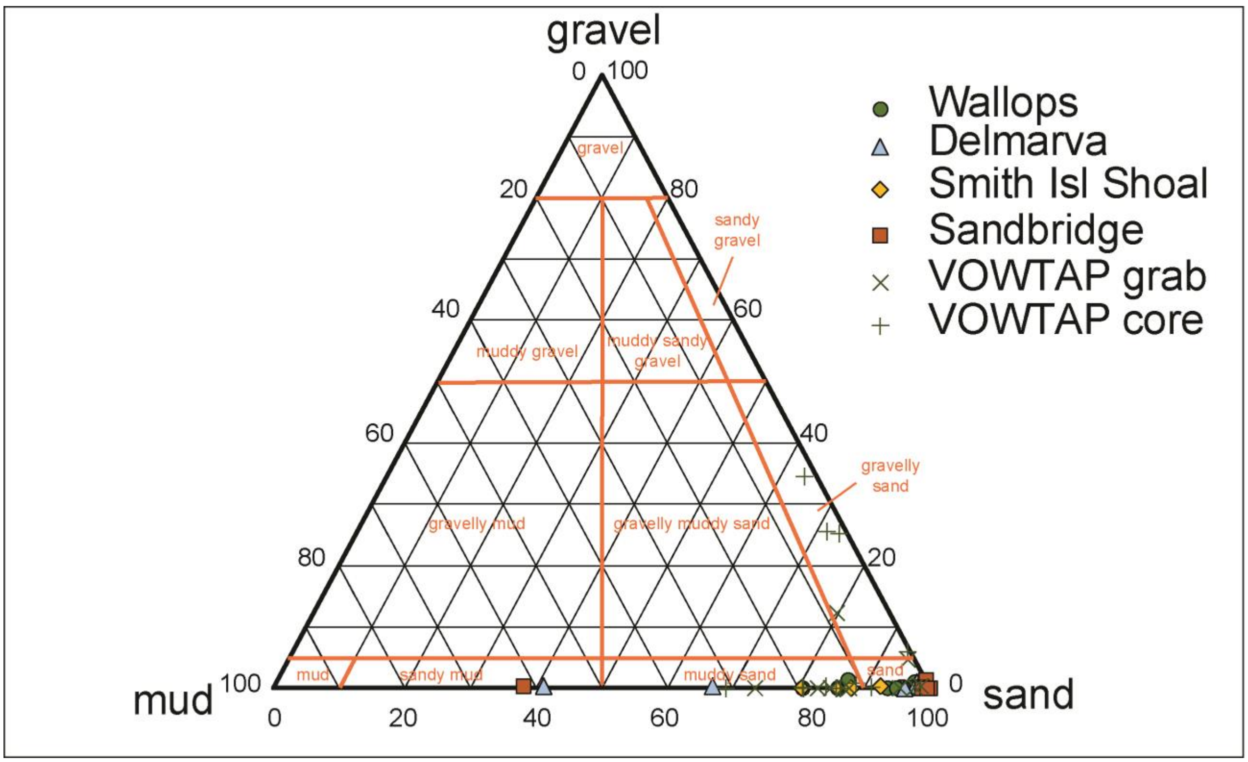

Figure 4. Grain size classification of sediment samples analyzed for heavy minerals, after Folk (1954), n=58.

Grain size and compositional characteristics of heavy mineral concentrates

The ActLabs reports for 63 heavy mineral concentrates are included in Appendix B, and include details concerning modal mineralogy, grain size distribution and mineral compositional mapping of representative particles. Table 4 summarizes the total heavy mineral (THM) fractions as the weight percent of the bulk dry weight of each sample. Also listed are the weight percents of the individual heavy minerals with economic importance, which are those listed in Table 1 containing critical commodities (ilmenite, rutile, leucoxene, titanite, zircon, monazite, xenotime, apatite, and chromite). The sum of the economic heavy minerals in each sample is given as ΣEHM as the weight percent of THM. Table 5 summarizes the weight percents of minerals with non-critical value or are non-economic minerals included in the THM fractions.

Overall, the mean value for THM was 0.60 wt%, with individual samples ranging from as low as 0.01 wt% up to 1.94 wt%. Note that one anomalous sample, VC-04A 2/2 (R-11352b), collected from core in the Sandbridge area, was not used in the statistical compilations. This was due to an unusual mineral composition that included relatively high pyrite content (61 wt%). No explanation for this lab result is evident in the core log or grain size data.

The highest THM concentrations (greater than 1 wt%) were associated with bulk sediments characterized by mean ϕ values ranging from about 2.0 to 3.6, corresponding to fine to very fine sand fractions (Figure 5). Although this study was constrained by the relatively small number of samples, the apparent link between higher THM content and depositional settings that favor finer grain sandy sediments might be an important guide to identifying economic deposits.

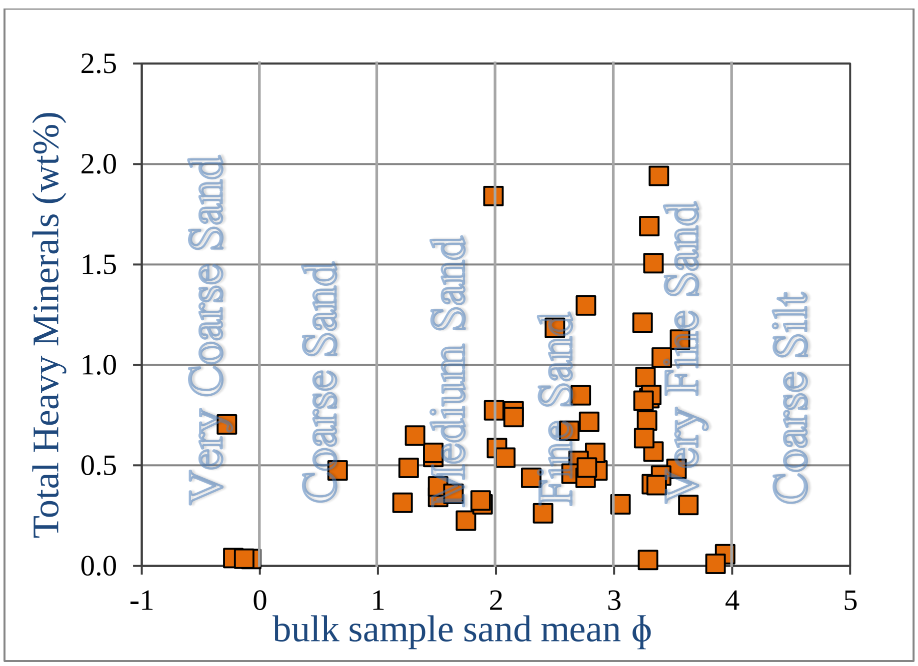

Figure 5. Higher THM values are associated with fine to very fine sandy sediments (n=58).

The results for modal mineralogical analysis show that titanium-bearing ilmenite was by far the most abundant of the economic minerals in the THM concentrates (mean values shown as color pie slices in Figure 6) with the mean value of 23.5 wt% of THM. Next most abundant were titanium-bearing rutile (8.7 wt%) and zirconium-bearing zircon (3.7 wt%). Minerals enriched in rare earth elements (REE) including monazite and xenotime were generally low in abundance averaging 0.2 wt% and 0.02 wt%, respectively. Apatite, also a potential source of REE, averaged 1.6 wt%. Chromite, a source of the critical commodity chromium, averaged 0.1 wt%. The mean values for titanium-bearing leucoxene and titanite were 1.4 wt% and 1.5 wt%, respectively. Overall, the average sum of the economic minerals, ΣEHM, was 40.5 wt% of THM.

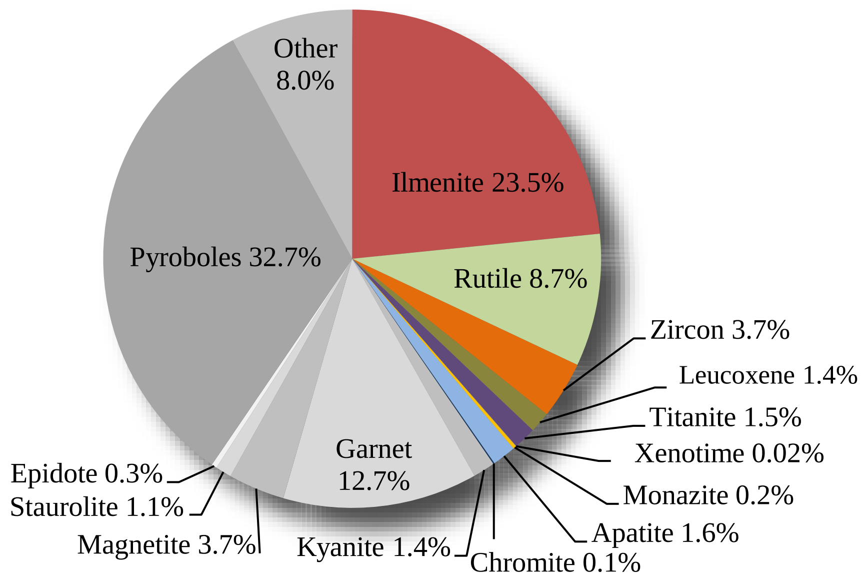

Figure 6. Average composition of the THM concentrates (n=62). Economic minerals are shown as color pie slices. “Pyroboles” is the combined wt% of amphibole and pyroxene.

The laboratory results include cumulative grain size distributions for the titanium- and zirconium-enriched minerals in the THM concentrates (Figure 7). This data allows for the calculation of the mean ϕ values for the individual mineral species. The largest detrital grains of those assessed in the THM concentrates were zircon and titanite, with mean ϕ sizes of 3.4 and 3.9 respectively (equivalent to the very fine sand fraction, 0.062 – 0.125 mm). Mean ϕ values for ilmenite and rutile, 4.3 and 4.8 respectively, indicated the size of these mineral grains typically in the range of coarse silt (0.031 – 0.062 mm). It is interesting to note the cumulative particle size distributions and mean ϕ values for leucoxene and pseudorutile, which place these minerals in the very fine silt particle size range (0.004 – 0.008 mm). These minerals occur as alteration products of the more abundant titanium-oxides and are typically more enriched in the critical commodity titanium. As part of the economic heavy mineral assemblage, the very fine grain nature of these detrital minerals may present special challenges in the methods used for separation and recovery. We also recognize the need to re-evaluate our sample preparation methods using the Humphrey spiral to ensure that these very small particle size fractions containing economic minerals are not being overlooked and discarded.

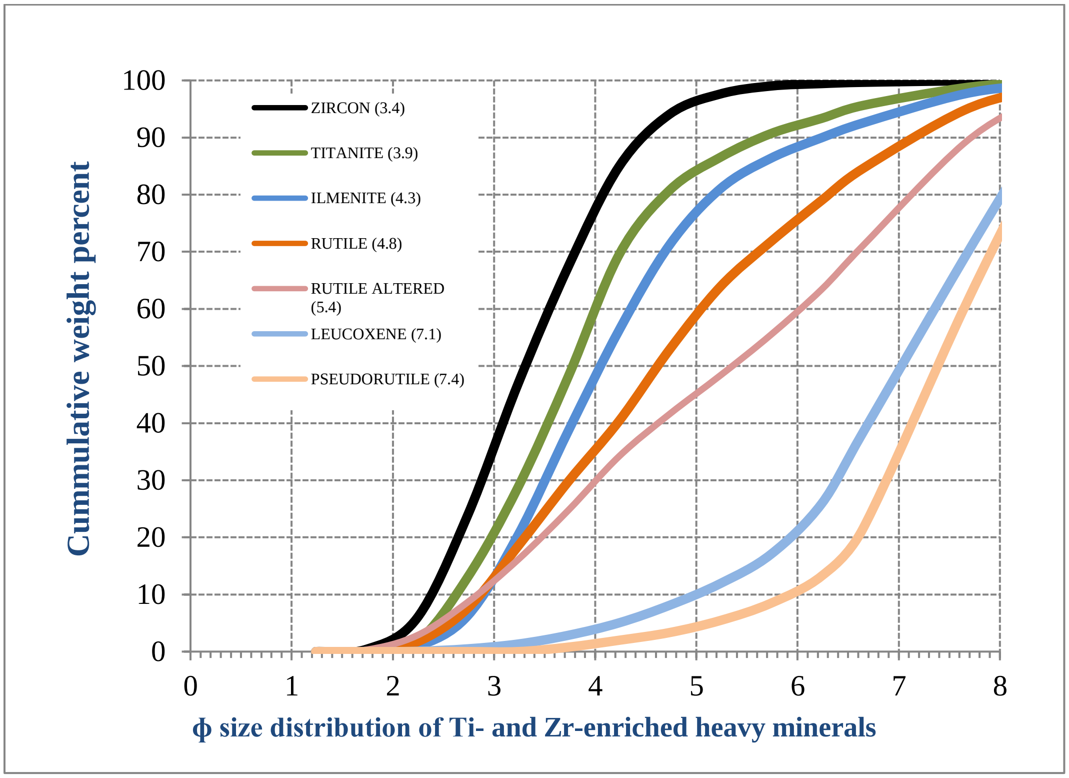

Figure 7. ϕ size distributions and mean values for Ti- and Zr-enriched heavy minerals.

The sub-economic heavy minerals include those that contain very low quantities of critical commodities, but may potentially have value depending upon mineral recovery grade, separation methods, and market conditions. These minerals and the average abundances found in THM concentrates of the present study include garnet (12.7 wt%) used for commercial abrasive sands, kyanite (1.4 wt%) as a source of aluminum and refractories, and staurolite (1.1 wt%) used for cement manufacture and abrasives.

Table 4. Summary of the modal mineralogy of economic heavy minerals reported in weight percent of the total heavy mineral concentrate (wt% THM). THM is reported as weight percent of the total sample.

DGMR Repository ID	THM wt% total sample	[1]ΣEHM wt% THM	[2]Ilmenite wt% THM	[3]Rutile wt% THM	Leucoxene wt% THM	Titanite wt% THM	Zircon wt% THM	Monazite wt% THM	Xenotime wt% THM	Apatite wt% THM	Chromite wt% THM
R-11031	0.85	20.84	6.74	4.82	2.22	2.17	1.24	0.09	0.00	3.56	0.01
R-11032	0.23	38.24	26.11	7.50	2.09	0.20	2.26	0.00	0.00	0.07	0.19
R-11033	0.47	56.92	41.98	10.40	1.23	0.09	2.94	0.17	0.01	0.10	0.06
R-11034	0.48	23.30	9.92	4.72	2.21	1.89	1.61	0.14	0.01	2.81	0.09
R-11035	0.31	29.98	15.86	7.47	1.28	1.15	2.05	0.03	0.00	2.15	0.03
R-11036	1.04	28.69	13.47	4.50	1.48	1.97	3.72	0.13	0.04	3.39	0.01
R-11037	0.77	39.69	26.25	6.05	1.35	1.08	3.33	0.07	0.02	1.55	0.03
R-11038	0.72	24.52	10.03	4.39	1.56	2.00	2.26	0.12	0.00	4.16	0.04
R-11039	0.94	29.09	13.97	4.56	1.20	2.42	3.52	0.15	0.01	3.26	0.11
R-11040	0.31	37.68	20.21	4.52	1.30	2.24	6.20	0.27	0.01	2.90	0.06
R-11041	1.21	30.12	14.69	4.19	1.20	2.48	3.83	0.13	0.02	3.57	0.08
R-11042	1.51	33.17	15.84	4.11	2.50	2.12	5.03	0.33	0.02	3.23	0.04
R-11043	0.04	33.27	18.14	4.61	1.17	1.96	4.19	0.37	0.01	2.83	0.01
R-11350a	0.31	79.88	58.15	13.14	0.96	0.29	7.08	0.21	0.02	0.04	0.18
R-11350c	0.05	61.76	33.44	17.67	2.28	1.70	5.93	0.47	0.04	0.23	0.14
R-11351a	0.34	67.88	47.60	13.35	1.16	0.66	4.88	0.21	0.01	0.01	0.06
R-11351ab	0.40	64.60	45.55	13.38	1.14	0.57	3.73	0.21	0.01	0.01	0.16
R-11352a	0.59	63.19	41.82	13.81	1.27	0.78	5.10	0.32	0.02	0.08	0.15
[4]R-11352b	0.05	7.53	3.96	2.12	0.32	0.30	0.62	0.05	0.01	0.02	0.01
R-11354a	0.44	62.24	40.03	13.90	1.91	1.10	4.93	0.27	0.02	0.08	0.08
R-11354b	0.33	68.61	44.66	14.86	1.33	0.67	6.76	0.29	0.01	0.04	0.10
R-11355	0.49	54.36	35.30	11.89	0.91	0.65	5.42	0.06	0.01	0.14	0.02
R-11356	0.54	39.54	21.60	10.54	1.15	1.33	3.65	0.25	0.01	1.00	0.09

DGMR Repository ID	THM wt% total sample	[1]ΣEHM wt% THM	[2]Ilmenite wt% THM	[3]Rutile wt% THM	Leucoxene wt% THM	Titanite wt% THM	Zircon wt% THM	Monazite wt% THM	Xenotime wt% THM	Apatite wt% THM	Chromite wt% THM
R-11357	1.19	43.76	24.82	12.09	1.10	1.07	4.19	0.23	0.01	0.25	0.04
R-11358	0.56	31.28	16.63	6.15	1.06	1.84	3.31	0.15	0.02	2.13	0.06
R-11359	0.47	28.11	13.64	6.40	1.24	1.77	2.66	0.25	0.07	2.07	0.06
R-11360	0.69	28.37	15.28	6.06	0.59	1.80	2.64	0.18	0.02	1.80	0.03
R-11361	0.67	34.67	18.34	8.36	1.11	1.57	3.34	0.24	0.05	1.65	0.10
R-11362	0.26	27.96	13.84	7.42	1.54	1.29	2.17	0.14	0.01	1.55	0.11
R-11363	0.56	32.05	16.42	7.99	1.56	1.55	2.81	0.22	0.01	1.50	0.03
R-11364	0.52	29.35	13.40	8.80	1.63	1.59	2.25	0.13	0.03	1.52	0.03
R-11365	0.46	28.11	13.03	8.77	1.52	1.62	1.80	0.13	0.01	1.23	0.02
R-11366	0.10	31.06	14.03	12.26	1.04	1.23	2.00	0.14	0.01	0.36	0.03
R-11367	0.77	62.98	40.66	12.07	0.73	0.32	8.86	0.22	0.01	0.10	0.26
R-11368	0.36	43.89	24.43	13.75	0.84	0.81	3.67	0.23	0.01	0.15	0.08
R-11369	0.03	21.87	8.09	4.96	1.18	2.35	1.35	0.08	0.00	3.86	0.03
R-11370	0.57	24.88	10.47	5.07	1.02	2.27	2.37	0.19	0.02	3.47	0.06
R-11371	0.83	28.06	12.77	5.68	0.95	2.45	2.33	0.12	0.00	3.76	0.10
R-11372	1.69	18.53	5.33	4.94	1.35	2.03	0.59	0.04	0.01	4.25	0.02
R-11373	0.65	55.73	37.16	9.90	1.14	1.11	4.69	0.20	0.01	1.52	0.02
R-11374	0.70	41.39	24.16	8.91	1.33	1.08	3.83	0.33	0.03	1.72	0.04
R-11375	0.65	35.92	18.70	9.09	2.53	1.44	2.06	0.14	0.01	1.96	0.05
R-11376	1.30	24.27	11.04	5.77	1.17	1.85	1.51	0.06	0.00	2.87	0.06
R-11377	0.85	39.42	22.21	7.75	1.19	1.68	3.85	0.11	0.03	2.60	0.07
R-11378	0.64	22.87	9.41	4.90	1.08	2.23	1.67	0.05	0.01	3.52	0.08
R-11379	1.94	18.14	5.40	4.42	1.17	2.04	0.63	0.10	0.00	4.38	0.03
R-11380	0.41	18.34	6.73	4.03	1.11	1.95	0.92	0.03	0.00	3.57	0.02
R-11382	0.45	18.23	6.19	4.55	1.09	2.26	0.99	0.02	0.00	3.13	0.02
R-11382	0.03	42.15	25.17	10.24	1.22	0.80	3.36	0.02	0.00	1.34	0.08

DGMR Repository ID	THM wt% total sample	[1]ΣEHM wt% THM	[2]Ilmenite wt% THM	[3]Rutile wt% THM	Leucoxene wt% THM	Titanite wt% THM	Zircon wt% THM	Monazite wt% THM	Xenotime wt% THM	Apatite wt% THM	Chromite wt% THM
R-11383	0.04	45.22	30.06	9.15	1.03	0.32	3.21	0.25	0.07	1.13	0.16
R-11434	0.54	58.84	35.43	14.48	1.42	1.78	5.19	0.48	0.05	0.02	0.13
R-11441	0.06	22.49	12.45	4.98	0.74	1.50	2.25	0.15	0.01	0.41	0.05
R-11462	0.30	35.69	21.17	5.67	1.67	1.80	4.41	0.18	0.02	0.77	0.13
R-11466	0.82	43.47	26.88	6.17	1.22	2.40	6.00	0.26	0.04	0.50	0.15
R-11470	0.40	47.31	30.62	6.84	1.34	2.01	5.88	0.30	0.02	0.29	0.18
R-11474	1.13	32.98	19.56	4.34	1.25	2.21	4.20	0.20	0.06	1.17	0.14
R-11478	0.44	60.81	37.37	12.27	1.98	1.02	7.46	0.61	0.04	0.06	0.12
R-11482	0.72	47.77	26.37	11.97	1.51	2.19	5.36	0.20	0.04	0.12	0.06
R-11486	0.49	70.25	42.27	15.63	1.81	1.87	8.07	0.57	0.00	0.02	0.20
R-11488	0.01	62.73	37.44	14.92	2.36	0.89	5.79	1.32	0.00	0.01	0.05
R-11494	0.74	72.75	52.17	12.90	1.08	0.35	6.04	0.18	0.02	0.01	0.16
R-11498	1.84	57.77	34.52	15.65	1.18	1.09	5.18	0.12	0.01	0.02	0.15
R-11500	0.01	34.31	22.10	6.61	1.69	0.54	3.02	0.25	0.00	0.10	0.02
Mean	0.60	40.51	23.50	8.65	1.37	1.48	3.73	0.21	0.02	1.55	0.08
Standard dev.	0.43	16.32	13.05	3.85	0.43	0.67	1.90	0.19	0.02	1.43	0.06
Median	0.53	35.81	20.69	7.63	1.23	1.60	3.58	0.18	0.01	1.42	0.06
Median abs dev.	0.22	10.93	8.24	2.91	0.17	0.52	1.41	0.07	0.01	1.35	0.04
Max	1.94	79.88	58.15	17.67	2.53	2.48	8.86	1.32	0.07	4.38	0.26
Min	0.01	18.14	5.33	4.03	0.59	0.09	0.59	0.00	0.00	0.01	0.01
Count	62	62	62	62	62	62	62	62	62	62	62

[1] ΣEHM is the sum of the wt% of economic minerals, including ilmenite, rutile, leucoxene, titanite, zircon, monazite, xenotime.
[2] Ilmenite is the sum of wt% reported by the lab as ilmenite, ilmenite (lower Ti), pseudobrookite, ilmenite-silicate mix.
[3] Rutile is the sum of wt% reported by the lab as rutile, rutile (altered leucoxene), pseudorutile, rutile-quartz.
[4] sample R-11352b (VC-04A 2/2): lab reported anomalously high pyrite content and is not included in statistical calculations.

Table 5. Summary of the modal mineralogy of sub- and non-economic heavy minerals reported in weight percent of the total heavy mineral concentrate (wt% THM).

DGMR Repository ID	Kyanite wt% THM	Garnet wt% THM	[1]Magnetite wt% THM	Staurolite wt% THM	Epidote wt% THM	[2]Pyroboles wt% THM	[3]Other wt% THM
R-11031	1.63	16.17	2.64	0.58	0.55	51.31	6.26
R-11032	4.08	21.23	2.58	1.13	0.33	26.18	6.03
R-11033	3.88	13.03	3.17	3.47	0.19	12.36	6.92
R-11034	1.12	14.95	3.04	0.61	0.70	44.20	11.98
R-11035	4.17	17.82	2.46	2.78	0.67	33.90	8.18
R-11036	1.04	18.94	7.72	0.37	0.55	38.16	4.54
R-11037	1.34	17.49	8.34	0.51	0.35	27.15	5.11
R-11038	1.18	17.97	4.94	0.35	0.67	45.00	5.33
R-11039	0.95	19.10	7.43	0.30	0.39	37.45	5.18
R-11040	0.93	19.54	12.14	0.27	0.36	25.08	3.93
R-11041	0.79	19.52	7.86	0.30	0.62	36.80	3.91
R-11042	0.85	18.48	8.89	0.37	0.47	32.83	4.89
R-11043	0.87	15.82	5.82	0.32	0.41	35.10	8.39
R-11350a	1.17	5.57	1.75			9.18	2.28
R-11350c	0.80	9.27	0.85			19.69	7.47
R-11351a	1.61	13.19	1.85			12.65	2.77
R-11351ab	2.09	16.98	1.66			12.07	2.44
R-11352a	1.62	7.83	5.02			11.56	10.64
[4]R-11352b	0.13	0.88	0.96			3.74	86.89
R-11354a	1.36	11.92	4.04			16.58	3.78
R-11354b	1.04	12.56	2.51			12.79	2.39
R-11355	1.86	11.37	1.16	3.71	0.14	18.90	8.51
R-11356	2.05	13.38	0.62	2.47	0.31	31.25	10.30
R-11357	1.48	11.65	0.26	1.35	0.34	29.90	11.27

DGMR Repository ID	Kyanite wt% THM	Garnet wt% THM	[1]Magnetite wt% THM	Staurolite wt% THM	Epidote wt% THM	[2]Pyroboles wt% THM	[3]Other wt% THM
R-11358	1.20	13.62	1.82	0.86	0.38	42.86	7.94
R-11359	1.38	13.06	1.87	0.65	0.36	47.28	7.22
R-11360	1.46	13.91	2.21	0.78	0.28	45.16	7.79
R-11361	1.67	13.61	0.73	1.07	0.32	41.11	6.74
R-11362	1.84	11.26	0.56	0.94	0.34	48.44	8.57
R-11363	1.18	11.85	0.86	0.79	0.32	45.51	7.44
R-11364	1.37	11.14	0.60	1.01	0.41	48.51	7.59
R-11365	1.34	9.63	0.63	0.90	0.43	52.23	6.73
R-11366	2.25	11.61	0.26	1.86	0.26	45.09	7.60
R-11367	1.36	8.57	0.41	1.70	0.16	16.23	8.35
R-11368	2.14	12.74	0.15	2.68	0.25	30.99	7.11
R-11369	1.17	18.48	2.29	0.56	0.19	47.18	8.22
R-11370	0.86	17.27	4.51	0.41	0.18	44.80	7.03
R-11371	0.80	20.22	2.32	0.50	0.19	42.19	5.65
R-11372	1.47	11.04	1.03	0.46	0.59	57.97	8.92
R-11373	1.67	12.35	2.05	1.50	0.08	21.76	4.85
R-11374	2.17	15.34	2.27	1.41	0.12	30.83	6.44
R-11375	2.45	12.69	1.29	1.18	0.77	37.40	8.25
R-11376	1.13	19.26	2.07	0.99	0.22	44.57	7.46
R-11377	1.03	17.17	2.73	0.87	0.14	33.65	4.92
R-11378	1.00	19.17	3.46	0.39	0.23	46.68	6.13
R-11379	1.27	16.87	0.90	0.52	0.29	55.05	6.93
R-11380	1.43	15.02	1.48	0.55	0.26	51.28	11.67
R-11382	1.35	15.83	2.28	0.49	0.33	52.45	9.04
R-11382	3.02	11.99	2.39	1.23	0.15	30.81	8.17
R-11383	3.17	10.62	3.15	0.94	0.16	26.42	10.17

DGMR Repository ID	Kyanite wt% THM	Garnet wt% THM	[1]Magnetite wt% THM	Staurolite wt% THM	Epidote wt% THM	[2]Pyroboles wt% THM	[3]Other wt% THM
R-11434	1.20	7.82	2.07			26.19	3.75
R-11441	0.18	3.98	10.54			22.22	40.54
R-11462	0.69	7.18	15.40			33.01	7.88
R-11466	0.53	7.42	13.79			29.49	5.15
R-11470	0.46	5.86	14.54			25.34	6.30
R-11474	0.43	7.71	19.09			33.23	6.41
R-11478	0.64	5.59	2.82			23.22	6.81
R-11482	0.66	8.28	1.96			36.11	5.17
R-11486	0.78	4.71	0.98			17.45	5.62
R-11488	0.27	2.19	2.74			14.24	17.77
R-11494	1.65	5.44	0.33			15.64	4.04
R-11498	1.22	8.91	1.62			26.03	4.30
R-11500	0.67	3.99	1.94			17.24	41.83
Mean	1.43	12.70	3.69	1.05	0.34	32.68	7.98
Standard deviation	0.84	4.80	4.12	0.85	0.18	13.08	6.65
Median	1.25	12.71	2.28	0.82	0.32	32.92	6.93
Median abs dev.	0.39	4.16	1.25	0.53	0.19	11.65	1.60
Max	4.17	21.23	19.09	3.71	0.77	57.97	41.83
Min	0.18	2.19	0.15	0.27	0.08	9.18	2.28
Count	62	62	62	42	42	62	62

[1] Magnetite is the sum of wt% reported by the lab as hematite-Ti, magnetite-hematite, goethite, and boehmite.
[2] Pyroboles is the sum of the wt% of amphiboles and pyroxene minerals.
[3] Other is the sum of the wt% of quartz, feldspars, spinel, mica, wollastonite, tourmaline, chlorite, carbonates, pyrite, and other trace minerals.
[4] sample R-11352b (VC-04A 2/2): lab reported anomalously high pyrite content and is not included in statistical calculations.

Geochemistry of heavy mineral concentrates

Laboratory whole rock analytical results show enrichments and depletions in the major oxide components when compared to the average concentrations found in rocks of the continental crust (Figure 8). The mean value of TiO_2 in the ilmenite- and rutile-rich concentrates is 20.6 wt%, over 32 times higher than the average abundance in crustal rocks, 0.64 wt% (Rudnick and Gao, 2003). Similarly, enrichments in total Fe_2O_3 and MnO are nearly 6 and 8 times greater, respectively, than the average crustal abundances due to the higher percentages of magnetite, hematite, pyrolusite and other oxides in the concentrates. The mean P_2O_5 content is 0.4 wt% in the concentrates, about 3 times greater than the average in crustal rocks, 0.15 wt%, due to the presence of the heavy phosphate minerals monazite and apatite. In contrast, lower concentrations of SiO_2, Al_2O_3, Na_2O, and K_2O in the concentrates reflect the lower percentages of aluminum-silicate minerals compared to crustal rocks. These lighter density minerals have specific gravities less than about 2.9, and were removed during spiral concentration and during the laboratory heavy liquid separation.

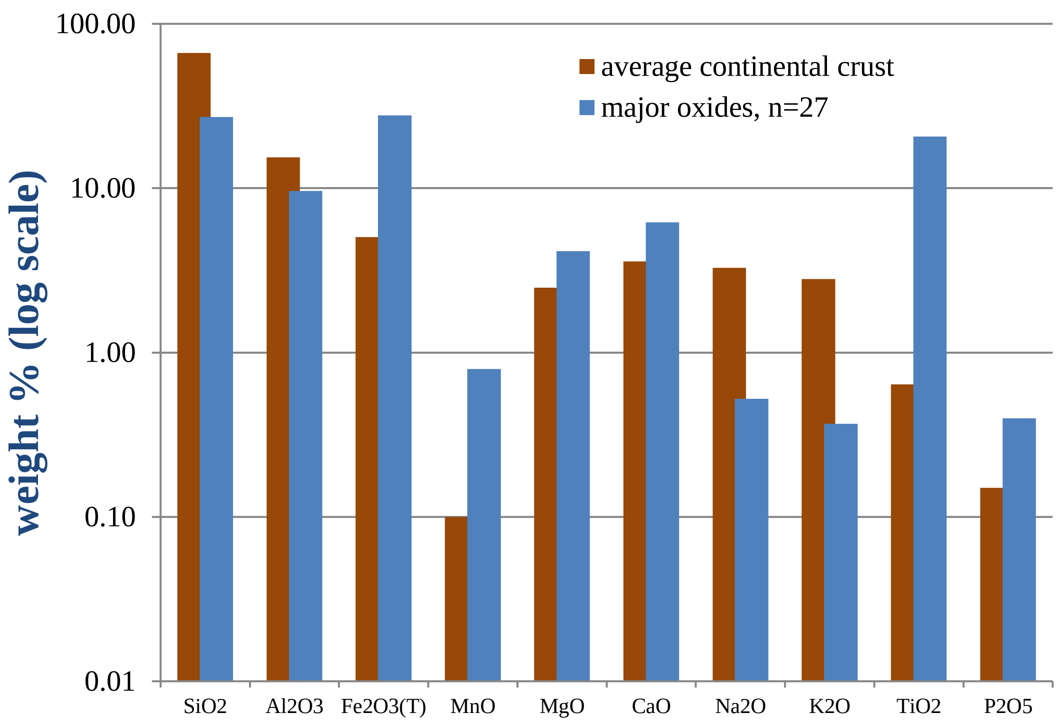

Figure 8. Comparison of major oxides content in THM concentrates to continental crustal rocks (Rudnick and Gao, 2003).

Trace element analytical results show that the heavy mineral concentrates are significantly enriched in critical mineral commodities. Of the 35 critical commodities listed by Fortier and others (2018), our results indicate average concentrations for 11 commodities that exceed 5 times enrichment compared to the crustal averages (Figure 9). Notably, the average concentrations of Hf, Nb, Ta, W, and Zr are each over 20 times higher than the mean abundances in crustal rocks. The relatively high values for Hf and Zr can be accounted for by the abundances of zircon reported in the laboratory modal mineral analyses. The enrichments of Nb, Ta, and W might be accounted for as trace components within the economic minerals identified in Table 1, or possibly indicate the presence of heavy minerals that have not been recognized previously in Virginia's offshore samples. These might include minerals of the columbite-tantalite group $(Fe,Mn,Mg)(Nb,Ta)_2O_6$, and tungstate group such as wolframite $(Fe,Mn)WO_4$ or Hübnerite $MnWO_4$.

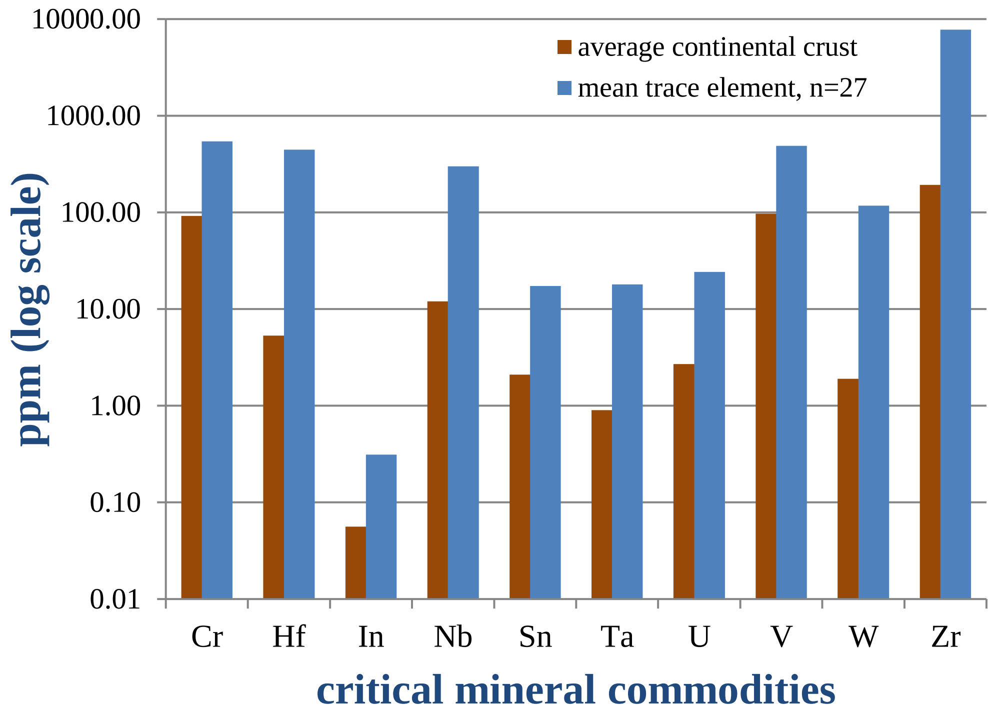

Figure 9. Critical mineral commodities that exceed 5X enrichment in THM concentrates compared to continental crustal rocks (Rudnick and Gao, 2003).

The rare earth elements (REE), together with scandium (Sc) and yttrium (Y) also show up to 11 times enrichment compared with the average crustal abundances. The likely sources of these trace metals in the heavy mineral concentrates include monazite, xenotime, zircon, and apatite. As a geochemically coherent group of elements with similar chemical properties, and a uniform pattern of decreasing ionic radius from La^{3+} to Lu^{3+}, the relative abundances of REE in detrital sediments can provide insight into provenance and other sedimentary processes.

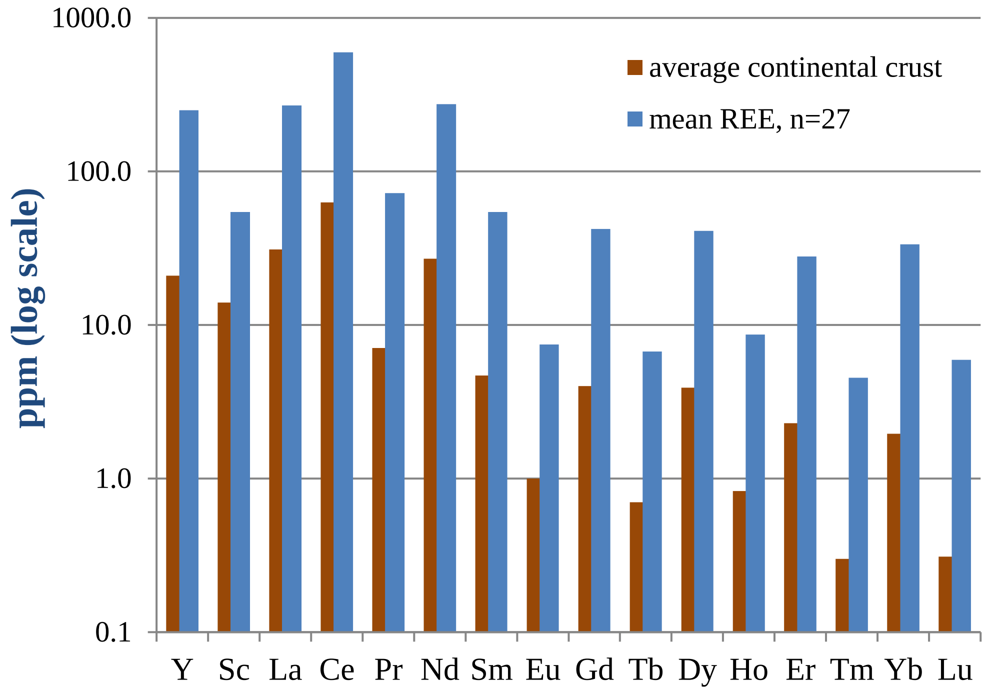

Figure 10. Comparison of Y, Sc and REE concentrations in THM concentrates to continental crustal rocks (Rudnick and Gao, 2003).

DISCUSSION

The modal mineralogical results from this study and previous investigations provide a valuable dataset to examine geospatial distributions that provide insight into provenance, the geologic framework of the Delmarva Peninsula, and sediment transport and concentration processes. This topic is addressed in a separate report by Berquist and Boon, 2019, as part of the BOEM-VA State Cooperative M14AC00013, entitled *Heavy mineral distributions in offshore sediments using Q-mode factor analysis*.

The whole rock and trace element geochemical results reported herein are also useful for geospatial analysis, although constrained by the limited number of samples, n=27. Nevertheless, the REE diagram shown in Figure 11 provides compelling insight into the nature of mineral occurrences in the two main areas from which samples were collected, Sandbridge and Wallops. The diagram was constructed using the chondrite-normalized method from Taylor and McLennan (1985). Heavy mineral concentrates are uniformly enriched in the light rare earth elements (LREE; La-Sm), showing the relative depletion of europium (Eu) that is typically observed in the average REE pattern of upper continental crustal rocks. In the Sandbridge area, LREE enrichment appears to be somewhat higher (as depicted by the green-shaded range of sample results in Figure 11) compared to the Wallops area (red-shaded range). One explanation for this difference may be the limited number of samples from both areas. Another more compelling explanation may be that there is a greater proportion of LREE-selective minerals such as monazite, xenotime, and allanite $(Ce,Ca,Y)_2(Al,Fe^{3+})_3(SiO_4)_3(OH)$ in the Sandbridge area. Allanite has not been specifically identified in Virginia's heavy mineral concentrates, yet it is a member of the common epidote mineral group that presently comprises 0.34 wt% of the average THM fraction, and is otherwise considered non-economic.

The normalized contents of heavy rare earth elements (HREE; Gd-Lu) in our mineral concentrates show an unusual pattern of higher enrichment in both the Sandbridge and Wallops areas compared to average crustal rocks (Figure 11). This is likely due to higher proportions of HREE-selective minerals such as garnet and possibly zircon (McLennan, 1989).

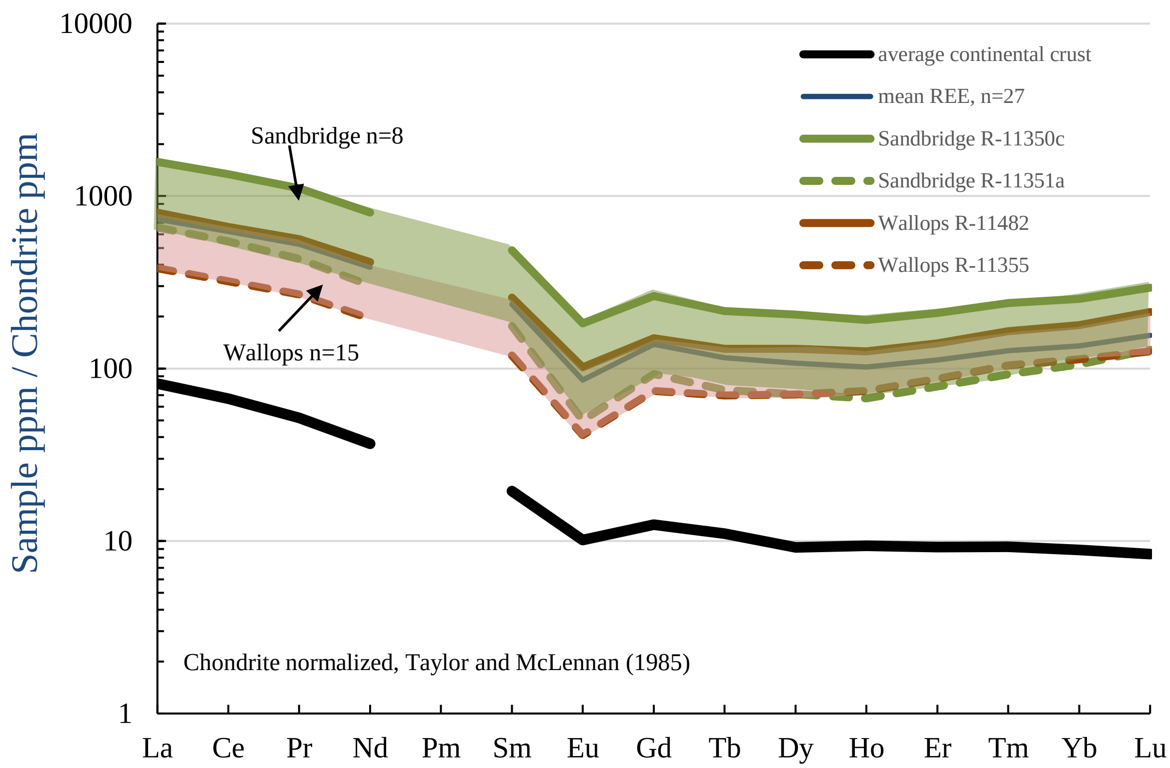

Figure 11. Comparison of chondrite-normalized REE in THM concentrates from the Sandbridge and Wallops resource areas.

CONCLUSIONS

The 63 sediment core and grab samples analyzed for heavy minerals as part of this study contained lower THM concentrations compared to previous studies. The mean THM content was 0.60 wt% (dry weight percent of the total sample), with individual samples ranging from 0.01 wt% to the maximum value of 1.94 wt%. The sum of economic minerals in the concentrates (ΣEHM) averaged 40.5 wt% of THM.

In earlier investigations, Berquist and others (2016) reported a revised mean value of 1.11 wt% for 60 samples and a maximum value 9.88 wt%. Berquist and others (1990) reported 3.3 wt% as the mean THM for 390 core and grab samples, with the highest value 14.7 wt%. Luepke (1990) reported the average THM in 72 core samples to be 2.14 wt%, with the maximum value of 6.3 wt%. Altogether, the offshore database containing 629 sample results averages 2.6 wt% THM, with individual samples ranging from 0.01 wt% to 14.7 wt% (Figure 12). The mean value for ΣEHM is 31.9 wt% of THM.

Economic heavy minerals identified in sample concentrates from offshore Virginia include: ilmenite, leucoxene, rutile, titanite, zircon, monazite, xenotime, apatite, and chromite. These contain the critical mineral commodities titanium, zirconium, REE, uranium, yttrium, and chromium. Geochemical analysis has provided new insight concerning additional critical commodities including niobium, tantalum, and tungsten. Future laboratory analysis will seek to identify the specific mineral sources that might include allanite, columbite, tantalite, and wolframite.

REE concentration patterns in heavy minerals, together with compositional Q-mode factor analysis may help identify specific mineral assemblages and transport processes in the offshore environment. In this regard, more work is needed to understand the geological evolution of the Chesapeake Bay, the Delmarva Peninsula, and paleo-drainage pathways.

Finally, all of the heavy minerals studies to date have indicated that the highest THM concentrations are associated with relatively clean (i.e. low mud content) marine sands that are typically fine to very-fine grained in texture (0.250 – 0.062 mm). These sand resources are suitable for beach restoration projects and thus provide a valuable opportunity to recover value-added heavy minerals to offset dredging costs.

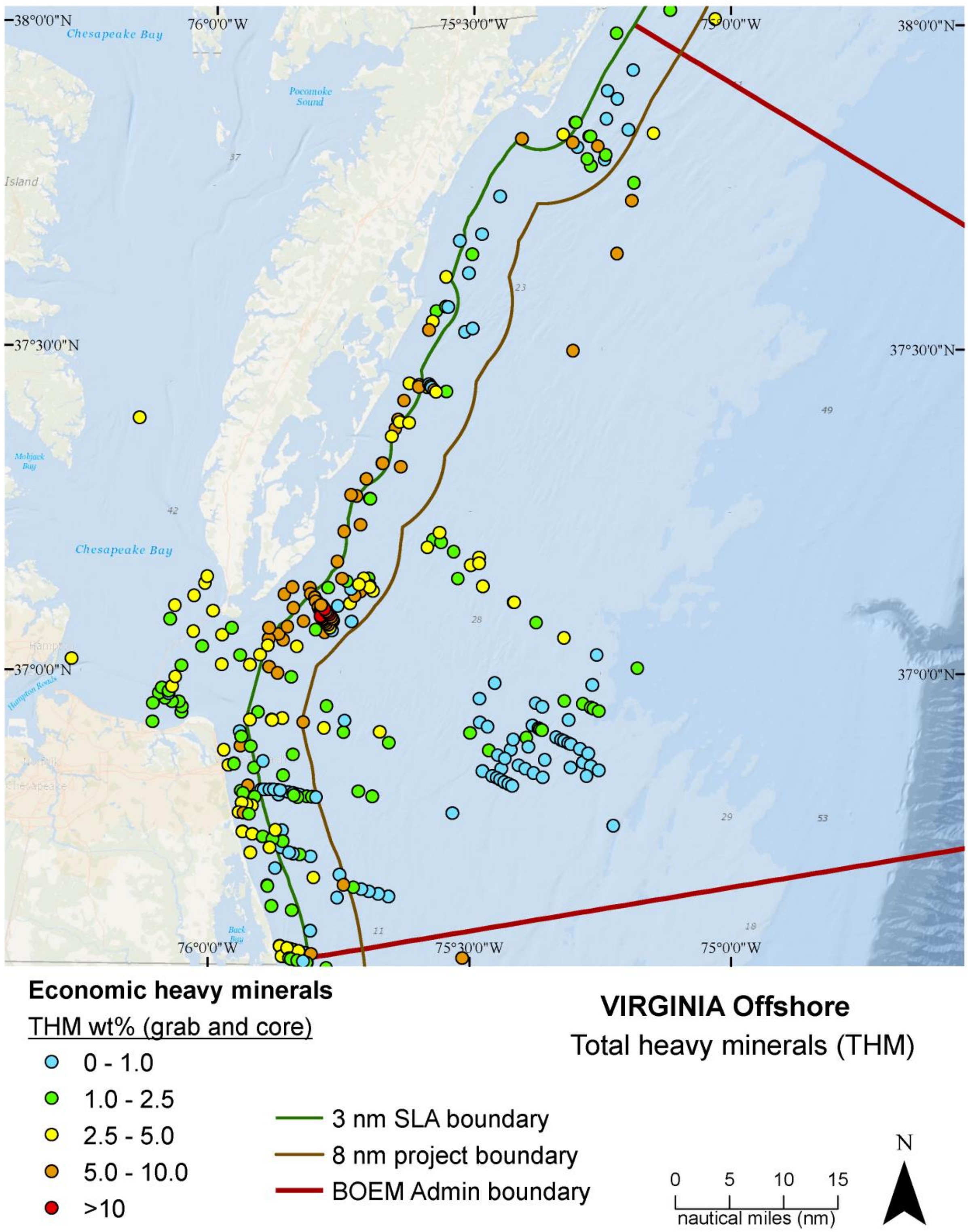

Figure 12. Sediment samples analyzed for economic heavy minerals along Virginia's coastline.

ACKNOWLEDGEMENTS

The authors greatly appreciate the technical contributions provided by Rick Berquist, retired DMME geologist, now retired/emeritus faculty at the College of William and Mary Department of Geology. Kelvin Ramsey and Robin Mattheus at the Delaware Geological Survey graciously provided grain size analytical data, lithologic logs, and valuable technical support. Thanks to the College of William and Mary Geology Department for allowing access to the "geobarn" facility in Williamsburg for the Humphrey spiral work. Patti Burton, Eleanor Worthington, and Mike Enomoto assisted with preparing samples, creating mineral concentrates, and managing the offshore databases. Dr. Mahdi Ghobadi at ActLabs answered many of our questions concerning modal mineral analytical methods and the results. Thanks to the U.S. Bureau of Ocean Energy Management for funding support through State Cooperative Agreement M14AC00013.

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APPENDIX A. Grain size scales and sieve sizes for sediment classification.

Phi (ϕ)	millimeters (mm)	inches (in)	ASTM No. (U.S. Standard)	Size Class (Wentworth, 1922)
≥ -8	>256	> 10.1		boulders
-6 to -8	64-256	2.5 – 10.1		cobbles
-5 to -6	32 – 64	1.26 – 2.5		very coarse pebbles
-4 to -5	16 - 32	0.63 – 1.26		coarse pebbles
-3 to -4	8 – 16	0.31 – 0.63		medium pebbles
-2 to -3	4 – 8	0.157 – 0.31 5		fine pebbles
-1 to -2	2 – 4	0.079 – 0.157	10	granules (gravel) very fine pebbles
0 to -1	1 – 2	0.039 – 0.079	18	very coarse sand
0.25	0.84	0.033	20	
1 to 0	0.5 – 1	0.020 – 0.039	35	coarse sand
1.25	0.42	0.017	40	
2 to 1	0.25 – 0.5	0.010 – 0.020	60	medium sand
2.75	0.149	0.0059	100	
3 to 2	0.125 – 0.25	0.0049 – 0.010	120	fine sand
4 to 3	0.0625 – 0.125	0.0025 – 0.0049	230	very fine sand
5 to 4	0.031 – 0.0625	0.0012 – 0.0025		coarse silt (mud)
6 to 5	0.0156 – 0.031	0.0006 – 0.0012		medium silt
7 to 6	0.0078 – 0.0156	0.0003 – 0.0006		fine silt
8 to 7	0.0039 – 0.0078	0.00015 – 0.0003		very fine silt
>8	<0.0039	<0.00015		clay

APPENDIX B. ActLabs Reports

A16-03579 May 2016

A17-03131 April 2017

A17-11430 December 2017

A18-05577 June 2018

Actlabs Code: A16-03579
Date: May, 2016
Attention: Rick Berquist

Report and Analysis:
Mahdi Ghobadi, PhD; MahdiGhobadi@Actlabs.com

Objective:
To charcaterize the mineralogy of the samples on the heavy liquid concentrated portion of the sample.

Samples:
13 samples were submitted for HLS. The results for concentrating the sink portion of the samples are presented in the corrosponding sheet. Around 2 grams materials from each sink portion was split using Rotary Micro Riffle Splitter, to prepare 30 mm transverse polished section.

Mineralogy Methods:

The mineralogical analysis was done using FEI FEG QEMSCAN.

The QEMSCAN instrument at Actlabs is based on the scanning electron microscope FEI QUANTA 650F, that is equipped with a field-emission gun (FEG) as an electron source. FEG enables high spatial resolution and sensitivity by decreasing the spot size of the focused electron beam to values as small as 0.3 µm and providing significant target currents, in the range of tens of nA. For imaging and X-ray based micro-chemical analysis the instrument is equipped with a four-quadrant, solid state back-scattered electron (BSE) detector and two Bruker XFlash 5030 detectors. For enhanced mineral identification capabilities, energy dispersive spectroscopy (EDS) spectra with a larger than standard number of photon counts per pixel were used in this project (3000 counts per pixel vs. the standard 1000 counts per pixel). The raw X-Ray data were evaluated using a customized SIP file for this project. The modal mineralogy data as well as particle data were generated using iDiscover software.

The data for this project were produced using two modes of measurements:

1. BMA or line scan which produced modal mineralogy data.
2. PMA or particle mapping which was used to determine size distribution.

Results:

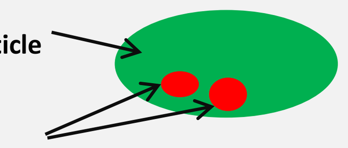
For this report modal mineralogy data and size distribution for Ti minerals are provided. Also representative mapped particle are provided, demonstrating major Ti mineral.

Note:

Particle Definition: A particle is a piece of material, and can contain one or more minerals.

Grain Definition: A grain is a piece of mineral matter contained within a particle.

Particle



Actlabd ID: A15-03579-	1	2	3	4	5	6	
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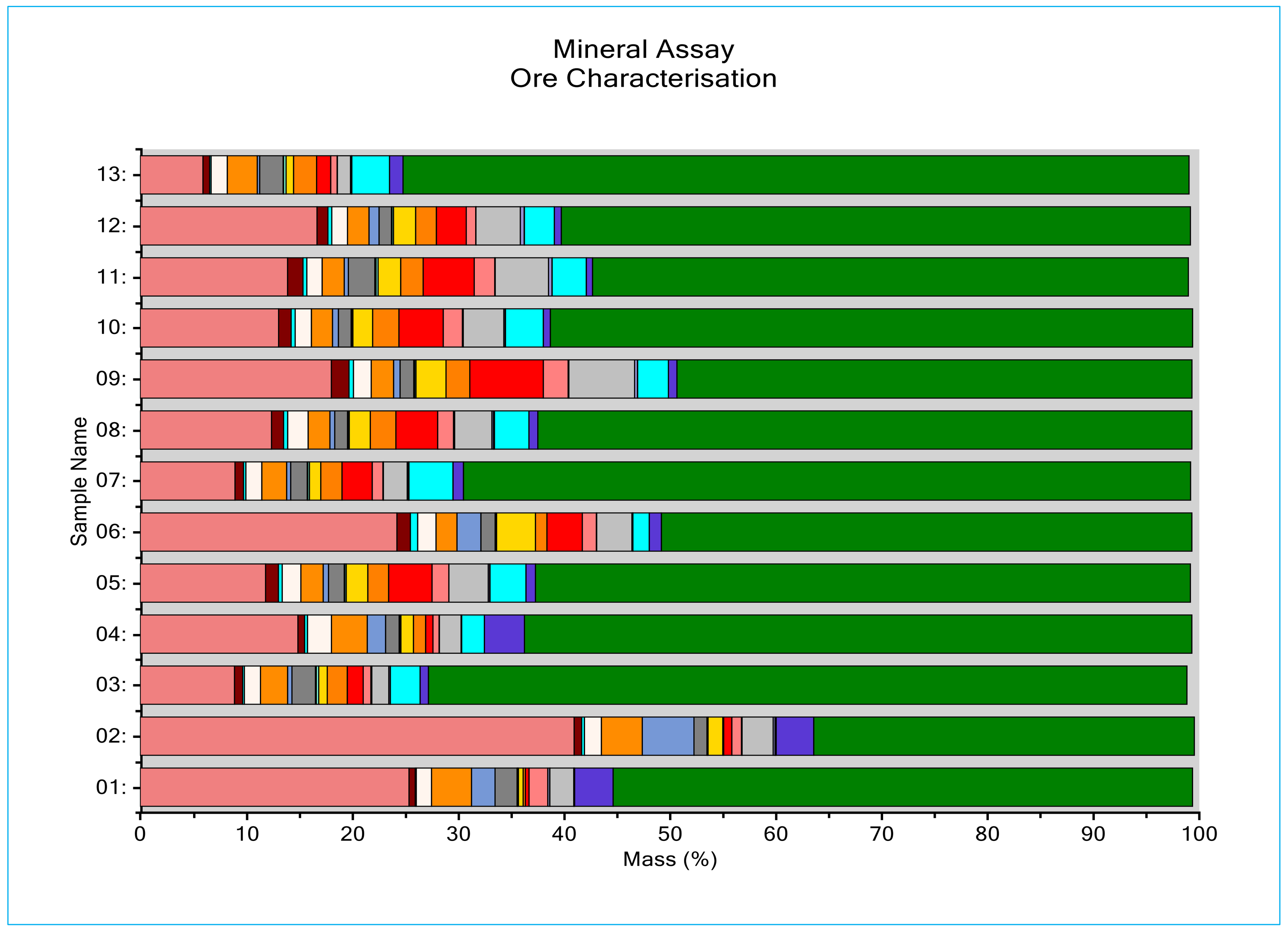
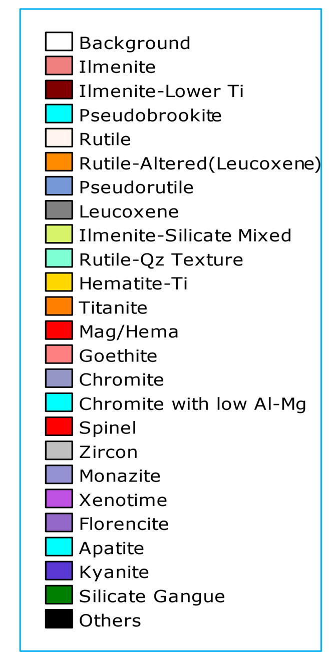
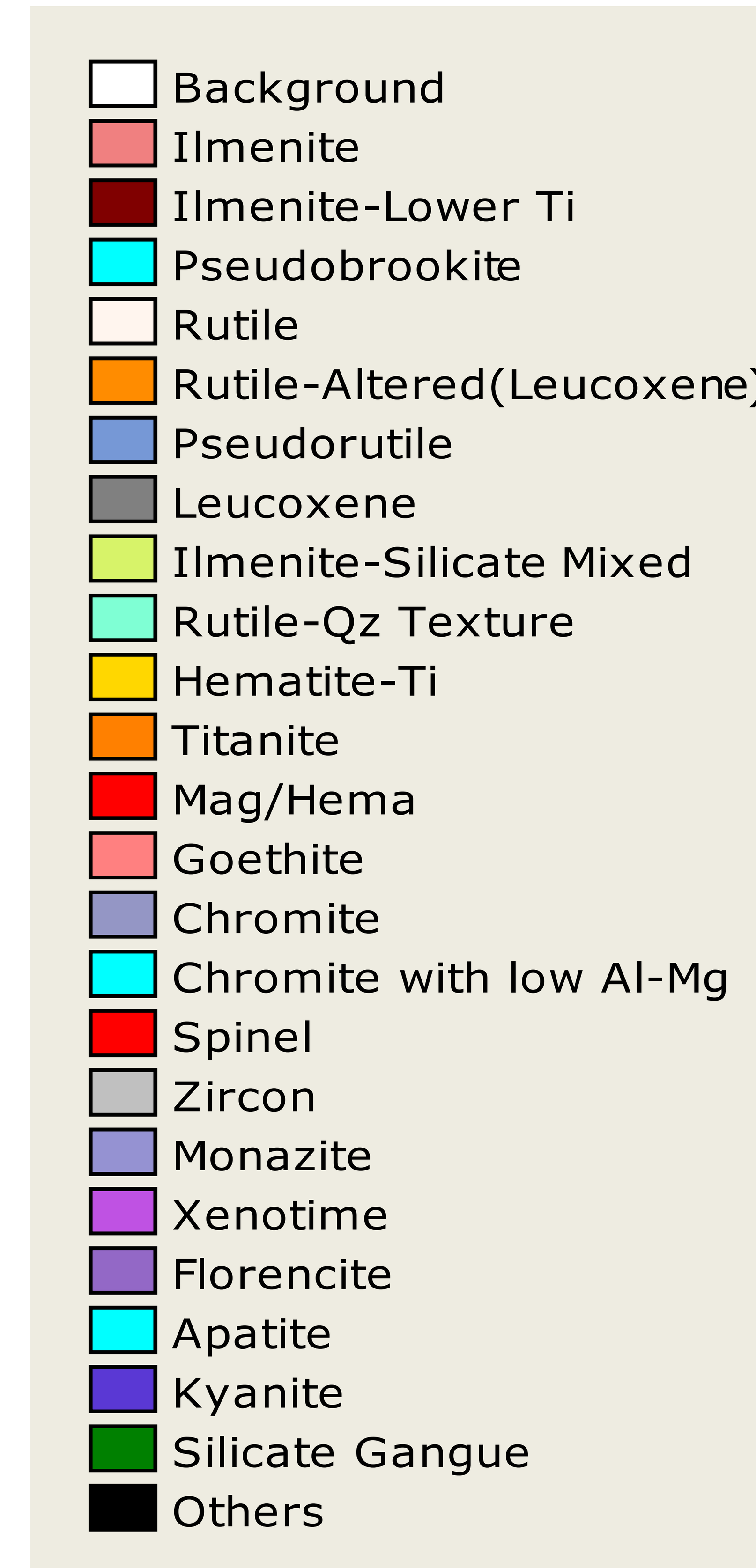
Client ID	GS-027R-11038	GS-028R-11039	GS-029R-11040	GS-030R-11041	GS-031R-11042	GS-032R-11043	REF-002R-1031

	Actlabd ID: A15-03579-	1	2	3	4	5	6	7	8	9	10	11	12	13
	Client ID	GS-021	GS-022	GS-023	GS-024	GS-025	GS-026	GS-027	GS-028	GS-029	GS-030	GS-031	GS-032	REF-002
	MASS %													
Ti Minerals	Ilmenite	25.38	40.97	8.90	14.89	11.84	24.24	8.95	12.40	18.05	13.07	13.92	16.70	5.93
	Ilmenite-Lower Ti	0.59	0.71	0.77	0.63	1.21	1.26	0.80	1.14	1.66	1.18	1.45	1.02	0.63
	Pseudobrookite	0.09	0.26	0.16	0.27	0.36	0.69	0.23	0.39	0.42	0.38	0.36	0.37	0.14
	Rutile	1.44	1.60	1.52	2.26	1.76	1.73	1.51	1.93	1.67	1.53	1.45	1.48	1.53
	Rutile-Altered(Leucoxene)	3.78	3.86	2.56	3.38	2.11	1.98	2.35	2.05	2.11	1.99	2.08	2.03	2.83
	Pseudorutile	2.22	4.88	0.41	1.73	0.50	2.26	0.38	0.46	0.61	0.56	0.39	0.95	0.23
	Leucoxene	2.09	1.23	2.21	1.28	1.48	1.35	1.56	1.20	1.30	1.20	2.50	1.17	2.22
	Ilmenite-Silicate Mixed	0.05	0.04	0.08	0.07	0.06	0.05	0.05	0.05	0.08	0.06	0.11	0.05	0.04
	Rutile-Qz Texture	0.07	0.06	0.23	0.10	0.13	0.08	0.15	0.12	0.12	0.10	0.19	0.14	0.23
	Hematite-Ti	0.45	1.39	0.80	1.19	2.04	3.67	1.07	1.99	2.84	1.86	2.14	2.09	0.71
	Titanite	0.20	0.09	1.89	1.15	1.97	1.08	2.00	2.42	2.24	2.48	2.12	1.96	2.17
Oxides/Hydroxides	Mag/Hema	0.35	0.77	1.50	0.69	4.09	3.34	2.85	3.94	6.94	4.18	4.81	2.81	1.33
	Goethite	1.77	0.90	0.72	0.58	1.59	1.33	1.01	1.49	2.35	1.80	1.93	0.91	0.60
	Boehmite	0.01	0.10	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.00	0.00
	Chromite	0.19	0.06	0.08	0.01	n.d.	0.03	0.03	0.08	0.04	0.02	0.02	0.00	n.d.
	Chromite with low Al-Mg	0.00	0.00	0.01	0.02	n.d.	0.00	0.01	0.02	0.03	0.06	0.03	0.00	n.d.
	Spinel	n.d	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.00	n.d.	n.d.	0.02
REE Minerals	Zircon	2.26	2.94	1.61	2.05	3.72	3.33	2.26	3.52	6.20	3.83	5.03	4.19	1.24
	Monazite	0.00	0.17	0.14	0.03	0.13	0.07	0.12	0.15	0.27	0.13	0.33	0.37	0.09
	Xenotime	0.00	0.01	0.01	n.d.	0.04	0.02	0.00	0.01	0.01	0.02	0.02	0.01	0.00
	Florencite	n.d.	0.00	0.00	0.03	n.d.	0.00	0.03	0.08	0.00	0.01	0.00	0.00	0.02
	Apatite	0.07	0.10	2.81	2.15	3.39	1.55	4.16	3.26	2.90	3.57	3.23	2.83	3.56
Silicates	Kyanite	4.08	3.88	1.12	4.17	1.04	1.34	1.18	0.95	0.93	0.79	0.85	0.87	1.63
	Quartz	3.75	4.93	5.92	3.60	1.06	1.56	1.34	1.41	1.08	0.84	1.37	3.27	1.89
	K-Feldspar	0.29	0.26	0.86	0.61	0.15	0.46	0.24	0.19	0.18	0.12	0.20	0.71	0.18
	Plagioclase	0.10	0.29	1.82	1.18	0.39	0.55	0.57	0.70	0.40	0.43	0.44	1.14	0.70
	Garnet	21.23	13.03	14.95	17.82	18.94	17.49	17.97	19.10	19.54	19.52	18.48	15.82	16.17
	Pyroxene	1.45	0.63	4.35	3.56	4.40	2.89	5.16	4.38	2.33	4.02	3.37	5.04	5.12
	Amphibole	24.73	11.73	39.85	30.34	33.75	24.25	39.84	33.08	22.75	32.78	29.46	30.06	46.20
	Mica	0.14	0.17	0.18	0.24	0.18	0.24	0.22	0.16	0.19	0.20	0.12	0.34	0.26
	Staurolite	1.13	3.47	0.61	2.78	0.37	0.51	0.35	0.30	0.27	0.30	0.37	0.32	0.58
	Wollastonite	0.01	0.01	0.36	0.21	0.37	0.24	0.41	0.36	0.23	0.36	0.31	0.43	0.50
	Schorl-Tourmaline	1.11	0.90	1.72	1.63	1.56	1.36	1.71	1.61	1.19	1.35	1.46	1.68	1.74
	Epidote	0.33	0.19	0.70	0.67	0.55	0.35	0.67	0.39	0.36	0.62	0.47	0.41	0.55
	Carbonates	0.01	0.02	0.31	0.05	0.19	0.14	0.19	0.19	0.16	0.11	0.10	0.20	0.08
Mixed-Unclassifiable Spectra	Hi BSE	0.01	0.01	0.02	0.01	0.02	0.06	0.02	0.02	0.03	0.03	0.04	0.05	0.05
	Low Counts	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Others	0.59	0.32	0.79	0.60	0.61	0.49	0.59	0.45	0.46	0.45	0.85	0.56	0.80
	Sum	100	100	100	100	100	100	100	100	100	100	100	100	100

Actlabd ID: A15-03579-	1	2	3	4	5	6	7	8	9	10	11	12	13
Client ID	GS-021	GS-022	GS-023	GS-024	GS-025	GS-026	GS-027	GS-028	GS-029	GS-030	GS-031	GS-032	REF-002







	1	2	3	4	5	6	7	8	9	10	11	12	13
	GS-021	GS-022	GS-023	GS-024	GS-025	GS-026	GS-027	GS-028	GS-029	GS-030	GS-031	GS-032	REF-002

Size Distribution of Ilmenite

Sieve Size in Micron/ Cumulative Passing	1	2	3	4	5	6	7	8	9	10	11	12	13
	GS-021	GS-022	GS-023	GS-024	GS-025	GS-026	GS-027	GS-028	GS-029	GS-030	GS-031	GS-032	REF-002
S<=5	1	2	2	2	2	2	2	2	1	2	2	1	2
S<=10	4	5	8	6	6	6	6	6	4	6	6	4	9
S<=13.25	6	7	12	9	11	8	9	9	7	8	9	6	14
S<=18.75	8	9	21	12	18	11	16	14	13	14	17	9	23
S<=26.5	12	11	33	18	33	15	27	24	24	26	33	16	34
S<=37.5	17	15	56	29	57	21	47	47	47	47	57	27	52
S<=53	26	20	83	42	87	33	77	76	77	80	85	45	81
S<=75	43	32	94	67	99	53	93	94	96	96	98	61	99
S<=106	68	55	100	87	100	75	100	100	100	100	100	80	100
S<=150	94	78	100	99	100	94	100	100	100	100	100	96	100
S<=212	98	96	100	100	100	100	100	100	100	100	100	100	100
S<=300	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=424													

Size Distribution of Ilmenite lower Ti

Sieve Size in Micron/ Cumulative Passing	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=5	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=10	71	77	63	68	63	66	61	62	62	61	61	64	57
S<=13.25	97	98	96	97	96	95	93	96	94	93	94	95	90
S<=18.75	98	100	99	99	99	98	98	99	98	97	99	98	94
S<=26.5	100	100	100	100	100	100	99	100	100	98	99	100	96
S<=37.5	100	100	100	100	100	100	100	100	100	98	100	100	100
S<=53	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=75	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=106													
S<=150													
S<=212													
S<=300													
S<=424													

Size Distribution of Pseudobrookite

Sieve Size in Micron/ Cumulative Passing	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=5	63	56	56	53	59	60	49	54	58	56	53	53	56
S<=10	91	89	87	88	91	91	82	82	90	90	88	87	84
S<=13.25	96	96	91	94	97	96	88	89	95	97	97	91	90
S<=18.75	99	99	98	99	99	99	99	93	100	100	99	97	99
S<=26.5	99	100	100	100	100	100	100	99	100	100	99	99	99
S<=37.5	99	100	100	100	100	100	100	100	100	100	100	100	100
S<=53	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=75	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=106													
S<=150													
S<=212													
S<=300													
S<=424													

Size Distribution of Rutile

Sieve Size in Micron/ Cumulative Passing	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=5	4	5	5	4	4	3	4	4	4	5	4	4	6
S<=10	10	17	16	11	13	8	14	11	12	15	13	13	18
S<=13.25	14	24	25	15	18	11	23	16	17	22	20	18	30
S<=18.75	16	32	34	21	30	18	33	23	27	31	28	26	46
S<=26.5	22	39	49	29	42	25	48	31	39	45	39	38	53
S<=37.5	30	44	62	38	60	30	64	50	57	63	58	62	71
S<=53	32	52	86	49	81	37	81	84	77	87	87	84	88
S<=75	54	65	100	60	100	44	97	97	95	98	100	87	93
S<=106	87	72	100	82	100	56	100	100	100	100	100	91	100
S<=150	87	92	100	87	100	90	100	100	100	100	100	100	100
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=300													
S<=424													

Size Distribution of Rutile-Altered

Sieve Size in Micron/ Cumulative Passing	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=5	8	10	12	10	15	16	12	15	16	14	15	14	10
S<=10	24	26	35	27	43	39	34	40	42	38	42	40	34
S<=13.25	32	33	46	35	56	50	43	51	52	49	54	49	44
S<=18.75	39	41	57	43	68	59	52	64	59	62	66	61	57
S<=26.5	49	48	67	47	78	65	59	72	66	72	76	69	66
S<=37.5	52	57	73	58	83	77	65	78	74	79	79	78	74
S<=53	58	60	81	67	88	82	71	83	82	87	84	83	80
S<=75	74	78	96	87	97	91	85	91	95	98	95	93	88
S<=106	79	91	100	96	100	96	96	95	100	100	100	100	100
S<=150	94	100	100	100	100	100	100	100	100	100	100	100	100
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=300													
S<=424													

Size Distribution of Pseudorutile

Sieve Size in Micron/ Cumulative Passing	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=5	37	25	40	31	45	28	52	52	50	42	50	39	57
S<=10	79	54	82	69	84	63	92	89	87	76	86	79	91
S<=13.25	88	63	91	77	96	72	99	98	95	87	95	89	94
S<=18.75	92	68	97	80	99	79	100	99	100	91	98	92	100
S<=26.5	94	72	100	84	100	85	100	100	100	96	100	100	100
S<=37.5	99	72	100	91	100	97	100	100	100	96	100	100	100
S<=53	100	86	100	100	100	100	100	100	100	100	100	100	100
S<=75	100	97	100	100	100	100	100	100	100	100	100	100	100
S<=106		100											
S<=150													
S<=212													
S<=300													
S<=424													

Size Distribution of Leucoxene

Sieve Size in Micron/ Cumulative Passing	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=5	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=10	18	34	19	28	30	27	22	30	35	31	20	33	16
S<=13.25	43	64	49	61	66	54	49	62	67	63	47	69	41
S<=18.75	54	74	62	73	79	67	60	74	77	73	59	82	55
S<=26.5	63	80	74	85	88	78	73	85	85	80	69	91	67
S<=37.5	78	85	88	93	93	85	78	89	95	87	76	95	78
S<=53	83	85	96	95	94	94	87	96	97	93	85	96	88
S<=75	89	85	98	96	95	100	96	97	97	97	94	98	98
S<=106	91	85	100	100	97	100	98	100	100	100	97	100	100
S<=150	100	85	100	100	100	100	100	100	100	100	100	100	100
S<=212	100	93	100	100	100	100	100	100	100	100	100	100	100
S<=300	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=424													

Size Distribution of Hematite-Ti

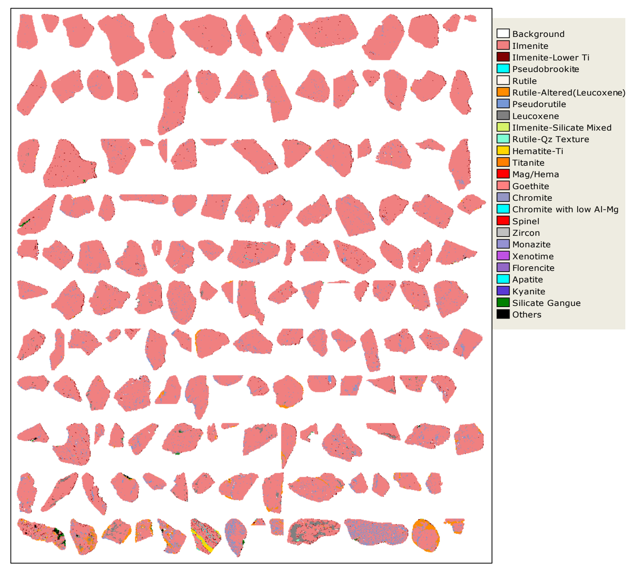
Sieve Size in Micron/ Cumulative Passing	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=5	6	2	6	5	6	3	7	6	6	7	5	5	7
S<=10	14	8	21	17	17	7	23	19	20	23	18	16	20
S<=13.25	17	10	31	24	26	10	34	26	31	30	27	21	29
S<=18.75	30	12	45	33	41	18	54	43	47	50	39	27	49
S<=26.5	42	16	71	51	65	24	73	66	69	75	60	41	68
S<=37.5	69	35	95	65	86	53	91	82	86	91	82	50	86
S<=53	79	46	100	87	96	67	93	93	98	99	94	64	100
S<=75	100	78	100	93	100	93	100	94	99	100	100	87	100
S<=106	100	95	100	100	100	100	100	97	100	100	100	100	100
S<=150	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=212													
S<=300													
S<=424													

Size Distribution of Titanite

Sieve Size in Micron/ Cumulative Passing	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=5	5	4	1	1	1	1	1	1	1	1	1	1	1
S<=10	13	10	3	3	3	3	3	4	3	3	3	3	3
S<=13.25	19	12	6	4	6	4	4	6	4	5	4	5	5
S<=18.75	21	12	10	7	9	5	7	8	7	8	7	7	9
S<=26.5	37	33	16	10	15	9	10	11	14	12	11	16	15
S<=37.5	55	39	32	22	27	18	17	21	22	20	21	34	27
S<=53	60	39	48	32	51	37	39	39	44	49	46	55	50
S<=75	60	100	84	66	89	56	80	85	85	85	85	85	79
S<=106	100	100	100	89	100	75	95	100	100	100	98	100	97
S<=150	100	100	100	100	100	82	100	100	100	100	100	100	100
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=300													
S<=424													

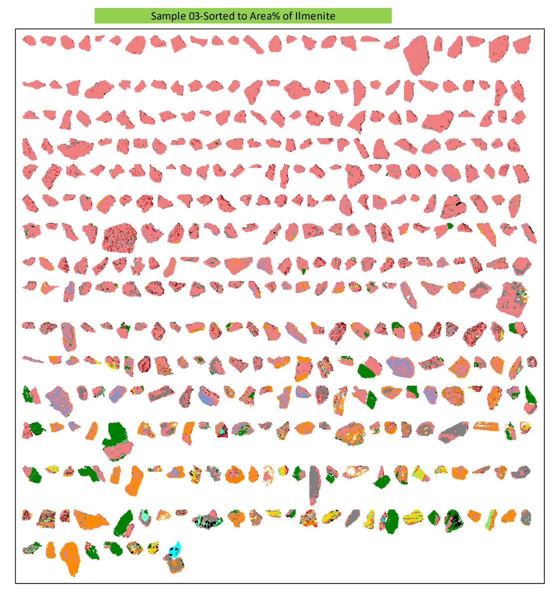
Size Distribution of Zircon

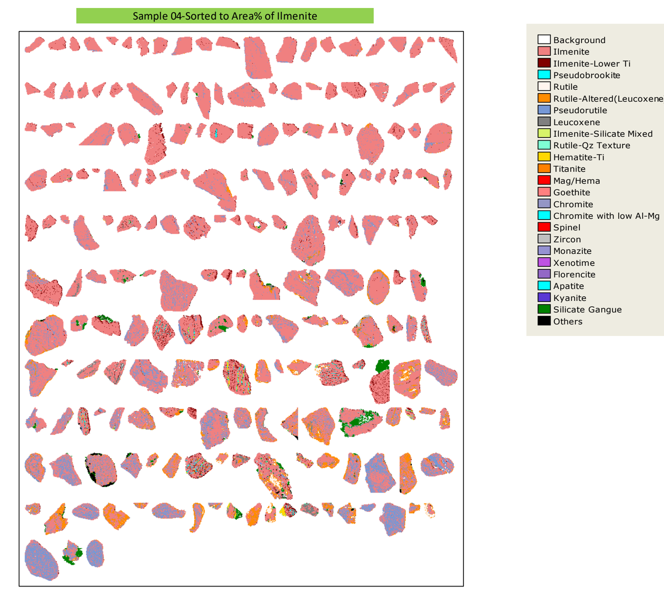
Sieve Size in Micron/ Cumulative Passing	01	02	03	04	05	06	07	08	09	10	11	12	13
S<=5	0	0	0	0	0	0	0	0	0	0	0	0	0
S<=10	0	0	1	0	1	0	1	0	0	1	1	0	0
S<=13.25	1	0	1	0	1	0	1	1	1	1	1	1	1
S<=18.75	1	1	4	1	3	0	3	2	1	2	3	1	3
S<=26.5	1	1	7	2	9	1	7	5	4	6	7	2	6
S<=37.5	2	1	17	4	18	4	18	16	10	17	18	4	15
S<=53	9	3	55	12	55	8	50	48	41	57	58	13	36
S<=75	18	11	87	40	98	19	80	88	88	88	94	24	77
S<=106	58	26	100	65	100	45	96	100	99	100	99	46	93
S<=150	84	55	100	88	100	86	100	100	100	100	100	69	100
S<=212	100	88	100	100	100	100	100	100	100	100	100	100	100
S<=300	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=424													

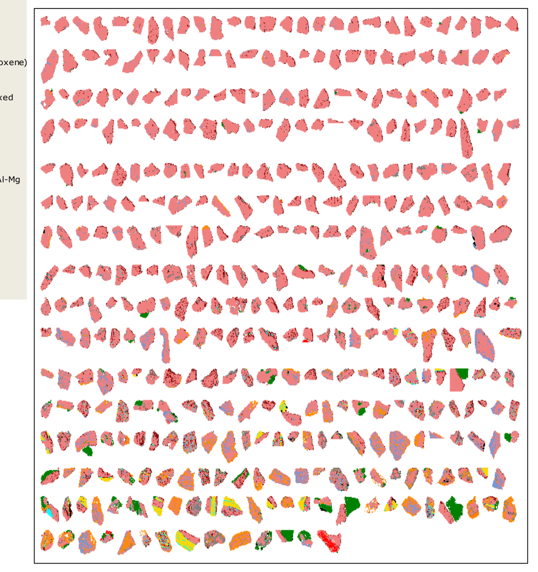


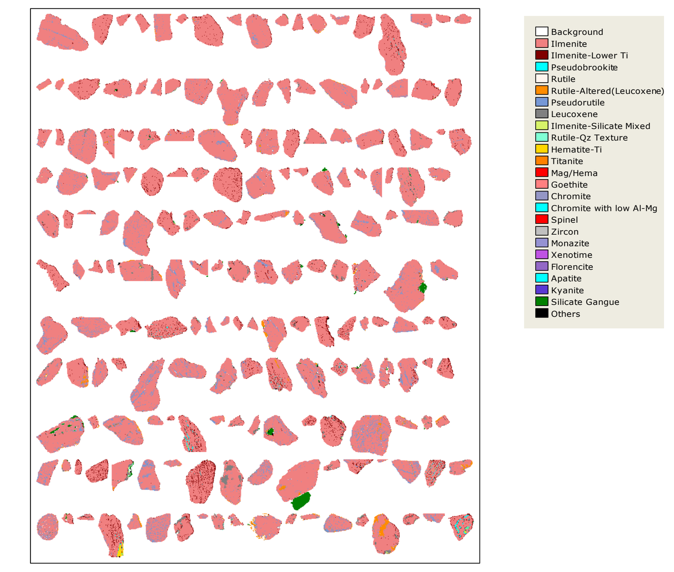
Sample 01-Sorted to Area% of Ilmenite

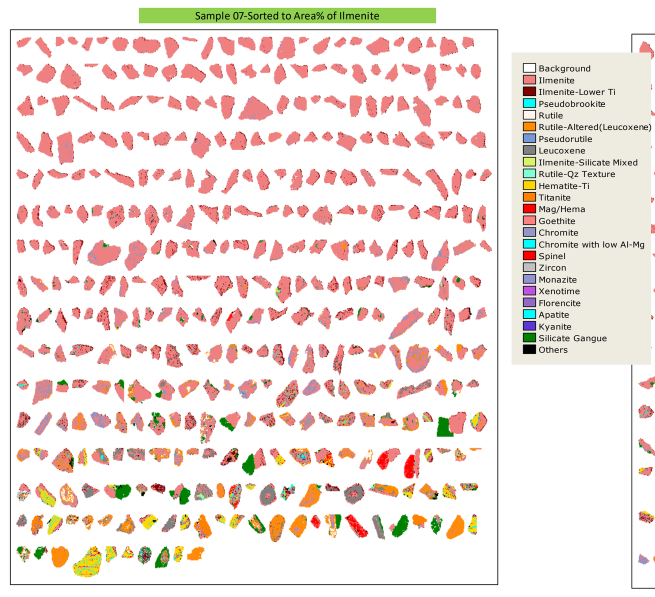

Sample 02-Sorted to Area% of Ilmenite

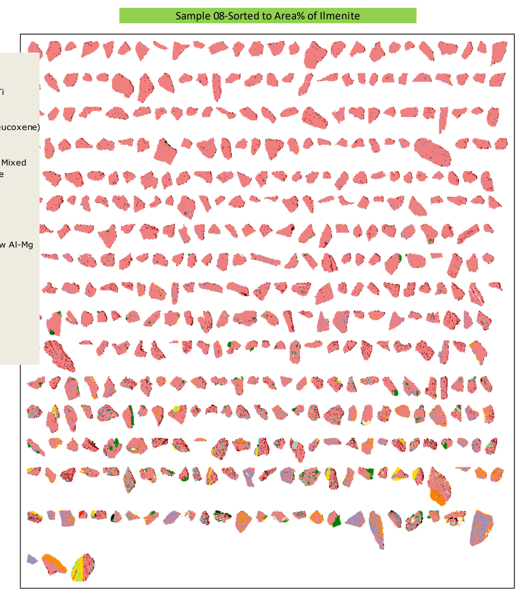

Sample 03-Sorted to Area% of Ilmenite


Sample 04-Sorted to Area% of Ilmenite

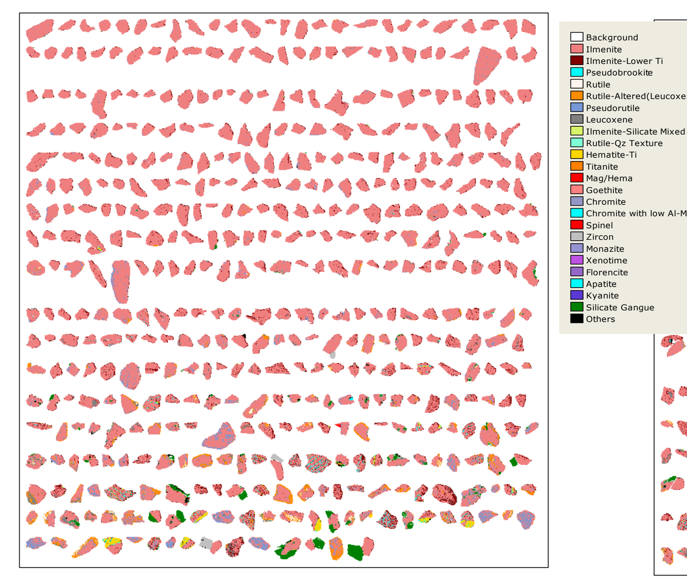

Sample 05-Sorted to Area% of Ilmenite

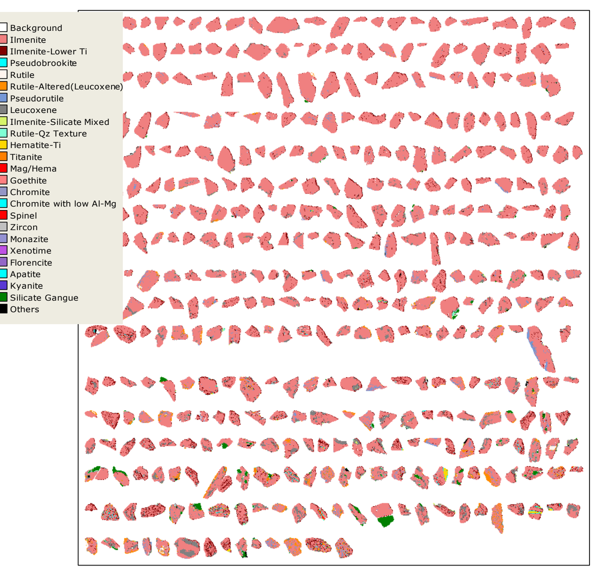

Sample 06-Sorted to Area% of Ilmenite

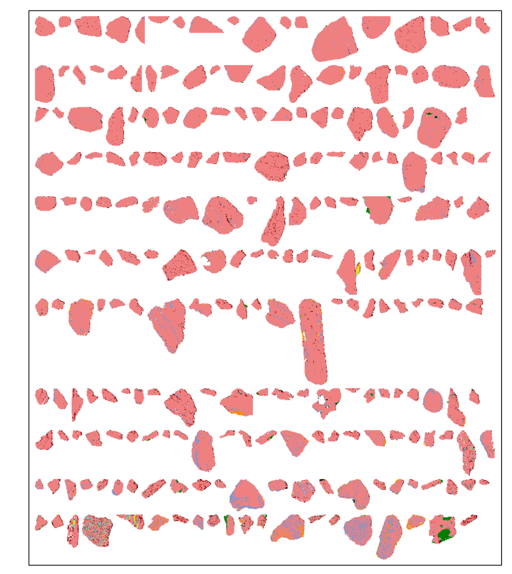

Sample 07-Sorted to Area% of Ilmenite

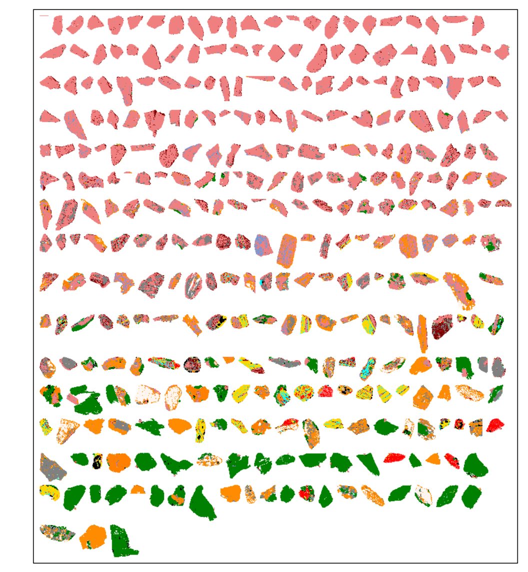

Sample 08-Sorted to Area% of Ilmenite


Sample 09-Sorted to Area% of Ilmenite


Sample 10-Sorted to Area% of Ilmenite


Sample 11-Sorted to Area% of Ilmenite


Sample 12-Sorted to Area% of Ilmenite


Sample 13-Sorted to Area% of Ilmenite

Sample 32-Sorted to Area% of Ilmenite

Sample 33-Sorted to Area% of Ilmenite

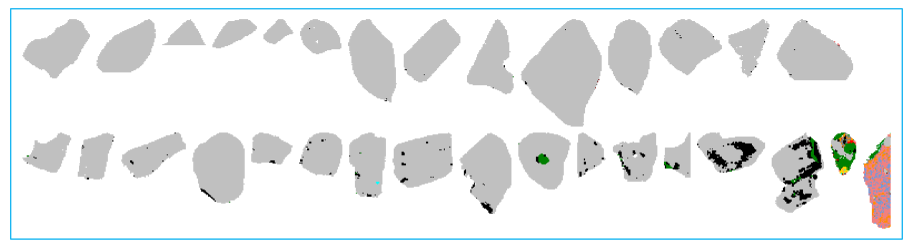
Sample 34-Sorted to Area% of Ilmenite

Sample 35-Sorted to Area% of Ilmenite

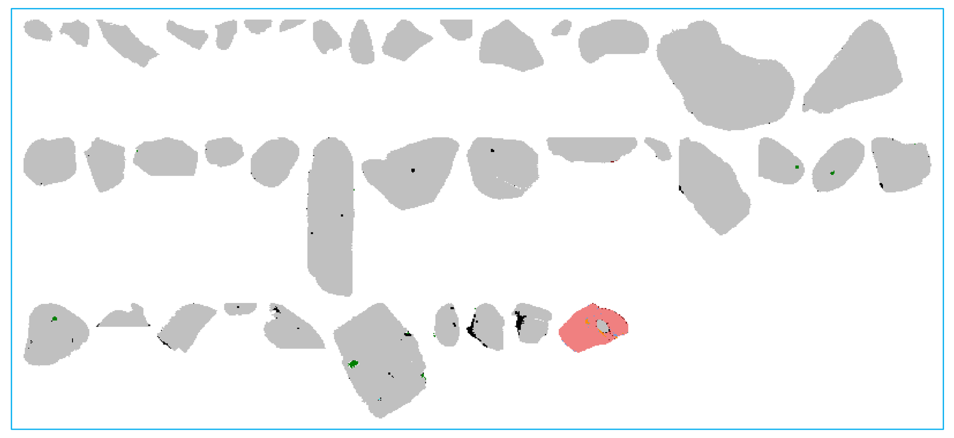
Sample 36-Sorted to Area% of Ilmenite

Sample 37-Sorted to Area% of Ilmenite

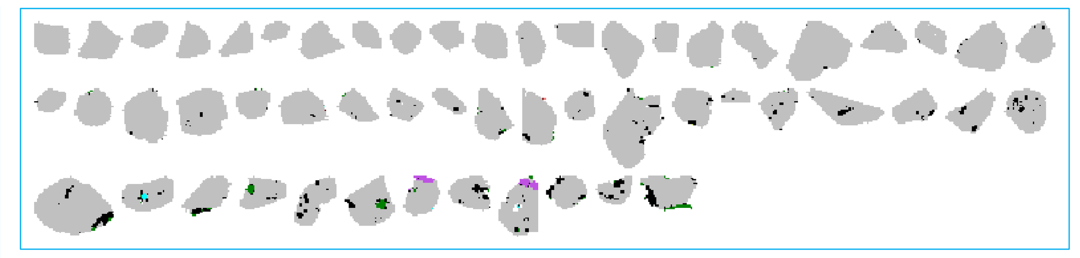
Sample 01



Sample 02

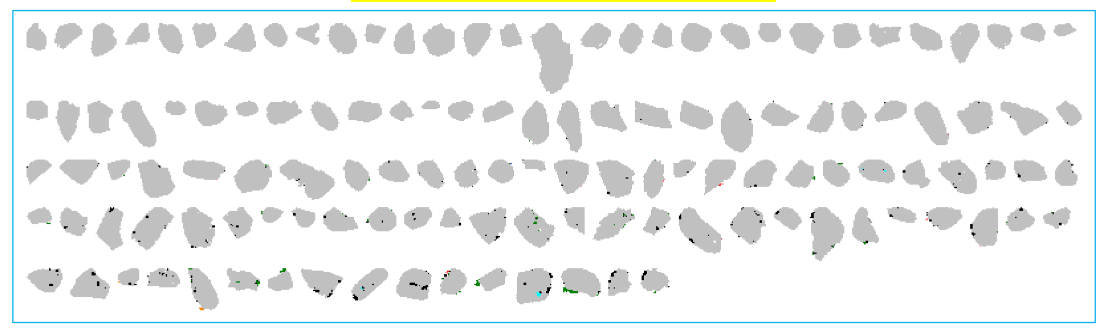


Sample 03

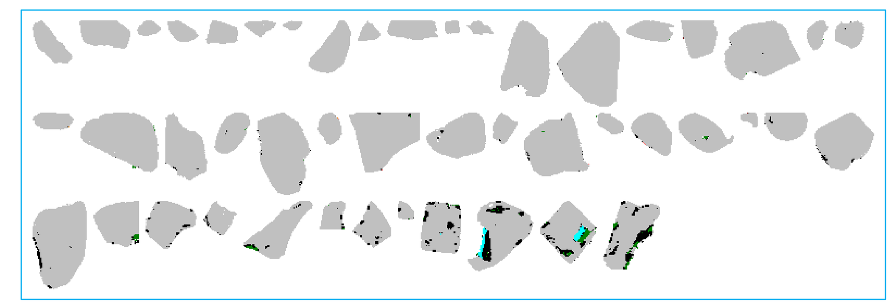


Sample 04

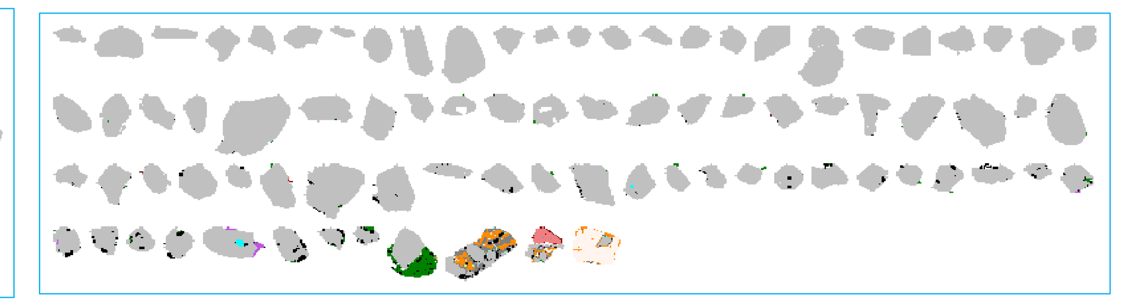
Sample 05



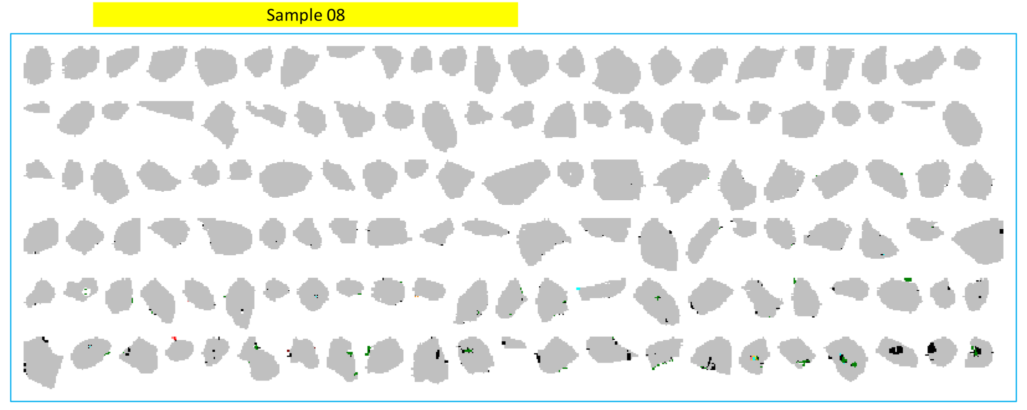
Sample 06



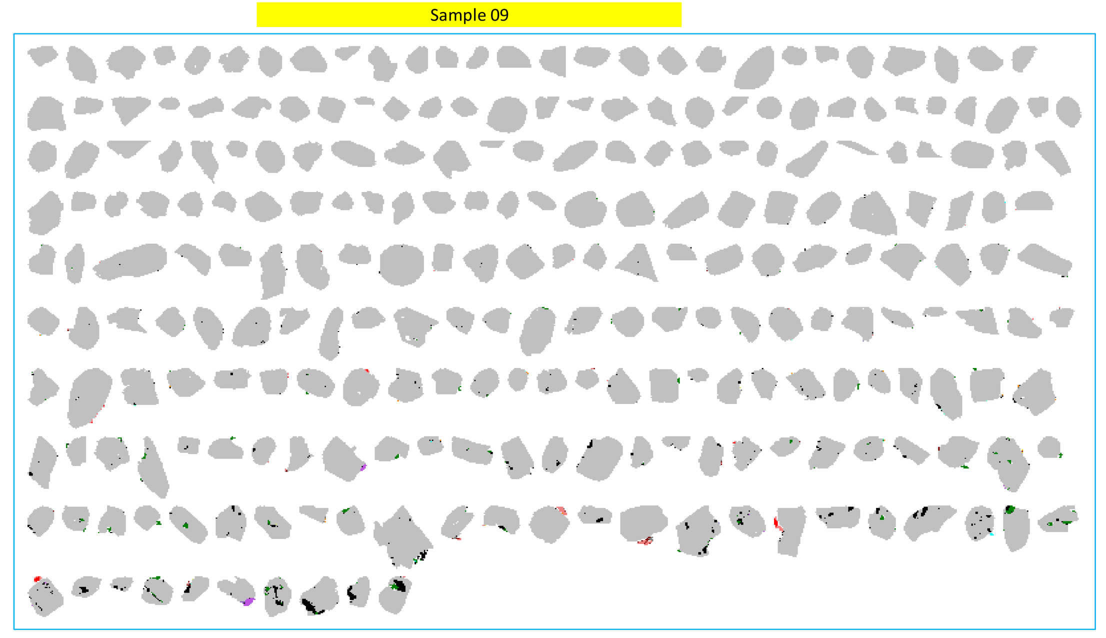
Sample 07



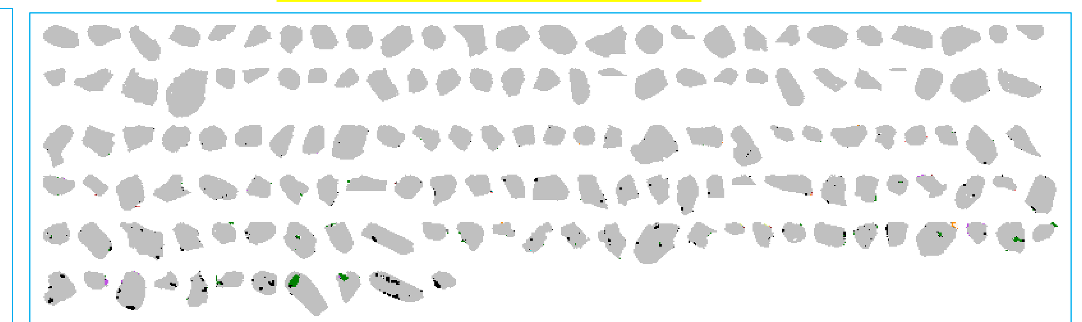
Sample 08



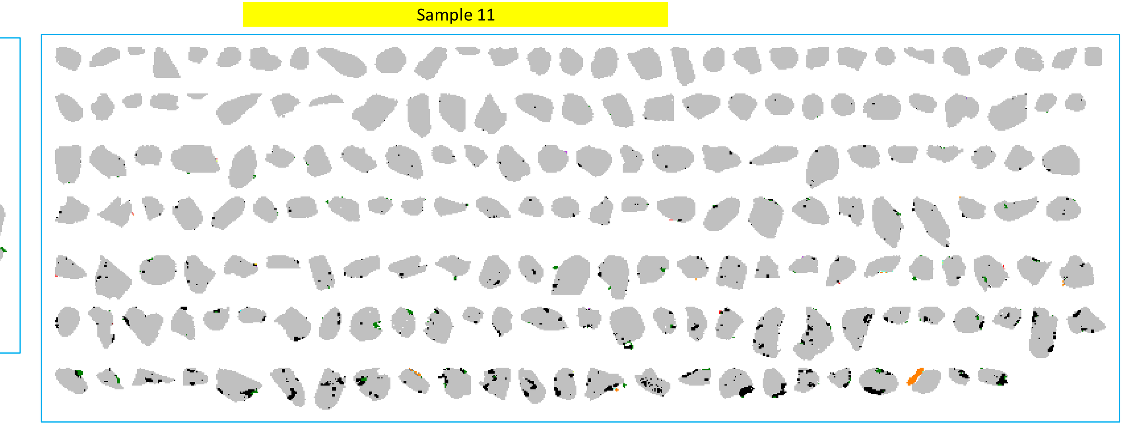
Sample 09



Sample 10

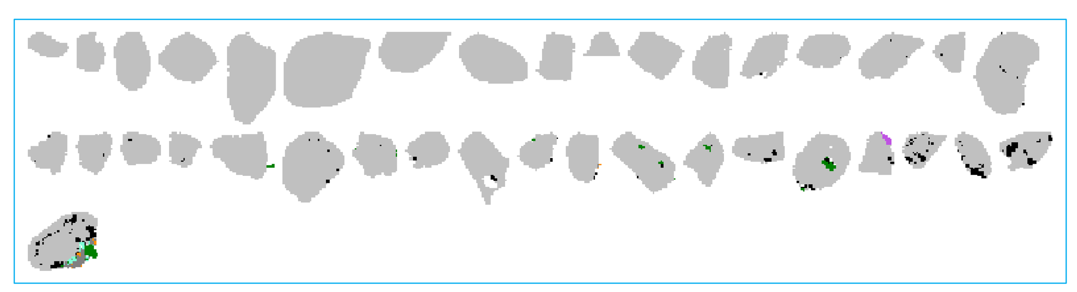


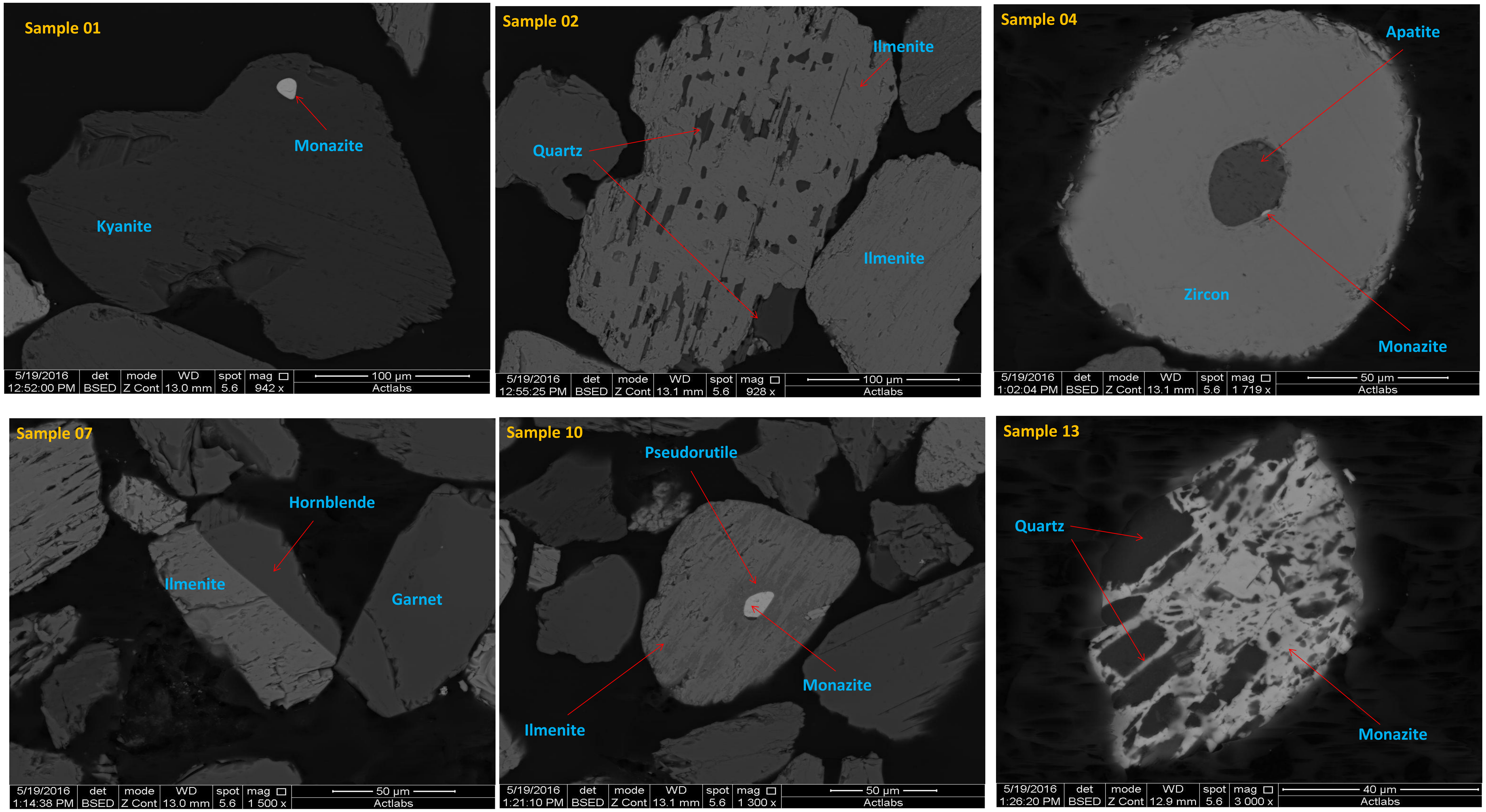
Sample 11



Sample 12

Sample 13




Sample 01
Monazite
Kyanite
5/19/2016 12:52:00 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 5.6 | mag 942 x | 100 µm | Actlabs
Sample 02
Ilmenite
Quartz
Ilmenite
5/19/2016 12:55:25 PM | det BSED | mode Z Cont | WD 13.1 mm | spot 5.6 | mag 928 x | 100 µm | Actlabs
Sample 04
Apatite
Zircon
Monazite
5/19/2016 1:02:04 PM | det BSED | mode Z Cont | WD 13.1 mm | spot 5.6 | mag 1 719 x | 50 µm | Actlabs
Sample 07
Hornblende
Ilmenite
Garnet
5/19/2016 1:14:38 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 5.6 | mag 1 500 x | 50 µm | Actlabs
Sample 10
Pseudorutile
Monazite
Ilmenite
5/19/2016 1:21:10 PM | det BSED | mode Z Cont | WD 13.1 mm | spot 5.6 | mag 1 300 x | 50 µm | Actlabs
Sample 13
Quartz
Monazite
5/19/2016 1:26:20 PM | det BSED | mode Z Cont | WD 12.9 mm | spot 5.6 | mag 3 000 x | 40 µm | Actlabs

Client ID	Sinks wt (g)	Float wt (g)	% Sinks (>2.95 SG)
GS-021 R-11032	1.87	38.50	4.6%
GS-022 R-11033	4.06	35.99	10.1%
GS-023 R-11034	5.53	34.85	13.7%
GS-024 R-11035	2.87	37.56	7.1%
GS-025 R-11036	10.89	29.37	27.0%
GS-026 R-11037	5.51	34.88	13.6%
GS-027 R-11038	7.47	32.73	18.6%
GS-028 R-11039	10.88	29.16	27.2%
GS-029 R-11040	10.61	17.78	37.4%
GS-030 R-11041	15.68	24.58	38.9%
GS-031 R-11042	16.02	24.47	39.6%
GS-032 R-11043	0.92	5.93	13.4%
REF-002 R-1031	9.67	30.49	24.1%

Actlabs Code: A16-03131
Date: April, 2017

Report and Analysis:
Mahdi Ghobadi, PhD; MahdiGhobadi@Actlabs.com
Rino Bindi, BSc

Objective:
To charcaterize the mineralogy of the sink fraction of the samples.

Samples:
13 samples were submitted for HLS. The results for concentrating the sink portion of the samples are presented in the corrosponding sheet. Around 2 grams materials from each sink portion was split using Rotary Micro Riffle Splitter, to prepare 30 mm transverse polished section.

Mineralogy Methods:

The mineralogical analysis was done using FEI FEG QEMSCAN.

The QEMSCAN instrument at Actlabs is based on the scanning electron microscope FEI QUANTA 650F, that is equipped with a field-emission gun (FEG) as an electron source. FEG enables high spatial resolution and sensitivity by decreasing the spot size of the focused electron beam to values as small as 0.3 µm and providing significant target currents, in the range of tens of nA. For imaging and X-ray based micro-chemical analysis the instrument is equipped with a four-quadrant, solid state back-scattered electron (BSE) detector and two Bruker XFlash 5030 detectors. For enhanced mineral identification capabilities, energy dispersive spectroscopy (EDS) spectra with a larger than standard number of photon counts per pixel were used in this project (3000 counts per pixel vs. the standard 1000 counts per pixel). The raw X-Ray data were evaluated using a customized SIP file for this project. The modal mineralogy data as well as particle data were generated using iDiscover software.

The data for this project were produced using two modes of measurements:

1. BMA or line scan which produced modal mineralogy data.
2. PMA or particle mapping which was used to determine size distribution.

Results:

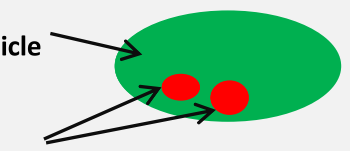
For this report modal mineralogy data and size distribution for Ti minerals are provided. Also representative mapped particle are provided, demonstrating major Ti mineral, as well as representative BSE images.

Note:

Particle Definition: A particle is a piece of material, and can contain one or more minerals.

Grain Definition: A grain is a piece of mineral matter contained within a particle.

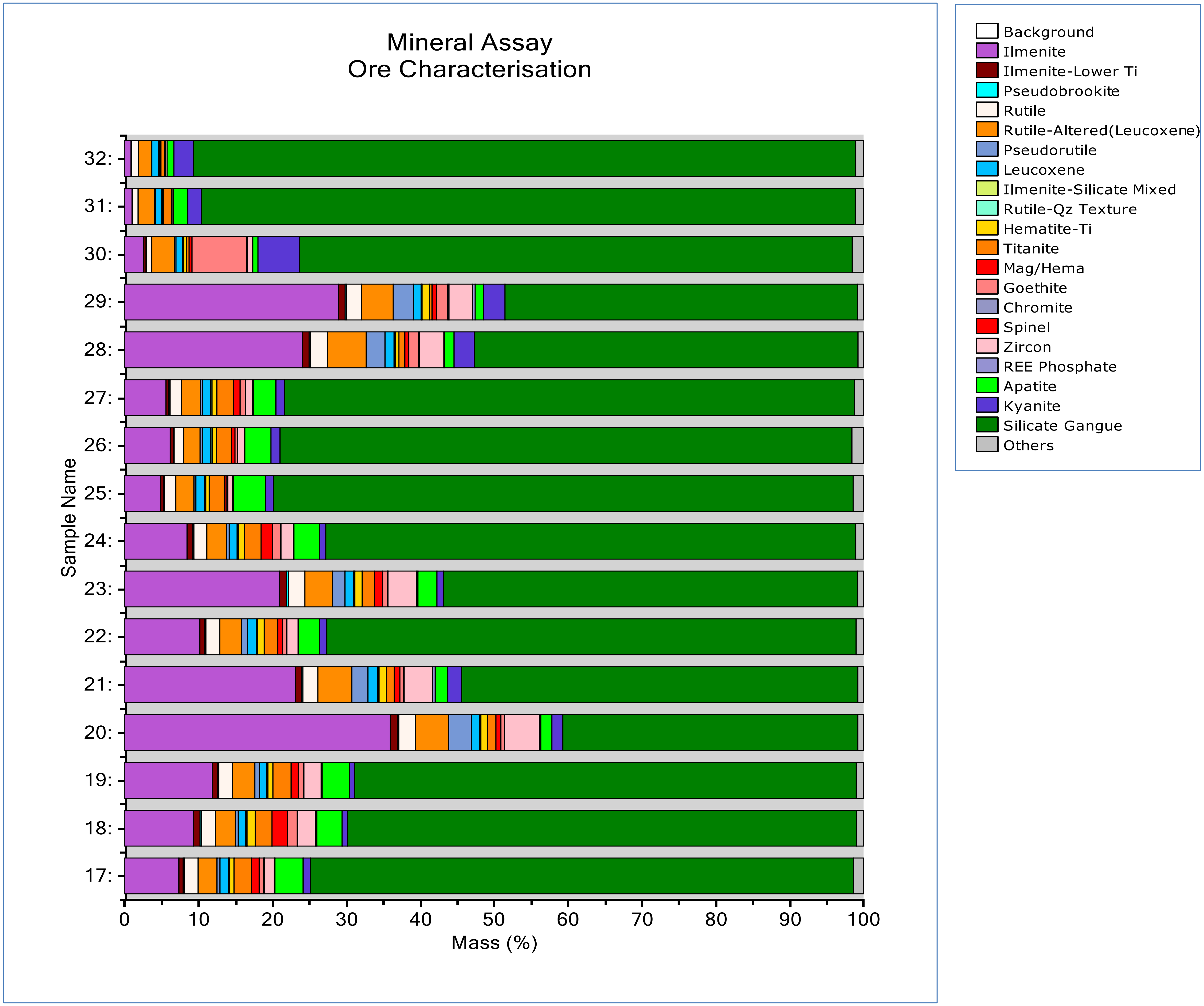
Particle



Actlab ID	Client ID
A17-03131--17	VC-001A 1/3 Sinks
A17-03131--18	VC-001A 2/3 Sinks
A17-03131--19	VC-001A 3/3 Sinks
A17-03131--20	VC-002B 1/2 Sinks
A17-03131--21	VC-002B 2/2 Sinks
A17-03131--22	VC-003 1/2 Sinks
A17-03131--23	VC-003 2/2 Sinks
A17-03131--24	VC-004 1/3 Sinks
A17-03131--25	VC-004 2/3 Sinks
A17-03131--26	VC-004 3/3 Sinks
A17-03131--27	VC-005 2/3 Sinks
A17-03131--28	VC-005 2/3 RED Sinks
A17-03131--29	VC-005 3/3 Sinks
A17-03131--30	GS-109-03 Sinks
A17-03131--31	GS-500-03 Sinks
A17-03131--32	GS-501-01 Sinks

	Actlabd ID: A16-03131-	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	Client ID	VC-001A 1/3 s	VC-001A 2/3 s	VC-001A 3/3 s	VC-002B 1/2 s	VC-002B 2/2 s	VC-003 1/2 s	VC-003 2/2 s	VC-004 1/3 s	VC-004 2/3 s	VC-004 3/3 s	VC-005 2/3 s	/C-005 2/3 RED	VC-005 3/3 s	GS-109-03 s	GS-500-03 s	GS-501-01 s
	MASS %																
	Ilmenite	7.35	9.33	11.87	35.94	23.15	10.17	20.95	8.46	4.89	6.18	5.60	24.03	28.95	2.60	1.01	0.87
	Ilmenite lower Ti	0.57	0.87	0.73	0.94	0.78	0.62	0.99	0.75	0.38	0.41	0.40	0.93	0.88	0.30	0.05	0.06
	Pseudobrookite	0.14	0.21	0.15	0.21	0.19	0.21	0.22	0.17	0.10	0.11	0.15	0.15	0.19	0.08	0.01	0.02
	Rutile	1.88	1.86	1.86	2.25	2.02	1.89	2.23	1.75	1.55	1.30	1.53	2.33	1.99	0.70	0.75	0.93
	Rutile-Altered(Leucoxene)	2.55	2.68	3.02	4.50	4.59	2.93	3.73	2.67	2.46	2.22	2.59	5.24	4.32	3.05	2.21	1.73
Ti Minerals	Pseudorutile	0.41	0.41	0.65	3.05	2.18	0.81	1.69	0.33	0.26	0.34	0.27	2.55	2.76	0.23	0.14	0.06
	Leucoxene	1.18	1.02	0.95	1.14	1.33	1.17	1.19	1.08	1.17	1.11	1.09	1.22	1.03	0.86	0.86	0.97
	Ilmenite-Silicate Mixed	0.03	0.06	0.02	0.07	0.04	0.04	0.05	0.03	0.03	0.03	0.04	0.06	0.04	0.10	0.01	0.02
	Rutile-Qz Texture	0.12	0.12	0.15	0.10	0.12	0.14	0.10	0.15	0.15	0.17	0.16	0.12	0.08	0.08	0.12	0.13
	Hematite-Ti	0.57	1.09	0.68	0.92	0.99	0.90	0.99	0.83	0.45	0.61	0.66	0.48	1.03	0.38	0.05	0.12
	Titanite	2.35	2.27	2.45	1.11	1.08	1.85	1.68	2.23	2.04	1.95	2.26	0.80	0.32	0.35	1.08	0.50
	Mag/Hema	1.05	2.09	0.97	0.67	0.77	0.61	1.08	1.58	0.25	0.52	0.87	0.52	0.58	0.39	0.06	0.04
	Goethite	0.63	1.32	0.66	0.45	0.49	0.55	0.65	1.04	0.19	0.34	0.71	1.34	1.54	7.41	0.05	0.05
Oxides/Hydroxides	Boehmite	0.04	0.01	n.d.	n.d.	0.02	0.00	n.d.	0.00	0.00	0.01	0.04	0.05	0.00	0.22	0.01	0.00
	Chromite	0.02	0.03	0.01	0.01	0.04	0.02	0.03	0.01	0.03	0.02	0.00	0.03	0.15	n.d.	n.d.	n.d.
	Chromite with Al-Mg	0.01	0.03	0.09	0.01	0.00	0.04	0.04	0.07	0.00	0.00	0.01	0.05	0.01	n.d.	n.d.	n.d.
	Spinel	0.02	n.d.	n.d.	0.03	0.02	n.d.	0.00	n.d.	n.d.	n.d.	0.01	n.d.	0.01	0.07	n.d.	n.d.
	Zircon	1.35	2.37	2.33	4.69	3.83	1.51	3.85	1.67	0.63	0.92	0.99	3.36	3.21	0.75	0.18	0.24
	Xenotime	0.00	0.02	n.d.	0.01	0.03	0.00	0.03	0.01	n.d.	n.d.	n.d.	n.d.	0.07	n.d.	n.d.	n.d.
REE Minerals	Monazite	0.08	0.19	0.12	0.20	0.33	0.06	0.11	0.05	0.10	0.03	0.02	0.02	0.25	n.d.	0.00	n.d.
	Florencite	0.00	0.01	n.d.	0.00	0.02	0.00	0.05	0.02	0.01	0.03	0.02	n.d.	n.d.	n.d.	0.03	n.d.
	Apatite	3.86	3.47	3.76	1.52	1.72	2.87	2.60	3.52	4.38	3.57	3.13	1.34	1.13	0.71	1.93	0.94
	Kyanite	1.17	0.86	0.80	1.67	2.17	1.13	1.03	1.00	1.27	1.43	1.35	3.02	3.17	6.18	2.09	3.06
	Quartz	2.92	2.43	1.22	1.73	2.33	2.78	1.26	1.44	1.33	4.84	3.22	3.67	4.89	7.95	9.26	12.21
	K-Feldspar	0.17	0.18	0.09	0.08	0.17	0.16	0.10	0.12	0.10	0.42	0.35	0.32	0.49	0.85	0.76	0.97
	Plagioclase	0.96	0.75	0.47	0.40	0.59	0.76	0.53	0.47	0.67	1.51	1.19	0.96	1.32	1.41	2.39	2.81
	Pyroxene	5.01	4.80	4.05	2.16	2.72	4.44	2.97	5.17	5.98	6.22	6.09	2.81	2.71	8.02	7.40	7.14
Silicates	Garnet	18.48	17.27	20.22	12.35	15.34	19.26	17.17	19.17	16.87	15.02	15.83	11.99	10.62	10.85	10.33	6.89
	Amphibole	42.17	40.00	38.14	19.60	28.11	40.13	30.68	41.51	49.07	45.06	46.36	28.00	23.71	35.30	53.60	55.50
	Mica	0.40	0.39	0.26	0.25	0.34	0.38	0.29	0.43	0.45	0.55	0.53	0.30	0.37	2.11	0.88	0.93
	Staurolite	0.56	0.41	0.50	1.50	1.41	0.99	0.87	0.39	0.52	0.55	0.49	1.23	0.94	2.90	0.69	0.48
	Wollastonite	0.45	0.45	0.37	0.19	0.22	0.36	0.25	0.45	0.52	0.45	0.48	0.17	0.16	0.32	0.45	0.36
	Schorl-Tourmaline	1.86	1.78	2.11	1.33	1.89	1.86	1.54	1.99	2.31	2.21	2.00	1.84	1.89	2.63	2.17	1.65
	Epidote	0.19	0.18	0.19	0.08	0.12	0.22	0.14	0.23	0.29	0.26	0.33	0.15	0.16	0.26	0.27	0.32
	Calcite	0.46	0.11	0.24	0.11	0.10	0.12	0.06	0.21	0.27	0.35	0.34	0.11	0.08	0.19	0.17	0.15
	Pyrite	0.00	0.02	0.02	0.07	0.00	0.09	0.09	0.00	0.01	0.03	0.01	0.00	n.d.	0.01	0.00	n.d.
Mixed-Unclassifiable Spectra	Silicates-Altered to Clays	0.27	0.26	0.21	0.16	0.21	0.28	0.20	0.31	0.28	0.33	0.26	0.32	0.35	1.97	0.32	0.32
	Low Counts	0.03	0.02	0.04	0.05	0.05	0.03	0.03	0.04	0.19	0.27	0.03	0.06	0.05	0.01	0.02	0.02
	Others	0.68	0.63	0.62	0.45	0.50	0.64	0.52	0.65	0.79	0.68	0.60	0.42	0.55	0.77	0.61	0.51
	Sum	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Actlabd ID: A16-03131-	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Client ID	/C-001A 1/3	/C-001A 2/3	/C-001A 3/3	/C-002B 1/2	/C-002B 2/2	/C-003 1/2	/C-003 2/2	/C-004 1/3	/C-004 2/3	/C-004 3/3	/C-005 2/3	-005 2/3 R	/C-005 3/3	G-109-03	G-500-03	G-501-01



	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Ilmenite	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	2	1	1	1	1	1	2	1	2	2	2	1	1	10	2	4
S<=5	3	2	2	2	2	2	3	2	3	3	3	2	2	16	4	6
S<=10	9	8	8	6	7	6	8	7	9	9	10	8	6	35	17	20
S<=13.25	13	12	11	7	9	8	9	10	12	12	14	10	8	36	20	23
S<=18.75	19	18	17	8	13	13	15	15	16	18	22	13	11	43	27	25
S<=26.5	32	34	24	13	18	19	22	26	29	26	35	18	14	51	29	29
S<=37.5	52	60	49	20	29	39	36	50	55	53	53	25	20	59	43	29
S<=53	77	87	72	34	45	58	64	80	80	79	87	34	28	73	58	55
S<=75	96	99	90	56	69	77	82	96	98	90	99	51	46	92	67	93
S<=106	100	100	98	80	87	87	91	100	100	100	100	77	72	100	83	100
S<=150	100	100	100	98	95	94	98	100	100	100	100	97	96	100	100	100
S<=212	100	100	100	100	99	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Ilmenite lower Ti	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	64	58	56	67	66	61	64	56	56	62	54	67	62	40	61	54
S<=5	80	75	71	80	79	78	79	73	73	78	71	79	77	57	71	73
S<=10	98	99	96	96	96	99	98	96	98	98	99	98	96	98	91	96
S<=13.25	99	100	100	97	97	100	100	97	100	99	100	99	99	100	91	100
S<=18.75	100	100	100	97	100	100	100	98	100	100	100	100	100	100	100	100
S<=26.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=37.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=53	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Pseudobrookite	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	49	57	51	53	55	51	51	51	47	55	51	51	49	60	57	73
S<=5	66	74	68	68	73	64	65	67	59	73	65	62	66	70	82	79
S<=10	92	97	97	94	97	96	96	95	97	97	96	91	89	97	100	100
S<=13.25	100	98	100	98	99	98	100	99	100	99	99	96	99	99	100	100
S<=18.75	100	100	100	98	100	99	100	100	100	99	100	100	100	100		
S<=26.5	100	100	100	99	100	99	100	100	100	99	100	100	100	100		
S<=37.5	100	100	100	100	100	100	100	100	100	99						
S<=53										99						
S<=75										100						

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Rutile	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	3	4	2	3	4	4	3	4	4	4	4	3	4	5	7	4
S<=5	6	5	4	5	7	7	4	6	6	7	6	5	6	9	13	8
S<=10	20	18	10	12	18	22	15	20	19	25	18	15	20	25	41	22
S<=13.25	27	26	16	18	26	30	20	24	27	39	26	20	25	37	50	33
S<=18.75	37	38	23	25	35	38	28	33	34	54	41	26	43	55	57	54
S<=26.5	53	54	39	31	44	47	35	43	48	65	62	35	49	65	75	61
S<=37.5	70	72	50	46	56	63	48	59	67	82	79	46	58	79	100	76
S<=53	85	90	78	58	86	80	61	92	92	100	93	65	67	100	100	88
S<=75	100	98	95	78	100	89	84	100	100	100	100	83	74	100	100	100
S<=106	100	100	100	85	100	100	88	100	100	100	100	100	83	100	100	100
S<=150	100	100	100	90	100	100	100	100	100	100	100	100	100	100	100	100
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Rutile-Altered	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	10	10	9	10	6	8	8	8	8	7	9	8	7	4	6	6
S<=5	16	16	15	16	10	14	13	14	14	13	17	13	11	7	10	11
S<=10	39	41	38	37	24	40	35	40	39	37	45	32	31	18	32	30
S<=13.25	48	49	46	48	29	48	44	47	49	45	55	38	41	20	45	43
S<=18.75	58	58	56	55	36	57	55	54	56	57	64	47	48	24	52	56
S<=26.5	67	65	65	63	41	60	63	63	62	63	69	56	54	24	60	80
S<=37.5	73	78	68	66	52	67	68	67	78	71	77	65	64	24	63	85
S<=53	79	90	76	74	61	81	73	77	86	88	94	77	75	51	73	85
S<=75	98	97	96	82	78	94	90	93	94	97	100	90	84	66	77	94
S<=106	100	100	100	95	92	100	100	100	100	100	100	100	92	66	100	100
S<=150	100	100	100	100	97	100	100	100	100	100	100	100	97	83	100	100
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Pseudorutile	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	37	42	34	27	29	34	27	42	44	43	48	22	26	14	24	36
S<=5	53	56	47	39	43	47	38	57	58	57	61	33	39	21	35	46
S<=10	92	91	83	75	79	76	68	92	94	88	99	73	76	44	98	68
S<=13.25	94	99	95	80	89	77	71	100	100	93	100	83	81	70	100	100
S<=18.75	95	100	99	88	93	92	78	100	100	100	100	85	83	100	100	100
S<=26.5	95	100	100	90	96	100	78	100	100	100	100	96	86	100	100	100
S<=37.5	100	100	100	92	98	100	100	100	100	100	100	98	91	100	100	100
S<=53	100	100	100	96	100	100	100	100	100	100	100	98	96	100	100	100
S<=75	100	100	100	100	100	100	100	100	100	100	100	98	100	100	100	100
S<=106	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Leucoxene	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	23	25	26	30	31	24	32	26	21	20	17	26	25	27	14	15
S<=5	33	34	37	42	43	35	45	37	32	31	26	37	35	41	25	22
S<=10	68	71	72	76	80	69	80	80	80	70	62	70	70	85	60	57
S<=13.25	80	81	82	87	89	77	89	88	88	84	73	77	79	95	71	70
S<=18.75	91	87	89	90	97	91	95	93	94	90	83	80	85	96	74	78
S<=26.5	94	96	97	93	100	97	97	94	98	92	87	88	96	100	74	87
S<=37.5	97	97	97	96	100	97	100	100	100	92	93	88	100	100	74	100
S<=53	97	100	100	100	100	100	100	100	100	95	96	92	100	100	80	100
S<=75	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

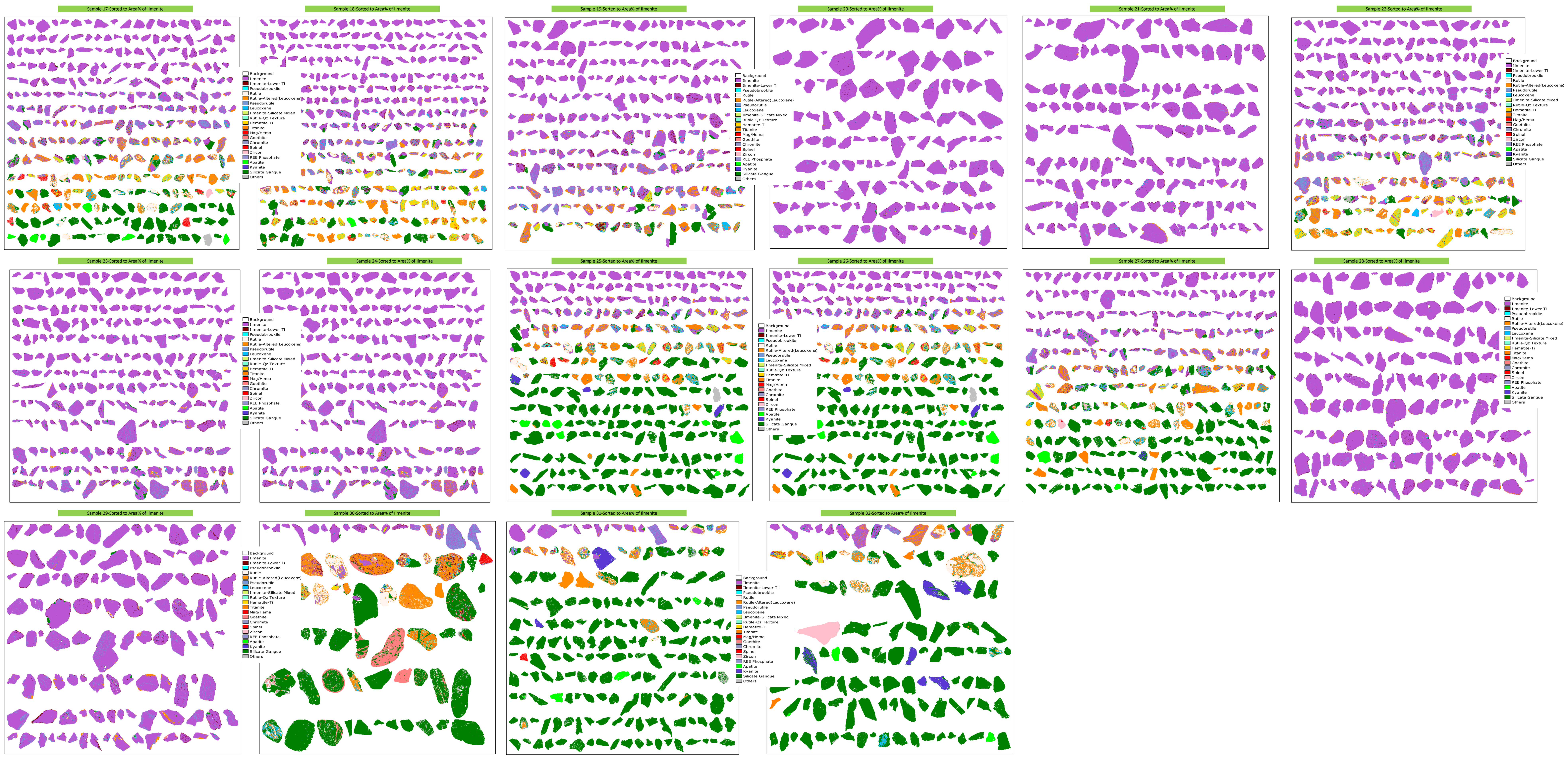
Size Distribution of Hematite-Ti	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	9	5	7	5	4	3	4	6	7	4	9	5	7	15	8	3
S<=5	16	7	10	8	6	6	6	9	12	8	14	8	10	20	13	4
S<=10	33	22	26	18	18	15	15	22	30	18	40	18	28	63	92	11
S<=13.25	40	28	40	21	22	22	22	36	37	28	52	20	36	75	100	19
S<=18.75	53	45	53	29	29	33	34	45	51	44	66	24	40	82	100	33
S<=26.5	85	68	77	46	37	59	55	75	78	61	72	45	54	82	100	49
S<=37.5	100	83	98	69	60	88	72	93	92	92	80	71	77	100	100	100
S<=53	100	95	100	89	73	100	84	100	100	100	82	71	100	100	100	100
S<=75	100	100	100	100	88	100	100	100	100	100	100	100	100	100	100	100
S<=106	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

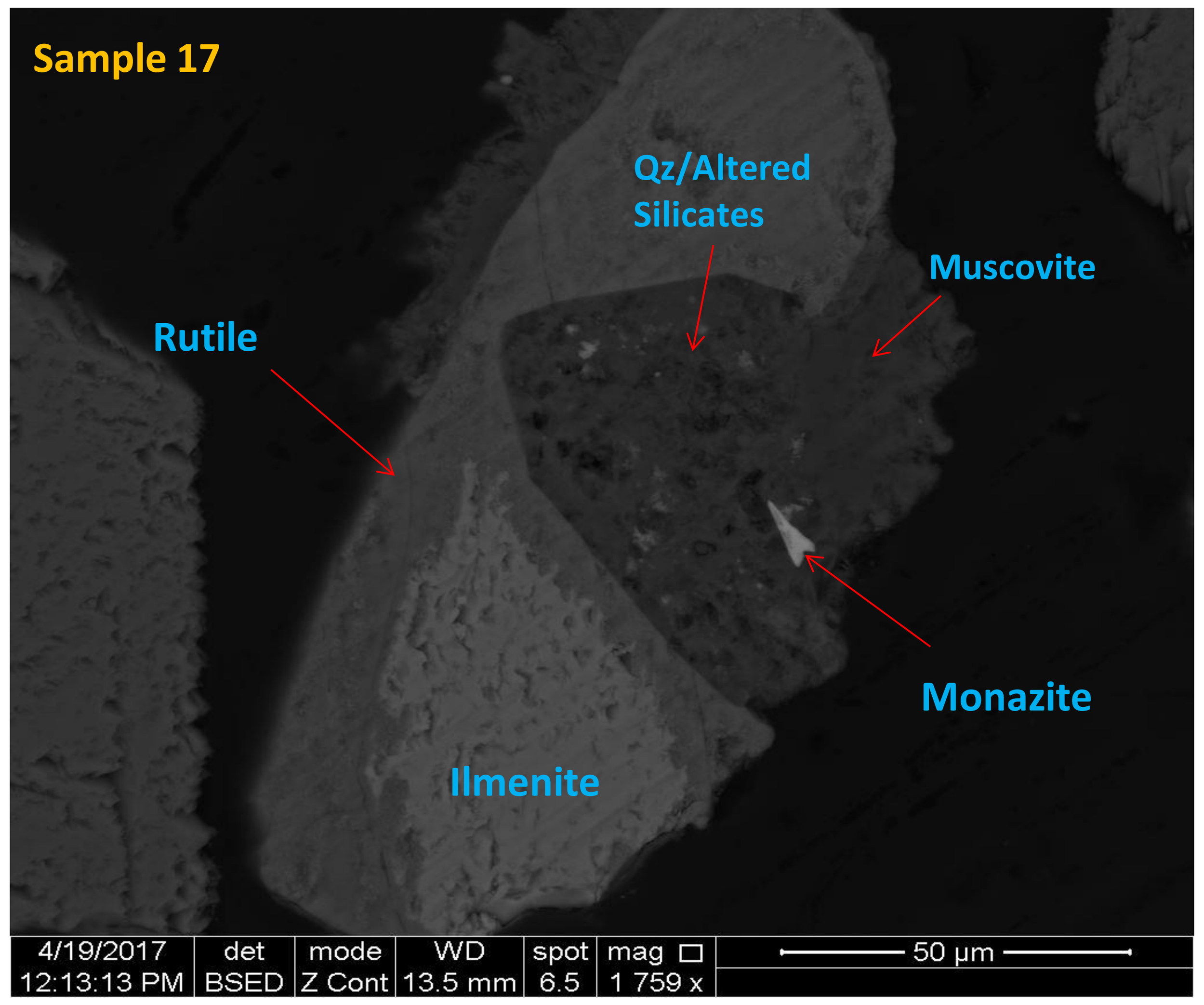
Sieve Size in Micron/ **Cumulative Passing**

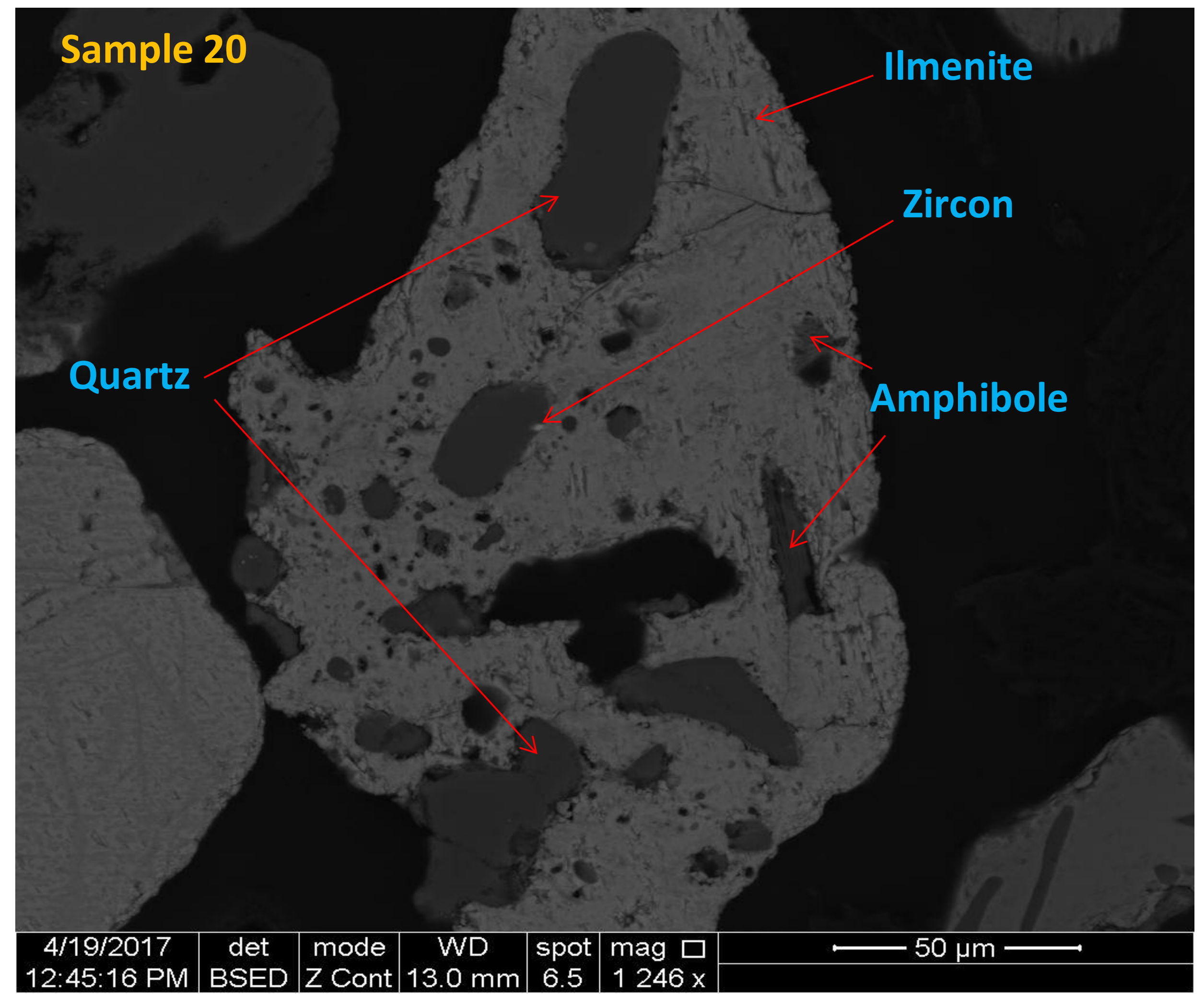
Size Distribution of Titanite	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	1	1	0	1	0	1	1	0	1	1	1	1	1	1	1	1
S<=5	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1
S<=10	3	4	3	3	2	3	3	3	3	4	4	4	3	5	7	5
S<=13.25	4	7	4	5	3	5	6	4	5	5	6	8	4	8	9	7
S<=18.75	7	9	6	8	4	7	8	9	7	9	10	10	9	13	12	10
S<=26.5	10	13	12	12	8	10	11	14	12	13	15	11	13	13	17	12
S<=37.5	22	25	19	25	18	23	17	25	21	22	27	18	19	15	17	14
S<=53	43	54	42	49	41	42	43	48	43	47	52	43	45	57	36	53
S<=75	80	94	72	66	65	83	81	71	84	86	88	88	67	70	81	91
S<=106	100	100	89	100	89	89	100	96	99	100	97	100	91	70	81	100
S<=150	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

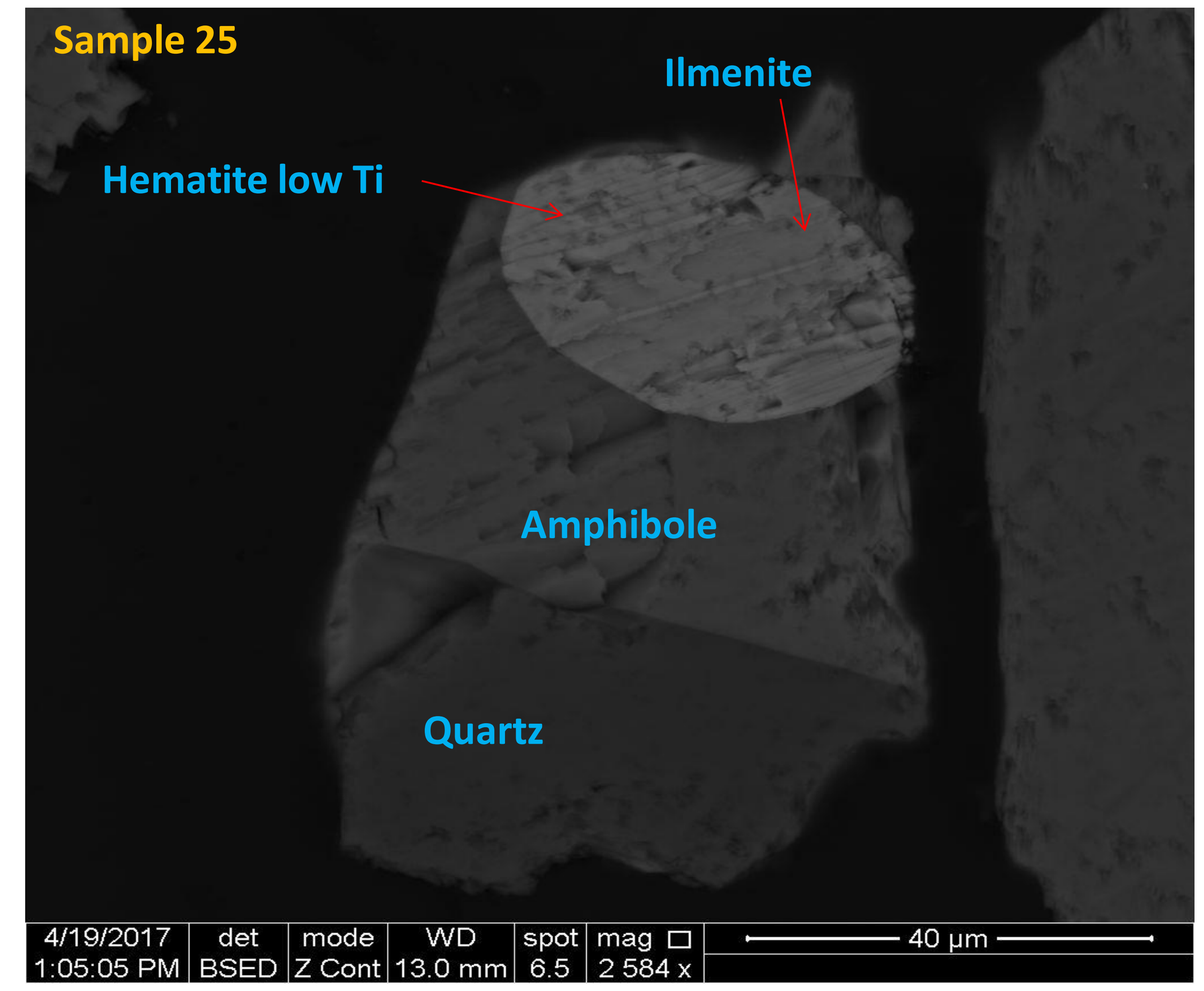
Sieve Size in Micron/ **Cumulative Passing**

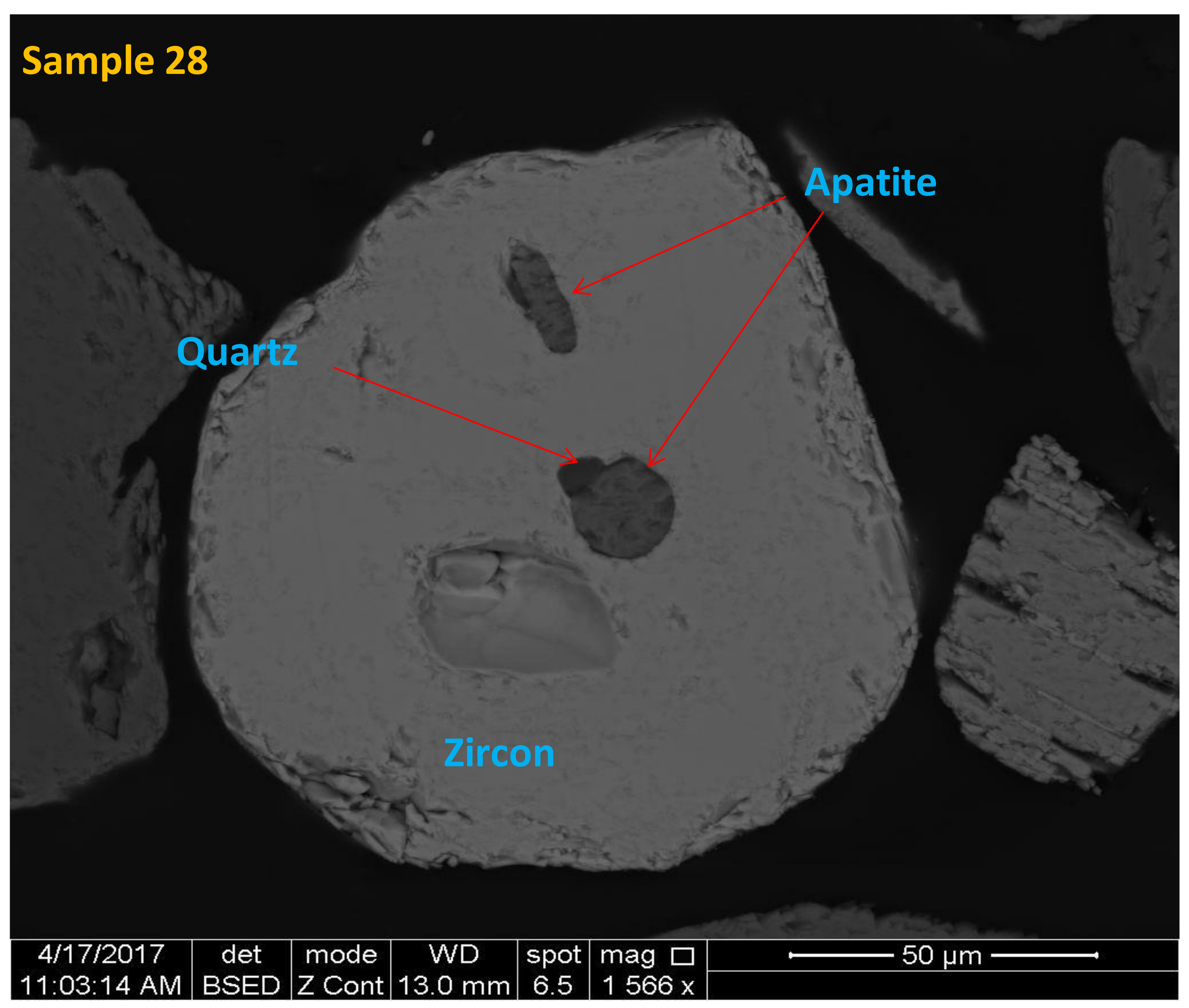
Size Distribution of Zircon	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	C-005 2/3 REI	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
S<=5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
S<=10	1	1	0	0	0	0	0	1	0	0	0	0	0	1	8	1
S<=13.25	1	1	1	0	0	0	0	1	0	0	1	0	0	1	14	1
S<=18.75	4	2	1	1	1	1	1	2	0	2	2	0	0	2	14	1
S<=26.5	7	9	4	2	1	4	3	7	1	3	3	0	0	2	55	3
S<=37.5	11	25	17	4	4	6	7	12	6	10	16	1	0	3	100	3
S<=53	42	66	43	10	12	10	17	49	18	25	54	7	4	3	100	3
S<=75	80	97	67	26	35	47	54	91	76	60	94	29	22	38	100	3
S<=106	100	100	90	60	76	81	83	100	100	84	100	58	63	38	100	17
S<=150	100	100	100	96	96	88	96	100	100	100	100	96	100	38	100	17
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	17
S<=300	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

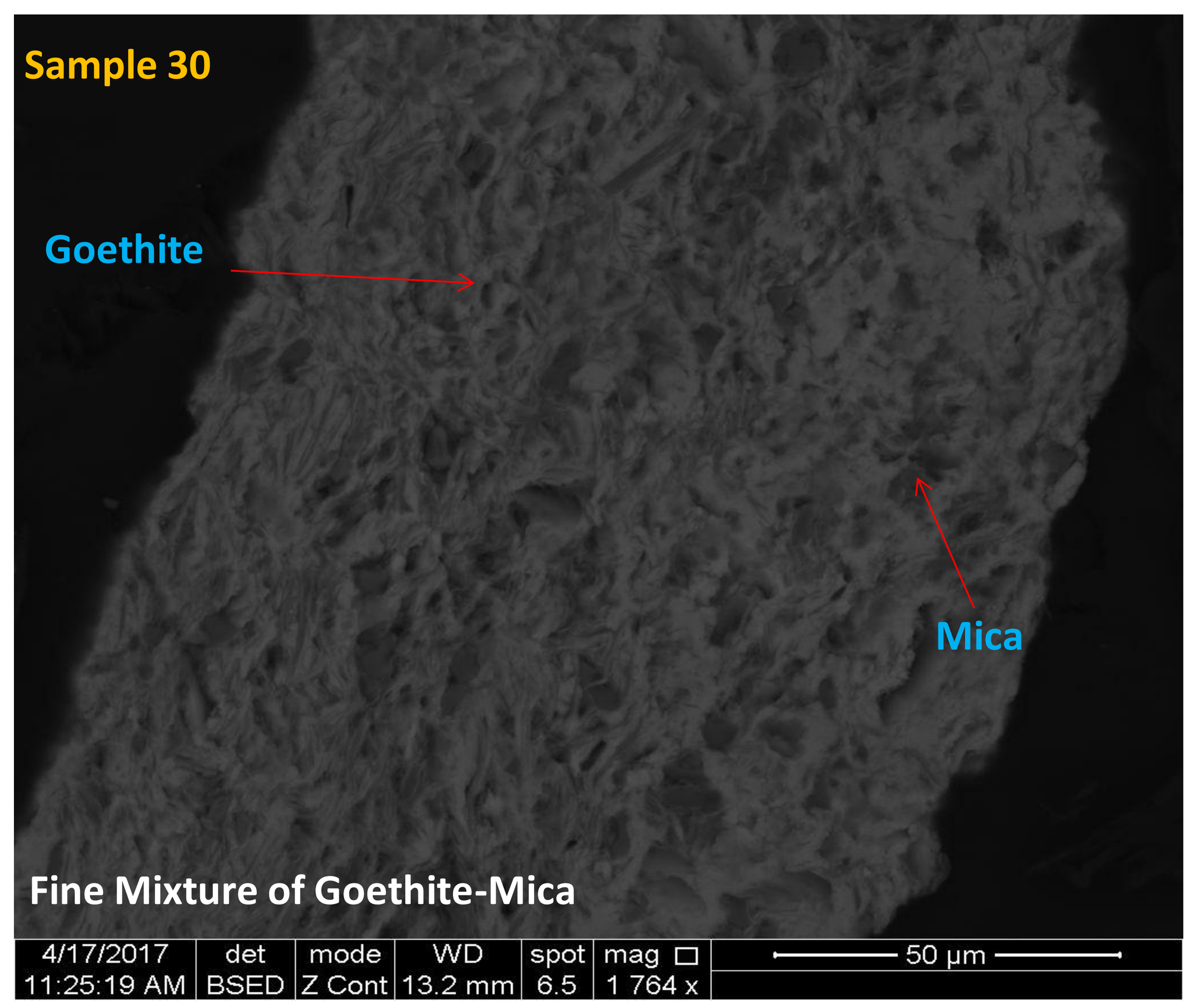

Sample 17-Sorted to Area% of Ilmenite
Sample 18-Sorted to Area% of Ilmenite
Sample 19-Sorted to Area% of Ilmenite
Sample 20-Sorted to Area% of Ilmenite
Sample 21-Sorted to Area% of Ilmenite
Sample 22-Sorted to Area% of Ilmenite
Sample 23-Sorted to Area% of Ilmenite
Sample 24-Sorted to Area% of Ilmenite
Sample 25-Sorted to Area% of Ilmenite
Sample 26-Sorted to Area% of Ilmenite
Sample 27-Sorted to Area% of Ilmenite
Sample 28-Sorted to Area% of Ilmenite
Sample 29-Sorted to Area% of Ilmenite
Sample 30-Sorted to Area% of Ilmenite
Sample 31-Sorted to Area% of Ilmenite
Sample 32-Sorted to Area% of Ilmenite
Background
Ilmenite
Ilmenite-Lower Ti
Pseudobrookite
Rutile
Rutile-Altered(Leucoxene)
Pseudorutile
Leucoxene
Ilmenite-Silicate Mixed
Rutile-Qz Texture
Hematite-Ti
Titanite
Mag/Hema
Goethite
Chromite
Spinel
Zircon
REE Phosphate
Apatite
Kyanite
Silicate Gangue
Others

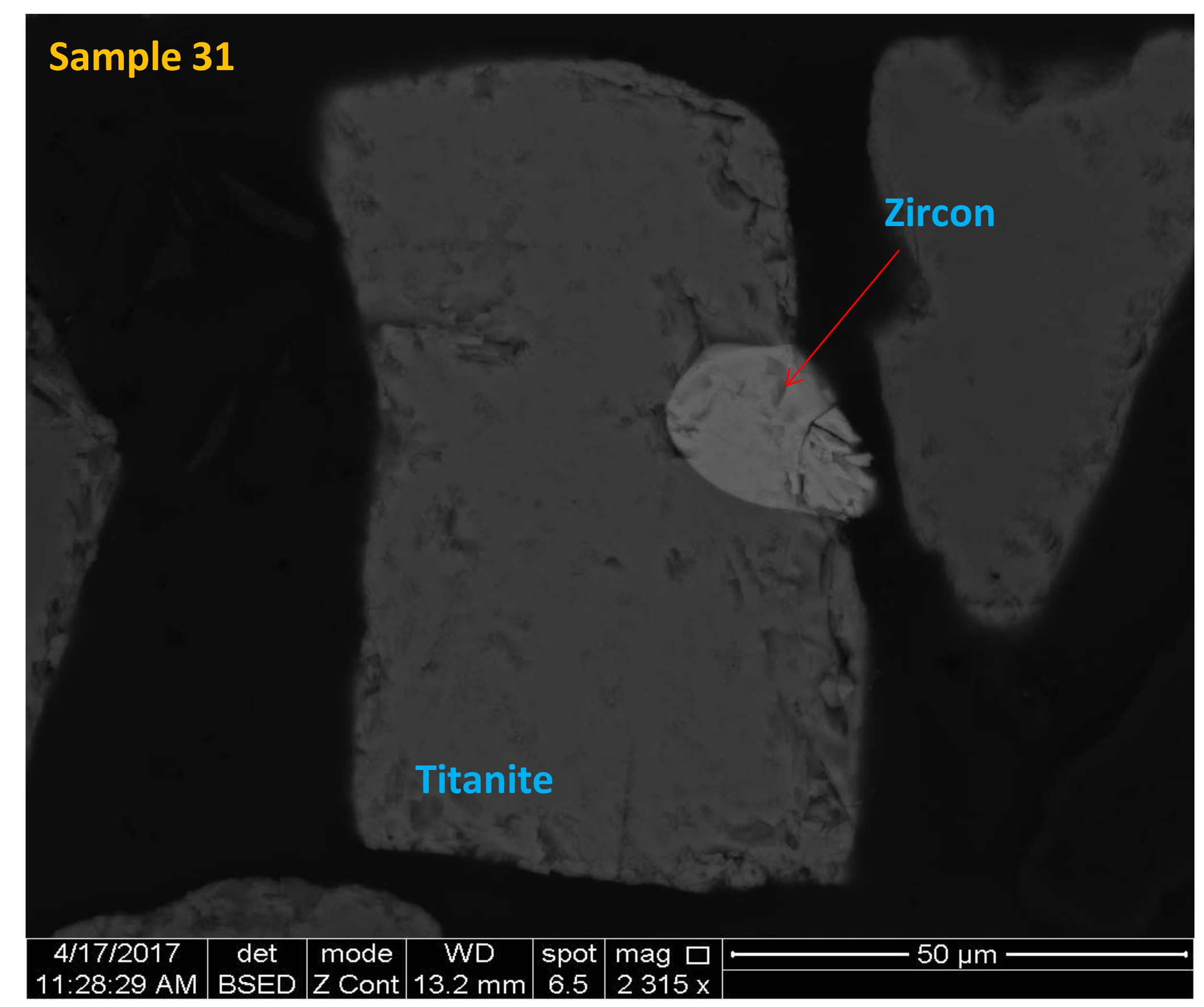

Sample 17
Qz/Altered Silicates
Muscovite
Rutile
Monazite
Ilmenite
4/19/2017 12:13:13 PM | det BSED | mode Z Cont | WD 13.5 mm | spot 6.5 | mag 1 759 x | 50 µm

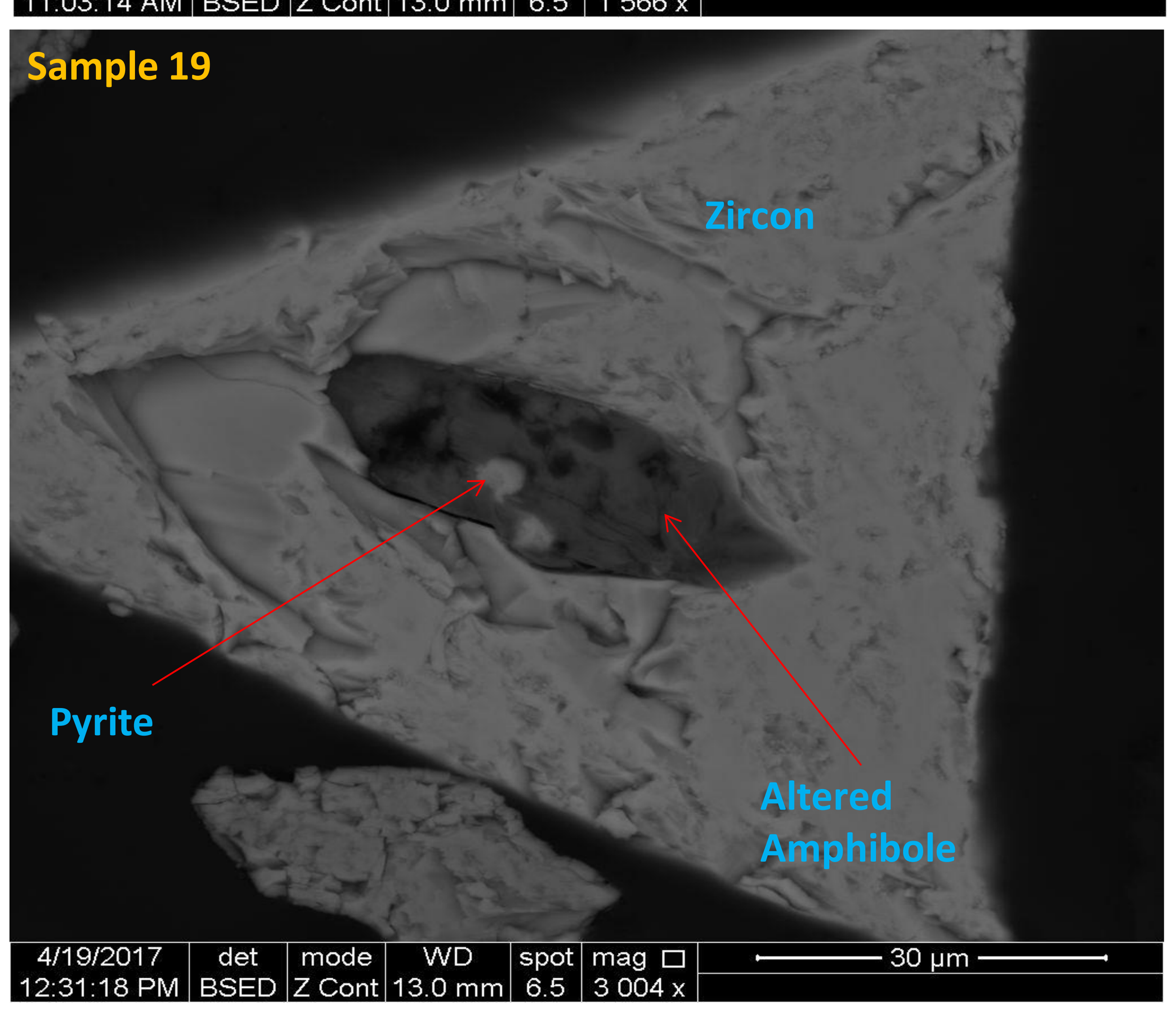

Sample 20
Ilmenite
Zircon
Quartz
Amphibole
4/19/2017 12:45:16 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 6.5 | mag 1 246 x | 50 µm


Sample 25
Ilmenite
Hematite low Ti
Amphibole
Quartz
4/19/2017 1:05:05 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 6.5 | mag 2 584 x | 40 µm


Sample 28
Apatite
Quartz
Zircon
4/17/2017 11:03:14 AM | det BSED | mode Z Cont | WD 13.0 mm | spot 6.5 | mag 1 566 x | 50 µm


Sample 30
Goethite
Mica
Fine Mixture of Goethite-Mica
4/17/2017 11:25:19 AM | det BSED | mode Z Cont | WD 13.2 mm | spot 6.5 | mag 1 764 x | 50 µm


Sample 31
Zircon
Titanite
4/17/2017 11:28:29 AM | det BSED | mode Z Cont | WD 13.2 mm | spot 6.5 | mag 2 315 x | 50 µm


Sample 19
Zircon
Pyrite
Altered Amphibole
4/19/2017 12:31:18 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 6.5 | mag 3 004 x | 30 µm

Sample	Mass (g)		
	Floats	Sinks	% Sinks
VC-001A 1/3	34.31	26.99	44%
VC-001A 2/3	24.84	20.62	45%
VC-001A 3/3	13.59	31.84	70%
VC-002B 1/2	26.05	27.34	51%
VC-002B 2/2	32.43	11.16	26%
VC-003 1/2	24.23	39.03	62%
VC-003 2/2	24.13	24.14	50%
VC-004 1/3	32.42	17.29	35%
VC-004 2/3	31.66	15.57	33%
VC-004 3/3	42.08	6.82	14%
VC-005 2/3	35.39	6.12	15%
VC-005 2/3 RED	14.47	1.27	8%
VC-005 3/3	13.75	1.10	7%
GS-109-03	16.37	0.83	5%
GS-500-03	45	3.41	7%
GS-501-01	58.15	3.45	6%

Actlabs Code: A17-11430
Date: December, 2017

Report and Analysis:
Mahdi Ghobadi, PhD; MahdiGhobadi@Actlabs.com
Rino Bindi, BSc

Objective:
To charcaterize the mineralogy of the sink fraction of the samples.

Samples:
Sixteen samples were submitted for HLS. The results for concentrating the sink portion of the samples are presented in the corrosponding sheet. Around 2 grams materials from each sink portion was split using Rotary Micro Riffle Splitter, to prepare 30 mm transverse polished section.

Mineralogy Methods:

The mineralogical analysis was done using FEI FEG QEMSCAN.

The QEMSCAN instrument at Actlabs is based on the scanning electron microscope FEI QUANTA 650F, that is equipped with a field-emission gun (FEG) as an electron source. FEG enables high spatial resolution and sensitivity by decreasing the spot size of the focused electron beam to values as small as 0.3 µm and providing significant target currents, in the range of tens of nA. For imaging and X-ray based micro-chemical analysis the instrument is equipped with a four-quadrant, solid state back-scattered electron (BSE) detector and two Bruker XFlash 5030 detectors. For enhanced mineral identification capabilities, energy dispersive spectroscopy (EDS) spectra with a larger than standard number of photon counts per pixel were used in this project (3000 counts per pixel vs. the standard 1000 counts per pixel). The raw X-Ray data were evaluated using a customized SIP file for this project. The modal mineralogy data as well as particle data were generated using iDiscover software.

The data for this project were produced using two modes of measurements:

1. BMA or line scan which produced modal mineralogy data.
2. PMA or particle mapping which was used to determine size distribution.

Results:

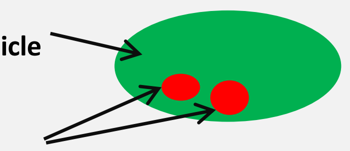
For this report modal mineralogy data and size distribution for Ti minerals are provided. Also representative mapped particle are provided, demonstrating major Ti mineral, as well as representative BSE images.

Note:

Particle Definition: A particle is a piece of material, and can contain one or more minerals.

Grain Definition: A grain is a piece of mineral matter contained within a particle.

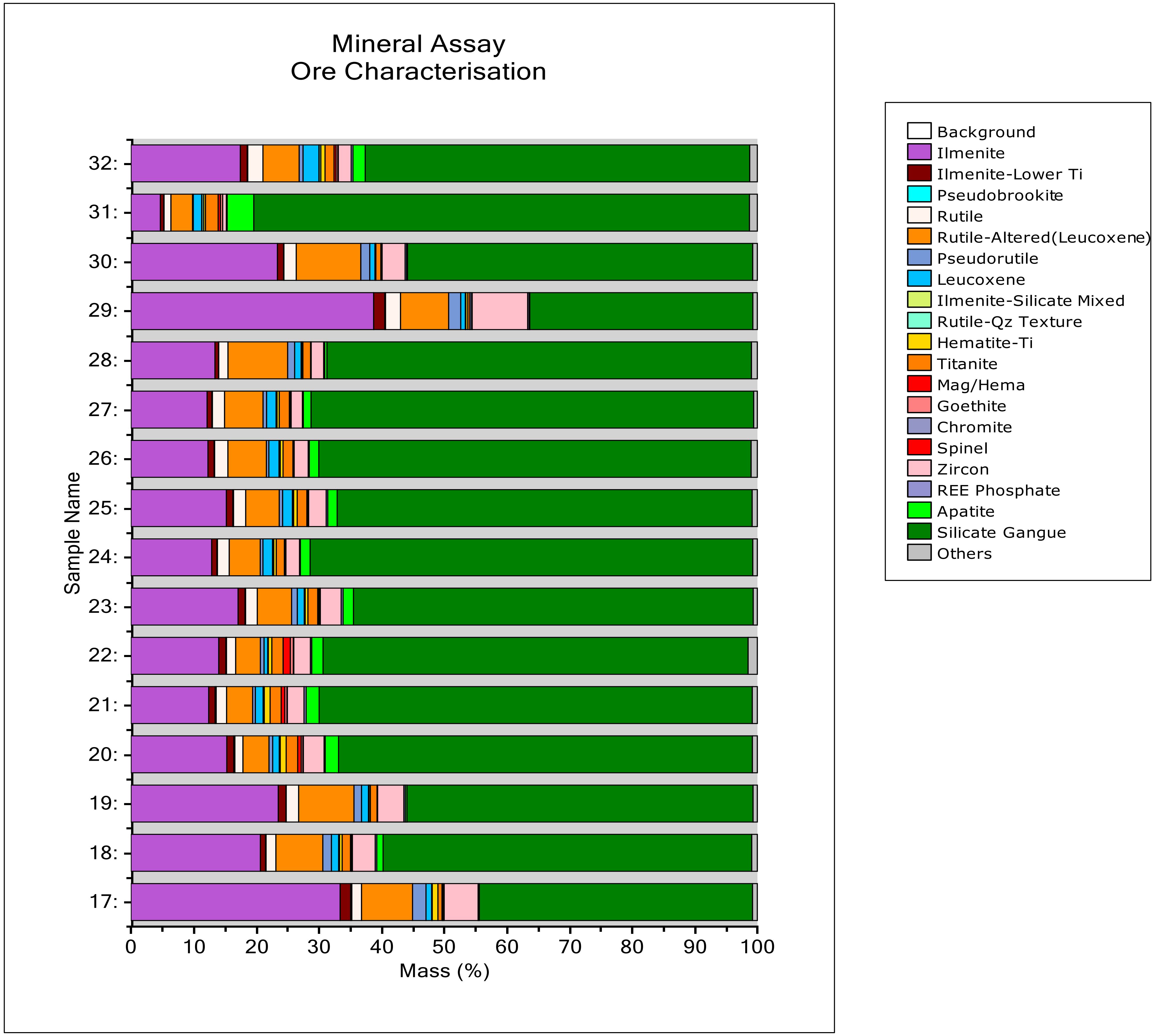
Particle



Actlab ID	Client ID
A17-11430--17	R-11355 Sinks
A17-11430--18	R-11356 Sinks
A17-11430--19	R-11357 Sinks
A17-11430--20	R-11358 Sinks
A17-11430--21	R-11359 Sinks
A17-11430--22	R-11360 Sinks
A17-11430--23	R-11361 Sinks
A17-11430--24	R-11362 Sinks
A17-11430--25	R-11363 Sinks
A17-11430--26	R-11364 Sinks
A17-11430--27	R-11365 Sinks
A17-11430--28	R-11366 Sinks
A17-11430--29	R-11367 Sinks
A17-11430--30	R-11368 Sinks
A17-11430--31	R-11372 Sinks
A17-11430--32	R-11375 Sinks

	Actlabd ID: A16-11430-	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	Client ID	R-11355 Sinks	R-11356 Sinks	R-11357 Sinks	R-11358 Sinks	R-11359 Sinks	R-11360 Sinks	R-11361 Sinks	R-11362 Sinks	R-11363 Sinks	R-11364 Sinks	R-11365 Sinks	R-11366 Sinks	R-11367 Sinks	R-11368 Sinks	R-11372 Sinks	R-11375 Sinks
	MASS %																
Ti Minerals	Ilmenite	33.40	20.66	23.52	15.30	12.41	14.02	17.10	12.89	15.24	12.29	12.16	13.40	38.75	23.39	4.70	17.47
	Ilmenite lower Ti	1.67	0.82	1.21	1.11	1.02	1.13	1.10	0.83	1.04	0.98	0.76	0.58	1.76	0.99	0.54	1.09
	Pseudobrookite	0.19	0.10	0.06	0.18	0.17	0.11	0.10	0.09	0.11	0.08	0.09	0.03	0.13	0.05	0.05	0.10
	Rutile	1.55	1.57	1.99	1.29	1.67	1.47	1.87	1.88	1.94	2.12	1.94	1.48	2.40	1.97	1.10	2.42
	Rutile-Altered(Leucoxene)	8.14	7.49	8.83	4.16	4.15	3.94	5.47	4.95	5.35	6.15	6.15	9.52	7.68	10.31	3.45	5.79
	Pseudorutile	2.15	1.38	1.21	0.58	0.44	0.59	0.92	0.43	0.54	0.38	0.56	1.12	1.93	1.43	0.12	0.62
	Leucoxene	0.91	1.15	1.10	1.06	1.24	0.59	1.11	1.54	1.56	1.63	1.52	1.04	0.73	0.84	1.35	2.53
	Ilmenite-Silicate Mixed	0.03	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.04	0.04	0.02	0.02	0.02	0.01	0.04	0.05
	Rutile-Qz Texture	0.05	0.10	0.07	0.11	0.15	0.06	0.10	0.16	0.16	0.15	0.13	0.14	0.06	0.04	0.27	0.26
	Hematite-Ti	0.91	0.43	0.21	0.95	0.94	0.57	0.44	0.40	0.57	0.45	0.36	0.12	0.32	0.08	0.29	0.68
	Titanite	0.65	1.33	1.07	1.84	1.77	1.80	1.57	1.29	1.55	1.59	1.62	1.23	0.32	0.81	2.03	1.44
Oxides/Hydroxides	Mag/Hema	0.11	0.10	0.02	0.56	0.58	1.15	0.19	0.08	0.18	0.10	0.19	0.03	0.02	<0.01	0.37	0.32
	Goethite	0.06	0.05	<0.01	0.27	0.35	0.48	0.08	0.06	0.08	0.05	0.06	0.02	0.01	0.01	0.35	0.28
	Boehmite	0.08	0.05	<0.01	0.04	0.02	0.02	0.01	0.01	0.03	<0.01	n.d.	0.08	0.07	0.05	0.03	<0.01
	Chromite	<0.01	0.03	0.02	<0.01	0.01	0.02	0.05	0.02	0.02	<0.01	<0.01	<0.01	0.15	0.03	<0.01	0.02
	Chromite with Al-Mg	0.01	0.06	0.02	0.05	0.05	0.01	0.05	0.09	n.d.	0.02	0.01	0.02	0.11	0.06	<0.01	0.03
	Spinel	0.18	0.11	0.07	0.03	0.06	0.07	0.07	0.01	0.03	0.07	0.02	0.11	0.11	0.13	<0.01	0.04
REE Minerals	Zircon	5.42	3.65	4.19	3.31	2.66	2.64	3.34	2.17	2.81	2.25	1.80	2.00	8.86	3.67	0.59	2.06
	Xenotime	n.d.	<0.01	<0.01	0.02	0.07	0.02	0.05	n.d.	<0.01	0.03	<0.01	<0.01	n.d.	<0.01	n.d.	0.01
	Monazite	0.06	0.25	0.23	0.15	0.25	0.18	0.24	0.14	0.22	0.13	0.13	0.14	0.22	0.23	0.04	0.14
	Florencite	n.d.	n.d.	n.d.	<0.01	<0.01	0.02	<0.01	n.d.	0.03	<0.01	0.02	0.02	<0.01	<0.01	0.09	0.13
	Apatite	0.14	1.00	0.25	2.13	2.07	1.80	1.65	1.55	1.50	1.52	1.23	0.36	0.10	0.15	4.25	1.96
Silicates	Kyanite	1.86	2.05	1.48	1.20	1.38	1.46	1.67	1.84	1.18	1.37	1.34	2.25	1.36	2.14	1.47	2.45
	Quartz	2.53	3.26	4.38	2.13	1.67	1.35	1.22	2.97	1.95	1.81	1.87	1.80	2.88	0.94	2.25	2.70
	K-Feldspar	0.33	0.33	0.61	0.05	0.10	0.09	0.05	0.11	0.09	0.06	0.22	0.16	0.38	0.04	0.10	0.18
	Plagioclase	0.44	1.14	1.42	0.69	0.46	0.53	0.29	0.62	0.51	0.42	0.40	0.36	0.90	0.22	0.73	0.51
	Pyroxene	1.19	1.90	1.50	3.59	3.65	3.18	3.18	4.73	4.55	4.34	5.42	3.16	0.84	1.64	6.42	3.84
	Garnet	11.37	13.38	11.65	13.62	13.06	13.91	13.61	11.26	11.85	11.14	9.63	11.61	8.57	12.74	11.04	12.69
	Amphibole	17.71	29.35	28.40	39.27	43.63	41.99	37.93	43.71	40.96	44.17	46.81	41.94	15.39	29.34	51.56	33.56
	Mica	0.19	0.28	0.28	0.28	0.38	0.32	0.28	0.47	0.40	0.48	0.49	0.24	0.19	0.15	0.72	0.44
	Staurolite	3.71	2.47	1.35	0.86	0.65	0.78	1.07	0.94	0.79	1.01	0.90	1.86	1.70	2.68	0.46	1.18
	Wollastonite	0.08	0.10	0.09	0.23	0.23	0.27	0.25	0.31	0.24	0.30	0.31	0.16	0.03	0.08	0.58	0.31
	Schorl-Tourmaline	2.31	2.61	2.35	2.54	2.64	2.28	2.79	2.58	2.58	2.50	2.05	2.59	1.69	3.04	2.53	2.11
	Chlorite	1.66	1.52	1.28	1.05	0.73	1.26	1.00	0.68	0.69	0.83	0.65	1.22	1.45	1.66	0.50	0.44
	Epidote	0.14	0.31	0.34	0.38	0.36	0.28	0.32	0.34	0.32	0.41	0.43	0.26	0.16	0.25	0.59	0.77
	Calcite	<0.01	<0.01	<0.01	0.03	0.05	0.02	<0.01	0.07	0.04	0.05	0.02	n.d.	<0.01	<0.01	0.35	0.23
	Pyrite	<0.01	0.12	0.03	<0.01	0.07	0.70	0.01	0.05	0.08	0.08	<0.01	0.27	0.07	0.11	0.02	0.08
Mixed-Unclassifiable Spectra	Silicates-Altered to Clays	0.13	0.21	0.22	0.23	0.21	0.21	0.18	0.19	0.23	0.22	0.20	0.16	0.13	0.16	0.34	0.27
	Low Counts	0.02	0.01	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.04	0.03	0.02	0.03
	Others	0.60	0.59	0.49	0.63	0.57	0.65	0.57	0.48	0.54	0.75	0.46	0.49	0.47	0.52	0.69	0.78
	Sum	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Actlabd ID: A16-11430-	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Client ID	R-11355	SinkR-11356	SinkR-11357	SinkR-11358	SinkR-11359	SinkR-11360	SinkR-11361	SinkR-11362	SinkR-11363	SinkR-11364	SinkR-11365	SinkR-11366	SinkR-11367	SinkR-11368	SinkR-11372	SinkR-11375 Sink



s

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01

Size Distribution of Ilmenite

Sieve Size in Micron/ Cumulative Passing	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	1	2	2	1	1	1	1	1	1	1	1	3	1	1	2	1
S<=5	2	4	3	2	2	2	2	2	2	2	2	4	1	2	3	1
S<=10	7	9	7	6	6	5	6	6	7	7	7	12	4	7	9	5
S<=13.25	8	12	10	8	8	6	7	9	9	9	9	15	5	8	14	7
S<=18.75	10	17	12	12	12	9	10	13	15	14	14	18	7	11	20	10
S<=26.5	14	21	15	17	19	14	15	18	21	20	19	22	9	14	29	17
S<=37.5	17	30	21	30	36	24	28	30	32	32	27	30	11	21	48	26
S<=53	26	39	38	49	63	50	49	51	50	55	51	43	17	34	73	42
S<=75	42	61	60	84	89	83	73	74	77	81	85	61	33	57	89	70
S<=106	65	80	84	100	99	97	97	95	96	99	99	83	66	77	100	89
S<=150	86	93	98	100	100	100	98	100	99	100	100	96	90	95	100	94
S<=212	98	100	100	100	100	100	100	100	100	100	100	100	99	99	100	100
S<=300	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Size Distribution of Ilmenite lower Ti

Sieve Size in Micron/ Cumulative Passing	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	56	56	58	55	56	49	54	53	52	53	51	49	51	54	43	55
S<=5	72	71	74	72	70	67	71	70	67	67	65	60	66	70	59	69
S<=10	96	93	98	98	97	96	97	96	97	95	93	91	95	98	89	93
S<=13.25	99	96	99	99	99	98	98	100	98	97	94	94	96	99	100	97
S<=18.75	100	97	100	100	100	98	100	100	99	100	95	96	97	100	100	97
S<=26.5	100	97	100	100	100	100	100	100	100	100	95	100	97	100	100	97
S<=37.5	100	98	100	100	100	100	100	100	100	100	95	100	97	100	100	97
S<=53	100	98	100	100	100	100	100	100	100	100	100	100	97	100	100	100
S<=75	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Size Distribution of Pseudobrookite

Sieve Size in Micron/ Cumulative Passing	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	57	56	60	43	43	44	52	55	48	51	58	41	54	46	66	57
S<=5	76	76	76	59	60	55	72	72	63	69	73	47	74	57	81	77
S<=10	99	99	99	83	86	69	98	98	96	97	97	93	99	84	99	98
S<=13.25	100	100	100	87	88	69	100	100	99	99	98	98	100	96	100	99
S<=18.75	100	100	100	93	89	70	100	100	99	100	100	100	100	100	100	100
S<=26.5	100	100	100	100	100	70	100	100	100	100	100	100	100	100	100	100
S<=37.5	100	100	100	100	100	70	100	100	100	100	100	100	100	100	100	100
S<=53	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Size Distribution of Rutile

Sieve Size in Micron/ Cumulative Passing	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	3	4	3	4	4	3	3	4	4	3	3	5	1	4	5	3
S<=5	5	6	4	7	7	6	6	8	7	6	5	9	2	6	9	4
S<=10	18	22	13	21	20	15	18	25	19	18	16	24	6	15	27	12
S<=13.25	21	32	17	27	26	23	24	34	27	24	21	30	7	18	36	15
S<=18.75	23	40	21	32	34	38	28	41	35	32	31	36	7	24	48	22
S<=26.5	23	53	25	40	49	38	35	44	44	41	37	45	9	27	61	36
S<=37.5	23	60	41	55	73	63	42	54	60	48	53	53	13	33	78	46
S<=53	37	74	48	70	81	70	50	80	80	65	61	67	15	55	92	73
S<=75	53	88	73	82	93	88	67	87	94	82	84	91	24	70	95	80
S<=106	83	100	89	100	100	88	76	100	100	100	100	92	49	82	100	100
S<=150	100	100	100	100	100	100	83	100	100	100	100	100	100	100	100	100
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Size Distribution of Rutile-Altered

Sieve Size in Micron/ Cumulative Passing	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	6	6	5	5	5	6	5	6	5	5	5	3	5	5	5	6
S<=5	9	10	9	8	8	9	9	9	9	8	8	5	8	8	8	10
S<=10	18	24	23	22	23	20	21	25	26	23	23	14	18	18	28	27
S<=13.25	23	29	28	27	32	25	30	34	33	30	30	17	21	23	37	33
S<=18.75	27	35	32	36	39	35	35	46	45	39	35	22	25	27	46	44
S<=26.5	29	42	38	50	47	45	41	52	51	47	43	28	31	33	52	50
S<=37.5	39	48	45	57	54	53	47	58	58	55	51	38	38	40	66	64
S<=53	42	53	54	72	65	60	53	73	69	65	61	48	46	48	87	76
S<=75	50	63	67	84	83	71	67	80	84	80	75	61	59	60	97	88
S<=106	61	88	83	97	93	95	81	91	96	96	87	76	76	73	100	94
S<=150	89	91	95	100	100	100	84	100	100	100	97	89	88	95	100	97
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Size Distribution of Pseudorutile

Sieve Size in Micron/ Cumulative Passing	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	28	30	32	38	47	41	33	37	43	38	42	39	34	34	56	40
S<=5	42	43	47	52	65	56	48	52	58	55	58	52	49	51	71	54
S<=10	83	80	88	87	98	91	92	84	96	98	91	90	97	97	97	97
S<=13.25	85	87	91	92	100	99	97	89	100	100	94	93	99	99	100	100
S<=18.75	90	95	93	100	100	100	100	100	100	100	94	93	100	100	100	100
S<=26.5	94	100	93	100	100	100	100	100	100	100	100	93	100	100	100	100
S<=37.5	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=53	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Size Distribution of Leucoxene

Sieve Size in Micron/ Cumulative Passing	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	32	25	21	21	17	30	16	16	17	16	14	13	6	29	17	19
S<=5	43	34	30	31	25	44	24	25	25	25	22	18	8	40	28	29
S<=10	88	66	67	65	62	82	54	62	61	65	55	43	14	72	69	65
S<=13.25	95	74	85	76	74	90	59	75	71	75	64	53	16	78	83	81
S<=18.75	97	84	98	79	85	99	63	91	84	83	77	59	20	83	92	92
S<=26.5	99	94	100	85	91	99	71	95	91	88	84	67	24	86	98	94
S<=37.5	99	94	100	89	92	100	82	98	98	93	93	71	29	89	98	94
S<=53	100	100	100	92	93	100	96	100	99	93	100	72	40	89	100	100
S<=75	100	100	100	100	100	100	100	100	100	100	100	92	51	89	100	100
S<=106	100	100	100	100	100	100	100	100	100	100	100	100	68	89	100	100
S<=150	100	100	100	100	100	100	100	100	100	100	100	100	93	100	100	100
S<=212													100			

Size Distribution of Hematite-Ti

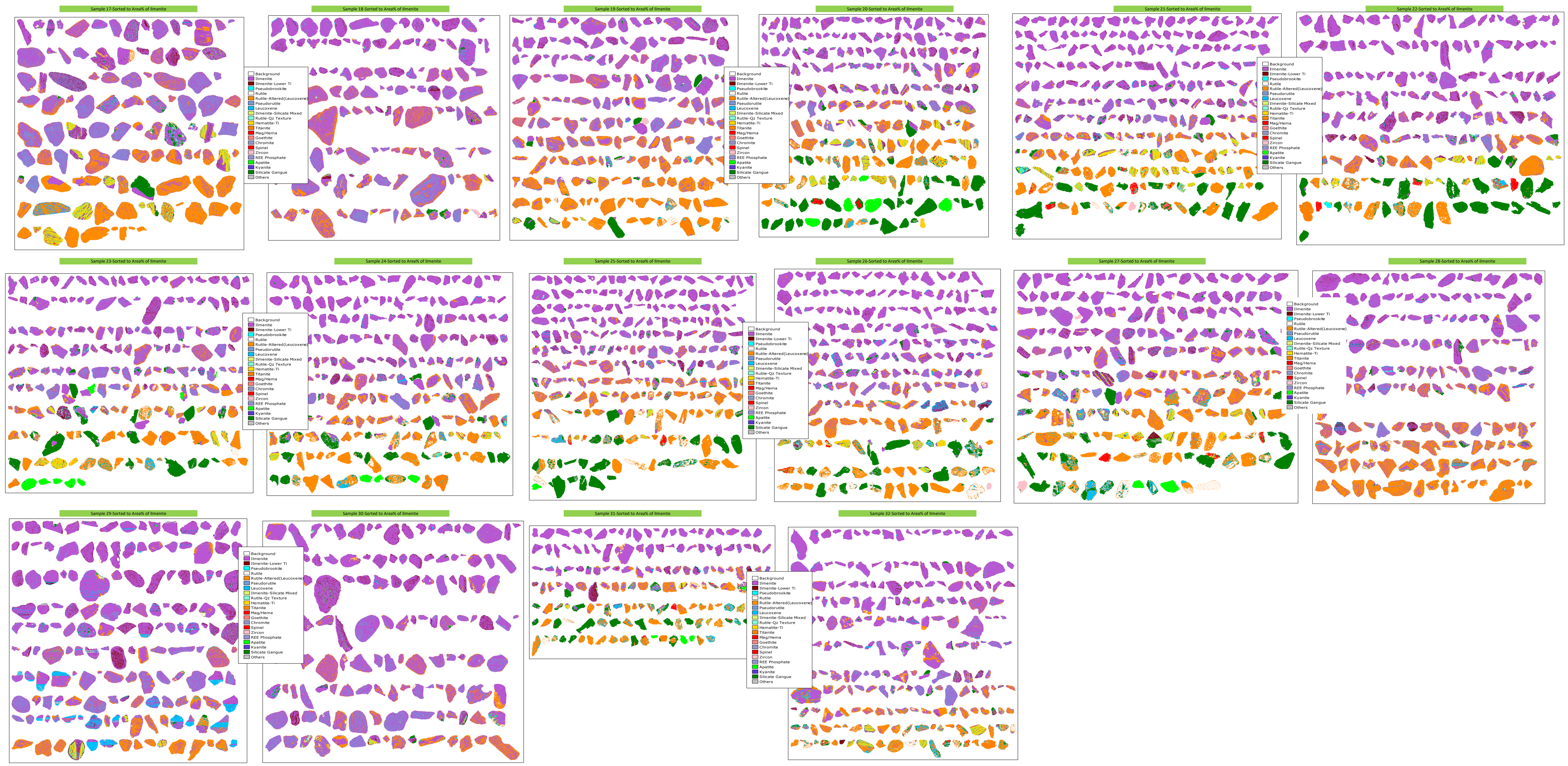
Sieve Size in Micron/ Cumulative Passing	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	3	2	7	3	4	5	1	4	6	4	4	6	4	8	8	5
S<=5	4	3	10	5	6	8	2	5	10	7	6	10	6	12	12	7
S<=10	15	9	19	13	21	23	6	16	24	20	26	24	12	16	38	18
S<=13.25	19	11	38	18	31	35	7	20	34	27	40	29	14	16	51	22
S<=18.75	21	46	61	27	49	49	16	39	56	48	55	36	34	16	65	32
S<=26.5	34	71	66	39	65	73	44	45	67	60	74	71	85	24	92	36
S<=37.5	54	73	75	70	87	93	58	66	100	74	93	100	85	63	100	48
S<=53	100	73	75	96	100	100	76	82	100	100	93	100	100	100	100	91
S<=75	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=106																

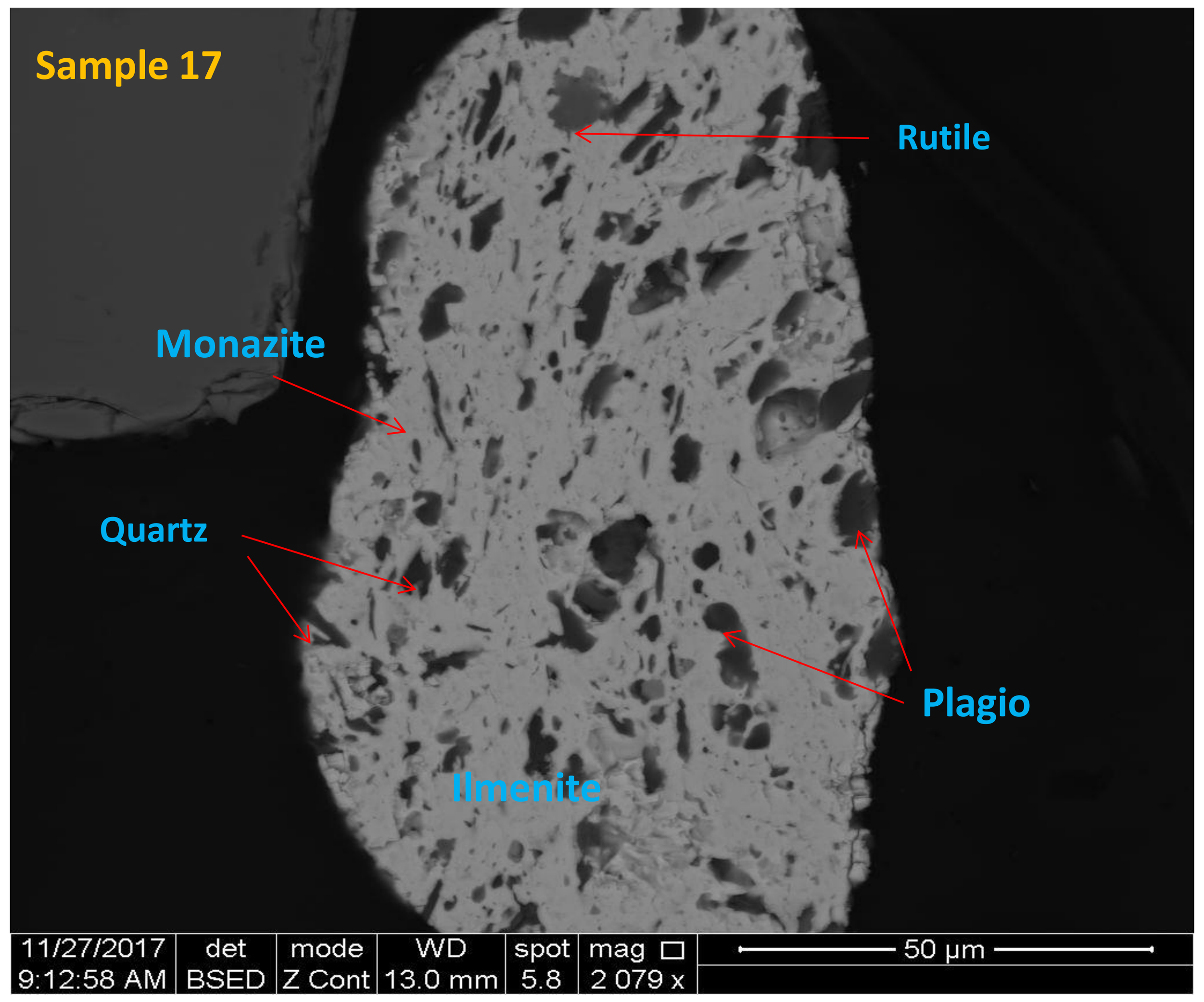
Size Distribution of Titanite

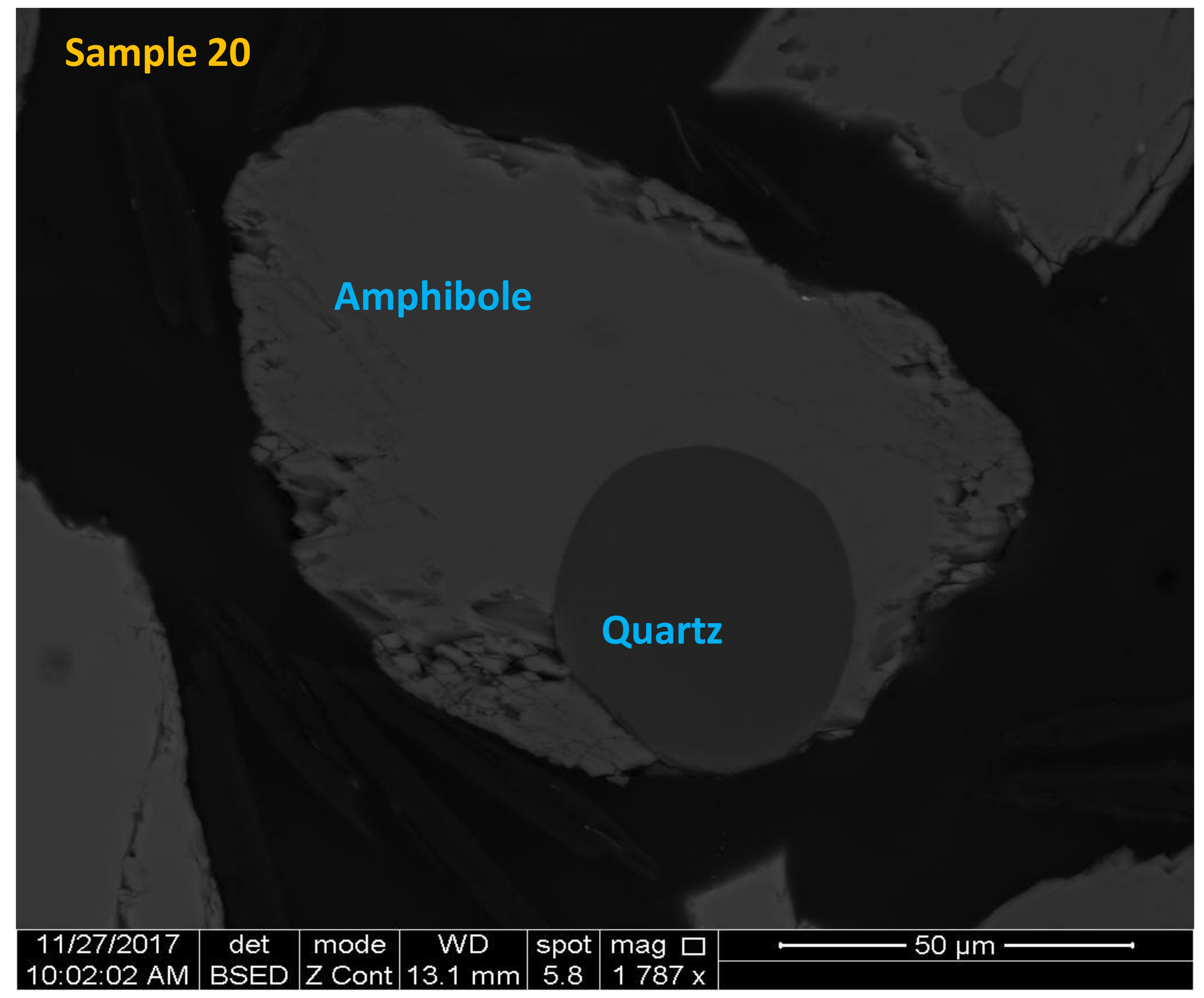
Sieve Size in Micron/ Cumulative Passing	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0
S<=5	0	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1
S<=10	2	4	2	2	4	2	1	3	5	2	4	3	1	2	3	3
S<=13.25	3	4	3	2	6	4	2	5	7	3	5	4	2	3	5	4
S<=18.75	3	8	6	3	7	6	3	7	8	7	7	5	4	4	6	8
S<=26.5	4	11	10	7	12	8	6	12	14	12	15	11	7	6	12	12
S<=37.5	6	19	10	10	18	11	7	21	20	23	24	20	14	8	21	24
S<=53	12	28	15	14	39	24	13	42	39	29	33	45	28	18	41	37
S<=75	23	54	30	33	74	63	41	61	63	64	71	70	42	38	79	77
S<=106	23	89	71	75	94	81	82	100	81	100	100	86	42	53	100	93
S<=150	23	100	78	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

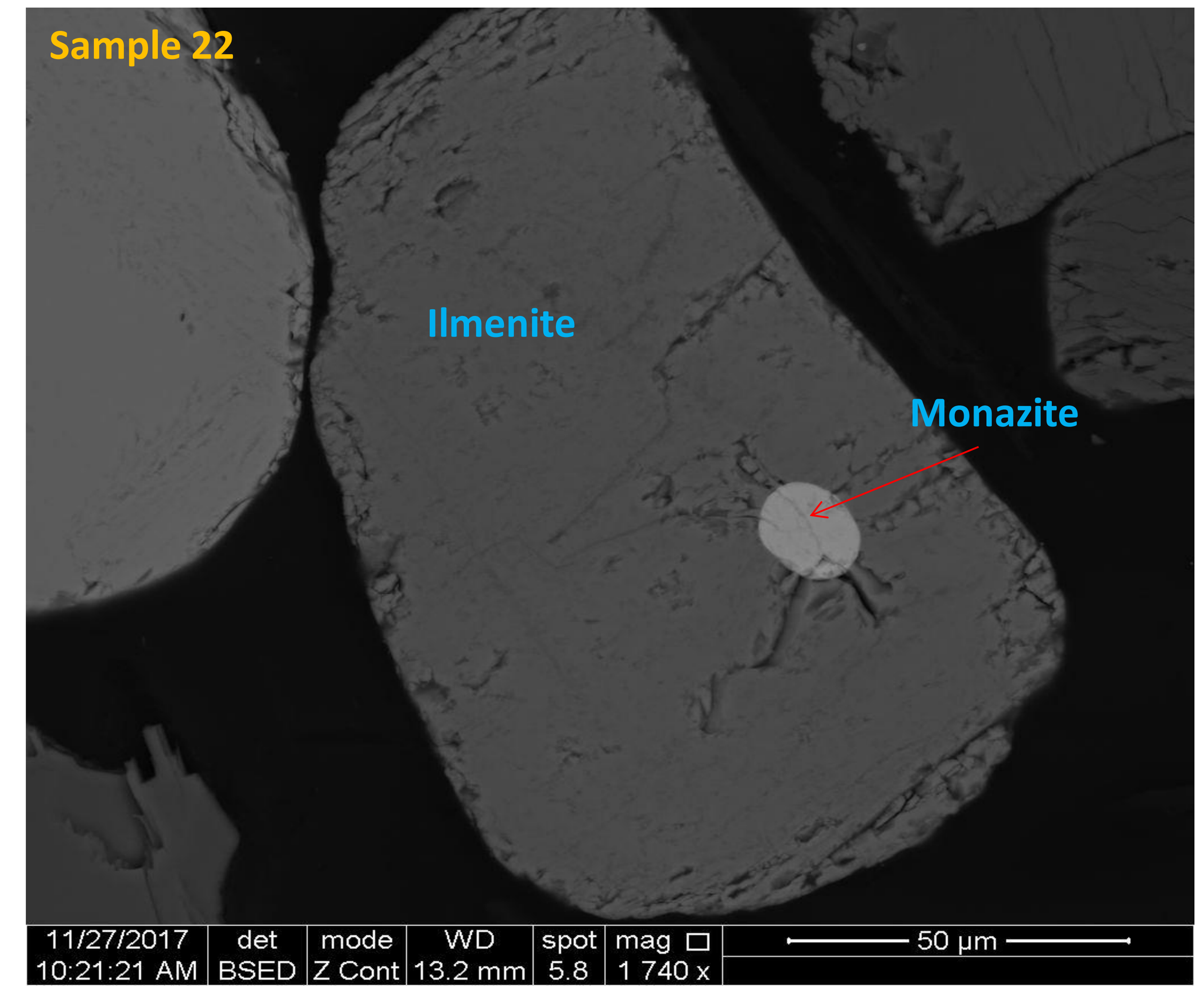
Size Distribution of Zircon

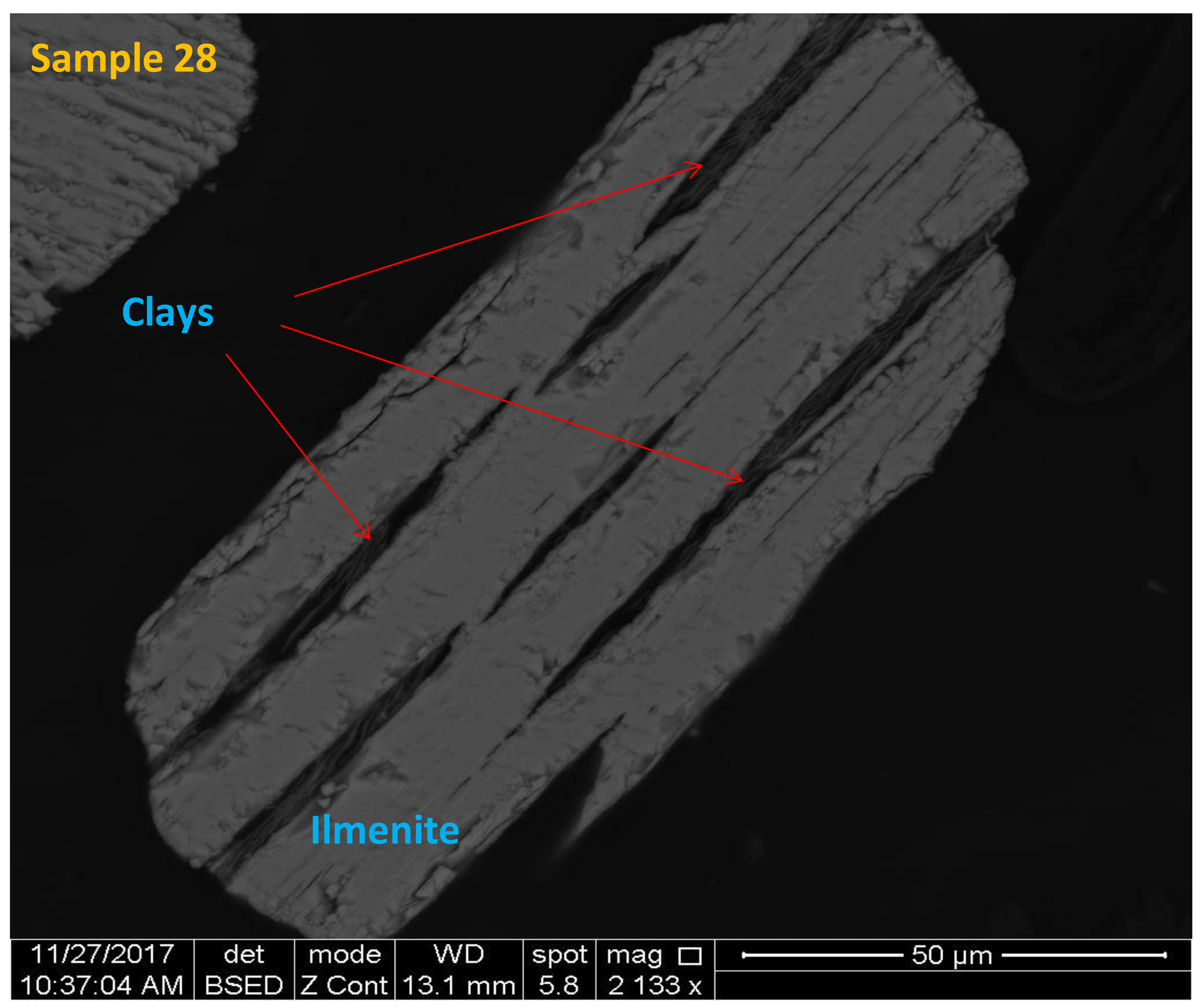
Sieve Size in Micron/ Cumulative Passing	VC-001A 1/3	VC-001A 2/3	VC-001A 3/3	VC-002B 1/2	VC-002B 2/2	VC-003 1/2	VC-003 2/2	VC-004 1/3	VC-004 2/3	VC-004 3/3	VC-005 2/3	VC-005 2/3 RED	VC-005 3/3	G-109-03	G-500-03	G-501-01
S<=3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S<=5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S<=10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S<=13.25	0	1	0	1	1	0	0	0	0	1	0	0	0	0	1	0
S<=18.75	0	1	0	1	1	1	1	1	1	2	1	0	0	0	1	0
S<=26.5	0	2	1	3	3	2	2	1	2	2	3	1	0	0	6	2
S<=37.5	0	5	1	5	10	6	4	5	7	4	5	2	1	0	23	5
S<=53	1	19	7	18	35	14	12	19	19	20	15	10	2	5	42	7
S<=75	9	42	26	60	73	44	48	50	43	70	49	28	5	13	67	30
S<=106	20	67	63	85	97	89	78	84	100	86	89	68	28	35	100	80
S<=150	61	100	92	100	100	100	94	84	100	100	94	100	72	52	100	100
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100	92	100	100
S<=300	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

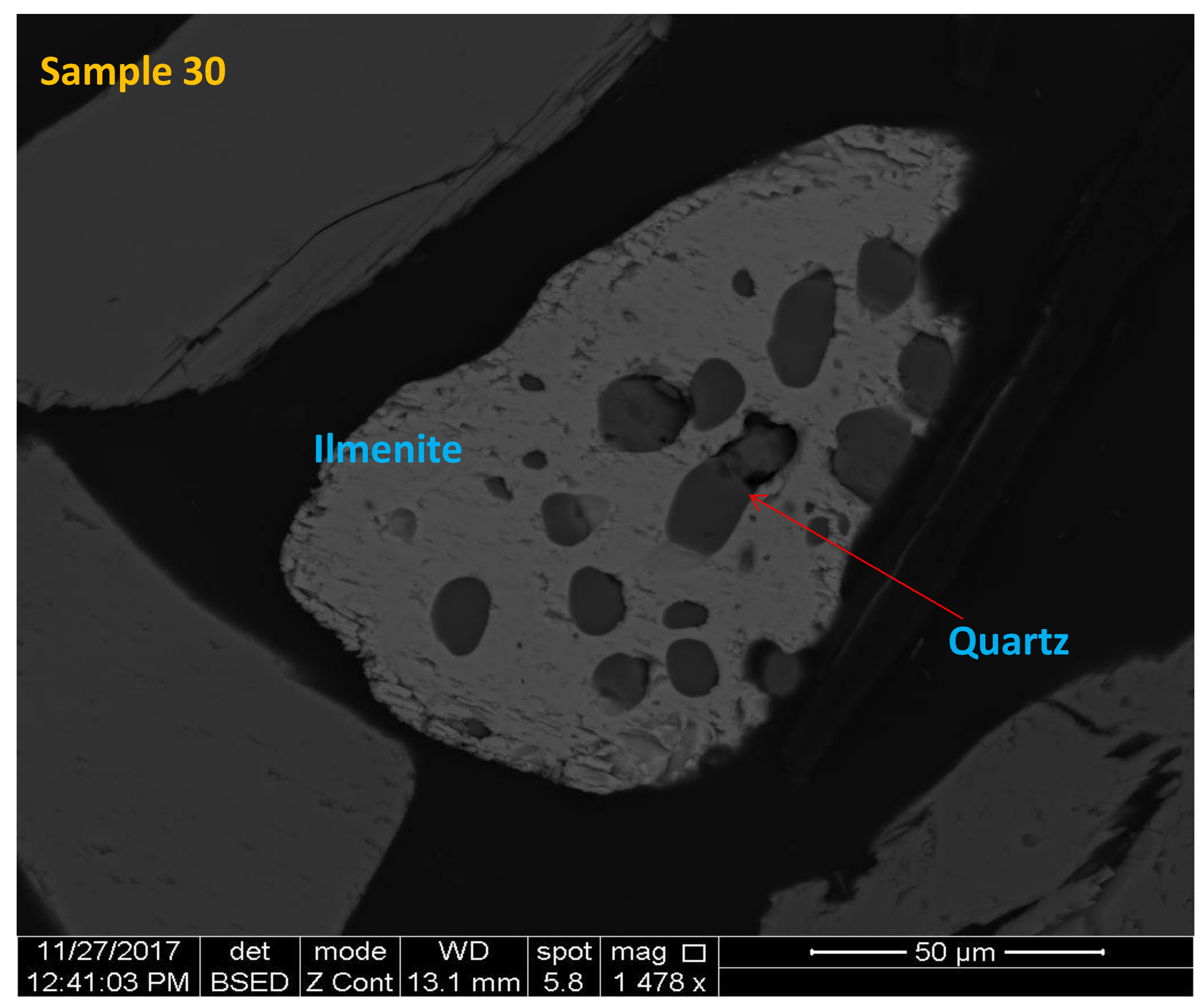

Sample 17-Sorted to Area% of Ilmenite
Sample 18-Sorted to Area% of Ilmenite
Sample 19-Sorted to Area% of Ilmenite
Sample 20-Sorted to Area% of Ilmenite
Sample 21-Sorted to Area% of Ilmenite
Sample 22-Sorted to Area% of Ilmenite
Sample 23-Sorted to Area% of Ilmenite
Sample 24-Sorted to Area% of Ilmenite
Sample 25-Sorted to Area% of Ilmenite
Sample 26-Sorted to Area% of Ilmenite
Sample 27-Sorted to Area% of Ilmenite
Sample 28-Sorted to Area% of Ilmenite
Sample 29-Sorted to Area% of Ilmenite
Sample 30-Sorted to Area% of Ilmenite
Sample 31-Sorted to Area% of Ilmenite
Sample 32-Sorted to Area% of Ilmenite
Background
Ilmenite
Ilmenite-Lower Ti
Pseudobrookite
Rutile
Rutile-Altered(Leucoxene)
Pseudorutile
Leucoxene
Ilmenite-Silicate Mixed
Rutile-Qz Texture
Hematite-Ti
Titanite
Mag/Hema
Goethite
Chromite
Spinel
Zircon
REE Phosphate
Apatite
Kyanite
Silicate Gangue
Others

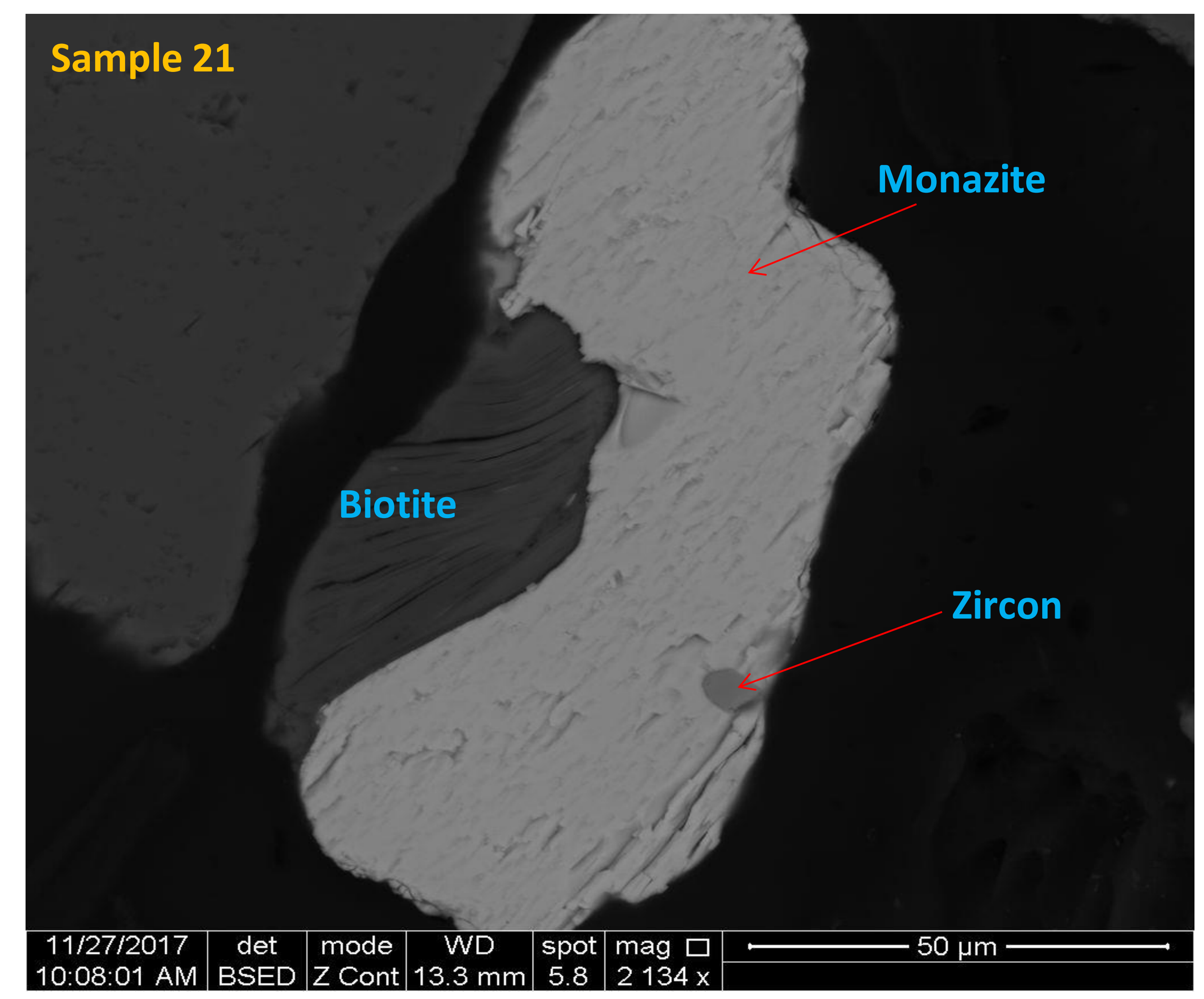

Sample 17
Rutile
Monazite
Quartz
Plagio
Ilmenite
11/27/2017 9:12:58 AM | det BSED | mode Z Cont | WD 13.0 mm | spot 5.8 | mag 2 079 x | 50 µm

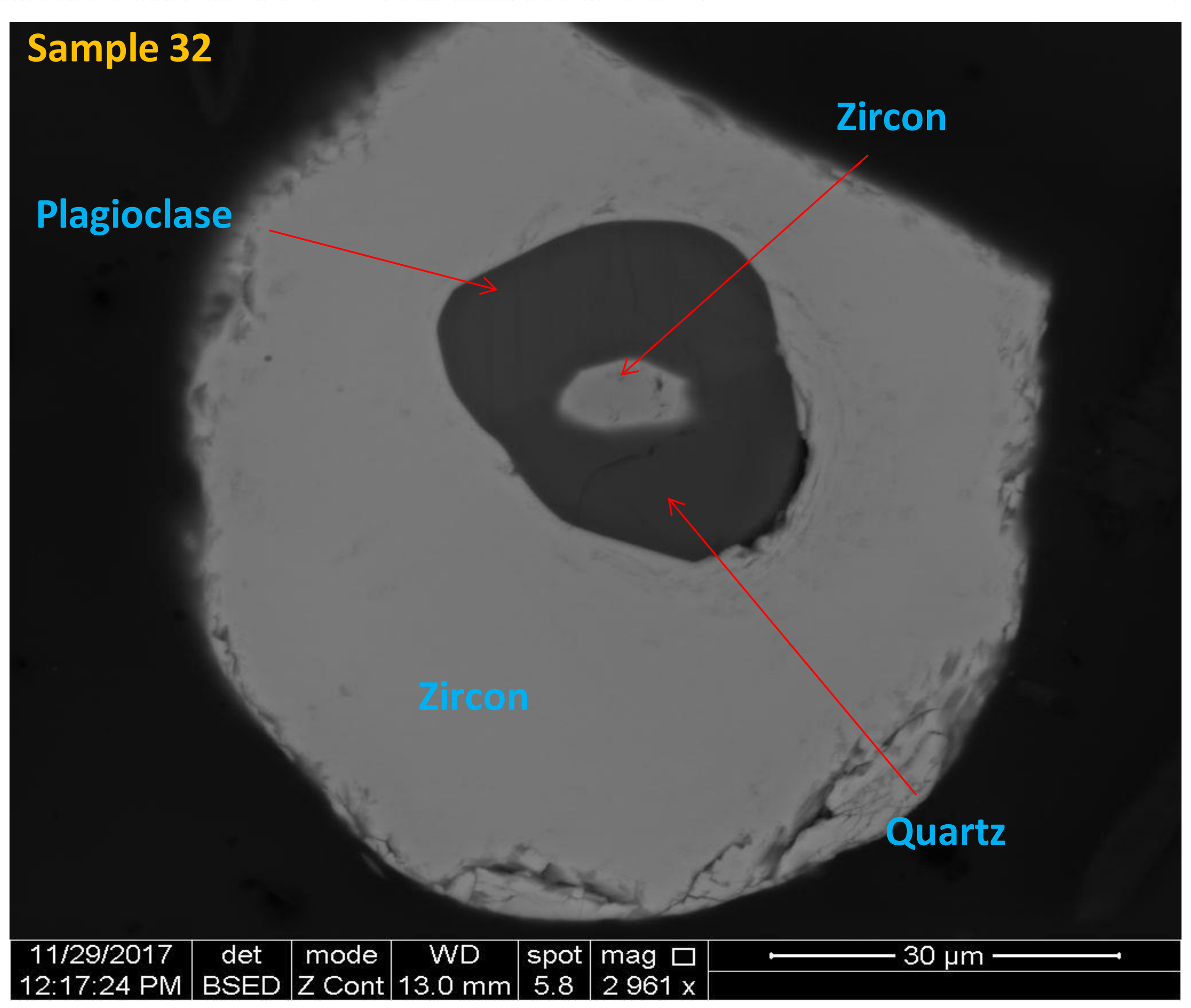

Sample 20
Amphibole
Quartz
11/27/2017 10:02:02 AM | det BSED | mode Z Cont | WD 13.1 mm | spot 5.8 | mag 1 787 x | 50 µm


Sample 22
Ilmenite
Monazite
11/27/2017 10:21:21 AM | det BSED | mode Z Cont | WD 13.2 mm | spot 5.8 | mag 1 740 x | 50 µm


Sample 28
Clays
Ilmenite
11/27/2017 10:37:04 AM | det BSED | mode Z Cont | WD 13.1 mm | spot 5.8 | mag 2 133 x | 50 µm


Sample 30
Ilmenite
Quartz
11/27/2017 12:41:03 PM | det BSED | mode Z Cont | WD 13.1 mm | spot 5.8 | mag 1 478 x | 50 µm


Sample 21
Monazite
Biotite
Zircon
11/27/2017 10:08:01 AM | det BSED | mode Z Cont | WD 13.3 mm | spot 5.8 | mag 2 134 x | 50 µm


Sample 32
Zircon
Plagioclase
Zircon
Quartz
11/29/2017 12:17:24 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 5.8 | mag 2 961 x | 30 µm

Sample	Mass (g)		
	Sinks	Floats	% Sinks
R-11355	19.26	33.31	37%
R-11356	20.2	38.47	34%
R-11357	22.42	31.32	42%
R-11358	25.45	35.73	42%
R-11359	21.2	31.96	40%
R-11360	18.71	25.77	42%
R-11361	13.98	28.85	33%
R-11362	10.42	34.58	23%
R-11363	12.32	32.55	27%
R-11364	11.14	28.28	28%
R-11365	7.15	33.30	18%
R-11366	4.56	40.14	10%
R-11367	18.27	36.06	34%
R-11368	9.04	28.20	24%
R-11372	3.62	37.19	9%
R-11375	5.14	35.61	13%

Quality Analysis ... **Actlabs** Innovative Technologies

Date Submitted: 16-Oct-17
Invoice No.: A17-11430 (i)
Invoice Date: 07-Dec-17
Your Reference:

VA DMME
900 Natural Resources Drives Suite 500
Charlottesville VIRGINIA 22903
United States

ATTN: William Lassetter

CERTIFICATE OF ANALYSIS

48 Heavy Mineral Concentrates samples were submitted for analysis.

The following analytical package(s) were requested: Code 4LITHORES (11+) Major Elements Fusion ICP(WRA)/Trace Elements Fusion ICP/MS(WRA4B2)

Code MLA Schedule 1 MLA Schedule 1

REPORT **A17-11430 (i)**

This report may be reproduced without our consent. If only selected portions of the report are reproduced, permission must be obtained. If no instructions were given at time of sample submittal regarding excess material, it will be discarded within 90 days of this report. Our liability is limited solely to the analytical cost of these analyses. Test results are representative only of material submitted for analysis.

Notes:

We recommend using option 4B1 for accurate levels of the base metals Cu, Pb, Zn, Ni and Ag. Option 4B-INAA for As, Sb, high W >100ppm, Cr >1000ppm and Sn >50ppm by Code 5D. Values for these elements provided by Fusion ICP/MS, are order of magnitude only and are provided for general information. Mineralized samples should have the Quant option selected or request assays for values which exceed the range of option 4B1. Total includes all elements in % oxide to the left of total. Zr is now being reported from FUS-ICP instead of FUS-MS.

Note: Cannot report Ag due to interference from Zr.

CERTIFIED BY:

Emmanuel Eseme , Ph.D.
Quality Control

ACTIVATION LABORATORIES LTD.
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TELEPHONE +905 648-9611 or +1.888.228.5227 FAX +1.905.648.9613
E-MAIL Ancaster@actlabs.com ACTLABS GROUP WEBSITE www.actlabs.com

Date Submitted: 16-Oct-17
Invoice No.: A17-11430 (i)
Invoice Date: 07-Dec-17
Your Reference:

VA DMME
900 Natural Resources Drives Suite 500
Charlottesville VIRGINIA 22903
United States

ATTN: William Lassetter

CERTIFICATE OF ANALYSIS

48 Heavy Mineral Concentrates samples were submitted for analysis.

The following analytical package(s) were requested: Code Metallurgy Metallurgy

REPORT **A17-11430 (i)**

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Notes:

We recommend using option 4B1 for accurate levels of the base metals Cu, Pb, Zn, Ni and Ag. Option 4B-INAA for As, Sb, high W >100ppm, Cr >1000ppm and Sn >50ppm by Code 5D. Values for these elements provided by Fusion ICP/MS, are order of magnitude only and are provided for general information. Mineralized samples should have the Quant option selected or request assays for values which exceed the range of option 4B1. Total includes all elements in % oxide to the left of total. Zr is now being reported from FUS-ICP instead of FUS-MS.

Note: Cannot report Ag due to interference from Zr.

CERTIFIED BY:

Emmanuel Eseme , Ph.D.
Quality Control

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E-MAIL Tbay@actlabs.com ACTLABS GROUP WEBSITE www.actlabs.com

Analyte Symbol	SiO2	Al2O3	Fe2O3(T)	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	LOI	Total	Sc	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	As
Unit Symbol	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01		0.01	1	1	5	20	1	20	10	30	1	0.5	5
Method Code	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
R-11355 Sinks	26.47	12.03	28.44	0.855	3.74	4.18	0.47	0.30	21.73	0.15	-0.68	97.68	57	2	508	650	36	100	20	380	31	3.2	10
R-11356 Sinks	30.10	11.89	24.90	0.717	4.43	6.18	0.61	0.38	18.67	0.41	-0.24	98.04	58	2	471	550	37	120	30	340	34	3.6	14
R-11357 Sinks	31.09	9.90	24.49	0.707	4.20	5.72	0.66	0.45	20.00	0.22	-0.33	97.12	55	1	470	560	33	120	10	280	31	3.0	8
R-11358 Sinks	33.84	10.50	23.67	0.624	5.82	8.50	0.67	0.49	12.79	0.73	-0.37	97.25	56	2	401	440	36	70	< 10	260	29	3.8	6
R-11359 Sinks	34.29	10.62	23.50	0.622	6.04	9.51	0.73	0.54	12.20	0.93	-0.21	98.77	58	2	405	420	35	80	< 10	250	29	3.6	7
R-11360 Sinks	32.96	10.77	25.86	0.704	5.88	8.78	0.66	0.46	12.50	0.72	-0.43	98.87	61	2	424	440	36	90	10	260	29	3.6	11
R-11361 Sinks	33.17	10.88	24.12	0.671	5.55	7.88	0.86	0.58	14.64	0.55	-0.46	98.44	56	2	422	460	35	100	10	270	30	3.7	8
R-11362 Sinks	34.83	10.03	22.80	0.600	6.06	8.70	0.75	0.55	13.05	0.64	-0.39	97.61	55	2	406	400	36	90	10	250	28	3.6	6
R-11363 Sinks	35.30	10.78	22.34	0.607	5.90	8.58	0.94	0.65	13.24	0.63	-0.26	98.71	55	2	404	410	34	100	10	260	28	3.5	7
R-11364 Sinks	34.14	10.19	23.52	0.629	6.05	8.72	0.75	0.54	13.51	0.69	-0.43	98.29	56	2	413	430	37	80	30	270	29	3.5	13
R-11365 Sinks	36.04	9.74	22.67	0.573	6.38	9.13	0.78	0.61	12.90	0.62	-0.34	99.11	58	2	422	400	38	110	10	260	29	3.4	7
R-11366 Sinks	32.98	12.13	22.40	0.628	5.61	7.42	0.88	0.58	16.14	0.19	-0.02	98.93	59	2	444	470	36	100	20	290	34	3.4	8
R-11367 Sinks	22.61	7.38	32.05	0.953	2.66	3.23	0.37	0.26	26.51	0.16	-1.19	95.00	51	< 1	579	800	33	150	20	340	26	2.6	10
R-11368 Sinks	26.72	11.05	27.13	0.825	4.46	5.54	0.50	0.35	21.81	0.17	-0.56	97.98	61	2	517	580	37	130	< 10	330	35	3.1	10
R-11372 Sinks	39.75	10.44	19.10	0.433	7.12	11.70	0.96	0.71	8.156	1.13	0.36	99.86	61	3	359	310	36	90	30	240	27	3.7	6
R-11375 Sinks	33.39	10.20	22.97	0.635	4.73	8.29	1.14	0.72	16.36	0.70	-0.19	98.93	53	2	440	390	31	100	20	310	27	3.2	8

Analyte Symbol	Rb	Sr	Y	Zr	Nb	Mo	Ag	In	Sn	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	1	2	0.5	1	0.2	2		0.1	1	0.2	0.1	2	0.05	0.05	0.01	0.05	0.01	0.005	0.01	0.01	0.01	0.01	0.01
Method Code	FUS-MS	FUS-ICP	FUS-MS	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
R-11355 Sinks	5	92	183	> 10000	248	8		0.3	16	1.7	0.8	74	140	307	36.8	138	27.5	3.58	22.7	4.05	26.9	6.30	21.7
R-11356 Sinks	5	168	221	> 10000	208	8		0.3	48	9.1	0.1	128	202	449	55.7	213	42.2	6.25	34.2	5.68	35.9	7.64	24.5
R-11357 Sinks	6	166	211	> 10000	240	8		0.3	14	1.1	0.2	100	233	514	62.5	237	45.6	5.91	35.5	5.59	33.5	7.31	24.0
R-11358 Sinks	6	172	267	> 10000	155	5		0.3	14	1.4	0.1	77	274	613	77.2	299	59.5	8.79	47.5	7.62	44.9	9.27	28.8
R-11359 Sinks	7	202	277	8741	130	4		0.3	10	0.7	0.2	73	259	590	74.3	295	60.7	9.33	48.9	7.77	46.1	9.63	29.6
R-11360 Sinks	5	175	242	8994	151	5		0.3	12	1.4	< 0.1	71	211	473	59.6	234	47.3	7.13	41.0	6.59	40.6	8.49	26.5
R-11361 Sinks	8	162	245	> 10000	172	6		0.3	14	1.1	0.2	75	253	570	71.8	281	55.6	8.48	43.5	6.88	39.9	8.45	26.8
R-11362 Sinks	7	173	229	8452	151	5		0.3	12	1.4	0.2	83	223	514	65.5	259	53.4	8.55	42.4	6.81	39.9	8.08	25.3
R-11363 Sinks	9	174	241	9194	155	5		0.3	12	1.3	0.2	80	245	562	71.5	280	57.4	8.80	44.9	6.90	41.2	8.41	26.5
R-11364 Sinks	7	176	246	9287	164	6		0.3	48	12.2	0.1	115	242	560	70.9	277	56.3	8.98	45.4	7.18	41.8	8.52	26.7
R-11365 Sinks	8	170	210	5931	152	5		0.3	13	1.6	0.2	88	214	498	63.8	254	51.9	8.28	41.0	6.32	37.2	7.48	22.9
R-11366 Sinks	7	188	175	9191	170	7		0.3	21	1.2	0.2	91	158	353	44.4	173	34.8	5.20	29.1	4.74	28.4	6.04	19.6
R-11367 Sinks	4	88	212	> 10000	334	10		0.4	23	3.0	< 0.1	85	259	552	66.7	246	44.1	4.24	33.6	4.89	30.3	6.92	24.5
R-11368 Sinks	4	132	197	> 10000	254	9		0.3	17	1.3	< 0.1	82	200	442	53.1	203	38.7	4.99	30.7	4.83	31.2	6.89	22.4
R-11372 Sinks	10	219	195	1424	82.3	3		0.3	8	1.1	0.2	88	152	358	47.4	195	43.5	7.42	38.0	6.39	36.4	7.28	21.1
R-11375 Sinks	10	199	216	8507	195	6		0.2	12	1.4	0.3	80	225	500	62.2	239	48.7	7.26	40.7	6.47	37.6	7.69	23.1

Analyte Symbol	Tm	Yb	Lu	Hf	Ta	W	Tl	Pb	Bi	Th	U
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.005	0.01	0.002	0.1	0.01	0.5	0.05	5	0.1	0.05	0.01
Method Code	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
R-11355 Sinks	3.71	28.0	4.79	419	18.7	331	< 0.05	86	0.3	46.0	15.4
R-11356 Sinks	3.95	29.7	5.07	349	14.9	209	< 0.05	280	0.2	55.3	17.7
R-11357 Sinks	3.90	29.6	5.16	476	17.3	176	< 0.05	60	0.3	69.8	21.1
R-11358 Sinks	4.37	31.8	5.40	288	11.2	176	< 0.05	53	0.2	64.4	20.3
R-11359 Sinks	4.51	32.6	5.30	227	9.30	122	< 0.05	30	0.2	55.6	19.5
R-11360 Sinks	4.13	29.5	4.87	252	11.1	179	< 0.05	41	0.2	52.7	16.2
R-11361 Sinks	4.30	30.5	5.18	318	12.2	163	< 0.05	52	0.2	59.8	19.5
R-11362 Sinks	3.93	28.0	4.49	233	11.0	134	< 0.05	41	0.2	45.9	17.0
R-11363 Sinks	4.16	29.2	4.72	255	10.9	183	< 0.05	42	0.2	53.5	18.5
R-11364 Sinks	4.06	29.1	4.79	245	11.9	239	< 0.05	369	0.2	49.4	18.4
R-11365 Sinks	3.53	24.4	3.99	166	11.1	149	< 0.05	42	0.2	41.8	14.0
R-11366 Sinks	3.04	22.5	3.82	252	11.6	189	< 0.05	57	0.3	42.4	13.2
R-11367 Sinks	4.22	33.8	6.26	826	22.6	220	< 0.05	120	0.3	90.4	25.9
R-11368 Sinks	3.69	27.7	4.94	411	18.1	167	< 0.05	61	0.3	63.6	19.3
R-11372 Sinks	3.06	19.8	3.00	31.8	6.81	138	< 0.05	26	0.2	23.6	7.32
R-11375 Sinks	3.59	25.1	4.13	226	14.3	251	< 0.05	40	0.3	61.3	16.9

Analyte Symbol	SiO2	Al2O3	Fe2O3(T)	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	LOI	Total	Sc	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	As
Unit Symbol	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01		0.01	1	1	5	20	1	20	10	30	1	0.5	5
Method Code	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
NIST 694 Meas	11.25	1.90	0.75	0.010	0.34	42.52	0.88	0.55	0.120	32.25					1654								
NIST 694 Cert	11.2	1.80	0.790	0.0116	0.330	43.6	0.860	0.510	0.110	30.2					1740								
DNC-1 Meas	48.15	18.83	10.11	0.150	10.16	11.64	1.93	0.22	0.490	0.07			32		158	260	54	240	90	70	14		
DNC-1 Cert	47.15	18.34	9.97	0.150	10.13	11.49	1.890	0.234	0.480	0.070			31		148	270	57	247	100	70	15		
LKSD-3 Meas																	29	40	30	150			28
LKSD-3 Cert																	30.0	47.0	35.0	152			27.0
TDB-1 Meas																260		100	350	160			
TDB-1 Cert																251		92	323	155			
W-2a Meas	51.10	15.07	10.27	0.160	6.59	10.98	2.16	0.59	0.990	0.14			35	< 1	263	100	44		110	80	18	1.6	
W-2a Cert	52.4	15.4	10.7	0.163	6.37	10.9	2.14	0.626	1.06	0.130			36.0	1.30	262	92.0	43.0		110	80.0	17.0	1.00	
SY-4 Meas	51.11	20.68	6.27	0.110	0.51	8.22	6.97	1.68	0.280	0.12			1	3	8								
SY-4 Cert	49.9	20.69	6.21	0.108	0.54	8.05	7.10	1.66	0.287	0.131			1.1	2.6	8.0								
CTA-AC-1 Meas																			60				
CTA-AC-1 Cert																			54.0				
BIR-1a Meas	47.89	14.94	11.43	0.170	9.39	13.63	1.81	0.02	0.970	0.01			44	< 1	336	370	50	160	120	70	15		
BIR-1a Cert	47.96	15.50	11.30	0.175	9.700	13.30	1.82	0.030	0.96	0.021			44	0.58	310	370	52	170	125	70	16		
NCS DC86312 Meas																							
NCS DC86312 Cert																							
ZW-C Meas																							
ZW-C Cert																							
NCS DC86316 Meas	70.81	14.09	0.38	0.022	0.08	0.65	4.18	3.94	0.698	0.04													
NCS DC86316 Cert	70.73	14.57	0.38	0.021	0.079	0.63	4.20	3.90	0.64	0.040													
NCS DC70009 (GBW07241) Meas																30	4		890	90	16	10.5	66
NCS DC70009 (GBW07241) Cert																30	3.7		960	100	16.5	11.2	69.9
OREAS 100a (Fusion) Meas																	18		160				
OREAS 100a (Fusion) Cert																	18.1		169				
OREAS 101a (Fusion) Meas																	46		410				
OREAS 101a (Fusion) Cert																	48.8		430				
OREAS 101b (Fusion) Meas																	45		440				
OREAS 101b (Fusion) Cert																	47		420				

Analyte Symbol	SiO2	Al2O3	Fe2O3(T)	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	LOI	Total	Sc	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	As
Unit Symbol	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01		0.01	1	1	5	20	1	20	10	30	1	0.5	5
Method Code	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
JR-1 Meas																	1	< 20	< 10	30	16	2.0	16
JR-1 Cert																	0.83	1.67	2.68	30.6	16.1	1.88	16.3
NCS DC86318 Meas																							
NCS DC86318 Cert																							
AMIS 0129 Meas	9.60	2.64	62.16	0.349	2.07	0.85			22.82						2747								
AMIS 0129 Cert	9.57	2.75	62.31	0.36	2.07	0.80			22.94						2689								
R-11372 Sinks Orig	39.83	10.33	19.15	0.430	6.96	11.70	0.96	0.71	7.940	1.14	0.36	99.50	61	3	357	320	36	90	20	250	27	3.9	6
R-11372 Sinks Dup	39.66	10.55	19.06	0.436	7.28	11.70	0.96	0.72	8.372	1.12	0.36	100.2	62	3	360	310	36	90	30	240	27	3.5	5
Method Blank	< 0.01	< 0.01	< 0.01	0.002	< 0.01	< 0.01	< 0.01	< 0.01	0.025	< 0.01			< 1	< 1	< 5	< 20	< 1	< 20	< 10	< 30	< 1	< 0.5	< 5

Analyte Symbol	Rb	Sr	Y	Zr	Nb	Mo	Ag	In	Sn	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	1	2	0.5	1	0.2	2	0.5	0.1	1	0.2	0.1	2	0.05	0.05	0.01	0.05	0.01	0.005	0.01	0.01	0.01	0.01	0.01
Method Code	FUS-MS	FUS-ICP	FUS-MS	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
NIST 694 Meas																							
NIST 694 Cert																							
DNC-1 Meas		150	17.1	41								108	3.60			4.90		0.590					
DNC-1 Cert		144.0	18.0	38								118	3.6			5.20		0.59					
LKSD-3 Meas	75		32.6			< 2			3		2.5		48.0	89.9		44.7	7.80	1.40			4.90		
LKSD-3 Cert	78.0		30.0			2.00			3.00		2.30		52.0	90.0		44.0	8.00	1.50			4.90		
TDB-1 Meas	22		36.3										18.3	42.5		25.2		2.10					
TDB-1 Cert	23		36										17	41		23		2.1					
W-2a Meas	21	188	22.5	82	7.5	< 2					0.9	168	10.9	24.6		13.6	3.60					0.81	2.30
W-2a Cert	21.0	190	24.0	94.0	7.90	0.600					0.990	182	10.0	23.0		13.0	3.30					0.760	2.50
SY-4 Meas		1261		523								356											
SY-4 Cert		1191		517								340											
CTA-AC-1 Meas			280										> 2000	> 3000		1100	159	44.5	123	13.4			
CTA-AC-1 Cert			272										2176	3326		1087	162	46.7	124	13.9			
BIR-1a Meas		107	15.7	12						0.6		8	0.66	1.70		2.50	1.00	0.520	2.00		3.60		
BIR-1a Cert		110	16	18						0.58		6	0.63	1.9		2.5	1.1	0.55	2.0		4		
NCS DC86312 Meas			943										> 2000	176		1560			234	33.5	188	34.4	98.2
NCS DC86312 Cert			976										2360	190		1600			225.0	34.6	183	36	96.2
ZW-C Meas					190																		
ZW-C Cert					198																		
NCS DC86316 Meas				> 10000																			
NCS DC86316 Cert				34670.000																			
NCS DC70009 (GBW07241) Meas	532		127				1.2	1.0	> 1000	3.3	38.1		23.8	59.0	7.90	32.3	12.4	0.150	15.0	3.30	21.2	4.20	13.2
NCS DC70009 (GBW07241) Cert	500		128				1.8	1.3	1700	3.1	41		23.7	60.3	7.9	32.9	12.5	0.16	14.8	3.3	20.7	4.5	13.4
OREAS 100a (Fusion) Meas			137			22							267	469	46.5	152	23.5	3.61	21.3	3.83	23.4	4.72	14.7
OREAS 100a (Fusion) Cert			142			24.1							260	463	47.1	152	23.6	3.71	23.6	3.80	23.2	4.81	14.9
OREAS 101a (Fusion) Meas			185			21							795	1360	127	382	47.1	7.62	39.3	5.95	31.0	6.16	18.8
OREAS 101a (Fusion) Cert			183			21.9							816	1396	134	403	48.8	8.06	43.4	5.92	33.3	6.46	19.5
OREAS 101b (Fusion) Meas			189			21									136	403	52.0	8.54			33.7	6.62	20.0
OREAS 101b (Fusion) Cert			178			21									127	378	48	7.77			32.1	6.34	18.7
JR-1 Meas	248		47.1		14.7	4		< 0.1	3	1.2	19.4		19.6	46.2	5.70	22.6	5.67	0.270	5.50	0.93		1.05	3.54

Analyte Symbol	Rb	Sr	Y	Zr	Nb	Mo	Ag	In	Sn	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	1	2	0.5	1	0.2	2	0.5	0.1	1	0.2	0.1	2	0.05	0.05	0.01	0.05	0.01	0.005	0.01	0.01	0.01	0.01	0.01
Method Code	FUS-MS	FUS-ICP	FUS-MS	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
JR-1 Cert	257		45.1		15.2	3.25		0.028	2.86	1.19	20.8		19.7	47.2	5.58	23.3	6.03	0.30	5.06	1.01		1.11	3.61
NCS DC86318 Meas	400		> 10000								11.1		> 2000	437	760	> 2000	> 1000	19.6	> 1000	491	> 1000	602	> 1000
NCS DC86318 Cert	369.42		17008								10.28		1960	430	740	3430	1720	18.91	2095	470	3220	560	1750
AMIS 0129 Meas																							
AMIS 0129 Cert																							
R-11372 Sinks Orig	10	217	194	1409	84.0	2		0.3	8	1.1	0.2	87	151	357	47.3	194	43.6	7.30	37.4	6.42	36.7	7.24	21.4
R-11372 Sinks Dup	10	222	196	1439	80.6	3		0.3	8	1.1	0.2	88	152	358	47.5	196	43.5	7.55	38.6	6.36	36.2	7.32	20.9
Method Blank	< 1	< 2	< 0.5	1	< 0.2	< 2	< 0.5	< 0.1	< 1	< 0.2	< 0.1	< 2	< 0.05	< 0.05	< 0.01	< 0.05	< 0.01	< 0.005	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Analyte Symbol	Tm	Yb	Lu	Hf	Ta	W	Tl	Pb	Bi	Th	U
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.005	0.01	0.002	0.1	0.01	0.5	0.05	5	0.1	0.05	0.01
Method Code	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
NIST 694 Meas											
NIST 694 Cert											
DNC-1 Meas		1.90									
DNC-1 Cert		2.0									
LKSD-3 Meas		2.70	0.400	4.5	0.73					11.2	4.60
LKSD-3 Cert		2.70	0.400	4.80	0.700					11.4	4.60
TDB-1 Meas		3.40								2.80	
TDB-1 Cert		3.4								2.7	
W-2a Meas		2.10	0.330	2.4	0.52	1.7		9		2.40	0.55
W-2a Cert		2.10	0.330	2.60	0.500	0.300		9.30		2.40	0.530
SY-4 Meas											
SY-4 Cert											
CTA-AC-1 Meas		10.5	1.09		2.71					22.2	4.30
CTA-AC-1 Cert		11.4	1.08		2.65					21.8	4.4
BIR-1a Meas		1.70	0.300	0.6				< 5			
BIR-1a Cert		1.7	0.3	0.60				3			
NCS DC86312 Meas	13.4	84.7	12.1							23.6	
NCS DC86312 Cert	15.1	87.79	11.96							23.6	
ZW-C Meas					82.2	327	33.5				
ZW-C Cert					82	320	34				
NCS DC86316 Meas											
NCS DC86316 Cert											
NCS DC70009 (GBW07241) Meas	2.20	15.4	2.21			2140	1.70			29.5	
NCS DC70009 (GBW07241) Cert	2.2	14.9	2.4			2200	1.8			28.3	
OREAS 100a (Fusion) Meas	2.29	14.6	2.19							54.6	137
OREAS 100a (Fusion) Cert	2.31	14.9	2.26							51.6	135
OREAS 101a (Fusion) Meas	2.70	17.4	2.55							36.7	428
OREAS 101a (Fusion) Cert	2.90	17.5	2.66							36.6	422
OREAS 101b (Fusion) Meas	2.88	18.9	2.70							39.4	427
OREAS 101b (Fusion) Cert	2.66	17.6	2.58							37.1	396
JR-1 Meas	0.660	4.85	0.710	4.3	1.72	1.5		20	0.5	28.7	8.70

Analyte Symbol	Tm	Yb	Lu	Hf	Ta	W	Tl	Pb	Bi	Th	U
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.005	0.01	0.002	0.1	0.01	0.5	0.05	5	0.1	0.05	0.01
Method Code	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
JR-1 Cert	0.67	4.55	0.71	4.51	1.86	1.59		19.3	0.56	26.7	8.88
NCS DC86318 Meas	271	> 1000	251							69.5	
NCS DC86318 Cert	270	1840	260.0							67.0	
AMIS 0129 Meas											
AMIS 0129 Cert											
R-11372 Sinks Orig	3.10	20.0	3.04	32.8	7.26	139	< 0.05	27	0.2	23.7	7.35
R-11372 Sinks Dup	3.03	19.7	2.96	30.8	6.36	137	< 0.05	25	0.2	23.6	7.30
Method Blank	< 0.005	< 0.01	< 0.002	< 0.1	< 0.01	< 0.5	< 0.05	< 5	< 0.1	< 0.05	< 0.01

Actlabs Code: A18-05577
Date: June, 2018

Report and Analysis:
Mahdi Ghobadi, PhD; MahdiGhobadi@Actlabs.com
Rino Bindi, BSc

Objective:
To characterize the mineralogy of the sink fraction of the samples.

Samples:
Twenty four samples were submitted for mineralogy analysis, from which twenty one samples were required HLS procedure prior to the mineralogy test.
The weights of the sinks are presented in the corresponding sheet. A representative portion of the samples was split using Rotary Micro Riffle Splitter, to prepare 30 mm transverse polished section.

Mineralogy Methods:

The mineralogical analysis was done using FEI FEG QEMSCAN.

The QEMSCAN instrument at Actlabs is based on the scanning electron microscope FEI QUANTA 650F, that is equipped with a field-emission gun (FEG) as an electron source. FEG enables high spatial resolution and sensitivity by decreasing the spot size of the focused electron beam to values as small as 0.3 µm and providing significant target currents, in the range of tens of nA. For imaging and X-ray based micro-chemical analysis the instrument is equipped with a four-quadrant, solid state back-scattered electron (BSE) detector and two Bruker XFlash 5030 detectors. For enhanced mineral identification capabilities, energy dispersive spectroscopy (EDS) spectra with a larger than standard number of photon counts per pixel were used in this project (3000 counts per pixel vs. the standard 1000 counts per pixel). The raw X-Ray data were evaluated using a customized SIP file for this project. The modal mineralogy data as well as particle data were generated using iDiscover software.

The data for this project were produced using two modes of measurements:

1. BMA or line scan which produced modal mineralogy data.
2. PMA or particle mapping which was used to determine size distribution.

Results:

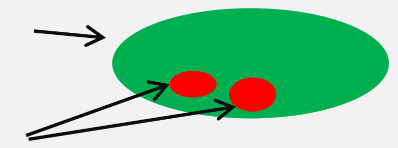
For this report modal mineralogy data and size distribution for Ti minerals are provided. Also representative mapped particle are provided, demonstrating major Ti mineral, as well as representative BSE images.

Note:

Particle Definition: A particle is a piece of material, and can contain one or more minerals.

Grain Definition: A grain is a piece of mineral matter contained within a particle.

Particle

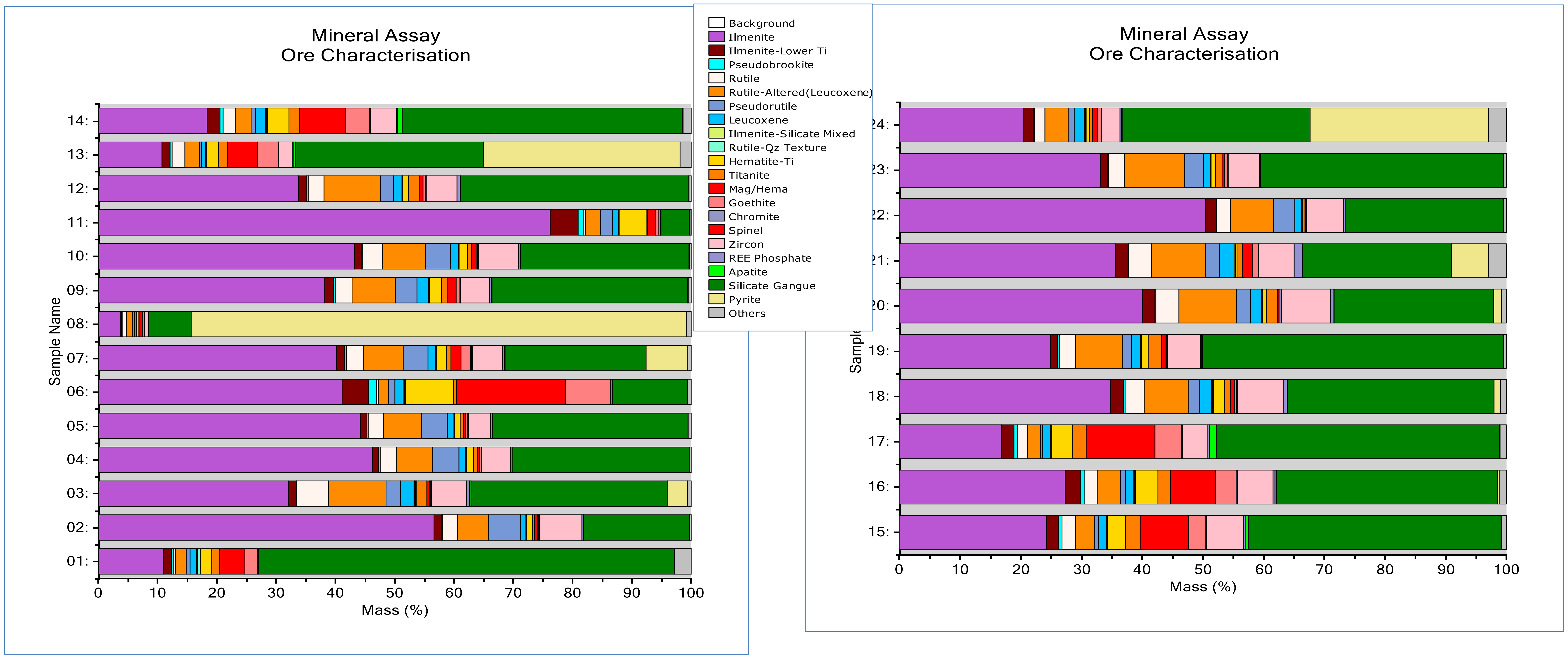


Grains

Actlab ID	Client ID	Actlab ID	Client ID
A18-05577-1	R-11007m	A18-05577-14	R-11462
A18-05577-2	R-11350a	A18-05577-15	R-11466
A18-05577-3	R-11350c	A18-05577-16	R-11470
A18-05577-4	R-11351a	A18-05577-17	R-11474
A18-05577-5	R-11351ab	A18-05577-18	R-11478
A18-05577-6	R-11351am	A18-05577-19	R-11482
A18-05577-7	R-11352a	A18-05577-20	R-11486
A18-05577-8	R-11352b	A18-05577-21	R-11488
A18-05577-9	R-11354a	A18-05577-22	R-11494
A18-05577-10	R-11354b	A18-05577-23	R-11498
A18-05577-11	R-11362m	A18-05577-24	R-11500
A18-05577-12	R-11434		
A18-05577-13	R-11441		

	Actlabd ID: A18-05577	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Client ID	R-11007m	R-11350a	R-11350c	R-11351a	R-11351ab	R-11351am	R-11352a	R-11352b	R-11354a	R-11354b	R-11362m	R-11434	R-11441	R-11462	R-11466	R-11470	R-11474	R-11478	R-11482	R-11486	R-11488	R-11494	R-11498	R-11500
	MASS %																								
Ti Minerals	Ilmenite	10.99	56.59	32.06	46.20	44.17	41.02	40.07	3.73	38.15	43.19	76.09	33.69	10.66	18.31	24.19	27.20	16.80	34.62	24.92	39.93	35.11	50.30	33.12	20.10
	Ilmenite lower Ti	1.32	1.28	1.27	1.11	1.14	4.48	1.36	0.18	1.44	1.15	4.80	1.48	1.38	2.22	2.08	2.62	2.12	2.26	1.19	2.06	2.10	1.78	1.18	1.75
	Pseudobrookite	0.37	0.21	0.05	0.24	0.21	1.39	0.31	0.04	0.35	0.26	0.97	0.22	0.34	0.51	0.52	0.67	0.54	0.34	0.21	0.15	0.06	0.06	0.18	0.10
	Rutile	0.37	2.53	5.32	2.78	2.60	0.27	2.92	0.68	2.81	3.36	0.24	2.67	2.14	2.04	2.25	2.01	1.68	2.98	2.72	3.78	3.70	2.25	2.57	1.71
	Rutile-Altered(Leucoxen	1.78	5.24	9.75	6.07	6.45	1.78	6.63	1.01	7.28	7.19	2.56	9.56	2.40	2.68	3.10	3.84	2.15	7.35	7.73	9.43	8.78	7.14	9.97	3.89
	Pseudorutile	0.65	5.32	2.45	4.43	4.28	1.03	4.18	0.40	3.67	4.23	2.02	2.17	0.37	0.78	0.70	0.87	0.37	1.80	1.43	2.31	2.31	3.47	3.04	0.86
	Leucoxene	1.10	0.96	2.28	1.16	1.14	1.40	1.27	0.32	1.91	1.33	0.98	1.42	0.74	1.67	1.22	1.34	1.25	1.98	1.51	1.81	2.36	1.08	1.18	1.69
	Ilmenite-Silicate Mixed	0.17	0.07	0.06	0.05	0.03	0.20	0.07	0.01	0.08	0.05	0.08	0.04	0.07	0.13	0.09	0.13	0.10	0.15	0.05	0.12	0.17	0.04	0.04	0.15
	Rutile-Qz Texture	0.46	0.05	0.16	0.07	0.05	0.15	0.08	0.02	0.14	0.08	0.07	0.08	0.07	0.17	0.11	0.12	0.15	0.15	0.09	0.11	0.14	0.03	0.06	0.14
	Hematite-Ti	1.95	1.02	0.25	1.14	0.96	8.13	1.67	0.21	1.98	1.44	4.68	1.00	2.03	3.63	2.99	3.71	3.43	1.78	1.12	0.61	0.19	0.17	0.72	0.51
	Titanite	1.33	0.29	1.70	0.66	0.57	0.47	0.78	0.30	1.10	0.67	0.09	1.78	1.50	1.80	2.40	2.01	2.21	1.02	2.19	1.87	0.89	0.35	1.09	0.54
Oxides/Hydroxides	Mag/Hema	4.23	0.53	0.41	0.43	0.36	18.33	1.69	0.45	1.39	0.76	1.31	0.66	4.94	7.75	7.96	7.45	11.28	0.67	0.60	0.20	1.67	0.01	0.40	0.77
	Goethite	2.07	0.19	0.16	0.25	0.25	7.69	1.63	0.28	0.65	0.28	0.62	0.39	3.57	4.02	2.84	3.35	4.39	0.31	0.24	0.16	0.88	0.04	0.42	0.66
	Boehmite	0.02	0.01	0.03	0.04	0.09	0.01	0.02	0.01	0.02	0.03	n.d.	0.02	n.d.	n.d.	0.01	0.02	0.00	0.05	0.00	0.01	n.d.	0.11	0.09	n.d.
	Brucite	0.04	n.d.	0.00	n.d.	n.d.	0.04	n.d.	n.d.	0.00	n.d.	0.01	n.d.	n.d.	0.02	n.d.	n.d.	0.00	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Chromite	0.09	0.10	0.08	0.05	0.14	0.14	0.09	n.d.	0.06	0.08	0.17	0.10	0.04	0.07	0.07	0.10	0.06	0.05	0.00	0.07	0.03	0.10	0.08	0.00
	Chromite with Al-Mg	0.01	0.07	0.07	0.02	0.02	0.09	0.06	n.d.	0.02	0.03	0.12	0.03	0.01	0.06	0.07	0.08	0.08	0.06	0.05	0.13	0.02	0.06	0.06	0.01
	Spinel	0.18	0.07	0.06	0.09	0.16	0.07	0.15	0.00	0.07	0.06	0.04	0.04	0.04	0.03	0.03	0.06	0.03	0.12	0.23	0.14	0.09	0.20	0.13	0.07
REE Minerals	Zircon	0.02	7.08	5.93	4.88	3.73	0.07	5.10	0.62	4.93	6.76	0.04	5.19	2.25	4.41	6.00	5.88	4.20	7.46	5.36	8.07	5.79	6.04	5.18	3.02
	Xenotime	n.d.	0.02	0.04	0.01	0.01	0.00	0.02	0.01	0.02	0.01	0.00	0.05	0.01	0.02	0.04	0.02	0.06	0.04	0.04	n.d.	n.d.	0.02	0.01	n.d.
	Monazite	0.03	0.21	0.47	0.21	0.21	n.d.	0.32	0.05	0.27	0.29	n.d.	0.48	0.15	0.18	0.26	0.30	0.20	0.61	0.20	0.57	1.32	0.18	0.12	0.25
	Apatite	0.11	0.04	0.23	0.01	0.01	0.04	0.08	0.02	0.08	0.04	0.03	0.02	0.41	0.77	0.50	0.29	1.17	0.06	0.12	0.02	0.01	0.01	0.02	0.10
Silicates	Kyanite	0.12	1.17	0.80	1.61	2.09	0.02	1.62	0.13	1.36	1.04	0.02	1.20	0.18	0.69	0.53	0.46	0.43	0.64	0.66	0.78	0.27	1.65	1.22	0.67
	Quartz	18.52	0.77	1.17	1.16	0.62	1.24	1.22	1.31	1.45	0.74	0.77	0.63	1.73	2.28	1.10	1.38	1.40	1.31	1.28	0.60	3.88	0.94	0.90	4.85
	K-Feldspar	2.73	0.05	0.06	0.10	0.04	0.12	0.10	0.18	0.03	0.03	0.04	0.00	0.18	0.12	0.10	0.14	0.12	0.10	0.06	0.05	0.61	0.07	0.05	0.49
	Plagioclase	12.37	0.15	0.13	0.12	0.06	0.70	0.18	0.37	0.12	0.06	0.28	0.09	0.54	0.48	0.35	0.44	0.53	0.24	0.18	0.16	1.00	0.11	0.11	1.17
	Pyroxene	3.53	0.47	1.23	0.60	0.94	0.88	0.68	0.39	1.28	0.87	0.33	1.97	2.59	3.42	2.81	1.76	3.70	0.96	3.43	0.49	0.35	0.17	1.53	0.66
	Garnet	1.61	5.57	9.27	13.19	16.98	0.70	7.83	0.88	11.92	12.56	0.11	7.82	3.98	7.18	7.42	5.86	7.71	5.59	8.28	4.71	2.19	5.44	8.91	3.99
	Amphibole	24.39	8.71	18.47	12.04	11.13	7.56	10.88	3.35	15.30	11.92	2.82	24.22	19.63	29.59	26.68	23.58	29.53	22.26	32.69	16.96	13.89	15.47	24.50	16.59
	Mica	2.71	0.08	0.24	0.09	0.12	0.35	0.18	0.27	0.16	0.08	0.15	0.09	0.84	0.63	0.34	0.66	0.56	0.58	0.19	0.37	2.00	0.20	0.12	2.02
	Schorl-Tourmaline	0.49	0.85	1.63	0.85	0.84	0.27	0.90	0.24	1.21	1.02	0.13	2.41	1.84	2.58	2.17	2.03	2.39	2.48	2.71	2.06	1.68	1.82	2.44	1.35
	Calcite	0.14	0.01	0.04	0.01	0.02	0.01	0.09	0.24	0.02	0.01	0.00	0.00	0.65	0.55	0.21	0.19	0.44	0.15	0.01	0.03	0.56	0.00	0.02	0.63
Sulfides	Pyrite/Fram. Pyrite	0.02	0.01	2.65	0.00	n.d.	0.01	5.17	61.03	0.07	0.04	0.09	0.02	31.70	0.05	0.10	0.31	0.09	0.94	0.03	1.25	5.84	n.d.	0.00	26.07
	Pyrite-Altered	0.01	0.00	0.74	0.00	0.00	0.02	1.84	20.27	0.02	0.00	0.04	0.00	1.11	0.01	0.03	0.02	0.01	0.06	0.01	0.07	0.04	0.00	0.00	2.75
	PyriteAltered-ClayMix	0.01	0.00	0.14	n.d.	n.d.	0.02	0.21	2.53	0.01	0.00	0.01	n.d.	0.64	0.01	0.02	0.04	0.00	0.09	0.01	0.05	0.27	0.00	0.00	0.65
Mixed-Unclassifiable Spectra	SIlicate Gangue	5.15	0.08	0.14	0.08	0.12	0.88	0.21	0.11	0.21	0.07	0.14	0.16	0.49	0.60	0.28	0.52	0.37	0.32	0.16	0.35	0.96	0.36	0.19	0.83
	Low Counts	0.03	0.04	0.08	0.03	0.08	0.02	0.05	0.13	0.04	0.04	0.01	0.05	0.17	0.02	0.04	0.04	0.03	0.06	0.02	0.07	0.19	0.08	0.03	0.22
	Others	0.87	0.17	0.40	0.23	0.36	0.38	0.33	0.23	0.39	0.23	0.13	0.26	0.62	0.53	0.38	0.49	0.43	0.35	0.27	0.43	0.66	0.25	0.29	0.74
	Sum	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Actlabd ID:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Client ID	R-11007m	R-11350a	R-11350c	R-11351a	R-11351ab	R-11351am	R-11352a	R-11352b	R-11354a	R-11354b	R-11362m	R-11434	R-11441	R-11462	R-11466	R-11470	R-11474	R-11478	R-11482	R-11486	R-11488	R-11494	R-11498	R-11500



Actlabd ID: A18-05577	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Client ID	R-11007m	R-11350a	R-11350c	R-11351a	R-11351ab	R-11351am	R-11352a	R-11352b	R-11354a	R-11354b	R-11362m	R-11434	R-11441	R-11462	R-11466	R-11470	R-11474	R-11478	R-11482	R-11486	R-11488	R-11494	R-11498	R-11500

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Ilmenite																								
S<=3	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	2	1
S<=5	2	2	3	2	2	2	2	2	2	2	1	2	3	2	2	1	2	2	3	2	2	2	3	2
S<=10	6	6	8	6	6	5	5	7	6	8	3	6	8	6	5	4	5	7	8	6	6	5	7	7
S<=13.25	9	7	11	7	7	7	7	9	8	9	4	7	12	10	6	5	7	8	11	7	8	7	9	9
S<=18.75	13	9	15	9	9	11	10	13	11	12	5	9	19	16	9	9	15	11	14	10	12	8	10	14
S<=26.5	21	11	22	12	12	19	15	17	17	17	9	11	38	27	16	16	27	15	19	14	18	9	13	20
S<=37.5	33	16	35	17	16	36	22	25	25	24	18	16	66	51	32	28	52	25	26	25	32	15	14	32
S<=53	48	23	54	23	25	66	34	45	42	34	38	26	89	79	60	55	87	43	42	42	56	20	24	60
S<=75	67	36	80	37	40	92	52	60	67	60	70	48	99	92	86	87	99	72	65	70	79	36	37	84
S<=106	81	64	96	59	61	100	75	74	90	84	95	80	100	98	97	98	100	93	90	92	96	69	66	97
S<=150	89	85	99	90	92	100	92	87	99	96	99	98	100	98	100	100	100	97	98	97	100	92	92	100
S<=212	100	99	100	99	100	100	100	87	100	100	100	100	100	100	100	100	100	100	100	100	100	99	100	100
S<=300	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Ilmenite lower Ti																								
S<=3	48	61	54	60	63	51	59	49	59	63	59	63	49	52	55	55	53	57	58	59	52	58	60	49
S<=5	64	76	65	72	75	68	74	62	75	74	73	78	66	68	70	70	67	73	74	73	68	74	73	68
S<=10	94	96	89	97	96	96	98	83	98	98	98	98	97	97	98	96	96	98	98	97	95	98	96	99
S<=13.25	97	98	91	98	98	99	99	84	99	99	99	100	100	99	99	99	99	100	99	99	98	99	100	100
S<=18.75	99	100	94	100	99	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	100	100	100	100
S<=26.5	100	100	95	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=37.5	100	100	95	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=53	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=75	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Pseudobrookite																								
S<=3	42	53	58	45	42	46	48	56	47	44	44	56	48	50	45	48	45	46	44	52	46	61	52	52
S<=5	56	72	75	63	55	61	64	71	64	59	61	76	62	64	63	61	60	64	63	67	63	69	69	67
S<=10	85	93	99	88	73	92	97	98	96	88	93	99	92	95	91	92	92	93	96	94	97	96	98	97
S<=13.25	86	97	100	95	77	96	99	99	99	93	98	100	95	98	94	97	97	97	99	98	100	99	99	99
S<=18.75	91	100	100	98	87	99	100	100	100	98	100	100	98	99	99	100	100	99	100	99	100	100	100	100
S<=26.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	100	100	100	100
S<=37.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=53	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Rutile																								
S<=3	6	3	3	3	4	12	5	2	4	2	17	3	2	2	3	3	3	3	3	3	3	1	4	5
S<=5	11	4	5	4	7	19	8	4	6	4	25	4	4	4	5	4	5	4	5	5	5	2	7	8
S<=10	29	12	16	12	21	49	20	13	16	10	60	11	12	11	16	12	14	14	15	14	15	6	21	28
S<=13.25	36	14	21	15	29	60	27	21	20	13	70	14	17	16	22	15	22	20	19	19	19	6	27	33
S<=18.75	50	18	29	17	41	66	36	28	25	18	90	19	30	21	30	21	31	29	28	24	31	8	40	39
S<=26.5	50	27	37	24	47	79	39	43	35	22	97	29	46	34	45	24	42	36	37	35	38	13	42	53
S<=37.5	57	33	48	33	50	88	53	55	49	28	100	32	76	61	57	41	66	47	54	44	51	17	49	69
S<=53	100	48	78	38	63	89	60	75	64	45	100	53	97	89	74	67	89	57	64	67	72	22	52	78
S<=75	100	55	90	45	74	100	75	84	79	66	100	57	100	100	97	92	100	72	74	84	72	41	64	100
S<=106	100	59	100	67	86	100	94	100	96	80	100	92	100	100	100	100	100	84	96	93	92	66	86	100
S<=150	100	88	100	85	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=212																								

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Rutile-Altered																								
S<=3	8	10	7	7	7	15	6	6	7	7	10	5	11	10	9	9	12	6	5	5	7	6	4	7
S<=5	14	15	11	10	10	24	10	9	11	10	16	8	18	15	14	15	19	9	8	8	11	10	7	12
S<=10	38	40	29	25	28	59	26	23	28	24	41	21	45	38	38	35	49	23	20	20	30	25	16	32
S<=13.25	48	52	36	31	34	72	31	29	35	31	55	26	54	46	47	43	63	28	27	26	37	31	19	39
S<=18.75	56	63	45	37	40	83	40	39	41	39	68	31	63	53	53	51	70	35	34	32	46	37	24	43
S<=26.5	70	71	55	42	49	91	47	47	48	45	79	35	73	61	59	59	80	42	37	37	58	42	29	51
S<=37.5	79	79	61	54	62	96	52	54	55	52	88	37	81	68	66	67	85	50	43	42	61	45	33	58
S<=53	90	83	68	56	68	99	59	56	64	57	93	42	90	87	71	73	94	60	47	49	68	55	37	71
S<=75	100	86	81	58	75	100	71	83	75	69	98	51	98	98	80	78	100	78	59	64	75	63	46	77
S<=106	100	89	94	80	79	100	76	100	90	82	98	73	100	100	87	100	100	89	77	80	82	76	65	90
S<=150	100	100	98	83	91	100	86	100	98	92	100	83	100	100	90	100	100	100	97	95	100	94	85	90
S<=212	100	100	100	100	96	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	94	94	100
S<=300	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Pseudorutile																								
S<=3	43	21	25	23	25	47	30	27	27	22	39	26	40	28	37	40	46	22	26	31	31	23	23	26
S<=5	59	31	37	35	36	62	44	39	40	33	53	37	57	37	52	55	61	32	38	45	45	33	35	38
S<=10	89	66	79	71	71	95	83	71	74	72	85	74	97	58	82	91	93	55	80	83	84	72	72	83
S<=13.25	94	74	87	77	78	99	89	77	79	83	90	79	99	59	89	95	95	57	83	87	92	79	79	92
S<=18.75	100	79	91	83	81	100	91	92	82	89	96	82	100	61	93	100	95	60	91	92	99	85	81	97
S<=26.5	100	84	96	89	86	100	98	100	90	99	97	85	100	61	96	100	100	68	91	95	100	87	86	97
S<=37.5	100	90	97	90	93	100	100	100	95	99	98	91	100	61	100	100	100	81	100	100	100	91	89	100
S<=53	100	92	100	91	93	100	100	100	97	100	100	94	100	61	100	100	100	90	100	100	100	94	94	100
S<=75	100	100	100	96	95	100	100	100	100	100	100	100	100	100	100	100	100	94	100	100	100	96	100	100
S<=106	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Leucoxene																								
S<=3	30	28	20	31	26	37	32	20	21	25	45	21	29	26	29	35	26	31	23	32	31	43	15	23
S<=5	42	38	30	45	35	48	42	30	29	34	57	28	41	38	40	49	39	43	33	44	46	57	21	35
S<=10	83	63	66	88	72	81	74	59	62	62	83	52	75	80	80	87	77	81	61	78	80	88	44	78
S<=13.25	95	68	77	95	88	89	85	71	72	71	87	56	81	90	89	93	85	88	71	84	88	97	47	89
S<=18.75	100	72	85	100	96	96	93	76	81	81	88	59	86	92	97	98	92	96	81	95	89	100	54	97
S<=26.5	100	73	94	100	98	97	100	81	84	87	95	59	88	96	97	98	100	97	83	96	93	100	56	100
S<=37.5	100	81	94	100	99	100	100	81	84	87	97	73	100	100	100	100	100	97	83	98	93	100	56	100
S<=53	100	100	96	100	100	100	100	81	85	93	100	90	100	100	100	100	100	100	83	100	95	100	56	100
S<=75	100	100	100	100	100	100	100	100	100	100	100	90	100	100	100	100	100	100	83	100	95	100	66	100
S<=106	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	92	100	100	100	82	100
S<=150	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	82	100
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Hematite-Ti																								
S<=3	8	2	7	1	3	5	3	9	2	1	3	2	7	6	6	5	7	3	2	2	12	34	4	4
S<=5	13	4	11	2	5	9	4	15	3	2	5	3	10	9	10	8	11	4	3	3	16	43	5	5
S<=10	32	7	36	5	8	23	11	30	9	5	13	7	26	24	26	21	29	10	10	7	34	51	10	11
S<=13.25	45	8	57	7	13	31	15	41	11	8	20	9	36	31	32	27	40	12	12	11	53	100	24	19
S<=18.75	62	10	81	8	13	47	25	62	19	20	33	18	58	45	46	42	53	26	30	32	63	100	49	38
S<=26.5	77	30	89	15	29	68	42	69	28	50	51	38	84	72	63	65	68	46	43	44	71	100	49	57
S<=37.5	93	46	100	58	57	84	60	81	46	57	73	59	99	89	78	86	87	64	66	57	100	100	59	69
S<=53	100	53	100	87	78	98	79	81	68	76	90	82	100	97	93	97	97	89	85	78	100	100	59	95
S<=75	100	66	100	97	100	99	98	100	93	83	98	100	100	100	100	100	100	92	100	78	100	100	100	100
S<=106	100	79	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
S<=150	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

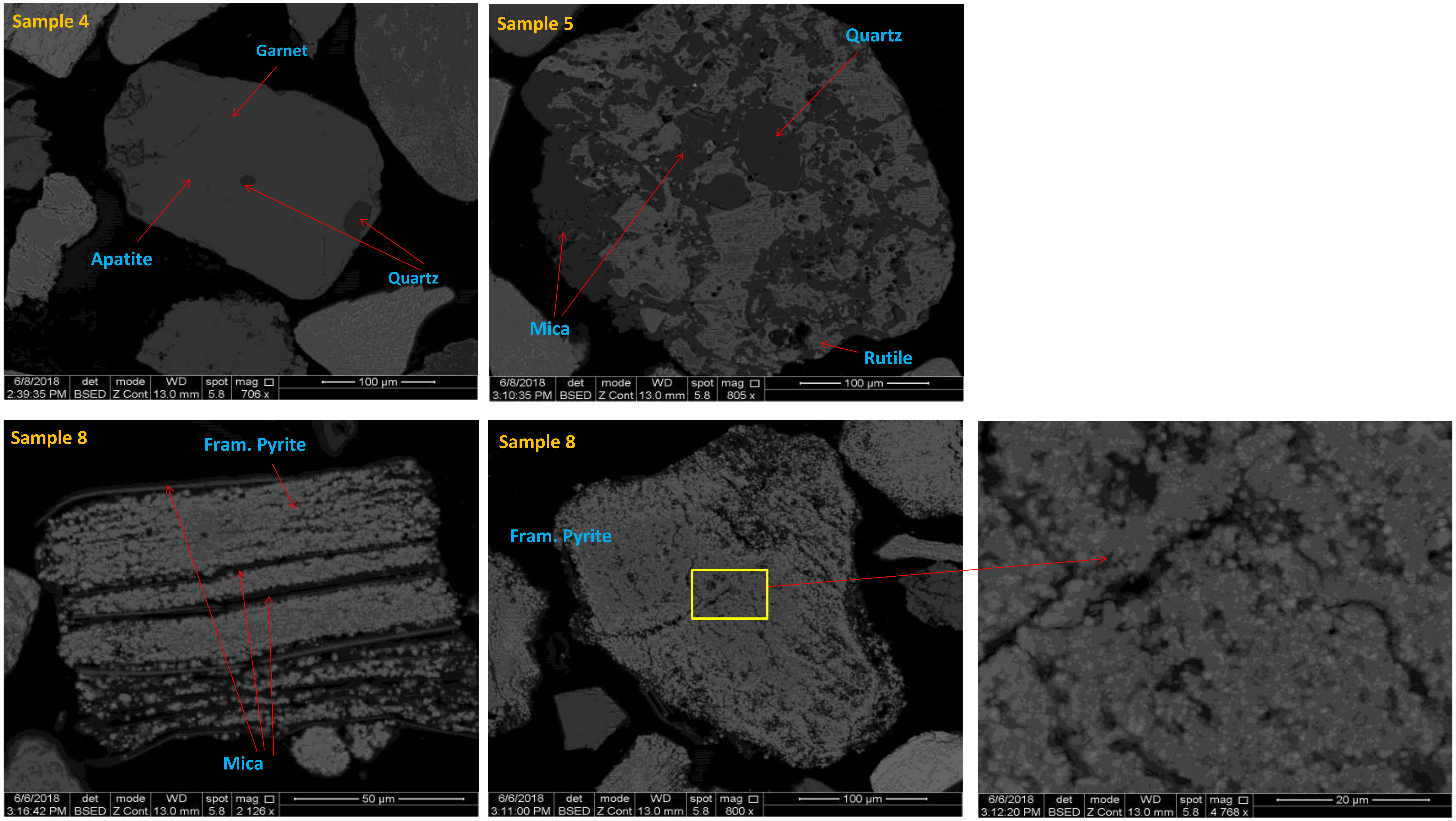
Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Titanite																								
S<=3	2	0	0	0	2	3	1	1	1	1	8	0	1	1	0	0	1	0	1	1	1	0	0	0
S<=5	4	1	1	1	3	7	1	1	1	1	12	0	1	1	1	1	1	0	1	1	2	0	0	1
S<=10	17	1	4	3	8	23	3	6	4	3	41	1	5	4	3	2	4	2	3	4	7	1	1	4
S<=13.25	25	2	5	4	11	32	5	9	7	4	53	2	7	5	4	2	6	3	4	5	10	1	1	5
S<=18.75	42	2	7	7	11	53	6	12	10	5	70	2	10	10	6	3	8	4	5	6	13	1	1	7
S<=26.5	54	4	11	8	11	62	9	14	14	9	83	3	16	16	9	6	14	7	6	6	17	1	1	8
S<=37.5	67	9	14	14	11	70	13	26	25	10	83	4	30	26	15	11	22	12	8	8	30	1	2	11
S<=53	89	15	27	18	31	78	26	45	52	16	100	6	72	49	28	27	55	22	13	16	38	1	2	39
S<=75	100	15	73	18	48	100	51	81	72	42	100	16	96	81	55	59	88	39	38	34	84	1	2	52
S<=106	100	15	100	37	48	100	78	100	100	55	100	49	100	96	91	83	100	75	79	81	100	36	7	69
S<=150	100	41	100	61	100	100	78	100	100	76	100	100	100	100	100	95	100	100	100	100	100	100	21	69
S<=212	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sieve Size in Micron/ **Cumulative Passing**

Size Distribution of Zircon																								
S<=3	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
S<=5	9	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
S<=10	36	0	0	0	0	4	0	0	0	0	33	0	1	0	0	0	0	0	0	0	1	0	0	0
S<=13.25	61	0	0	0	0	12	1	0	1	0	56	0	1	1	1	0	0	0	0	0	1	0	0	0
S<=18.75	100	0	1	0	0	12	1	1	1	1	100	1	3	2	1	1	2	1	1	1	2	0	1	0
S<=26.5	100	0	2	0	0	31	3	1	2	1	100	1	9	5	2	2	6	2	1	1	5	1	1	2
S<=37.5	100	0	6	1	1	31	10	5	5	2	100	2	42	21	8	8	23	4	3	5	10	2	1	6
S<=53	100	3	19	3	2	31	17	11	16	7	100	8	78	65	33	26	61	17	9	18	31	5	2	13
S<=75	100	8	60	8	4	100	41	54	44	24	100	23	95	95	71	69	96	52	34	50	60	16	15	43
S<=106	100	29	96	29	21	100	71	66	85	55	100	69	100	98	95	96	100	81	70	88	85	37	34	84
S<=150	100	61	100	52	72	100	100	75	100	96	100	100	100	100	100	100	100	96	87	96	100	71	72	100
S<=212	100	88	100	91	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	91	100	100
S<=300	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100


Sample 1; sorted to Ilmenite
Sample 2; sorted to Ilmenite
Sample 3; sorted to Ilmenite
Sample 4; sorted to Ilmenite
Sample 5; sorted to Ilmenite
Sample 6; sorted to Ilmenite
Sample 7; sorted to Ilmenite
Sample 8; sorted to Ilmenite
Sample 9; sorted to Ilmenite
Sample 10; sorted to Ilmenite
Sample 11; sorted to Ilmenite
Sample 12; sorted to Ilmenite
Sample 13; sorted to Ilmenite
Sample 14; sorted to Ilmenite
Sample 15; sorted to Ilmenite
Sample 16; sorted to Ilmenite
Sample 17; sorted to Ilmenite
Sample 18; sorted to Ilmenite
Sample 19; sorted to Ilmenite
Sample 20; sorted to Ilmenite
Sample 21; sorted to Ilmenite
Sample 22; sorted to Ilmenite
Sample 23; sorted to Ilmenite
Sample 24; sorted to Ilmenite
Background
Ilmenite
Ilmenite-Lower Ti
Pseudobrookite
Rutile
Rutile-Altered(Leucoxene)
Pseudorutile
Leucoxene
Ilmenite-Silicate Mixed
Rutile-Qz Texture
Hematite-Ti
Titanite
Mag/Hema
Goethite
Chromite
Spinel
Zircon
REE Phosphate
Apatite
Silicate Gangue
Pyrite
Others


Sample 4
Garnet
Apatite
Quartz
6/8/2018 2:39:35 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 5.8 | mag 706 x | 100 µm
Sample 5
Quartz
Mica
Rutile
6/8/2018 3:10:35 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 5.8 | mag 805 x | 100 µm
Sample 8
Fram. Pyrite
Mica
6/6/2018 3:16:42 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 5.8 | mag 2 126 x | 50 µm
Sample 8
Fram. Pyrite
6/6/2018 3:11:00 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 5.8 | mag 800 x | 100 µm
6/6/2018 3:12:20 PM | det BSED | mode Z Cont | WD 13.0 mm | spot 5.8 | mag 4 768 x | 20 µm

Heavy Mineral Processing Weights

	Weight of -0.25 mm Table Concentrate (g)				
			Heavy Liquid Separation at		
				HMC	
	Sample Number	Total	Lights S.G <3.2	Total	
A18-05577-2	R-11350a	57.2	42.3	14.9	
A18-05577-3	R-11350c	98.3	95.0	3.3	
A18-05577-4	R-11351a	98.0	80.0	18.0	
A18-05577-5	R-11351ab	202.2	201.4	0.8	
A18-05577-7	R-11352a	204.4	203.2	1.2	
A18-05577-8	R-11352b	200.1	200.0	0.1	
A18-05577-9	R-11354a	109.2	85.7	23.5	
A18-05577-10	R-11354b	100.4	83.1	17.3	
A18-05577-12	R-11434	204.2	203.1	1.1	0.54%
A18-05577-13	R-11441	171.9	171.8	0.1	0.06%
A18-05577-14	R-11462	197.6	197.0	0.6	0.30%
A18-05577-15	R-11466	206.7	205.0	1.7	0.82%
A18-05577-16	R-11470	199.4	198.6	0.8	0.40%
A18-05577-17	R-11474	195.3	193.1	2.2	1.13%
A18-05577-18	R-11478	205.2	204.3	0.9	0.44%
A18-05577-19	R-11482	195.1	193.7	1.4	0.72%
A18-05577-20	R-11486	204.5	203.5	1.0	0.49%
A18-05577-21	R-11488	189.1	189.1	0.01	0.01%
A18-05577-22	R-11494	215.9	214.3	1.6	0.74%
A18-05577-23	R-11498	157.5	154.6	2.9	1.84%
A18-05577-24	R-11500	192.8	192.8	0.02	0.01%

Quality Analysis ... **Actlabs** *Innovative Technologies*

Date Submitted:	30-Apr-18
Invoice No.:	A18-05577
Invoice Date:	15-Jun-18
Your Reference:	EP2747577

VA DMME
900 Natural Resources Drives Suite 500
Charlottesville VIRGINIA 22903
United States

ATTN: William Lassetter

CERTIFICATE OF ANALYSIS

24 Heavy Mineral Concentrates samples were submitted for analysis.

The following analytical package(s) were requested:

Code 4LITHORES (11+) Major Elements Fusion ICP(WRA)/Trace Elements Fusion ICP/MS(WRA4B2)

Code MLA Schedule 1 MLA Schedule 1

REPORT **A18-05577**

Notes:

We recommend using option 4B1 for accurate levels of the base metals Cu, Pb, Zn, Ni and Ag. Option 4B-INAA for As, Sb, high W >100ppm, Cr >1000ppm and Sn >50ppm by Code 5D. Values for these elements provided by Fusion ICP/MS, are order of magnitude only and are provided for general information. Mineralized samples should have the Quant option selected or request assays for values which exceed the range of option 4B1. Total includes all elements in % oxide to the left of total. Zr is now being reported from FUS-ICP instead of FUS-MS.

CERTIFIED BY:

Elitsa Hrischeva, Ph.D.
Quality Control

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Analyte Symbol	SiO2	Al2O3	Fe2O3(T)	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	LOI	Total	Sc	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	As
Unit Symbol	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01		0.01	1	1	5	20	1	20	10	30	1	0.5	5
Method Code	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
R-11007m																							
R-11350a	12.81	5.89	34.26	1.147	1.29	2.15	0.06	0.07	36.69	0.14	-0.63	93.88	45	< 1	651	730	34	80	< 10	380	16	1.9	15
R-11350c	21.17	8.30	27.72	0.984	2.50	4.51	0.17	0.20	28.47	0.30	0.00	94.33	55	< 1	495	730	30	60	< 10	320	23	2.4	14
R-11351a	15.49	8.26	32.65	1.146	1.43	3.38	0.06	0.08	33.25	0.13	-0.32	95.55	51	< 1	623	440	27	80	< 10	340	18	2.3	16
R-11351ab																							
R-11351am																							
R-11352a	16.25	7.26	34.53	1.008	1.64	3.02	0.10	0.14	30.84	0.19	0.00	94.99	47	< 1	604	610	67	70	20	320	19	1.9	38
R-11352b																							
R-11354a	19.46	8.50	30.74	0.959	2.24	4.80	0.14	0.16	28.61	0.22	-0.28	95.56	56	< 1	591	620	30	60	50	350	23	2.8	15
R-11354b	17.05	8.46	30.36	1.014	1.74	4.00	0.08	0.10	32.54	0.13	-0.34	95.14	53	< 1	612	580	31	60	< 10	370	23	2.6	15
R-11362m																							
R-11434	21.64	9.59	29.21	0.958	3.39	4.10	0.26	0.13	26.25	0.13	0.00	95.65	55	3	501	740	36	60	< 10	290	28	3.0	15
R-11441																							
R-11462																							
R-11466	23.38	7.89	36.76	0.784	3.26	5.57	0.43	0.27	17.19	0.25	0.00	95.78	47	< 1	487	520	30	70	< 10	240	25	3.2	7
R-11470																							
R-11474	25.78	8.41	37.58	0.669	3.92	7.15	0.53	0.34	12.94	0.34	0.00	97.66	47	< 1	491	620	29	80	< 10	200	23	3.2	7
R-11478																							
R-11482	24.45	9.55	31.04	0.920	3.73	4.93	0.35	0.18	21.50	0.13	0.00	96.79	54	< 1	452	670	32	60	< 10	290	22	2.8	6
R-11486																							
R-11488																							
R-11494	15.05	8.68	33.15	1.066	1.70	1.77	0.21	0.09	33.95	0.14	0.00	95.82	49	< 1	575	700	32	70	< 10	340	23	2.1	8
R-11498																							
R-11500																							

Analyte Symbol	Rb	Sr	Y	Zr	Nb	Mo	Ag	In	Sn	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	1	2	0.5	1	0.2	2	0.5	0.1	1	0.2	0.1	2	0.05	0.05	0.01	0.05	0.01	0.005	0.01	0.01	0.01	0.01	0.01
Method Code	FUS-MS	FUS-ICP	FUS-MS	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
R-11007m																							
R-11350a	2	97	197	> 10000	653	16	> 100	0.3	20	0.5	< 0.1	44	267	571	65.5	239	46.2	4.20	32.8	5.04	30.7	6.60	22.8
R-11350c	5	201	475	> 10000	524	10	97.6	0.3	27	1.0	0.2	84	579	1280	152	570	112	15.9	80.6	12.5	78.4	16.3	52.4
R-11351a	2	154	172	> 10000	563	10	69.9	0.3	13	0.5	< 0.1	43	241	522	59.3	216	40.7	4.35	28.4	4.35	27.0	5.71	19.6
R-11351ab																							
R-11351am																							
R-11352a	4	144	237	> 10000	505	19	89.3	0.3	11	0.3	0.2	59	384	820	93.7	342	62.8	6.01	43.3	6.53	38.7	8.15	26.8
R-11352b																							
R-11354a	4	200	300	> 10000	506	10	98.0	0.4	16	0.5	0.1	53	414	891	103	386	73.8	8.93	54.5	8.39	50.6	10.7	34.2
R-11354b	3	193	257	> 10000	581	12	> 100	0.4	16	0.9	0.1	53	332	709	82.0	302	57.6	6.83	43.5	6.76	41.5	8.90	29.9
R-11362m																							
R-11434	2	145	310	> 10000	467	11	88.7	0.4	17	0.4	< 0.1	51	312	728	89.3	345	69.5	9.74	50.8	7.94	49.6	10.6	35.3
R-11441																							
R-11462																							
R-11466	5	135	368	> 10000	296	8	90.6	0.3	15	0.2	0.2	46	443	961	113	425	82.0	11.0	61.3	9.74	59.9	12.5	40.9
R-11470																							
R-11474	6	155	302	> 10000	178	6	45.1	0.2	10	< 0.2	0.2	51	236	519	62.6	240	50.0	8.00	43.7	7.60	50.0	10.6	34.5
R-11478																							
R-11482	3	104	303	> 10000	332	8	77.7	0.3	14	0.4	0.1	46	294	635	77.2	294	59.6	8.85	45.8	7.56	49.6	10.7	34.9
R-11486																							
R-11488																							
R-11494	3	66	264	> 10000	543	11	89.8	0.4	16	< 0.2	0.1	54	282	597	67.5	244	45.8	4.38	35.8	6.04	39.7	8.92	30.1
R-11498																							
R-11500																							

Analyte Symbol	Tm	Yb	Lu	Hf	Ta	W	Tl	Pb	Bi	Th	U	Mineral Separation
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	g
Lower Limit	0.005	0.01	0.002	0.1	0.01	0.5	0.05	5	0.1	0.05	0.01	
Method Code	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	TIMS
R-11007m												
R-11350a	3.87	30.6	5.89	795	31.5	13.2	0.11	58	0.3	105	28.5	
R-11350c	8.54	62.9	11.2	735	32.2	15.7	0.07	52	0.3	143	48.8	
R-11351a	3.29	26.2	4.89	526	27.9	11.5	< 0.05	52	0.5	92.6	23.9	
R-11351ab												
R-11351am												
R-11352a	4.54	35.1	6.64	635	26.3	10.8	0.06	44	0.2	135	34.3	
R-11352b												
R-11354a	5.78	43.5	8.11	720	27.7	14.8	< 0.05	77	0.5	133	40.6	
R-11354b	5.07	38.6	7.19	741	30.1	22.5	< 0.05	64	0.6	109	36.3	
R-11362m												
R-11434	5.78	44.5	8.19	654	24.3	15.0	< 0.05	64	0.2	82.5	32.6	
R-11441												
R-11462												
R-11466	6.72	50.3	9.53	679	16.4	7.4	< 0.05	35	0.2	119	43.5	
R-11470												
R-11474	5.50	40.1	7.03	343	10.1	4.2	< 0.05	22	0.1	51.2	24.5	
R-11478												
R-11482	5.86	44.2	8.10	576	19.0	10.0	< 0.05	41	0.1	78.7	32.0	
R-11486												
R-11488												
R-11494	5.14	40.0	7.48	657	26.3	10.3	< 0.05	53	0.2	90.6	30.9	
R-11498												
R-11500												

Analyte Symbol	SiO2	Al2O3	Fe2O3(T)	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	LOI	Total	Sc	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	As
Unit Symbol	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01		0.01	1	1	5	20	1	20	10	30	1	0.5	5
Method Code	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
NIST 694 Meas	11.41	1.90	0.75	0.010	0.33	42.38	0.86	0.54	0.120	30.23					1642								
NIST 694 Cert	11.2	1.80	0.790	0.0116	0.330	43.6	0.860	0.510	0.110	30.2					1740								
DNC-1 Meas	47.45	19.34	10.13	0.150	10.07	11.60	1.97	0.23	0.490	0.07			32		153	280	62	260	110	80	14		
DNC-1 Cert	47.15	18.34	9.97	0.150	10.13	11.49	1.890	0.234	0.480	0.070			31		148	270	57	247	100	70	15		
LKSD-3 Meas																90	32	50	40	140			26
LKSD-3 Cert																87.0	30.0	47.0	35.0	152			27.0
W-2a Meas	52.19	15.23	10.65	0.160	6.10	11.09	2.23	0.62	1.090	0.12			35	< 1	271	100	45	80	110	80	19	1.5	
W-2a Cert	52.4	15.4	10.7	0.163	6.37	10.9	2.14	0.626	1.06	0.140			36.0	1.30	262	92.0	43.0	70.0	110	80.0	17.0	1.00	
SY-4 Meas	50.10	20.81	6.21	0.110	0.52	8.21	6.95	1.66	0.290	0.12			< 1	3	7								
SY-4 Cert	49.9	20.69	6.21	0.108	0.54	8.05	7.10	1.66	0.287	0.131			1.1	2.6	8.0								
CTA-AC-1 Meas																			60				
CTA-AC-1 Cert																			54.0				
BIR-1a Meas	47.99	16.06	11.33	0.170	9.39	13.64	1.82	0.02	0.990	0.02			43	< 1	333	390	56	180	130	70	16		
BIR-1a Cert	47.96	15.50	11.30	0.175	9.700	13.30	1.82	0.030	0.96	0.021			44	0.58	310	370	52	170	125	70	16		
NCS DC86312 Meas																							
NCS DC86312 Cert																							
NCS DC70009 (GBW07241) Meas																	3		1040	90	16	10.5	64
NCS DC70009 (GBW07241) Cert																	3.7		960	100	16.5	11.2	69.9
OREAS 100a (Fusion) Meas																	18		180				
OREAS 100a (Fusion) Cert																	18.1		169				
OREAS 101a (Fusion) Meas																	51		450				
OREAS 101a (Fusion) Cert																	48.8		430				
JR-1 Meas																	1	< 20	< 10		17	2.1	16
JR-1 Cert																	0.83	1.67	2.68		16.1	1.88	16.3
NCS DC86318 Meas																							
NCS DC86318 Cert																							
R-11354b Orig	17.20	8.37	30.40	1.020	1.72	4.01	0.08	0.10	32.33	0.14	-0.34	95.04	54	< 1	607	630	31	60	< 10	370	23	2.2	16
R-11354b Dup	16.91	8.55	30.32	1.008	1.76	3.98	0.08	0.09	32.74	0.13	-0.34	95.23	53	< 1	617	520	30	70	< 10	360	23	2.9	14
Method Blank	0.01	0.01	0.02	0.002	< 0.01	< 0.01	< 0.01	< 0.01	0.001	< 0.01			< 1	< 1	< 5								
Method Blank	0.01	< 0.01	< 0.01	0.002	0.01	< 0.01	< 0.01	< 0.01	< 0.001	< 0.01			< 1	< 1	< 5	< 20	< 1	< 20	< 10	< 30	< 1	< 0.5	< 5

Analyte Symbol	Rb	Sr	Y	Zr	Nb	Mo	Ag	In	Sn	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	1	2	0.5	1	0.2	2	0.5	0.1	1	0.2	0.1	2	0.05	0.05	0.01	0.05	0.01	0.005	0.01	0.01	0.01	0.01	0.01
Method Code	FUS-MS	FUS-ICP	FUS-MS	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-ICP	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
NIST 694 Meas																							
NIST 694 Cert																							
DNC-1 Meas	5	153	16.6	36						1.0		108	3.70			5.00		0.620					
DNC-1 Cert	5	144.0	18.0	38						0.96		118	3.6			5.20		0.59					
LKSD-3 Meas	71		27.7			< 2	2.8		2		2.4		48.0	89.2		44.6	7.90	1.50		0.90	5.10		
LKSD-3 Cert	78.0		30.0			2.00	2.70		3.00		2.30		52.0	90.0		44.0	8.00	1.50		1.00	4.90		
W-2a Meas	20	198	22.2	90	7.4	< 2					0.8	174	10.5	25.1		13.7	3.50	1.10		0.66	3.80	0.80	2.30
W-2a Cert	21.0	190	24.0	94.0	7.90	0.600					0.990	182	10.0	23.0		13.0	3.30	1.00		0.630	3.60	0.760	2.50
SY-4 Meas		1179		522								347											
SY-4 Cert		1191		517								340											
CTA-AC-1 Meas			296										> 2000	> 3000		1140	165	46.1	131	14.4			
CTA-AC-1 Cert			272										2176	3326		1087	162	46.7	124	13.9			
BIR-1a Meas		113	15.1	15								7	0.60	1.90		2.50	1.10	0.520	1.90		3.80		
BIR-1a Cert		110	16	18								6	0.63	1.9		2.5	1.1	0.55	2.0		4		
NCS DC86312 Meas			1010										> 2000	174		1550			231	31.2	190	35.2	101
NCS DC86312 Cert			976										2360	190		1600			225.0	34.6	183	36	96.2
NCS DC70009 (GBW07241) Meas	503						1.9	1.0	> 1000	2.9	43.8		24.0	61.4	8.20	33.5	12.5	0.160	15.4	3.10	22.1	4.30	13.9
NCS DC70009 (GBW07241) Cert	500						1.8	1.3	1700	3.1	41		23.7	60.3	7.9	32.9	12.5	0.16	14.8	3.3	20.7	4.5	13.4
OREAS 100a (Fusion) Meas			137			23							260	468	46.4	149	23.3	3.67	22.8	3.80	23.6	4.85	15.0
OREAS 100a (Fusion) Cert			142			24.1							260	463	47.1	152	23.6	3.71	23.6	3.80	23.2	4.81	14.9
OREAS 101a (Fusion) Meas			176			21							803	1380	128	389	48.7	8.04	44.9	5.71	33.0	6.34	19.8
OREAS 101a (Fusion) Cert			183			21.9							816	1396	134	403	48.8	8.06	43.4	5.92	33.3	6.46	19.5
JR-1 Meas	243		40.7		15.0	3		< 0.1	3		20.7		20.2	47.6	6.10	23.7	5.69	0.280		0.97	5.54	1.15	
JR-1 Cert	257		45.1		15.2	3.25		0.028	2.86		20.8		19.7	47.2	5.58	23.3	6.03	0.30		1.01	5.69	1.11	
NCS DC86318 Meas	387		> 10000								11.1		1900	405	720	> 2000	> 1000	18.8	> 1000	478	> 1000	574	> 1000
NCS DC86318 Cert	369.42		17008								10.28		1960	430	740	3430	1720	18.91	2095	470	3220	560	1750
R-11354b Orig	3	193	253	> 10000	575	13	> 100	0.4	16	1.0	0.1	54	347	735	85.0	314	59.3	7.13	44.6	6.98	42.3	9.17	31.0
R-11354b Dup	3	194	261	> 10000	588	11	96.8	0.4	16	0.9	0.1	53	318	682	79.0	289	56.0	6.53	42.3	6.53	40.7	8.63	28.9
Method Blank		< 2		3								< 2											
Method Blank	< 1	< 2	< 0.5	2	< 0.2	< 2	< 0.5	< 0.1	< 1	< 0.2	< 0.1	< 2	< 0.05	< 0.05	< 0.01	< 0.05	< 0.01	< 0.005	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Analyte Symbol	Tm	Yb	Lu	Hf	Ta	W	Tl	Pb	Bi	Th	U
Unit Symbol	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lower Limit	0.005	0.01	0.002	0.1	0.01	0.5	0.05	5	0.1	0.05	0.01
Method Code	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS	FUS-MS
NIST 694 Meas											
NIST 694 Cert											
DNC-1 Meas		2.10						6			
DNC-1 Cert		2.0						6.3			
LKSD-3 Meas		2.70	0.420	4.5						11.4	4.70
LKSD-3 Cert		2.70	0.400	4.80						11.4	4.60
W-2a Meas		2.10	0.330	2.6	0.51	< 0.5	0.59	10	< 0.1	2.40	0.54
W-2a Cert		2.10	0.330	2.60	0.500	0.300	0.200	9.30	0.0300	2.40	0.530
SY-4 Meas											
SY-4 Cert											
CTA-AC-1 Meas		11.3			2.81						4.50
CTA-AC-1 Cert		11.4			2.65						4.4
BIR-1a Meas		1.70		0.6				< 5			
BIR-1a Cert		1.7		0.60				3			
NCS DC86312 Meas	13.8	88.5	12.6								
NCS DC86312 Cert	15.1	87.79	11.96								
NCS DC70009 (GBW07241) Meas	2.30	16.1	2.33			2300	1.94			30.9	
NCS DC70009 (GBW07241) Cert	2.2	14.9	2.4			2200	1.8			28.3	
OREAS 100a (Fusion) Meas	2.32	15.7	2.29							54.3	139
OREAS 100a (Fusion) Cert	2.31	14.9	2.26							51.6	135
OREAS 101a (Fusion) Meas	2.80	18.3	2.63							37.2	452
OREAS 101a (Fusion) Cert	2.90	17.5	2.66							36.6	422
JR-1 Meas	0.670	4.72	0.670	4.1			1.55	20	0.5	28.9	8.90
JR-1 Cert	0.67	4.55	0.71	4.51			1.56	19.3	0.56	26.7	8.88
NCS DC86318 Meas	260	> 1000	238							65.9	
NCS DC86318 Cert	270	1840	260.0							67.0	
R-11354b Orig	5.28	40.0	7.50	786	30.6	28.0	< 0.05	67	0.6	114	38.1
R-11354b Dup	4.85	37.3	6.89	697	29.5	17.1	< 0.05	60	0.5	103	34.5
Method Blank											
Method Blank	< 0.005	< 0.01	< 0.002	< 0.1	< 0.01	< 0.5	< 0.05	< 5	< 0.1	< 0.05	< 0.01