A capacity assessment on the recovery of critical and economic minerals from sand used for coastal resilience projects

February 29, 2024

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OPEN-FILE REPORT 2024-16

Prepared under BOEM Cooperative Agreement No. M21AC00010
Award Period: July 01, 2021 – February 29, 2024

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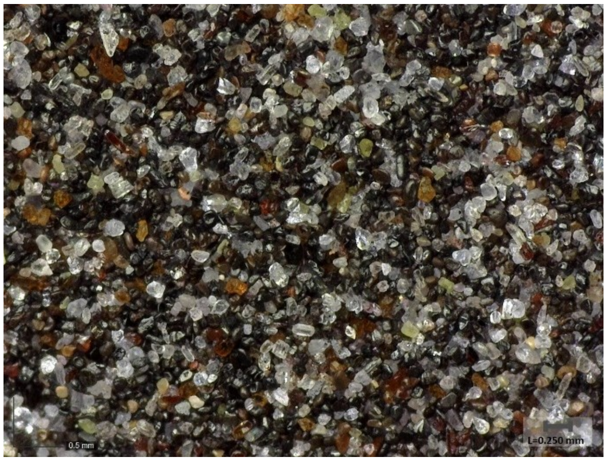

Microscope image of heavy mineral sand concentrate.

Prepared for:
United States Department of the Interior
Bureau of Ocean Energy Management
Leasing Division Marine Minerals Program
Sterling, VA 20166

DISCLAIMER

Study collaboration and funding were provided by the United States Department of the Interior, Bureau of Ocean Energy Management (BOEM), Marine Minerals Program, [Sterling, VA], under Agreement Number M21AC00010, with additional funding contributions from the Virginia Department of Energy. This report has been technically reviewed by BOEM, and it has been approved for release as an open-file report. 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 BOEM or the Virginia Department of Energy, nor does mention of trade names or commercial products constitute endorsement or recommendation for use by the Commonwealth of Virginia or the United States Government.

REPORT AVAILABILITY

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CITATION

Nelson, M.S., Hawkins, D.W., and Lassetter, W.L., 2024, A capacity assessment on the recovery of critical and economic minerals from sand used for coastal resilience projects: Virginia Department of Energy, Geology and Mineral Resources Program, Open-file report 2024-16, 76 p. and Appendices A-E.

ACKNOWLEDGEMENTS

This project was funded by the United States (U.S.) Bureau of Ocean Energy Management (BOEM) and the Virginia Department of Energy (VE) under Cooperative Agreement M21AC00010. Jeffrey Waldner, Dr. Paul Knorr, Kerby Dobbs, and Geoffrey Wikel with the BOEM Marine Minerals Program, Office of Strategic Resources completed technical reviews, contributed valuable insight, and provided encouragement throughout the Cooperative Agreement. The authors greatly appreciate their feedback and time as part of this collaborative project. We thank the speakers and participants at the 2022 Mid-Atlantic Marine Heavy Mineral Sands Forum, virtually hosted by VE, for their time and the fruitful discussions that provided critical information for this capacity assessment and future planning needs. The authors extend thanks to Schnabel Engineering LLC and the U.S. Army Corps of Engineers for providing access to the Sandbridge and Atlantic Channel sediment cores. Many thanks are also extended to the College of William and Mary for use of the Geology Storage facility "Geobarn" and the three-turn Humphreys spiral. The authors wish to thank the dedicated team at VE for their assistance in sample processing, including Dr. Jenny Meng, Jeremy Wyman, Trevor Gunn, Wendy Kelly, and Victoria Ralph. Dr. Michael Smith (VE contractor) and Dr. Rick Berquist (retired, Professor Emeritus – William & Mary) provided valuable technical assistance with analytical standards and heavy mineral sands, respectively. Many thanks to Anne Witt for providing technical review of the associated geodatabase and technical report. We extend thanks to Matthew Heller, Marcie Occhi, and Patrick Finnerty for their internal reviews of this document. We wish to thank Dr. Tassos Grammatikopoulos with SGS Canada, Inc. for his expertise and services regarding analytical mineralogy and geochemistry for the submitted samples. Thanks should also go to Atlantic Strategic Minerals for their insight into heavy mineral sand processing operations. We also greatly appreciate the technical assistance provided by SciAps, Inc. during training and operation of our portable x-ray fluorescence analyzer.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

BOEM	Bureau of Ocean Energy Management
CFR	Code of Federal Regulations
cy	cubic yards
EPMA	Electron Probe Micro Analysis
g	grams
g/cc	grams per cubic centimeter
gpm	gallons per minute
HL	heavy liquid
HM	heavy mineral
HMC	heavy mineral concentrate
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy
ICS	Inner Continental Shelf
KeV	kiloelectronvolt
m	meters
MMP	Mineral Mining Program
NAD	North American Datum
NEPA	National Environmental Protection Act
NOAA	National Oceanic and Atmospheric Administration
NORM	Naturally Occurring Radioactive Material
NRC	Nuclear Regulatory Commission
OCS	Outer Continental Shelf
pXRF	portable x-ray fluorescence
REE	rare earth element
SBB	Sandbridge Borrow
THM	total heavy minerals
TIMA	Tescan Integrated Mineral Analyzer
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
VE	Virginia Department of Energy
VMRC	Virginia Marine Resources Commission
wt%	percent by weight (ratio of individual mass to total mass)
XRD	x-ray diffraction

1.0 EXECUTIVE SUMMARY

This report serves as a comprehensive summary of our investigation of critical commodities found in marine heavy mineral sands off the coast of Virginia, and their potential for co-extraction during beach sand nourishment operations. Five main tasks were completed: 1) VE convened the *2022 Mid-Atlantic Marine Heavy Mineral Sands forum* to evaluate the benefits and drawbacks to heavy mineral sand separation and released the proceedings as an open-file report, 2) VE identified existing regulatory requirements for heavy mineral sand co-extraction during beach sand nourishment operations, 3) VE characterized the geology of occurrences of heavy mineral sands offshore of Virginia, 4) VE developed rapid screening methods for critical commodities within marine sediment using a portable x-ray fluorescence (pXRF) instrument, and 5) VE identified the potential next steps to test the feasibility of extracting heavy mineral sands during beach nourishment.

In 2022, the VE Mid-Atlantic Marine Heavy Mineral Sands forum was convened to gather stakeholder and regulator insights regarding heavy mineral separation during beach sand nourishment, resulting in published proceedings (Hawkins and Lassetter, 2022). The recovery of non-fuel minerals in offshore sand is a novel initiative within the existing regulatory and permitting framework, which requires proactive collaboration between federal, state, and local governments. Additionally, although there is interest from the sand mining industry in collaborating on coastal resilience projects, it is likely that sustained government and municipal commitments will be necessary to make such projects economically viable.

Sediments offshore of Virginia contain heavy mineral sands that range in concentration from 0.1-17 percent by weight (wt%). The minerals ilmenite, zircon, garnet, rutile, pyroxene, and amphibole collectively make up the largest share of the heavy minerals in 640 sediment samples included in the accompanying geodatabase. At the Sandbridge Shoal Federal Outer Continental Shelf (OCS) lease area, a proven sand source for nourishment, heavy mineral sands constitute an average of 0.85 wt% of bulk material sampled using vibracore methods. A preliminary economic estimate based on the heavy mineral data indicates a potential value of up to $5.5 million for the heavy mineral sands within the dredged material used for the 2020 Sandbridge Beach nourishment project. The Atlantic Ocean Federal Navigation Channel, which is dredged for navigation purposes, contains heavy mineral sands averaging 1.06 wt% of bulk material.

A screening protocol using pXRF equipment has been developed along with empirically-derived geochemical thresholds to identify potential critical minerals. The intent of this pXRF screening is to rapidly detect the presence of minerals rich in titanium, zirconium, and rare earth elements in marine sediments and onshore paleobeach deposits. We have identified a correlation between increased concentrations of titanium, zirconium, and iron with higher heavy mineral content, potentially indicating economic heavy minerals in bulk sediment samples.

A review of current heavy mineral separation operations and processes reveals some potential to adapt these operations and processes to extract heavy minerals from sands used in beach nourishment operations. Considering the available technologies and necessary stakeholders, this could effectively mitigate nourishment expenses, establish a domestic supply of critical minerals, and enhance the overall quality of beach sands.

2.0 INTRODUCTION

The Commonwealth of Virginia has worked with the United States (U.S.) Bureau of Ocean Energy Management (BOEM) and its predecessor since the 1980s to identify offshore areas suitable for beach nourishment, and other coastal resilience projects important to the Commonwealth (Hardaway et al. 1995; DMME 2012; Berquist et al. 2016; Blanchette and Lassetter 2019). Through the Disaster Relief Appropriations Act of 2013 following Hurricane Sandy, the Department of the Interior was funded to rebuild and repair coastal assets and make strategic investments to improve coastal resilience for 13 Atlantic coastal states from Maine to Florida. Many local, state, and federal agencies and institutions have prioritized the characterization of offshore sand resources due to coastal shoreline loss during hurricanes and nor'easters, and long-term changes associated with a dynamic coastline. For example, Sandbridge Beach (Figure 1) along the southeastern coast of Virginia replenished nearly 9 million cubic yards (cy) of sand at the shoreline between 1998 and 2020 as part of erosion control and hurricane protection measures, costing nearly $65 million (Hawkins and Lassetter 2022). The most recent OCS dredging and nourishment event at Sandbridge Beach was completed in 2020 with 1.7 million cy of sand applied to a 725-foot wide, 5-mile-long project area, and cost the City of Virginia Beach $20.3 million dollars (see D.F. Adams presentation in Hawkins and Lassetter 2022).

While offshore sand resources are dominated by quartz-rich sand, there is strong evidence that many deposits contain economic concentrations of heavy minerals such as titanium-rich ilmenite, leucoxene, and rutile, zirconium-rich zircon, and rare earth element-bearing monazite and xenotime adding to the value of offshore sand for coastal restoration projects (Berquist 1990). According to the 2022 list of critical minerals defined by the U.S. Geological Survey (USGS) 87 FR 10381 (Federal Register 2022), titanium (Ti), zirconium (Zr), and rare earth elements (REEs, e.g., cerium (Ce), lanthanum (La), neodymium (Nd)) are considered critical to meet the needs of the U.S. economy, national security, infrastructure, and assist in the transition to renewable energy (Table 1). Additionally, the 2017 U.S. Federal Executive Order 13817 encourages the characterization of domestic resources of critical commodities for future exploration. Based on 2020-2021 published unit prices for raw commodities including ilmenite, monazite, rutile, and zircon mineral concentrates among others, estimates of the potential value of one cy of marine sand with 1-2 wt% total heavy minerals (THM) ranges between $5-$10 (Hawkins and Lassetter 2022). This suggests that the added value of heavy mineral sands contained within the dredged material for an average beach nourishment project could be in the millions or tens of millions of dollars. A rigorous assessment of the economic costs of recovery of heavy minerals depends on many factors, which are discussed later in this report.

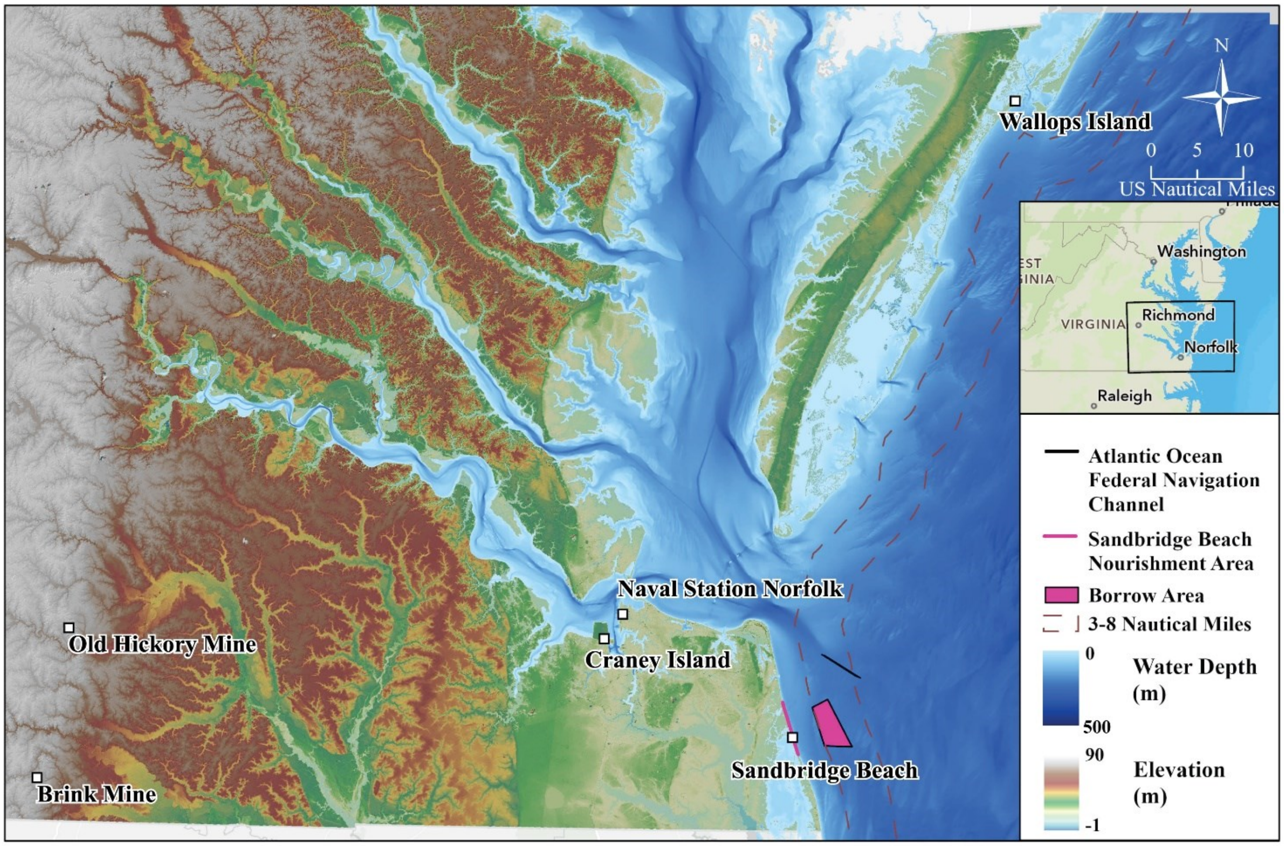


Figure 1: Eastern Virginia 5-meter digital elevation model compiled from lidar datasets[1] and 10-meter offshore Virginia and Chesapeake Bay bathymetry[2]. Areas of interest discussed throughout the text include the Old Hickory and Brink Mines at the Fall Zone, Wallops Island on the eastern shore, Naval Station Norfolk, Craney Island, and Sandbridge Beach. The Sandbridge Borrow Area (pink polygon) and Atlantic Ocean Federal Navigation Channel (black line) are areas of investigation presented in this report. [1]USGS 2015; OCM 2024a-d. [2]NOAA.gov.

Table 1: Heavy minerals and critical commodities in sand deposits offshore and onshore in Virginia.

Mineral Name (abbreviation)[1]	**Composition**[3]	**Specific gravity**[4]	**Critical commodities**[5]	**Other economic commodities**
Monazite (Mzn)	$(Ce,La,Nd,Th)PO_4$	4.6 - 5.4	REE, Y	Th
Xenotime (Xtm)	$Y(HREE)PO_4$	4.4 - 5.1	Y, REE	U
Ilmenorutile	$TiNbO_2$	4.7 - 4.8	Ti, Nb	-
Ilmenite (Ilm)	$Fe^{2+}TiO_3$	4.7	Ti	-

Table 1: Heavy minerals and critical commodities in sand deposits offshore and onshore in Virginia.

Mineral Name (abbreviation)[1]	**Composition**[3]	**Specific gravity**[4]	**Critical commodities**[5]	**Other economic commodities**
Zircon (Zrn)	$ZrSiO_4$ +/- U, Th, Hf, and REE	4.7	Zr, Hf, REE	U, Th, refractory
Chromite (Chr)	$(Fe,Mg)Cr_2O_4$	4.6	Cr	refractory
Davidite (n/a)	$(La,Ce,Ca)(Y,U)(Ti,Fe^{3+})_{20}O_{38}$	4.3 - 4.5	REE, Y, Ti	U
Rutile (Rt)	TiO_2	4.2 - 4.3	Ti	-
Leucoxene *(Lcx)*[2]	altered Fe-Ti oxide	3.6 - 4.3	Ti	-
Allanite (Aln)	$(Ca,Ce)(AlAlFe^{2+})O[Si_2O_7][SiO_4](OH)$	3.5 - 4.2	Ce	-
Ti silicates (e.g.,titanite, sphene) (Ttn, Spn)	$Ca,Ti(SiO_4)O$	3.5 - 3.6	Ti	-
Apatite (Ap)	$Ca_5(PO_4)_3(Cl/F/OH)$ +/- REE, U, and Sr	3.2	REE, Sr	U, fertilizer (P)
Hematite (Hem)	Fe_2O_3	5.3	-	Fe ore
Magnetite (Mag)	Fe_2O_3	5.2	-	Fe ore
Pyrite (Py)	FeS_2	5.0	-	S
Garnet group (Grt)	$\mathbf{X}_3\mathbf{Z}_2(SiO_4)3$	3.4 - 4.6	-	abrasive
Staurolite (St)	$Fe^{2+}{}_2Al_9Si_4O_{23}(OH)$	3.6	-	abrasive, cement
Kyanite (Ky)	Al_2SiO_5	3.5 - 3.7	-	Al, refractory
Sillimanite (Sil)	Al_2SiO_5	3.2	-	Al, refractory
Spinel (Spl)	$MgAl_2O_4$	3.5 - 4.1	-	-
Pyroxene group (Px)	$\mathbf{AD}Si_2O_6$ **A** = Ca, Cu, Li, Fe^{2+}, Mg, Mn^{2+}, Na **D** = Al, Cr, Fe^{3+}, Mg, Mn^{2+}, Ti^{3+}, V^{3+}, Zn	3.5 - 3.7	-	-
Epidote (Ep)	$Ca_2(Al,Fe)_3(SiO_4)_3(OH)$	3.4 - 3.5	-	-
Schorl (Srl) **Tourmaline** (Tur)	$NaFe^{2+}{}_3Al_6(Si_6O_{18})(BO_3)_3(OH)_3(OH)$	3.2 / 2.9 - 3.1	-	-
Amphibole group (Amp)	$\mathbf{AB}_2\mathbf{C}_5((Si,Al,Ti)_8O_{22})(OH,F,Cl,O)_2$ **A** = Na, K, Ca, Pb_{2+} **B** = Li, Na, Mg, Fe^{2+}, Mn^{2+}, Ca **C** = Li, Na, Mg, Fe^{2+}, Mn^{2+}, Zn, Co, Ni, Al, Fe^{3+}, Cr^{3+}, Mn^{3+}, V^{3+}, Ti, Zr	2.9 - 3.6	-	-
Chlorite group (Chl)	$\mathbf{A}_{5\text{-}6}\mathbf{T}_4\mathbf{Z}_{18}$ **A =** Al, Fe^{2+}, Fe^{3+}, Li, Mg, Mn, or Ni **T =** Al, Fe^{3+}, and/or Si **Z =** O and/or OH	2.6 - 3.3	-	-

[1] Original abbreviation by Kretz (1983), expanded by Whitney and Evans (2010), unless otherwise noted.

[2] Leucoxene is an alteration product of ilmenite, rutile, sphene or anatase and does not have an accepted mineral abbreviation.

[3] mindat.org.

[4] Van Gosen et al. (2014); Garner (1978).

[5] Fortier et al. (2018); critical commodities per 87 FR 10381 (Federal Register 2022).

This report includes new findings on the occurrence of economic heavy minerals in marine sands at an active lease area and federal navigation channel offshore of Virginia and provides a pXRF screening protocol. In addition, a geodatabase of existing heavy mineral data offshore of Virgina is provided. The assessment considers logistics, regulations, technological needs, and potential environmental impacts, along with stakeholder interest and concerns to assess the viability and capability of heavy mineral sand extraction alongside beach nourishment operations in the Mid-Atlantic region. The assessment includes a workplan for a pilot study to test the viability of co-production of heavy mineral sands with offshore sand dredging efforts.

2.1 Objectives

The first objective of this study was to assess the offshore heavy mineral sand resource potential and grade at an active offshore sand lease site. Regional-scale studies have demonstrated the presence of economically valuable heavy minerals occurring in marine sediments on the continental shelf offshore of Virginia. In terms of weight percent, the average abundances are generally low (< 3 wt%), but potentially economic as a co-product of beach sand resource management (Berquist and Hobbs 1986; Berquist and Hobbs 1988a; Berquist and Hobbs 1988b; Berquist 1990; Berquist 2012). Data points (n=620) offshore of Virginia have been analyzed, compiled, and are provided in a heavy mineral sample geodatabase that includes sample locations, geochemistry, mineralogy, and THM content. This study added new data to include the heavy mineral content of high-density sands from 20 sand and 3 mud subsamples from vibracores collected at Sandbridge Shoal located east of Sandbridge, VA and the Atlantic Ocean Federal Navigation Channel.

The second objective of this study was to establish a screening protocol using pXRF analysis for marine sand deposits extracted during beach nourishment projects, aiding in the detection of critical minerals. The benefits include increased data density at minimal costs and well-targeted sampling for laboratory analyses. The extraction of economic minerals from marine sand deposits during dredging and beach nourishment operations is a relatively new concept. Consequently, standardized procedures for screening economic minerals during these activities, especially concerning sand dredged for marine navigation or applied to eroding shorelines, are either inadequate or remain to be fully developed.

The third objective of this study was to outline the advantages and challenges associated with simultaneously extracting heavy mineral sands and sand aggregate material, introduced through a pioneering forum focused on the Mid-Atlantic region. Drawing insights from regulators and stakeholders, this assessment includes a conceptual work plan for a pilot study to test the feasibility of co-extracting economic minerals from marine sands during an upcoming nourishment event.

2.2 Economic Overview of Heavy Mineral Sand

Ti-enriched minerals and zircon are the main products extracted from surface mining of heavy mineral sands globally. Since 2010, more than 90% of zircon and rutile, 30% of ilmenite, and 80% of monazite necessary to meet global demand were recovered from heavy mineral sand placer deposits (Van Gosen and Ellefsen 2018). Pigment producers in the U.S. use domestically produced Ti mineral concentrates for paints, paper, plastics, and ink (USGS 2024). Other domestic uses for Ti include welding-rod coatings, light-weight alloys, and components for smart technologies (Carrara et al. 2023).

The U.S. production of Ti mineral concentrates varied between 100,000 and 200,000 metric tons from 2014 to 2023, with 2022 and 2023 production hovering around 200,000 metric tons produced each year. In 2023, one company recovered Ti-rich minerals from surface mining operations in Georgia and Florida, and another company in California recovered Ti-rich minerals from mine tailings. Imports primarily from Canada, Australia and Africa heavily outweigh U.S. production and exports (USGS 2024). The USGS estimated that 9.2 million metric tons of Ti mineral concentrates were produced globally in 2023 (USGS 2024). The 10-year trend in U.S. consumption tracks closely with imports and is driven by U.S. titanium dioxide (TiO_2) pigment production (Figure 2). The estimated 2023 domestic consumption for Ti mineral concentrates is 800,000 metric tons. Thus, the TiO_2 pigment industry is still heavily reliant on imports of Ti mineral concentrates for TiO_2 pigment production (~75%; USGS 2024).

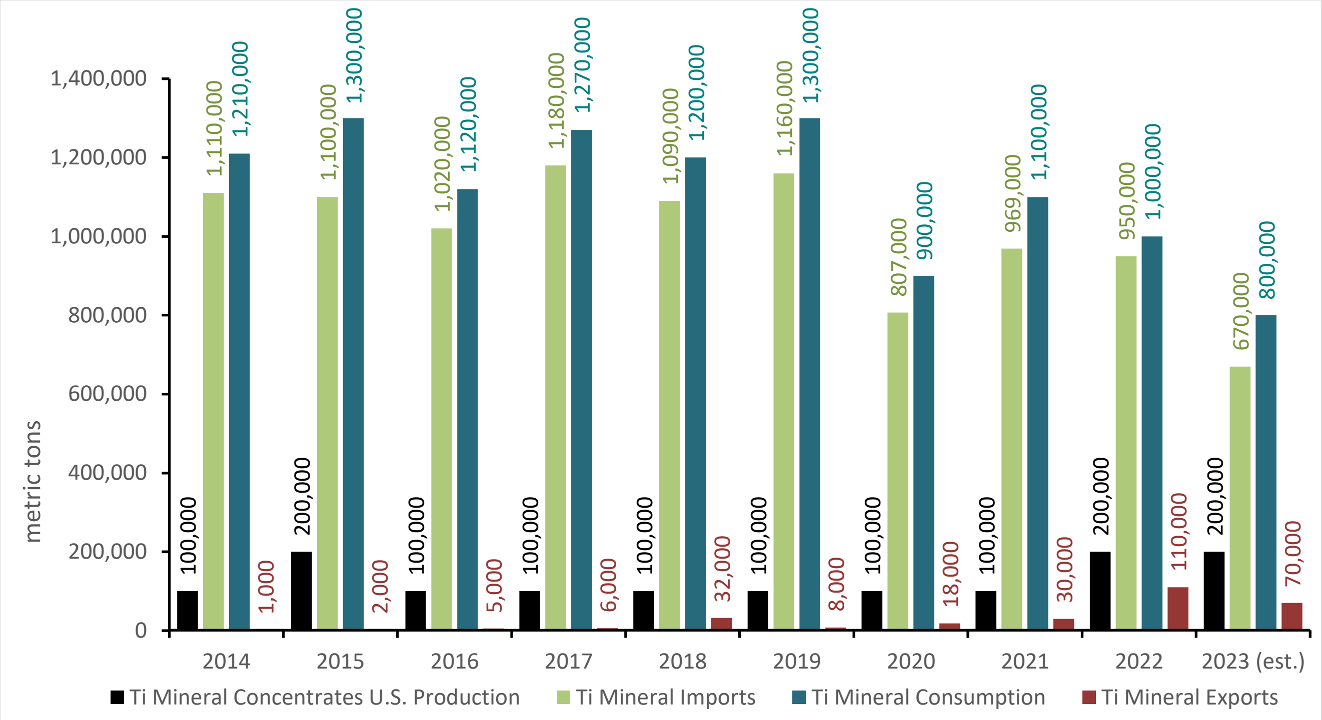


Figure 2: 10-year U.S. trend for Ti mineral concentrate production, imports, consumption, and exports (USGS 2019; USGS 2024).

Zircon, monazite, and garnet are typical co-products of Ti minerals from domestic surface sand mining operations (USGS 2024). Zircon is primarily used in the ceramics industry for surface glazes and pigments, and other uses of zircon and derivative products are emerging (ZIA 2022). Prior to 2020, the U.S. was a net exporter of Zr ores and concentrates, however, imports exceeded exports from 2020-2023 (USGS 2024). Global production of Zr mineral concentrates increased to about 1.6 million metric tons in 2023, with Australia and South Africa as the leading global exporters. U.S. production of Zr mineral concentrates is not precisely reported in commodity reports and is estimated to be about 100,000 metric tons or less for 2023 (USGS 2024). One company recovered zircon from surface-mining operations in Georgia and Florida, and a second company processed existing mineral sand tailings in California. The net import reliance for the U.S. in 2023 was <25% Zr-rich ores and concentrates.

The REE-bearing phosphate mineral monazite is an accessory mineral in heavy mineral sand ores and is considered a source for REEs (Ce, La, Nd) in U.S. production (USGS 2024). REEs are used as catalysts, additives to ceramics/glass, in metal alloys, permanent magnets, and for polishing. While the only domestic mining for REEs was at a hard rock mine in Mountain Pass, California, monazite mineral concentrate was stockpiled as a separated concentrate or included as an accessory mineral in heavy-mineral sand concentrates in the southeastern U.S. (USGS 2024). Though it is not considered a critical mineral, garnet is another common accessory mineral in heavy mineral deposits. U.S. garnet production was estimated to be about 7% of total global garnet production. The U.S. is >95% import reliant for domestic consumption (USGS 2024). Garnet is an industrial mineral that is used in abrasive blasting, water filters, water-based cutting, sandpaper, automotive manufacturing, ceramics/glass, and electronics.

3.0 FINDINGS FROM THE MID-ATLANTIC MARINE HEAVY MINERAL SANDS FORUM AND STAKEHOLDER INFORMATION

VE hosted a virtual *Mid-Atlantic Marine Heavy Mineral Sands Forum* on March 31, 2022. This forum focused on modern seafloor sand deposits containing critical minerals in the form of heavy mineral sands along the east coast that might be extracted during beach restoration projects. The purpose of this one-day virtual event was to bring together key maritime stakeholders and gather relevant information that would help assess the feasibility of extracting economic heavy minerals from marine sand deposits, the regulatory framework surrounding such a process, and those who would be impacted from these efforts.

Nearly 75% of the 74 participants to the forum were from state and federal agencies. Environmental and mining consultants made up 12% of the forum participants, while mining companies, local municipalities, laboratory staff, academics, and fisheries experts all made up <5% each. Sixteen presentations were given by professionals and scientists from VE's Geology and Mineral Resources and Mineral Mining Programs, BOEM, Karst Geo Solutions, LLC, City of Virginia Beach, State Geological Surveys (DE, MD, NC), USGS, SC Department of Health and Environmental Control, VA Department of Environmental Quality-Coastal Zone Management Program, Virginia Marine Resources Commission (VMRC), and SGS Canada, Inc.

The discussions were structured into 5 sessions that included the economics of critical mineral co-extraction, leasing of offshore sand resources, federal and state regulations, environmental regulations, and offshore exploration. The first session addressed the rationale for considering the economic significance of co-extracting critical minerals during beach nourishment operations. It offered insights into international operations and the methodologies employed for recovering heavy minerals. While the economic aspect drives interest in heavy mineral recovery, this session also spotlighted crucial environmental, public safety, regulatory, and varied stakeholder considerations within the offshore region. The second session delved into the federal marine minerals leasing program by BOEM and further examined the practical applications of OCS sand specifically along Virginia Beach and Sandbridge Beach.

Session 3 aimed to pinpoint potential issues and concerns surrounding a prospective offshore industry in state and federal waters, evaluating prevailing state permitting and regulatory prerequisites across Virginia, Maryland, North Carolina, and South Carolina. It highlighted the varying degrees of regulations at the state level, emphasizing how states manage essential shared-ocean uses at the regional level, such as fisheries and marine conservation.

Regulatory oversight varies among states and adapts in response to the evolving utilization of ocean resources. Additionally, the session stressed the importance of involving stakeholders early in the planning and discussion phases. In Session 4, an overview was provided regarding prevailing environmental standards, best practices, and the spectrum of issues pertinent to stakeholders in the marine and coastal environment.

The fifth and final session shed light on essential tools used to locate and characterize critical mineral occurrences and discovery of economic deposits. This session encompassed various topics, including expanding geological mapping coverage from terrestrial to marine environments for heavy minerals, state-of-the-art geochemical and mineralogical analytical techniques, and geophysical methods used to identify potential resources. A comprehensive overview of the forum, including presentation abstracts, summaries, and slides, is available in Open-file report 2022-20 (Hawkins and Lassetter 2022; Appendix A).

Seven significant issues were identified during the forum and steps for addressing each issue were developed:

1. Regulations on the OCS do not differentiate between non-fuel minerals (excluding metals) and sand/gravel aggregate.
    a. Should there be a proposal to extract heavy minerals from offshore borrow area material, it would necessitate an environmental impact assessment and review. This assessment would involve collaboration among several federal agencies and cooperating entities, particularly the U.S. Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA), and BOEM if OCS resources were involved.
    b. Federal and state regulatory agencies should engage in discussions regarding permit application procedures and potential variations in lease terms for non-fuel heavy minerals. For example, these discussions should consider:
        i. Virginia's State Subaqueous Minerals Management Plan designates the VMRC as the primary agency overseeing leasing and extraction activities in subaqueous lands.
        ii. Water quality permitting similar to Maryland's Water Quality Certification requirement when a federal license or permit is mandated for a marine minerals project.
2. As part of environmental policy implementation (e.g., National Environmental Policy Act - NEPA), regulators will need to address transport and disposal requirements of THM concentrates from the marine and/or coastal environmental to a land facility. If a project intends to produce a monazite product, then the project plan will need to address management of naturally occurring radioactive material (NORM) in accordance with the current environmental and regulatory standards.
    a. The Virginia Department of Environmental Quality issues permits related to water and air quality.

    b. The Virginia Department of Health issues radioactive materials permits.
    c. The Virginia Department of Emergency Management regulates transportation of radioactive materials.
3. The ownership rights to heavy mineral sands during dredging and nourishment operations are currently ambiguous.
    a. To resolve this, stakeholders involved in the project must collaboratively establish a legally binding document outlining ownership rights and royalty payments.
    b. State governments should consult their regulations regarding transport of aggregate and non-fuel minerals across state jurisdictional boundaries, as specific transportation requirements, costs, or documentation may be necessary.
4. The mining industry has emphasized the necessity for long-term commitments to attract investments for potential operations.
    a. Achieving this may necessitate collaboration among federal, state, and local governments, alongside other marine and coastal stakeholders.
    b. Assessing the THM concentration offshore before commencing extraction operations is crucial. This evaluation serves as due diligence in selecting borrow sites for beach nourishment projects and assessing their economic potential.
5. Offshore heavy mineral sand development opportunities will need to leverage current offshore data and incorporate onshore heavy mineral sand exploration technologies and techniques for mining, processing, and reclamation.
    a. Depending on the size of the operation, start-up and operating costs for a mobile-capable separation method may need to be estimated as part of the pilot study.
    b. Subaqueous exploration methods include using magnetic field measurements, via airborne sensors or tow fish. These methods are unaffected by water and can detect superficial minerals like magnetite, hematite, and maghemite found in small amounts within a heavy mineral assembly. In scenarios where the sensor platform can be closer to the ground—such as shipboard or walking surveys—subtle anomalies indicating concentrations of heavy mineral sands may be discernible, especially in tranquil waters.
    c. Tescan Integrated Mineral Analyzer (TIMA) analysis can provide a quantitative assessment of sample mineralogy, speciating the minerals and their mass percent among other parameters. This technique is advantageous over bulk mineralogical identification techniques because it provides accurate mineral identifications at low detection limits, and additional mineralogical parameters.
6. Evaluation of existing dredge spoil areas offshore and onshore for heavy minerals is needed.
    a. Sampling these disposal areas would be appropriate to determine if heavy minerals are present in economic concentrations.
    b. VMRC prefers beneficial use of the dredge spoil material for beach nourishment, living shorelines, and/or wetland creation and encourages use of existing mine and dredging waste before creating new dredging sites offshore of Virginia.

7. The USACE and dredging operators were not present at the forum leaving data gaps from these regulatory and industry concerns.
    a. This could be resolved with a separate meeting with USACE personnel and dredging experts in the Mid-Atlantic region to gauge interest and expectations for a heavy mineral separation during offshore dredging.

3.1 Marine Economy

The marine economy stands as the largest among four key sectors in the U.S., superseding utilities, big tech, and agriculture. In 2021, the marine economy contributed $432 billion in gross domestic product and $730 billion in current-dollar gross output for the U.S. (USBEA 2023). Coastal communities, where nearly 40% of the U.S. population resides, play a pivotal role in driving the marine economy's success. This multifaceted economy relies on collaboration and resource sharing for various purposes, including housing, tourism, economic activities, transportation, natural resource extraction, energy development, and national defense. Coastal areas are highly susceptible to environmental changes, requiring careful consideration and planning to protect marine species and other natural resources. Projects in these regions require thorough environmental impact assessments to identify environmentally and/or ecologically sensitive areas. These assessments are crucial in preserving marine and nearshore ecosystems while facilitating economic development. Introducing a mineral recovery operation during dredging or beach nourishment projects requires engagement with primary stakeholders who will play a fundamental role in decision-making processes. Additional stakeholders (e.g., recreational, military, fisheries, conservatories) may be needed to ensure comprehensive and inclusive discussions.

3.2 Coastal Communities, Tourism and Recreation, Habitat

The shorelines and beaches of Virginia accounted for 32% of the marine economy in 2020 (NOAA 2022), while also serving as critical nesting habitat for sea turtles and shorebirds. Shoreline resilience often relies on nature-based solutions (such as living shorelines and restoration of salt marshes, dunes and beaches) to counter infrastructure and ecosystem degradation. This often requires human intervention and geoengineering, especially following high-intensity natural disasters. Across the Mid-Atlantic region, coastal resilience relies on accessible sand and gravel resources. Matching the texture and color of the existing original beach sand for periodic nourishment is especially important for habitat, durability, and aesthetics. The proximity to suitable material significantly impacts project costs, with expenses for aggregate transportation doubling with distances exceeding 30 miles (Robinson and Brown, 2002). The supply of offshore sand for beach nourishment is managed by BOEM’s Marine Minerals Program, for leases of sand, gravel, and shell resources in the federal OCS. Operational duties for such projects are handled by the USACE and federal contractors. Presently, there are no offshore heavy mineral sand operations in state or federal waters along the Mid-Atlantic coast, however, if less compatible resources become available, pre-processing (i.e., removal of opaques, fines, gravel, etc.) may be a requirement prior to beach application.

Balancing the desire for a visually appealing beach with the preservation of the natural ecosystem is key when making decisions about modifying beach sand composition. For example, dark-colored heavy mineral sands (e.g., magnetite, ilmenite, rutile) and fine-grained material can affect the visual appearance of the beach. Removing the darker grains and fines has been shown to increase the hue (i.e., brightness) of the color space for the beach material (Priestas 2022), which can enhance the beach aesthetic. In fact, some beach areas require color and textural conditions to be met prior to application (FDEP 2022). Furthermore, a more uniform textural composition could create a more erosion-resistant coastline (Bozzeda et al. 2023). On the other hand, removing opaque sand and fines could disrupt the ecological balance of the beach and affect biodiversity.

A predominantly light-colored beach will reflect more sunlight and absorb less heat, compared to a beach with a higher concentration of black sand. Changes in beach temperature due to the removal of black sand grains have indirect effects on local ecosystems such as nesting habitats, microhabitats, and feeding grounds. Some species of turtles, for instance, rely on specific temperature conditions for nesting, while insects and crustaceans rely on these heavy minerals for camouflage or habitat creation. Cooler beach sands influence inhabitation potentially impacting population dynamics of sea turtles or other shoreline nesters (Laloë et al. 2016).

Offshore sand and gravel dredging is important to the fisheries and seafood industries, including watermen, aquaculturists, processors, and distributors. Given that Virginia is a prominent seafood producer on the East Coast, ranking fourth in marine product production in the U.S. (VCZMP 2021), and the Chesapeake Bay and the offshore Atlantic Ocean fisheries represent approximately 2% of Virginia's state gross domestic product (Gonçalves et al. 2022; USBEA 2023), nourishment operations must consider any potential impact to these stakeholders. Continued engagement with these sectors is critical so as not to have a negative effect on the fisheries economy.

3.3 Critical Infrastructure

Critical coastal infrastructure ranges from national defense installations to maritime energy resources and power plants. Naval Station Norfolk, situated at the Chesapeake Bay's mouth in southeastern Virginia (Figure 1), is the world's largest naval complex. Adjacent to it lies Craney Island, a dredge spoil disposal site overseen by the USACE. As per the recommendations from the VE forum in 2022 (Hawkins and Lassetter 2022), Craney Island was identified as a suggested site for screening dredged material for heavy mineral sands.

In northeastern Virginia, the National Aeronautics and Space Administration (NASA) Wallops Island Facility operates as a multi-tenant facility hosting the U.S. Navy Surface Combat Systems Center, the Mid-Atlantic Regional Spaceport, and other governmental and commercial operations. Documented shoreline change has indicated that the Wallops Island beach has been eroding at least over the last 150 years (King et al. 2010). A replenishment operation in 2012 costing $42 million and applying 3.2 million cy of material, aimed to safeguard federal and state assets worth $1 billion. However, in the same year, Hurricane Sandy removed some of this new material, prompting a minor nourishment application in 2014. Given the typical timeline of 3-7 years for beach nourishment projects, Wallops Island is a potential site for heavy mineral sand screening and co-extraction during subsequent nourishment events, pending collaboration between the USACE and the mining industry.

Offshore wind energy holds promise in the Mid-Atlantic region. Virginia's 2022 Energy Plan advocates responsible wind energy development on the federal OCS, which is a collaborative effort involving VE, BOEM, the Virginia Coastal Zone Management Program (VCZMP), NOAA, fisheries, state and local authorities, and electric utilities. The proposed Coastal Virginia Offshore Wind project, outlined in the plan, is slated for the OCS BOEM lease area (OCS-A 0483), 23.75 nautical miles off the Virginia Beach coastline, spanning 112,799 acres. Dominion Energy's 2023 Construction and Operations Plan proposes the installation of up to 176 wind turbines over a three-year construction period commencing in 2024 (VE 2022; Dominion Energy 2023).

4.0 REGULATIONS

4.1 Environmental Considerations

Under U.S. Title 40 policy per NEPA, federal agencies must consider the environmental impacts of their actions in the decision-making process. The NEPA process requires an environmental assessment (EA) of potential impacts to benthic habitats, turbidity and sedimentation, water and air quality, and noise, for use of OCS sand. Since the co-extraction of heavy mineral sands has not occurred as part of an existing borrow area dredging project, it must first be determined whether the extraction would occur offshore or onshore. In typical dredging activities, there is a natural loss of finer material (≤ 63-micron grains) during overflow at the vessel and during outwash at the beach placement stage (Priestas 2022). USACE, in collaboration with BOEM, conducted a study to assess the loss of fines during dredging and pump-out activities offshore of Mississippi. The study found that 87% of the finer material was lost between dredging and beach outwash (Smith et al. 2019). Quantifying the loss of silt- and clay-sized particles is valuable to understand the impacts on turbidity in nearby waters during these processes, and the sediment characteristics, aesthetics, and habitat suitability of the final material at the beach.

4.2 Federal Regulatory Framework

BOEM's Marine Minerals Division oversees leasing and permitting for non-fuel minerals on the federal OCS under the Outer Continental Shelf Lands Act and U.S. Title 30 subchapter B. Since 1995, the program has executed 64 non-competitive negotiated agreements in the East Coast and Gulf of Mexico OCS regions. Under the current federal regulations (30 CFR Part 580-582), BOEM has not yet issued a competitive lease for commercial minerals other than sand. Other federal agencies with input for decisions and projects on the federal OCS are included in Table 2 below.

Table 2: Federal regulatory framework

Regulatory Agency	Statutory Basis and/or Environmental Jurisdiction	Permitting Oversight and Involvement
BOEM Marine Minerals Program	30 CFR Part 580-582 (prospecting, leasing, operations) NEPA 42 U.S.C §§ 4321 *et seq*. Energy Policy Act of 2005	Management of marine minerals on the federal OCS
USACE (District Specific, e.g., Norfolk for Sandbridge Area)	Rivers and Harbors Act—Section 10 33 U.S.C. §§ 333I, 403 Clean Water Act (CWA) Section 404 33 U.S.C. § 1344	Oversight of dredging operations in federal navigable waterways
NOAA's National Marine Fisheries Service	Marine Mammal Protection Act 16 U.S.C. §§ 1361 *et seq*. Magnuson-Stevens Fishery Conservation and Management Act 16 U.S.C. §§ 1801 *et seq*. Endangered Species Act (ESA) 16 U.S.C. § 660 16 U.S.C. §§ 1531 *et seq*. Coastal Zone Management Program (coastal regions)	Fisheries and marine habitat management in the U.S. Exclusive Economic Zone and federal waters, federal consistency through state Coastal Zone Management Programs in state waters
U.S. Fish and Wildlife Service	ESA 16 U.S.C. §1531 Migratory Bird Treaty Act, 16 U.S.C. §§ 703 *et seq*. Bald and Golden Eagle Protection Act 16 U.S.C. § 668	Endangered and protected animal species, migratory bird concerns

Table 2: Federal regulatory framework

Regulatory Agency	Statutory Basis and/or Environmental Jurisdiction	Permitting Oversight and Involvement
Environmental Protection Agency	Clean Air Act 42 U.S.C. §§ 7401 *et seq*.	Disposal/dumping, air and water quality concerns in federal and state waters, state waters managed under the Virginia Department of Environmental Quality
Other Federal Agencies for Potential Consultation		
Department of Defense, Federal Aviation Administration, U.S. Coast Guard	Public Law 114-92, National Defense Authorization Act (NDAA) of 2016, Amendment to § 358, FY11 NDAA 10 U.S.C. § 2710; 14 CFR Part 77, as applicable 14 CFR § 77.9; 49 U.S.C. § 44718, 33 U.S.C. § 1221	Unexploded ordnance, aviation obstruction, military training, and operations

U.S. Title 30 Part 580 provides a guide for permitting and prospecting for minerals on the OCS, excluding oil, gas and sulfur administered by BOEM. Part 581 details the leasing guidelines for minerals other than oil, gas, and sulfur on the OCS, and Part 582 covers operations. Section 582.24 requires that a mining plan include comprehensive detailed descriptions, illustrations, and explanations of the proposed OCS mineral development, production, and processing activities. Each of the activities of the mining cycle from extraction through processing and waste disposal should be included as well as a description of equipment to be used in mining, processing, and transporting of the ore. For onshore processing, a description of how OCS minerals will be processed, weighed, assayed, and how royalty determinations are determined, should be provided. For at-sea processing, onshore processing information should be provided in addition to information on the type and size of installation or structures and the method of tailings disposal (CFR Title 30).

4.3 State and Local Regulatory Framework

In the Commonwealth of Virginia, sediments from state-owned submerged bottomlands are regulated under the VMRC. The VE Mineral Mining Program (MMP) regulates surface and subsurface mining in state-owned waters (including the Inner Continental Shelf (ICS)), while adhering to VMRC regulations pertaining to dredging. The MMP does not have jurisdiction over sediments mined for use in beach nourishment projects, nor for general maintenance dredging projects. VE's MMP has regulatory oversight of "for profit" non-coal subsurface and surface mineral mines within the Commonwealth per the Code of Virginia - Title 45–2 - Subtitle III - Chapter 11 (https://law.lis.virginia.gov/vacodefull/title45.2/subtitleIII/). The MMP provides permitting and licensing guidance and oversight for mines on state-owned lands, including submerged lands, in conjunction with other regulatory requirements. Additionally, the MMP oversees environmental compliance in cooperation with other agencies such as the VMRC for coastal areas in state-owned waters and the Virginia Department of Transportation for land use permits. Operators with a permit under the MMP work with the Department of Environmental Quality to obtain Virginia Pollutant Discharge Elimination System (VPDES) permits and non-metallic mineral processing general permits. VE provides oversight for reclamation of mine lands and worker safety per the Code of Virginia – Title 45.4 – Subtitle III – Chapter 12 and Virginia Administrative Code –Title 4 – Agency 25, Chapters 35 and 40, respectively (https://law.lis.virginia.gov/vacode/title45.2/chapter12/; https://law.lis.virginia.gov/admincode/title4/agency25/chapter35/; https://law.lis.virginia.gov/admincode/title4/agency25/chapter40/).

Virginia's MMP has never received a permit application for an offshore mining operation. Current regulations and laws are limited and do not address for-profit mining in offshore waters and/or the transport of material from offshore locations for onshore processing (Hawkins and Lassetter 2022). Mineral concentrates from initial gravity separation are not anticipated to exceed state or U.S. Nuclear Regulatory Commission (NRC) NORM thresholds, but if this did occur, a radioactive materials license may be required. The concern would most likely be with a concentrated monazite or rare earth product that contains naturally-occurring thorium. The Virginia Department of Health, Department of Emergency Management, and the NRC should be consulted during the planning stages of a project to assess any need for special handling, transportation, or disposal of radioactive materials.

The VMRC provides regulatory oversight for marine fisheries, habitat, and shellfish management within state-owned waters. Habitat areas may include state-owned submerged lands, wetlands, and coastal primary sand dunes and beaches per Subtitle III of Title 28.2 (Chapters 12-14) (Hawkins and Lassetter 2022). Section "§ 10.1-704" of the Code of Virginia also directs that dredged material for beneficial use be prioritized for beach nourishment (Hawkins and Lassetter 2022). Under the VCZM, multiple agencies participate in a federal consistency review process (Section 307 of the Coastal Zone Management Act of 1972, 16 U.S.C. §), and VMRC serves as the clearinghouse for these joint permit application processes (Hawkins and Lassetter 2022). Other states have similar coastal zone consistency regulations, such as Maryland and South Carolina and implement similar joint permitting requirements (Hawkins and Lassetter 2022). The North Carolina Mining Act of 1971 does not accommodate a permitting process for offshore mining of placer sands or any other commodity such as phosphate. In North Carolina, material used for beach nourishment is not considered mining and therefore this law does not apply (Hawkins and Lassetter 2022).

Other Virginia state agencies that may need to be consulted include the Department of Conservation and Recreation, Department of Wildlife Resources, and Department of Historic Resources. Regional and local planning districts and commissions should also be involved if projects occur in their localities, outside of federal and state waters. Other local permitting needs may include conditional use permits for activities occurring on land, transportation permits for transporting processed sediment, and land disturbance permits, if applicable. Additionally, the respective local wetlands board should be consulted if potential impacts to wetlands may be present within the project's site plan.

5.0 GEOLOGIC SETTING

The U.S. Atlantic ICS and the OCS region of Virginia are the submerged eastward extensions of the Virginia Coastal Plain geologic province. The Atlantic Ocean basin began to develop during the fragmentation and rifting of the Pangean supercontinent at ca. 250 million years ago (Ma) (Lucas 2005). Rifting during the Mesozoic Era was succeeded by passive margin sedimentation, and the eastern mid-Atlantic region remains a major sink for sediments eroding from the Piedmont and Blue Ridge geological provinces of the Appalachian Mountains. Many of the igneous and metamorphic rock units mapped in these provinces (Witt et al. 2021) are likely sources of zircon, monazite, and rutile, among other high-density minerals.

Over the past 3 million years, substantial climate fluctuations and variations in global ice volumes have modified the shoreline's position during interglacial and glacial periods (Lambeck et al. 2002). High sea levels during interglacial periods are marked by scarps, shown on Figure 3A, while lower sea levels during glacial periods moved the shoreline further east (Lambeck et al. 2002). These ice volume changes were particularly dynamic over the last 800 thousand years, with the southern extent of the Laurentide ice sheet reaching deep into Pennsylvania and southern Illinois during the last glacial maximum in the late Pleistocene (Dyke et al. 2002).

During significant glacial periods, including marine oxygen isotope stages 16 (~625 ka), 12 (~430 ka), 6 (~138 ka), and 2 (~28 ka), sea levels were 100 to 150 meters (m) lower than today (Batchelor et al. 2019). At these lower sea levels, the modern continental shelf would have been exposed, with major river systems flowing across the plain to the ancient shoreline at the current slope break (Kimball et al. 1991; Krantz et al. 2016) (Figure 3B). The low-angle submerged Coastal Plain in Virginia is underlain by thousands of feet of unconsolidated sedimentary deposits that are Cretaceous and younger in age (Krantz et al. 2016). Offshore of the present-day coastline, the Neogene and Pleistocene deposits are overlain by a veneer of Holocene sediments deposited by long-shore drift and transport of material from the Chesapeake Bay, and other shoreface sources (Kimball et al. 1991). The extensive geological history of the mid-Atlantic coastline and near-shore currents have led to the accumulation of offshore sand resources and the fine-grained, well-sorted sand found on modern beaches. While quartz dominates the mineralogy of sediments deposited on the Coastal Plain and current shoreline, resistant heavy minerals like zircon and monazite also persist through multiple cycles of erosion, transportation, and deposition, contributing to the composition of these unconsolidated geological formations.

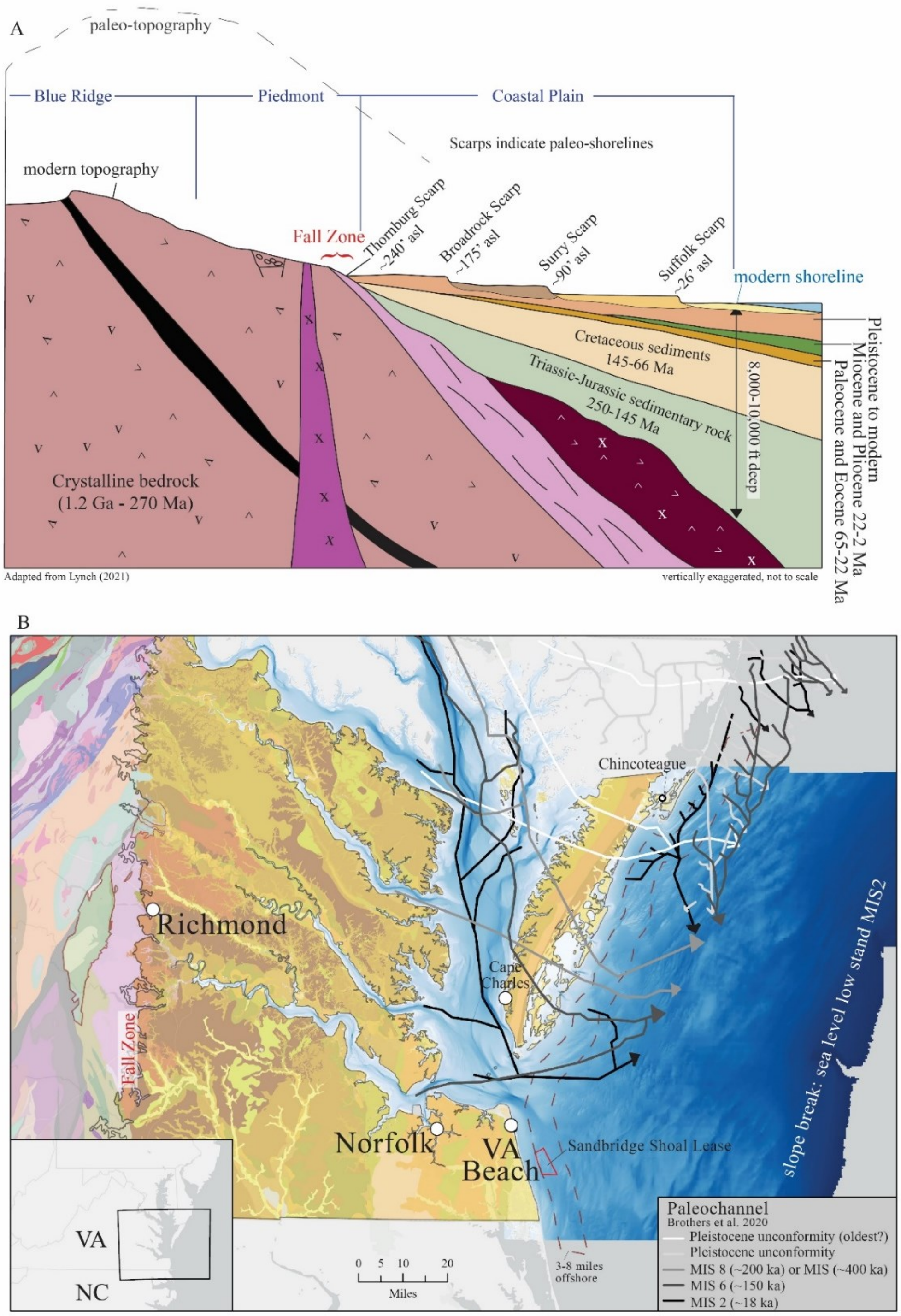
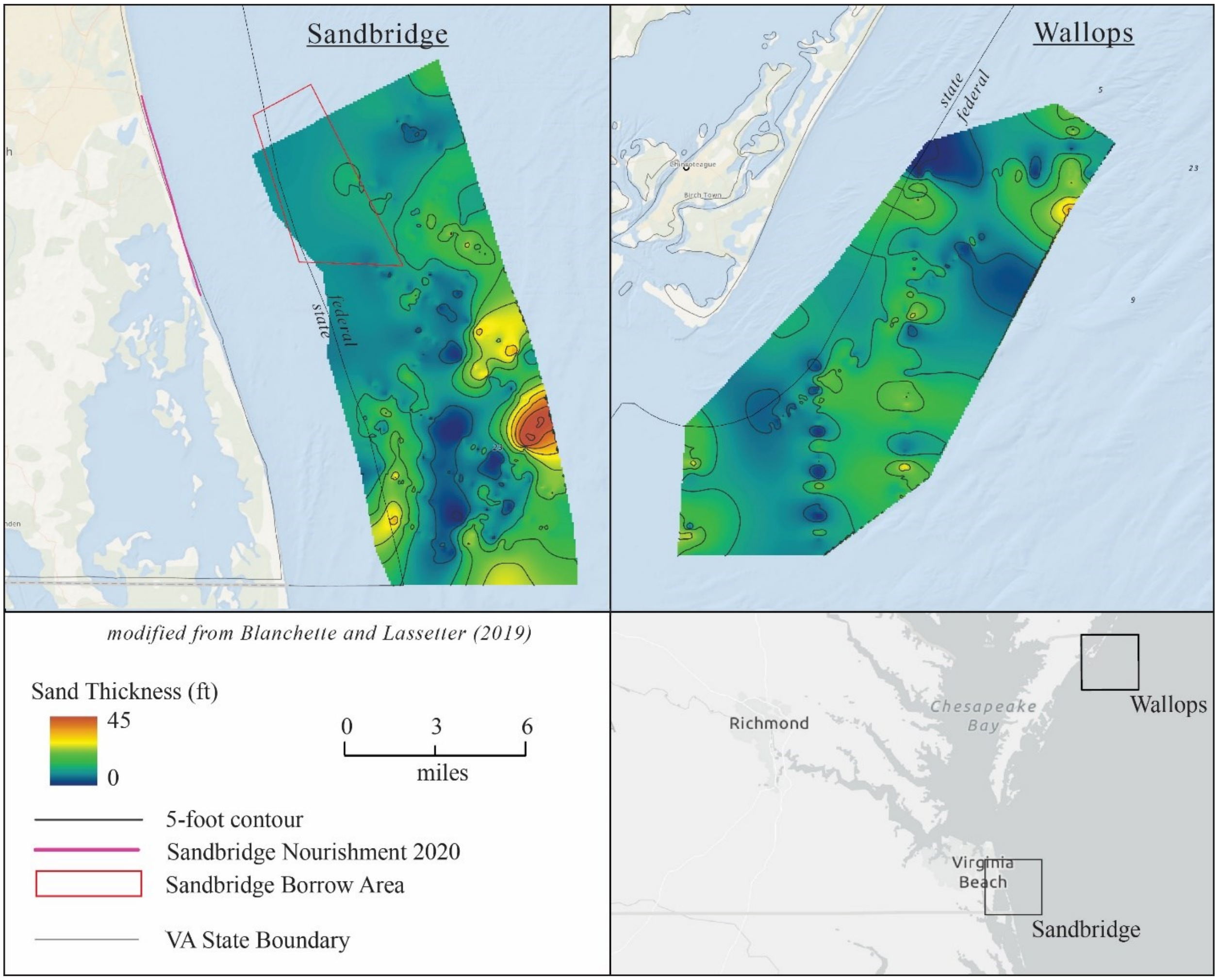


Figure 3: Generalized geology of the Piedmont and Coastal Plain physiographic provinces of Virginia. A: Cross section adapted from Lynch (2021), vertically exaggerated and not to scale. Coastal Plain sediments form an eastward dipping 8,000-10,000-foot-thick wedge of sediment, derived from the eroding Appalachian Mountains since the breakup of the Pangean supercontinent (250 Ma). B: Geology of eastern Virginia, extracted from the Geologic Map of Virginia (Witt et al. 2021). Purples, pinks, blues west of the Fall Zone are Piedmont igneous, metamorphic, and sedimentary rocks greater than 250 Ma (excluding Triassic rift basins that are outlined in red), while browns, oranges, and yellows east of the Fall Zone are Cretaceous and younger in depositional age.

5.1 OCS Sand and Gravel Deposits

The generalized stratigraphy of the shallow sedimentary units offshore of Virginia consist of a basal Pliocene deposit with at least two unconformities. The overlying units are Pleistocene fluvial- to marginal-marine deposits, overlain by Holocene sands with shells and clay (Williams 1988; Kimball et al. 1991; Blanchette and Lassetter 2019). The primary offshore features targeted for aggregate material for coastal resilience projects are paleochannels and modern shoals. The paleochannels contain fine to coarse sand and gravel aggraded during marine transgressions (Hobbs 1996), while shoals are derived from migrating offshore sand bars and submerged barrier islands. Substantial deposits of fine- to medium-grained sand have been identified in two main areas on the federal OCS offshore of Virginia in: (1) shoal and sheeted sand deposits located offshore of Assateague and Wallops Islands, and (2) shoal deposits located about 3 miles offshore of the community of Sandbridge (Sandbridge Shoal). These deposits occur within 10 feet of the sub-bottom at shallow water depths of less than 60 feet (Blanchette and Lassetter 2019).

Blanchette and Lassetter (2019) evaluated reconnaissance-scale sand resources from Sandbridge Shoal, and offshore of Wallops Island on the Eastern Shore of Virginia. Given the reduction in sediment transport capacity associated with shoals and linear ridges, quartz-rich sand and finer-grained heavy mineral sands have the potential to accumulate in shallow waters offshore. The 2019 study estimated 271 million cy of beach-quality sand with a thickness of 10 feet or more offshore of Sandbridge Beach and 393 million cy of beach-quality sand with a thickness of 10 feet or more offshore of Wallops Island (Figure 4). The authors excluded areas with overburden thickness of more than 2 feet from volumetric calculations. These estimates are representative of intact material at the time of vibracore and seismic reconnaissance efforts (e.g., 2015-2017) and not of previously dredged materials from the federal lease borrow areas (prior to 2015). Areas with surficial beach-quality sand thickness less than 10-feet or with overburden of more than 2-feet are not typically viable for use in coastal resilience projects (Blanchette and Lassetter 2019).



modified from Blanchette and Lassetter (2019)

Figure 4: Map created from vibracore data showing predicted surficial sand thickness at offshore locations near Sandbridge and Wallops, VA. Original data provided in Blanchette and Lassetter (2019).

5.2 Offshore Heavy Mineral Sand Occurrences and New Geodatabase

Research on heavy mineral sands in offshore sand deposits has been a priority for Virginia since the 1980s. A gravity-fed procedure to concentrate heavy minerals from continental shelf sediments was developed by Berquist (1990) using a Humphreys three-turn spiral and is still the basis for the pre-concentration technique used on large bulk samples today. Further refined heavy mineral concentrates using heavy liquids are quantified in terms of THM percentage, mineral composition, and elemental geochemistry.

Blanchette and Lassetter (2019) details heavy mineral assemblages offshore of Virginia in state and federal waters and describe multiple decades of heavy mineral research in offshore sediments (Figure 5). These data have been incorporated into an ArcGIS database that accompanies this report. The value of this new geodatabase is the capability to query for detailed heavy mineral information in offshore sand resources lease areas, or other offshore areas with high critical mineral potential. Statistics can also be calculated using the attribute table and related geochemical non-spatial tables. For example, the average and standard deviation THM content from 620 points offshore of VA is 2.88 ± 2.57 wt%, and a range of 0.01-16.6 wt%. The mass percent of individual heavy minerals within the THM fraction is also available in the geodatabase. Commonly identified heavy minerals include ilmenite, rutile, leucoxene, titanite, magnetite, chromite, zircon, kyanite, monazite, garnet, pyroxene, and amphibole. The analytical techniques for mineral separation and identification have varied and evolved over the course of these previous projects. The variable outputs from each study and dataset limitations are outlined in Appendix B. Digital data are available for download at https://www.energy.virginia.gov/geology/ocssands.shtml.

Reconnaissance THM offshore of Virginia shows a relatively high concentration of heavy mineral sands around Smith Island (Figure 5). In this area off the southeastern tip of the Delmarva Peninsula, there are 65 grab and core samples with >5 wt% THM. Thorium-rich (Th) economic heavy minerals in these samples include ilmenite (up to 44 wt% of THM fraction), zircon (up to 37% of THM), and monazite (up to 2.2 wt% of THM), among others. The grade at this location appears to be above the average of current onshore heavy mineral sand operations (~4-5 wt% THM with < 1 wt% monazite). While Smith Island is not an active OCS borrow lease area, the information in the geodatabase can serve as a basis for potential critical mineral co-extraction if beach-quality sand resources also occur.

The THM data near Wallops Island and Sandbridge are variable (e.g., hot spots and cold spots) and data gaps are present within the large polygon areas. To mitigate this low data density, high resolution THM and mineralogical data was acquired from the active borrow areas at Sandbridge Shoal and is discussed in detail in section 6.

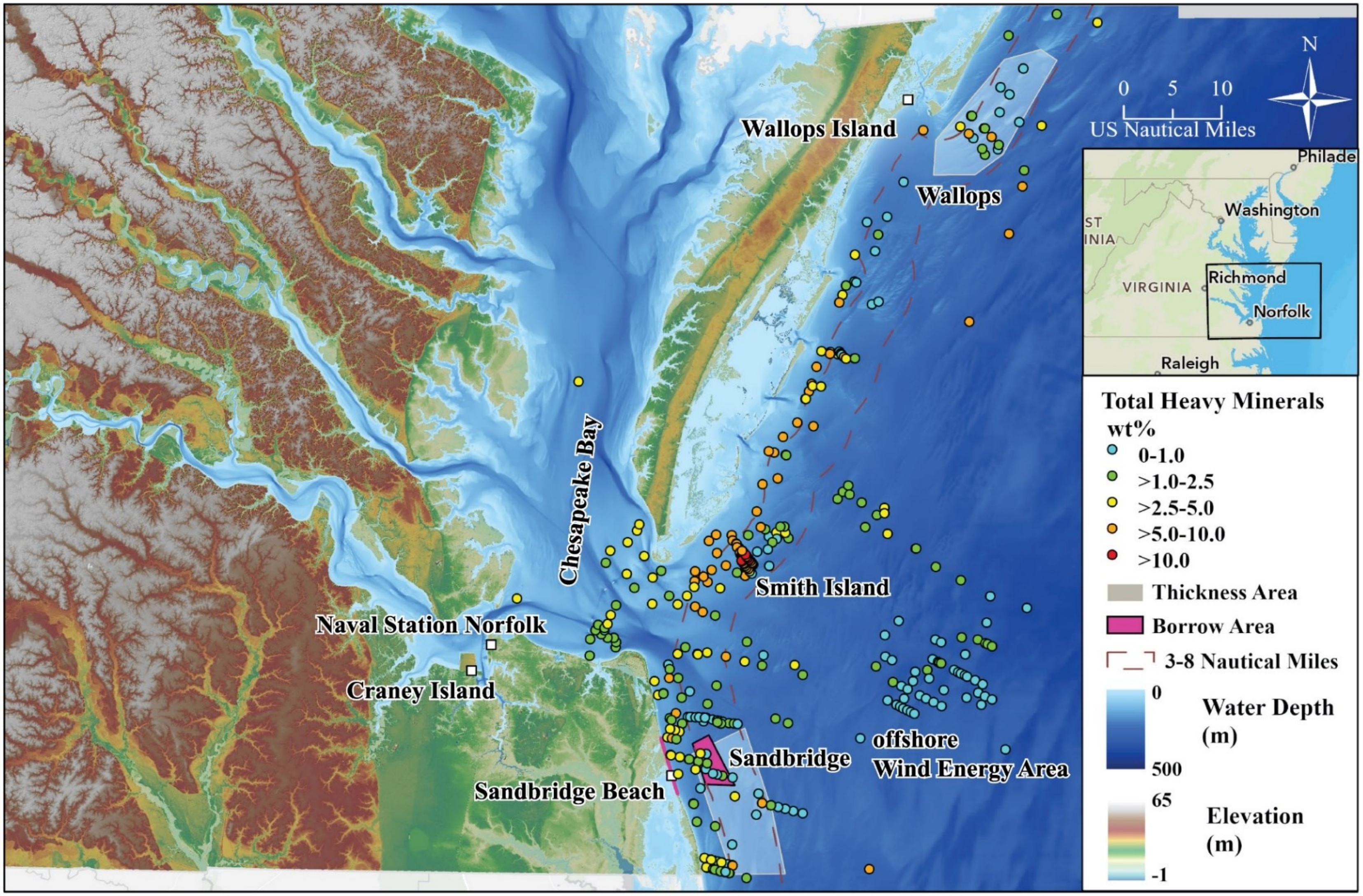


Figure 5: Total heavy mineral distribution from historical sample localities (modified from Lassetter and Blanchette 2019) (see Appendix B and Geodatabase digital data or more details). Sand thickness estimates for Wallops and Sandbridge are shown in Figure 4.

5.3 Onshore Heavy Mineral Sand Deposits

Heavy mineral sand placer deposits form by earth-surface processes that segregate minerals based on density. In the Mid-Atlantic, fluvial systems are the primary transport mechanism and supply of physically weathered material. Generally, long-transport river systems winnow the largest sedimentary particles first, and particles decrease in diameter with increased transport distance. Coastal wave action further winnows silt and clay, resulting in beach-front environments dominated by sand-sized particles at the terminus of such systems. Along the modern east coast of the U.S., beach sand is predominantly composed of quartz due to its physical and chemical stability at the earth's surface, determined by factors like relative hardness, cleavage, density, and solubility. Certain heavy minerals, such as zircon, rutile, and monazite, and exhibit high resistance to weathering and can endure numerous cycles of erosion, deposition, and transportation. While heavy minerals often occur with quartz in shoreline deposits, they tend to be finer-grained in comparison. Eolian processes contribute to concentrating heavy minerals by removing lighter density sands and create interdunal lag deposits. Wave action and storm deposition lead to further reworking of tidal deltas, beaches, and coastal dunes and can also concentrate heavy minerals (Van Gosen et al. 2014).

Depositional environments hosting ore-grade mineral sands encompass diverse settings: 1) eolian sand complexes like the Trail Ridge Complex in Florida and Mission Mine in Georgia (Van Gosen et al. 2018); 2) Neogene-age paleobeach and marginal marine deposits, such as the Iluka Old Hickory and Brink mine operations along the Fall Zone in southeastern Virginia (Figure 3A), and the proposed Titan Project hosted in the Cretaceous-age McNairy Sand deposit in western Tennessee (IperionX 2022); 3) lithified paleo-placers in South Africa and Australia; 4) fluvial placers in Sierra Leone; and 5) modern beach systems in India along the Kerala and Odisha State coastlines (Van Gosen et al. 2014). VE's Open-file report 2022-20 (Hawkins and Lassetter 2022) provides more information about global deposits and operations.

Onshore paleoplacer deposits can span a few kilometers in width and tens of kilometers in length, with a general thickness of less than 45 meters (Van Gosen et al. 2014). Minable deposits are characterized as shallow, unconsolidated to poorly consolidated, and substantial in volume (>10 million metric tons), holding an average THM percentage exceeding 2 wt% (Van Gosen et al. 2014). The Old Hickory and Brink mine sites in southeastern Virginia contained an average THM content of 4 wt% in bulk sediment (Van Gosen and Ellefsen 2018). The heavy mineral suite prevalent at Old Hickory and Brink primarily consists of ilmenite, rutile, iron-oxide minerals, and zircon, with an average TiO_2 to zircon ratio of 5:1 (Iluka 2009).

Commercial heavy mineral placer mining is an industry established over multiple decades with existing regulatory frameworks governing onshore operations. States have enacted permitting and reclamation requirements for active surface mining, complementing federal mandates. These regulations and commercial leases do not extend to offshore environments. The Chemours Company mines heavy mineral sands abundant in Ti, Zr, and REEs in Clay County, Florida. Similarly, Atlantic Strategic Minerals intends to commence comparable operations in Dinwiddie County, Virginia, adjacent to the site previously mined by Iluka Resources (ASM 2023). IperionX recently concluded a scoping study for a sand mining venture northwest of Camden, Tennessee, known as the 'Titan Project' (IperionX 2022). Numerous other potential deposits and ore bodies in the southeastern U.S. have been precluded from development due to various land use decisions including residential and resort development, timber and farming practices, conservation easements, and environmental concerns (Pirkle et al. 2013).

6.0 NEW HEAVY MINERAL ANALYSIS FOR SANDBRIDGE SHOAL AND THE ATLANTIC CHANNEL

In 2020, VE was granted an opportunity to examine marine sands collected from the OCS during pre-dredging feasibility studies of beach sand replenishment borrow areas (Schnabel Engineering 2018; Schnabel Engineering 2019). VE scientists analyzed marine sediment core samples from 2 primary offshore locations within federals waters as shown in Figure 6 (Sandbridge Borrow Areas A and B, and the Atlantic Ocean Federal Navigation Channel). These new data are representative of material that was recently dredged (2018) and are from federal OCS locations where sand for beach nourishment has been utilized (Hawkins and Lassetter 2022). Schnabel Engineering and subcontractors conducted a geotechnical investigation and hydrographic survey of the Sandbridge Borrow (SBB) sites A and B and the Atlantic Channel and Thimble Shoal Channel in the summer and fall of 2018 (Figure 6). The USACE Norfolk District contracted with Schnabel Engineering to evaluate the suitability of material to be utilized for beach protection programs and nourishment of the Sandbridge Beach area. Upon discussions with the USACE and Schnabel Engineering, VE scientists obtained archived halves of 37 total vibracores from these investigations. Twenty-seven were from the Sandbridge Shoal Project Area covering approximately 490 feet of marine sediment in 5-foot core sections. Ten cores from the Atlantic Channel project Area cover approximately 196 feet of marine sediment in 5-foot core sections. Of the 37 cores, 32 were processed for heavy mineral abundance and mineralogy, with extra material stored at VE GMR repository in Charlottesville, Virginia.

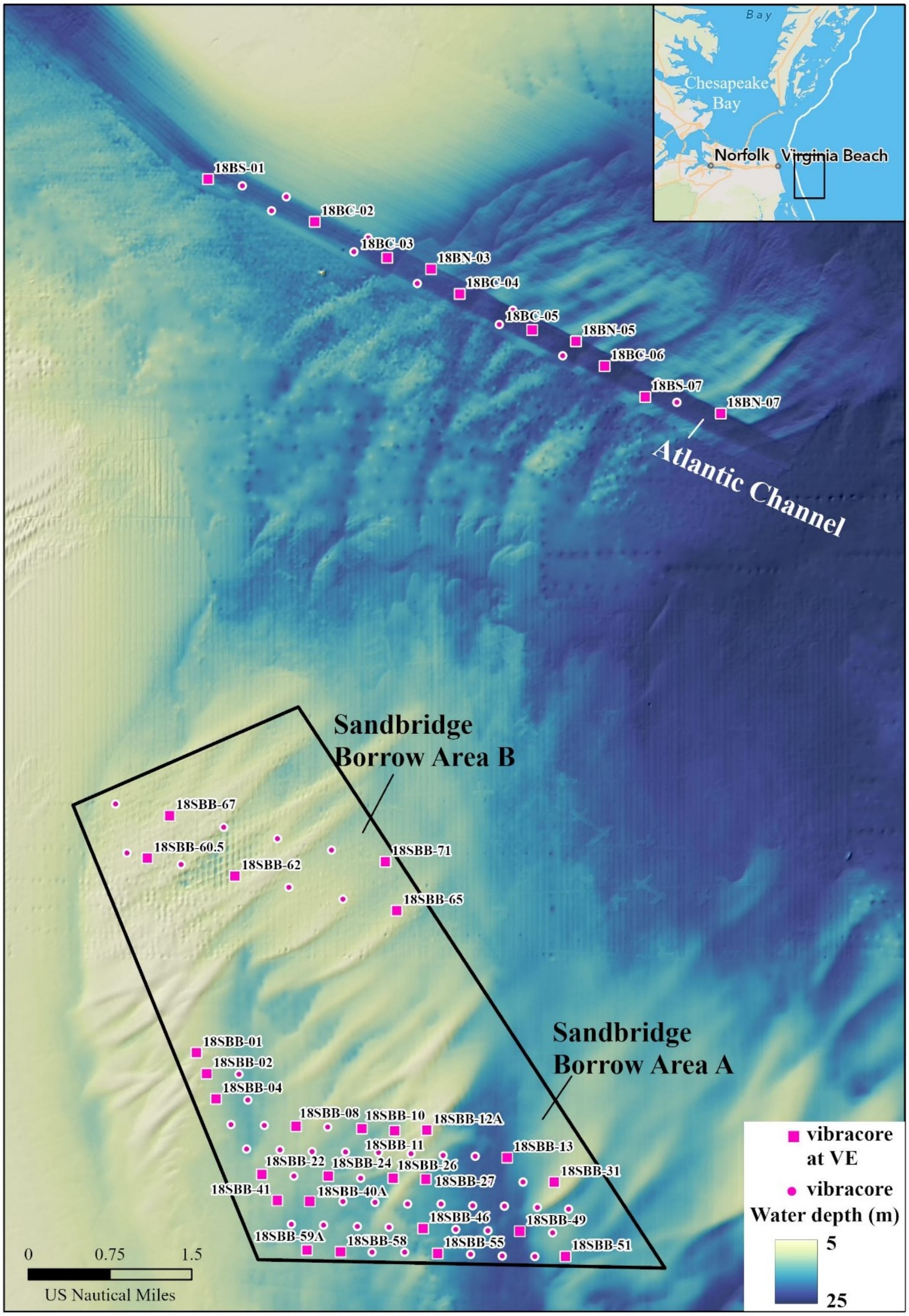


Figure 6: Location map for Atlantic Ocean Federal Navigation Channel ("Atlantic Channel") and Sandbridge Borrow Areas A and B. All points represent boreholes drilled for Schnabel Engineering in 2018. Labeled cores were sent to VE for mineralogical sampling as part of this study.

6.1 Sample Processing and Total Heavy Mineral Content

Marine sediment cores were sampled and analyzed for heavy mineral content. Sample intervals were selected to 1) provide adequate lateral spatial coverage over the borrow areas, 2) examine a sufficiently thick surface sand layer (≥5 feet) with little to no lithologic breaks and an absence of overburden, and 3) provide enough bulk material representative of that vertical interval to be used for heavy mineral concentration using gravity separation. Core sections sampled for heavy mineral analysis were visually examined for changes in grain size, abundance of shell material and other lithological descriptors, and screened with a portable gamma spectrometer for baseline radiometric data (Appendix C). Schnabel Engineering performed grain-size analysis on core samples (Tables 3 and 4; Appendix C). Samples were wet sieved to remove greater than 2-millimeter (mm) diameter shell and gravel material. The less than 2-mm fraction was dried and weighed to obtain a total dry bulk weight prior to spiral processing. A 3-turn Humphreys spiral was used to concentrate denser minerals from the less dense mineral fraction. The water and sediment mixture flows from the top of the spiral while centrifugal force causes differential settling and separation of mineral grains. Grains with higher specific gravities are concentrated in the interior of the spiral, while the lighter density (and often lighter-colored) minerals flow to the outside of the spiral (Figure 7).

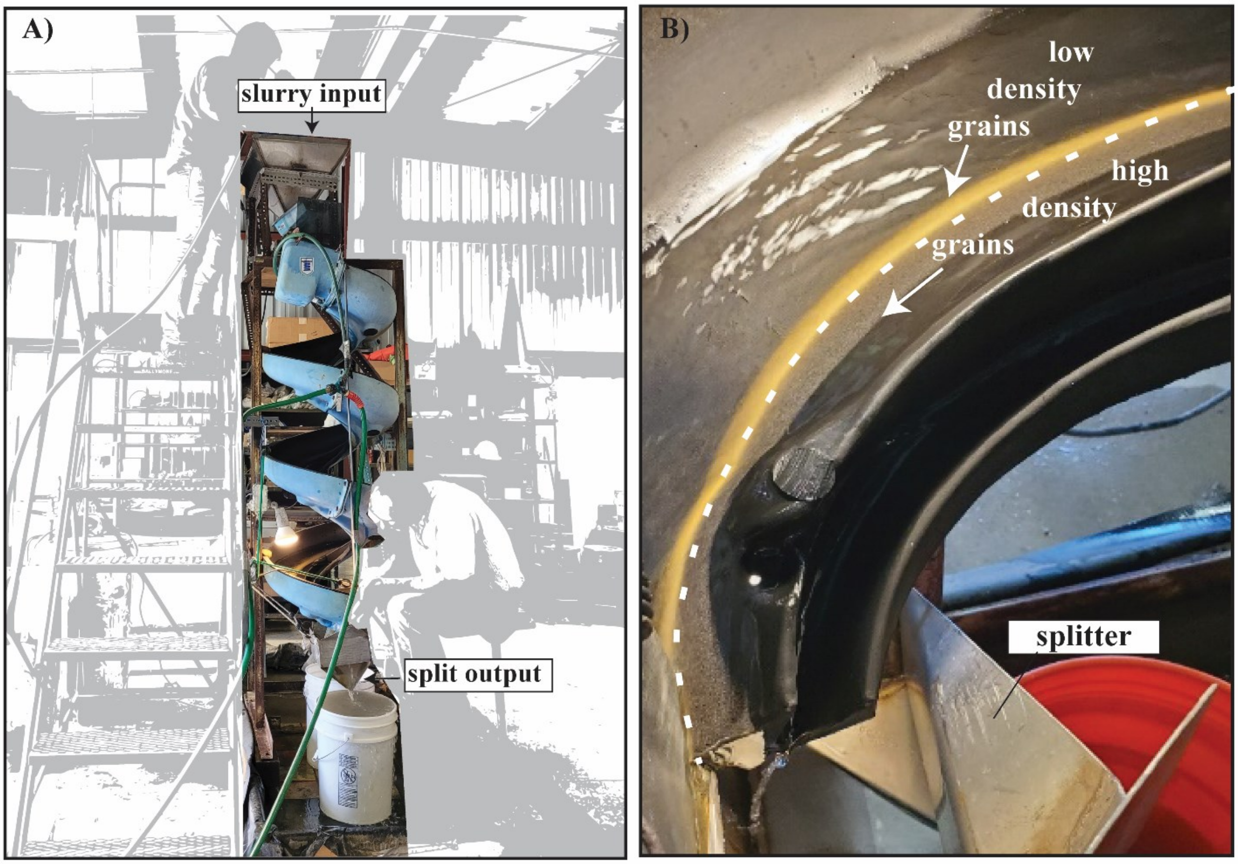


Figure 7: A) Two-person operated Humphreys 3-turn spiral concentrator. B) View of mineral separation at the splitter located at the base of the spiral. The denser minerals are visible in the darker band of material on the interior of the spiral.

The water flow rate was typically set at one gallon per minute (gpm) (~3.8 liters per minute) for samples dominated by sand, while for samples containing higher fractions of silt and clay, it was kept below one gpm. This controlled flow rate helped in separating lower density minerals like quartz grains, organic matter, and shell material from the denser heavy mineral assemblage. At the bottom of the spiral, a splitter was positioned to divide the material. The primary aim of this spiral separation was to generate an initial concentrated sample that would undergo further refinement at the SGS laboratory. These initial heavy mineral concentrates were dried and sub-sampled using a calibrated sediment splitter before being dispatched to the SGS laboratory for analytical analyses.

During heavy liquid separation, grains with densities exceeding 2.9 or 3.1 g/cc were identified as the sink fraction. To calculate the THM concentration as the dry weight percent of the total bulk sample, the percent of sinks (% sinks) was multiplied by the dry weight of the spiral concentrate:

$$\text{THM} = (\%\text{Sinks} * \text{HMC}_t) / \text{Sample}_b$$

THM = total heavy minerals, as weight percent of total dry-weight sample
%Sinks = calculated percent dry weight sinks (Sinks/(Sinks + Float))
  Sinks = heavy liquid separation sink fraction reported by lab, in g
  Float = heavy liquid separation float fraction reported by lab, in g
HMC_t = dry weight of heavy mineral concentrate recovered by spiral, in g
Sample_b = dry weight of bulk sample (<2 mm), in g

Table 3: Samples collected from Sandbridge Shoal vibracores for heavy mineral analyses.

Virginia GMR Rock Repository ID	Alternative Sample ID (heavy mineral sample interval, ft)	Grain-size Interval (ft)[1]	% Sand (75-2,000 µm)	% Fines (<75 µm)	% Gravel (> 2mm)	% THM Fraction[2]	Water Depth (feet)[3]	Latitude (NAD83)	Longitude (NAD83)
R-12221	18SBB-02 (10-15)	10-15	98.4	1.6	0	0.6	45.3	36.732735	-75.869567
R-12222	18SBB-04A (0-5)	0-5	93.2	6.4	0.4	1.9	50	36.728881	-75.868137
R-12223	18SBB-12A (0-10)	0-5	98	2	0	0.4	41	36.724097	-75.835900
R-12224	18SBB-12A (10-20)	10-15	97.8	2.1	0.1	0.7	41	36.724097	-75.835900
R-12225	18SBB-26 (0-12)	0-5.1	92.4	7.6	0	1.0	49.8	36.716753	-75.841021
R-12226	18SBB-41 (0-11)	0-5	94.6	0.8	4.6	0.6	47.9	36.713343	-75.858761
R-12227	18SBB-46 (0-13)	0-5	92.6	5.7	1.7	0.9	54.2	36.709069	-75.836457
R-12227m	18SBB-46 (0-13, mud subsample)	0-5	--	100	--	n/a	54.2	36.709069	-75.836457
R-12228	18SBB-49 (0-7.5)	0-4.5	89.6	10.4	0	1.0	56.1	36.708635	-75.821658
R-12231	18SBB-58 (0-3, 5-9)	0-4.7	95	4.4	0.6	0.6	55.4	36.705492	-75.849083
R-12232	18SBB-60.5 (0-14)	0-4.6	98.8	1.2	0	1.2	41.65	36.765679	-75.878647
R-12233	18SBB-65 (0-10)	0-4.5	98.6	1.2	0.2	0.7	47.55	36.757668	-75.840500
R-12234	18SBB-65 (10-19.6)	9.6-14.6	96.3	3.7	0	1.2	47.55	36.757668	-75.840500
R-12236	18SBB-71 (0-15)	0-5	97.8	1.6	0.6	0.7	51.8	36.765143	-75.842233
R-12236m	18SBB-71 (0-15, mud subsample)	0-5	--	100	--	n/a	51.8	36.765143	-75.842233

Table 3: Samples collected from Sandbridge Shoal vibracores for heavy mineral analyses.

Virginia GMR Rock Repository ID	Alternative Sample ID (heavy mineral sample interval, ft)	Grain-size Interval (ft)[1]	% Sand (75-2,000 µm)	% Fines (<75 µm)	% Gravel (> 2mm)	% THM Fraction[2]	Water Depth (feet)[3]	Latitude (NAD83)	Longitude (NAD83)
R-12245	18SBB-08 (2-11)	2.1-6.8	88.6	4.4	7	0.8	50	36.724689	-75.855888
R-12245m	18SBB-08 (2-11, mud subsample)	2.1-6.8	--	100	--	n/a	50	36.724689	-75.855888
R-12246	18SBB-13 (13.5-18.5)	13.7-18.5	91	9	0	0.8	58.7	36.719898	-75.823592
R-12318	18SBB-62 (0-7)	0-4.6	98.3	1.5	0.2	0.6	45.5	36.762956	-75.865245

[1] Grain-size and sample location data from Schnabel Engineering (2018). Schnabel Engineering followed ASTM D422 for grain-size classification.

[2] This fraction was obtained from laboratory analytical data from SGS laboratory using heavy liquid separation techniques. Heavy mineral estimates from Humphreys spiral data are provided in Appendix C.

[3] Water depth data is in feet and was obtained from Schnabel Engineering (2018).

Table 4: Samples collected from Atlantic Ocean Federal Navigation Channel vibracores for heavy mineral analyses.

Virginia GMR Rock Repository ID	Alternative Sample ID (heavy mineral sample interval, ft)	Grain-size Interval (ft)[1]	% Sand (75-2,000 µm)	% Fines (<75 µm)	% Gravel (> 2mm)	% THM Fraction[2]	Water Depth (feet)	Latitude (NAD83)	Longitude (NAD83)
R-12319	18BS-01 (0-4.7)	0-4.7	62.6	37.4	0	1.4	57.6	36.869503	-75.869362
R-12321	18BC-02 (0-10)	0-5	94	6	0	1.1	57.7	36.862986	-75.8530223
R-12325	18BN-03 (0-10)	0-3.9	82.3	17.1	0.6	1.1	62.5	36.855742	-75.835234
R-12334	18BS-07 (0-10)	0-3.2	89	10.4	0.6	0.7	64	36.836188	-75.802483

[1] Grain-size, sample location, and water depth data from Schnabel Engineering (2019). Schnabel Engineering followed ASTM D422 for grain-size classification.

[2] This fraction was obtained from laboratory analytical data from SGS laboratory using heavy liquid separation techniques. Heavy mineral estimates from Humphreys spiral data are provided in Appendix C.

Twenty-seven marine sediment samples from 22 vibracore locations across the Sandbridge Shoal area and 18 sediment samples from 10 vibracore locations from the Atlantic Ocean Federal Navigation channel were sieved and spiraled for heavy mineral analysis (Figure 8). Heavy mineral concentrations determined through spiraling separation methods ranged from 0.5 wt% to 18.2 wt%, with a mean of 2.6 wt% and median of 1.8 wt%. These concentrations may be inflated due to the presence of coarse-grained, lighter density minerals like quartz and feldspar, observed in small quantities within the concentrate fraction. Twenty sand samples, processed through spiraling methods, were forwarded to the Advanced Mineralogy Facility at SGS Canada Inc. (SGS) for detailed modal mineralogy and mineral geochemistry analyses of the heavy mineral concentrates. One sample from core 18SBB-04A (R-12222) contained 18.2 wt% heavy mineral content in the bulk sample, which was 16.3 wt% greater than the 1.9 wt% determined by the SGS laboratory, suggesting an overestimation. Table 5 summarizes heavy mineral content statistics (mean, median, standard deviation, minimum, maximum) for all sites, including Sandbridge Borrow areas and Atlantic Channel sand samples (excluding mud samples). The heavy liquid separation method revealed an average heavy mineral grade of just under 1 wt% in Sandbridge Borrow Areas A and B. In the Atlantic Channel, grade ranged from 0.4 wt% to 1.9 wt% (Figure 8).

Notably, the THM wt% values resulting from heavy liquid separation at the lab are much lower than the THM wt% values attained by preconcentration using the Humphreys spiral method. Although there are noticeable THM differences between these methods, a preconcentrate via gravity separation is the industry standard and is necessary to reduce bulk material size, while preserving the representative THM portion. This is a good indicator that the initial preconcentration methodology is sufficiently conservative with respect to the recovery of a high proportion of heavy minerals in the large bulk samples.

Table 5: Percent total heavy mineral (THM) statistics for heavy liquid and spiral separation methods.

THM Percent from Heavy Liquid Separation				
	All Areas	**SBB A**	**SBB B**	**AC**
Count	20	11	5	4
Mean	0.9%	0.8%	0.9%	1.1%
Median	0.8%	0.8%	0.7%	1.1%
St. Dev.	0.4%	0.4%	0.3%	0.3%
Min.	0.4%	0.4%	0.6%	0.7%
Max.	1.9%	1.9%	1.2%	1.4%
THM Percent from Spiral				
	All Areas	**SBB A**	**SBB B**	**AC**
Count	43	21	6	16
Mean	2.6%	3.1%	2.9%	1.7%
Median	1.8%	2.3%	2.3%	1.1%
St. Dev.	2.9%	3.8%	1.8%	1.3%
Min.	0.5%	0.7%	1.4%	0.5%
Max.	18.2%	18.2%	6.1%	5.6%
THM HL / THM Spiral				
	All Areas	**SBB A**	**SBB B**	**AC**
Count	20	11	5	4
Mean	0.33	0.32	0.33	0.35
Median	0.33	0.31	0.34	0.36
St. Dev.	0.13	0.15	0.13	0.07
Min.	0.11	0.11	0.19	0.25
Max.	0.63	0.63	0.47	0.42

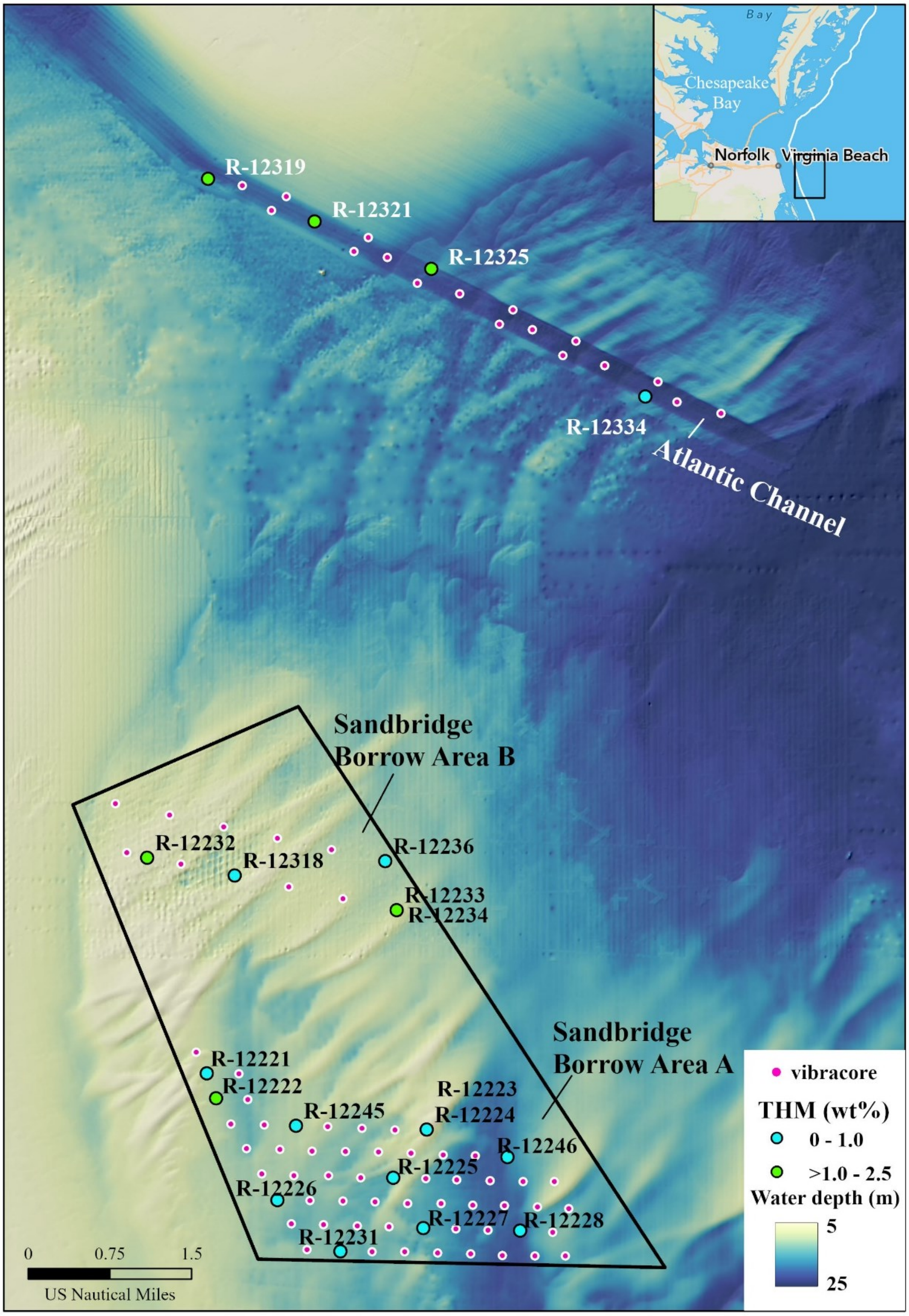


Figure 8: Core locations for samples submitted for heavy mineral analysis. Samples indicated with an 'R' prefix refers to Virginia GMR Rock Repository ID. % THM refers to the percent total heavy mineral fraction of a bulk sample collected from a depth interval (see Tables 3 and 4, heavy mineral sample interval, ft).

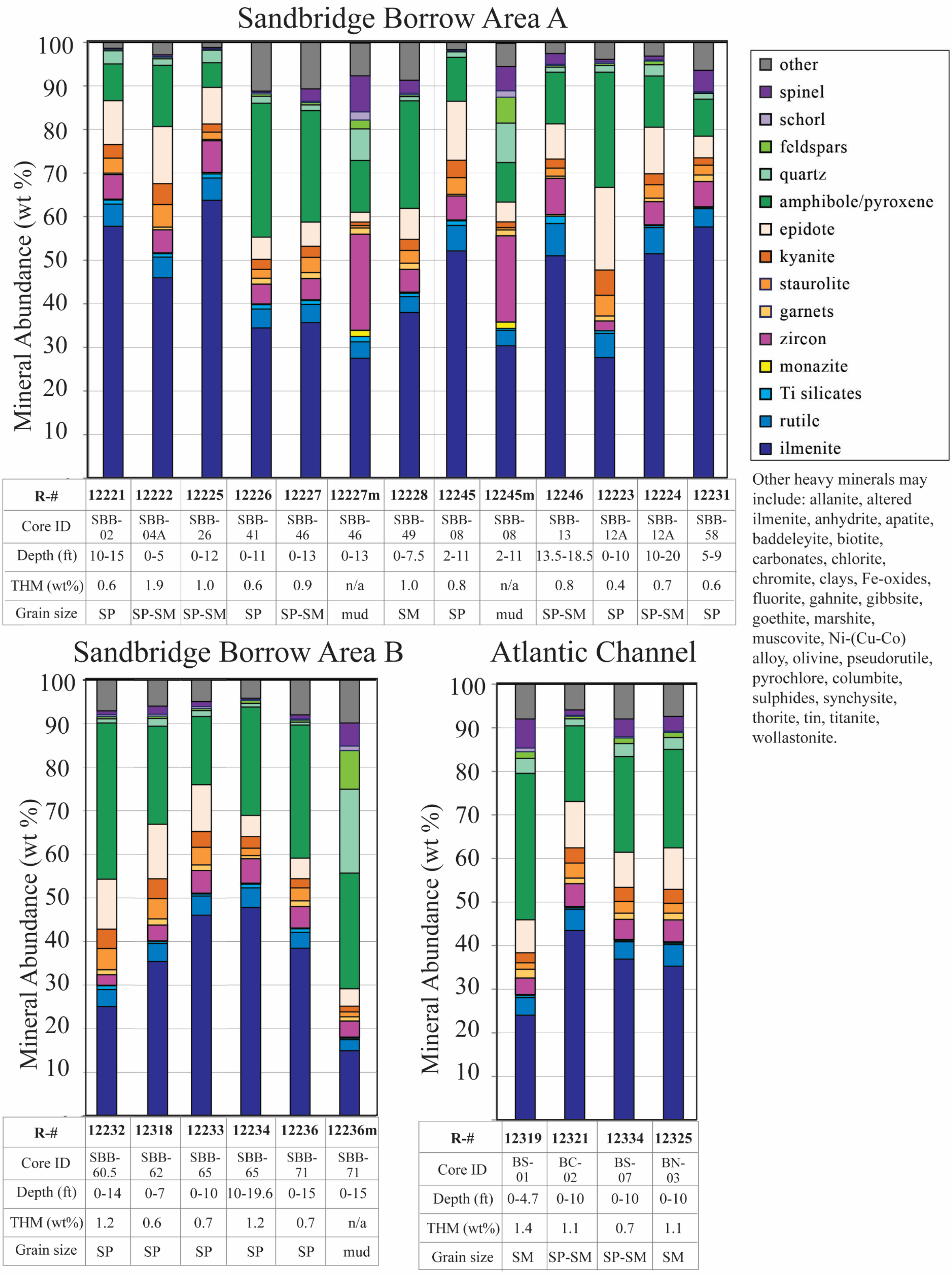
6.2 Mineralogy and Geochemistry of Heavy Mineral Concentrate Samples

SGS Canada received 20 sand and 3 mud subsamples for laboratory mineralogical and geochemical analysis: 11 sand samples and 2 mud subsamples from SBB area A, 5 sand samples and 1 mud subsample from SBB area B, and 4 sand samples from the Atlantic Channel (Figures 8 and 9). The primary objective was to identify and quantify critical heavy minerals, particularly those containing Ti, Zr, and REEs. The analysis employed TIMA-X technology, which is an automated system capable of quantifying mineral speciation, distribution, grain size characteristics, and the liberation degree of heavy mineral sand grains within the sink fraction for grains with a density >2.9 g/cc. Two polished sections were prepared to ensure an adequate representation of grains on the mounts. Furthermore, Electron Probe Micro Analysis (EPMA) was conducted on specific samples to determine the chemical composition of individual mineral grains. The sink fraction underwent analysis for bulk geochemical composition using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and ICP-Atomic Emission Spectrometry (ICP-AES). These methods provided concentration data for 56 major and trace elements.

Qualitative bulk mineral identification was conducted using x-ray diffraction (XRD) analysis on a selected subset of samples. The XRD analysis of sink samples R-12225, R-12226, R-12227, and R-12236 detected ilmenite, amphibole, garnet, and minor occurrences of zircon, quartz, epidote, chlorite, hematite, rutile, and trace amounts of monazite and davidite. Appendix C includes bulk and spiraled fraction weights, total concentrations of heavy minerals derived from the spiral method, and the full array of findings provided by SGS Canada Inc.

The modal mineralogy is summarized in Figure 9 and Tables 6-8 and provide the average mineral abundance obtained through TIMA-X analysis at SGS for the sink material (>2.9 g/cc density). The mud subsamples are R-12227m, R-12236m, and R-12245m. Across all samples, ilmenite was the predominant Ti-bearing mineral with concentrations ranging from 12.6 wt% to 56.3 wt% and an average of 33.7 wt%. Altered ilmenite has concentrations ranging from 2.3 wt% to 10.8 wt% and an average of 6.3 wt%. Amphibole and pyroxene average around 20 wt% in distribution. Epidote, zircon, and rutile combined contributed approximately 20 wt% of the THM assemblage. Ti-bearing rutile ranges from 2.6 wt% to 7.4 wt% and averages 4.5 wt%, Zr-bearing zircon ranges from 2.2 wt% to 22.1 wt% and averages 6.4 wt%, and epidote ranges from 2.3 wt% to 19.0 wt% and averages 8.6 wt%. Metamorphic silicate minerals such as kyanite, staurolite, and garnet, containing varying proportions of Fe, Mg, Al, and Ca, are present as minor components within the heavy mineral sands. Spinels, primarily sourced from mafic igneous rocks, constitute about 2 wt% of the THM fraction. Trace amounts of REE-bearing minerals, monazite (ranging from 0.05 wt% to 1.48 wt%, averaging 0.31 wt%) and xenotime (ranging from nil to 0.14 wt%, averaging 0.02 wt%), were identified within the samples.

Heavy liquid separation of the samples indicates that the sink fractions account for 10.6 wt% to 62.9 wt% of the total mass of the concentrate samples submitted to SGS. The average sink fraction for the mud subsamples is much less at 0.16 wt%. Mineralogical analyses show that ilmenite, rutile, zircon and monazite are the main economic minerals in these cores. Gravity separation methods should be suitable to separate the heavy minerals from marine quartz-rich sediments used in beach nourishment projects, with additional separation and concentration into economic components requiring magnetic and electrostatic technologies (see section 8.1 for examples).



R-#	12221	12222	12225	12226	12227	12227m	12228	12245	12245m	12246	12223	12224	12231
Core ID	SBB-02	SBB-04A	SBB-26	SBB-41	SBB-46	SBB-46	SBB-49	SBB-08	SBB-08	SBB-13	SBB-12A	SBB-12A	SBB-58
Depth (ft)	10-15	0-5	0-12	0-11	0-13	0-13	0-7.5	2-11	2-11	13.5-18.5	0-10	10-20	5-9
THM (wt%)	0.6	1.9	1.0	0.6	0.9	n/a	1.0	0.8	n/a	0.8	0.4	0.7	0.6
Grain size	SP	SP-SM	SP-SM	SP	SP-SM	mud	SM	SP	mud	SP-SM	SP	SP-SM	SP

Other heavy minerals may include: allanite, altered ilmenite, anhydrite, apatite, baddeleyite, biotite, carbonates, chlorite, chromite, clays, Fe-oxides, fluorite, gahnite, gibbsite, goethite, marshite, muscovite, Ni-(Cu-Co) alloy, olivine, pseudorutile, pyrochlore, columbite, sulphides, synchysite, thorite, tin, titanite, wollastonite.

R-#	12232	12318	12233	12234	12236	12236m
Core ID	SBB-60.5	SBB-62	SBB-65	SBB-65	SBB-71	SBB-71
Depth (ft)	0-14	0-7	0-10	10-19.6	0-15	0-15
THM (wt%)	1.2	0.6	0.7	1.2	0.7	n/a
Grain size	SP	SP	SP	SP	SP	mud

R-#	12319	12321	12334	12325
Core ID	BS-01	BC-02	BS-07	BN-03
Depth (ft)	0-4.7	0-10	0-10	0-10
THM (wt%)	1.4	1.1	0.7	1.1
Grain size	SM	SP-SM	SP-SM	SM

Figure 9: TIMA-X results of condensed modal mineralogy (average wt% mineral abundance) for sink material from 20 heavy mineral sand concentrates and 3 mud fractions (m). Percent THM determined through heavy liquid separation at SGS Canada Inc. (n/a for mud). Grain size codes provided in Schnabel Engineering (2018; 2019) following the Unified Soil Classification System. The complete SGS Canada Inc. mineralogy and geochemical report is provided in Appendix C.

Table 6: Modal Mineralogy for Heavy Mineral Sand Fraction from TIMA-X Analysis at SGS Canada Inc. Sandbridge Borrow Area A.

	Core	18SBB -02	18SBB -04A	18SBB -26	18SBB -41	18SBB -46	18SBB -46	18SBB -49	18SBB -08	18SBB -08	18SBB -13	18SBB -12A	18SBB -12A	18SBB -58
	Sample	**R-12221**	**R-12222**	**R-12225**	**R-12226**	**R-12227**	**R-12227 m**	**R-12228**	**R-12245**	**R-12245 m**	**R-12246**	**R-12223**	**R-12224**	**R-12231**
Mineral Mass (wt%)	*Ilmenite/ altered ilmenite*	57.8	46.0	63.7	34.5	35.7	27.5	38.0	52.1	30.4	51.0	27.7	51.5	57.6
	rutile	5.07	4.74	5.12	4.33	4.14	3.77	3.65	5.85	3.56	7.44	5.55	6.07	4.18
	Ti silicates	0.96	0.78	0.94	1.01	0.93	1.19	0.77	1.03	0.41	1.67	0.55	0.42	0.32
	monazite	0.20	0.18	0.30	0.16	0.15	1.46	0.23	0.20	1.48	0.36	0.05	0.17	0.12
	zircon	5.61	5.30	7.33	4.57	4.85	22.1	5.24	5.52	19.79	8.34	2.22	5.31	5.84
	garnets	0.36	0.60	0.31	1.32	1.39	1.40	1.43	0.39	1.33	0.50	1.16	0.83	1.50
	staurolite	3.41	5.21	1.66	2.05	3.52	0.58	2.94	3.80	0.55	1.85	4.73	3.06	2.25
	kyanite	3.14	4.77	1.85	2.30	2.54	0.81	2.54	4.01	1.30	2.09	5.79	2.53	1.69
	epidote	10.1	13.1	8.40	5.11	5.55	2.26	7.10	13.5	4.55	8.06	19.0	10.7	4.98
	amphibole/pyroxene	8.44	14.0	5.67	30.7	25.5	11.9	24.7	10.1	9.1	11.8	26.4	11.7	8.46
	quartz	3.01	1.53	2.87	1.59	1.36	7.27	0.98	1.26	9.06	1.19	1.52	2.58	1.29
	feldspars	0.31	0.36	0.24	0.57	0.54	2.01	0.44	0.21	5.94	0.38	0.49	0.89	0.26
	schorl	0.13	0.18	0.13	0.29	0.30	1.86	0.32	0.17	1.47	0.25	0.34	0.22	0.19
	spinel	0.13	0.38	0.27	0.33	2.82	8.27	2.97	0.12	5.51	2.49	0.61	0.86	4.90
	ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
	xenotime	0.01	0.00	0.01	0.01	0.01	0.14	0.00	0.01	0.08	0.02	0.00	0.01	0.01
	synchysite	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	pyrochlore/columbite	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.12	0.00	0.00	0.00	0.00
	gorceixite	0.00	0.02	0.00	0.02	0.00	0.01	0.02	0.00	0.02	0.03	0.01	0.00	0.00
	other	1.34	2.82	1.16	11.2	10.7	7.53	8.69	1.66	5.38	2.51	3.90	3.17	6.40
	total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	%Total Heavy Minerals	**0.6%**	**1.9%**	**1.0%**	**0.6%**	**0.9%**	**n/a**	**1.0%**	**0.8%**	**n/a**	**0.8%**	**0.4%**	**0.7%**	**0.6%**

Table 7: Modal Mineralogy for Heavy Mineral Sand Fraction from TIMA-X Analysis at SGS Canada Inc. Sandbridge Borrow Area B.

	Core	18SBB-60.5	18SBB-62	18SBB-65	18SBB-65	18SBB-71	18SBB-71
	Sample	**R-12232**	**R-12318**	**R-12233**	**R-12234**	**R-12236**	**R-12236m**
Mineral Mass (wt%)	*Ilmenite/altered ilmenite*	25.0	35.4	46.1	47.8	38.4	14.9
	rutile	3.96	4.13	4.42	4.52	3.66	2.60
	Ti silicates	0.86	0.41	0.47	0.84	0.81	0.33
	monazite	0.09	0.17	0.16	0.24	0.16	0.23
	zircon	2.45	3.64	5.22	5.60	4.95	3.69
	garnets	1.14	1.40	1.25	0.72	1.31	0.95
	staurolite	4.90	4.65	4.06	1.71	2.97	1.14
	kyanite	4.42	4.55	3.63	2.62	2.07	1.32
	epidote	11.5	12.5	10.7	4.89	4.74	4.00
	amphibole/pyroxene	35.8	22.5	15.6	24.9	30.5	26.5
	quartz	0.96	1.80	1.40	0.87	0.69	19.26
	feldspars	0.52	0.54	0.47	0.66	0.47	8.86
	schorl	0.44	0.42	0.41	0.15	0.26	1.04
	spinel	0.84	1.83	1.17	0.36	0.92	5.31
	ilmenorutile	0.00	0.00	0.00	0.00	0.01	0.00
	xenotime	0.00	0.01	0.00	0.01	0.00	0.02
	synchysite	0.00	0.00	0.00	0.00	0.00	0.00
	pyrochlore/columbite	0.00	0.00	0.00	0.00	0.00	0.05
	gorceixite	0.01	0.00	0.00	0.02	0.01	0.00
	other	7.09	5.99	4.92	4.15	7.99	9.79
	total	100.0	100.0	100.0	100.0	100.0	100.0
	%Total Heavy Minerals	**1.2%**	**0.6%**	**0.7%**	**1.2%**	**0.6%**	**n/a**

Table 8: Modal Mineralogy for Heavy Mineral Sand Fraction from TIMA-X Analysis at SGS Canada Inc. Atlantic Ocean Channel.

	Core	18BS-01	18BC-02	18BS-07	18BN-03
	Sample	**R-12319**	**R-12321**	**R-12334**	**R-12325**
Mineral Mass (wt%)	*Ilmenite/altered ilmenite*	24.0	43.4	36.9	35.3
	rutile	4.08	4.90	3.98	4.96
	Ti silicates	0.45	0.36	0.32	0.35
	monazite	0.21	0.26	0.20	0.26
	zircon	3.81	5.27	4.63	5.06
	garnets	2.00	1.29	1.42	1.53
	staurolite	1.50	3.43	2.71	2.27
	kyanite	2.30	3.48	3.21	3.20
	epidote	7.57	10.7	8.07	9.54
	amphibole/pyroxene	33.6	17.3	21.9	22.6
	quartz	3.41	1.66	3.00	2.72
	feldspars	1.54	0.54	1.26	1.15
	schorl	0.85	0.22	0.35	0.30
	spinel	6.69	1.23	4.03	3.37
	ilmenorutile	0.00	0.00	0.00	0.00
	xenotime	0.01	0.01	0.01	0.02
	synchysite	0.00	0.00	0.00	0.00
	pyrochlore/columbite	0.00	0.00	0.00	0.00
	gorceixite	0.01	0.00	0.02	0.01
	other	7.94	5.91	7.94	7.39
	total	100.0	100.0	100.0	100.0
	% Total Heavy Minerals	**1.4%**	**1.1%**	**0.7%**	**0.7%**

SGS Canada conducted liberation analysis of individual grains using the TIMA-X. Zircon yielded liberation ranges of 89% to 96%, with an average of 93%. Ilmenite yielded liberation ranges of 90% and 96%, averaging 93%. Monazite exhibited liberation within the range of 71% to 97%, averaging 87%. Rutile yielded liberation ranges of 49% and 72%, averaging 59%. This indicates that zircon, ilmenite, and monazite have predominantly pure compositions (≥ 95% single mineral composition per particle). Rutile is more closely associated with ilmenite or has other mineral or compositional inclusions (Appendix C).

SGS Canada selected samples from the sink fractions to determine the quantitative mineral compositions of monazite, xenotime, zircon, rutile, and ilmenite using EPMA analyses. Geochemical analysis of 132 ilmenite grains shows average TiO_2 concentration is 51.34 wt%, and average FeO concentration is 45.57 wt%, with the remainder as mainly MnO (1.75 ave wt%)

and Nb_2O_5 (0.10 ave wt%). Average TiO_2 concentration based on EPMA of 98 rutile grains is 99.26 wt%, average FeO is 0.35 wt% and average Nb_2O_5 is 0.31 wt%. For the heavy mineral sand sink fractions, Fe is predominantly hosted by ilmenite (35-83 wt%), altered ilmenite (5-15 wt%), and varying proportions in Fe-oxides (from non-detect to 23 wt%), goethite (non-detect to 18%), amphiboles/pyroxenes (1-14 wt%). Chlorite (1-16 wt%), epidote (1-15 wt%), sulfides (non-detect to 12 wt%), and staurolite (0.5-3 wt%) account for the remaining Fe content, while other minerals contribute minor amounts, averaging less than 1-2 wt% (Appendix C).

The average ZrO_2 concentration based on EPMA analysis of 297 zircon grains is 65.97 wt%, average HfO_2 is 1.28 wt%, and average Y_2O_3 0.09 wt%. Geochemical analysis of 226 monazite grains shows an abundance of Ce_2O_3 (28.59 ave wt%), La_2O_3 (13.42 ave wt%), and Nd_2O_3 (12.28 ave wt%), accompanied by trace amounts of Pr_2O_3 (3.21 ave wt%) and Sm_2O_3 (2.03 ave wt%), aligning with observations from other southeastern offshore samples (Grammatikopoulos et al. 2020). Average Y_2O_3 content for monazite is 1.31 wt%, while ThO_2 concentration averages 5.45 wt%, and average UO_2 concentration is 0.49 wt% (Appendix C). Y_2O_3 is also found in xenotime, and the average is 41.42 wt% based on geochemical results from 30 xenotime grains. Average ThO_2 is 0.12 wt% and average UO_2 is 0.86 wt% for xenotime (Appendix C).

6.3 Economic Resource Estimation for Sandbridge Shoal

The comprehensive modal mineralogic analysis of the heavy mineral sand fraction at Sandbridge Shoal offers an opportunity to compute an unconventional critical mineral resource estimate. The reported sand volumes for lease areas A and B stand at 13.5 million (M) cy and 15 M cy, respectively (Schnabel Engineering 2018). Based upon the SGS results identifying heavy minerals in 16 samples taken from 14 vibracores (Table 3), the mean values were 0.8 wt% THM in Area A and 0.9 wt% THM in Area B (Table 5). The analytical results indicate ilmenite to be the most prevalent economic heavy mineral, constituting 35-45 wt% of the THM fraction. Zircon and rutile each contribute 5-7 wt% to the THM, whereas monazite and xenotime account for <0.1 wt% THM.

Utilizing the mean wt% THM with the reported sand resource volumes for Sandbridge Shoal's individual borrow areas, we calculated the heavy mineral sand resource to be 108,000 cy in Area A and 135,000 cy in Area B, for a total of 243,000 cy of THM. Using a conversion factor of 1.36 metric tons per cy (USBM 1987), this amount is equivalent to approximately 330,000 metric tons of THM, containing critical commodities such as Ti, Zr, and REEs. Considering current export commodity prices for this distribution of economic minerals at $254 per metric ton of THM, the total estimated value of the economic heavy minerals across the Sandbridge Shoal borrow areas is approximately $83.9 million. Detailed information regarding this estimation is available in W. Lassetter's abstract and presentation slides found in the Forum

Proceedings (Appendix A). This underscores the potential presence of a domestic resource for heavy mineral sand commodities within existing lease areas where dredging operations are permitted.

7.0 SCREENING FOR HEAVY MINERAL SANDS

A hand-held, portable XRF (pXRF) spectrometer offers non-destructive, real-time analyses that could significantly aid in assessing offshore sand resources and deciding on heavy mineral separation strategies. Widely used in geology, mining, archaeology, and soil studies, these pXRF analyzers provide quick analysis, ease of use, and portability (Lemière 2018). They present an attractive option for initial exploration, screening work, and geochemical evaluations, such as resource potential characterization and heavy metal contamination assessments (Lemière et al. 2014; Declercq et al. 2019; Zhou et al. 2023). Despite advancements, ensuring data quality is crucial (Shefsky 1997; USEPA 2007; Lemière et al. 2014; Lemière 2018; Knight et al. 2021), with consistency in sample preparation being a primary concern (Laperche and Lemière 2020). Standardizing the approach for unconsolidated sediments hosting critical commodities will enhance the pool of usable data, enabling consistent evaluation across diverse offshore geological settings (e.g., Atlantic OCS, Gulf of Mexico, Pacific OCS) and steer sampling efforts.

Field screening via pXRF does not replace certified laboratory analytical data but provides essential insights into geochemical concentration distribution, aiding efficient mineral exploration (Zhou et al. 2023). Two analytical paths are presented for core screening and assessing heavy mineral sand commodities, specifically Ti- and Zr-rich minerals contained in offshore sand resources. One path involves in-situ core scanning, while the ex-situ scanning assesses minimally-processed sediment samples (e.g., sieved, dried, packed). Supplementary analytical data and charts for the pXRF protocol can be found in Appendix D.

7.1 Instrumentation and Screening Protocol

VE uses the SciAps X-555 pXRF analyzer, powered by a 14.5-volt lithium-ion battery and equipped with a gold anode to moderate the electron beam which serves as the x-ray excitation source. This analyzer has three separate energy beams that operate within the kiloelectronvolt (KeV) range of 10 to 55. Lower energies detect lighter elements such as Mg, Si, and Al, while the highest energies identify heavier elements, notably light REEs which tend to occur in low concentrations.

The SciAps X-555 comes preprogramed with different analytical modes of operation, with mining and soil (REE) modes utilized in this study. The mining mode focuses on major rock geochemistry, evaluating elements typically present at concentrations exceeding one percent and normalized to 100%. The soil/REE mode, referred to as "soil" hereafter, is best for targeting elements ranging from parts per million up to less than one percent, without normalization to 100%. SciAps has factory-calibrated 44 elements for this pXRF unit, with the capability to calibrate additional elements. However, it is important to note that the fundamental analytical principles that underpin this XRF technology (i.e., x-ray excitation followed by quantitative determinations of electron emissions that are characteristic of each element) require the interpretation of overlapping emission spectra. In other words, as more elements are added to the instrument calibration, overlapping emission spectra (interferences) increases the analytical uncertainty.

Protocol for In-Situ Core Scanning with pXRF Analyzer

Objective

The objective of this protocol is to provide guidelines for conducting in-situ scanning on unconsolidated, loose, sediment core using a pXRF analyzer. In-situ core scanning is a non-destructive technique used to analyze the elemental composition of geological core samples. This protocol ensures accurate and reproducible results while minimizing sample handling and contamination.

Equipment and Materials

- Portable XRF analyzer – calibrated to sample media (e.g., sediment, rock, ore, etc.) and elements of interest (e.g., Fe, Ti, Zr, REEs, Th, U)
- Geological core samples – split and dried
- Protective film: sub-mm prolene or food-grade plastic wrap
- Core holder or analyzer kickstand (optional)
- Sample labeling system
- Protective gear (e.g., safety glasses, gloves)
- Field notebook and pen
- GPS device for location recording

Safety Precautions

- Always follow safety guidelines provided by the manufacturer of the XRF analyzer.
- Wear appropriate personal protective equipment (PPE) when operating the analyzer.

Sample Preparation

- Ensure that core samples are clean, free of loose debris, organics, coarse gravel and/or shell material and have a flat, stable surface.
- If needed, level the split core face to ensure a flat and uniform surface.

- Label each core sample with a unique identifier and record the information either in a field notebook or electronic device.

Instrument Setup

- Turn on the portable XRF analyzer and follow any manufacturer-recommended start-up procedures and (typically preset) energy beam(s) calibration.
- Set the analysis parameters (e.g., voltage, current, measurement time) according to the specific requirements of your study.
    - o For soil mode (trace elements ~<1%), beam settings should be no less than 30 seconds each to ensure proper counting statistics and lower standard error.
    - o Example of soil mode beam settings and elements (based on SciAps X500 Series): *{other units may vary}*
        - ▪ Beam 1 (high): 55 KeV
            - Elements: Ag, Cd, Sn, Sb, Te, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd
        - ▪ Beam 2 (medium): 40 KeV
            - Elements: Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Hg, Tl, Pb, Th, U
        - ▪ Beam 3 (low): 15 KeV
            - Elements: P, S, K, Ca, Sc, Ti, V, Cr

Data Recording

- Optional: Position the core sample on the core holder or kickstand in a stable and horizontal position.
- Place (or manually hold) the XRF analyzer probe in contact with the core sample surface. Ideally there should be no gap between the sample surface and the analyzer window. Plastic films (e.g., food-grade plastic wrap or thin (4 µm) prolene) provide protection to the analyzer window.
- Initiate the XRF analysis. Ideally, record scans at 3 or more separate locations in the core interval of interest to account for sample variability.
- A digital image of the core or specific core interval is recommended. If a physical sample is also to be collected, pre- and post-sample images are useful. Include a label if appropriate.
- Record the geographic coordinates and the depth of the core sample using a GPS device.

Data Quality Control

- Perform regular quality control checks with certified reference materials (CRM), or a known calibration reference standard to verify the accuracy of the XRF readings. The original matrix (lithology and texture) of the CRM or standard should be closely matched to the core material.

- Check for analytical drift or systematic errors during the analysis and recalibrate the instrument if necessary.

Data Analysis

- Transfer the spectra and elemental concentration data to a computer for further analysis.
- Use appropriate software (e.g., Excel) to calculate averages and interpret the data. A recommended chart option is to utilize the results for the CRM or reference standard to plot 'box and whisker' and/or elemental concentration versus time to help evaluate analytical drift or other errors.

Reporting

- Prepare a detailed report that includes the following information:
  - Sample location information
  - Core sample identifier
  - Elemental concentrations and their uncertainties
  - Calibration details
- Clearly specify the analytical conditions used during the XRF analysis (e.g., beam settings and run times).

Data Storage and Archiving

- Store the raw data, analysis results, and related documentation in a secure and organized manner.
- Ensure long-term archiving and data backup for future reference.

Cleanup

- Clean the core sample surface and XRF analyzer probe after each analysis to prevent contamination. Compressed air can be effective using short bursts that are directed across (not into) the analyzer window.

Protocol for Ex-Situ Sampling of Sediment Core with pXRF Analyzer

Objective

The objective of this protocol is to provide guidelines for conducting ex-situ sediment core sampling and preparation for analysis with a pXRF analyzer. This protocol ensures accurate and reproducible results, while minimizing heterogeneity and moisture variations.

Equipment and Materials

- Portable XRF analyzer – calibrated to media being measured and elements of interest (e.g., Fe, Ti, Zr, REEs, Th, U)
- Geological core samples – split
- Protective film: sub-mm prolene
- pXRF test stand (optional)
- Sample labeling system
- Protective gear (e.g., safety glasses, gloves)
- Field notebook and pen
- GPS device for location recording
- Scoopula or sampling spoon

Safety Precautions

- Always follow safety guidelines provided by the manufacturer of the XRF analyzer.
- Wear appropriate personal protective equipment (PPE) when operating the analyzer.

Sample Preparation and Collection

- Ensure that core samples are clean, free of loose debris, organics, coarse gravel and/or shell material prior to subsampling.
- If needed, level the split core face to ensure a flat and uniform surface prior to sampling.
- Make note of sedimentology, structure, or other stratigraphic features of the target unit.
- Collect samples with clean scoopula in baggie or beaker, avoid sampling at the core liner edge-sediment interface as the outer material could be transported downward during coring.
- Follow sample preparation procedure as outlined in Appendix D.
- Note depth interval sampled and label each core sample with a unique number.

Instrument Setup

- Turn on the portable XRF analyzer, allow at least 10 minutes for start up, and run the manufacturer-recommended (typically preset) energy beam(s) calibration.
- Set the analysis parameters (e.g., voltage, current, measurement time) according to the specific requirements of your study.

For soil mode (trace elements ~<1%), beam settings should be no less than 30 seconds each to ensure proper counting statistics and lower standard error.

  - Example of soil mode beam settings and elements (based on SciAps X500 Series): *{other units may vary}*
    - Beam 1 (high): 55 KeV
      - Elements: Ag, Cd, Sn, Sb, Te, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd

        - Beam 2 (medium): 40 KeV
            - Elements: Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Hg, Tl, Pb, Th, U
        - Beam 3 (low): 15 KeV
            - Elements: P, S, K, Ca, Sc, Ti, V, Cr

Data Recording

- Place the sample cup into the portable test stand (4 µm prolene side down).
- Place the XRF analyzer probe in contact with the core sample surface. Plastic films (e.g., food-grade plastic wrap or thin (4 µm prolene) provide protection to the analyzer window and prevents cross contamination.
- Initiate the XRF analysis. Recommend taking three sample readings across the puck surface and averaging results to account for sample variability.
- Record the geographical coordinates and the depth of the core sample using a GPS device.

Data Quality Control

- Perform regular quality control checks with certified reference materials to verify the accuracy of the XRF readings.
- Check for any drift or systematic errors during the analysis and recalibrate the instrument if necessary.

Data Analysis

- Transfer the spectra and elemental concentration data to a computer for further analysis.
- Use appropriate software (e.g., Excel) to calculate averages and interpret the data. A recommended chart option is to utilize the results for the CRM or reference standard to plot ‘box and whisker’ and/or elemental concentration versus time to help evaluate analytical drift or other errors.

Reporting

- Prepare a detailed report that includes the following information:
    - Sample location information
    - Core sample identifier
    - Elemental concentrations and their uncertainties
    - Calibration details
- Clearly specify the analytical conditions used during the XRF analysis (e.g., beam settings and run times).

Data Storage and Archiving

- Store the raw data, analysis results, and related documentation in a secure and organized manner.
- Ensure long-term archiving and data backup for future reference.

While this protocol does not address specific x-ray certification, inspection, or training requirements of equipment manufacturers, a discussion of general handling procedures and further details on datasets that went into this protocol are included (Appendix D). This protocol is based on best practices identified during a literature review of recent studies, laboratory-setting sample preparation, and considerations of real-time field conditions (Shefsky 1997; USEPA 2007; Lemière et al. 2014; McComb et al. 2014; Weindorf et al. 2014; Gallhofer and Lottermoser 2018; Lemière 2018; Declercq et al. 2019; Goff et al. 2020; Laperche and Lemière, 2020; Ravansari et al. 2020; Williams et al. 2020; Knight et al. 2021, Zhang et al. 2021).

7.2 Indicator Elements for THM

There is an absence of published literature describing the use of pXRF devices to identify high-density minerals in offshore sand resources. Because of this, we compared the pXRF data with wt% THM by calculating correlation coefficients. The correlation coefficient quantifies the strength and direction of the relationship between two variables (e.g., elemental concentration from pXRF and wt% THM). The most common correlation coefficient is the Pearson correlation coefficient (CORREL in Excel) which ranges from -1 to 1, where:

- 1 indicates a perfect positive correlation: as one variable increases, the other also increases proportionally.
- -1 indicates a perfect negative correlation: as one variable increases, the other decreases proportionally.
- 0 indicates no correlation between the variables.

Performing a correlation analysis aids in decision-making, identifying patterns, and predicting outcomes based on the data. Correlation does not imply causation; a strong correlation between variables does not necessarily mean that changes in one variable cause changes in the other. A strong correlation between certain elements and wt% THM can be used to guide further sampling for mineralogy or analytical geochemistry depending on the needs of the project.

The correlation coefficient for comparing wt% THM from heavy liquid separation to pXRF data (soil mode) is 0.54-0.59 (Table 9), which suggests that the elemental concentration of Zr in bulk samples has a moderately strong linear correlation with wt% THM, for both offshore and onshore sediment samples. Fe has a weak to moderate correlation to wt% THM for offshore samples with a correlation coefficient of 0.40, while Y and Ti have correlation coefficients of 0.31 and 0.26. There appears to be no correlation between Th and U with wt% THM for offshore samples (Table 9, Appendix D). Ti has a moderate correlation coefficient with wt% THM for onshore samples at 0.50, while Th, Fe, Y and U have weak to very weak correlation with wt% THM. We infer that Zr can be a key indicator for higher wt% THM in both offshore and onshore sediment samples, while Fe is the next preferable element for offshore samples and Ti for onshore samples. Increasing concentrations of Zr, Fe (offshore) and Ti (onshore) may represent increased wt% THM and associated economic heavy minerals in bulk sediment samples with unknown chemistry and mineralogy.

Table 9: Correlation coefficient values for selected elements and percent total heavy minerals for offshore and onshore sediment samples.

Ratio of element to percent total heavy minerals	Correlation coefficient- offshore samples	Correlation coefficient - onshore samples
Zr / wt% THM	0.59	0.54
Fe / wt% THM	0.40	0.10
Y / wt% THM	0.31	-0.39
Ti / wt% THM	0.26	0.50
Th / wt% THM	-0.08	0.27
U / wt% THM	-0.23	-0.24

7.3 Thresholds for identifying critical minerals in bulk samples

Three elemental threshold ranges for Ti, Fe, Zr, Th, Y were derived from onshore heavy mineral ore samples containing rutile, ilmenite, and zircon using the mean and standard deviation of pXRF data, unless otherwise noted. These threshold ranges are intended to guide sample selection for more detailed analyses (i.e., wt% THM, mineralogy, geochemistry). The highest threshold range is “Prospective”. Prospective values were determined using pXRF data on heavy mineral sand ore samples archived in the VE Rock Repository. Prospective values equal or exceed the mean for the dataset (Table 10, Figure 10). Values that fall in the prospective column should be considered a good target for further analytical sampling. Fe may represent ilmenite and/or leucoxene; however, Fe is common to some non-economic heavy minerals (Table 1), therefore Fe concentration should be used with other indicator elements. The lowest threshold range was “Inconclusive.” Inconclusive values are equal to or less than the mean concentration for samples with <1 wt% THM (Table 10, Appendix D). The intermediate threshold range is “limited.” Limited values are those between prospective and inconclusive values (Table 10, Appendix D). Values that fall into the limited and inconclusive columns may or may not contain abundant critical commodities and further qualitative measures (e.g., visual opaque grains, magnetic attraction) should be utilized. The statistics utilized to generate elemental thresholds in Table 10 are shown in Figure 10.

The threshold values might vary depending on the spectrometer and specific mineral concentrates. The specific threshold values may require updating for future studies, however the methodology for analyzing mineral concentrates alongside bulk material using the same analyzer to derive threshold values is adaptable and transferrable.

Table 10: Elemental threshold table.

Element	Related Economic Mineral(s)	Prospective[1]	Limited	Inconclusive[2]
Ti	Rutile, Ilmenite	>74,000 ppm min: 9,875 ppm max: 221,340 ppm (n=13 measurements)	74,000 – 4,700 ppm	<4,700 ppm (n=21 samples, 2-4 measurements per sample)
Fe	Ilmenite, Leocoxene[3]	>22,170 ppm min: 1,085 ppm max: 77, 075 ppm (n=13 measurements)	22,170 – 14,060 ppm	<14,060 ppm (n=21 samples, 2-4 measurements per sample)
Zr	Zircon	>14,270 ppm min: 1,980 ppm max: 81,600 ppm (n=14 measurements)	14,270 – 3,340 ppm	<3,340 ppm (n=21 samples, 2-4 measurements per sample)
Th	REE-bearing minerals, Zircon	>56 ppm min: 2ppm max: 215 ppm (n=14 measurements)	56 - 5 ppm	<5 ppm (n=21 samples, 2-4 measurements per sample)
Y	REE-bearing minerals, Zircon	>18 ppm[4] min: 5 ppm max: 25 ppm (n=10 measurements)	18 – 10 ppm	<10 ppm (n=21 samples, 2-4 measurements per sample)

[1] Determined using the pXRF mean value from heavy mineral sand ore samples in the VE Rock Repository, rounded to the nearest multiple of 5.

[2] Determined using the pXRF mean value from all offshore and onshore bulk sediment samples in Table D5 Appendix D with <1 wt% THM, rounded to the nearest multiple of 5.

[3] Fe may represent ilmenite and/or leucoxene, however, can be found in other non-economic heavy minerals (see Table 1). Fe concentration should not be used as a sole indicator of economic heavy minerals.

[4] Determined using the pXRF mean plus 1-standard deviation from heavy mineral sand ore samples at VE, rounded to the nearest multiple of 5.

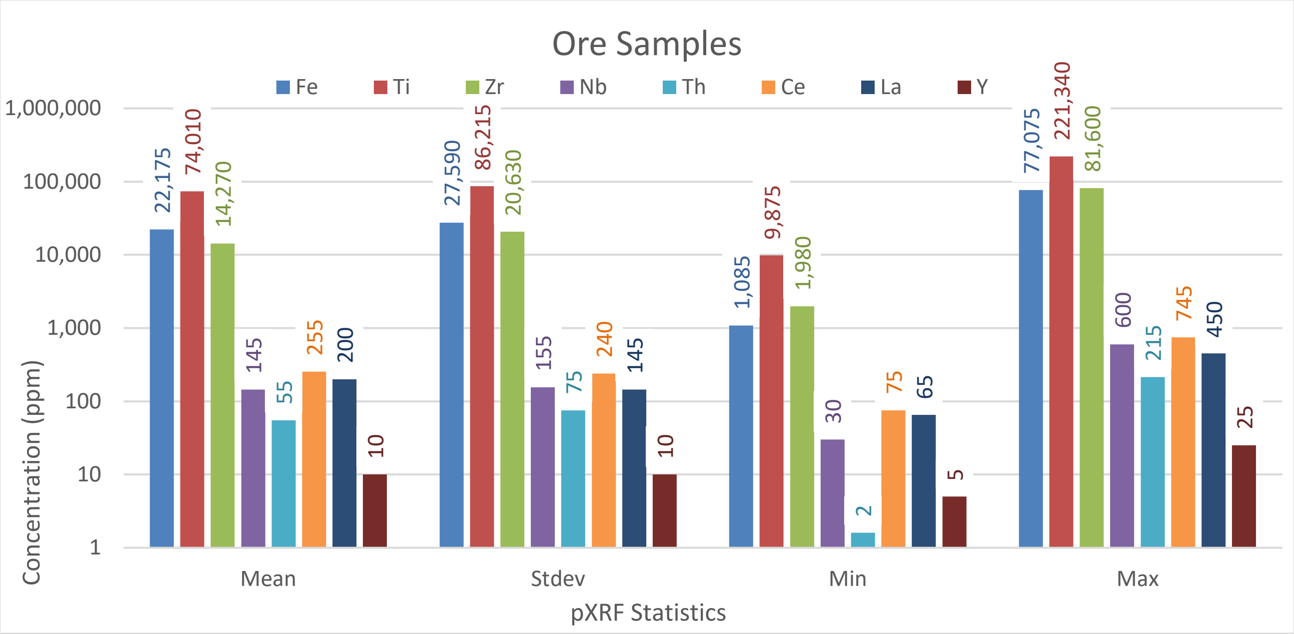


Figure 10: Statistics from portable XRF analysis (soil mode) on heavy mineral sand ore samples in the VE Rock Repository. Data represents spread in values used to calculate threshold limits for Fe (n data points =13), Ti (n=13), Zr (n=14), Nb (n=14), Th (n=14), Ce (n=7), La (n=5), Y (n=10).

8.0 HEAVY MINERAL SAND MINING AND PROCESSING

Historical and active heavy mineral sand placer mines across the globe vary in their scale of operation, primary minerals extracted, and geographical locations (Table 11). Australia has active operations mainly along the coast with a few inland sites. High-quality rutile is mined in Sierra Leone (Van Gosen et al. 2014). India has some of the highest monazite concentrations in heavy mineral deposits and stockpiles the mineral as a source of thorium for their nuclear power reserves (Van Gosen et al. 2014).

Globally, offshore shallow-ocean mining activities on continental shelves primarily focus on extracting sand and gravel for aggregate purposes. However, offshore placer deposits are also mined for valuable resources like gold (northwestern North America), diamonds (southwestern Africa), and tin (southeastern Asia) (U.S. Congress 1987; Rona 2008; Schneider 2020). Commercial mining of offshore heavy mineral sands other than gold placers has not occurred within the U.S., and an existing regulatory framework has not been sufficiently established.

Table 11: Examples of historical and prsent onshore and offshore heavy mineral sand mining operations around the world.

Locality	Commodity Notes	Geology/Occurrence	Mining Information
United States			
McNairy Sand, Tennessee	Up to 17% THM	Late Cretaceous shoreline facies	IperionX[1]
Millrun Project, Virginia	HM sands (Ti and Zr)	Fall Zone (marginal marine-nearshore)	Atlantic Strategic Minerals[2]
Concord Plant (Old Hickory Mine), Virginia	HM sands (Ti and Zr)	Fall Zone (marginal marine-nearshore)	Iluka Resources[3]
Brink Mine, Virginia	HM sands (Ti and Zr)	Fall Zone (marginal marine-nearshore)	Iluka Resources[3]
Mission Mine, Georgia	HM sands	Coastal Plain/ paleo-barrier island	Southern Ionics (Part of Chemours Company)[3]
Trail-Ridge Complex, Florida (Trail Ridge, Maxville, Highland)	HM sands (Ti and Zr)	Coastal Plain/ paleo-dune	Chemours Company[3]
Jacksonville District, Florida (Folkston, Boulogne, Trail Ridge, Highland, Green Cove Springs deposits)	Ilmenite	Coastal Plain/ paleo-modern dune and beach	Iluka Resources[3]
Australia			
Jacinth-Ambrosia deposits, Eucla Basin	HM sands	Inland fossil beach deposits	Iluka Resources[4]
Murray Basin	HM sands	Inland fossil beach deposits	Bemax Resources Limited (Ginkgo Mine, Snapper Mine; Iluka Resources (multiple sites); Astron Limited (Donald Mineral Sands)[5]
Perth Basin, Eneabba mining district (Pliocene-Pleistocene)	HM sands, rutile and zircon, monazite near 7% in southern part of district	Fossil beach strandline, many operations in this district	Iluka Resources, Sheffield Resources Limited, Bemax Resources Limited[5]
Dampier HM sands, Canning Basin, NE Western Australia	HM sands	Weathered sandstone	Sheffield Resources Limited[5]

Table 11: Examples of historical and prsent onshore and offshore heavy mineral sand mining operations around the world.

Locality	Commodity Notes	Geology/Occurrence	Mining Information
North Stradbroke Island, Queensland	HM sands	Onshore and **offshore**	Sibelco Australia[5]
Coburn Mineral Sands Project, western Australia	Zircon and Ti-rich heavy mineral sands	Fossil near-coastal dune system	Strandline Resources Limited[6]
New Zealand			
South Taranaki Bight and Westland Sands	Iron sands	**Offshore**	Trans-Tasman Resources Limited[7]
Brazil			
Guaju Deposits, eastern coastal Brazil	Ilmenite	Eolian coastal dunes (modern)	NA[5]
Bujuru Deposits, southern coastal Brazil	4.66% THM, ~60% ilmenite	Backshore dune	NA[5]
Buena Placer District, Buena Norte and Buena Sol deposits	Monazite, REO content up to 60%	Modern coastal placers	NA[5]
Guaju heavy-mineral sands mine	HM sands, ilmenite	Modern coastal placers	NA[5]
India			
Southern coast of India	Monazite	Modern coastal placers	Malhotra, 2012; Indian Rare Earths Limited, 2013; Kerala Minerals & Metals Limited, 2013[5]
Chavara and Kollam, Kerala State (Southern India)	Ti-oxides, coproducts of zircon, sillimanite, and monazite	Modern coastal placers	Kerala Minerals and Metals Limited, 2013; Indian Rare Earths Limited, 2013[5]
Eastern and western shores of southern India	Monazite for thorium stockpiles	Modern coastal placers	Rare Earths Division of Indian Rare Earths Limited[5]
SE India	Monazite, rutile, garnet, zircon, and sillimanite coproducts	Modern coastal placers	Trimex Industries[5]

Table 11: Examples of historical and prsent onshore and offshore heavy mineral sand mining operations around the world.

Locality	Commodity Notes	Geology/Occurrence	Mining Information
Odisha State coast (NE India)	Up to 50% sillimanite and others	Modern coastal placers	Indian Rare Earths Limited, 2013[5]
Sri Lanka			
Southwestern Sri Lanka	Monazite	Fluvial placer and modern coastal sands	NA[5]
China			
Beihai, Haikang, Dianbai, Nanshanhai districts. Sai-Lao, Wuzhaung and Xinglong placer districts - southern China	Monazite produced as byproduct. 1-2% THM including Ti-oxides.	Modern coastal placers	NA[5]
Mozambique			
NE coast of Mozambique	83% ilmenite	Placer	Kenmar Resources PLC[5]
Mutamba mine, Inhambane, Mozambique	Ilmenite	Undeveloped mineral sands	Rio Tinto[8]
Madagascar			
QIT Madagascar Minerals, Fort Dauphin Mine, SE Madagascar	Ilmenite and zircon	Ancient beach sands	Rio Tinto[8]
Senegal			
Grande Cote heavy-mineral sands deposit	1-2% THM	Mobile eolian dune field	Mineral Deposits Limited[5]
Sierra Leone			
Mokaba	Rutile	Placer	Sierra Rutile Limited (formally Titanium Resources Group Limited) [5]
South Africa			

Table 11: Examples of historical and prsent onshore and offshore heavy mineral sand mining operations around the world.

Locality	Commodity Notes	Geology/Occurrence	Mining Information
Zulti South, Richards Bay, Kwazulu-Natal, South Africa	Zircon, rutile, ilmenite	Stacked eolian dunes	Rio Tinto and Blue Horizon[8]
Tormin Mineral Sands	Zircon, ilmenite, rutile, magnetite and garnet	Modern coastal placer	Mineral Commodities[9]

Note: NA: data not available; geology/occurrence information from respective source provided in the mining information column. [1]IperionX (2022); [2]ASM (2023); [3]Van Gosen et al. (2018); [4]Iluka Resources Limited (2024); [5]Van Gosen et al. (2014); [6]Strandline Resources Limited (2024); [7]Miller et al. (2018); [8]Rio Tinto (2024), [9]Mineral Commodities (2023).

Heavy mineral sands often accumulate and concentrate through wave action and longshore currents, forming disseminated beach placers (Rona 2008). The exploration for offshore heavy mineral sands typically begins with seafloor sampling and seismic surveys, followed by geochemical prospecting to identify indicator elements and mapping anomalies (Rona 1972). Offshore mining of unconsolidated deposits in shallow waters involves dredges mounted on floating platforms specially designed for operation in protected waters (U.S. Congress 1987). Bucket-line and suction dredging techniques are used to lift material from the seabed to the surface.

The exploration for onshore heavy mineral sand deposits involves airborne geophysical surveys to detect radiometric anomalies associated with Th-bearing minerals (Hammarstrom and Dicken 2019). Upon identifying a resource, drilling is conducted in a closely spaced grid pattern to map the ore body's extent (Iluka 2009). Site exploration requires land access permits, geological interpretation, and mineralogical analyses to progress to the potential project stage if a resource is confirmed (Iluka 2009). Small and discontinuous high-grade onshore heavy mineral sand ore bodies are excavated through dry mining techniques. For larger tonnage operations or laterally continuous ore found in unconsolidated sediments, wet mining methods are utilized (Iluka 2009).

8.1 Processing Technologies

Heavy mineral sands are processed via wet and dry separation methods using gravity, magnetic, and electrostatic techniques (Figure 11) depending on the physical properties (Table 12).

Table 12: Attribute table for separation methods and current processing technologies.

Separation Method	Technology	Medium/ mechanism	Physical properties	Minerals	Product
Gravity	Spiral	Water	Size, shape, and density sorting	Separates large quantities of quartz sand from valuable heavy minerals	Heavy mineral concentrate (HMC), ready for dry milling
	Up-current classifier	Water	Size and density	Removes fine quartz and clay from heavy mineral concentrate	HMC, ready for dry milling
	Kelsey centrifugal jig	Water + centrifugal force	Density	Scavenges zircon from kyanite	HMC, ready for dry milling
	Air table separator	Air + shaking	Specific gravity	Separates large quantities of quartz sand from valuable heavy minerals	HMC, ready for dry milling
	Water table separator	Water + shaking	Size and specific gravity	Scavenges zircon from kyanite and staurolite	HMC, ready for dry milling
Magnetic dry milling	Magnetic separator	Magnetic rollers	Magnetism	Magnetic ilmenite and high-purity (non-magnetic) zircon	Magnetic and non-magnetic heavy minerals
Electrostatic dry milling	Electrostatic separator	Ionization and centrifugal force	Conduction	Conductive rutile and non-conductive zircon, kyanite and staurolite	Conductive and non-conductive heavy minerals
	Electrostatic plate separator	Ionization and gravity	Size and conduction	Conductive rutile and non-conductive zircon, kyanite and staurolite	Fine-grained conductors and coarse non-conductor HMC

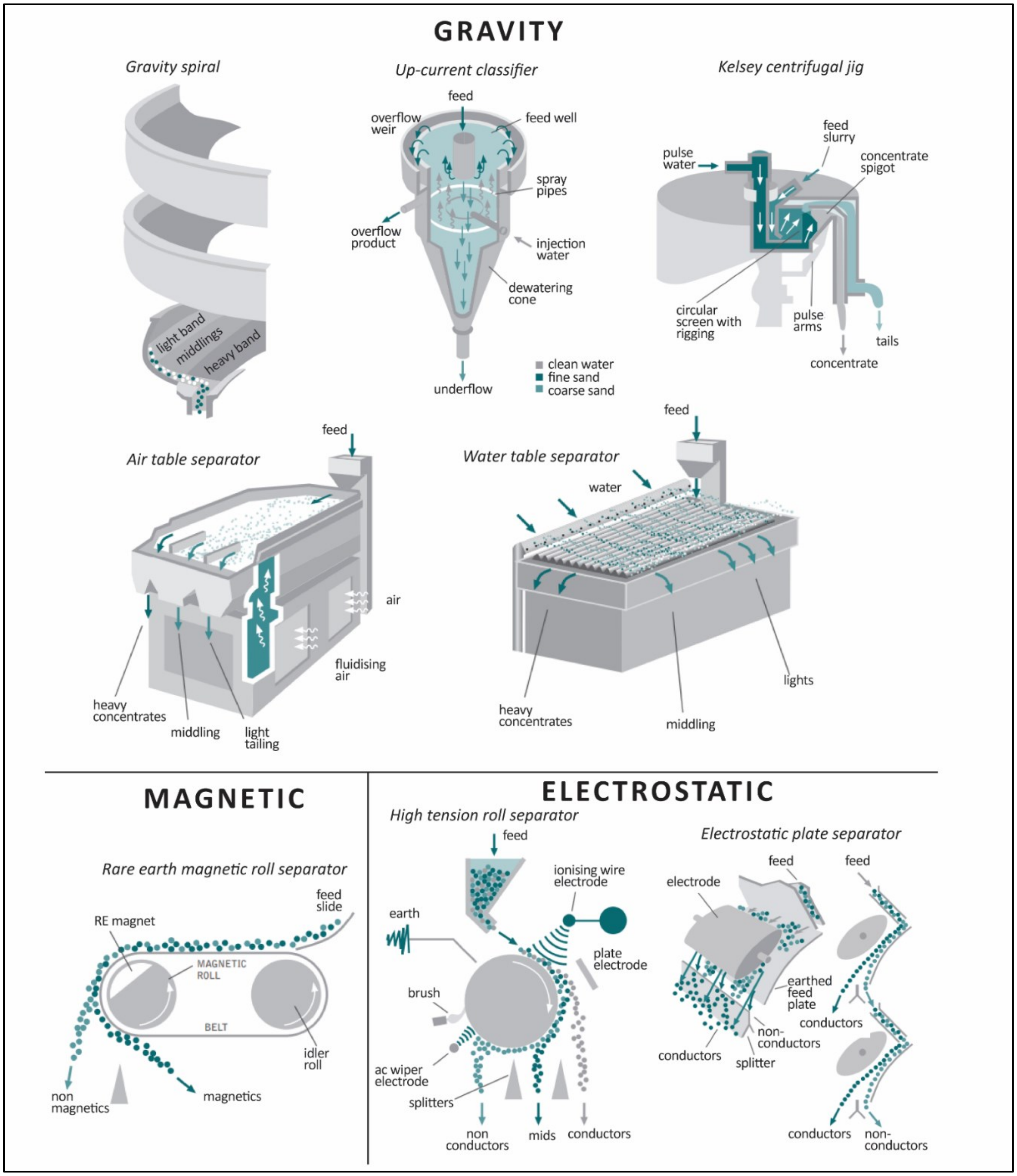


Figure 11: Common gravity, magnetic and electrostatic separation methods for terrestrial mineral sand deposits. Figure assembled and modified from Iluka (2009).

Initially, a hydrocyclone may be used to clean grain surfaces by removing clay or iron coatings. Gravity concentration techniques then separate the clean materials. Vertical spirals remove large quantities of quartz-rich and low-density particles (approximately <2.9 g/cc) from heavy minerals with higher specific gravities. Modular spiral separators are available in some markets and are commonly used at gold-placer mining sites in coastal and alluvial settings.

These modular and portable units are applied to other heavy mineral sand ores and have a wide range in enrichment capacity in terms of tonnage per hour. Most gravity separation methods require water as the fluidized medium, except for the air table (Iluka 2009). The resultant product is a heavy mineral concentrate that is then dry-processed using magnetic and electrostatic separation. Ilmenite, one of the most magnetic heavy minerals, can be separated from zircon and rutile using magnetic separation. Rutile, which is highly conductive, can then be separated from zircon through electrostatic processing. Iluka Resources summarized key technical aspects of terrestrial mineral sand mining in their Technical Guidance document (Iluka 2009).

9.0 FUTURE WORK

The implementation of heavy mineral sand separation in conjunction with beach nourishment activities has not yet been tested in the U.S. This study and previous work by VE has established the economic value of heavy minerals contained in offshore marine sand deposits suitable for beach nourishment. A logical step is to develop a pilot study in conjunction with a beach sand nourishment operation.

Co-extracting heavy minerals sands during a beach nourishment project necessitates specialized mineral processing equipment and skilled operators. It requires collaboration between various entities (i.e., government entities, researchers, and industry) to ensure proper oversight, scientific input, and proficient management across each phase. Two hypothetical scenarios are proposed in Appendix E. In the first scenario, a small subset of offshore material would be transported as bulk sediment to an inland heavy mineral sand processing facility. The second scenario involves a small portion of the dredged material being redirected to a temporary concentrator, stockpiled on the beach, and then transported to an inland processing facility. In both scenarios, sampling at monitoring plots for geochemical and mineralogical analyses is planned prior to and post-nourishment. These data will provide information regarding the economic grade of the heavy minerals. Additionally, repeat monitoring of reworked dredged material through state-of-the-art luminescence tracer techniques promises valuable insights to the fate of placed sediments and can inform future placement strategies (Appendix E).

10.0 CONCLUSIONS

This study of heavy minerals in beach sand offshore of Virginia shows that there is a reasonable potential for this resource to help fulfill the objectives of Federal Executive Order 13817 to ensure secure and reliable supplies of critical commodities (i.e., Ti, Zr, REEs). Based on the comprehensive offshore geodatabase compiled as part of this work, currently-known offshore sand resource areas (i.e., Wallops and Sandbridge) contain <5 wt% THM, with the primary economic minerals being ilmenite, rutile, zircon, and a trace amount of monazite, among other industrial heavy minerals. Newly-acquired data obtained as part of this study provides heavy mineral information for the current BOEM sand resource lease area at Sandbridge Shoal, and the Atlantic Ocean Federal Navigation Channel. The average THM content of these areas is 0.8-0.9 wt% and 1.1 wt% respectively. This grade is less than onshore heavy mineral sand ore deposits that typically average 4-5 wt% THM but given that the volume of sand typically used in a beach nourishment operation is in the millions of cubic yards, even 1% of that could amount to an economic co-product.

Evaluating such a vast resource using solely laboratory analyses alone would be costly and inefficient. Two analytical paths (in-situ and ex-situ) were developed for core screening utilizing a handheld XRF unit. A process to rapidly screen sands within large resource areas for critical minerals has been established. The estimated thresholds for predicting Ti- and Zr-rich heavy mineral sand commodities within offshore quartz-rich sand resources were empirically derived. Reliable and consistent elements used as part of this exploratory protocol are Zr, Fe, and Ti. Elemental uranium data derived as part of this protocol has demonstrated not to be a reliable indicator element for critical commodities in these types of deposits/media.

Efficient and regulatory compliant methods to co-extract heavy minerals with beach nourishment sands have not yet been established in the U.S. or within VA state waters. Existing regulations do not adequately cover a potential operation of this type. The conversation surrounding regulations and engineering designs began with a gathering of Mid-Atlantic stakeholders for a virtual forum as part of this project. The purpose was to discuss the viability, costs, and benefits of mineral extraction as part of coastal resilience projects. A major outcome from this forum was a recognition of the need for a scoped pilot project to evaluate the feasibility and economics of heavy mineral separation operations during beach nourishment. Such an undertaking requires collaboration between industry and regulators, as specialized equipment, expertise, and proper oversight is needed throughout all phases of the project. Recommendations for a pilot study to test the feasibility of concentrating and further processing of heavy mineral sands at an inland facility alongside a beach nourishment project is scoped in Appendix E. These proposed next steps are meant to provide a starting point for potential future endeavors related to heavy mineral sand recovery from nourishment sands.

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APPENDIX A

2022 Mid-Atlantic Marine Heavy Mineral Sands Forum Proceedings

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Proceedings of the
2022 Mid-Atlantic Marine Heavy Mineral Sands Forum

March 31, 2022
Virtual Forum
Charlottesville, Virginia

Co-Sponsors:
Virginia Department of Energy
United States Bureau of Ocean Energy Management

OPEN FILE REPORT 2022-20

Prepared under Bureau of Ocean Energy Management
Cooperative Agreement No. M21AC00010
Award Period: July 01, 2021 – February 29, 2024

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2022 Mid-Atlantic Marine Heavy Mineral Sands Forum

ABSTRACT

The Virginia Department of Energy (Virginia Energy) hosted the 2022 Mid-Atlantic Marine Heavy Mineral Sands Forum on March 31, 2022. Virginia Energy and the United States Bureau of Ocean Energy Management (U.S. BOEM) co-sponsored the event. The idea and purpose for the forum was originally conceived as an information gathering activity to support Virginia Energy's Cooperative Agreement with BOEM, *M21AC00010 - Analysis of Critical and Strategic Mineral Recovery from Sand Used for Beach Nourishment*. The virtual forum was open to the public and included sixteen invited speakers. This proceedings document serves as partial fulfillment of Virginia Energy's commitment under the Cooperative Agreement.

The virtual forum began at 9:00 am Eastern Standard Time (EST) with a brief description of meeting logistics by the moderator, Christina Wood-Smith (Virginia Energy). William Lassetter (Virginia Energy, Economic Geology Projects Manager) provided an overview of the major goals and objectives for the forum. Jeffrey Waldner (BOEM, Project Officer) provided a brief introduction and opening comments on behalf of BOEM. A total of 74 registered participants including scientists, regulators, consultants, representatives of non-profit organizations, and other stakeholders heard prepared presentations and engaged in open discussions on the capacity of extracting heavy minerals containing critical commodities from marine sand deposits. An important objective of the forum was to examine the viability, costs, and benefits of extracting mineral resources as an integral part of coastal resiliency improvement projects under the current regulatory, permitting, and environmental framework. Marine sand deposits containing domestic sources of critical minerals could help achieve the goals of Federal Executive Order 13817 ([1]2017) to ensure secure and reliable supplies of materials that are vital to the Nation's security and economic prosperity.

Organizers arranged the forum into five sessions with common themes. Presenters provided an overview of critical commodities and heavy minerals in placer deposits, with examples from domestic and global mining operations. BOEM presented an overview of the federal marine minerals leasing program and regulatory framework. The City of Virginia Beach Public Works Coastal Engineering Section provided a history of beach nourishment activities in Virginia Beach, with details on specifications for beach sand and source areas. Several state agencies provided insight into the permitting and regulatory processes for mineral mining and coastal resources. Before the lunch break, breakout group discussions evaluated hypothetical scenarios for offshore and onshore mineral extraction. The last two sessions of the day included an overview of federal and Virginia environmental policies applicable to marine minerals, and current methods and techniques utilized to assess heavy minerals. The forum concluded at 3:45 pm EST.

[1] 1: Exec. Order No. 13817, 82 FR 60835 (2017). https://www.govinfo.gov/content/pkg/FR-2017-12-26/pdf/2017-27899.pdf.

TABLE OF CONTENTS

PRESENTATION SUMMARIES

Introduction and statement of purpose for the Mid-Atlantic Marine Heavy Mineral Sands Forum

Presenter affiliation: Economic Geology Projects Manager, Virginia Department of Energy, william.lassetter@energy.virginia.gov

(William Lassetter provided the following transcript)

Good morning, I am William Lassetter, the Economic Geology Projects Manager for the Virginia Department of Energy, Geology and Mineral Resources Program. The program serves as the state geological survey.

I want to start by thanking the Bureau of Ocean Energy Management (BOEM) for supporting our continuing partnership in offshore sand and heavy mineral assessments, and supporting this forum.

Since you have taken the time to join today, you are probably aware of the current interest in critical mineral commodities, and the imperative of federal government agencies that oversee our nation's natural resources to better understand where domestic resources are located. The possibility that modern seafloor sand deposits along the eastern coastline and the Atlantic Ocean continental shelf, might contain some of these critical minerals underpins what we will be discussing in the forum today. That these resources might be extracted as an integrated operation associated with existing programs dredging large volumes of offshore sand for beach restoration is also a key factor.

As a brief refresher, the U.S. Department of Interior published a list of critical minerals in 2018 that was subsequently revised in 2022 to include 50 mineral commodities (mostly elements). These commodities include non-fuel minerals that are considered essential to our nation's economy and national security. For most of these, the U.S. is heavily reliant on foreign imports and the supply chains are vulnerable to disruption. As far as we are aware, there has never been significant commercial recovery of economic or critical minerals from sand deposits on the Mid-Atlantic Continental Shelf in the past. Thus an opportunity awaits.

Our purpose today is to gather information that will inform a feasibility study for the recovery of marine economic critical minerals. Beach renourishment using suitable sand resources from the continental shelf has been conducted for several decades, and expected to continue to be an important tool for sustaining our coastlines that are subject to erosion and loss of beach resources.

Our plan for today:

In session 1, we will lay the foundation for why and how we should seriously consider the economic value of extracting critical minerals, conducted as an activity offshore during the dredging operation, or perhaps onshore when the sand material is delivered to the beach. We will hear about operations in other countries around the globe; and get an inside-the-industry perspective on heavy mineral recovery operations. The economic view is only part of the story. There are environmental and public safety considerations, regulatory requirements, and a wide range of competing interests in the offshore region that are equally important.

In session 2, we will hear about BOEM's federal marine minerals leasing program, followed by a review of the practical applications of OCS sand along the Virginia Beach – Sandbridge Beach coastline. This will be followed by a short combined break and open discussion period, and during this and all the discussion sessions today, we would like to address any questions that arise during the preceding talks.

In Session 3, our invited speakers will describe the current state permitting and regulatory requirements in Virginia, Maryland, North Carolina, and South Carolina. This will be a key session in identifying possible issues and concerns for a potentially new offshore industry that may take place in state or federal waters. Again, this will be followed by a quick break and discussion session that will lead into two breakout sessions in which we will consider a couple of hypotheticals.

We plan to break for lunch at 12:30, leave the virtual streaming platform open, and reconvene around 1:30 pm.

In Session 4, our invited speakers will provide insight on current environmental standards and best practices, and the scope of issues and concerns that are important to stakeholders in the marine and coastal environment. Again followed by an open discussion during which time we would like to address any questions and concerns.

In our final session 5, scheduled to begin at 2:30, we are going to pivot our focus to speakers describing key tools that are being used now to search for, identify and characterize critical mineral occurrences and ultimately economic deposits. Our invited speakers have expert knowledge concerning the importance of extending good geologic map coverage from the terrestrial sources of heavy minerals to the marine environment, state-of-the-art geochemical and mineralogical analytical techniques, and geophysical methods for identifying potential resources.

We have organized the forum to include a lot of time for discussions, Q&A, gathering and recording comments and suggestions. During all the discussion sessions we would like to address any questions that arise during the preceding talks. We ask that you hold questions till that period, and also post them using the chat box so that we can record them and make sure they are addressed.

This will include documenting what are bound to be many uncertainties that will need to be evaluated. Each discussion will start off with a quick poll using the poll box in the lower right corner, the results of this will be posted within a minute or so, so as to stimulate the following discussion. Our plan is to compile a written proceedings of the forum, published as a publication or open-file report from our department, made available from our web store.

Finally, special thanks to all the invited speakers who agreed to give presentations covering many of the concerns and issues that deserve full and careful consideration as part of the feasibility study.

Session 1: Marine mineral sands – feasibility of extracting critical mineral resources

LASSETTER, W.L. – Marine mineral sands on Virginia's Outer Continental Shelf (OCS) – The case for extracting critical minerals as part of beach restoration projects (WLassetter.pdf)

Presenter affiliation: Economic Geology Projects Manager, Virginia Department of Energy, william.lassetter@energy.virginia.gov

(William Lassetter provided the following abstract)

Since the mid-1980s, Virginia's state geological survey (Department of Energy, Geology and Mineral Resources Program) has worked collaboratively with the U.S. Bureau of Ocean Energy Management, the U.S. Geological Survey, and the Virginia Institute of Marine Science at the College of William and Mary to assess marine sand resources on the continental shelf. Reconnaissance survey cruises have collected subbottom seismic profiles, side-scan sonar images of the seafloor, vibracores, and seafloor sediment samples for the analysis of grain size characteristics and mineral compositions. To date, substantial deposits of clean, fine- to medium-grained sand have been identified in two main areas: (1) in shoal and sheeted sand deposits located offshore of Assateague and Wallops Islands, and (2) shoal deposits located about 5 kilometers offshore of the community of Sandbridge. These deposits occur within 10 feet of the subbottom at shallow water depths of less than 60 feet, and are accessible by marine dredging operations for use as beach nourishment sand. In addition to providing resources for future shoreline protection projects, these sand deposits contain heavy minerals including ilmenite, zircon, rutile, and monazite, among others that are potential sources of critical mineral commodities such as titanium (Ti), zirconium (Zr), and rare earth elements (REE).

A capacity assessment study is presently underway evaluating alternative methodologies for recovering economic heavy minerals in marine sands. Three main goals of the study are to: (1) assess separation and recovery methods that may be integral to beach nourishment operations, (2) develop a field protocol for rapid screening of critical elements using portable X-ray fluorescence (pXRF) and gamma scintillometer equipment, and (3) assess environmental and public safety concerns associated with mineral separation processes. The positive benefits of recovering heavy minerals from beach sand placements are threefold. First, the value of these

marketable minerals has the potential to significantly offset the economic costs of coastal restoration projects. Second, these mineral occurrences represent a potential source of domestic critical commodities that by definition are essential to economic and national security. Third, the removal of opaque heavy minerals from beach sand placed in resort and tourist areas results in a more desirable lighter, cleaner appearance.

The total heavy mineral content assessed in over 600 sediment samples taken from shallow core and seafloor grab samples averages 2.7% by weight, ranging from 0.01% up to 14.7%. The average composition of the separated heavy mineral fractions indicates ilmenite 25.4%, rutile 7.3%, and zircon 3.4% are the main components, with lesser amounts of leucoxene 1.6%, xenotime 1%, titanite 0.6%, and monazite 0.2%. Based on recent market prices of mineral concentrate commodities, the estimated value of 1 cubic yard of offshore sand containing 2.7 wt% total heavy minerals is about $10.80. Applying this unit value to a recent beach nourishment project that placed about 1.8 million cubic yards of sand on Sandbridge Beach, the estimated value of the contained heavy minerals is nearly $20 million.

HAWKINS, D.W. – Overview of global coastal and nearshore mineral recovery operations (DHawkins.pdf)

Presenter affiliation: Geologist, Virginia Department of Energy,
david.hawkins@energy.virginia.gov

(David Hawkins provided the following abstract)

Heavy mineral sand (HMS) placer deposits are mined across paleo- and modern-beach complexes, typically along trailing-edge passive margin coastlines. Highly weathered high-grade metamorphic rocks and mafic igneous rocks provided mineral source material to these paleo-beach strandlines and marginal marine sediments. Placer deposits are associated with transgressive and regressive sea-level cycles and occur in shallow, unconsolidated packages up to 45 meters thick and are on the scales of up to a few kilometers wide by tens of kilometers in length. The primary mineral commodities in these deposits are Ti-bearing minerals such as ilmenite and rutile, zircon, and REE-bearing minerals (e.g. monazite). Most domestic and global operations involve Ti-bearing minerals, but may extract zircon and monazite as co-products. Australia, South Africa, China, Madagascar, Mozambique, and India have typically dominated in the production of ilmenite, leucoxene, and/or rutile. Australia and South Africa have been dominant producers of zircon. Historically and presently, Brazil and India have mined monazite for stockpiling of thorium for energy reserves. Presently in the United States, the primary locations for mining are in Georgia, Florida, and Tennessee. Types of operations range from dry mining using bulldozers and mechanical separation, to dredge mining, which employs the use of an artificial pond to create a slurry of material for the gravity separation plant. To date, offshore marine mining has not occurred for HMS placer deposits, although some projects are in feasibility study stages.

KARST, A.T. – Onshore heavy mineral sands: Exploration, mining, processing, and reclamation (AKarst.pdf)

Presenter affiliation: President/Principal Geologist, Karst Geo Solutions, LCC, atkarst@gmail.com

(David Hawkins summarized this presentation)

Mr. Adam Karst is a consulting geologist with 17 years' experience working in the mineral sands industry across the U.S. and international localities. Mr. Karst provided a general overview of the exploration, mining, processing, and reclamation techniques and considerations for terrestrial shallow unconsolidated sand placer deposits. Generally, explorations methods start with desktop research and lead into field reconnaissance and mapping. As part of initial assessments, geophysics including radiometric and magnetic methodology may be useful to help identify potential localities that may host economic heavy minerals (e.g. monazite and zircon via airborne radiometric surveys). Scientists use drilling and sampling to identify deposits in the subsurface. Mr. Karst expanded on the two primary mining methods: 1) dredging, commonly used where shallow deposits intersect the water table; and 2) dry mining, involving excavation via bucket and haul methods.

Following mining, wet separation using a gravity separation method produces a heavy mineral concentrate (HMC) consisting of up to ~90% HM. The HMC is then dried and further refined via dry separation techniques at a mineral separation plant (MSP). The MSP may be located off-site and involves electrostatic and magnetic separation to produce the following general end products: ilmenite, leucoxene, rutile, zircon, and monazite. Some additional dry mill tails will be present comprising non-valuable minerals. Mr. Karst expanded on the reclamation stage of a mining project, which involves restoration of the land to pre-mining conditions to the best extent possible.

Lastly, Mr. Karst discussed the importance of properly managing naturally occurring radioactive material (NORM) as a result of concentrated monazite, and to lesser extents, zircon concentrates. Mining operators must meet each of the appropriate permits and licenses to properly ensure safe handling and disposal. To achieve reclamation, the existing mine tailings will need to be dried, diluted, and restored back to existing mined areas and/or sold. Mr. Karst's talk was an overview of the traditional land mining techniques and served as a framing discussion for further talks in the forum.

(Adam Karst provided the following abstract)

Offshore mineral sands/critical mineral development opportunities will need to leverage current technologies and techniques from current onshore heavy mineral sands exploration, mining, processing, and reclamation. This will also need to include the management of potential NORM (naturally occurring radioactive material).

Session 2: Current offshore sand mining operations for beach replenishment

KNORR, P.O. – Federal marine minerals leasing program in the Mid-Atlantic (PKnorr.pdf)

Presenter affiliation: Critical Minerals Geologist, U.S. Bureau of Ocean Energy Management, paul.knorr@boem.gov

(David Hawkins summarized this presentation)

Dr. Paul Knorr is a Critical Minerals Geologist with BOEM's Marine Minerals Division. Dr. Knorr provided an overview of the OCS marine minerals leasing program and discussed the types of aggregate materials and minerals under the leasing program. The leasing program consists of Non-Competitive Negotiated Agreements (NNAs), typically used for coastal resiliency projects, and competitive leasing. Since 1995, the program has executed 64 NNAs in the East Coast and Gulf of Mexico OCS regions. Dr. Knorr expanded on the NNA process, which covers federal shore protection, beach restoration, coastal wetlands restoration and federal construction projects and briefly mentioned the environmental assessment components which fall under the umbrella of the National Environmental Protection Act (NEPA). Dr. Knorr touched on the domestic competitive leasing framework for commercial prospecting and leasing of marine minerals. Under the current federal regulations (30 CFR Part 581), BOEM has not yet issued a competitive lease for commercial minerals. Dr. Knorr closed the presentation with some questions for how the current regulations and leasing process may be different when considering heavy mineral processing and extraction.

ADAMS, D.F. – City of Virginia Beach, Beach Nourishment Program (DAdams.pdf)

Presenter affiliation: Coastal Program Manager, City of Virginia Beach, dadams@vbgov.com

(David Hawkins summarized this presentation)

Mr. Daniel Adams, the Coastal Program Manager with the City of Virginia Beach, provided an overview of beach nourishment programs for the Resort Beach, Sandbridge Beach, and the Bay Beaches. Since 2002, the Resort Beach area has received 6.8 million cubic yards of sand from the Thimble Shoals Channel and/or the Atlantic Ocean Channel (2001-2002; 2012-2013; and 2019). Sandbridge Beach has received 9.1 million cubic yards of sand since 1998, with the most recent replenishment in 2020, sourcing material from Sandbridge Shoal. The Bay Beaches consist of Chesapeake Beach, Ocean Park Beach, and Cape Henry Beach along the northern shoreline of the City of Virginia Beach. Within the last decade, multiple projects along the Bay shoreline have been completed delivering volumes of sand typically less than 400,000 cubic yards for each event. Mr. Adams closed his talk by emphasizing the importance of collaboration in maintaining partnerships with federal agencies such as the U.S. Army Corps of Engineers (USACE) and BOEM, and continuing to identify new sand resources and beneficial uses for the material.

Session 3: Permitting and regulatory framework for marine minerals: Federal and state waters

HAMM, S. – Permit requirements for mineral mines in Virginia (SHamm.pdf)

Presenter affiliation: Compliance/Permit Review Specialist, Virginia Department of Energy, sarah.hamm@energy.virginia.gov

(Sarah Hamm provided the following abstract)

This presentation reviews the requirements to obtain a new, on-shore, mineral mining permit and license in Virginia from the Virginia Department of Energy. For offshore mining, Virginia's State Subaqueous Minerals Management Plan authorizes the Virginia Marine Resources Commission as the lead agency for any mining and extraction activities taking place on subaqueous lands. Additional permits from other state agencies, such as a radioactive materials permit from the Virginia Department of Health or permits related to air and water quality from the Virginia Department of Environmental Quality, may be required for processing mineral sands in Virginia.

VAN RYSWICK, S. – Maryland permitting and regulatory framework for marine minerals (SVanRyswick.pdf)

Presenter affiliation: Program Chief of the Coastal & Environmental Geology Program, Maryland Geological Survey, stephen.vanryswick@maryland.gov

(David Hawkins summarized this presentation)

Mr. Stephen Van Ryswick, the Chief Geologist of the Maryland Geological Survey's Coastal and Environmental Geology Program provided an overview of Maryland's marine minerals permitting requirements. The Maryland Department of the Environment (MDE) is the state regulatory agency providing oversight for offshore sand resources in state waters and the USACE Baltimore District oversees federal regulatory requirements. For marine minerals, MDE would require a Section 401 Water Quality Certification when a federal license or permit is required for a project. Additionally, the project would need a Coastal Zone Management Act (CZMA) consistency determination if federal funds are used and a Joint Permit Application for work within state tidal waters. The MD Board of Public Works (BPW) Wetland Administration would issue a Tidal Wetland License if warranted by MDE. Mr. Van Ryswick mentioned other potential screening requirements to consider for a project, including but not limited to, historical resources, rare, threatened, endangered species, sensitive habitats, and time of year restrictions. Mr. Van Ryswick stated that if a project occurs in state waters, then the MD BPW would likely expect compensation for the extraction of mineral rights. Onshore processing would likely require additional upland regulations as there is currently no offshore mineral separation projects.

TAYLOR, K.B. and FARRELL, K.M. – Status report on marine offshore heavy mineral sands, North Carolina (KTaylor_KFarrell.pdf)

Presenter affiliation: Kenneth Taylor, PhD, PG, State Geologist, North Carolina Geological Survey, kenneth.b.taylor@ncdenr.gov; Kathleen Farrell, PhD, PG, Senior Geologist, North Carolina Geological Survey, kathleen.farrell@ncdenr.gov

(Kathleen Farrell, PhD provided the following abstract)

The NC Geological Survey (NCGS) summarized: 1) the legal status of mining offshore NC; and 2) the history of heavy mineral research offshore NC. The North Carolina Mining Act of 1971 defines the permitting process for on-land mining above the low-tide zone. The area seaward of the low-tide zone is available for beach renourishment, but 'mining' offshore is not authorized. The current law does not recognize, authorize or accommodate a permitting process for offshore mining of placer sands or any other commodity such as phosphate. As a consequence of funding provided by the MMS-AASG Continental Margins Program, NCGS participated in a series of studies to characterize heavy mineral assemblages in sands from surficial grab samples and cores from the continental shelf (YRS 6 -10). The analytical results are posted in a series of OFRs published by the NCGS (OFR 90-3; OFR 91-3; OFR 93-37; OFR 94-2; OFR 97-2; https://deq.nc.gov/about/divisions/energy-mineral-land-resources/north-carolina-geological-survey/ncgs-maps/open-file-reports-maps-2004-to-1943).

NEALE, B. – Permitting in SC waters (BNeale.pdf)

Presenter affiliation: Senior Program Analyst, S.C. Department of Health & Environmental Control, nealeb@dhec.sc.gov

(David Hawkins summarized this presentation)

Ms. Barbara Neale, with the South Carolina Department of Health and Environmental Control (SCDHEC) provided an overview of applicable regulations within the South Carolina Coastal Program. Ms. Neale mentioned the importance of the tourism and fisheries industries, ports, and natural resources along the South Carolina coastal zone as drivers for the need for coastal management, protection and oversight. SCDHEC oversees activities within eight coastal counties through indirect certification and direct permitting. SCDHEC's indirect authority applies to federal permits and licenses, direct federal activities, federally-funded projects, and the OCS. The Department's direct coastal authority covers coastal waters, tidelands, beaches, and beach/dune systems. SCDHEC has direct authority for permitting activities associated with coastal recreation, dredging, beach renourishment, and coastal infrastructure. Projects pertaining to offshore energy siting and development and transmission cable locations in state waters may also warrant review from SCDHEC under their indirect authority.

Session 4: Environmental standards, compliance, best practices applied to marine minerals

WIKEL, G.L. – Synopsis of the federal environmental review process for marine mineral extraction in the marine environment (GWikel.pdf)

Presenter affiliation: Oceanographer, U.S. Bureau of Ocean Energy Management,
Geoffrey.wikel@boem.gov

(Geoffrey Wikel provided the following abstract)

A robust federal environmental review and consultation process would be followed if heavy minerals were actually proposed to be separated from offshore borrow area material typically dredged for navigation or coastal resilience projects. The exact process, documents, consultations, and public engagement strategies would depend on the details of the proposal, its location and timing, agencies involved, and the nature of public participation and concerns. The resources potentially affected, or nature of potential effects, in the marine environment would depend on the details of that proposal - dredging, handling, separation, transport, processing, tailings and material management. Impacts related to onshore stockpiling, processing, and material management may also need to be evaluated if those activities were to occur in context of typical beach nourishment or coastal restoration operations. No such proposals exist at this time.

If such a proposal were to emerge, detailed environment impact assessments, public involvement opportunities and meetings, and coupled technical analyses would be led by the lead federal agency. Typically, such an environmental impact assessment and review would be a collaborative effort between multiple federal agencies and cooperating entities, notably the USACE, National Oceanic and Atmospheric Administration (NOAA), and BOEM provided OCS resources were implicated. The lead agency would comply with the complex and important fabric of federal environmental requirements in play in the marine environment, the centerpiece of which is the National Environmental Policy Act. Numerous federal laws and requirements, coupled with potential state or local environmental review requirements, dictate the scope, timing, and nature of environmental review. The ultimate goal of the process would be to meaningfully disclose and mitigate potential environmental effects of federal decisions, relying on high-quality or best-available scientific information and effective public engagement.

PEABODY, R. – State regulatory and permitting framework, onshore mineral beneficiation (RPeabody.pdf)

Presenter affiliation: Director of Coastal Policy, Restoration and Resilience, Virginia Marine Resources Commission, rachael.peabody@mrc.virginia.gov

(David Hawkins summarized this presentation)

Ms. Rachael Peabody is the Director of Coastal Policy with the Virginia Marine Resources Commission (VMRC). Ms. Peabody discussed the regulatory and permitting framework for use of Virginia’s submerged lands for natural resources. VMRC has authority over marine fisheries, habitats, and shellfish management within state-owned bottomlands, wetlands, and coastal primary sand dunes and beaches. The review process for projects involves a joint permit application where VMRC acts as a clearinghouse for the review and provides the application to other applicable regulatory authorities such as the Department of Environmental Quality, U.S. Corps of Engineers, and local wetland boards. Ms. Peabody stated that all projects involve a public interest review as part of the process. In the context of dredged sand material, VMRC prefers beneficial use of the material for use in beach nourishment, living shorelines, and/or wetland creation. VMRC also provides Coastal Zone Management Program consistency review authority. VMRC recommends evaluation and utilization of existing upland and overboard sediment disposal sites for beneficial use. This includes the ever expanding Craney Island and the Virginia Ocean disposal site prior to the creation of new ocean mining sites off our coast.

MCKAY, L. – Coastal/ocean policy and planning (LMcKay.pdf)

Presenter affiliation: Program Manager, Virginia Coastal Zone Management Program, laura.mckay@deq.virginia.gov

(David Hawkins summarized this presentation with consultation and additions from Laura McKay)

Ms. Laura McKay is the Program Manager for the Virginia Coastal Zone Management (CZM) Program, which is a network of state agencies and coastal localities. The program is housed at and led by CZM staff at the Virginia Department of Environmental Quality. The program incorporates state coastal laws and policies approved by NOAA. Ms. McKay discussed the formation of the Mid-Atlantic Regional Council on the Ocean (MARCO), and its Mid-Atlantic Committee on the Ocean (MACO) and how these initiatives have allowed for inter-state, tribal and federal collaboration in the conception of the 2016 Mid-Atlantic Ocean Action Plan. Ms. McKay shared information on the MARCO Ocean Data Portal (https://portal.midatlanticocean.org/), which contains over 6,000 data layers that can help with ocean planning and resources of concern. Ms. McKay touched on the current CZM 5-year grant strategy to develop a Virginia Ocean Plan, and CZM's interest in involving more stakeholders in its development as part of this long-term grant effort.

Session 5: Advanced technologies for heavy minerals identification, assessment, and monitoring

TOMLINSON, J. – Insights from the BOEM Atlantic Sand Assessment Project (JTomlinson.pdf)

Presenter affiliation: Geologist, Delaware Geological Survey, jaimet@udel.edu

(Jaime Tomlinson provided the following abstract)

In 2020, the Delaware Geological Survey published a detailed surficial geologic map of the Atlantic seafloor of Delaware from the shoreline to approximately 15 km (9.3 mi) offshore (Mattheus et al., 2020). Thirteen stratigraphic units were recognized and mapped from examination of 500 km of subbottom high-resolution chirper data ground-truthed by approximately 60 cores and descriptive logs from an additional 200 cores. The data were supplemented by 47 radiocarbon dates of organic material and over 200 amino acid racemization analyses of shells from cores used to determine if the mapped units were Holocene or pre-Holocene. In addition to mapping the surficial stratigraphic units, the geophysical data allowed for mapping of the thickness and extent of sand bodies as well as onshore-offshore buried Pleistocene paleovalleys that transected the map area.

A detailed offshore geologic map such as this is an important tool for future resource exploration and for providing a scientific basis for resolving competitive use issues. The map by Matthaeus and others is being used for sand resource analysis for areas of beach-replenishment material in both state and federal waters. The map is also being used to help delineate potential cable routes from a planned offshore wind farm to the shoreline.

GRAMMATIKOPOULOS, T. – Mineralogical and geochemical investigation of REE offshore sands from Virginia, USA (TGrammatikopoulos.pdf)

Presenter affiliation: Senior Geoscientist, SGS Canada Inc., tassos.grammatikopoulos@sgs.com

(Tassos Grammatikopoulos, PhD provided the following abstract)

Ore deposits are complex and display a high degree of variability, arising from their inherent geological and mineralogical characteristics, which impact their beneficiation. Automated mineralogy is established as an integral part for both exploration and mineral processing in the mining industry for critical minerals. The TIMA (Tescan Integrated Mineral Analyser), coupled with geochemical assays, X-ray diffraction and mineral chemistry, were used to characterize twenty (20) mineral sand samples on behalf of the Virginia Department of Energy Geology and Mineral Resources Program. Each sample was submitted for heavy liquid separation (HLS) at a specific gravity (S.G.) of 2.9. g/cc^3 to upgrade the heavy minerals. The sink fractions account for 4% to 72% of the total mass of all samples. The sink fractions were analyzed for REE and a large suite of other elements. The total REE+Y ranges from <509 ppm to 7,292 ppm, reflecting mainly monazite and, less commonly, xenotime.

TIMA data show that the main economic minerals include monazite and traces of xenotime and columbite, significant zircon, rutile and ilmenite. The remainder of the minerals include spinels (Fe-Cr-oxides), staurolite, kyanite, and other minerals. The economic minerals are well liberated; monazite liberation ranges from 71% to 100%, zircon from 90% to 99%, rutile from 54% to 93%, and ilmenite from 87% to 98%. Electron microprobe analyses show that monazite is enriched in LREE, has a similar average concentration of the major oxides, and it contains significant thorium, and minor uranium. Xenotime is Y-bearing and carries some of the heavy REE. Zircon is barren of detectable REE but it hosts traces of yttrium. Rutile and ilmenite hosts traces of niobium.

TIMA analysis is extremely useful because it can provide quantitative mineralogical parameters, speciating the minerals and their mass% and providing data on liberation and association, morphological characteristics, grain size, elemental deportment among other parameters. This technique is more advantageous than other bulk mineralogical techniques (i.e., XRD) because it provides accurate mineral identifications at low detection limits, and additional mineralogical parameters.

SHAH, A.K. – Geophysical approaches to imaging heavy mineral sand content in offshore environments (AShah.pdf)

Presenter affiliation: Research Geophysicist, U.S. Geological Survey, ashah@usgs.gov

(Anjana Shah, PhD provided the following abstract)

Geophysical data play a key role in “connecting the dots” between geologic samples by showing the continuity of certain characteristics and facilitating an interpreted geologic context. With respect to heavy mineral sand concentrations, grain size information can be obtained from lidar data onshore and sonar data offshore. Geophysical tools, especially radiometric, magnetic, and induced polarity (IP) methods, are helpful with determining compositional variations.

On land, one of the most efficient and effective approaches to imaging heavy mineral sand concentrations is the radiometric method, i.e. gamma ray spectrometry for K, Th, and U (Force et al., 1982; Grosz et al., 1989; Shah et al., 2021). Heavy mineral sands in the southeastern U.S., both onshore and offshore, typically contain some amount of monazite, which is highlighted by radiometric Th. Surveys are conducted using a passive sensor most often from an airplane, but other platforms are also suitable. In the offshore environment, the gamma rays can’t be sensed though the fluid medium, so the sensor is towed deep enough to maintain contact with the seafloor (Jones, 2001). The tow speed may be anywhere from 4-10 knots, depending on survey conditions and depth of the seafloor, with deeper areas requiring longer cables and slower speeds.

IP methods, which involves measuring the time-response to an induced electrical charge, have also been deployed offshore using a system that requires continuous contact with the seafloor (Wynn, 1988; 2012). This method is especially sensitive to ilmenite. The tow cable includes both electrical transmitters and receivers and the system is typically towed at speeds of about 3 knots, so it is best for very targeted surveys over small areas. System noise can impact the resolution of the data.

Magnetic field measurements can be conducted using an airborne sensor or tow fish since they are not impacted by the presence of water. The magnetic field responds to minerals such as magnetite, hematite, and maghemite, which may be present in small amounts in a heavy mineral assemblage. Measured anomalies are typically dominated by sources in crystalline basement, but if the platform allows the sensor to be closer to the ground, such as with shipboard or walking surveys, subtle anomalies due to heavy mineral sand concentrations may be detectable (Siddiquie et al., 1984; Mudge and Teakle, 2003). Post-processing such as high-pass filtering can enhance such anomalies (Shah and Harris, 2012; Shah et al., 2012). Such anomalies are most easily observed in relatively calm waters where there is limited sensor motion due to currents, waves, etc. Systems may be towed at speeds of 8-10 knots, facilitating surveys of larger areas.

Cited references are available from the Author upon request.

HAWKINS, D.W. and LASSETTER, W.L. – Field methods for assessment and monitoring of heavy mineral sands: Terrestrial and offshore insights (DHawkins_WLassetter.pdf)

(David Hawkins provided the following abstract)

To assess heavy mineral sand (HMS) deposits, we rely on an array of field methods and techniques. Starting with a regional-scale reconnaissance approach, scientists can target HMS deposits for more detailed and localized assessment. Up-to-date geologic mapping data is critical to understand the depositional environment, mineral provenance, and overall distribution of HMS deposits in the surface and subsurface geologic units. Airborne radiometric data, such as equivalent thorium (eTh) is a proxy for the presence for thorium-bearing minerals (i.e. monazite), which can accumulate in placer deposits. Additionally, scientists can interpret crystalline bedrock types from aeromagnetic data, providing data for mineral provenance. Targeted sampling will typically involve drilling, field screening, and processing of heavy mineral concentrates for laboratory analysis. Due to the extensive history of HMS mining globally, most techniques focus on terrestrial deposits. To aid in offshore exploration, it is important that scientists emphasize geologic mapping and seismic stratigraphy to understand the marine deposits. As LiDAR provides interpretative insight for geomorphic and topographic features on land, bathymetry data provides details on morphologic features that may concentrate HMS deposits on the continental shelf. As part of this capacity assessment study, we are working on developing a rapid field screening protocol using a portable x-ray fluorescence (pXRF) analyzer to apply to sediments during and/or following the dredging process as well as for exploration, environmental, and regulatory purposes. Through laboratory testing, correlation with analytical results and other screening tools, we hope to be able to provide a protocol to assist with critical commodity evaluations in terrestrial and marine sand deposits in the field.

FACILITATED DISCUSSION FINDINGS

Facilitators structured the forum into five sessions hosting presentations relating to a common theme. Open discussion was encouraged at the end of most sessions as outlined in the agenda. Virginia Energy compiled questions and comments from the virtual platform chat function into a document shared with participants during the discussion periods.

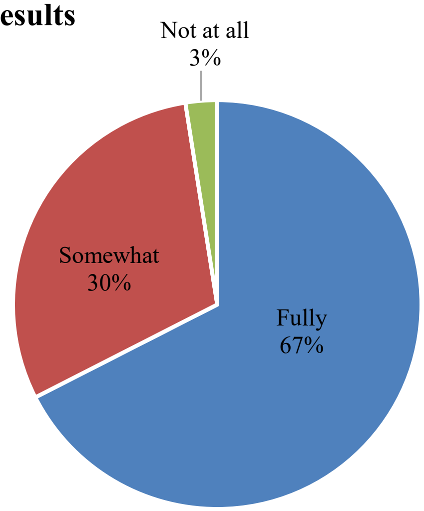
Polling Results

As part of participant engagement, four survey questions were polled throughout the forum as follows:

#1 Prior to this forum, I was _____ aware of the presence of minerals containing critical materials such as titanium, zirconium, rare earth elements in association with marine sand deposits on the OCS:

A. Fully
B. Somewhat
C. Not at all

Poll #1 Results

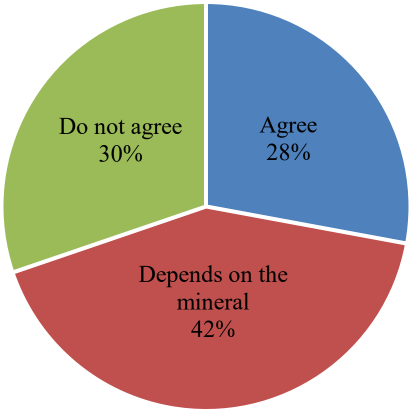


Note: data based on 40 responses

#2 Timelines for permit application reviews and decisions related to marine mineral extraction operations that would increase the availability and supply of domestic critical minerals should be expedited because of the “critical” nature of these commodities:

A. Agree
B. Depends on the mineral
C. Do not agree

Poll #2 Results

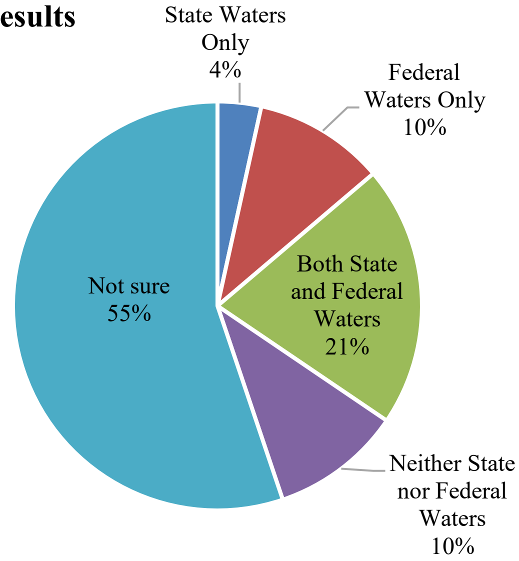


Note: data based on 43 responses

#3 Current operational permitting requirements and environmental protection standards that would apply to the separation and recovery of <u>marine minerals other than sand</u> on the OCS are adequate for:

A. State waters only
B. Federal waters only
C. Both state and federal waters
D. Neither state or federal waters
E. Not sure

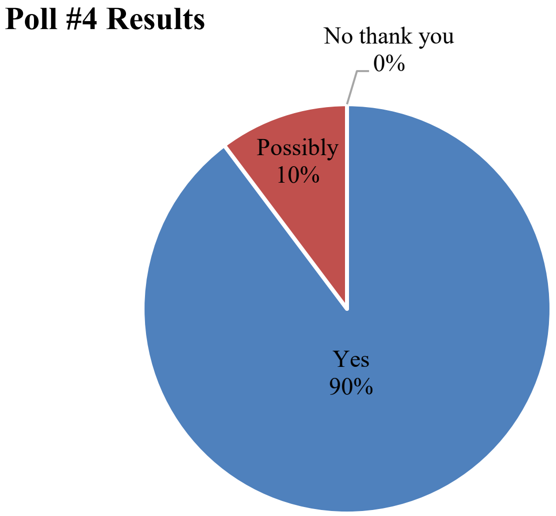
Poll #3 Results



Note: data based on 29 responses

#4 I would consider participating in a future workshop to learn more about technologies used to identify and assess marine critical mineral resources (on the OCS):

A. Yes
B. Possibly
C. No thank you



Note: data based on 39 responses

Observations for the polling results indicated a general awareness of critical commodities on the OCS, variable opinions on the applicability of current permits and regulations as they apply to OCS mineral recovery and processing, and a majority interest in participating in a subsequent workshop. Not every attendee provided a response to each polling question. After running each poll, Virginia Energy opened the forum to discussion. This document addresses questions and comments raised throughout the forum in the subsequent sections under *Discussion Periods*. We also provide a synopsis of significant talking points and potential follow-up items in the *Findings and Recommended Actions* section of this document.

Discussion Periods

Virginia Energy utilized polling results and compiled questions and comments from each respective session to kick-off open discussions between the attendees. The following bullet points provide general topics and/or open-ended questions posed throughout the forum. This is not a complete list of questions and comments from the forum; these discussion points help to provide additional context and "take-home" ideas.

Introduction and Session 1: Marine mineral sands – feasibility of extracting critical mineral resources

- A discussion period did not follow the introduction for the forum and three presentations in Session 1. Facilitators informed the participants that the first discussion period would follow Session 2.

Session 2: Current offshore sand mining operations for beach replenishment

- According to Dr. Paul Knorr, BOEM has not issued a competitive lease for commercial mineral mining under current federal regulations.
- Mr. Dan Adams presented an overview of beach nourishment projects in Virginia Beach which have occurred within the past few decades. Mr. Adams mentioned that the City of Virginia Beach has not used state funding for beach nourishment projects.
- "Beach quality" sand typically has a median grain size of 0.30 to 0.32 millimeters, but that definition may vary by state. Some states may specify requirements for color as well.
- According to Mr. Adam Karst, a total heavy mineral (THM) content of at least 1% by weight would be appropriate to consider an OCS mining operation. Other variables to consider may include the location and capacity of an existing processing mill near the OCS operation; the percentage of zircon and rutile in a deposit as being primary drivers for prospecting a potential resource; and the practicality of such operations in the context of current technology and economic needs.
- Some participants raised questions about potential re-use of existing dredge spoil material (i.e. Craney Island facility-Portsmouth, VA; offshore dredge waste disposal areas) for heavy mineral assessments, rather than assessing new locations.
- Many participants were interested in how to quantify the amount of fine-grained sediment lost during the dredging process (i.e., silt, clay). Several studies have been published by BOEM and the USACE pertaining to the quantification of fines during the dredging process(https://espis.boem.gov/final%20reports/BOEM_2019-010.pdf;https://erdc-library.erdc.dren.mil/jspui/handle/11681/36997; https://erdc-library.erdc.dren.mil/jspui/handle/11681/37656).
- Participants were interested in the typical feed rate of the sand slurry mixture coming onto a dredger into the hopper, and the typical pump-out rate of the material onto the beach. Rates may be variable depending on the project.

Session 3: Permitting and regulatory framework for marine minerals: Federal and state waters

- Two breakout groups followed Session 3, and a joint discussion after the two groups convened. These breakout sessions were hypothetical scenarios for extraction, processing, and transport of heavy mineral sand concentrates either in an onshore beach setting or offshore in federal and/or state waters. These ideas serve as talking points and “food for thought”.

- Breakout group #1 (onshore heavy mineral separation):
    - Logistics:
        - Determine if a mobile mineral concentrator would be located just offshore or if a separation operation would or could occur onshore.
        - The initial separation in the vicinity of the operation would be for the bulk material and further separation would be completed offsite at another facility.
        - Consider the logistics of processing the material from a stockpile or directly from the pump-out pipe.
        - General logistics with having an operation in a popular beach destination.
    - Uncertainties and challenges:
        - Need to determine appropriate ownership of the heavy mineral concentrates once onshore.
        - Consider necessary easements and origin of the source material (i.e. federal vs. state waters).
        - Address ownership rights of the sand material and whether the material falls under public domain. Projects would need to clearly define royalties.
        - Consider time of year restrictions or preferences for potential separation operations.
        - Involvement of each appropriate regulating agency.
- Breakout group #2 (offshore heavy mineral separation):
    - Logistics:
        - Determine the logistics between offshore and onshore processing.
        - Determine the best separation method as part of the normal hopper dredging process.
        - Appropriate to know the THM concentration offshore prior to an extraction operation. Preliminary data collection and analysis is important.
        - Evaluate the potential for the extraction to occur as part of a beach nourishment project.
        - Consider all of the relevant marine stakeholders and the overall geographical presence of these industries and where shared resources between states and federal entities are located (e.g. fisheries industry, offshore renewables, and conservation).
        - Determine the volume of sand to dredge to account for potentially lower THM grades and/or if more sand than original specifications would need to be dredged to offset removal of heavy mineral sands.

    - Quantify the effluent from the dredge during the extraction process and what may be lost to the sea, and how this could affect the marine ecosystem (i.e. turbidity considerations, marine life, substrate environments).
  - Uncertainties and challenges:
    - Consider the necessary permits for offshore heavy mineral exploration and if the current permitting framework would be appropriate for these non-fuel type minerals.
    - Marine species habitat protection and conservation needs in the context of dredging operations. Ensure all of the appropriate stakeholders are involved throughout the process.
    - Time of year considerations, fishing activities, marine mammals, ocean space sharing considerations.
    - Establish clear commitments and plans between the mining companies and appropriate owner(s) of the material prior to the consideration of operations.
    - Consider all possible waste products or handling requirements for concentrates and spoil material, including naturally occurring radioactive material (NORM) in environmental assessments and studies prior to the conception of a project and throughout a project's life cycle.

Session 4: Environmental standards, compliance, best practices applied to marine minerals

- Importance of being transparent with the available data and information in the environmental assessment stage; take efforts to mitigate environmental risks.
- BOEM wants to ensure that each of the applicable stakeholders are involved in these assessments and decisions, and that thorough environmental assessments and/or environmental impact statements are completed.
- Review and evaluate the available data and involve the relevant stakeholders throughout the process.
- Determine if the current environmental regulations are appropriate for existing heavy mineral extraction methods and technologies.

Session 5: Advanced technologies for heavy minerals identification, assessment, and monitoring

- Detailed offshore geologic mapping provides pertinent information for mineral resource assessments.
- Certain geophysical methods may be more appropriate than others when considering regional-scale or more localized heavy mineral assessments.
- Utilize knowledge and data from terrestrial assessments and methodology to apply to the marine environment
- Determine the limitations with current geophysical and geochemical methods for marine heavy mineral assessments.

FINDINGS AND RECOMMENDED ACTIONS

This forum provided a broad overview of critical commodities contained in heavy minerals, commonly found in shallow marine sand deposits on the OCS. The forum brought together a diverse group of stakeholders across industries and public entities to discuss a common interest, marine resources and responsible stewardship of these resources. The primary goal of the forum was to facilitate information sharing and gauge ideas from those involved to help with the development of a capacity assessment study for the recovery of heavy minerals from marine sand deposits as part of future beach nourishment projects. The implementation of Federal Executive Order 13817 (2017) requires that the United States support projects and work that will further characterize domestic critical mineral resources. The USGS lists titanium, zirconium, and REE (among others) as "critical minerals" (https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals) and this project supports the goals of the Executive Order by producing new data for offshore sand and mineral resources.

To support the capacity assessment, we compiled the following recommended actions that should be considered in preparation for a future pilot study:

1) Current federal and state regulatory agencies should discuss how lease terms may vary for non-fuel minerals, other than sand and gravel from federal and state waters. Current regulations do not explicitly differentiate between non-fuel minerals and sand/gravel aggregate on the OCS and where there should be a distinction.
2) The U.S. Army Corps of Engineers and dredging community were not present for this forum. It is critical to gather input from those stakeholders prior to development of a pilot study. Additionally, industry stakeholders from the mining community stated the need for long-term commitments for there to be investments in a potential operation. This may involve collaboration between federal, state, local government and other marine and coastal stakeholders.
3) There should be clear distinction made between heavy minerals and heavy metals. Heavy minerals refer to specific minerals that are present based on density through sorting through geological processes and may include non-metallic minerals (i.e. silicates).
4) As part of the current environmental processes (i.e., NEPA), regulators will need to address transport and disposal requirements of THM concentrates from the marine and/or coastal environmental to a land facility. Additionally, if a project intends to produce a monazite product, then the project plan will need to clearly address management of NORM in accordance with the current environmental and regulatory standards.
5) Stakeholders should outline ownership rights of sediment material and royalty payments in the planning stages of the project.
6) Part of this capacity assessment will assess the heavy mineral content in fine material (silt, clay). Published studies have addressed the quantification of fines lost during the

dredging process, which may allow for projects to target areas with finer material that have otherwise not been assessed to allow for greater flexibility in sourcing material for beneficial use projects. For example, if an existing maintenance dredging project of a shipping channel could continue to provide a sediment source for concurrent beneficial use projects and has a prospective heavy mineral fraction, this may be economically feasible.

7) Many stakeholders mentioned evaluating existing dredge spoil areas offshore and onshore for heavy minerals. A reconnaissance level sampling event would be appropriate to determine if heavy minerals are present within these disposal areas prior to a pilot study.
8) Studies should look at the costs associated with typical dredging and beach nourishment operations, and start-up and operating costs with a mobile-capable separation method.

The recommended actions listed above will be considered in greater depth as part of the development of a future pilot study, the recommended next step. We will utilize new sample analytical data from two localities in federal waters (Sandbridge Shoal Borrow Area and the Atlantic Ocean Federal Navigation Channel) to provide a reconnaissance-level resource estimate based on current market commodity prices. We plan to incorporate this data into cost savings scenarios to demonstrate how coastal resilience projects may benefit from extraction of heavy minerals during beach sand placement and serve as a potential future domestic critical mineral resource.

The presentations summarized above are included in digital format as separate PDF files in Appendix C for additional reference for the reader, and provide more detail pertaining to those topics. We thank each of the speakers and participants for their involvement and contributions to the forum. The capacity assessment study (to be released as a separate technical document) will incorporate information gathered from this forum, reflecting each of the stakeholder's input, and will contribute new publicly available data that can be utilized in future studies.

APPENDIX A: 2022 Mid-Atlantic Marine Heavy Mineral Sands Forum Agenda

Mid-Atlantic Marine Heavy Mineral Sands Forum
Virginia Department of Energy and the U.S. Bureau of Ocean Energy Management

March 31, 2022 – 9am – 4:30pm (EST)
Virtual format – *Cisco Webex*

The Virginia Department of Energy (Virginia Energy), in collaboration with the U.S. Bureau of Ocean Energy Management (BOEM), is developing a feasibility study for the recovery of economic minerals from marine sand deposits, ideally as an integral part of coastal resilience projects. Economic minerals include critical minerals[1] containing titanium, zirconium, and rare earth elements, as well as other valuable commodities such as garnet, sillimanite minerals, and precious metals. Among the key factors we are considering as part of the study are alternative methodologies for mining and economic mineral separation, potential environmental impacts at mining and processing locations, current Federal, State, and local regulatory requirements that apply to mining and mineral recovery operations in coastal and offshore areas, and impacts on stakeholders with interests in coastal and marine policymaking.

Purpose:

The goals of the Forum are to convene scientists and stakeholders from Federal, State, and local government and industry to gather information pertaining to: 1) the Federal, State, and local permitting and regulatory framework that impacts mining and mineral extraction operations in coastal and offshore areas; 2) environmental standards and best practices for management of marine seafloor mineral resources on the Continental Shelf; and 3) logistical criteria and economic feasibility for mining of critical commodities as part of ongoing coastal resilience projects. From this Forum, we will cultivate a list of questions and data needs to help inform our feasibility study, potentially leading to future cooperative studies.

The Forum will be held on March 31, 2022 from 9:00 am to 4:30 pm Eastern Standard Time (EST) and will be conducted in a virtual format, moderated by Virginia Energy, using the Cisco Webex video conferencing platform. The agenda includes speakers whom have been involved with offshore marine minerals and/or critical mineral assessments, particularly in the Mid-Atlantic region. Invited speakers will share experiences related to the mapping, assessment, and recovery of mineral sand resources, including sands for beach replenishment and economic heavy minerals.

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1 – Nassar, N.T., and Fortier, S.M., 2021, Methodology and technical input for the 2021 review and revision of the U.S. Critical Minerals List: U.S. Geological Survey Open-File Report 2021–1045, 31 p., https://doi.org/10.3133/ ofr20211045.

Objectives and Outcomes:

Utilizing a virtual format, we have grouped presentations into five (5) session themes:

1) An overview of critical mineral commodities associated with marine mineral sands and the feasibility of extracting mineral resources;
2) Current offshore sand mining operations for beach replenishment;
3) Federal and State regulatory framework and permitting requirements;
4) Environmental standards and best practices; and
5) Current technologies for heavy minerals assessment.

We will cover each of these topics at a relatively high level to allow for a comprehensive scoping of additional informational needs. There will be multiple discussion and information sharing opportunities throughout the day. We will emphasize applications and scenarios focused on economic mineral extraction from a sand replenishment source area under the currently known permitting and regulatory framework.

Agenda

Morning Sessions

Introduction and statement of purpose for the Forum (Virginia Energy, BOEM)

9:00-9:10 EST	Overview, desired outcomes, plans for Forum proceedings

Session 1: Marine mineral sands – feasibility of extracting critical mineral resources

9:10-9:20 EST	What are economic (critical) heavy minerals? (William Lassetter, Virginia Energy)
9:20-9:30 EST	Overview of global coastal/nearshore mineral recovery operations (David Hawkins, Virginia Energy)
9:30-9:40 EST	Onshore heavy mineral sands: Exploration, mining, processing, and reclamation (Adam Karst, Karst Geo Solutions, LLC)

Session 2: Current offshore sand mining operations for beach replenishment

9:40-9:50 EST	Federal marine minerals leasing program in the Mid-Atlantic (Paul Knorr, U.S. Bureau of Ocean Energy Management)
9:50-10:00 EST	City of Virginia Beach, Beach Nourishment Program (Dan Adams, City of Virginia Beach)
10:00-10:40 EST	***Poll question #1***, Q&A, group discussion and short break

Session 3: Permitting and regulatory framework for marine minerals: Federal and State waters

10:40-10:50 EST	Virginia – (Sarah Hamm, Virginia Energy)
10:50-11:00 EST	Maryland – (Stephen Van Ryswick, Maryland Geological Survey)
11:00-11:10 EST	North Carolina – (Kenneth Taylor and Kathleen Farrell, North Carolina Geological Survey)
11:10-11:20 EST	South Carolina – (Barbara Neale, South Carolina Department of Health & Environmental Control)
11:20-11:45 EST	***Poll question #2***, Q&A, group discussion and short break
11:45-12:30 EST	**Breakout group discussion**

- *Case studies: hypothetical onshore and offshore mineral separation in the context of a coastal resilience project (Additional details to be provided in Forum).*
- *Potential Questions: What are the regulatory, legal, and logistical constraints? Are there differences between States? Do we consider valuating sand & gravel resources differently than heavy mineral sand resources? Are the current regulations sufficient (i.e. handling of radioactive elements, contaminants)?*
- *Q&A, touch on questions from prior talks as needed.*

12:30-1:30 EST	Lunch break (1 hour)

Afternoon Sessions

Session 4: Environmental standards, compliance, best practices applied to marine minerals

1:30-1:40 EST	Federal regulatory framework and overview (Geoffrey Wikel, U.S. Bureau of Ocean Energy Management)
1:40-1:50 EST	State regulatory and permitting framework, onshore mineral beneficiation (Rachael Peabody, Virginia Marine Resources Commission)
1:50-2:00 EST	Coastal/ocean policy and planning (Laura McKay, VA Coastal Zone Management Program)
2:00-2:30 EST	***Poll question #3***, Q&A, group discussion and short break *Hypothetical on/offshore mineral separation* *What are key stakeholder issues at the local, State, and Federal level?* *What are the environmental unknowns?*

Session 5: Advanced technologies for heavy minerals identification, assessment, and monitoring

2:30-2:40 EST	Insights from the BOEM Atlantic Sand Assessment Project (Jaime Tomlinson, Delaware Geological Survey)
2:40-2:50 EST	Techniques in geochemistry and mineralogy (insights from mineral sand samples, Virginia, USA) (Tassos Grammatikopoulos, SGS Laboratory)
2:50-3:00 EST	Geophysical methods (Anji Shah, U.S. Geological Survey)
3:00-3:10 EST	Field methods for assessment and monitoring of heavy mineral sands: Terrestrial and offshore insights (William Lassetter and David Hawkins, Virginia Energy)
3:10-4:20 EST	***Poll question #4***, Q&A, additional time for demos (e.g. geophysics, handheld scintillometer), open-ended discussion, next steps

- *Other questions to consider:*
- *How should we prioritize the available technologies to identify a resource?*
- *Are there ways to carry out a pilot study that leverages involvement from local municipalities, academia, and government to help lower the costs of implementation?*
- *From a mining engineering standpoint, what are the significant data needs to formulate appropriate methodologies?*
- *What are the data gaps? Needs for additional focused Forum(s).*
- *Summarize key findings from the Forum and prioritize action items*

4:20-4:30 EST	**Closing remarks**
4:30 EST	Forum wrap-up

Contact Information:

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BOEM: www.boem.gov

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APPENDIX B: 2022 Mid-Atlantic Marine Heavy Mineral Sands Forum Participants

2022 Mid-Atlantic Heavy Mineral Sands Forum
Sponsored by the Virginia Department of Energy and United States Bureau of Ocean Energy Management

March 31, 2022
Cisco Webex Virtual Event
Charlottesville, Virginia

List of Presenters

William Lassetter, Economic Geology Projects Manager, Virginia Department of Energy, Geology and Mineral Resources Program
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Jaime Tomlinson, P.G., Geologist, Delaware Geological Survey
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Tassos Grammatikopoulos, Ph.D., P.Geo., Senior Geoscientist, SGS Canada, Inc.
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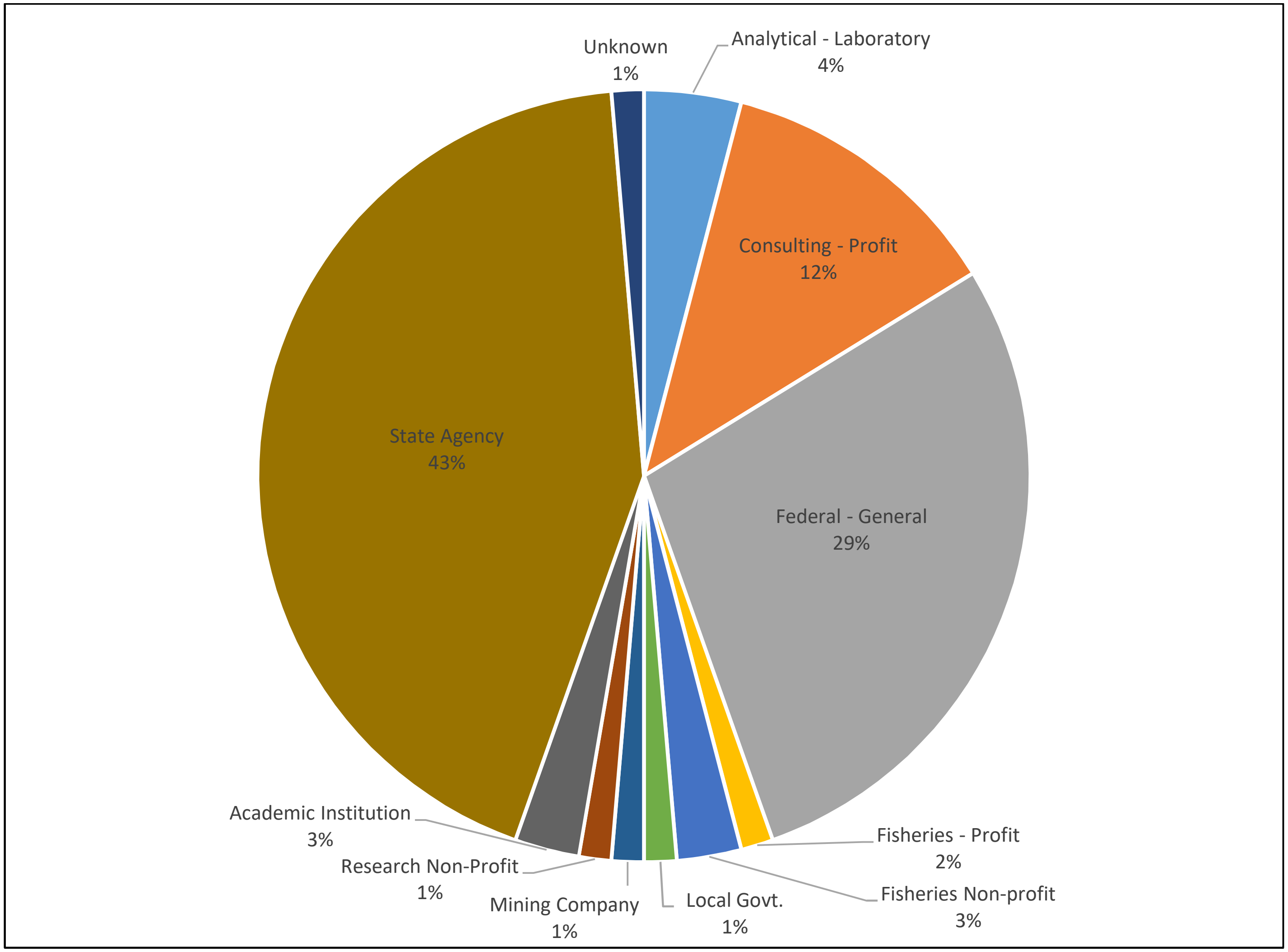
Anjana Shah, Ph.D., Research Geophysicist, U.S. Geological Survey, Geology, Geophysics, and Geochemistry Science Center
ashah@usgs.gov

Participant by Industry (74 people):



Note: Industry type was acquired from the Webex attendance report. The report was generated when attendees signed into the meeting and recorded their organization or affiliation.

APPENDIX C: 2022 Mid-Atlantic Marine Heavy Mineral Sands Forum Presentations

C

Session 1: Marine mineral sands – feasibility of extracting critical mineral resources

LASSETTER, W.L. – Marine mineral sands on Virginia's outer continental shelf – The case for extracting critical minerals as part of beach restoration projects (WLassetter.pdf)

Marine mineral sands on Virginia's outer continental shelf - The case for extracting critical minerals as part of beach restoration projects

William Lassetter

Virginia Energy - Geology and Mineral Resources

Mid-Atlantic Marine Heavy Mineral Sands Forum
Charlottesville VA

31 March 2022

BOEM
Bureau of Ocean Energy Management

VIRGINIA Energy

What we have learned from recent studies

Analysis of marine data (subbottom seismic, vibracores) collected as part of BOEM-Virginia Cooperative projects indicate substantial beach-quality sand resources in two offshore regions:

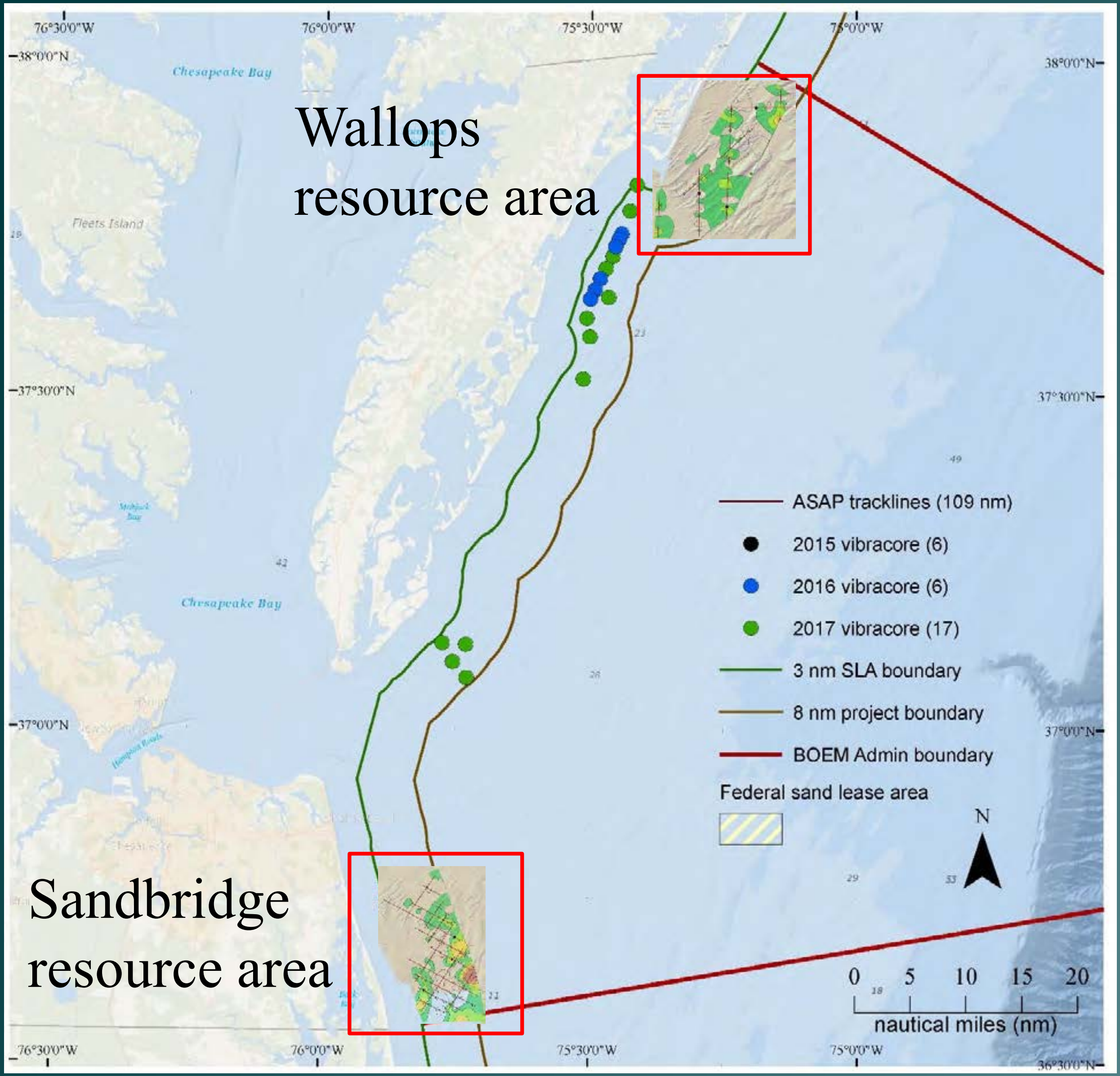
resource area	minimum 10-ft thickness	minimum 5-ft thickness
Sandbridge	271 million yd^3	333 million yd^3
Wallops	393 million yd^3	421 million yd^3

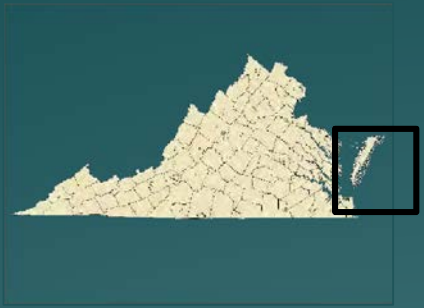
Over 600 seafloor sediment samples (grab, core) from the OCS indicate:

- THM content averaging 2.7 wt %, ranging from 0.01% up to 14.7%
- EHM minerals containing critical commodities such as Ti, Zr, REE, U, Hf, among others, make up about 41% of the THM concentrate
- based on recent commodity prices, estimated value of 1 yd^3 of dredged sand containing 2.7 wt% THM is about $10.80

There is significant potential for the recovery of economic mineral resources offshore of Virginia that could offset the costs of dredging for beach sand re-nourishment projects.

Recon estimated sand resources – seafloor to 10-ft depth



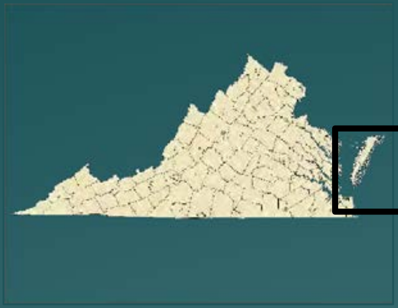


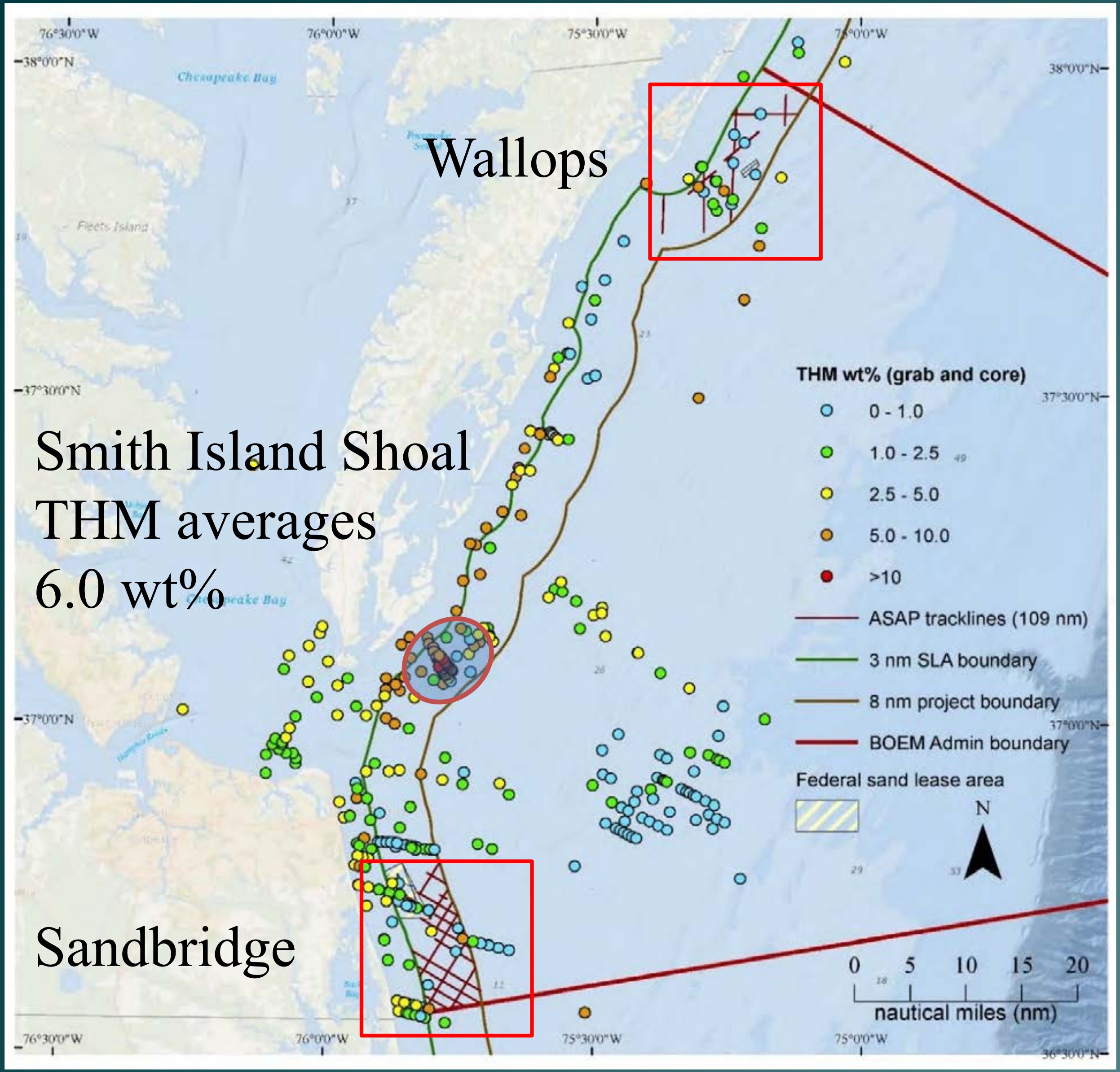
Wallops:
393 million yd^3

OCS sand resources
ϕ mean = 2.1 (0.23 mm)
fine to medium sand

Sandbridge:
271 million yd^3

Heavy minerals – seafloor to 10-ft depth





Wallops

Smith Island Shoal
THM averages
6.0 wt%

Sandbridge

THM content averages 2.7 wt %, ranging from 0.01% up to 14.7%

OCS sand resources
ϕ mean = 2.1 (0.23 mm)
fine to medium sand

OCS heavy minerals
ϕ mean values

zircon	3.4 (0.10 mm)
titanite	3.9 (0.07 mm)
ilmenite	4.3 (0.05 mm)
rutile	4.8 (0.04 mm)
leucoxene	7.1 (0.01 mm)

(v. fine sand to v. fine silt)

BOEM-Virginia Cooperative Agreement 2021-23

- Examine alternative methodologies for recovering EHM from marine sand deposits (onshore-offshore)

  gravity (spiral, jig, etc.), up-flow hydroseparator, magnetic susceptibility, electrostatic, flotation, grain size classification

- Evaluate protocols for rapid field screening of critical elements.

  visual opaques, portable X-ray fluorescence (XRF), gamma scintillometer

- Assess public safety and environmental concerns, potential impacts on stakeholders (processing locations, stockpiles, etc.)

  e.g. extraction of opaque heavy minerals may result in beach sand replenishments with lighter color, affecting temperature of coastal habitat

- What permits will be required and from whom?

Economic heavy minerals in marine sands

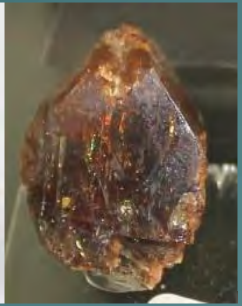
Mineral	composition	critical commodities*
Ilmenite	$\mathrm{FeTiO_3}$	**Ti**
Leucoxene	*altered* $\mathrm{FeTiO_3}$	**Ti**
Rutile	$\mathrm{TiO_2}$	**Ti**
Titanite	$\mathrm{Ca(La,Ce)TiO(SiO_4)}$	**Ti, REE**
Zircon	$\mathrm{ZrSiO_4}$	**Zr, U, Th, Hf, REE**
Xenotime	$\mathrm{(Y,Nd,Yb)PO_4}$	**Y, REE**
Monazite	$\mathrm{(Ce,La,Sm,Th)PO_4}$	**La, Ce, Sm, Nd, Th**
Sillimanite group	$\mathrm{Al_2SiO_5}$	**Al**
Chromite	$\mathrm{(Fe, Mg)Cr_2O_4}$	**Cr**
Garnet group	$\mathrm{(Ca,Fe,Mg,Al)(SiO_4)_3}$	**abrasive sand**


Ilmenite


Leucoxene


Rutile


Zircon

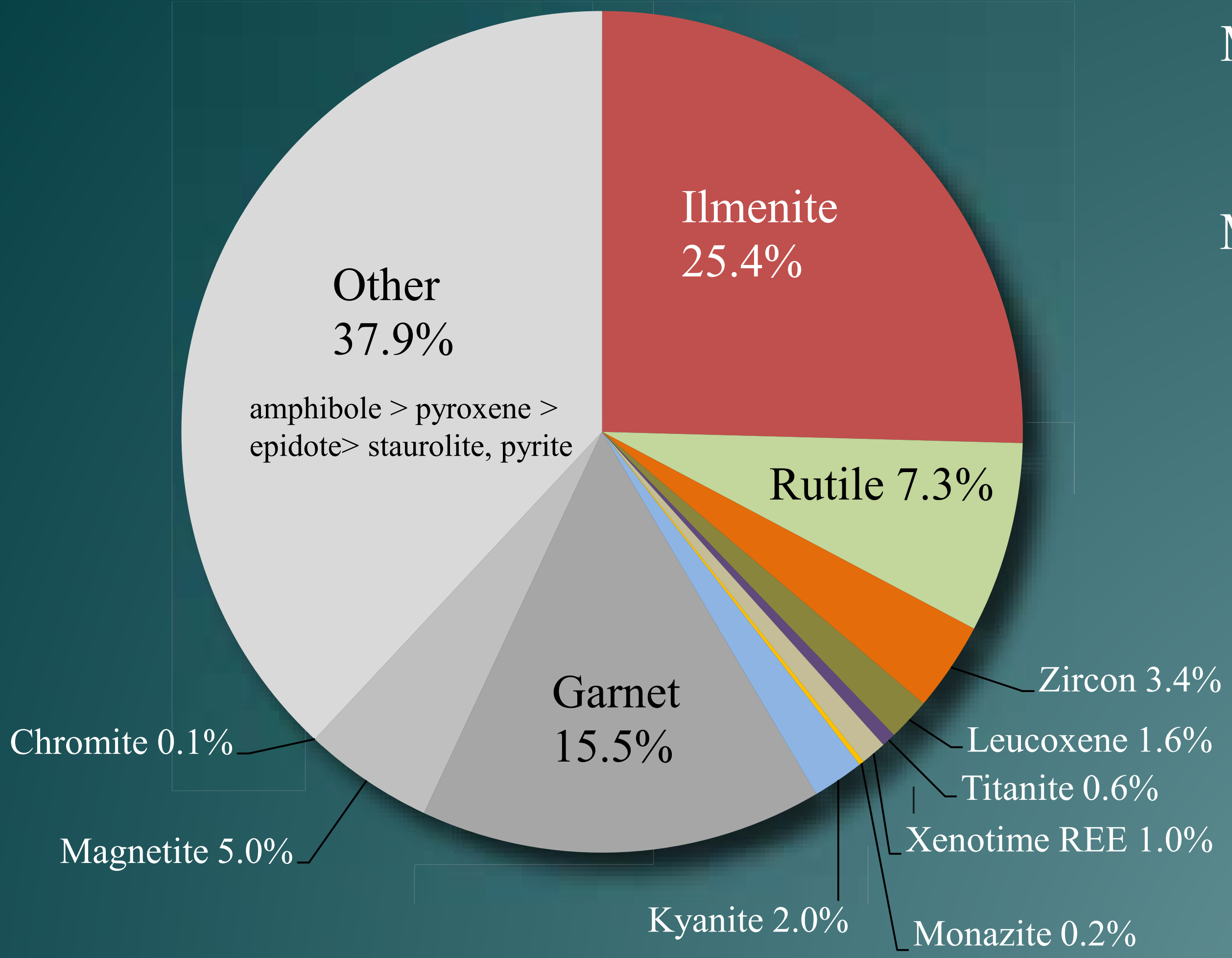

Monazite


Kyanite

https://energy.virginia.gov/geology/CriticalMinerals.shtml

Sources: Garner, 1978; Van Gosen and others, 2014; Fortier and others 2018

Average composition of heavy mineral concentrates offshore Virginia, wt % of heavy mineral fraction

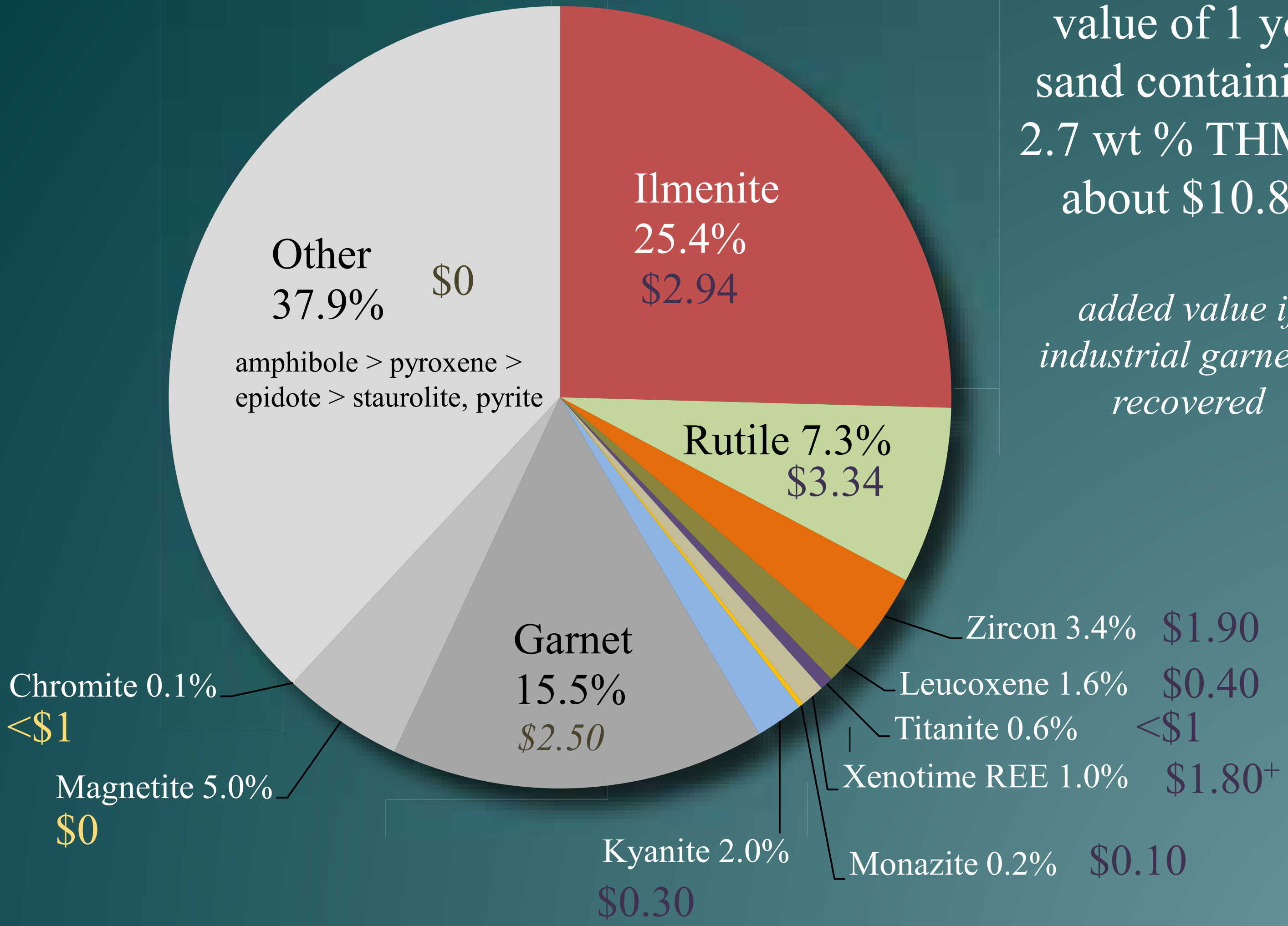


Mean THM
2.7 wt %

Mean EHM
41 wt %
of THM

Sources: Berquist and Hobbs, 1986; 1988; Berquist and others, 1990; Berquist and others, 2016; Lassetter and Blanchette, 2019

Value of commodities based on current market price ranges



value of 1 yd^3 sand containing 2.7 wt % THM is about $10.80

added value if industrial garnet is recovered

Sources: *Industrial Minerals*, 2020; US Census Bureau (export prices); SME *Mining Engineering* Industrial Minerals Review, 2021; USGS Mineral Commodity Summaries, 2021; Institute for Rare Earths and Metals AG; Bloomburg; per. comm.

Key properties of economic heavy minerals

Mineral name	Composition	Specific gravity	Hardness (Mohs)	Magnetic susceptibility[1]	Electrostatic response[2]	Weathering stability	Radioactivity[3]	Fluorescence
Monazite	$(Ce,La,Sm,Th)PO_4$	4.8 5.5	5 5.5	paramagnetic	non conductor	high	weak - strong	none
Ilmenite	$FeTiO_3$	4.7 4.8	5 5.5	paramagnetic	conductor	mod high	none	none
Zircon	$ZrSiO_4$	4.6 4.7	7.5	non magnetic	non conductor	high	mild	yes
Chromite	$(Fe,Mg)Cr_2O_4$	4.5 5.09	5.5	paramagnetic	conductor	mod high	none	none
Xenotime	$(Y,Nd,Yb)PO_4$	4.4 5.1	4 5	paramagnetic	non conductor	high	none - weak	none
Rutile	TiO_2	4.2 4.3	6 6.5	non magnetic	non conductor*	high	none	none
Leucoxene	altered $FeTiO_3$	3.6 4.3	4 4.5	paramagnetic*	conductor	high	none	none
Garnet group	$(Ca,Fe,Mg,Al)(SiO_4)_3$	3.4 4.6	7.5	non magnetic	non conductor*	mod	none	none
Allanite	$(Ce,Ca,La,Y)2(Al,Fe)_3(SiO_4)_3(OH)$	3.5 4.2	5.5	paramagnetic	non conductor	low mod	mild - weak	none
Titanite	$Ca(La,Ce)TiO(SiO_4)$	3.4 3.56	5 5.5	non magnetic	non conductor*	mod	mild	yes
Sillimanite minerals	Al_2SiO_5	3.1 3.7	4 7	non magnetic	non conductor	Mod	none	none
Quartz	SiO_2	2.6 – 2.65	7	non magnetic	non conductor*	high	none	none

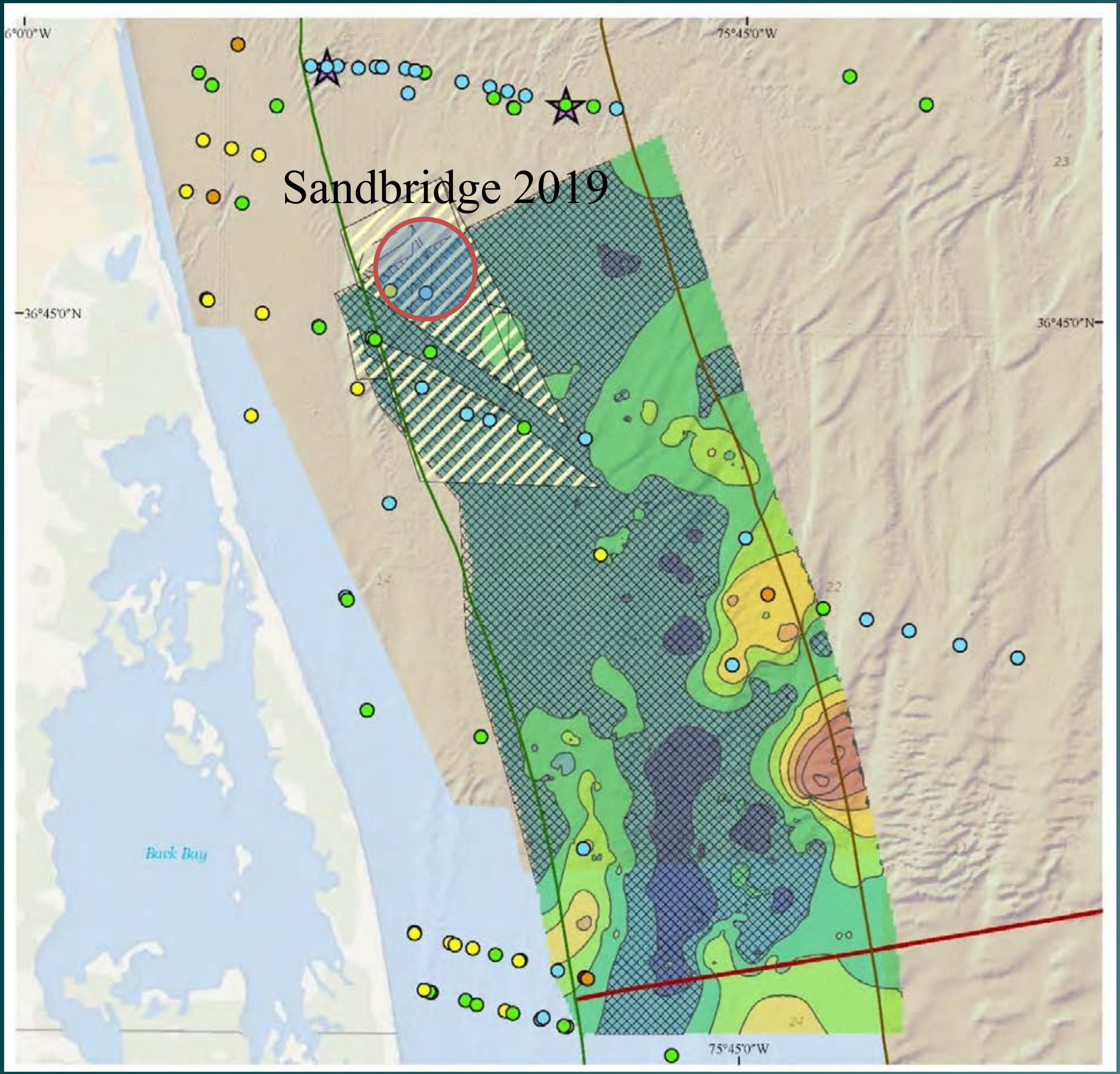
1 * variation in response based on actual mineral composition

2 * mineral becomes more conductive with treatment at elevated temperatures

3 classified by API gamma units

Sources: Mindat.org; WebMinerals.com; Carpco, Inc.;

Sandbridge resource area



Sandbridge 2019 Project

1.84M yd^3 from
Sandbridge Shoal
Fed Sand Lease Area
placed on Virginia Beach,
Sandbridge Beach 2019-20

If we assume
THM ~2.7 wt %

est. value $19.91 million

https://www.boem.gov/marine minerals/requests and active leases

Contact information

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434-951-6361

Virginia Energy web site:

https://energy.virginia.gov

For more info about critical minerals, visit:

https://energy.virginia.gov/geology/CriticalMinerals.shtml

Session 1: Marine mineral sands – feasibility of extracting critical mineral resources

HAWKINS, D.W. – Overview of global coastal and nearshore mineral recovery operations
(DHawkins.pdf)

Overview of global coastal and nearshore mineral recovery operations

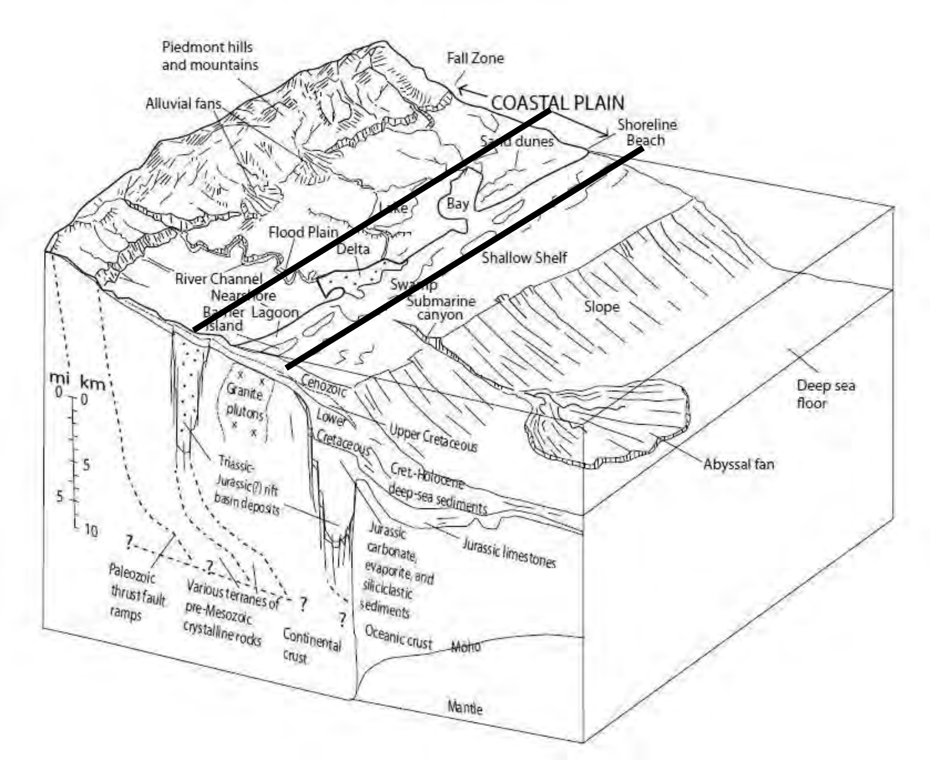
Credit: Royal IHC website

David W. Hawkins, P.G.

Virginia Department of Energy, Geology and Mineral Resources Program

VIRGINIA Energy

Geologic Context – Heavy Mineral Sands



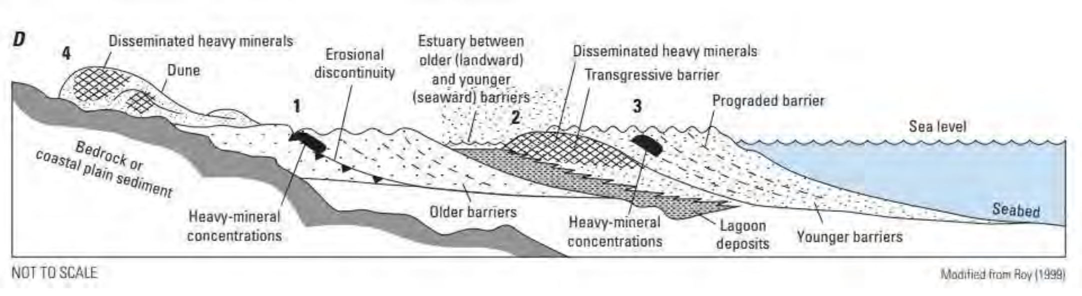
Generalized geologic cross-section (Powars et al., 2016)

Passive margin coastline backed by highly weathered high-grade metamorphic and mafic igneous rocks

Transgressive-regressive sea-level cycles

Commonly associated with placer deposits; ore deposits are typically <1 km to 4 km wide and upwards of 45 m thick

Terrestrial deposits: shallow, unconsolidated to poorly consolidated, voluminous, well-established separation techniques, >2% THM



Example depositional setting for heavy minerals in the coastal zone (Schulz and others, 2017)


Surf zone at Virginia Beach (June, 2021), credit: D. Hawkins

Vibracore sections from Sandbridge Shoal (D. Hawkins)


Heavy mineral laminae in sand, credit: Dr. Rick Berquist

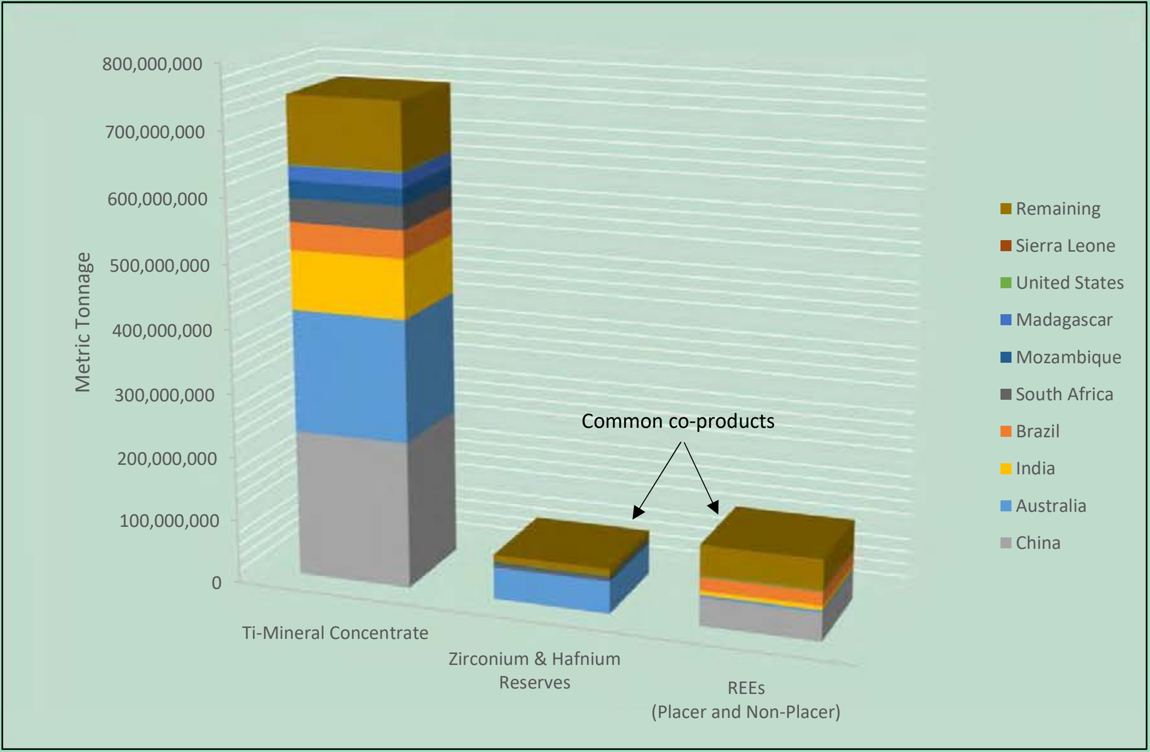
Time + Weathering + Burial


Modern beach at Pea Island, Dare County, North Carolina, credit: USGS


Drill cuttings of Pliocene sand and clay near Old Hickory (D. Hawkins)


Old Hickory Deposit excavation, credit: Dr. Rick Berquist

Commodities



Mineral Commodity Statistics for 2021 (USGS, National Minerals Information Center)

- Upwards of 1,000 Mt of HM sands ore globally^{2}
- Typical suite ~up to 20% HM

Major HM Sand Commodity	Primary Producer(s) 2021 Placer deposits (does not reflect other sources)
Titanium-minerals (i.e. ilmenite, rutile)	Australia, South Africa, China, Madagascar, Mozambique, India
Zirconium	Australia, South Africa
REE placers (i.e. monazite, xenotime, apatite)	India, Brazil
Other economic minerals*	Varied

Notes:

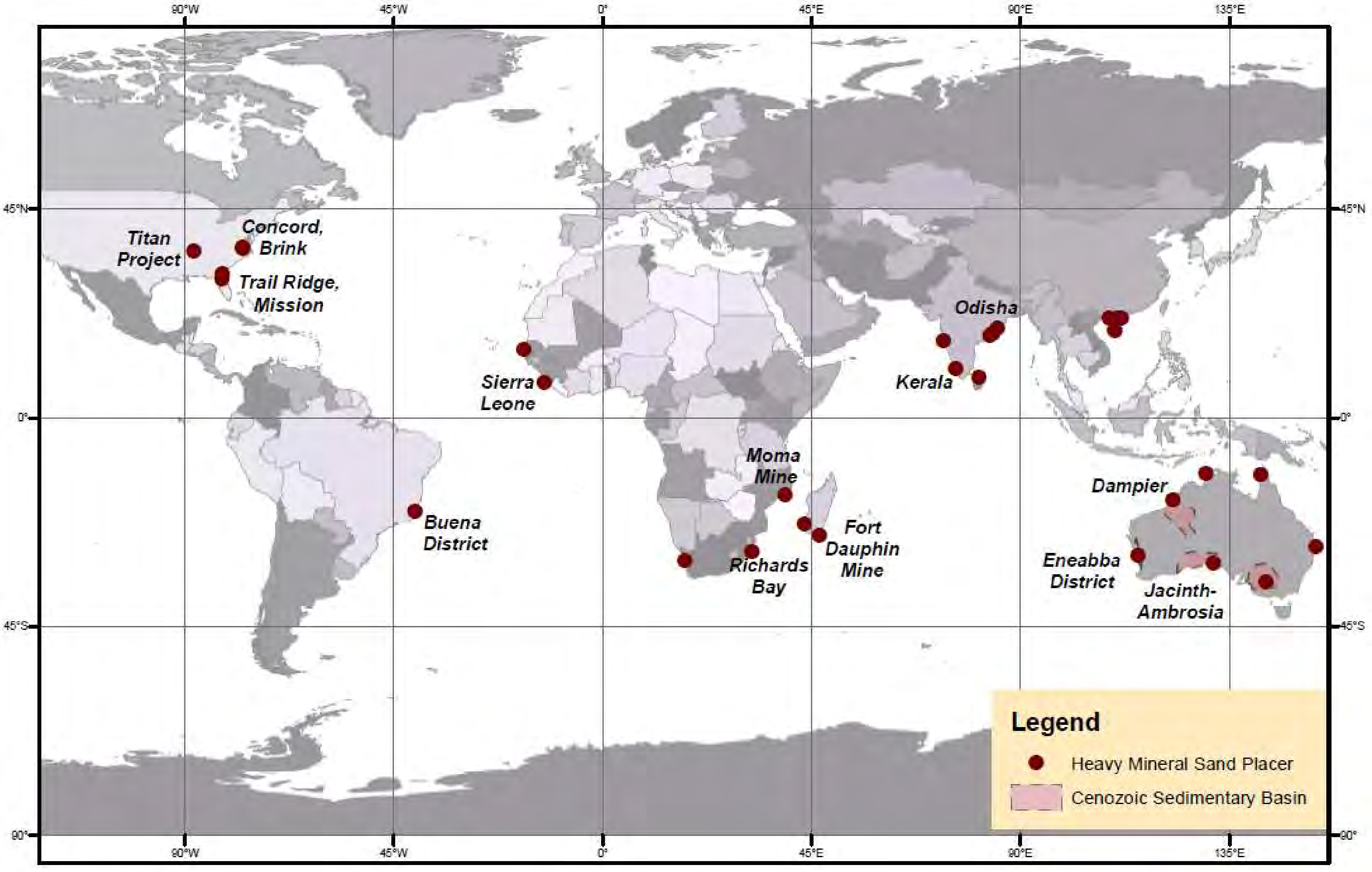
1) Other minerals historically or presently mined may include gold, tin, and diamond placers

2) Economic minerals* - refers to other accessory minerals within the typical heavy mineral (HM) sand suite (i.e. garnet, chromite, epidote, sillimanite, etc.)

Wet concentration plant and dredge, Senegal (Eramet website)

Localities

Examples of global heavy mineral sand placer deposits (note: not all known resources and/or deposits are depicted)

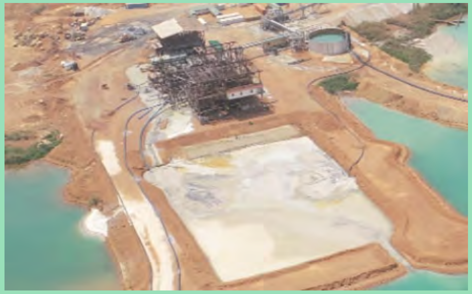


Localities

its (note:

Moma Plant (ArcGIS)

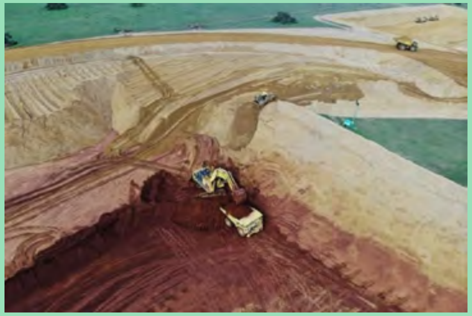
Concord Plant (photo from Berquist et al., 2015) SEG, Post-GSA Field Trip



Sierra Rutile (image from Iluka's website)

Moma operation (image from Kenmare Resources website)

Mineral processing (image from Kerala Minerals and Metals Ltd. Website)



Mining operations at Boonanerring (Image Resources, photo from businessnews.com.au)

Thunderbird Project (image from Sheffield's website)

Trimex Sands (Srikurman Deposit, western India)

Localities and Operations

United States (Florida, Georgia, Tennessee) – Southern Ionics, Chemours, Hyperion Metals, Iluka (reclamation)

- Titanium-minerals, zircon
- Fall zone Pliocene – Quaternary placers

Australia (Eneabba District, Jacinth-Ambrosia, Canning Basin, Murray Basin) – Iluka Resources, Sheffield Resources

- Titanium-minerals, zircon, REEs (monazite)
- Variable Cenozoic age, sedimentary basins and modern coastal strandlines

Africa (Sierra Leone, Mozambique, South Africa, Madagascar, Senegal) – Sierra Rutile, Rio Tinto, Kenmare, Eramet

- High quality rutile, titanium-minerals, zircon

India (Kerala and Odisha) – India Rare Earths Limited (IREL), Kerala Minerals and Metals Ltd – ***state-owned operations***

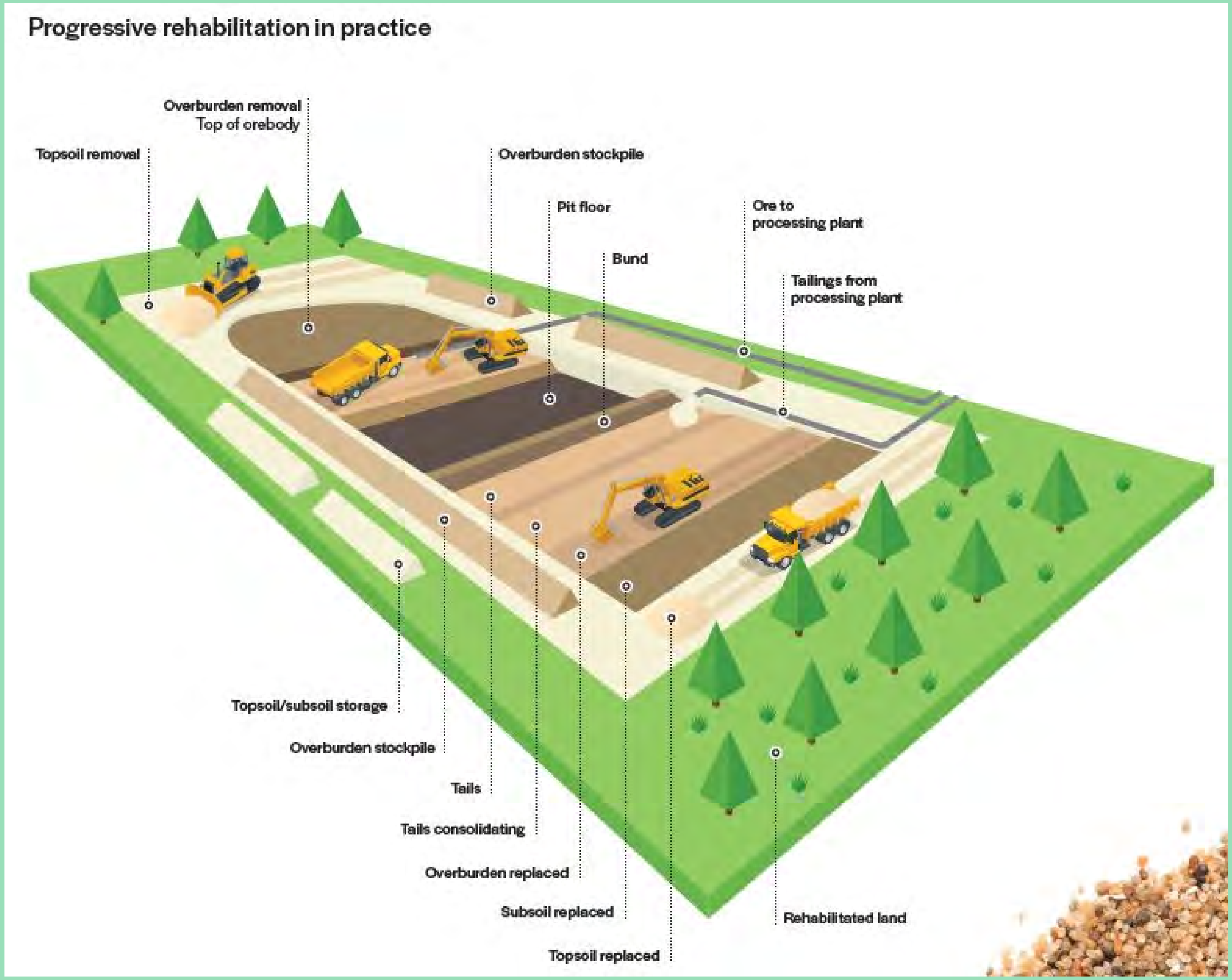
- Titanium-minerals, monazite, thorium stockpiles for nuclear power (25% of world's reserves), sillimanite
- Modern beach deposits (5 primary districts along western and eastern coasts, 15-30 km stretches up to 2 km wide)

Brazil (Buena District) – stockpile mining of monazite

- Formerly large producer of monazite from placers, 20th century

Other localities include prospects and/or current operations in SE China, Malaysia, Sri Lanka, Kenya

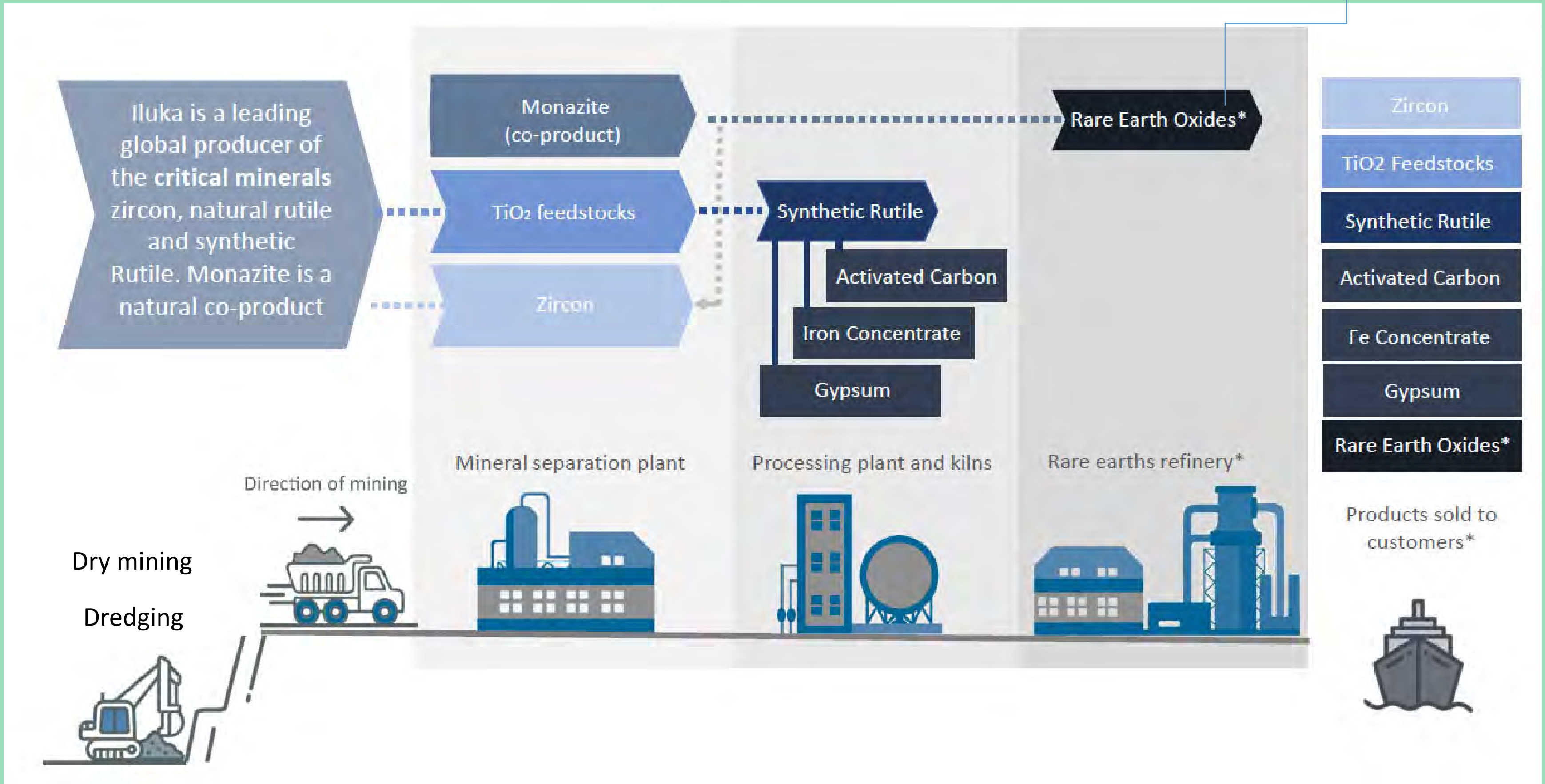
Typical Operations



Mineral sands overview (credit: minerals.org.au)

Typical Operations

Feasibility stages



Iluka is a leading global producer of the **critical minerals** zircon, natural rutile and synthetic Rutile. Monazite is a natural co-product

Dry mining

Dredging

Typical flow of operations (credit: Iluka Resources, Minerals Sands Conference 2021)

Offshore operations are essentially non-existent for titanium-mineral placers, aside from operations in conjunction with modern beach deposits

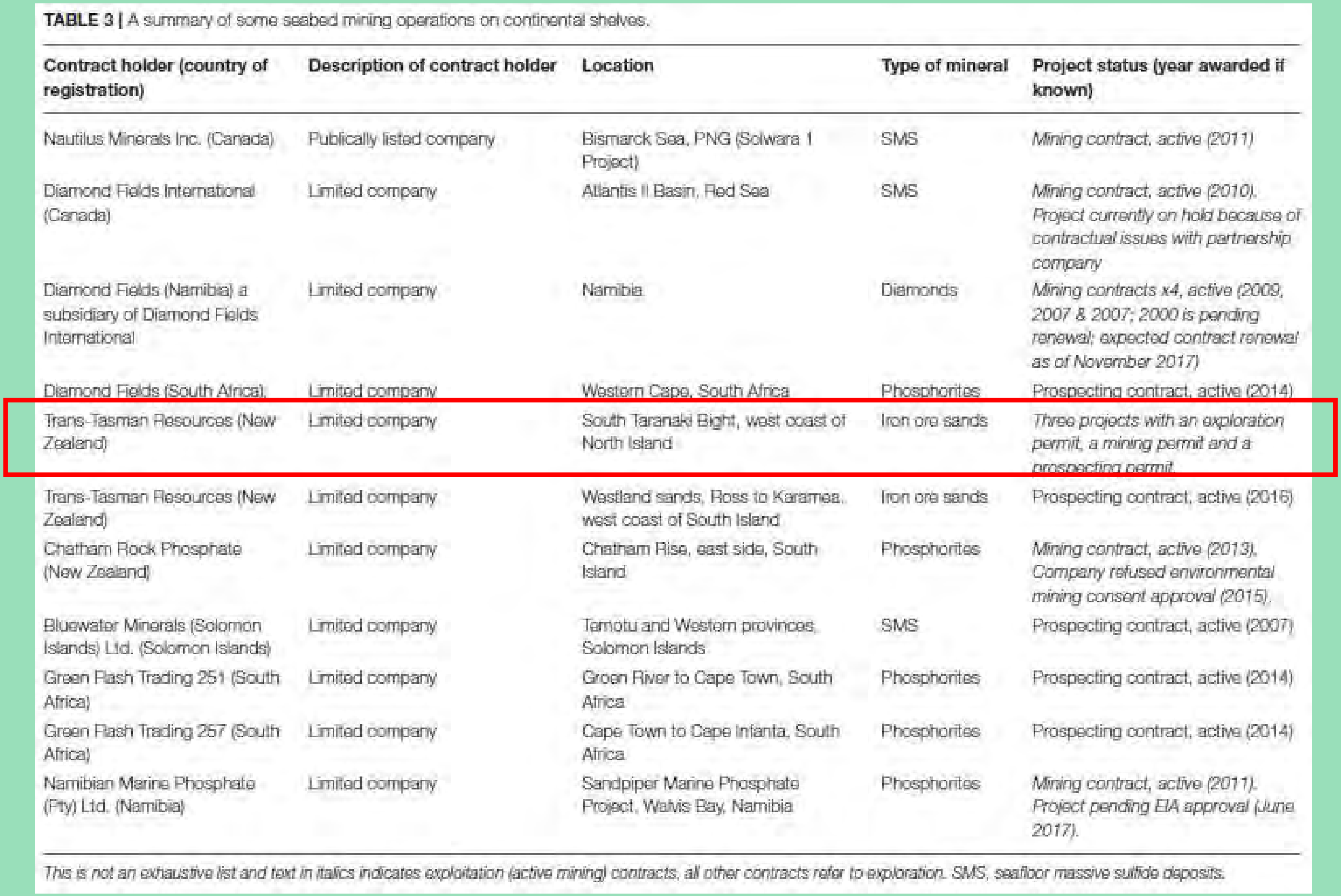


TABLE 3 | A summary of some seabed mining operations on continental shelves.

Contract holder (country of registration)	Description of contract holder	Location	Type of mineral	Project status (year awarded if known)
Nautilus Minerals Inc. (Canada)	Publically listed company	Bismarck Sea, PNG (Solwara 1 Project)	SMS	*Mining contract, active (2011)*
Diamond Fields International (Canada)	Limited company	Atlantis II Basin, Red Sea	SMS	*Mining contract, active (2010). Project currently on hold because of contractual issues with partnership company*
Diamond Fields (Namibia) a subsidiary of Diamond Fields International	Limited company	Namibia	Diamonds	*Mining contracts x4, active (2009, 2007 & 2007; 2000 is pending renewal; expected contract renewal as of November 2017)*
Diamond Fields (South Africa)	Limited company	Western Cape, South Africa	Phosphorites	Prospecting contract, active (2014)
Trans-Tasman Resources (New Zealand)	Limited company	South Taranaki Bight, west coast of North Island	Iron ore sands	*Three projects with an exploration permit, a mining permit and a prospecting permit*
Trans-Tasman Resources (New Zealand)	Limited company	Westland sands, Ross to Karamea, west coast of South Island	Iron ore sands	Prospecting contract, active (2016)
Chatham Rock Phosphate (New Zealand)	Limited company	Chatham Rise, east side, South Island	Phosphorites	*Mining contract, active (2013). Company refused environmental mining consent approval (2015).*
Bluewater Minerals (Solomon Islands) Ltd. (Solomon Islands)	Limited company	Temotu and Western provinces, Solomon Islands	SMS	Prospecting contract, active (2007)
Green Flash Trading 251 (South Africa)	Limited company	Green River to Cape Town, South Africa	Phosphorites	Prospecting contract, active (2014)
Green Flash Trading 257 (South Africa)	Limited company	Cape Town to Cape Infanta, South Africa	Phosphorites	Prospecting contract, active (2014)
Namibian Marine Phosphate (Pty) Ltd. (Namibia)	Limited company	Sandpiper Marine Phosphate Project, Walvis Bay, Namibia	Phosphorites	*Mining contract, active (2011). Project pending EIA approval (June 2017).*

This is not an exhaustive list and text in italics indicates exploitation (active mining) contracts, all other contracts refer to exploration. SMS, seafloor massive sulfide deposits.

Examples of shallow seabed mining operations (Miller et al., 2018)

South Taranaki Bight Project:

- Fe sand resource
- 25-60 m depth
- Mineral separation offshore
- Multiple support vessels

<u>Status: ?</u>

Selected References

Powars, D.S., Edwards, L.E., Johnson, G.H., and Berquist, C.R., 2016, Geology of the Virginia Coastal Plain: New insights from continuous cores and geophysical surveys, in Bailey, C.M., Sherwood, W.C., Eaton, L.S., and Powars, D.S., eds., The Geology of Virginia: Virginia Museum of Natural History Special Publication 18, pgs. 193-240.

(1) Schulz, K.J., DeYoung, J.H., Jr., Seal, R.R., II, and Bradley, D.C., eds., 2017, Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply: U.S. Geological Survey Professional Paper 1802, 797 p., http://doi.org/10.3133/pp1802.

(2) Van Gosen, B.S., Fey, D.L., Shah, A.K., Verplanck, P.L., and Hoefen, T.M., 2014, Deposit model for heavy-mineral sands in coastal environments: U.S. Geological Survey Scientific Investigations Report 2010–5070–L, 51 p., http://dx.doi.org/10.3133/sir20105070L.

(3) Van Gosen, B.S, and Ellefsen, K.J., 2018, Titanium mineral resources in heavy-mineral sands in the Atlantic Coastal Plain of the southeastern United States: U.S. Geological Survey Scientific Investigations Report 2018–5045, 32 p., https://doi.org/10.3133/sir20185045.

(4) USGS, 2022, United States Geological Survey, National Minerals Information Center, Commodity Statistics and Information, https://www.usgs.gov/centers/national-minerals-information-center/commodity-statistics-and-information.

Session 1: Marine mineral sands – feasibility of extracting critical mineral resources

KARST, A.T. – Onshore heavy mineral sands: Exploration, mining, processing, and reclamation (AKarst.pdf)

Onshore heavy mineral sands

Exploration, mining, processing, and reclamation

Adam Karst, P.G.
President and Principal Geologist
Karst Geo Solutions, LLC

Exploration

Primarily looking for unconsolidated marine placer deposits of heavy minerals (HMs)

Traditional methods

- Desktop research – USGS, state surveys, academic papers, prior exploration
- Mapping and field reconassience – not as effective for buried deposits

Geophysics

- Radiometric (monazite and zircon contain U, Th)
- Magnetic (some valuable HMs are weakly magnetic)

Drilling

- Auger – low cost, good for shallow depths
- Sonic – highest cost, high-quality large-volume samples
- RC air-core – low cost, fast, only cuttings

Mining

Dredging

- Low-cost
- Requires flat-lying deposit with shallow water table (coastal areas)
- Falling out of favor due to environmental concerns (stigma)

Dry mining

- Truck and shovel – highest cost, largest equipment fleet
- Dozer trap – lowest cost, bulk mining method
- Mobile mining unit – selective, minimizes equipment
- Often involves slurry transport system – need water source

Processing

Wet concentration (Wet Concentrator Plant – WCP)

- Gravity separation – spirals
- Produces Heavy Mineral Concentrate (HMC) – all HMs that can be recovered with some silica/lights (~90% HM)
- Non-valuables (silica sand/fines/oversize) form tails stream and are retuned to the mining void
- Transport HMC to MSP

Dry separation (Mineral Separation Plant – MSP)

- Dry the HMC – energy intensive
- Electrostatic and magnetic separators
- Wet/gravity circuits
- Produces final products for sale – ilmenite, leucoxene, rutile, zircon, monazite
- Dry mill tails (DMT) – non-valuable minerals

Reclamation

- Reclamation varies based on fines content of orebody
- Sandier orebodies are easier to reclaim with quick de-watering of mine tails and stability shortly after placement
- Orebodies with higher fines content may take several years to dry/decant mine tails to support heavy equipment

Other considerations

NORM – Naturally Occurring Radioactive Material

- Some HMs (zircon, monazite) contain appreciable NORM (U and Th)
- Handling and transportation of HMC and products may require permits/licenses depending on concentrations involved
- DMT (dry mill tailings) must be managed and diluted back into the mine tailings stream (or sold)

Session 2: Current offshore sand mining operations for beach replenishment

KNORR, P.O. – Federal marine minerals leasing program in the Mid-Atlantic (PKnorr.pdf)

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

BOEM Bureau of Ocean Energy Management

Outer Continental Shelf Minerals Leasing

Offshore Heavy Minerals Forum
Paul O. Knorr
March 31, 2022

Overview

- Sand and Minerals
- Non-Competitive Negotiated Agreements (NNA)
- Competitive Leasing Framework
- Uncertainties

Sand and Minerals, but not Elements

- Sand -> **Sand, gravel, and shell** (OCLSA 43 USC 1301 8(k)(2)(A)(1).
- Minerals -> Oil, gas, sulphur, geopressured-geothermal and associated resources, and **all other minerals** which are authorized by an Act of Congress to be produced from "public lands" as defined in section 103 of the Federal Land Policy and Management Act of 1976 (OCSLA 43 USC 1301(2)(q)).
- Hard Minerals -> Any deposit or accretion on, or just below, the surface of the deep seabed of **nodules** which include one or more minerals, at least one of which contains **manganese, nickel, cobalt, or copper** (DSHMRA, 30 USC 1403(6)).
- Heavy Minerals –> Dense minerals that have a **specific gravity >2.85**, vs.quartz ~2.65 (USGS SIR 2010-5070-L).
  - E.g., contain titanium, zirconium, REE
- Critical Minerals -> A **mineral** (1) **identified *(by USGS)*** to be a nonfuel mineral or mineral material essential to the economic and national security of the United States, (2) from a supply chain that is vulnerable to disruption, and (3) that serves an essential function in the manufacturing of a product, the absence of which would have substantial consequences for the U.S. economy or national security (Executive Order 13817).
  - E.g., contain aluminum, cobalt, iridium, manganese, nickel, platinum group, REE, titanium, zinc, zirconium

NNA Authority and Framework

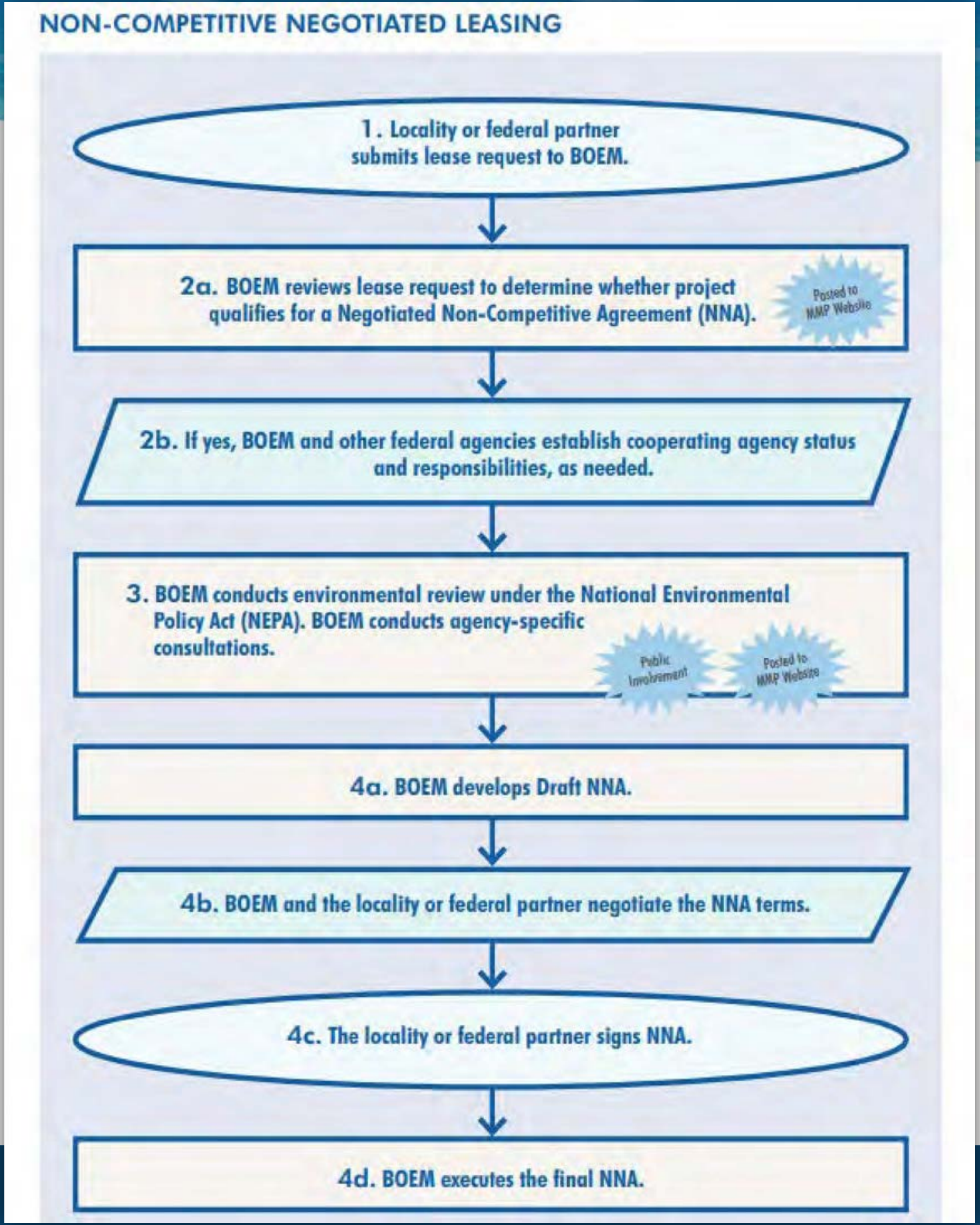
- Authority
  - **Outer Continental Shelf Lands Act** (OCSLA) (43 U.S.C. 1331, et. seq.)
  - **Public Law 103-426** (43 U.S.C. 1337(k)(2)) (1994)
  - **1999 Amendment**
- Non-Competitive Negotiated Agreement (NNA)
  - For government shore protection, beach restoration, coastal wetlands restoration, or for Federal construction projects
    - **3-party MOA** – (e.g., USACE Civil Works)
    - **2-party MOA** – (e.g., BOEM / PAFB)
    - **2-party lease** – (e.g., USACE Regulatory)

Source: Charles St. Martin, Rhode Island DOT

Source: Weeks Marine

BOEM Bureau of Ocean Energy Management

NNA Leasing Process



NON-COMPETITIVE NEGOTIATED LEASING

1. Locality or federal partner submits lease request to BOEM.

2a. BOEM reviews lease request to determine whether project qualifies for a Negotiated Non-Competitive Agreement (NNA).

Posted to MMP Website

2b. If yes, BOEM and other federal agencies establish cooperating agency status and responsibilities, as needed.

3. BOEM conducts environmental review under the National Environmental Policy Act (NEPA). BOEM conducts agency-specific consultations.

Public Involvement

Posted to MMP Website

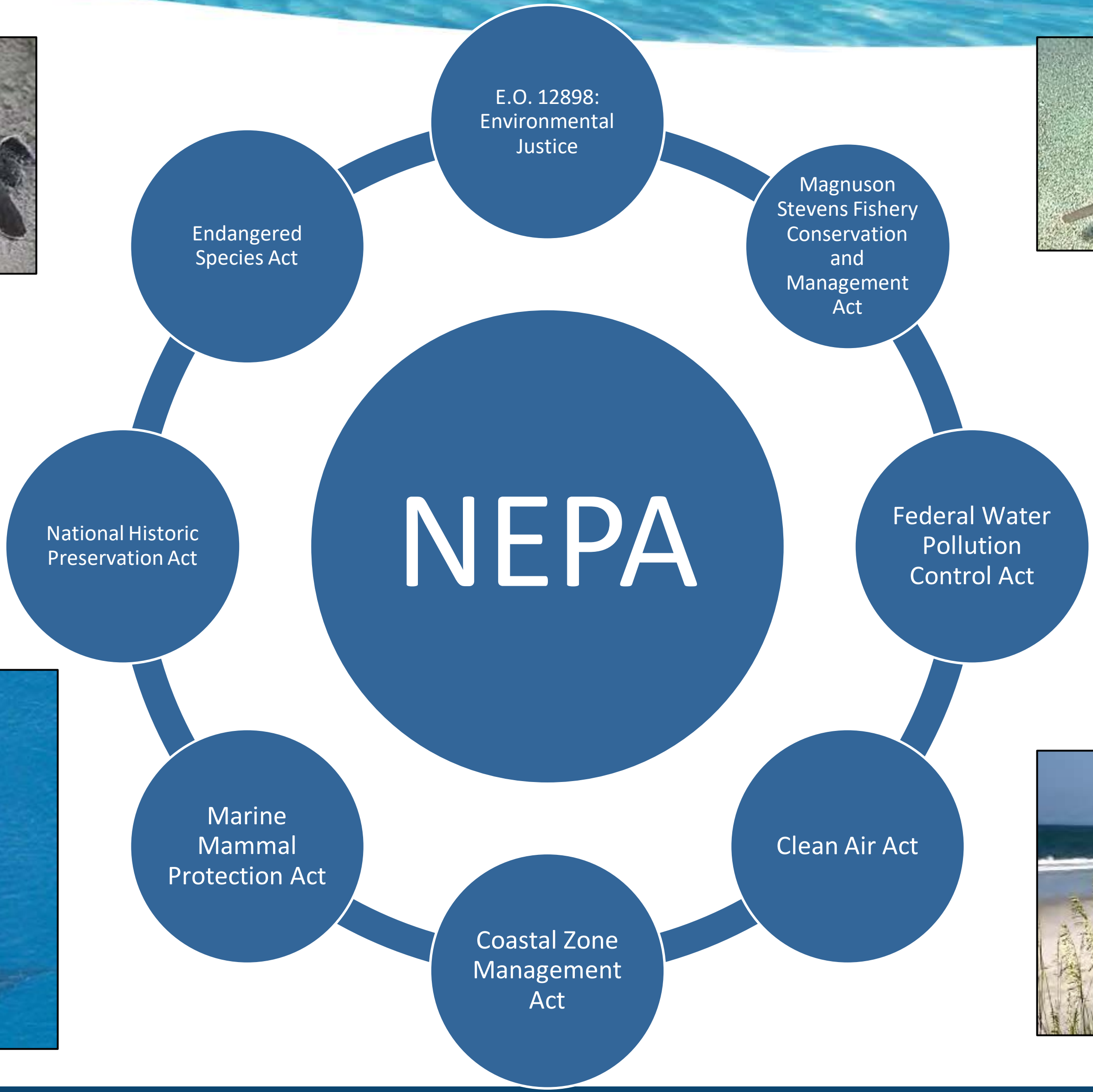
4a. BOEM develops Draft NNA.

4b. BOEM and the locality or federal partner negotiate the NNA terms.

4c. The locality or federal partner signs NNA.

4d. BOEM executes the final NNA.

Environmental Components



NEPA

E.O. 12898: Environmental Justice

Magnuson Stevens Fishery Conservation and Management Act

Federal Water Pollution Control Act

Clean Air Act

Coastal Zone Management Act

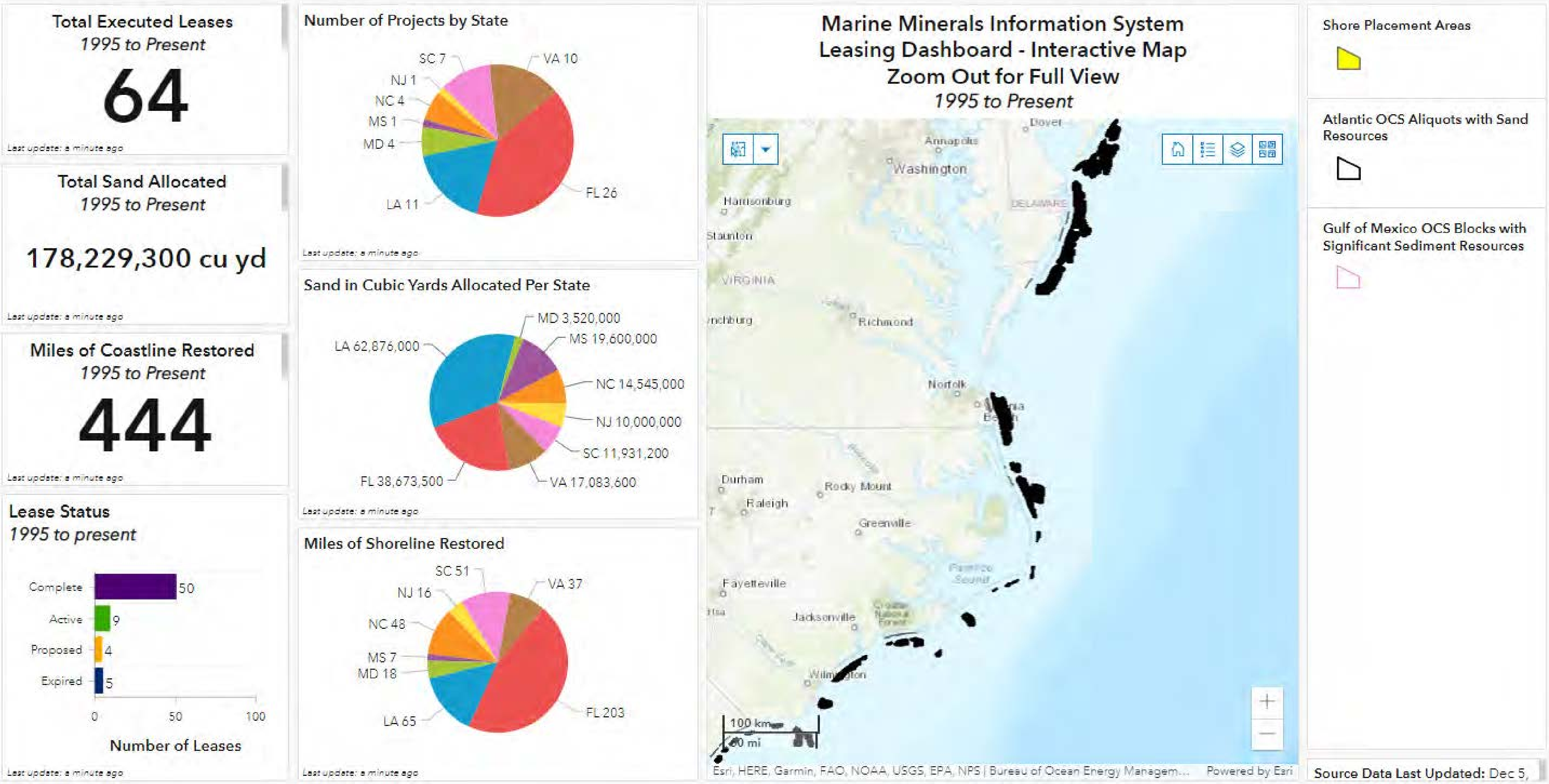
Marine Mammal Protection Act

National Historic Preservation Act

Endangered Species Act

Current Statistics

https://mmis.doi.gov/boemmmis/



Total Executed Leases
1995 to Present
64
Last update: a minute ago

Total Sand Allocated
1995 to Present
178,229,300 cu yd
Last update: a minute ago

Miles of Coastline Restored
1995 to Present
444
Last update: a minute ago

Lease Status
1995 to present

Last update: a minute ago

Number of Projects by State

Last update: a minute ago

Sand in Cubic Yards Allocated Per State

Last update: a minute ago

Miles of Shoreline Restored

Last update: a minute ago

Marine Minerals Information System
Leasing Dashboard - Interactive Map
Zoom Out for Full View
1995 to Present

Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS | Bureau of Ocean Energy Managem... Powered by Esri

Shore Placement Areas

Atlantic OCS Aliquots with Sand Resources

Gulf of Mexico OCS Blocks with Significant Sediment Resources

Source Data Last Updated: Dec 5,

Current Statistics

Requests and Active Leases

CURRENT REQUESTS					
State	**Applicants(s)**	**Request Date**	**Project Area**	**Volume Requested (cubic yards)**	**Borrow Area Location**
N/A	N/A	N/A	N/A	N/A	N/A
ACTIVE NEGOTIATED AGREEMENTS					
State	**Lessee(s)**	**Agreement Expiration Date**	**Project Area**	**Volume (cubic Yards)**	**Construction Status**
NC	Dare County, NC Shoreline Protection Project	11/30/2024	11.7 miles of coast within Duck, Southern Shores, Kitty Hawk, and Kill Devil Hills	6,600,000	Not Begun
FL	St. Johns County, Ponte Vedra Beach	9/30/2024	8.9 miles of coastline	2,200,000	Not Begun
FL	Department of the Army/Corps of Engineers and Flagler County	3/23/2023	3 miles of Flagler County Beaches	700,000	Not Begun
FL	Flagler County	8/11/2023	Flagler County Beaches	1,800,000	Not Begun
FL	St. Lucie County and USACE	7/8/2024	3.3 miles of coast	800,000	Est. Commencement March 2022
FL	St. Johns County, FL South Ponte Vedra	4/9/2024	5 miles of St. Johns County FL beaches at South Ponte Vedra Beach	1,064,000	Not Begun
LA	East Timbalier (TE-118) and Terrebonne Basin Barrier Island and Beach Nourishment (TE-143)	6/3/2023	East Timbalier Island, extending the West Belle Headland, westward from the previously constructed West Belle Pass Headland (TE-118). Trinity East Island and Timbalier Island beach, dune, and intertidal marsh habitat (TE-143).	10,000,000	Has Begun

Domestic Competitive Leasing Framework

- **Leasing is a separate competitive process** from prospecting permit

- Current regulations
  - **30 CFR Section 580 (Prospecting)**
  - **30 CFR Section 581 (Leasing)**
  - **30 CFR Section 582 (Operations)**

30 CFR Part 580 - Prospecting for Minerals

- OCSLA requires all parties who are prospecting marine minerals for **commercial** purposes to receive authorization.
- Under BOEM regulations, **pre-lease geological and geophysical explorations** can only be performed under a **permit, authorization, or scientific research notice**.
- Interested parties are required (under 30 CFR 580.12) to submit permit application form (Form BOEM-0134) **at least 30 days before the start date**.
  - Application provides the information necessary to evaluate potential lessee's qualifications, and upon approval, a permit or authorization is issued.
  - Environmental assessment may be required as part of permitting process.

30 CFR Part 581 – Leasing of Minerals

Leasing is a separate competitive process from the prospecting permit

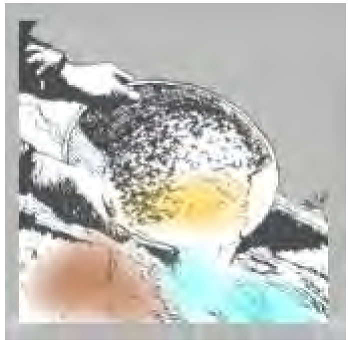
- The lease sale process can be initiated by:
  - ***An unsolicited request for a lease sale (30 CFR 581.11)***
  - On DOI's own initiative (30 CFR 581.12)
  - Followed by:
    - A request for OCS mineral information and interest (30 CFR 581.12) "RFI"
    - Joint State/Federal coordination (30 CFR 581.13).
- Lease term - not less than **20 years** (other than sand and gravel).
- BOEM has yet to issue a competitive lease under these regulations.

Source: *nih.gov*

30 CFR Part 582 – Operations

- Requirements for **Delineation, Testing, and Mining Plans** (30 CFR 582.21 – 582.24)
- Operations conducted in a manner that protects the environment and promotes orderly development of OCS minerals (30 CFR 582.12)
- Opportunities for review and comments on plans and environmental documentation (30 CFR 582.4)
- Environmental protection measures and monitoring (30 CFR 582.28)
- Reporting requirements (30 CFR 582.29)
- Noncompliance, remedies, and penalties (30 CFR 582.14)

Delineation ~ Exploration



Testing ~ Pilot Studies

Mining ~ Extraction

Image Sources: *usgs.gov, blm.gov*

BOEM Bureau of Ocean Energy Management

A80

Uncertainties / Food for Thought

- NNA process authorized by OCSLA 8k(2)(A)
  - No fee for use in:
    - a program of, or project for, **shore protection, beach restoration, or coastal wetlands restoration** undertaken by a Federal, State, or local government agency; or
    - a **construction project** … that is funded in whole or in part by or authorized by the Federal Government.
  - For other uses:
    - the Secretary **may** assess a fee based on an assessment of the value of the resources and the public interest served by promoting development of the resources.
- Does the location of extraction alter the status of the sediment (e.g., process at sea vs. on land)?
- Are modified or new regulations needed?
- Is a competitive lease sale required?
  - Negotiated fees? Royalties? Who benefits?

Questions?

Paul O. Knorr, PhD *paul.knorr@boem.gov*

BOEM
Bureau of Ocean Energy Management

BOEM.gov

Session 2: Current offshore sand mining operations for beach replenishment

ADAMS, D.F. – City of Virginia Beach, Beach Nourishment Program (DAdams.pdf)

City of Virginia Beach
Beach Nourishment Program

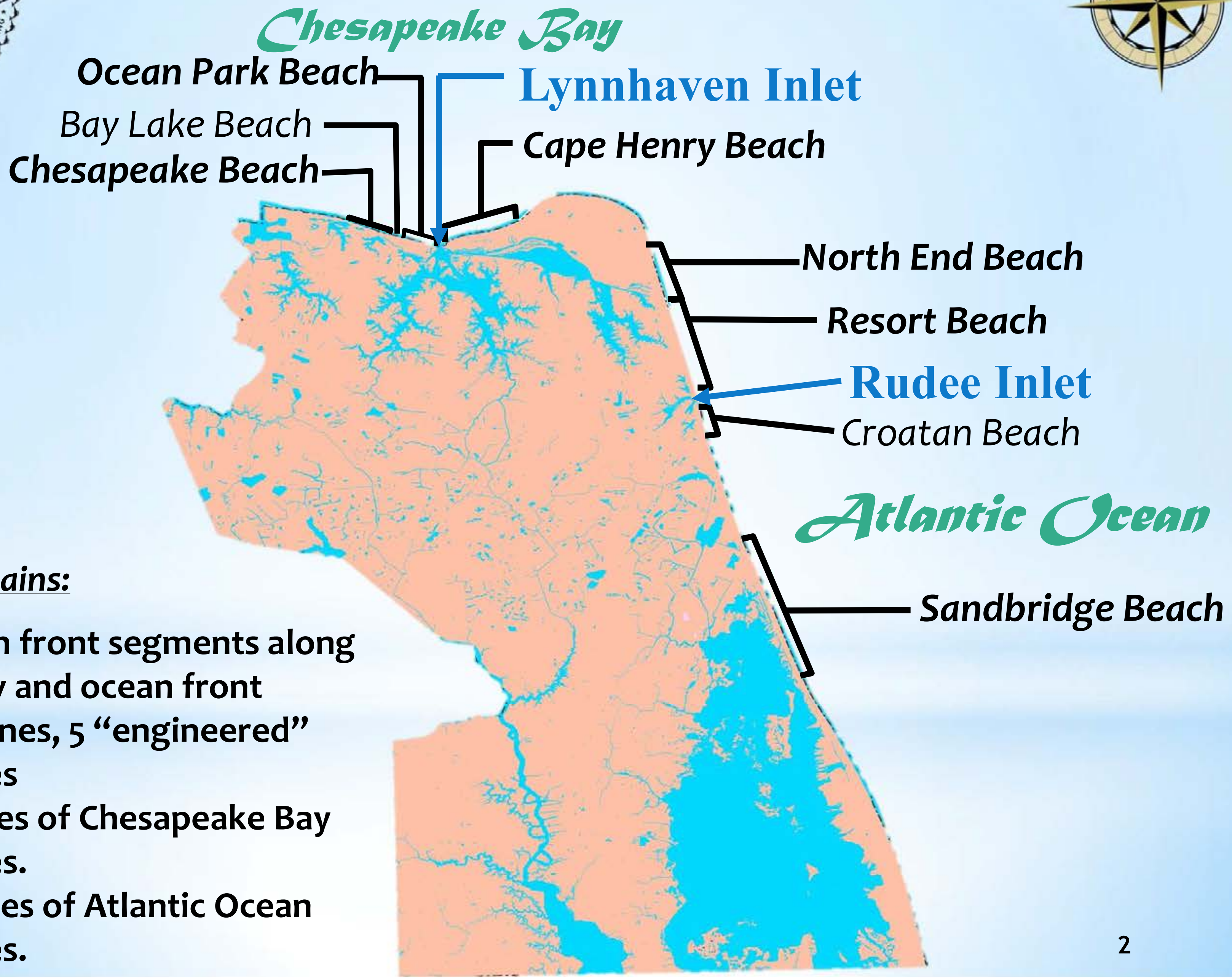
Sandbridge Beach

Resort Beach

Bay Beaches

Mid-Atlantic Marine Heavy Mineral Sands Forum
Virginia Department of Energy and the U.S. Bureau of Ocean Energy Management
March 31, 2022

Beach Segments

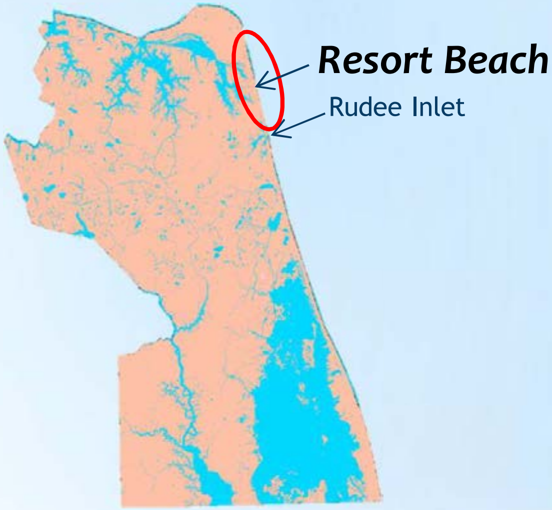


City Maintains:

- 8 beach front segments along the bay and ocean front shorelines, 5 “engineered” beaches
- 4.6 miles of Chesapeake Bay beaches.
- 11.8 miles of Atlantic Ocean beaches.

Virginia Beach Erosion Control and Hurricane Protection Project

Summer 2002



- 4 Million cy of sand placed from Thimble Shoals Channel.
- Project limits between Rudee Inlet and 89th St.
- Completed in June 2002
- Nourishment cost = $22.5 Million.
- City share = $7.6 Million.

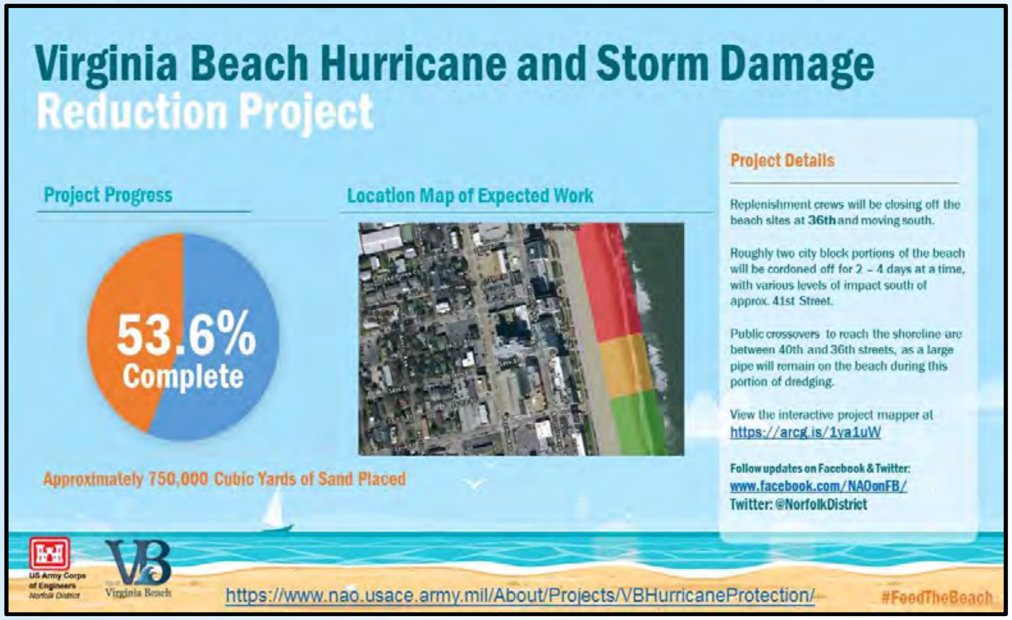
Virginia Beach Erosion Control and Hurricane Protection Project

Winter – Summer 2013

- 1.44 Million cy of sand mined from Thimble Shoals Channel & the Atlantic Ocean Channel.
- Limits of project are from 15th St. to 70th St.
- Project completed August 2013
- Construction Cost = $14.0 Million
- City Cost = $4.7 Million

Virginia Beach Erosion Control and Hurricane Protection Project

Summer 2019



Virginia Beach Hurricane and Storm Damage Reduction Project

Project Progress

Approximately 750,000 Cubic Yards of Sand Placed

Location Map of Expected Work

Project Details

Replenishment crews will be closing off the beach sites at **36th** and moving south.

Roughly two city block portions of the beach will be cordoned off for 2 - 4 days at a time, with various levels of impact south of approx. 41st Street.

Public crossovers to reach the shoreline are between 40th and 36th streets, as a large pipe will remain on the beach during this portion of dredging.

View the interactive project mapper at https://arcg.is/1ya1uW

Follow updates on Facebook & Twitter:
www.facebook.com/NAOonFB/
Twitter: @NorfolkDistrict

US Army Corps of Engineers Norfolk District
Virginia Beach

https://www.nao.usace.army.mil/About/Projects/VBHurricaneProtection/ #FeedTheBeach

- **1.4 Million cy of sand mined from Thimble Shoals Channel & the Atlantic Ocean Channel.**
- **Limits of project are from 15th St. to 70th St.**
- **Construction Cost = $22.6 Million (Base Bid + One Option).**
- **City Share = $7.9 Million.**

24th Street
July 2019

Ocean Beach Club
August 13

Virginia Beach Erosion Control and Hurricane Protection Project

Nourishment Summary

2001 - 2002: "Big Beach"
4Million CY Nourishment
($22 Million)

Winter 2012/2013: 1.44 Million CY
Replenishment ($14 Million)

Summer 2019: 1.4 Million CY
Replenishment ($22.6 Million)

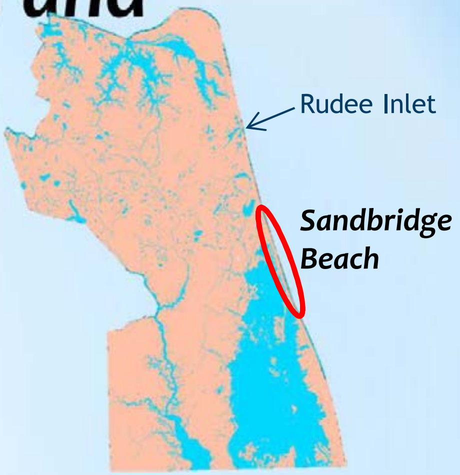
6.8 Million CY

Local Sponsor Share of Costs to Date: <u>$20.2 Million</u>

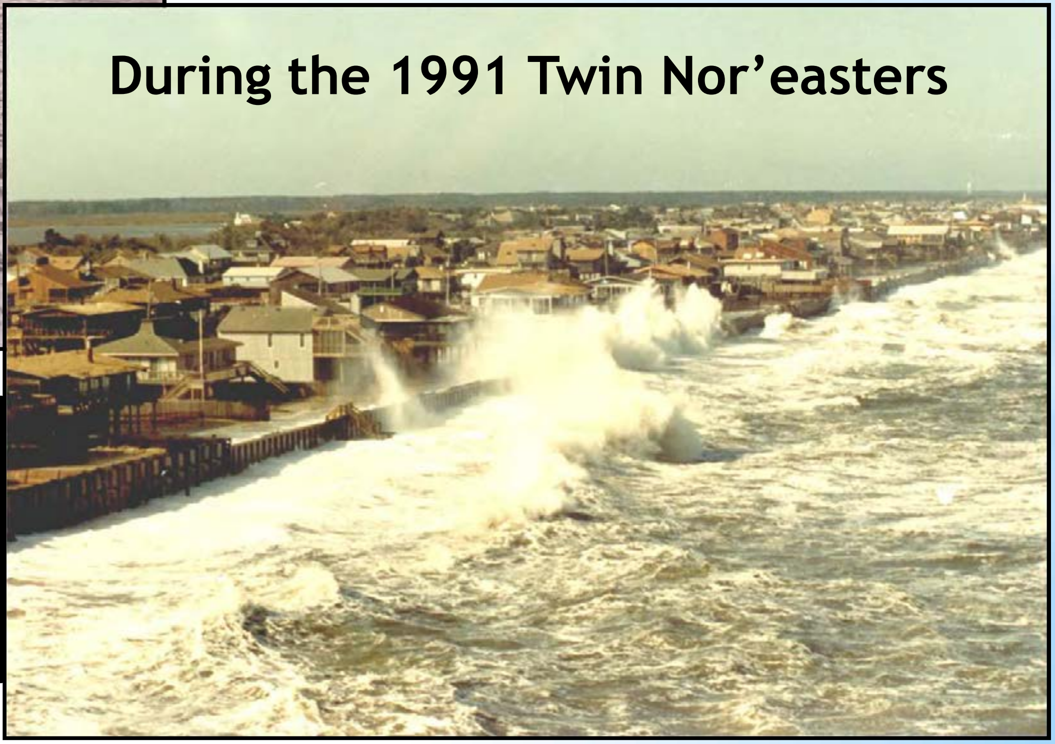
Storm Damage Aversion Since 2003 > $430 Million

CITY OF VIRGINIA BEACH VIRGINIA · LANDMARKS OF OUR NATION'S BEGINNING

Sandbridge Beach Erosion Control and Hurricane Protection Project




April 1988


During the 1991 Twin Nor’easters

Historically:
- No beach nourishment program
- Segmented bulkheads built to protect against storm conditions
- Vital community that required a solution

CITY OF VIRGINIA BEACH · VIRGINIA · LANDMARKS OF OUR NATIONS BEGINNING

Sandbridge Beach Restoration

Project History

- 1998 Initial replenishment - 100% City Funded
- 2003 Second cycle – 65% federal, 35% City
- 2007 Third cycle – approximately 20% federal, 80% City
- 2013 Fourth cycle – 100% City Funded
- 2019 Fifth cycle – City Funded, $3.1M federal assistance

2013/03/20

2013 Sandbridge Beach Nourishment

Project Summary:

1. Project Duration: March 2013 to June 2013.
2. Project Limits: 5.3 miles.
3. Constructed Project Volume = 2.18MCY.
4. Berm Height : +7.0 ft. NAVD 88.
5. Berm Width: 90ft from seawalls or +7.0 ft. NAVD 88 contour.
6. Width to MHW (+1.3ft NAVD 88): 200ft from seawalls or +7.0 ft. NAVD 88 contour.
7. 1V:20H beachface slope to sea.
8. Total Project Cost = $15.9 Million.

2200 Block Sandfiddler Rd
June 2013

Market Place
June 2013

2019 Sandbridge Beach Nourishment

Proposed Project:

1. Project Duration: Nov. 2019 to April 2020.
2. Project Limits: 5.3 miles.
3. Project Volume = 1.7MCY.
4. Berm Height : +7.0 ft. NAVD 88.
5. Berm Width: 90ft from seawalls or +7.0 ft. NAVD 88 contour.
6. Width to MHW (+1.3ft NAVD 88): 200ft from seawalls or +7.0 ft. NAVD 88 contour.
7. 1V:20H beachface slope to sea.
8. Awarded Bid Price = $20.3 Million.

Tuna Lane
August 2017

Chub Lane
March 2018

Sandbridge Beach Restoration

Nourishment Summary

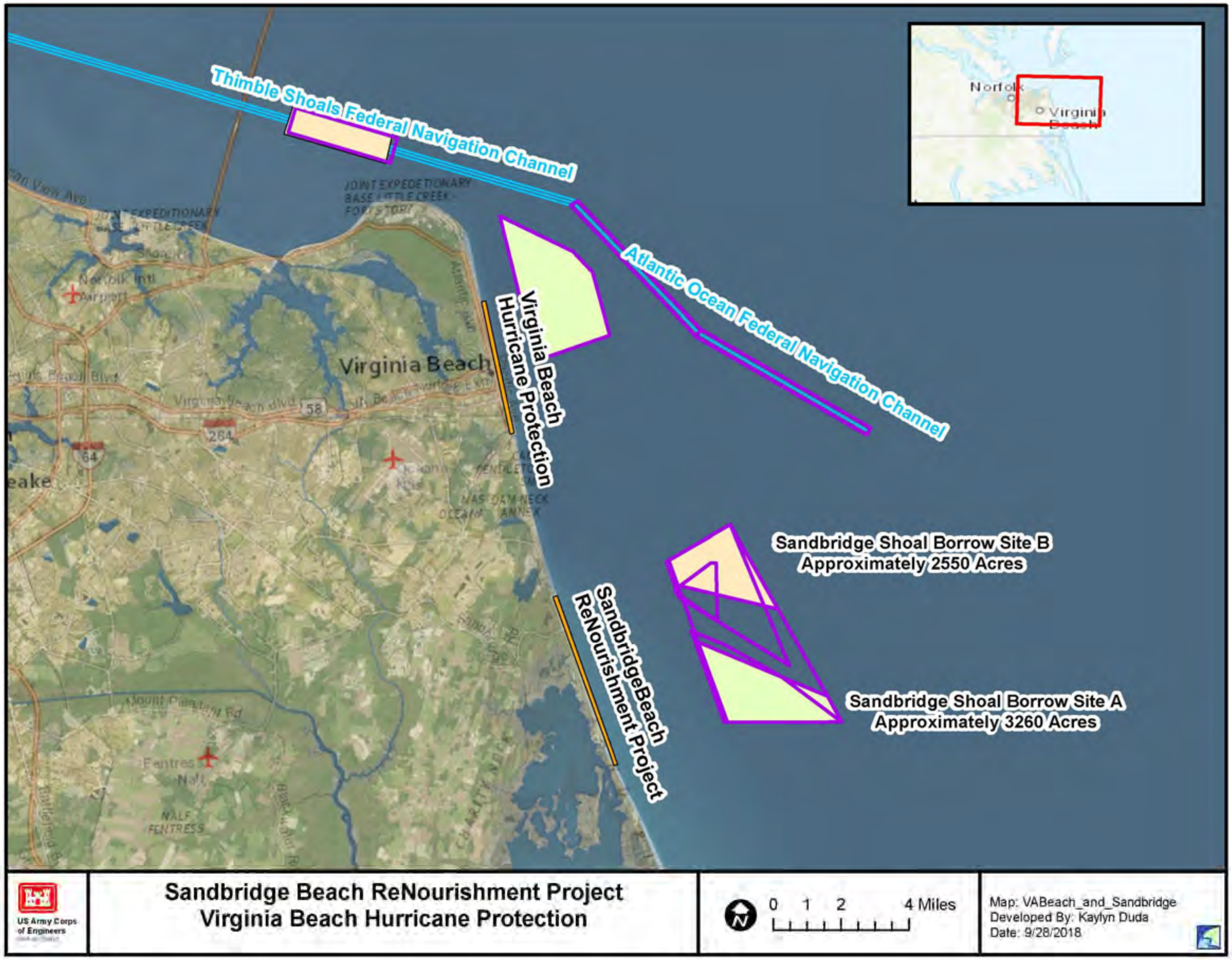
1998 – 1.5MCY Initial Const. ($8 Mil)
2003 – 1.7MCY Replenishment ($11 Mil)
2007 – 2.0MCY Replenishment ($10 Million)
2013 – 2.2 MCY Replenishment ($16 Million)
2019 – 1.70 MCY Replenishment ($20 Million)

9.1 Million CY

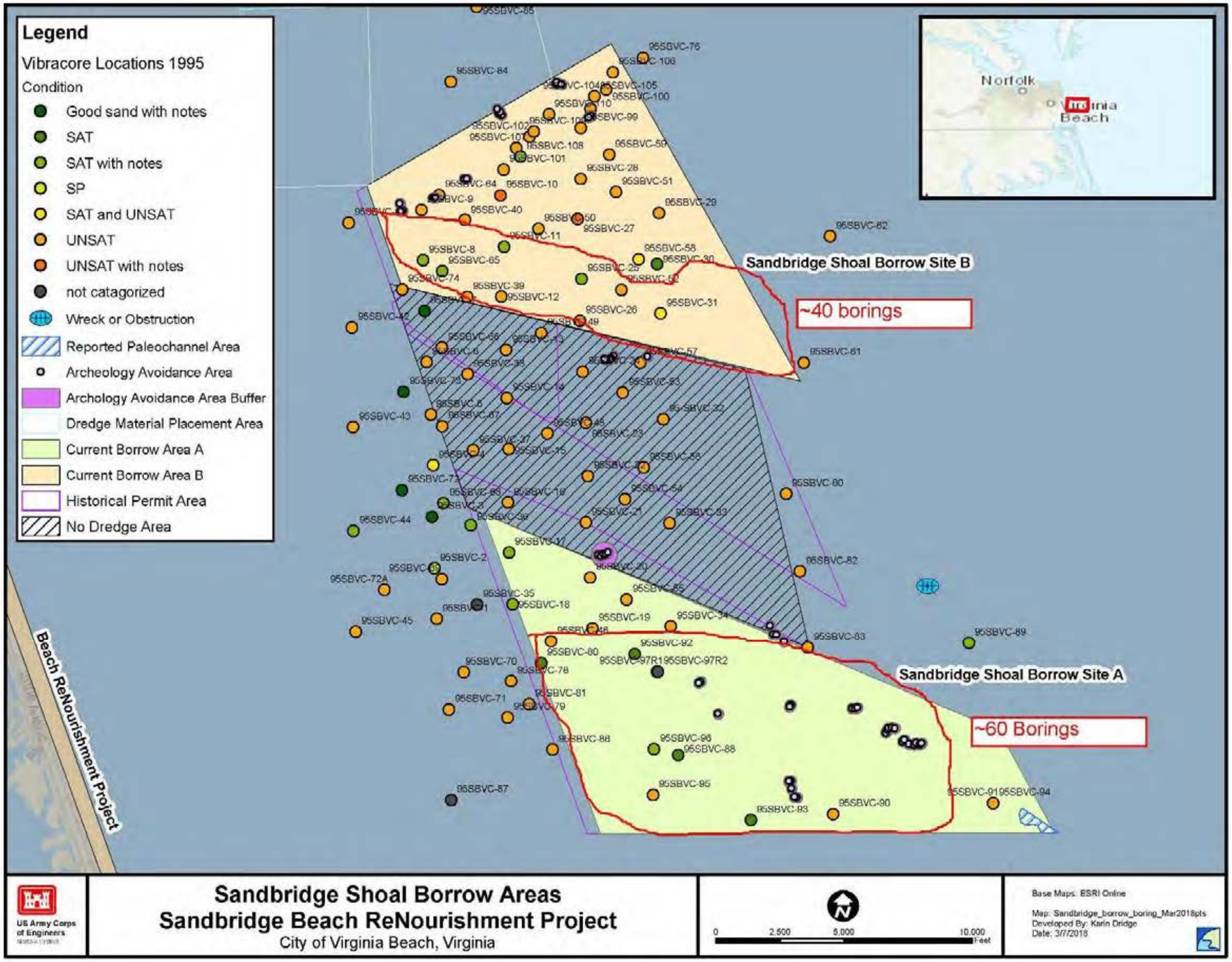
Local Sponsor Costs to Date = $55.8 Million

Storm Damage Aversion Since Hurricane Isabel (Approx. $100Mil.)

Sandridge & Virginia Beach Sand Sources



Sandbridge Shoal



CITY OF VIRGINIA BEACH VIRGINIA
LANDMARKS OF OUR NATIONS BEGINNING

The Bay Beaches

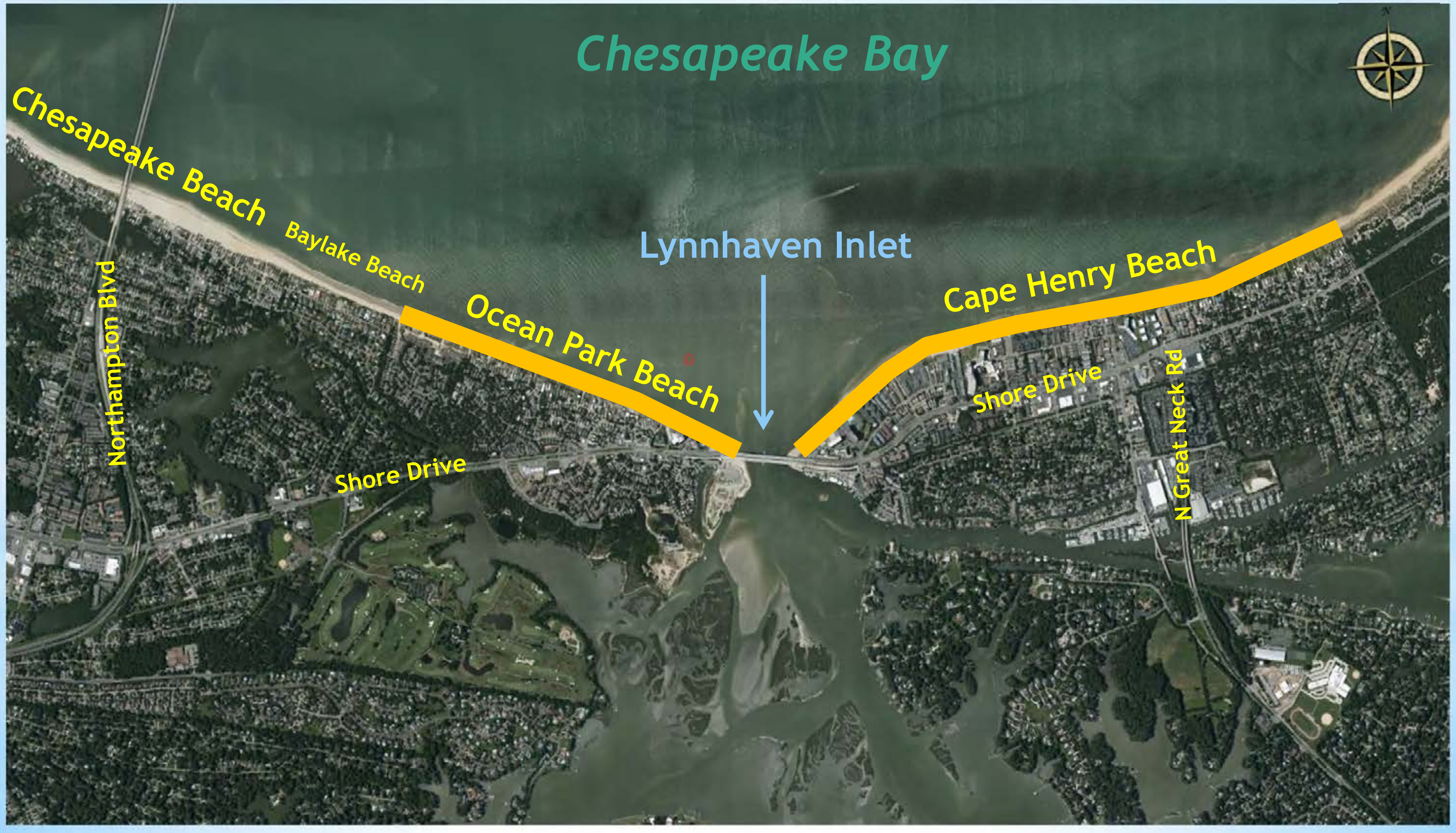
Storms of Significance


Cape Henry Beach
Superstorm Sandy 2012


Chesapeake Beach
2009 Nor'easter


Ocean Park Beach
Hurricane Earl 2010

The Bay Beaches



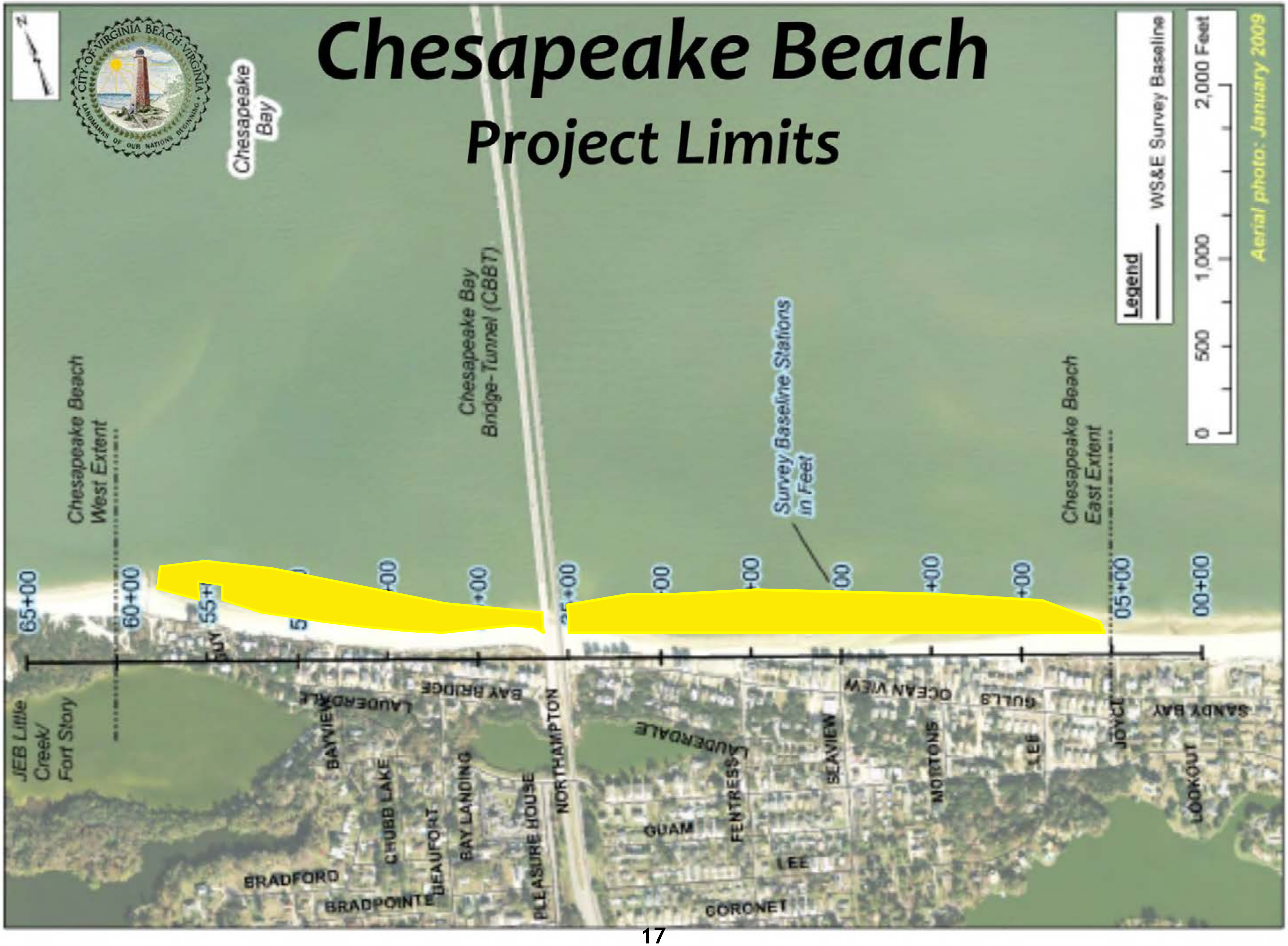
Chesapeake Beach

City of Virginia Beach, Virginia

- 1.0 Mile beach restoration project with periodic maintenance
- Favorable court ruling that public interest in beach does exist
- Critical for coastal protection and resiliency, most erosive section of City's coastline
- 360,000 cy of sand placed to nourish the beach and restore the dunes
- Construction Completed in May 2018
- Total project costs = <u>$5.0 Million</u>, 100% City Funded

Chesapeake Beach

Project Limits



CITY OF VIRGINIA BEACH VIRGINIA
LANDMARKS OF OUR NATIONS BEGINNING

Chesapeake Beach

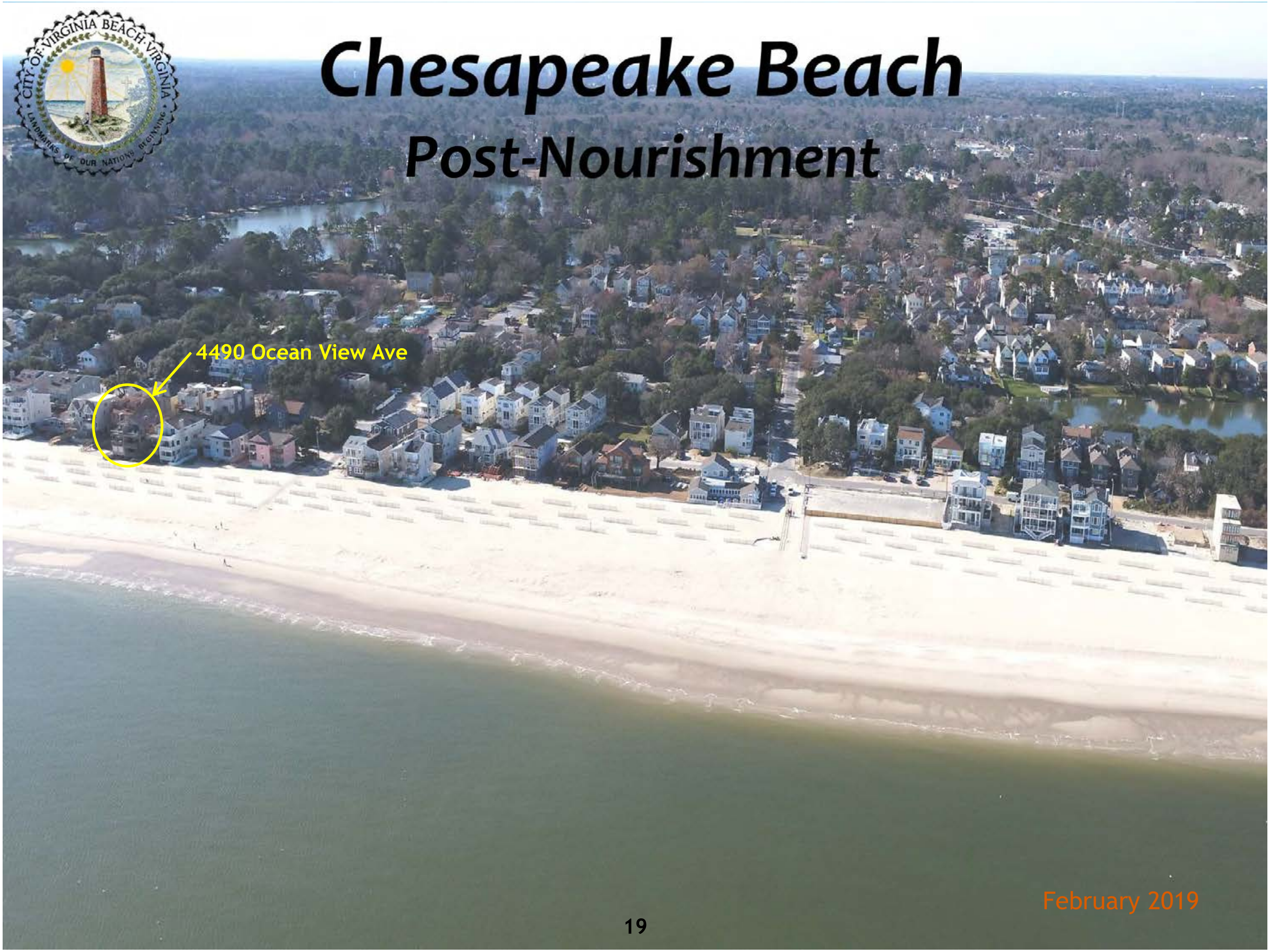
Pre-Nourishment

4490 Ocean View Ave

09/08/2017

CITY OF VIRGINIA BEACH VIRGINIA

Chesapeake Beach
Post-Nourishment

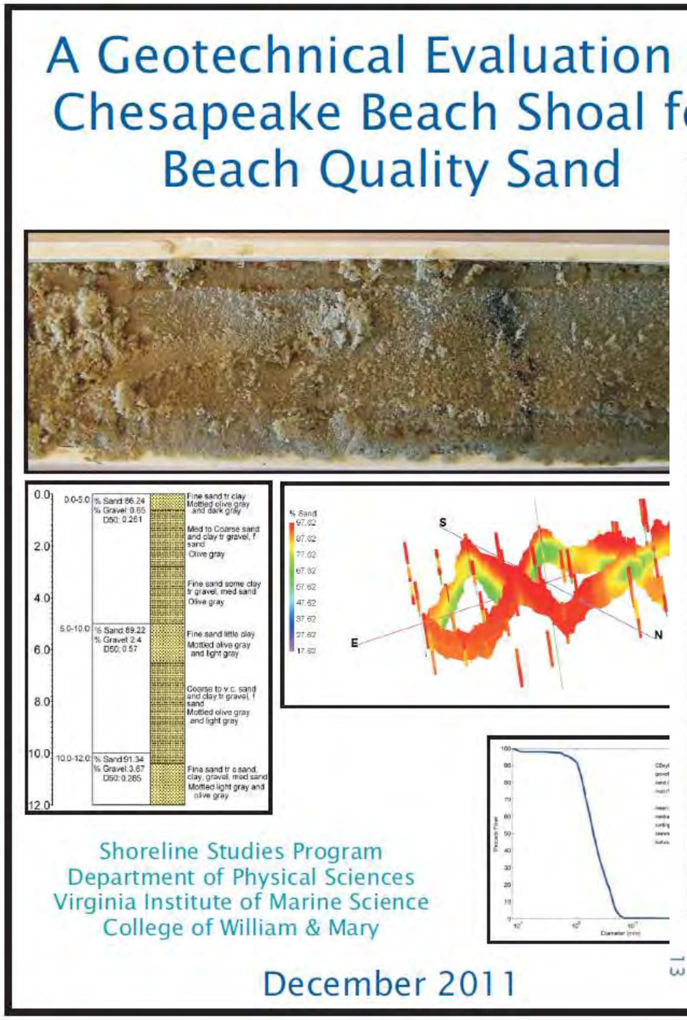


4490 Ocean View Ave

February 2019

Chesapeake Beach

Sand Source



A Geotechnical Evaluation of Chesapeake Beach Shoal for Beach Quality Sand

Shoreline Studies Program
Department of Physical Sciences
Virginia Institute of Marine Science
College of William & Mary

December 2011

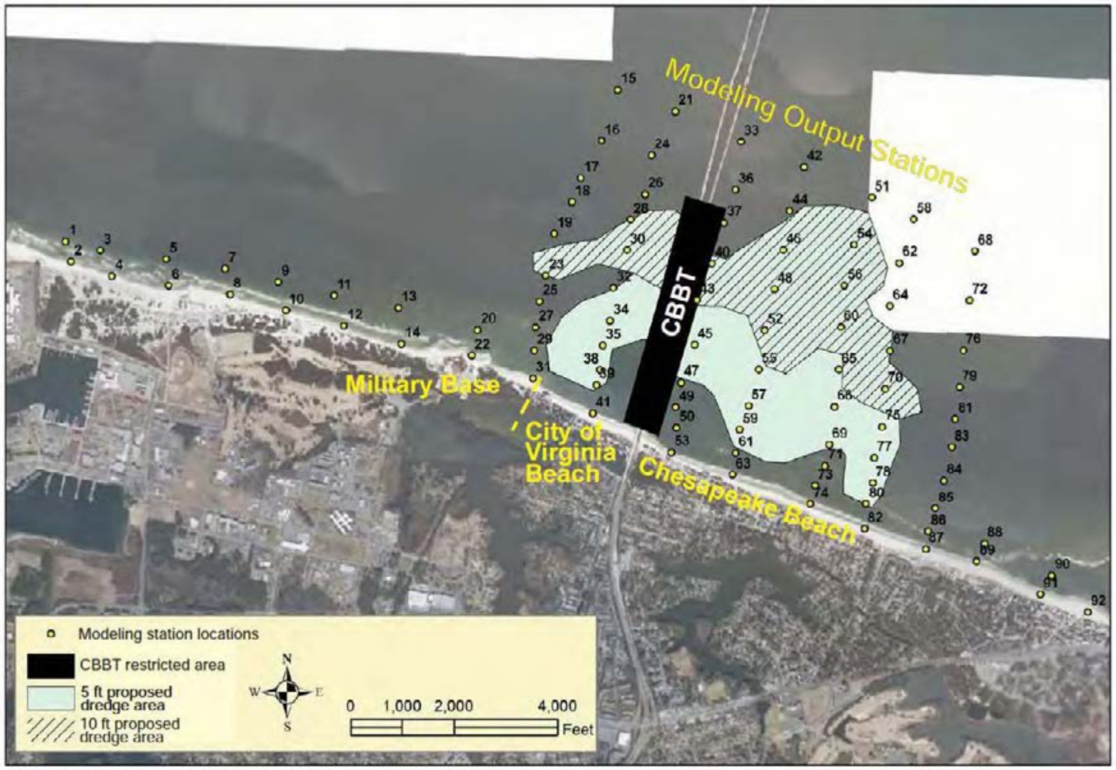
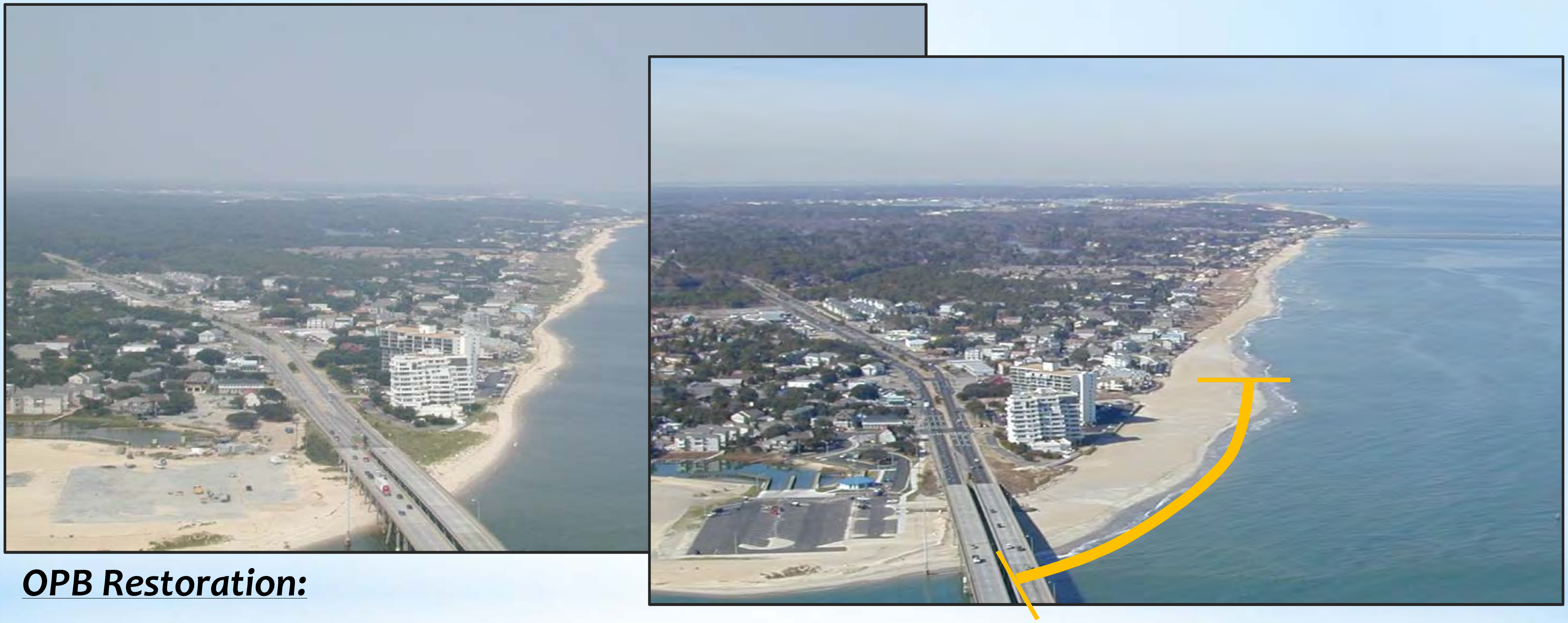


Figure 2-3. Proposed 5 ft and 10 ft dredging scenarios for modeling purposes, and output station locations for the nearshore wave modeling.

Ocean Park Beach
Restoration



OPB Restoration:

- **0.5-mile project.**
- **Winter 2013 66,000 cy of sand placed on beach from the USACE’s Lynnhaven Inlet dredging as a placement site**
- **May 2022 400,000 cy of sand to be placed from Norfolk Harbor Deepening Project – Thimble Shoal Channel by Port of Virginia for a full restoration based on “engineered” storm protection template**

CITY OF VIRGINIA BEACH VIRGINIA
LANDMARKS OF OUR NATIONS BEGINNING

Cape Henry Beach

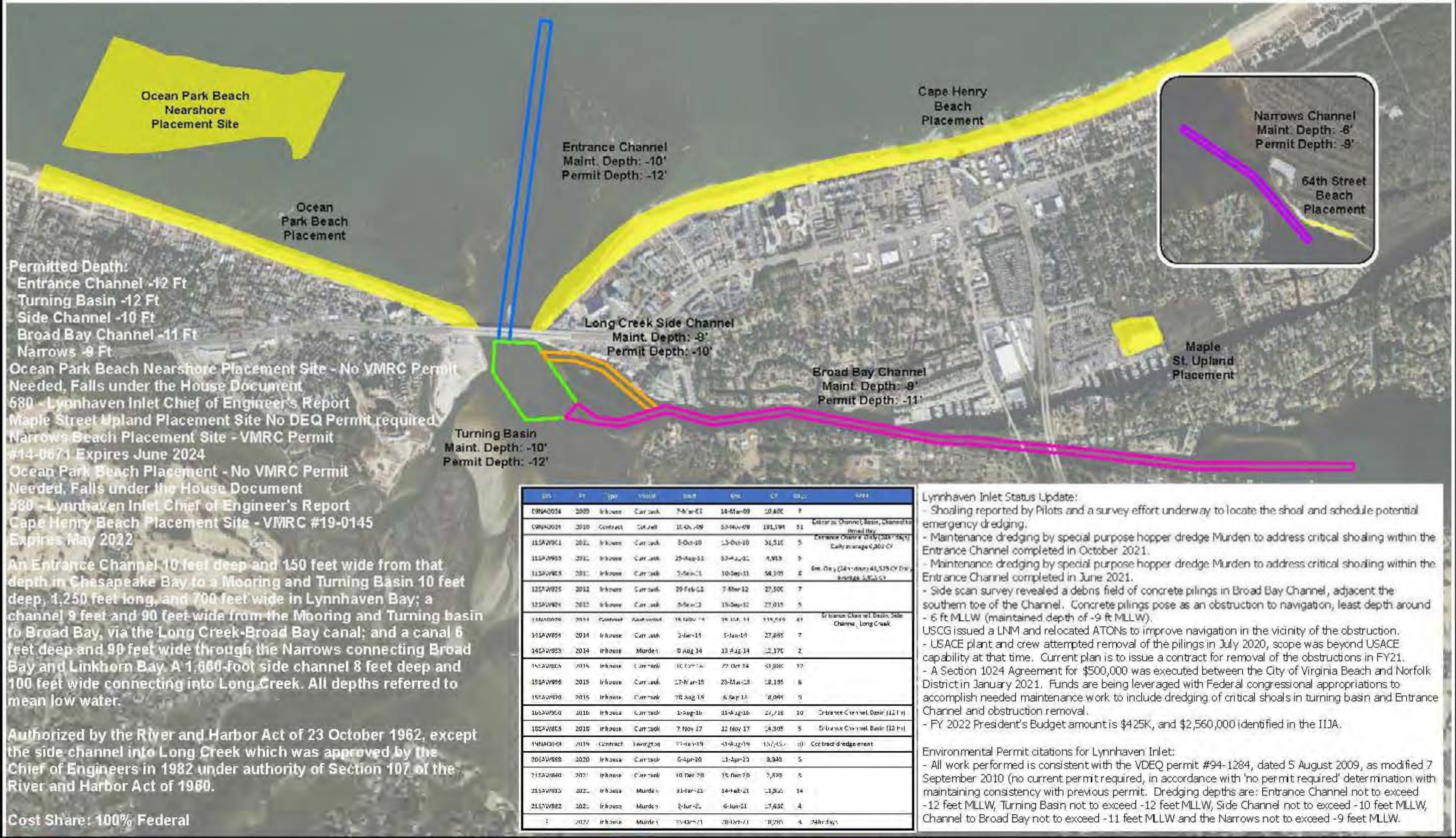
Restoration

2019 Beach Nourishment Effort:

- 2 mile project length.
- 170,000 cy along CHB shoreline.
- Material mined from USACE Lynnhaven Inlet Navigation Dredging Project
- Cape Henry is now part of the Bay Beaches Resiliency effort to have a designated nourishment cycle and sand source

Ocean Park & Cape Henry

Sand Sources



Permitted Depth:
Entrance Channel -12 Ft
Turning Basin -12 Ft
Side Channel -10 Ft
Broad Bay Channel -11 Ft
Narrows -9 Ft
Ocean Park Beach Nearshore Placement Site - No VMRC Permit Needed, Falls under the House Document 580 - Lynnhaven Inlet Chief of Engineer's Report
Maple Street Upland Placement Site No DEQ Permit required
Narrows Beach Placement Site - VMRC Permit #14-0671 Expires June 2024
Ocean Park Beach Placement - No VMRC Permit Needed, Falls under the House Document 580 - Lynnhaven Inlet Chief of Engineer's Report
Cape Henry Beach Placement Site - VMRC #19-0145 Expires May 2022

An Entrance Channel 10 feet deep and 150 feet wide from that depth in Chesapeake Bay to a Mooring and Turning Basin 10 feet deep, 1,250 feet long, and 700 feet wide in Lynnhaven Bay; a channel 9 feet and 90 feet wide from the Mooring and Turning basin to Broad Bay, via the Long Creek-Broad Bay canal; and a canal 6 feet deep and 90 feet wide through the Narrows connecting Broad Bay and Linkhorn Bay. A 1,660-foot side channel 8 feet deep and 100 feet wide connecting into Long Creek. All depths referred to mean low water.

Authorized by the River and Harbor Act of 23 October 1962, except the side channel into Long Creek which was approved by the Chief of Engineers in 1982 under authority of Section 107 of the River and Harbor Act of 1960.

Cost Share: 100% Federal

DIS	FY	Type	Vessel	Start	End	CY	Days	Area
09NAO024	2009	Inhouse	Currituck	7-Mar-09	14-Mar-09	10,400	7	
09NAO024	2010	Contract	Cottrell	10-Oct-09	30-Nov-09	181,594	51	Entrance Channel, Basin, Channel to Broad Bay
11SAW901	2011	Inhouse	Currituck	5-Oct-10	10-Oct-10	31,510	5	Entrance Channel Only (24hr days) Daily average 6,302 CY
11SAW953	2011	Inhouse	Currituck	25-Aug-11	30-Aug-11	4,915	5	
11SAW903	2011	Inhouse	Currituck	2-Sep-11	10-Sep-11	58,105	8	Ent. Only (24hr days) 44,525 CY Daily average [illegible] CY
12SAW825	2012	Inhouse	Currituck	29-Feb-12	7-Mar-12	27,500	7	
12SAW924	2012	Inhouse	Currituck	8-Sep-12	13-Sep-12	27,015	5	
[illegible]	2014	Contract	[illegible]	15-Nov-13	[illegible]	115,540	61	Entrance Channel, Basin, Side Channel, Long Creek
14SAW854	2014	Inhouse	Currituck	2-Jan-14	9-Jan-14	27,865	7	
14SAW933	2014	Inhouse	Murden	8 Aug 14	10 Aug 14	12,170	2	
15SAW805	2015	Inhouse	Currituck	10 Oct 14	22 Oct 14	31,880	12	
15SAW956	2015	Inhouse	Currituck	17-Mar-15	23-Mar-15	18,185	6	
15SAW970	2015	Inhouse	Currituck	28 Aug 15	6 Sep 15	18,065	9	
16SAW950	2016	Inhouse	Currituck	1-Aug-16	11-Aug-16	27,719	10	Entrance Channel, Basin (12 Ft)
18SAW805	2018	Inhouse	Currituck	7 Nov 17	12 Nov 17	14,305	5	Entrance Channel, Basin (12 Ft)
19NAO049	2019	Contract	Lexington	22-Jun-19	31-Aug-19	[illegible]	70	Contract dredge event
20SAW888	2020	Inhouse	Currituck	6-Apr-20	11-Apr-20	3,340	5	
21SAW840	2021	Inhouse	Currituck	10 Dec 20	15 Dec 20	7,670	5	
21SAW815	2021	Inhouse	Murden	31-Jan-21	14-Feb-21	[illegible]	14	
21SAW822	2021	Inhouse	Murden	2-Jun-21	6-Jun-21	17,650	4	
?	2022	Inhouse	Murden	25-Oct-21	28-Oct-21	[illegible]	4	24hr days

Lynnhaven Inlet Status Update:
- Shoaling reported by Pilots and a survey effort underway to locate the shoal and schedule potential emergency dredging.
- Maintenance dredging by special purpose hopper dredge Murden to address critical shoaling within the Entrance Channel completed in October 2021.
- Maintenance dredging by special purpose hopper dredge Murden to address critical shoaling within the Entrance Channel completed in June 2021.
- Side scan survey revealed a debris field of concrete pilings in Broad Bay Channel, adjacent the southern toe of the Channel. Concrete pilings pose as an obstruction to navigation, least depth around - 6 ft MLLW (maintained depth of -9 ft MLLW).
USCG issued a LNM and relocated ATONs to improve navigation in the vicinity of the obstruction.
- USACE plant and crew attempted removal of the pilings in July 2020, scope was beyond USACE capability at that time. Current plan is to issue a contract for removal of the obstructions in FY21.
- A Section 1024 Agreement for $500,000 was executed between the City of Virginia Beach and Norfolk District in January 2021. Funds are being leveraged with Federal congressional appropriations to accomplish needed maintenance work to include dredging of critical shoals in turning basin and Entrance Channel and obstruction removal.
- FY 2022 President's Budget amount is $425K, and $2,560,000 identified in the IIJA.

Environmental Permit citations for Lynnhaven Inlet:
- All work performed is consistent with the VDEQ permit #94-1284, dated 5 August 2009, as modified 7 September 2010 (no current permit required, in accordance with 'no permit required' determination with maintaining consistency with previous permit. Dredging depths are: Entrance Channel not to exceed -12 feet MLLW, Turning Basin not to exceed -12 feet MLLW, Side Channel not to exceed -10 feet MLLW, Channel to Broad Bay not to exceed -11 feet MLLW and the Narrows not to exceed -9 feet MLLW.

US Army Corps of Engineers
Norfolk District

Lynnhaven Inlet
Federal Navigation Project

Reach Names

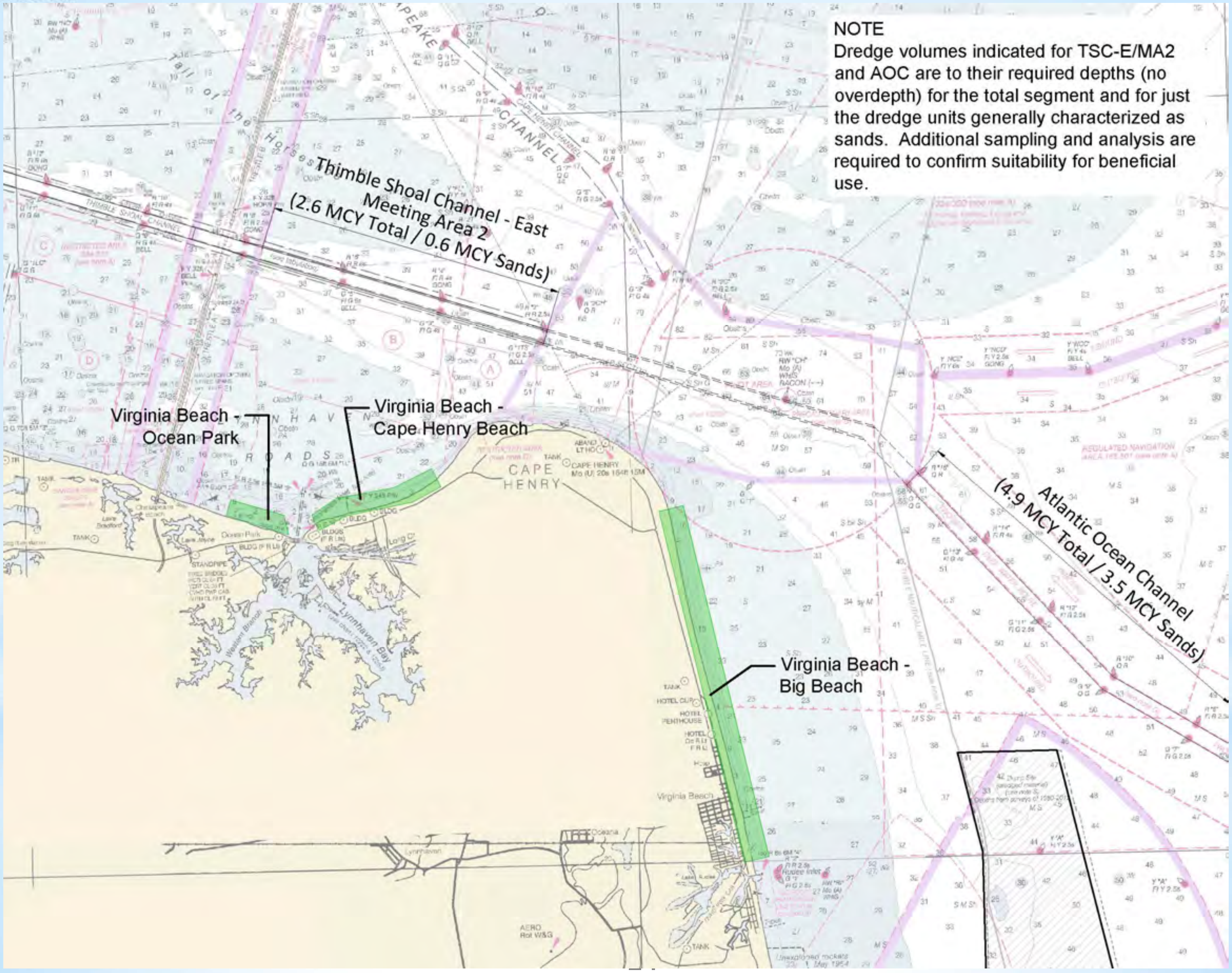
▭	Entrance Channel
▭	Turning Basin
▭	Long Creek Side Channel
▭	Broad Bay Channel
▭	Narrows
▨	Dredge Material Placement Area

0 500 1,000 2,000 Feet

PM: Tom Luehman
Map: LynnhavenInletProjectMap11x17_2022
Developed By: Jeff Swallow
Date of Map: 1/21/2022

Ocean Park & Cape Henry

Sand Sources



NOTE
Dredge volumes indicated for TSC-E/MA2 and AOC are to their required depths (no overdepth) for the total segment and for just the dredge units generally characterized as sands. Additional sampling and analysis are required to confirm suitability for beneficial use.

CITY OF VIRGINIA BEACH VIRGINIA

Keys to Future Success

- Maintain Federal Partnerships
- USACE & BOEM
- Beneficial Use of Dredge Material (BUD)
- Identification of new sand resources
- Regional Sediment Management (RSM)

Session 3: Permitting and regulatory framework for marine minerals: Federal and state waters

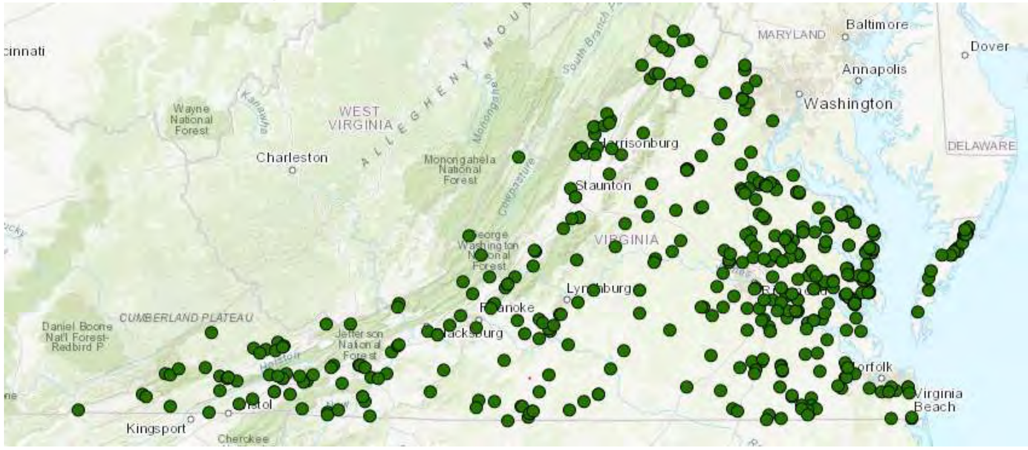
HAMM, S. – Permit requirements for mineral mines in Virginia (SHamm.pdf)

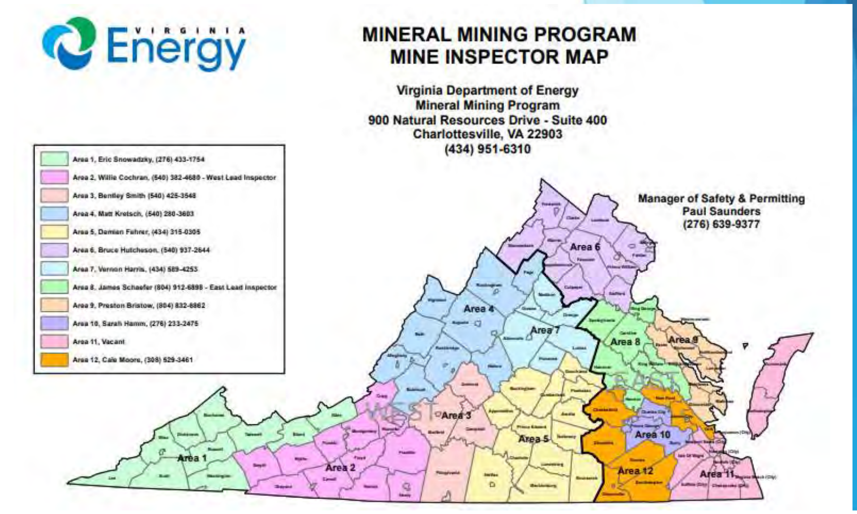
Permit Requirements for Mineral Mines in Virginia

Sarah Hamm

About the Virginia Energy’s Mineral Mining Program

- Over 400 permitted mineral mines in the state of Virginia
- The mineral mining program conducts reclamation and safety (non-MSHA sites only) inspections at all non-coal mineral mining operations
- In addition to regulatory activities, Mineral Mining Program also manages certification programs, offers training assistance to mine operators, sponsors mine safety and reclamation award programs, and administers the Orphaned Land Program





Permit Requirements

- General Requirements
  - Permit Map and Legend
  - Operations, Drainage, and Reclamation plan
  - Notifications
  - Right of entry
  - Permits from other state agencies

- For this project, on shore processing facilities would be permitted/licensed following normal permitting procedures
- Permitting of offshore operations would be dependent on what other permits are required from other agencies

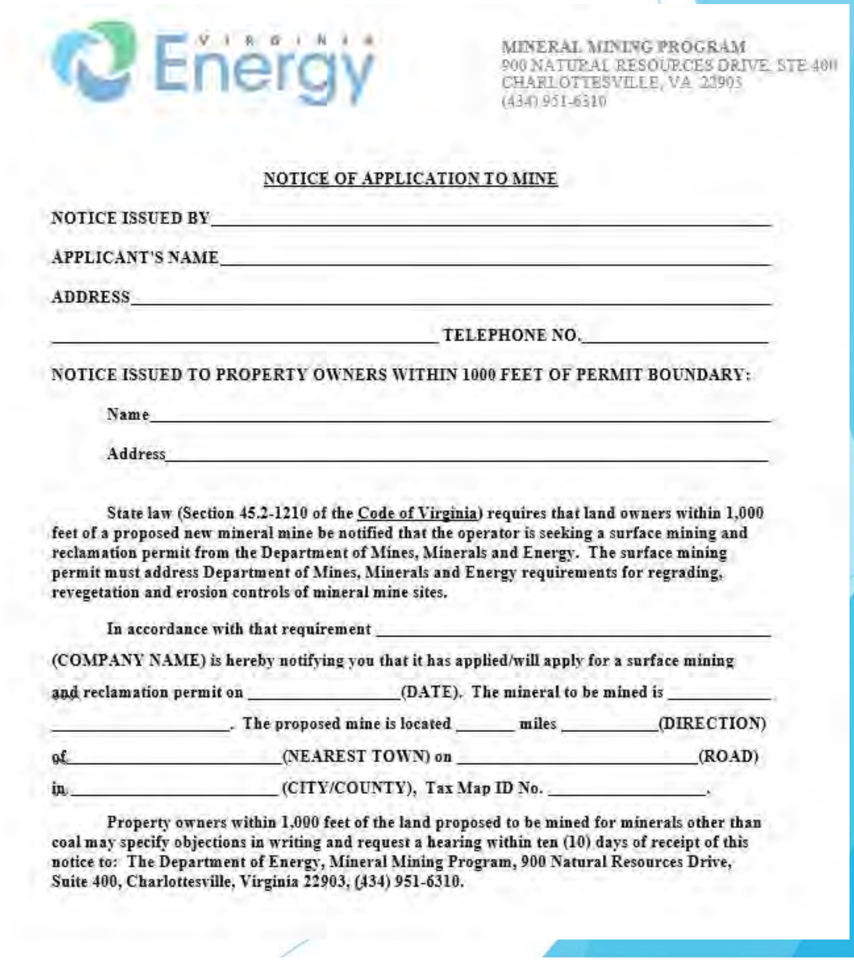
- **NOTE: it is the operator's responsibility to also obtain any county permits required.**

Permit Map

- Permit Map and Legend - shows permitted, bonded, reclaimed areas.
  - Sensitive features map: state waters, cemeteries, oil and gas wells, underground mine workings, public utilities and utility lines, buildings, roads, schools, churches, and occupied dwellings within 500 feet
  - Property owner map within 1000 feet of the permit line

Notifications of Intent to Mine

- State law requires that land owners within 1,000 feet of a proposed new mineral mine be notified that the operator is seeking a surface mining and reclamation permit from Virginia Energy.
- The chief administrative official of the county or city in which the proposed mine shall also be notified by certified mail.
- Notifications must be sent by certified mail and proof of notification must be submitted.
- Residents may file written objections with the Director and may request a hearing.



VIRGINIA Energy

MINERAL MINING PROGRAM
900 NATURAL RESOURCES DRIVE, STE 400
CHARLOTTESVILLE, VA 22903
(434) 951-6310

NOTICE OF APPLICATION TO MINE

NOTICE ISSUED BY ____________________

APPLICANT'S NAME ____________________

ADDRESS ____________________

____________________ **TELEPHONE NO.** ____________

NOTICE ISSUED TO PROPERTY OWNERS WITHIN 1000 FEET OF PERMIT BOUNDARY:

Name ____________________

Address ____________________

State law (Section 45.2-1210 of the Code of Virginia) requires that land owners within 1,000 feet of a proposed new mineral mine be notified that the operator is seeking a surface mining and reclamation permit from the Department of Mines, Minerals and Energy. The surface mining permit must address Department of Mines, Minerals and Energy requirements for regrading, revegetation and erosion controls of mineral mine sites.

In accordance with that requirement ____________________

(COMPANY NAME) is hereby notifying you that it has applied/will apply for a surface mining

and reclamation permit on ____________**(DATE). The mineral to be mined is** __________

____________**. The proposed mine is located** ______ **miles** __________**(DIRECTION)**

of ________________**(NEAREST TOWN) on** ________________**(ROAD)**

in ________________**(CITY/COUNTY), Tax Map ID No.** ____________**.**

Property owners within 1,000 feet of the land proposed to be mined for minerals other than coal may specify objections in writing and request a hearing within ten (10) days of receipt of this notice to: The Department of Energy, Mineral Mining Program, 900 Natural Resources Drive, Suite 400, Charlottesville, Virginia 22903, (434) 951-6310.

Operation, Drainage, and Reclamation Plan

- The operation plan shall include a description of the proposed method of mining and processing; the location of top soil storage areas; overburden, refuse, and waste disposal areas; stockpiles, equipment storage, and maintenance areas; internal roadway information. Plans for the storage and disposal of scrap metal, scrap tires, used lubricants, coolants, and other equipment service products, batteries, process chemicals, trash, debris, and other hazardous materials should be included. All related design and construction data shall be included with the plans.
- The drainage plan describes the drainage system to be constructed before, during, and after mining. A map or overlay showing the natural drainage system and all sediment and drainage control structures to be installed along with all related design and construction data shall be included with the plans.
- The reclamation plan outlines the post mining land use, seed mixes to be used during reclamation, final grading, etc. This section tells us how the operator will reclaim the site to achieve the defined post mining land use.

Right of Entry

- On shore facilities
    - Deed
    - Deed book and page number where land transfer was recorded
    - Lease agreement
- Offshore facilities*
    - Approved dredging permit allowing the operator to dredge in state water

Other Permits/Licenses that may be needed

- Virginia Department of Transportation: Land Use Permit for entrance
- Virginia Department of Environmental Quality
  - Virginia Pollutant Discharge Elimination System (VPDES) General Permit for Nonmetallic Mineral Mining
  - Non metallic Mineral Processing General Permit
- Virginia Department of Health: Radioactive Materials License

Questions

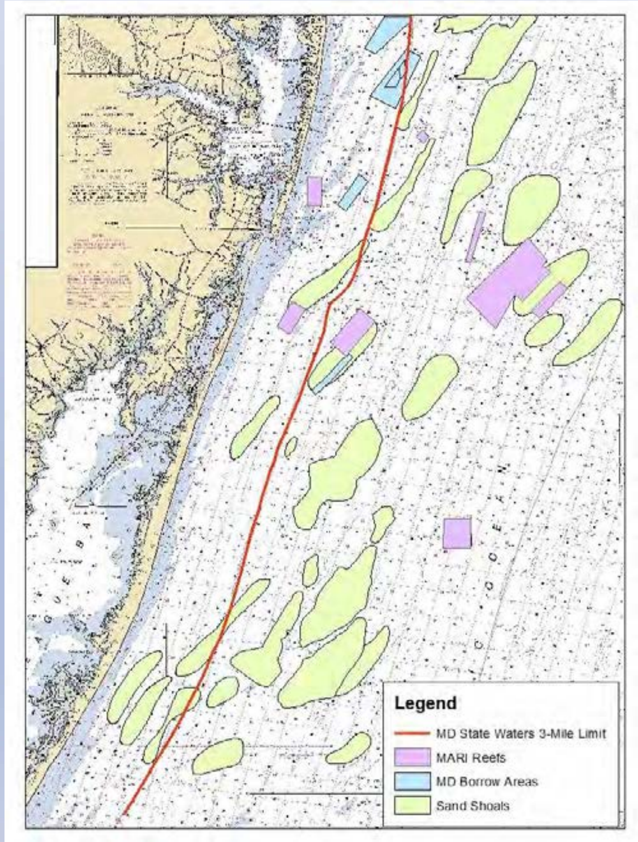
Session 3: Permitting and regulatory framework for marine minerals: Federal and state waters

VAN RYSWICK, S. – Maryland permitting and regulatory framework for marine minerals (SVanRyswick.pdf)

Maryland Permitting and Regulatory Framework for Marine Minerals

MARYLAND
DEPARTMENT OF
NATURAL RESOURCES

Maryland State Waters
3-mile Extent



Maryland Regulatory Agencies

- State Authorizations
  - Maryland Department of the Environment (MDE)
    - Water Management Administration
      - Tidal Wetlands Division
      - Nontidal Wetlands and Waterways Division
      - Wetlands and Waterways Program
    - Maryland Board of Public Works (BPW)
      - Wetlands Administration
    - Maryland Department of Natural Resources (MD DNR)
      - Chesapeake and Coastal Services
        - Coastal Zone Management Act (CZMA)

- Federal Permits
  - U.S. Army Corp of Engineers
    - Baltimore District

Maryland Permitting and Regulatory Framework for Marine Minerals

MARYLAND DEPARTMENT OF NATURAL RESOURCES

Permitting Requirements

- Section 401 Water Quality Certification
  - Required per Section 401 of Clean Water Act when a federal license or permit is also required for a project
  - https://mde.maryland.gov/programs/Water/WetlandsandWaterways/Pages/WQC.aspx

- Coastal Zone Management Act (CZMA)
  - Consistency determination needed
  - Would be provided during the application decision process
  - If project receives federal funding, the activity will require a CZMA consistency determination
  - https://mde.maryland.gov/programs/Water/WetlandsandWaterways/Pages/CZM.aspx

- Joint Permit Application (long form)
  - Required for all work within State Tidal waters

Permitting Requirements

- Tidal Wetland License
  - Issued by the MD BPW Wetlands Administration
  - https://bpw.maryland.gov/wetlands/Pages/default.aspx
  - Based on MDE's review and recommendation of the proposed project following MDE review

- Additional Screening Requirements
  - Maryland Historical Trust
  - Rare, Threatened, Endangered Species
  - Sensitive Habitats
  - Time of Year Restrictions

Additional Considerations

- Required plans based on proposed extraction, placement of dredged material, site(s)
  - Note: Overboard disposal of dredged material is prohibited in MD unless for beneficial reuse

- Since State tidal wetlands are owned by the State, expected requirement for compensation to the BPW for the extraction of the mineral rights

- Upland disposal/processing (Minerals Separation NOT performed offshore)
  - Additional upland regulations would apply
    - Erosion and sediment control plans
    - Grading permits
    - Potentially additional nontidal wetland and waterway permit
    - Critical Area approvals
    - Possible water appropriations permit and/or National Pollutant Discharge Elimination System (NPDES) permit

Session 3: Permitting and regulatory framework for marine minerals: Federal and state waters

TAYLOR, K.B. and FARRELL, K.M. – Status report on marine offshore heavy mineral sands, North Carolina (KTaylor_KFarrell.pdf)

At the time of submission of this document, a copy of the North Carolina Geological Survey presentation had not been received.

Please contact the North Carolina Geological Survey directly for additional information.

Session 3: Permitting and regulatory framework for marine minerals: Federal and state waters

NEALE, B. – Permitting in SC waters (BNeale.pdf) dhec

Healthy People. Healthy Communities.

Mid-Atlantic Marine Heavy Minerals Sands Forum

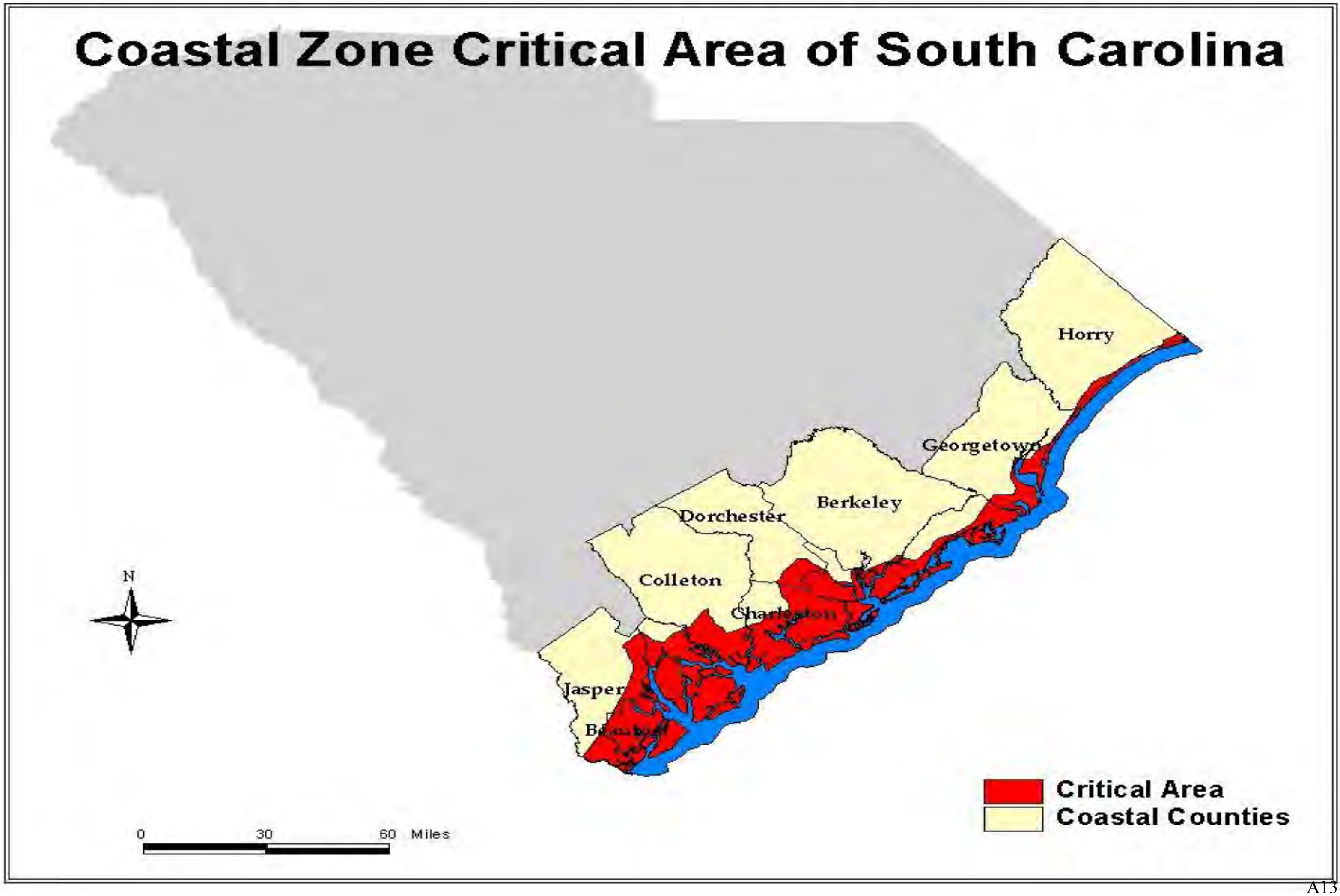
Permitting in SC Waters

Overview Coastal Program

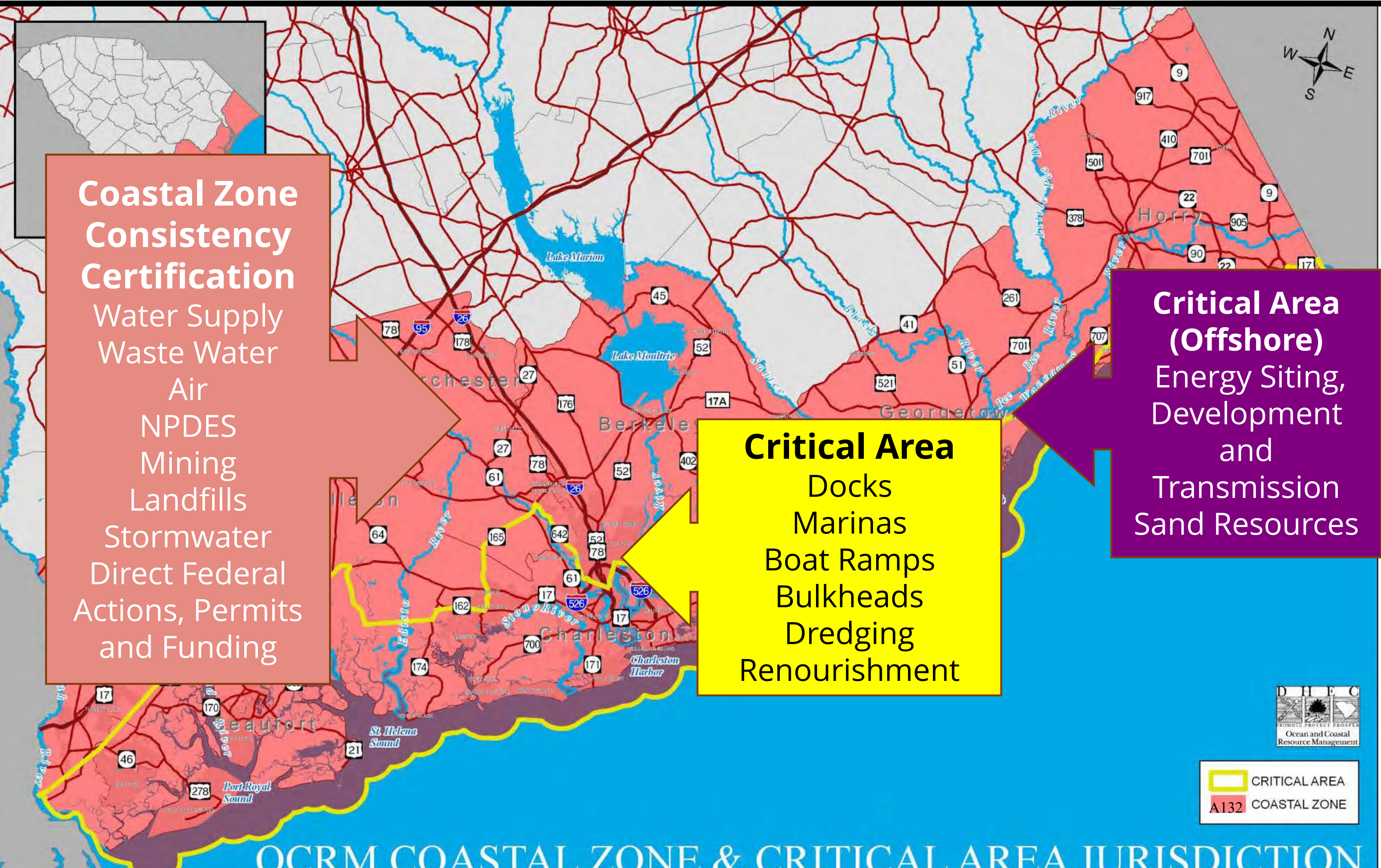
- 1972 Federal Coastal Zone Management Act
- 1977 - Coastal Tidelands and Wetlands Act, SC Code § 48-39-10 et seq.
- 1978 – Critical Area Regulations, R.30-10 et seq.
- 1979 - Coastal Management Plan
- **Direct** permitting authority for the Critical Area (tidelands, coastal waters, beaches and oceanfront sand dune system)
- **Indirect** Certification authority for state and federal activities

Value of Coastal Resources

- Over 15 million coastal tourists each year, supporting a $9 billion industry and over 200,000 jobs
- Fisheries are a $42 million industry
- Ports support 1 in 10 jobs and over $63.4 billion in economic impact annually and 1.1 billion in tax revenue in South Carolina
- Marshes and dune systems provide critical and invaluable buffer from storms and flooding



Coastal Zone Critical Area of South Carolina



Coastal Zone Consistency Certification

Water Supply
Waste Water
Air
NPDES
Mining
Landfills
Stormwater
Direct Federal Actions, Permits and Funding

Critical Area

Docks
Marinas
Boat Ramps
Bulkheads
Dredging
Renourishment

Critical Area (Offshore)

Energy Siting, Development and Transmission
Sand Resources

Direct Permitting Authority

Critical Areas of SC Coastal Zone

- Coastal Waters
- Tidelands
- Beaches
- Beach/Dune Systems

Indirect Authority

- Federal Permits/Licenses
- Direct Federal Activities
- Federal Funds to State and Local Govts
- Outer Continental Shelf
- State Permits

Thank You!

Barbara Neale

nealeb@dhec.sc.gov

(O) (843) 953-0245

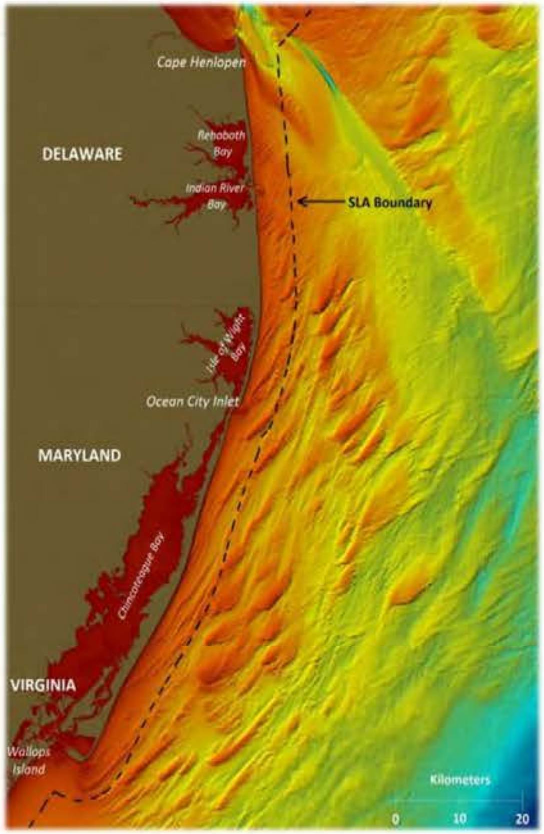
(M) (843) 697-2891

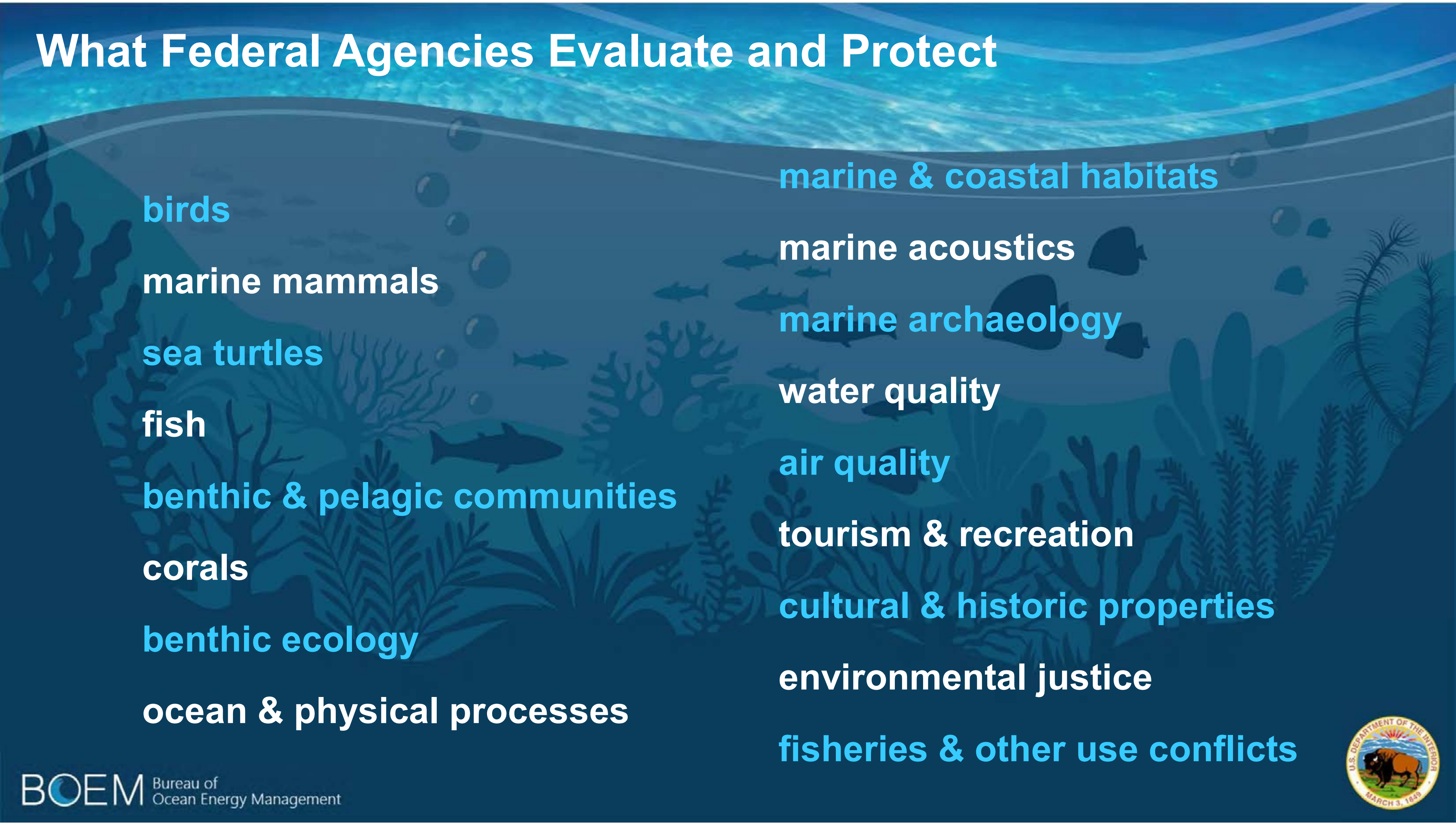
Session 4: Environmental standards, compliance, best practices applied to marine minerals

WIKEL, G.L. – Synopsis of the Federal environmental review process for marine mineral extraction in the marine environment (GWikel.pdf)

Environmental Impact Assessment Objectives

- Consider environmental impacts of federal decisions
- Based on best available or high-quality scientific information
- Comply with environmental laws and regulations
- Seek meaningful approaches to assess and mitigate risk
- Clearly describe environmental risks to decision-makers, stakeholders, and public
- Are based on purposeful stakeholder engagement
- Withstand legal challenge





What Federal Agencies Evaluate and Protect

- birds
- marine mammals
- sea turtles
- fish
- benthic & pelagic communities
- corals
- benthic ecology
- ocean & physical processes

- marine & coastal habitats
- marine acoustics
- marine archaeology
- water quality
- air quality
- tourism & recreation
- cultural & historic properties
- environmental justice
- fisheries & other use conflicts

BOEM Bureau of Ocean Energy Management

U.S. DEPARTMENT OF THE INTERIOR MARCH 3, 1849

Assessment and Consultation Process

PROPOSE ACTIVITY

DESCRIBE THE ENVIRONMENT

ASSESS POTENTIAL IMPACTS & ENGAGE STAKEHOLDERS

MITIGATE IMPACTS

MAKE PROJECT DECISIONS

ASSESS IMPACTS & IMPROVE MITIGATION

STUDY ENVIRONMENTAL RESOURCES

Physical / Biological / Socio-Economic

Affected resources

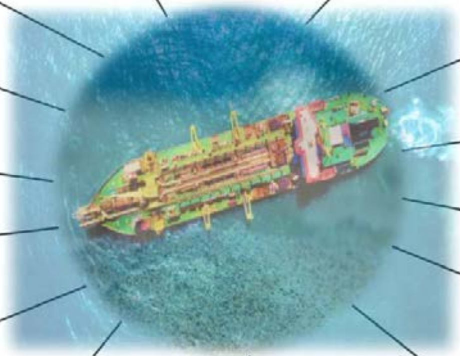
Effects of activities

Cumulative impacts

Mitigation

Compliance and monitoring

Regulations in the Ocean Environment



Outer Continental Shelf Lands Act

National Environmental Policy Act

Coastal Zone Management Act

Endangered Species Act

Rivers and Harbors Act

BOEM Bureau of Ocean Energy Management

Marine Mammal Protection Act

National Historic Preservation Act

Magnuson-Stevens Fishery Conservation Management Act

Ocean Dumping Act

Clean Water Act

Clean Air Act

Executive Order 13175: Consultation with Indian Tribal Governments

Executive Order 12898: Environmental Justice

Migratory Bird Treaty Act

Session 4: Environmental standards, compliance, best practices applied to marine minerals

PEABODY, R. – State regulatory and permitting framework, onshore mineral beneficiation (RPeabody.pdf)

State regulatory and permitting framework, onshore mineral beneficiation

RACHAEL PEABODY, DIRECTOR OF COASTAL POLICY, VIRGINIA MARINE RESOURCES COMMISSION

VIRGINIA'S MARINE RESOURCES COMMISSION

MISSION:

WE ARE STEWARDS OF VIRGINIA'S MARINE AND AQUATIC RESOURCES FOR PRESENT AND FUTURE GENERATIONS

MARINE FISHERIES

Manage
Recreational & Commercial
Fisheries/Landings

MARINE HABITAT

5,000 miles tidal shoreland
1,472,000 acres bottomlands

Shellfish Management

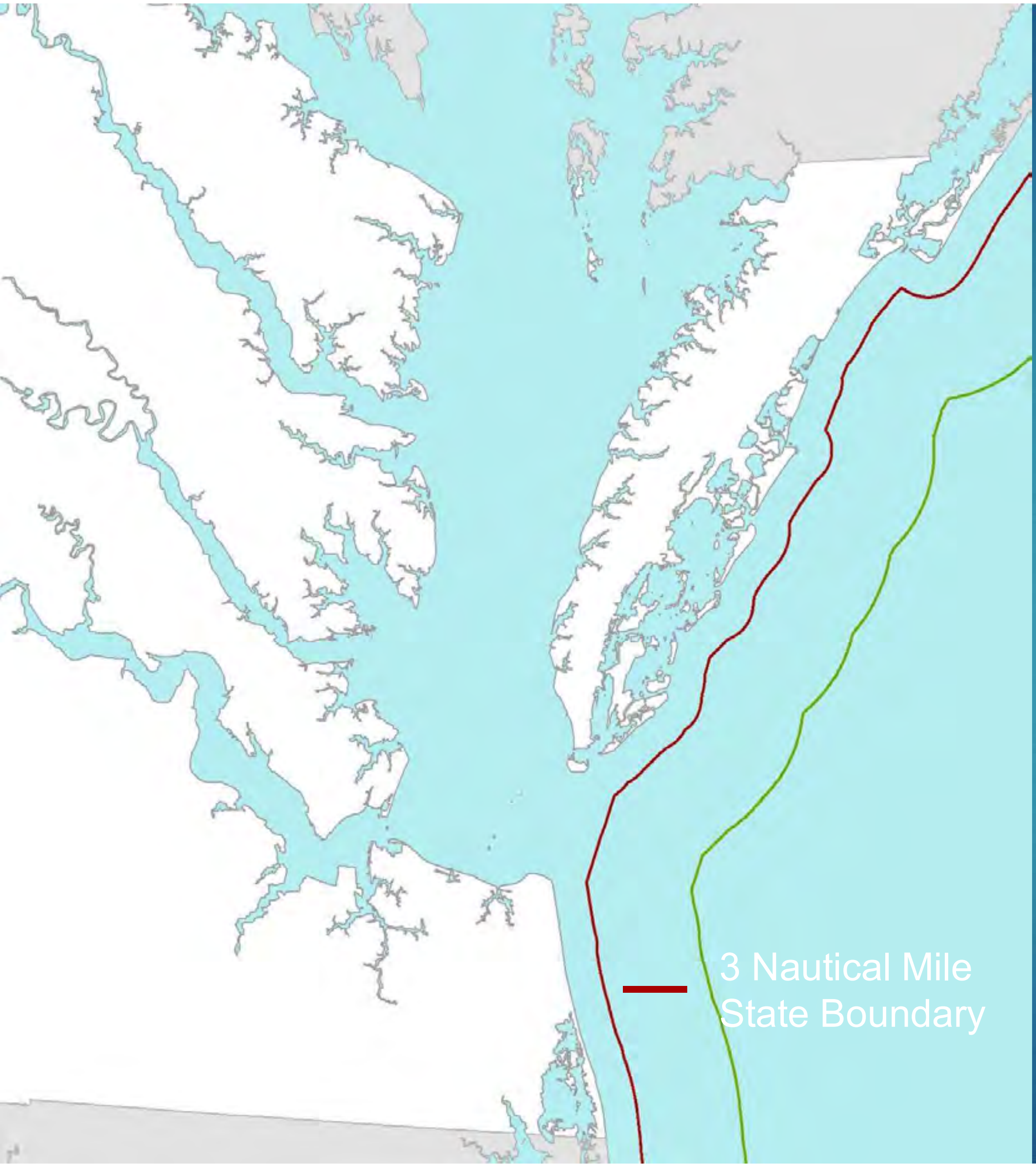
FISHERIES MANAGEMENT DIVISION

GOAL

To conserve and enhance finfish and shellfish resources, and to preserve and promote both commercial and recreational fisheries, thereby maximizing food production and recreational opportunities.

REGULATORY AUTHORITIES

- HABITAT MANAGEMENT
  - Subtitle II (Fisheries) of Title 28.2
    - Chapter 6 - Planting Grounds (1928)
  - Subtitle III (Habitat) of Title 28.2
    - Chapter 12 – State-Owned Submerged Lands (1962)
    - Chapter 13 - Wetlands (1972 & 1982)
    - Chapter 14 - Coastal Primary Sand Dunes/Beaches (1980)



Chapter 12 – State-Owned Submerged Lands

Regulate via proprietary ownership of State bottomlands

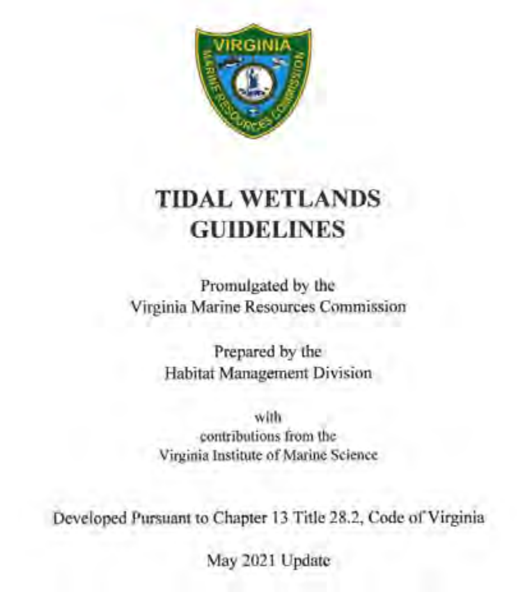
Certificate of Ownership

VMRC

VIRGINIA MARINE RESOURCES COMMISSION

Chapter 13 - Tidal Wetlands

- “The Commission shall preserve and prevent the despoliation and destruction of wetlands while accommodating necessary economic development in a manner consistent with wetlands preservation.”
- Localities may voluntarily manage this resource through the local wetlands board process.



TIDAL WETLANDS GUIDELINES

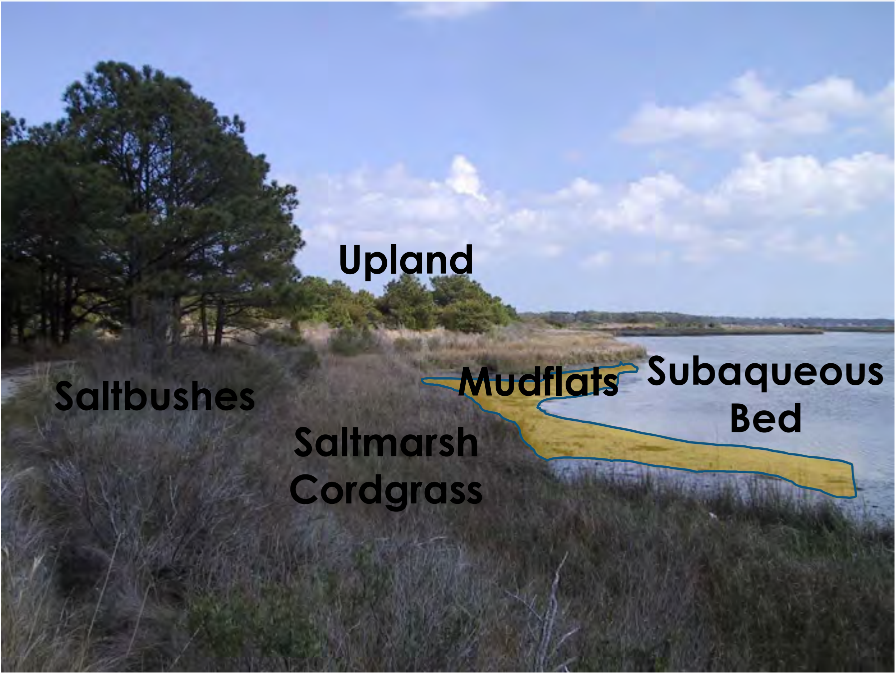
Promulgated by the
Virginia Marine Resources Commission

Prepared by the
Habitat Management Division

with
contributions from the
Virginia Institute of Marine Science

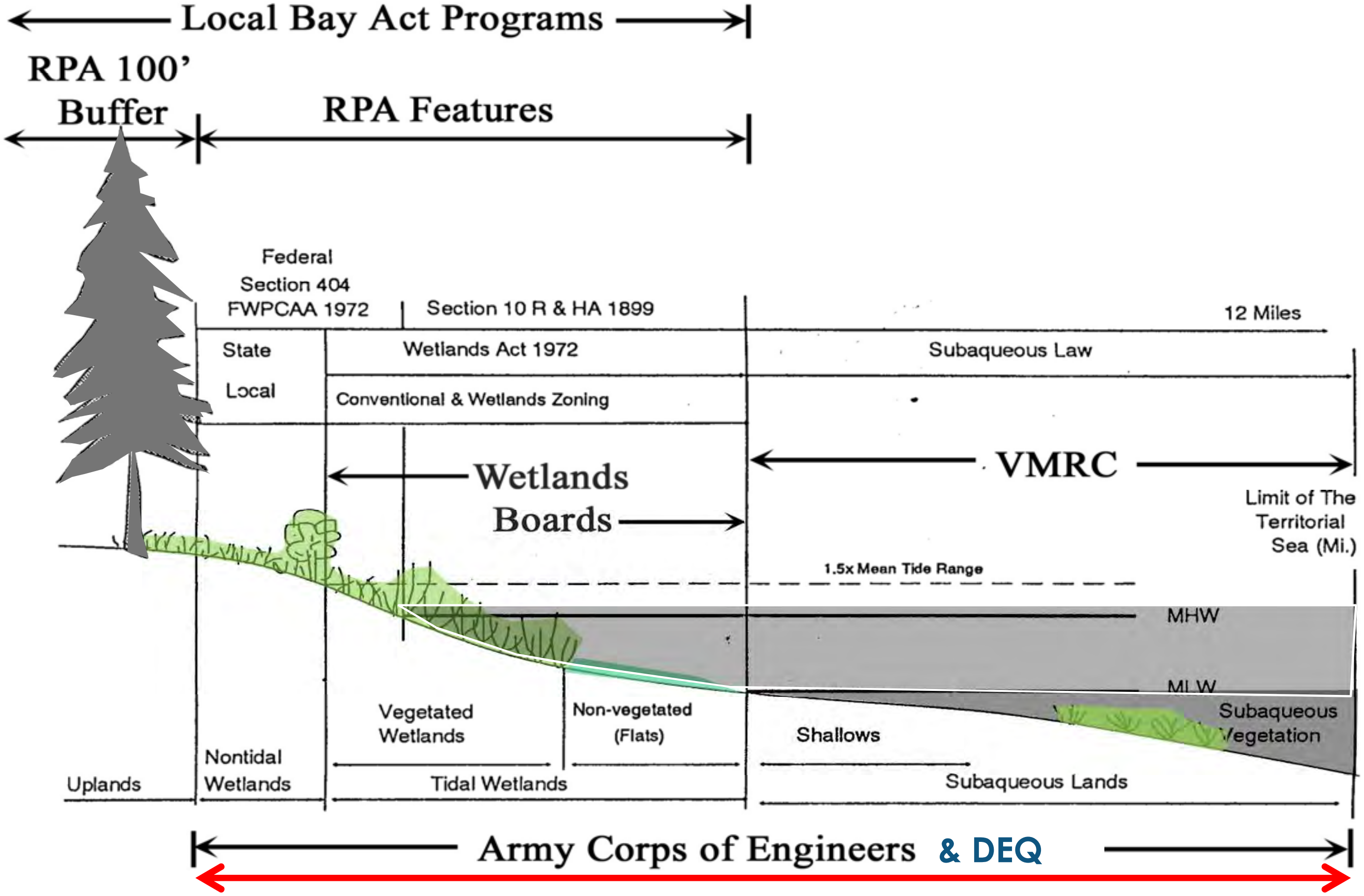
Developed Pursuant to Chapter 13 Title 28.2, Code of Virginia

May 2021 Update



JURISDICTIONAL BOUNDARIES

Tidal Waters



Local Bay Act Programs

RPA 100' Buffer

RPA Features

Federal
Section 404
FWPCAA 1972

Section 10 R & HA 1899

12 Miles

State

Wetlands Act 1972

Subaqueous Law

Local

Conventional & Wetlands Zoning

Wetlands Boards

VMRC

Limit of The
Territorial
Sea (Mi.)

1.5x Mean Tide Range

MHW

MLW

Vegetated
Wetlands

Non-vegetated
(Flats)

Shallows

Subaqueous
Vegetation

Uplands

Nontidal
Wetlands

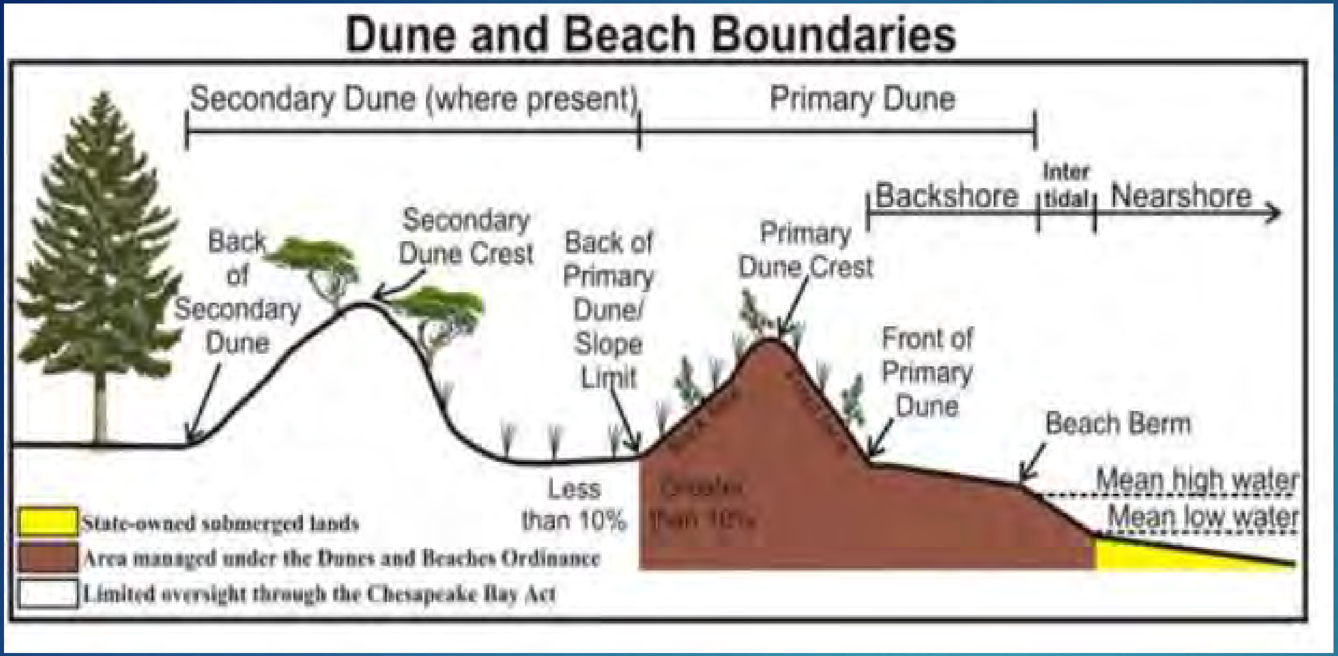
Tidal Wetlands

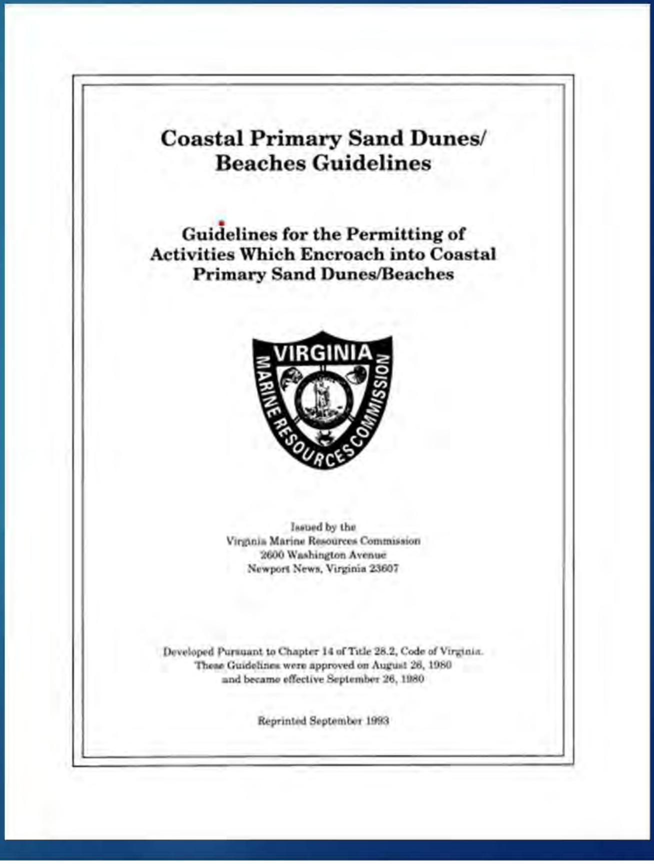
Subaqueous Lands

Army Corps of Engineers **& DEQ**

Chapter 14 - Coastal Primary Sand Dunes/Beaches

- “The Commission shall preserve and protect coastal primary sand dunes and beaches and prevent their despoliation and destruction.”
    - Flood and Erosion Protection
    - Sand Replenishment
    - Habitat
- **CHAPTER 4VAC20-1340-10 ET SEQ - “REGULATION: FAST-TRACK PERMITTING PROGRAM FOR DISPOSAL OF DREDGED MATERIAL”**
    - Preference for using sandy dredged material for beach nourishment, living shorelines, wetland creation.
- **§ 10.1-704 of the Code of Virginia** directs that the beaches of the Commonwealth shall be given priority consideration as sites for the disposal of that portion of dredged material determined to be suitable for beach nourishment.





Coastal Primary Sand Dunes/ Beaches Guidelines

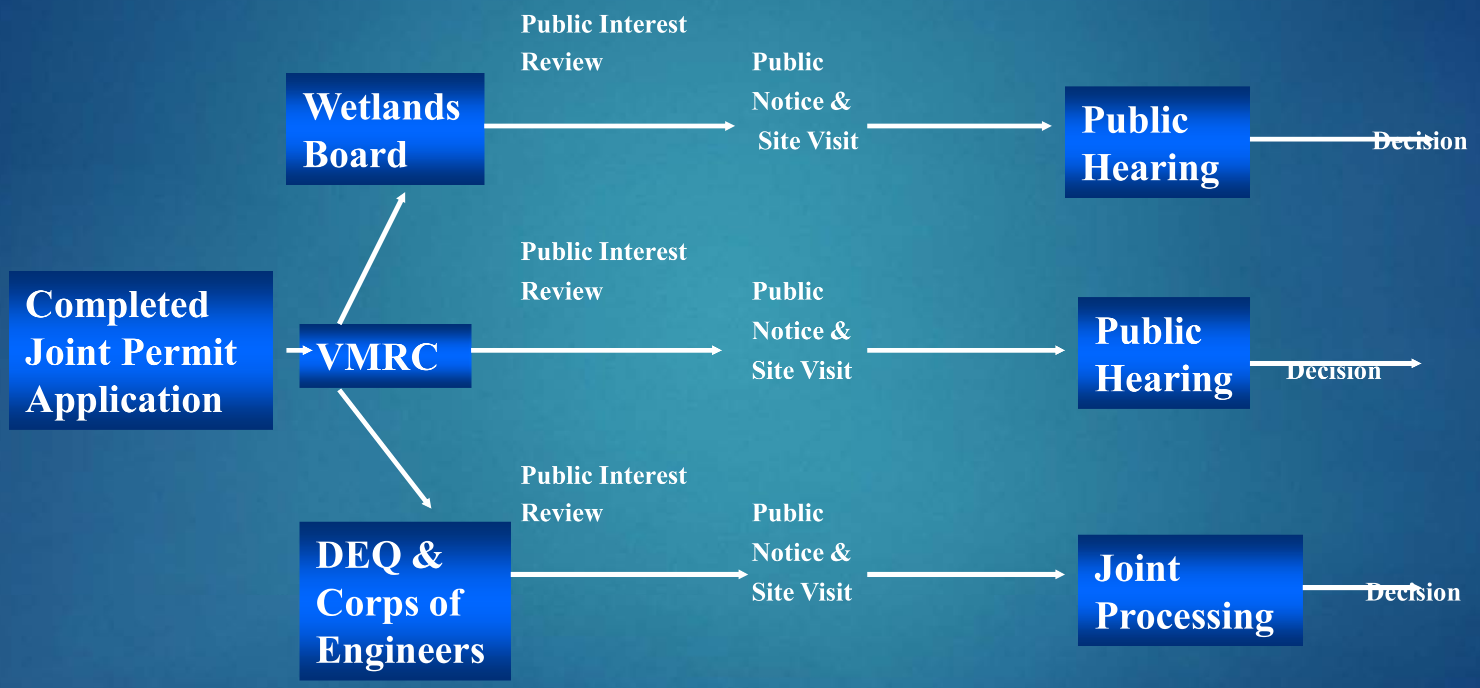
Guidelines for the Permitting of Activities Which Encroach into Coastal Primary Sand Dunes/Beaches

Issued by the
Virginia Marine Resources Commission
2600 Washington Avenue
Newport News, Virginia 23607

Developed Pursuant to Chapter 14 of Title 28.2, Code of Virginia.
These Guidelines were approved on August 26, 1980
and became effective September 26, 1980

Reprinted September 1993

Virginia's Shoreline Permit Process



Completed Joint Permit Application

VMRC

Wetlands Board

Public Interest Review

Public Notice & Site Visit

Public Hearing

Decision

VMRC

Public Interest Review

Public Notice & Site Visit

Public Hearing

Decision

DEQ & Corps of Engineers

Public Interest Review

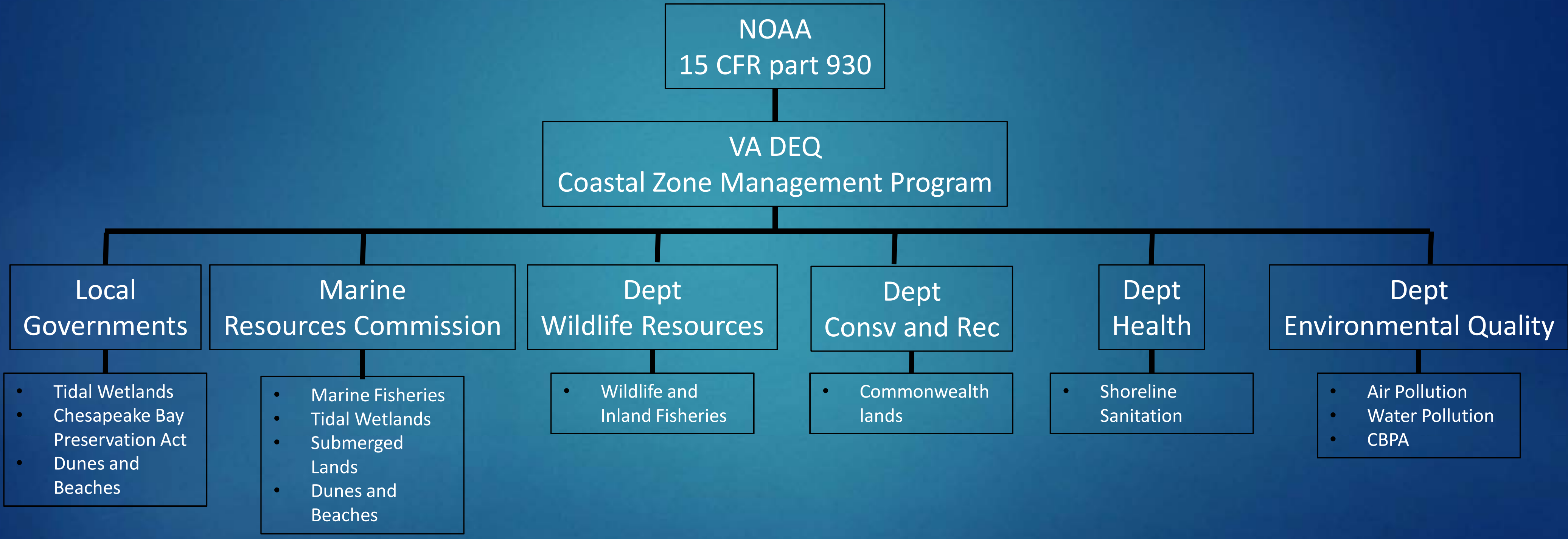
Public Notice & Site Visit

Joint Processing

Decision

MUST HAVE ALL FOUR PERMITS

CZM Consistency Review – Review Authority



NOAA
15 CFR part 930

VA DEQ
Coastal Zone Management Program

Local Governments
- Tidal Wetlands
- Chesapeake Bay Preservation Act
- Dunes and Beaches

Marine Resources Commission
- Marine Fisheries
- Tidal Wetlands
- Submerged Lands
- Dunes and Beaches

Dept Wildlife Resources
- Wildlife and Inland Fisheries

Dept Consv and Rec
- Commonwealth lands

Dept Health
- Shoreline Sanitation

Dept Environmental Quality
- Air Pollution
- Water Pollution
- CBPA

VMRC Enforceable Policies

- Marine Fisheries
  - State and Federal Waters – Ecosystem and Economics
    - Spawning, TOYR, Commercial and Recreational Harvest, Fish Habitat
  - Dunes and Beaches
    - Preserve, Protect, Restore, Enhance
  - Tidal Wetlands
    - Avoid, Minimize, Mitigate, No Net Loss
  - Submerged Lands
    - - effect on other uses, fisheries resources, tidal wetlands, adjacent properties, SAV.

Session 4: Environmental standards, compliance, best practices applied to marine minerals

MCKAY, L. – Coastal/ocean policy and planning (LMcKay.pdf)

Coastal/Ocean Policy & Planning

Mid-Atlantic Marine Heavy Mineral & Sands Forum

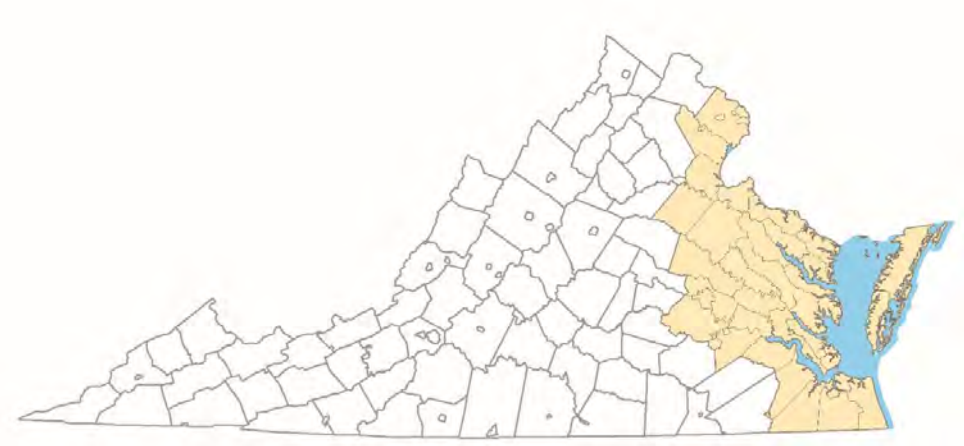
Laura McKay

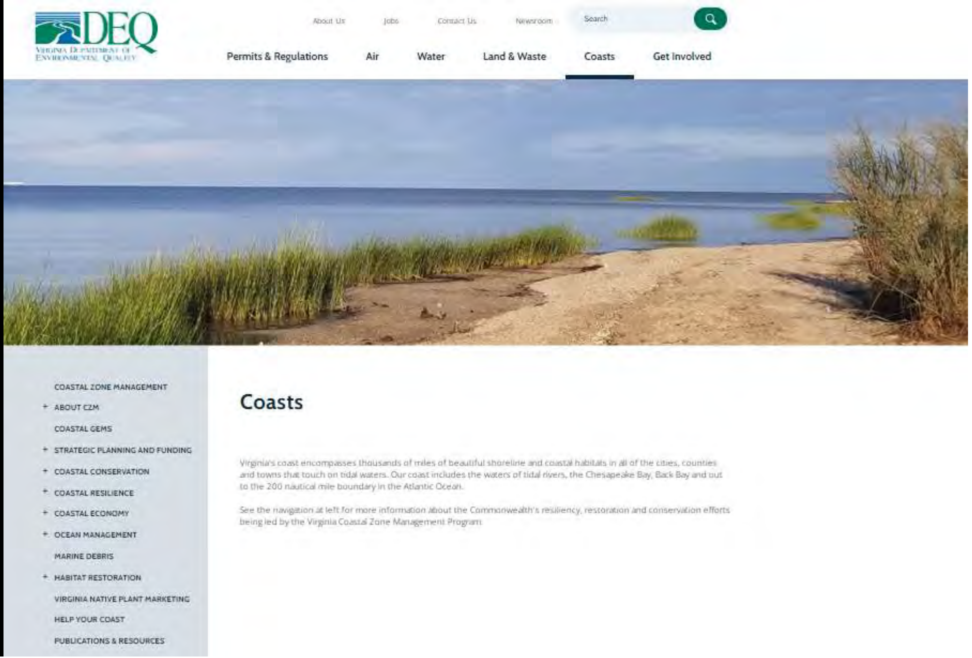
VA CZM Program Manager

Virginia Coastal Zone
MANAGEMENT PROGRAM

What is the Virginia CZM Program?

- Network of state agencies and coastal localities
- Guided by the inter-agency Coastal Policy Team led by CZM staff at DEQ
- Virginia Energy is a member
- All the coastal laws and policies incorporated into the program and approved by NOAA
- Funded 100% by NOAA with ~ $3M per year for grants
- www.deq.virginia.gov/coasts





Coasts

Virginia's coast encompasses thousands of miles of beautiful shoreline and coastal habitats in all of the cities, counties and towns that touch on tidal waters. Our coast includes the waters of tidal rivers, the Chesapeake Bay, Back Bay and out to the 200 nautical mile boundary in the Atlantic Ocean.

See the navigation at left for more information about the Commonwealth's resiliency, restoration and conservation efforts being led by the Virginia Coastal Zone Management Program.

VIRGINIA CZM PROGRAM

(DEQ LEAD COORDINATING AGENCY)

AIR POLLUTION
DEQ

SHORELINE SANITATION
VDH

DUNES & BEACHES
MRC &
Local Wetlands Boards

SUBAQUEOUS LANDS
MRC

POINT SOURCE

& NONPOINT SOURCE WATER POLLUTION
DEQ & Coastal Localities

MARINE FISHERIES
MRC

TIDAL AND NONTIDAL WETLANDS
MRC, DEQ &
Local Wetlands Boards

CHESAPEAKE BAY PRESERVATION AREAS
DEQ (CBPA)

PLANT PESTS & NOXIOUS WEEDS
VDACS

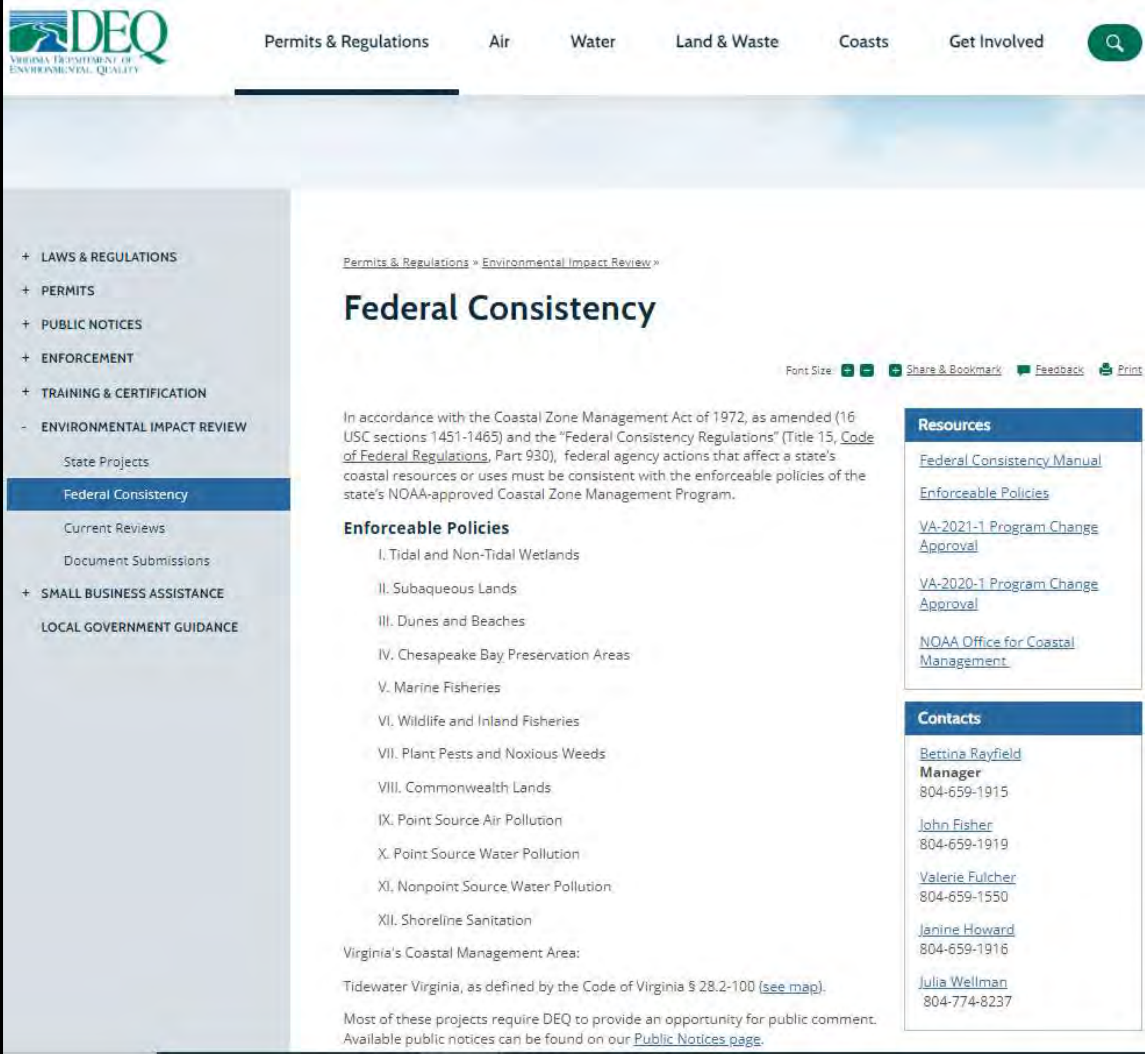
COMMONWEALTH LANDS
DWR & DCR

WILDLIFE & INLAND FISHERIES
DWR

Federal Consistency

- Federal actions must be consistent with NOAA-approved Virginia laws and policies

- DEQ can review federal actions that are on our NOAA-approved "Listed Activities"



Permits & Regulations » Environmental Impact Review »

Federal Consistency

In accordance with the Coastal Zone Management Act of 1972, as amended (16 USC sections 1451-1465) and the "Federal Consistency Regulations" (Title 15, Code of Federal Regulations, Part 930), federal agency actions that affect a state's coastal resources or uses must be consistent with the enforceable policies of the state's NOAA-approved Coastal Zone Management Program.

Enforceable Policies

I. Tidal and Non-Tidal Wetlands

II. Subaqueous Lands

III. Dunes and Beaches

IV. Chesapeake Bay Preservation Areas

V. Marine Fisheries

VI. Wildlife and Inland Fisheries

VII. Plant Pests and Noxious Weeds

VIII. Commonwealth Lands

IX. Point Source Air Pollution

X. Point Source Water Pollution

XI. Nonpoint Source Water Pollution

XII. Shoreline Sanitation

Virginia's Coastal Management Area:

Tidewater Virginia, as defined by the Code of Virginia § 28.2-100 (see map).

Most of these projects require DEQ to provide an opportunity for public comment. Available public notices can be found on our Public Notices page.

Resources

Federal Consistency Manual

Enforceable Policies

VA-2021-1 Program Change Approval

VA-2020-1 Program Change Approval

NOAA Office for Coastal Management

Contacts

Bettina Rayfield
Manager
804-659-1915

John Fisher
804-659-1919

Valerie Fulcher
804-659-1550

Janine Howard
804-659-1916

Julia Wellman
804-774-8237

Mid-Atlantic Ocean Planning

- VA, MD, DE, NJ, NY created MARCO in 2009

  (5 state Governor's Agreement on Ocean Conservation)

- Joined the Mid-Atlantic Regional Planning Body in 2013 and produced the Mid-A Ocean Plan in 2016

- MARCO created MACO in 2017

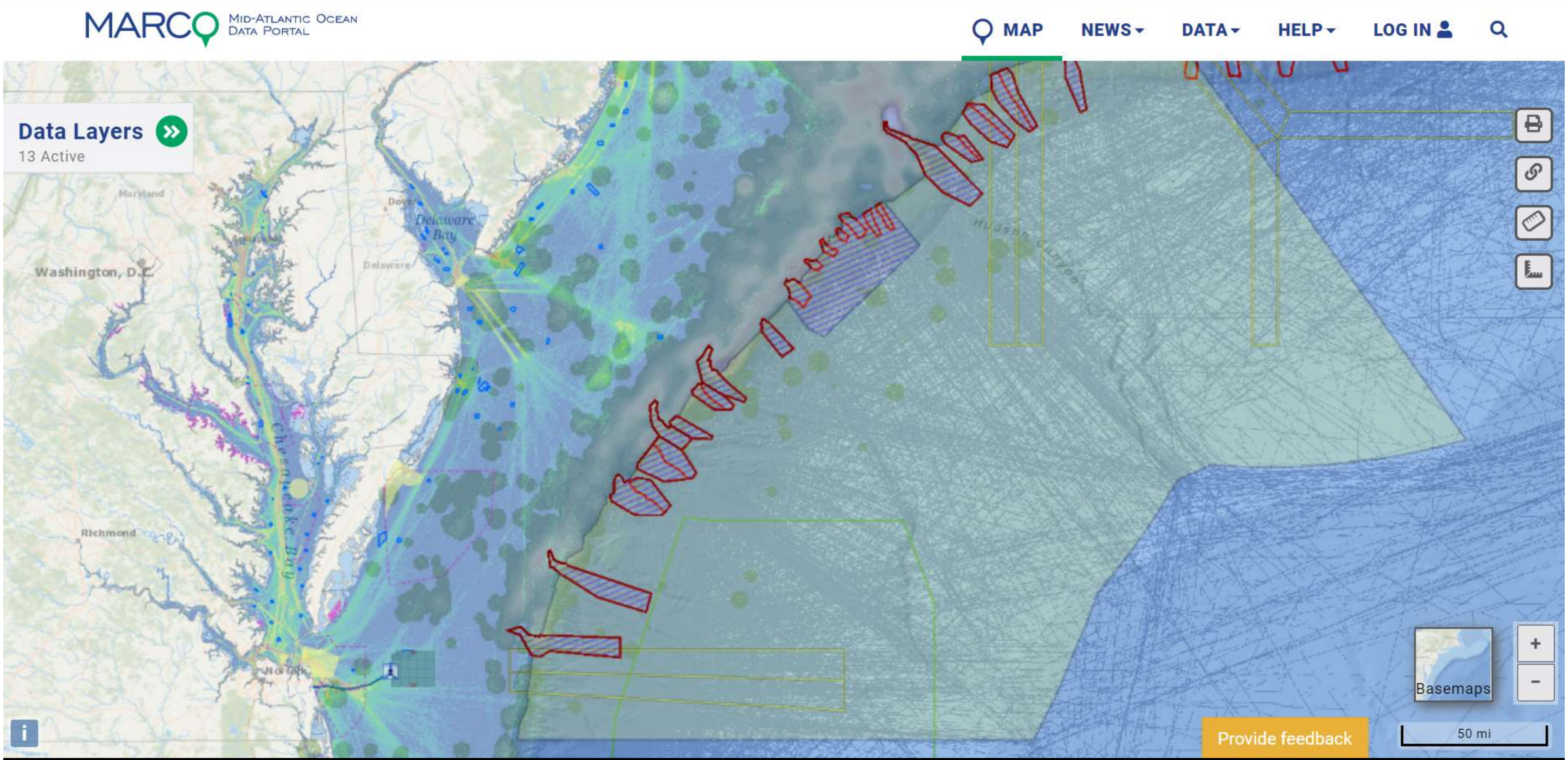
MARCO

MID-ATLANTIC REGIONAL COUNCIL ON THE OCEAN

MID-ATLANTIC COMMITTEE ON THE OCEAN

2010 Created MARCO Ocean Data Portal

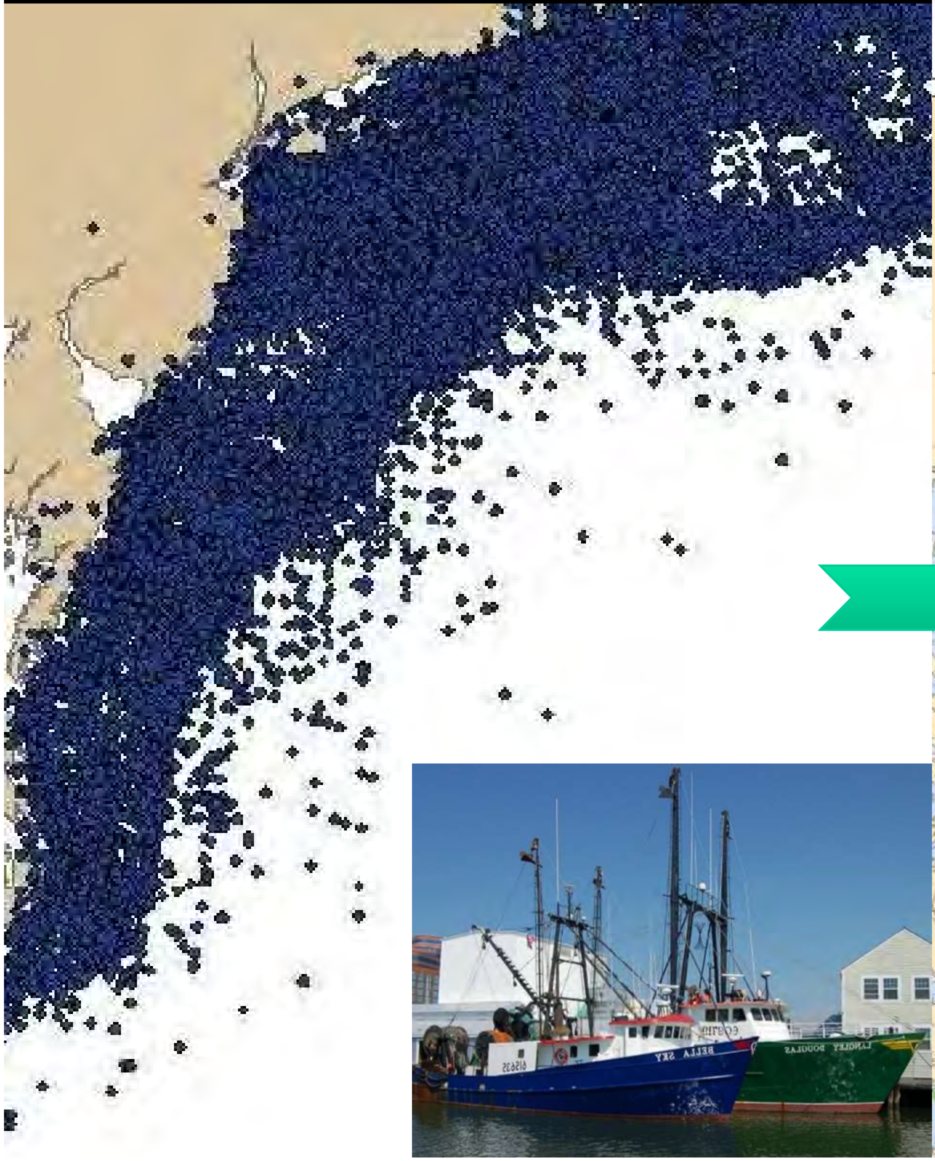
https://portal.midatlanticocean.org/

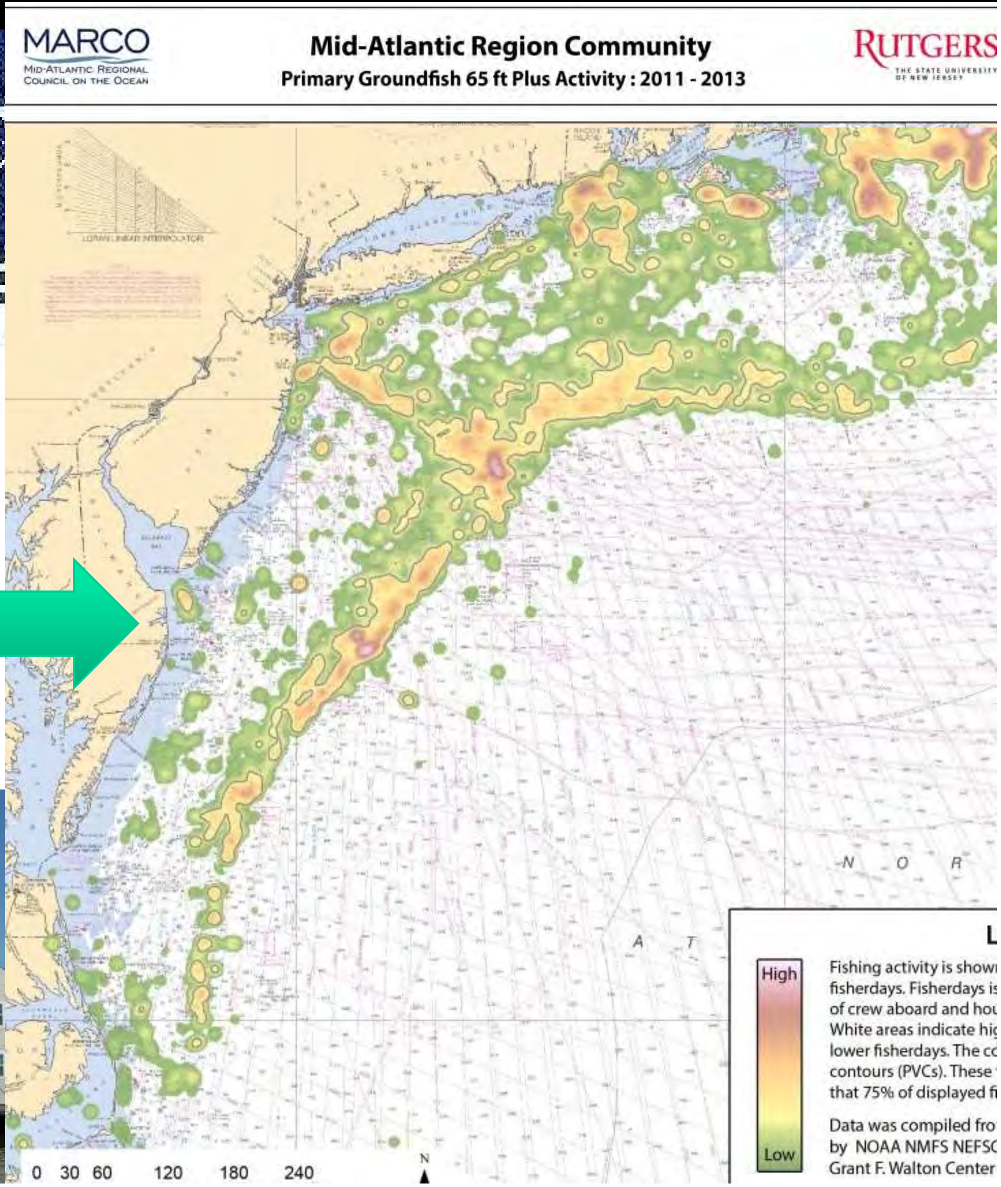


6,000+ maps in 12 themes: Administrative, Fishing, Fishing-Communities at Sea (by Port), Marine Life Library, Maritime, Oceanography, Recreation, Renewable Energy, Seafloor Habitat, Security, Socioeconomic, Water Quality

Ocean Resources of Concern

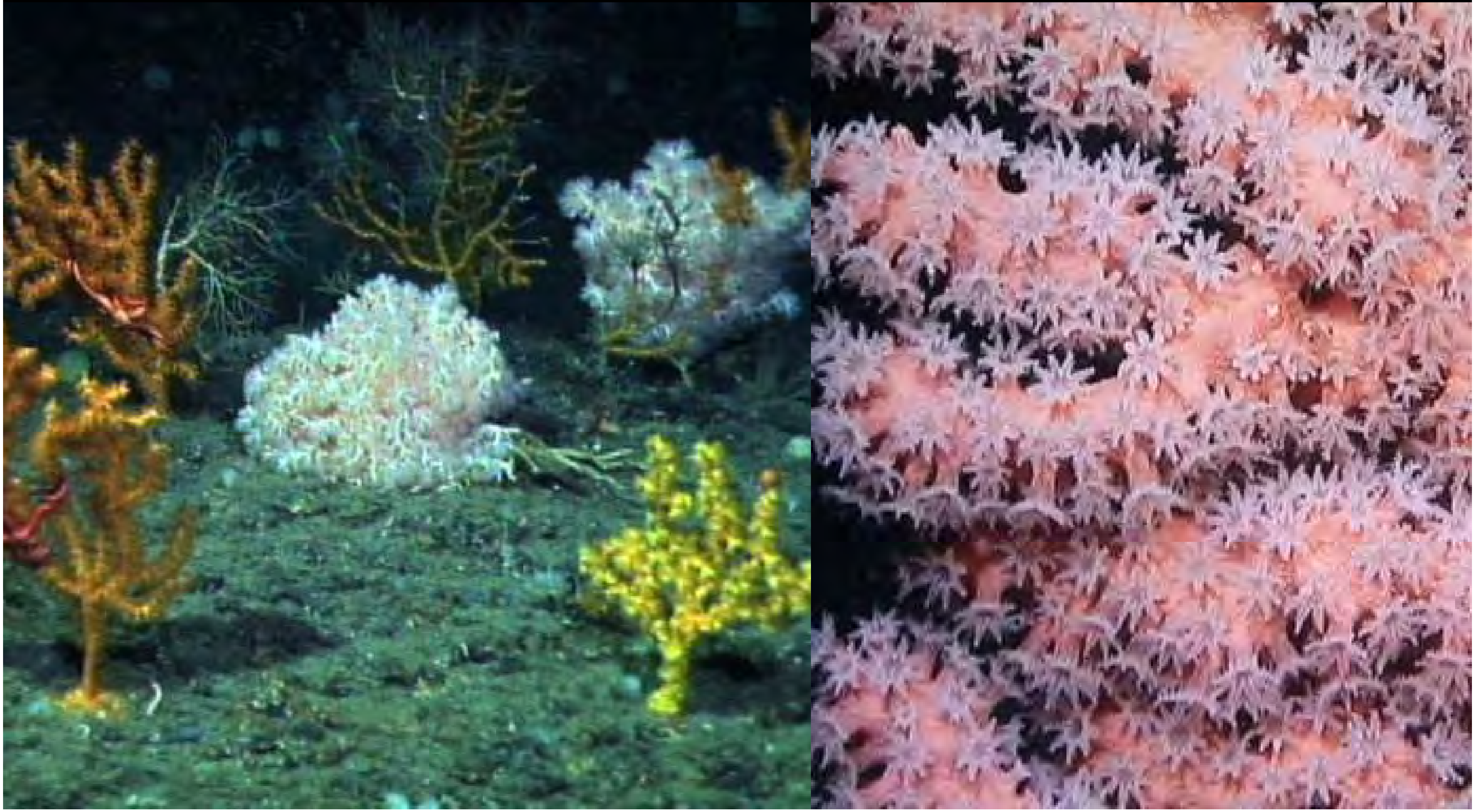
Important Fishing Areas: “Communities at Sea”





Ocean Resources of Concern

2016 Mid-A Fisheries Management Council Protects 38,000 sq. mi. of Canyon – Coral Habitat from Bottom Dredging



Ocean Resources of Concern

Marine Mammals and Other Protected Species

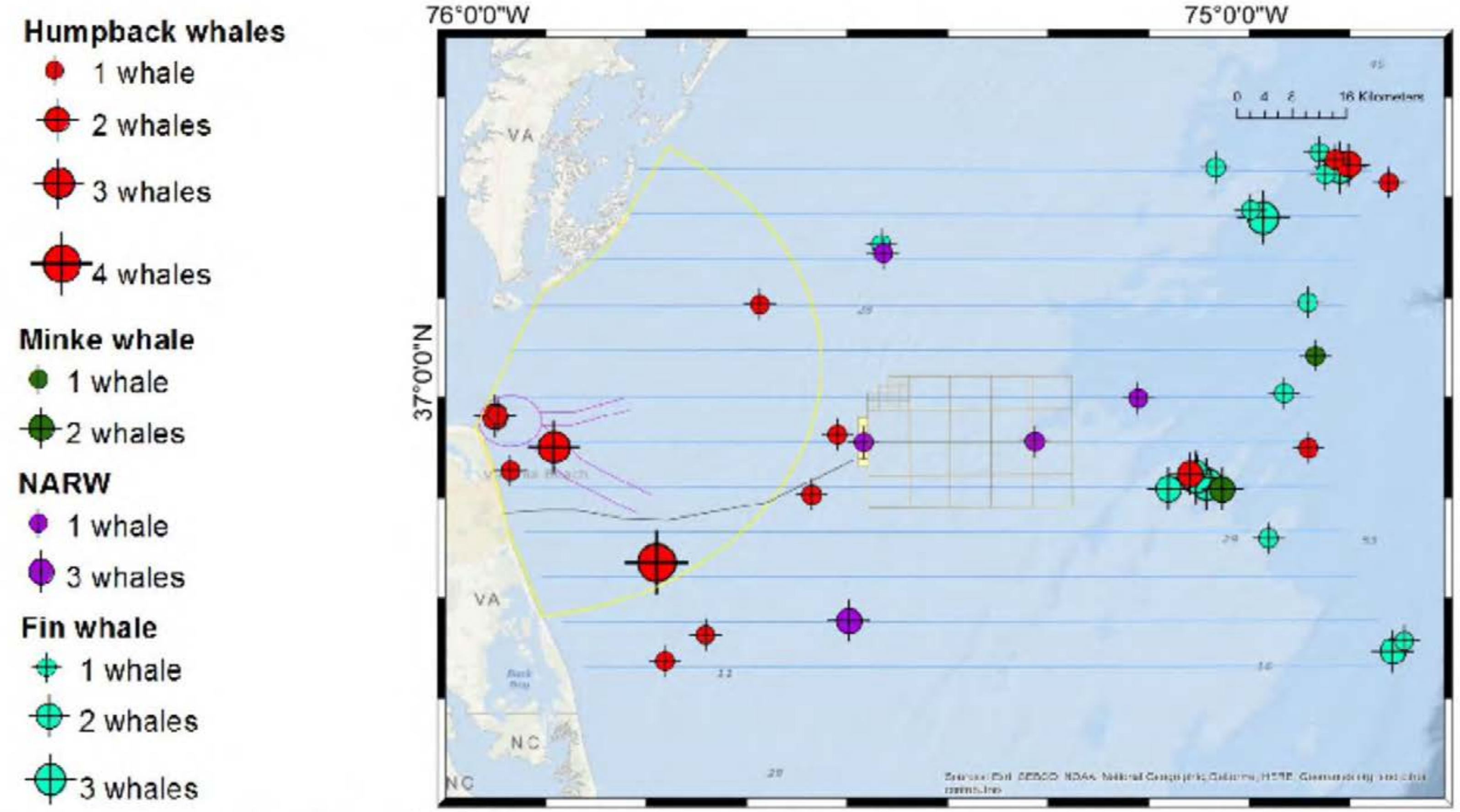
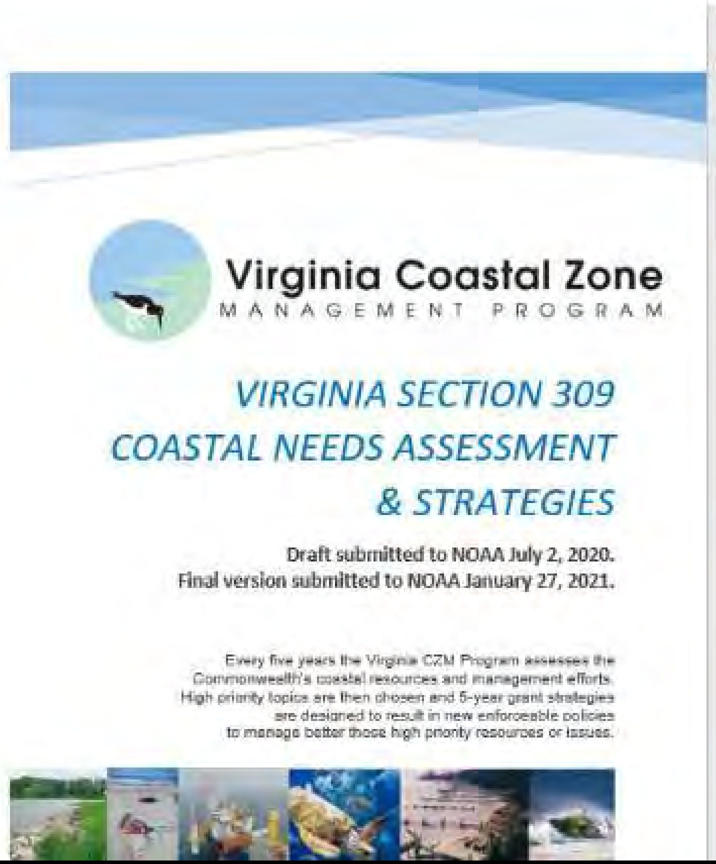


Figure 1. All large whales documented during aerial surveys in the proximity of the Virginia Wind Energy Area (VA WEA) from November 2012 through March 2015. Size of each point reflects groups size.

Aerial surveys were funded under Virginia Coastal Zone Management Grant NA14NOS4190141 Task 95.04

Current CZM 5-year Grant Strategies October 2021 – September 2026



Virginia Coastal Zone
MANAGEMENT PROGRAM

VIRGINIA SECTION 309
COASTAL NEEDS ASSESSMENT
& STRATEGIES

Draft submitted to NOAA July 2, 2020.
Final version submitted to NOAA January 27, 2021.

Every five years the Virginia CZM Program assesses the Commonwealth's coastal resources and management efforts. High priority topics are then chosen and 5-year grant strategies are designed to result in new enforceable policies to manage better those high priority resources or issues.

VIRGINIA SECTION 309 COASTAL NEEDS ASSESSMENT & STRATEGIES

Table of Contents

5-YEAR BUDGET SUMMARY BY STRATEGY

Strategy Title	Anticipated Funding Source (309 or other)	Year 1 Funding	Year 2 Funding	Year 3 Funding	Year 4 Funding	Year 5 Funding	Total
Coastal Hazards	309	$176,000	$167,000	$167,000	$167,000	$167,000	$844,000
Ocean Resource	309	$183,000	$183,000 XXXXXXX	$176,000	$176,000	$176,000	$894,000 XXXXXXX
Marine Debris	309	$170,000	$160,000	$160,000	$160,000	$160,000	$810,000
Total Funding		$529,000	$503,000	$503,000	$503,000	$503,000	$2,541,000

2021-25 CZM to Create a Virginia Ocean Plan

What is Your Vision for Virginia's Ocean?

Year 1 Grants

- W&M CPC: research other state plans, develop draft plan outline and communication strategy
- VCU Fisheries Coordinator: continue to address fisheries concerns
- DWR: update marine mammal/sea turtle conservation plans

Plan to address:

- Additional offshore wind leases
- Potential offshore aquaculture
- Marine habitat & fisheries protection
- Ocean acidification
- Climate impacts
- Military & shipping needs
- *Ocean sand & heavy minerals mining?*

Session 5: Advanced technologies for heavy minerals identification, assessment, and monitoring

TOMLINSON, J. – Insights from the BOEM Atlantic Sand Assessment Project (JTomlinson.pdf)

Insights from the BOEM Atlantic Sand Assessment Project

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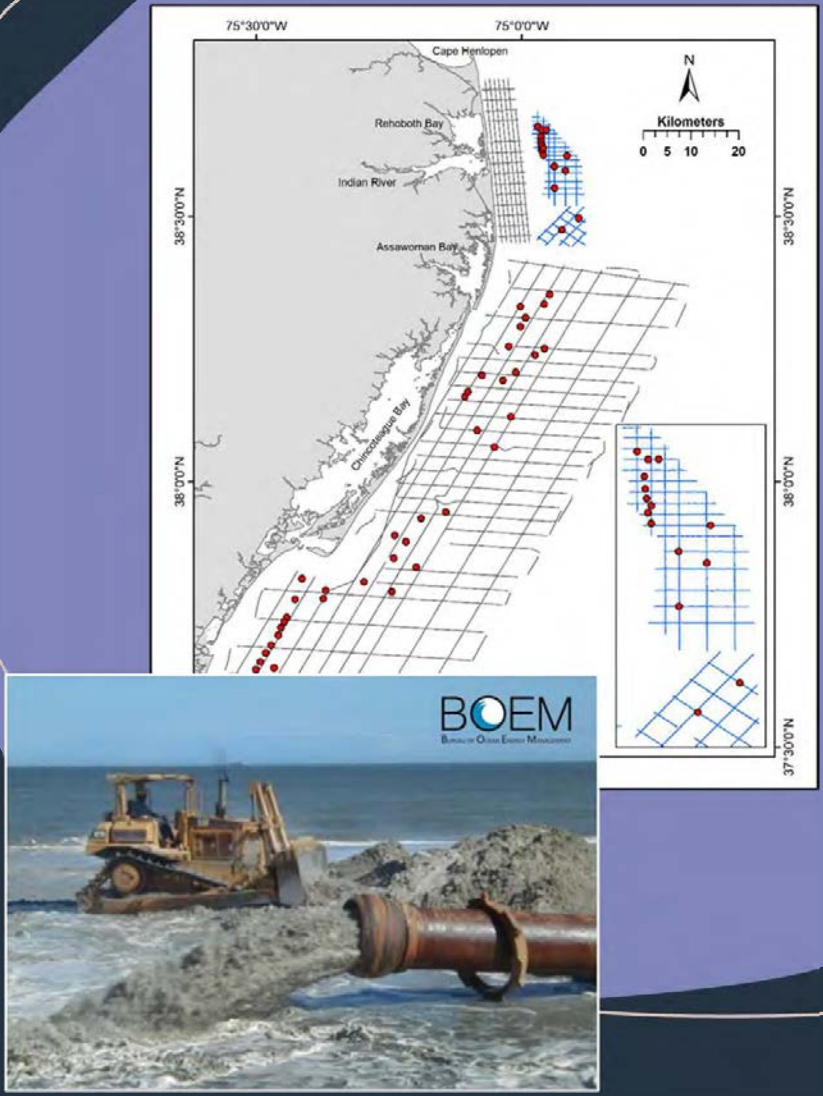
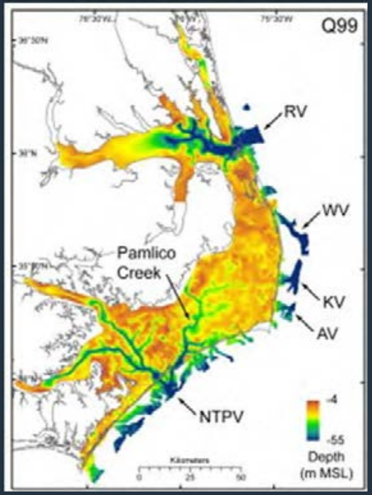
Delaware Geological Survey
C. Robin Mattheus
Illinois State Geological Survey
Kelvin Ramsey
Delaware Geological Survey

Project Overview

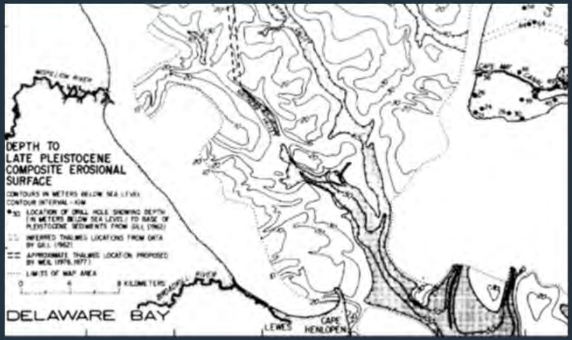
- Renewed offshore mapping activity was facilitated by the Bureau of Ocean Energy Management (BOEM) Atlantic Sand Assessment Project (ASAP)
  - Provided 100s of trackline kilometers of geophysical data
  - 60 vibracores from offshore DE, MD, and VA collected from 2015-2017
- Motivations
  - Primary
    - Hurricane Sandy response, recovery, and resiliency
    - Constraint of sand resources available in proximity to Delaware's coastal communities
  - Secondary
    - Improvement of stratigraphic framework models and mapping paleovalleys along the central to northern Delmarva



Offshore Geologic Mapping: Big Picture



Thieler et al. (2010)



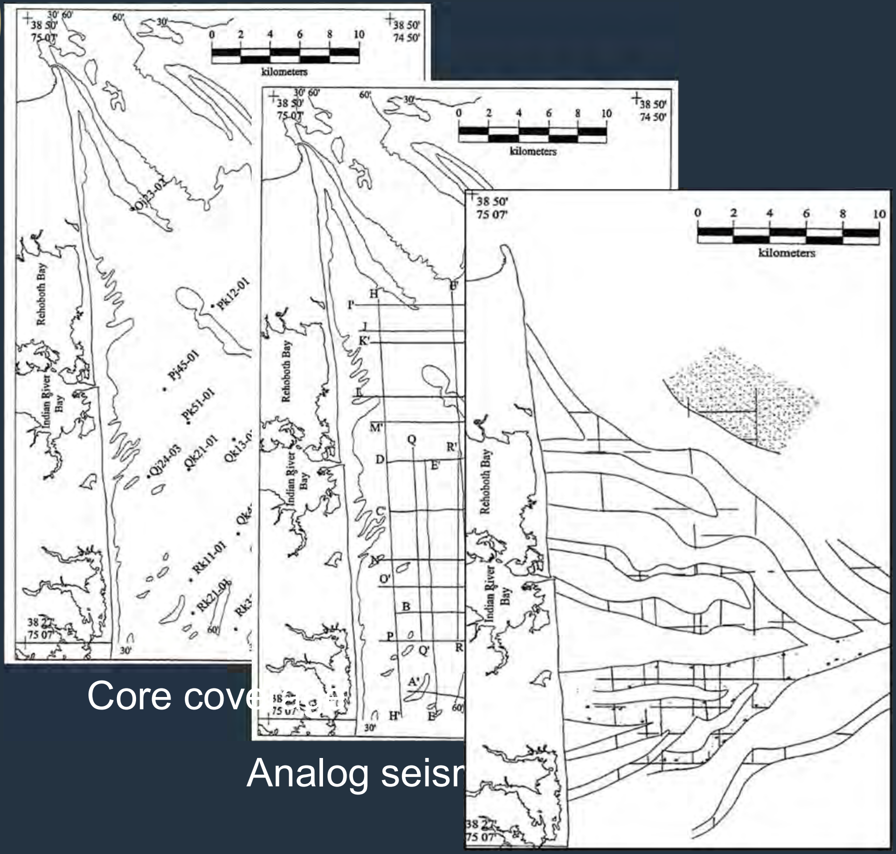
Knebel et al. (1988)

Metz, 2015

Improving stratigraphic maps and constraints of paleovalley locations is also important for:

- Offshore infrastructure design
- Characterizing groundwater flow pathways/submarine discharge
- Understanding Holocene coastal and seafloor evolution
- Parameterizing models of future change based on sea-level rise and storm-climate predictions

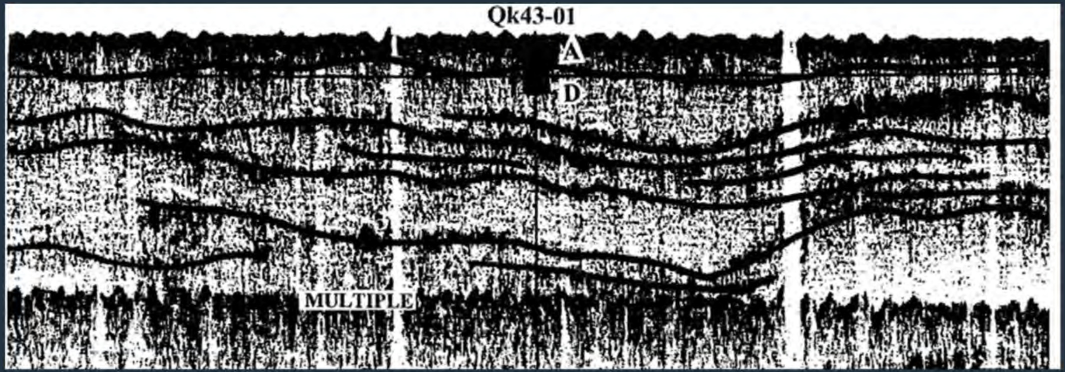
Previous Study: Williams (1999)

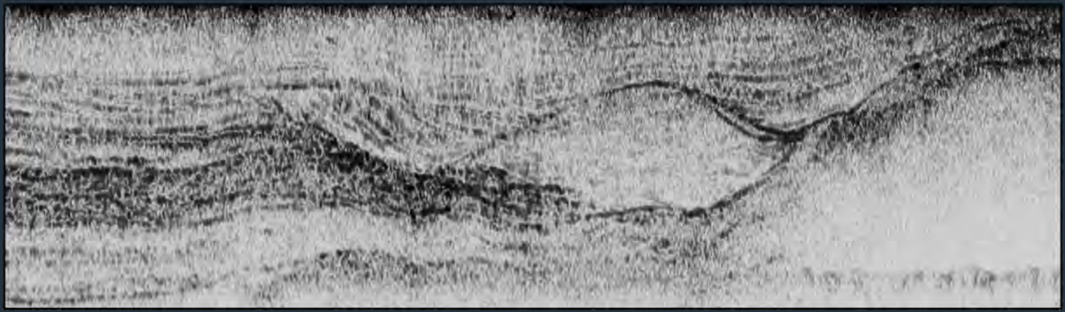


Core cove

Analog seis

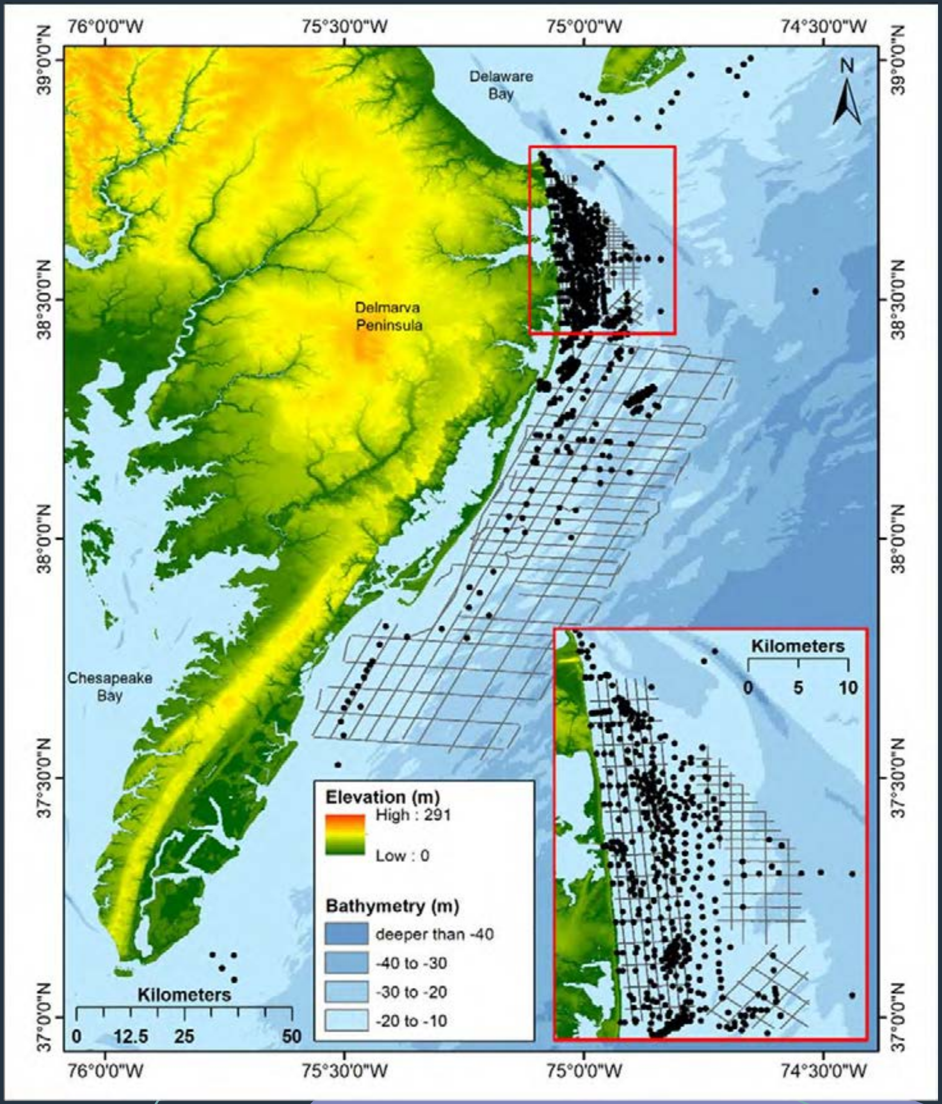
Offshore paleovalleys



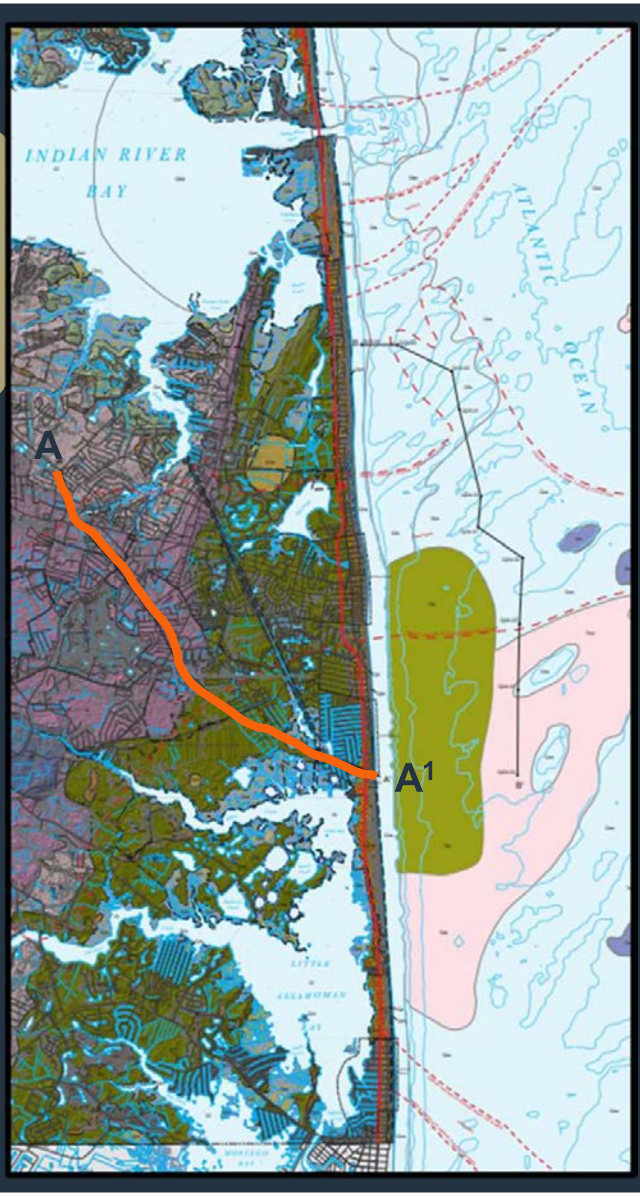


1990s Analog vs 2010s Digital

This Study



- Lithologic information (466 cores off DE; 230 cores of MD & VA)
  - DGS database information
    - Sediment texture
    - Stratigraphic picks
    - Photographs
    - Lithologic logs
    - Radiocarbon dates
    - AAR age estimates
- Marine geophysics
  - 'Chirper' seismic reflection
    - 1672 trackline km off the central Delmarva, from MD-DE state line to offshore Exmore, VA (USGS 2014 dataset)
    - ~500 trackline km in off DE (BOEM 2015 and DNREC 2013 dataset)



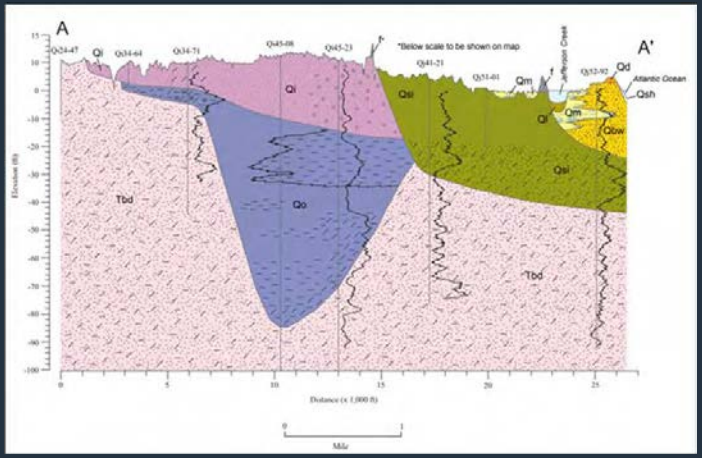
Lessons from Coastal Plain Mapping

Beaverdam Formation

- Heterogeneous unit (vc sand with pebbles to silty clay)
- Laminae and beds of vc sand with pebbles to gravel common
- Absence of shells
- Sands have a white silt matrix that gives samples a milky appearance when wet

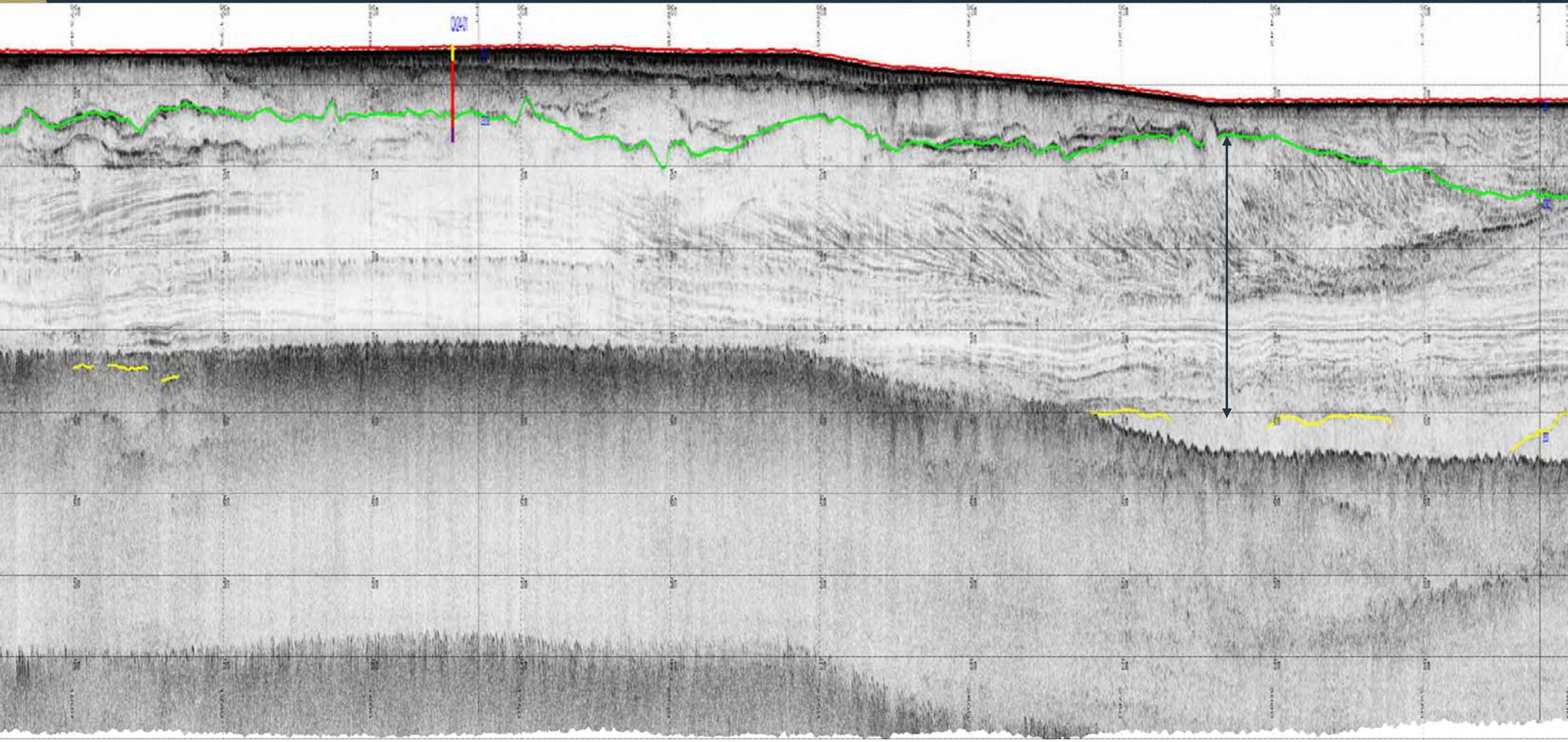
Omar Formation

- Gray clays
- Varying % of organics
- Silt and sand laminae common
- M sand beds common

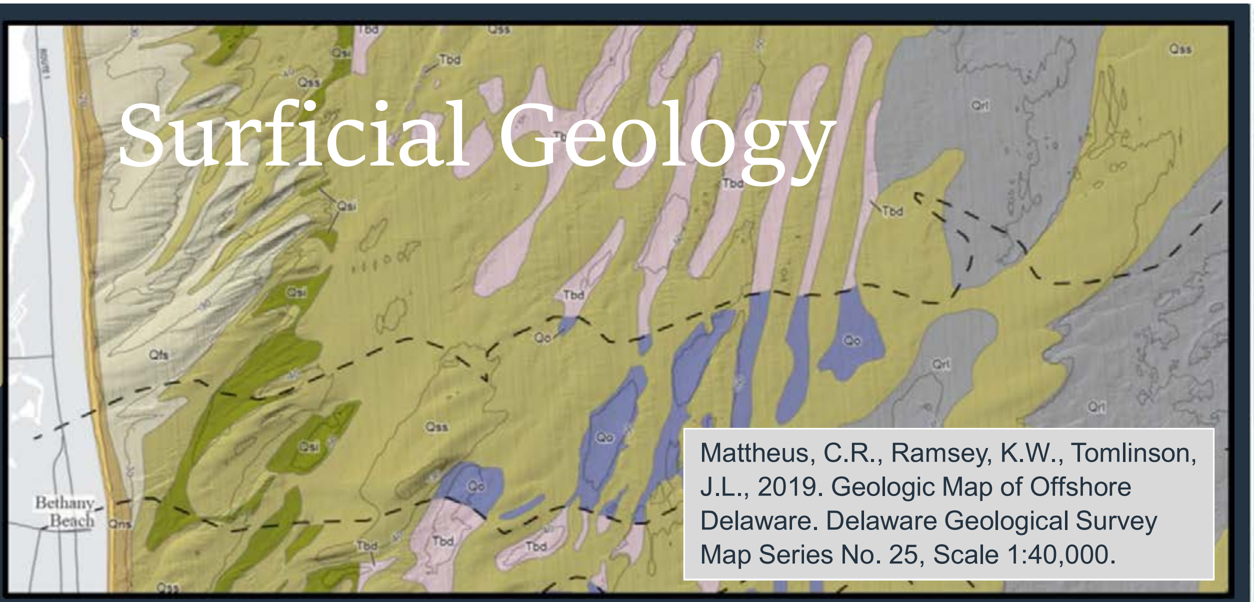


Ramsey and Tomlinson, 2012

Stratigraphic Framework Offshore Delaware

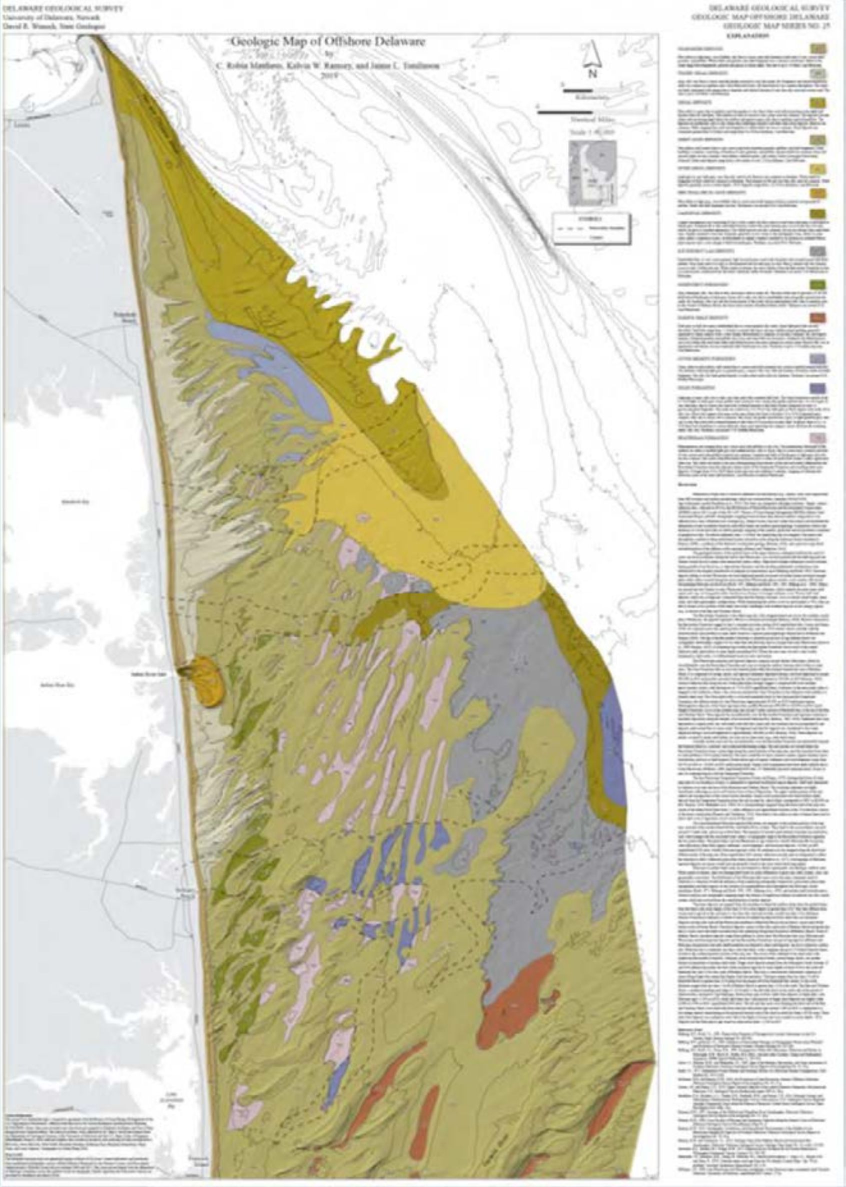


Surficial Geology



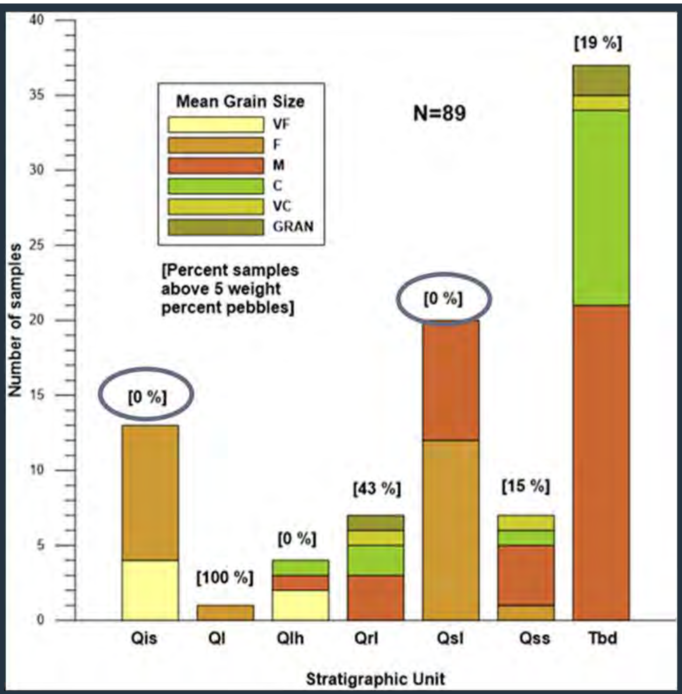
Mattheus, C.R., Ramsey, K.W., Tomlinson, J.L., 2019. Geologic Map of Offshore Delaware. Delaware Geological Survey Map Series No. 25, Scale 1:40,000.

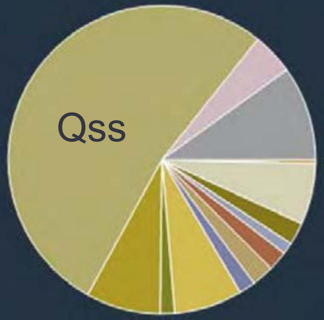
- Strongly influenced by underlying structure (e.g., paleovalleys versus interfluves)
- Sheet sands are mostly thin and discontinuous, and are sourced (at least in part) by the reworking of the Beaverdam Formation
- Textural variances of Holocene sediments dictated largely by modern hydrodynamics



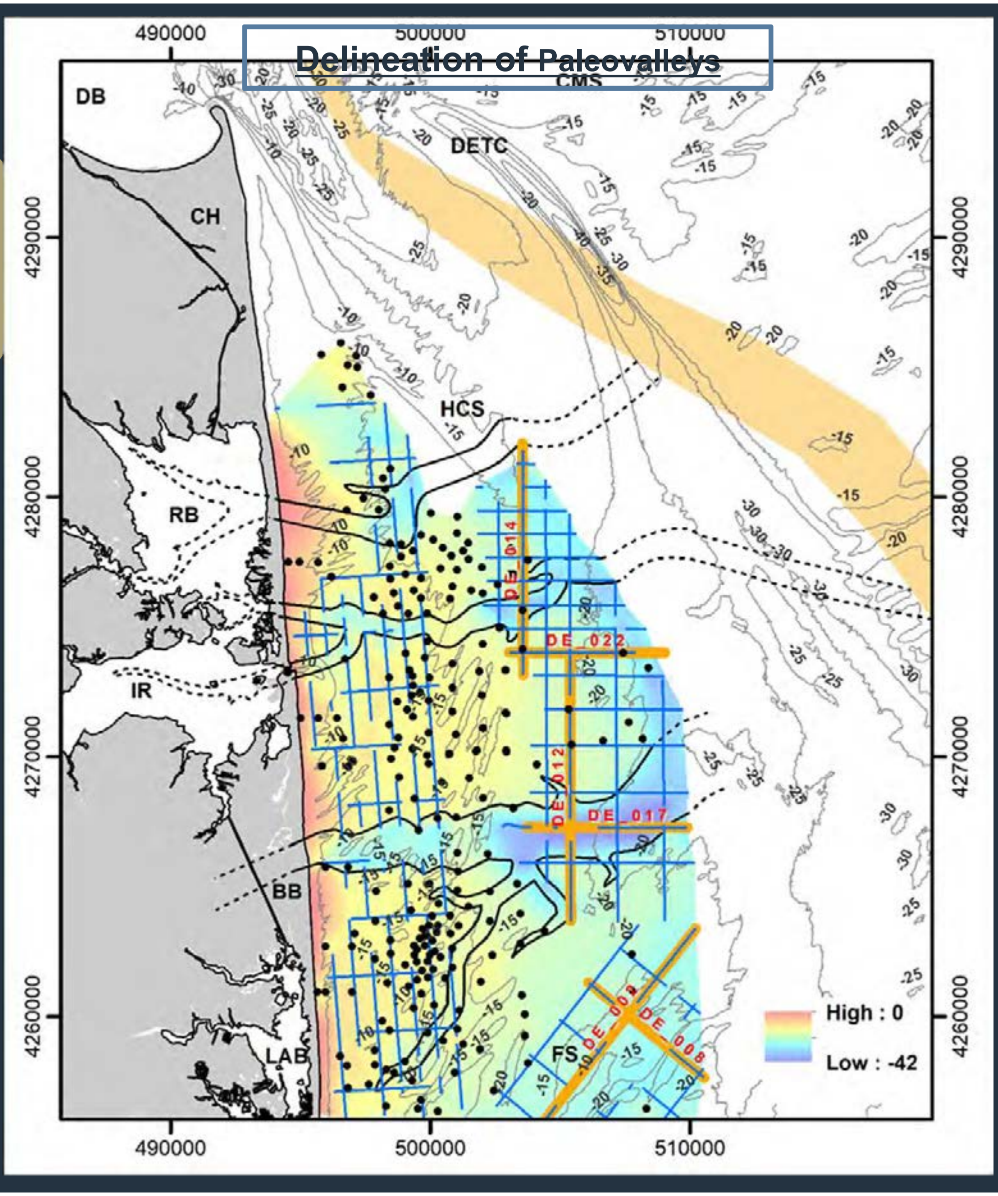
Map Unit	Defining Unit Characteristics	Unit Age	Environmental Interpretation	Formation Name	Resource Potential
Qets	White to light-gray, fine to very fine mud-laminated sand.	Holocene	Ebb-tidal delta	NA	Poor
Ql	Dark olive-gray, slightly silty clay with sandy burrows.	Holocene	Estuarine central basin	NA	None
Qo	Interbedded dark-gray silty clay and fine-medium clayey to silty sand.	Pleistocene	Estuarine central basin	Omar	None
Qrl	Gray, poorly-sorted sands and gravels.	Unknown	High-energy, shallow shelf during inundation	NA	Poor
Qss	Light yellowish-brown medium sand with scattered quartz and chert pebbles, shell fragments, and heavy minerals	Holocene	Mid-shelf shoal	NA	Excellent
Qlh	Shell-rich, mottled and slightly oxidized brown to dark gray silt and very fine sand with heavy mineral laminae.	Pleistocene	Subtidal to intertidal lagoon	Lynch Heights	None
Tbd	Light-gray, interbedded silty sands ranging from fine to very coarse with scattered Q and chert pebbles and heavy mineral laminae.	Pliocene-Pleistocene	Fluvio-deltaic braid plain	Beaverdam	Poor to Excellent
Qms	Interbedded and burrowed very dark gray to black fine silty sands, clays, and gravels.	Pleistocene	Estuarine/marine	NA	None
Qsl	Well sorted, pale yellowish-gray fine to medium sands with zones of abundant dark gray clay-lined burrows.	Holocene	Shoal	NA	Excellent
Qis	Greenish-black, bioturbated and silty, very fine to fine sand containing organic debris.	Holocene	Low-energy marine/inter-shoal	NA	Poor to good
Qfs	Tan to yellowish, well-sorted fine to medium sands, shelly, heavy minerals and few silty burrows.	Holocene	Inner shelf shoals	NA	Excellent

Some litho-units represent excellent sand resources



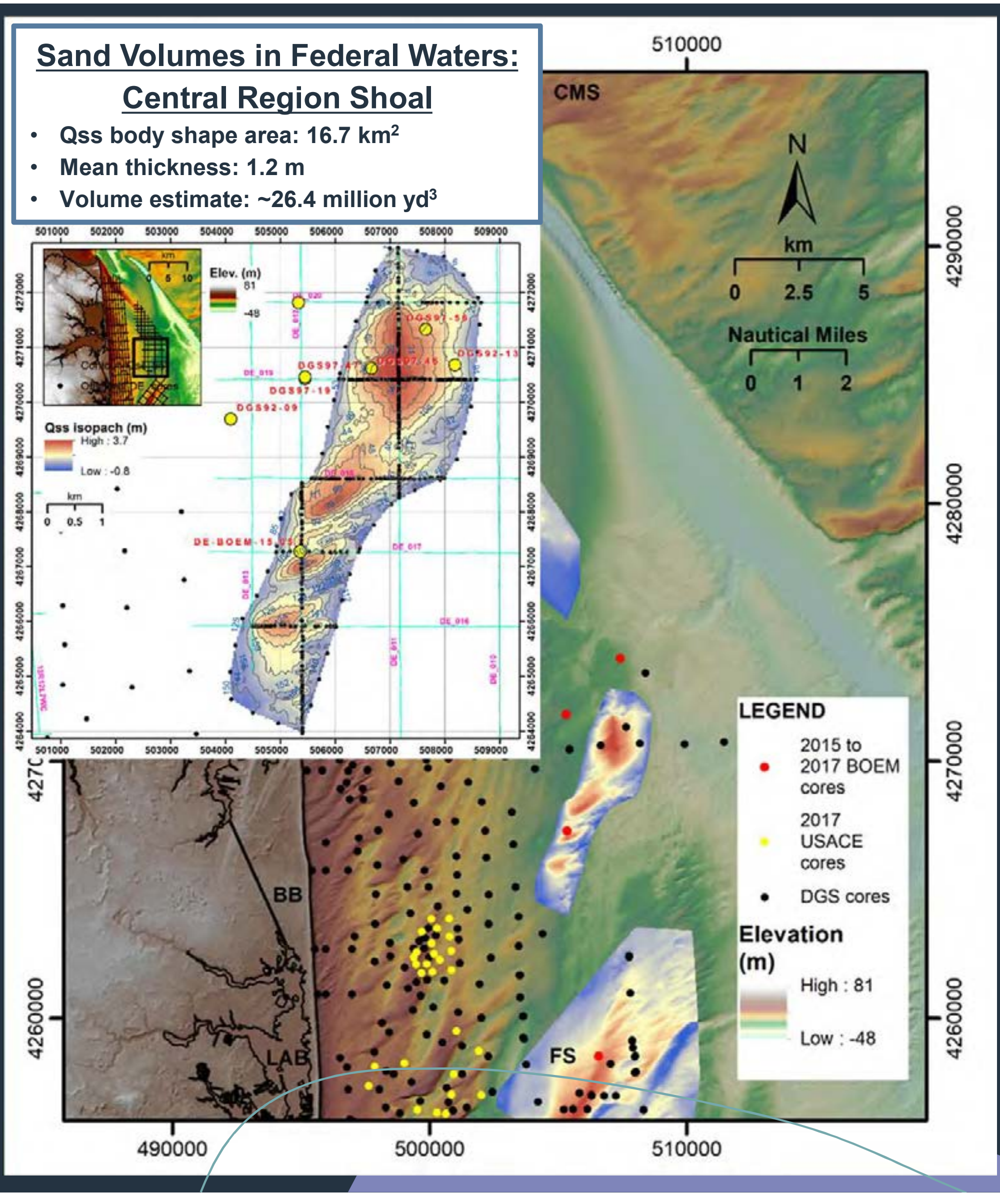


Delineation of Paleovalleys



Sand Volumes in Federal Waters: Central Region Shoal

- Qss body shape area: 16.7 km^2
- Mean thickness: 1.2 m
- Volume estimate: ~26.4 million yd^3



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GRAMMATIKOPOULOS, T. – Mineralogical and geochemical investigation of REE offshore sands from Virginia, USA (TGrammatikopoulos.pdf)

Natural Resources – North America

Metallurgy & Consulting

Delivering Metallurgical Expertise Across The Entire Mining Life Cycle

Mineralogy of Mineral Sand Samples, Virginia, USA

Tassos Grammatikopoulos, SGS Canada

William L. Lassetter Virginia Department of Energy Geology and Mineral Resources Program

VDEGMRP - SGS | March 31, 2022

SGS MINERALS

AGENDA

1. ABOUT SGS – LAKEFIELD SITE
2. AUTOMATED MINERALOGY
3. HLS, GEOCHEMISTRY
4. MINERALOGICAL DELIVERABLES
5. CONCLUSIONS
6. Q & A

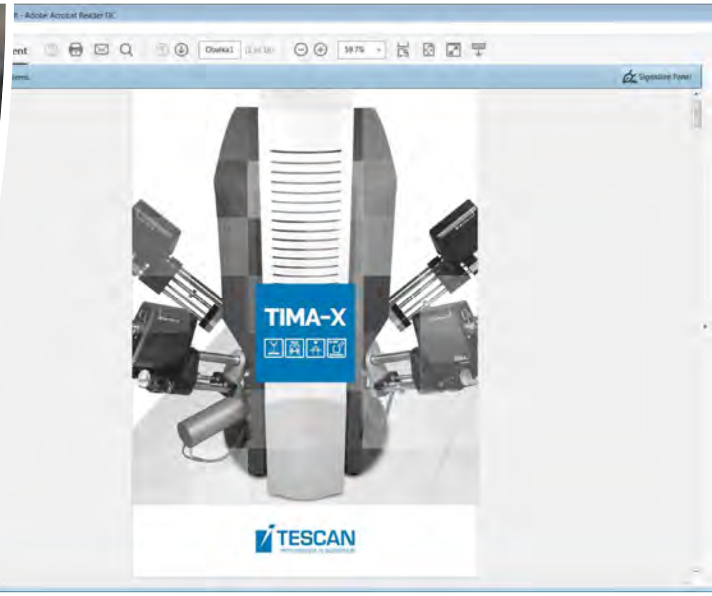
SGS Lakefield Site Capabilities

- Metallurgy
  - Mineral Processing
  - Extractive Metallurgy (Gold and Hydromet)
  - Solid-Liquid Separation and Rheology
  - Environmental Metallurgy
- Mineralogy
- Geochemistry

- 250 skilled staff
- Specialization in flowsheet development solutions for complex metallurgy and integrated processes
- Extensive piloting capabilities
- Vast experience with sulphide mineral systems and precious metals

Mineralogy

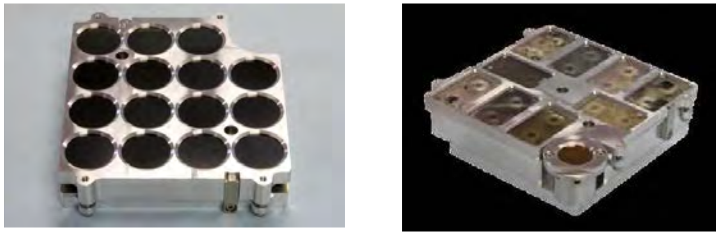
- QEMSCAN/TIMA-X Mineralogical analysis
- X-ray Diffraction Analysis
- NIR
- FTIR
- Optical microscopy
- Electron Microscopy
- Electron Microprobe Analyses
- LA-ICP-MS, ToF SIMS, D-SIMS, Raman, TEM
- Geochemistry



TIMA-X Hardware

- Field Emission (FEG), with GM-Chamber (*ion pumps and gun valve)*
- Typical working conditions: 25 kV, WD (working distance) 15 mm, probe current 7 nA
- 2 million counts per second
- Calibration on a Pt Faraday cup
- 15 epoxy blocks (ϕ 30 mm)
- 22 epoxy blocks (ϕ 25 mm)
- 9 thin sections (27 x 47 mm)

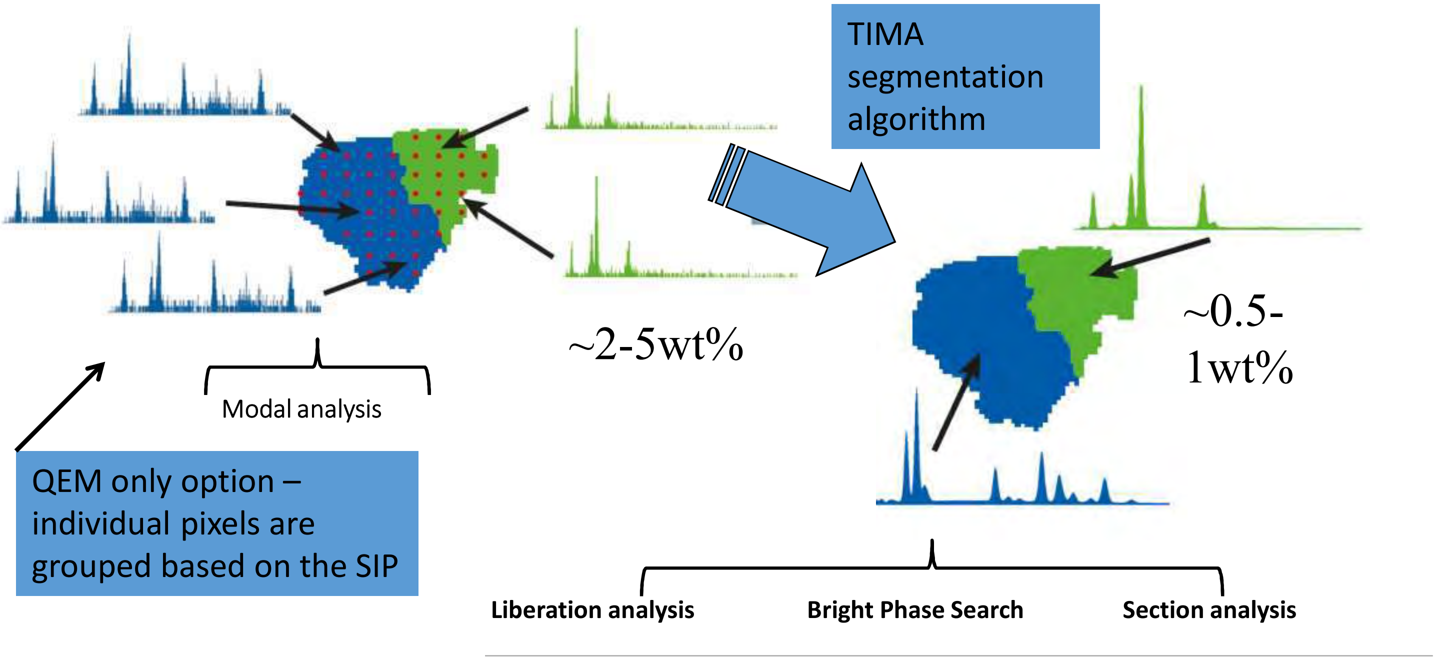
Active anti-vibration table



No rotation of the stage for better precision

Detection Limits in a Single Phase - Patented TESCAN Segmentation Algorithm

- TIMA Measurements (modal or segmented data):



TIMA segmentation algorithm

~2-5wt%

~0.5-1wt%

Modal analysis

QEM only option – individual pixels are grouped based on the SIP

Liberation analysis **Bright Phase Search** **Section analysis**

Heavy Liquid Separation (HLS)

- HLS at 3.1 SG to concentrate the heavy minerals
- Mass balance to determine the wt% distribution
- Mass balance for elements of interest

Sample ID	**Initial wt/g**	**wt%**	**Sample ID**	**Initial wt/g**	**wt%**
R-11945c	299.79	100.0	R-11961c	126.35	100.0
Sink	65.81	22.0	Sink	21.00	16.6
Float	233.98	78.0	Float	105.35	83.4
R-11947c	303.05	100.0	R-11962c	221.7	100.0
Sink	46.01	15.2	Sink	134.2	60.5
Float	257.04	84.8	Float	87.5	39.5
R-11948c	54.7	100.0	R-11964c	206.3	100.0
Sink	3.27	6.0	Sink	21.65	10.5
Float	51.43	94.0	Float	184.65	89.5

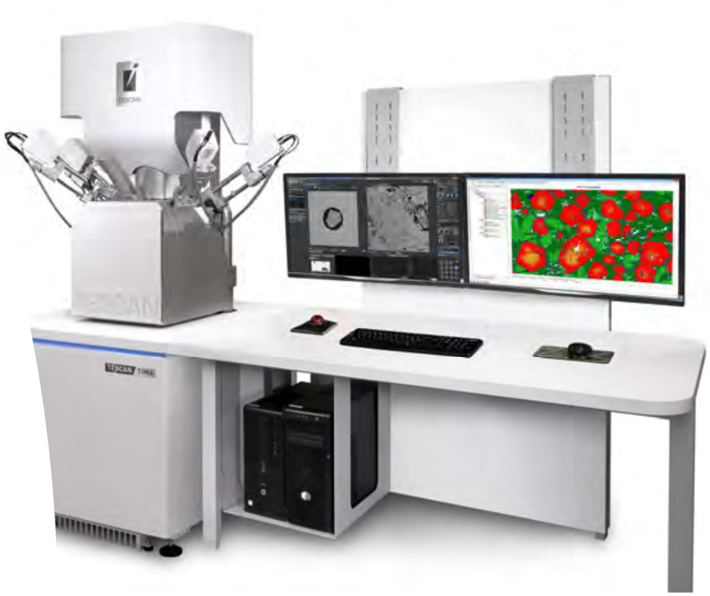
Geochemistry

- Each sink fraction, a 2-5 g sub-sample was obtained to complete the following chemical assays
  - sodium peroxide fusion ICP-MS analysis (IMS93A) for REE, Th, U, Cs, Ga, In, Nb, Rb and Ta
  - sodium peroxide fusion ICP-AES analysis (ICP93A) for Al, Ca, Cr, Fe, K, Mg, Mn, Si, Ti and V, Sc, and Zr
  - strong acid digest / ICP-AES (ICP42C) for 30 element
  - ICM90A for As, Ge and Hf.

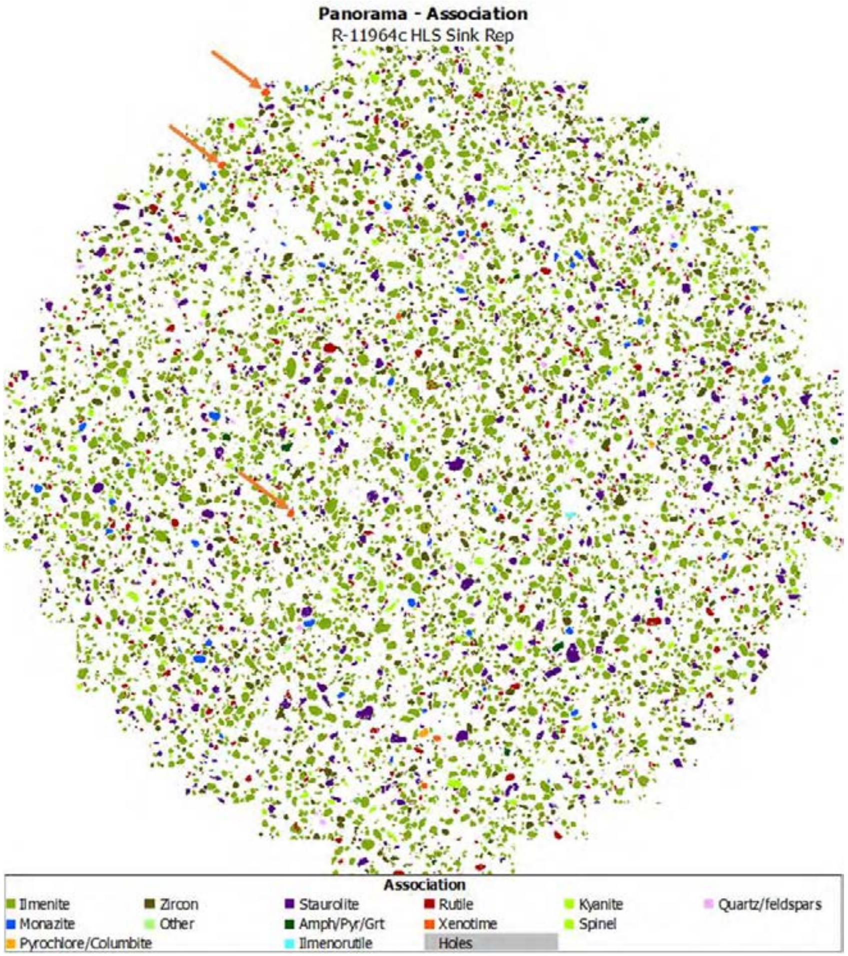
Sample ID	La g/t	Ce g/t	Pr g/t	Nd g/t	Sm g/t	Eu g/t	Gd g/t	Tb g/t	Dy g/t	Ho g/t	Er g/t	Tm g/t	Yb g/t	Lu g/t	Y g/t	Total REE+Y	LREE	HREE	LREE/HREE
R-11945c HLS Sink	139	286	32	114	19	1	16	2	11	2	8	2	11	2	15	660	591	69	8.6
R-11947c HLS Sink	344	704	79	306	56	2	35	5	24	5	17	3	24	4	41	1648	1492	156	9.6
R-11949c HLS Sink	299	638	74	267	50	3	38	4	27	5	20	3	26	5	37	1498	1331	167	8.0
R-11951c HLS Sink	225	494	57	216	38	3	32	4	25	7	23	4	33	6	35	1200	1033	167	6.2
R-11953c HLS Sink	363	763	85	326	55	3	36	4	24	5	18	3	24	5	34	1747	1594	153	10.4
R-11955c HLS Sink	242	520	59	217	40	2	27	4	22	4	16	3	20	4	31	1211	1080	131	8.3
R-11956c HLS Sink	372	779	88	317	58	3	43	5	26	5	18	3	25	5	37	1784	1617	167	9.7
R-11960c HLS Sink	111	253	29	103	17	1	15	3	24	6	26	5	45	9	15	663	514	149	3.4
R-11961c HLS Sink	112	220	27	94	16	2	19	3	26	7	33	6	47	10	16	638	471	166	2.8
R-11962c HLS Sink	94	190	22	73	16	2	17	3	34	9	43	8	59	13	17	599	397	203	2.0
R-11964c HLS Sink	817	1630	178	629	108	5	76	11	70	14	48	7	54	10	97	3754	3367	387	8.7
R-11965c HLS Sink	139	277	34	116	20	1	15	3	22	6	24	4	36	7	16	722	587	134	4.4
R-11968c HLS Sink	93	190	22	77	16	1	12	2	14	5	23	4	33	7	10	509	399	110	3.6
R-11969c HLS Sink	132	271	31	124	23	1	17	2	18	5	24	4	36	7	11	707	581	126	4.6
R-11970c HLS Sink	124	275	32	117	19	1	21	3	31	9	43	7	60	13	15	770	568	203	2.8
R-11971c HLS Sink	174	361	38	136	27	1	25	4	40	11	48	9	77	16	22	988	737	251	2.9
R-12149c HLS Sink	223	473	55	197	37	3	28	4	19	4	13	3	19	4	30	1109	987	122	8.1
R-11948c HLS Sink	315	678	77	295	50	5	50	8	56	12	49	9	67	11	72	1754	1420	334	4.3
R-11958c HLS Sink	420	898	105	399	67	7	61	8	53	12	42	7	54	10	93	2234	1895	339	5.6
R-12147c HLS Sink	1540	3200	348	1250	220	9	154	22	128	25	86	13	97	16	185	7292	6567	725	9.1

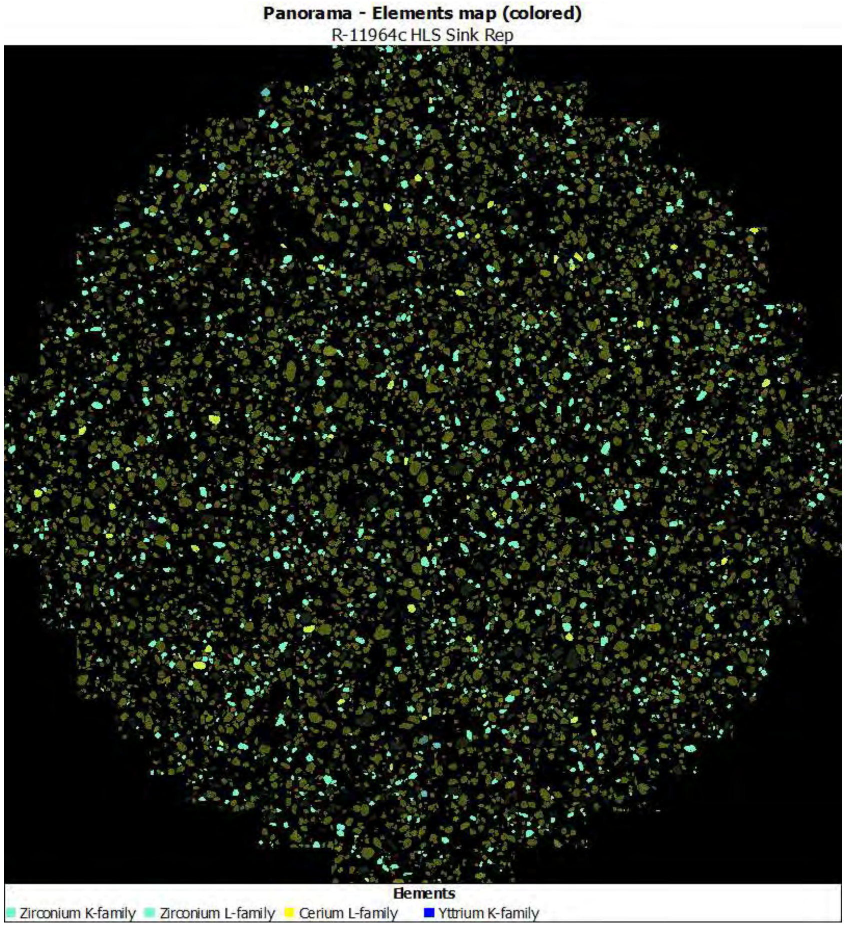
Mineralogy

- Modal mineralogy
- Grain and particle size
- Liberation/association
- Particle maps
- Element deportment
- Shape factors
- Grade-recovery



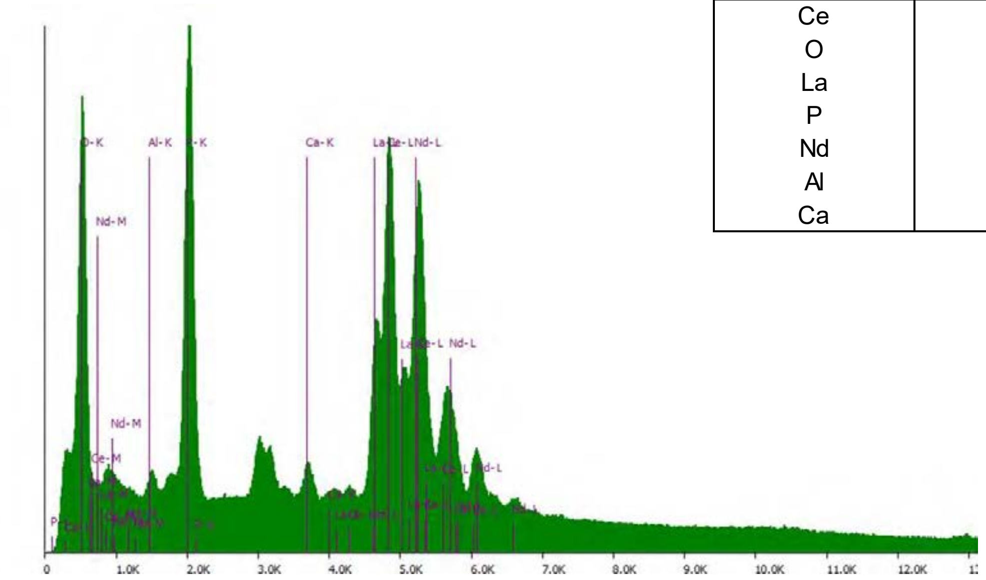
TIMA-X- Panorama – Illustrates the Entire Sample



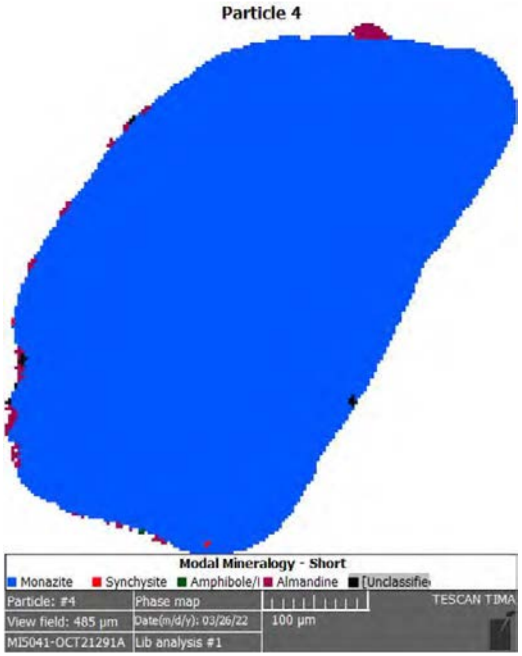


TIMA-X Analysis – Classification Scheme

- Mineral identification is based on the X-rays



Element	weight %
Ce	30.7
O	27.1
La	14.5
P	12.9
Nd	11.7
Al	2.0
Ca	1.2



TIMA-X Analysis – Classification Scheme

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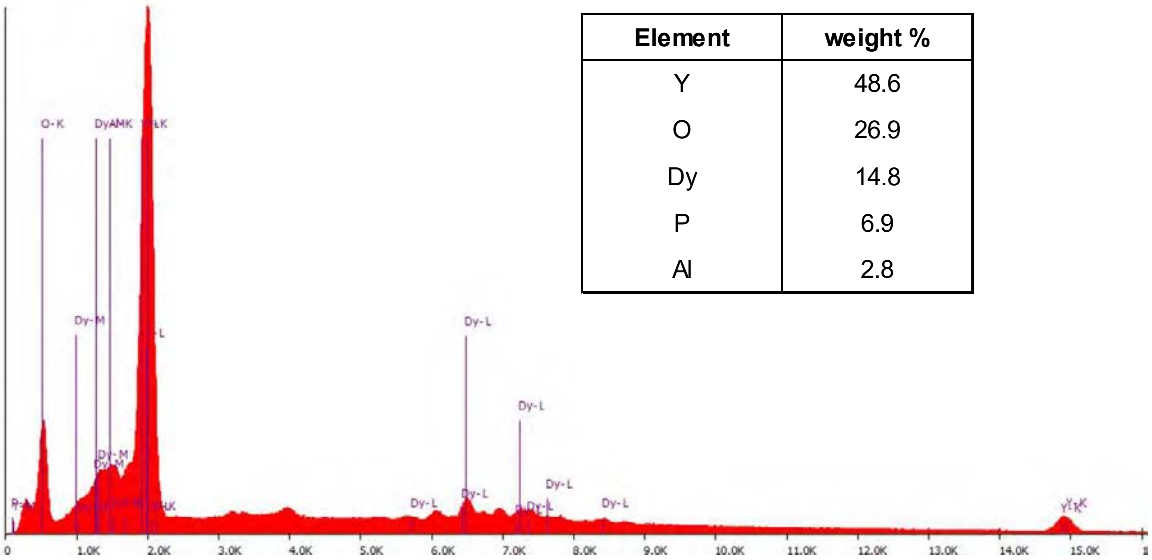
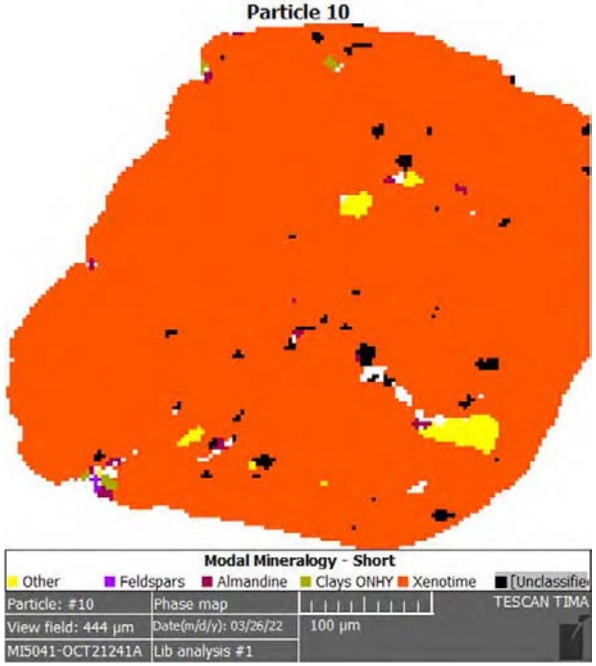
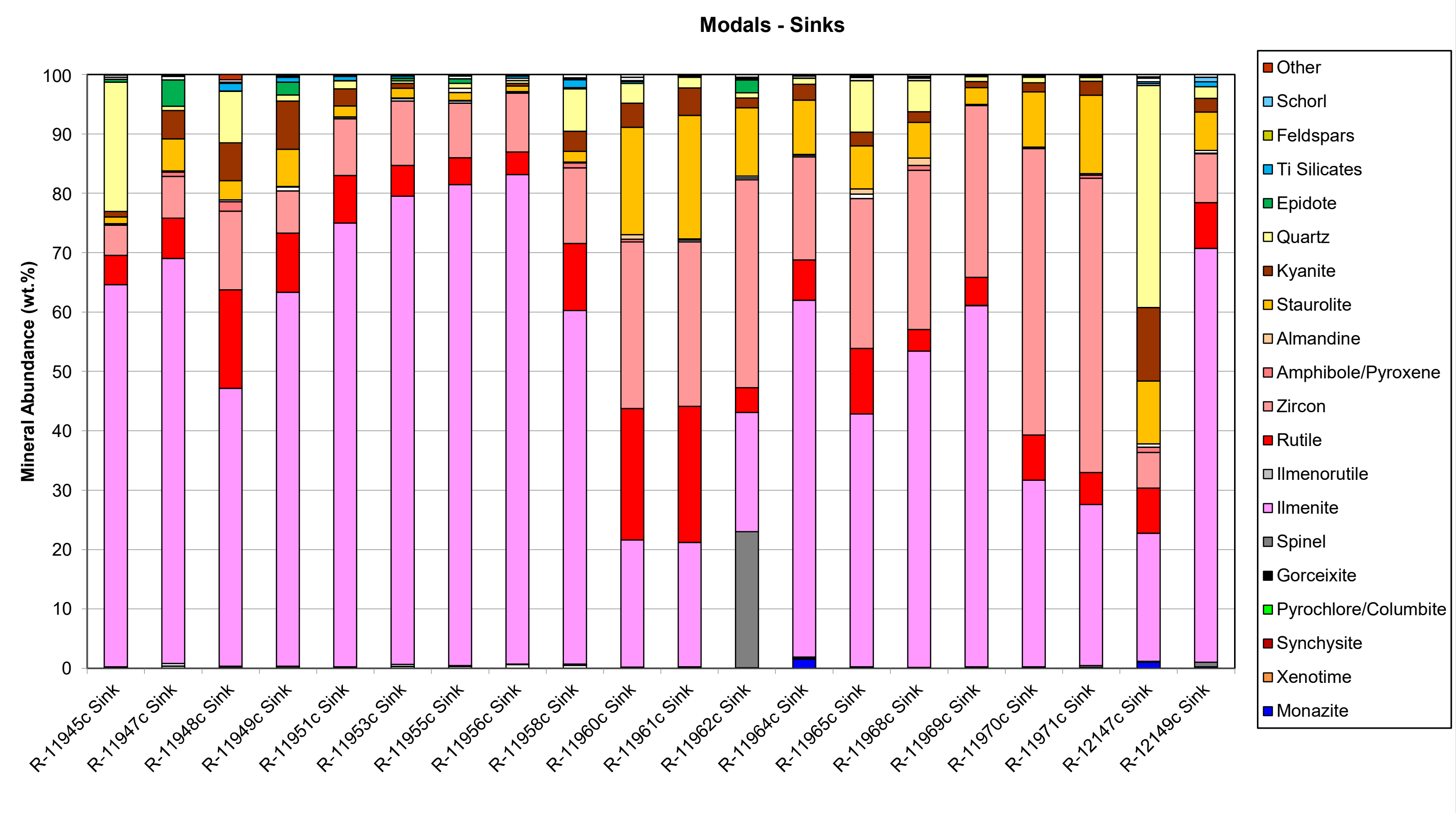


Element	weight %
Y	48.6
O	26.9
Dy	14.8
P	6.9
Al	2.8



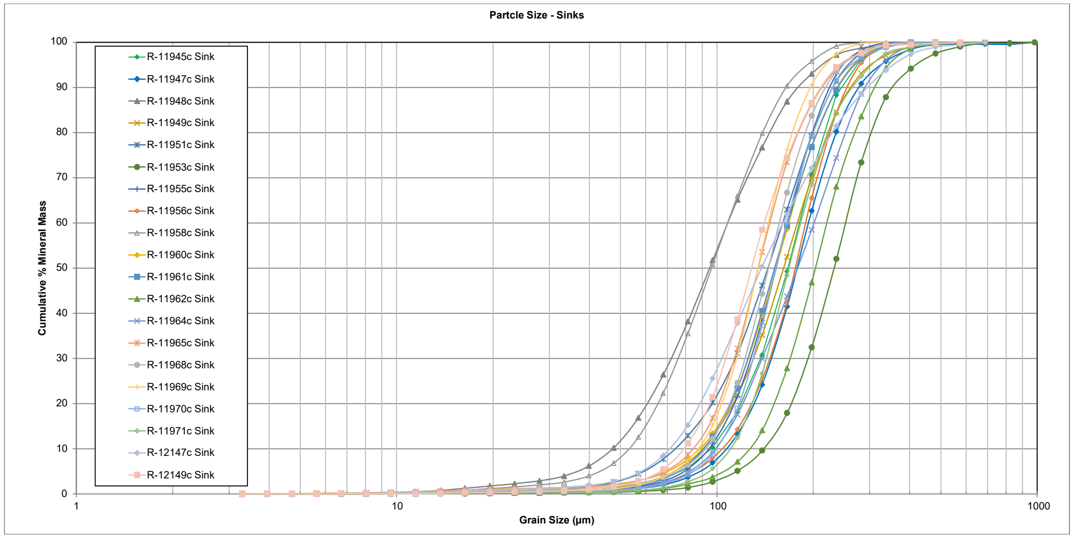
TIMA-X Analysis - Mineral mass% distribution



TIMA-X Analysis – Grain Size

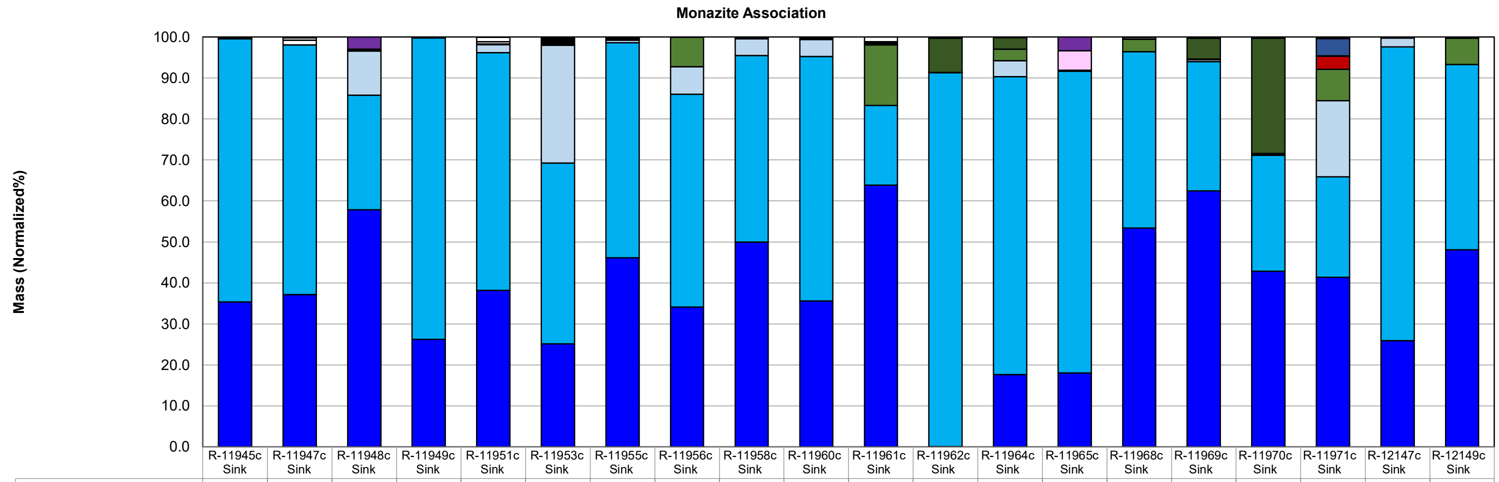
- The grain size report serves to study the distribution of the grain size of a specific phase, within the TIMA software; it is defined as equivalent circle diameter (*d*). It is the diameter of a circle that has the same area (*A*) as the particle (or grain). The diameter is defined in pixels and then multiplied by pixel spacing (*Ps*) to obtain size in micrometres. The precise definition is described in the following formula: $d = 2 \cdot \sqrt{A / \pi} \cdot Ps$.

Grain Size	**Monazite**	**Xenotime**	**Pyrochlore/ Columbite**	**Ilmenite**	**Altered Ilmenite**	**Rutile**	**Pseudorutile**	**Zircon**
R-11945c								
Median	136	7	3	169	165	145	8	160
P80	199	12	3	210	210	235	12	212
R-11947c								
Median	154	239	18	167	152	230	11	151
P80	222	239	18	212	205	230	16	202
R-11948c								
Median	62	45	8	92	83	72	12	74
P80	84	55	8	139	132	114	23	105
R-11949c								
Median	125	17	6	146	131	122	11	123
P80	144	29	6	191	180	185	16	182
R-11951c								
Median	117	69	8	134	98	93	11	116
P80	162	96	8	184	154	152	15	163
R-11953c								
Median	149	80	174	176	135	195	11	183
P80	380	80	174	226	207	303	16	246
R-11955c								
Median	127	103		145	124	115	11	139
P80	174	103		188	164	172	17	182
R-11956c								
Median	160	102	22	163	128	128	11	162
P80	204	102	22	209	183	208	16	208
R-11958c								
Median	74	59	13	96	69	70	11	82
P80	144	59	13	137	104	108	16	112
R-11960c								
Median	87	5	242	108	127	123	12	141
P80	113	5	242	154	166	162	49	181
R-11961c								
Median	107	17	7	121	131	122	10	141
P80	108	17	7	172	165	157	18	183



TIMA-X Analysis – Liberation and Association

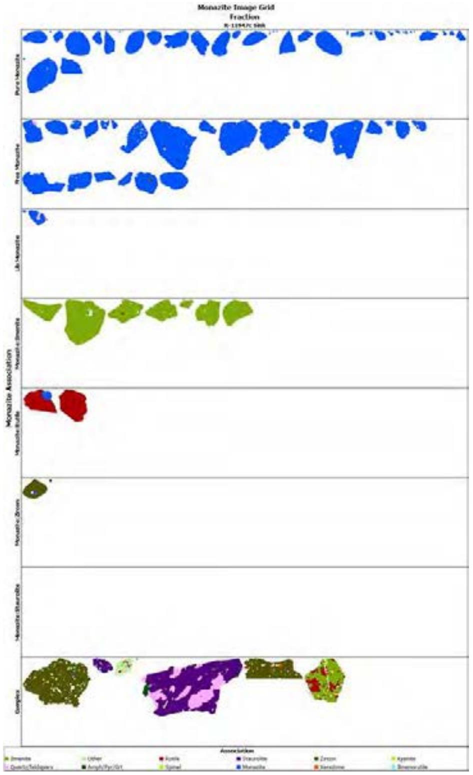
- Indicates the liberation and association of the mineral of interest with other phases
- Data to be used for provenance and recovery potential

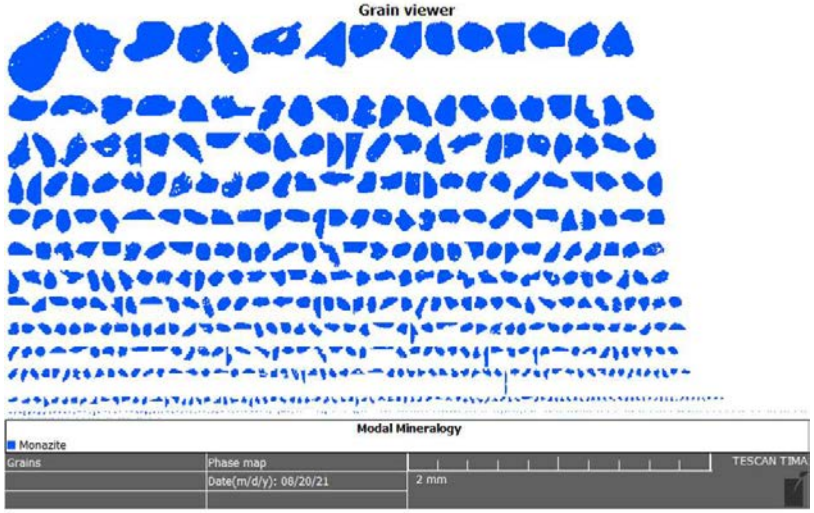


	R-11945c Sink	R-11947c Sink	R-11948c Sink	R-11949c Sink	R-11951c Sink	R-11953c Sink	R-11955c Sink	R-11956c Sink	R-11958c Sink	R-11960c Sink	R-11961c Sink	R-11962c Sink	R-11964c Sink	R-11965c Sink	R-11968c Sink	R-11969c Sink	R-11970c Sink	R-11971c Sink	R-12147c Sink	R-12149c Sink
■ Complex	0.25	0.10	2.93	0.15	0.06	0.06	0.03	0.03	0.11	0.15	1.19	0.10	0.05	3.29	0.09	0.01	0.10	0.00	0.19	0.12
■ Monazite:Other Minerals	0.01	0.02	0.28	0.00	1.07	0.00	0.18	0.00	0.20	0.00	0.04	0.00	0.00	0.00	0.39	0.00	0.06	0.00	0.02	0.00
■ Monazite:Quartz/Feldspars	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.77	0.00	0.00	0.00	0.00	0.00	0.00
■ Monazite:Kyanite	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.15	0.00	0.00	0.00	0.01	0.00	0.00
■ Monazite:Staurolite	0.07	0.00	0.00	0.03	0.00	1.93	0.36	0.01	0.00	0.40	0.63	0.22	0.00	0.13	0.00	0.00	0.15	0.34	0.00	0.00
■ Monazite:Amph/Pyr/Grt	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	4.21	0.00	0.00
■ Monazite:Zircon	0.01	0.06	0.04	0.00	0.06	0.02	0.01	0.01	0.00	0.00	0.03	8.31	2.86	0.00	0.02	5.08	28.07	0.11	0.03	0.00
■ Monazite:Rutile	0.00	0.55	0.00	0.02	0.00	0.00	0.01	0.01	0.00	0.03	0.00	0.02	0.00	0.00	0.04	0.00	0.00	3.22	0.00	0.16
■ Monazite:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Monazite:Ilmenite	0.10	0.05	0.06	0.04	0.06	0.04	0.20	7.15	0.09	0.00	14.77	0.01	2.78	0.00	3.02	0.09	0.17	7.63	0.01	6.45
■ Monazite:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Monazite:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Monazite:Synchysite	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Monazite:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
■ Lib Monazite	0.00	1.14	10.75	0.00	2.00	28.7	0.55	6.72	4.12	4.15	0.00	0.08	3.88	0.00	0.00	0.45	0.28	18.6	2.20	0.00
■ Free Monazite	64.2	60.9	28.0	73.5	58.0	44.1	52.5	52.0	45.5	59.7	19.5	91.2	72.7	73.7	43.0	31.6	28.3	24.6	71.7	45.2
■ Pure Monazite	35.4	37.1	57.8	26.2	38.2	25.1	46.1	34.1	50.0	35.6	63.9	0.1	17.6	18.0	53.4	62.4	42.8	41.4	25.9	48.1

TIMA-X Analysis – Particle Maps as a Function of Liberation and Association

- Graphical illustration of particle maps of the mineral association





- Granulated monazite grains irrespective of their occurrence

TIMA-X Analysis – Monazite Mass% as a Function of Size Class

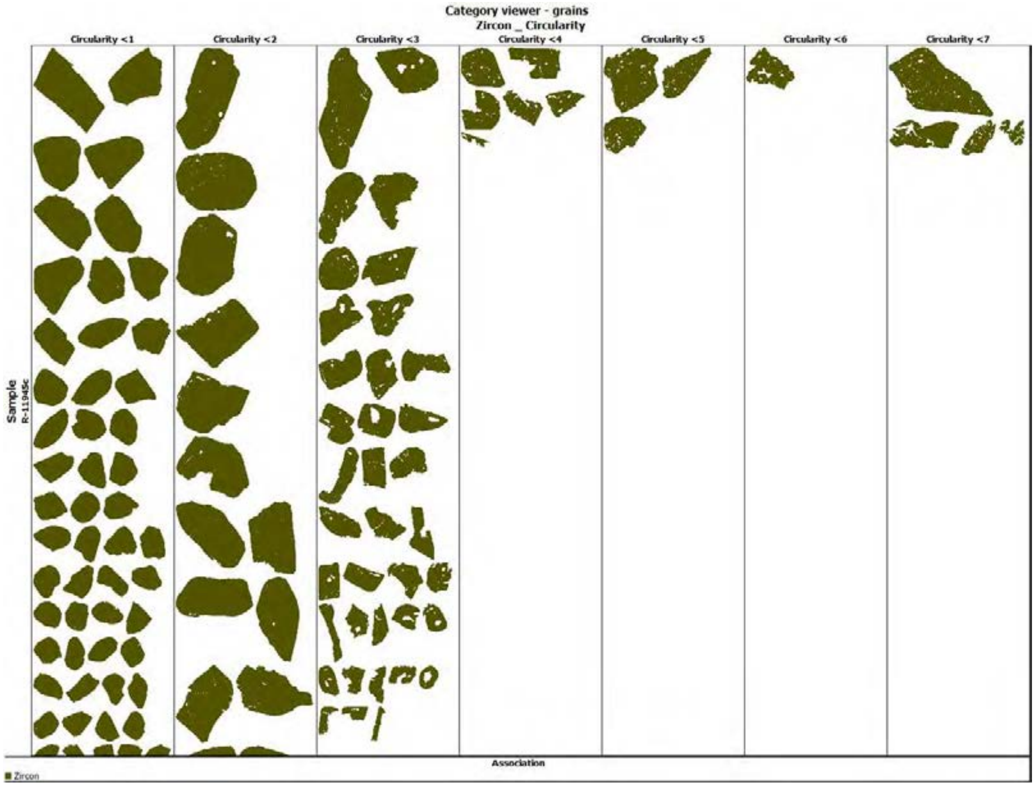
Size Monazite / Product	R-11945c Sink	R-11947c Sink	R-11948c Sink	R-11949c Sink	R-11951c Sink	R-11953c Sink	R-11955c Sink	R-11956c Sink	R-11958c Sink	R-11960c Sink	R-11961c Sink	R-11962c Sink	R-11964c Sink	R-11965c Sink	R-11968c Sink	R-11969c Sink	R-11970c Sink	R-11971c Sink	R-12147c Sink	R-12149c Sink
<=3um	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3-5um	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0
5-10um	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.2	0.0	0.0	0.1	0.0	0.1
10-15um	0.1	0.1	0.7	0.0	0.1	0.1	0.1	0.0	0.2	0.2	0.6	0.1	0.0	0.0	0.3	0.2	0.0	0.4	0.1	0.1
15-20um	0.1	0.1	1.7	0.4	0.4	0.0	0.1	0.2	0.8	1.5	0.0	0.0	0.1	0.4	0.2	0.4	0.2	0.2	0.3	0.6
20-25um	0.2	0.2	4.0	0.3	0.9	0.0	0.4	0.0	1.4	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.3	0.5	0.3	0.4
25-30um	0.0	0.3	4.0	0.3	0.0	0.0	0.3	0.1	0.7	0.0	1.2	0.0	0.1	0.0	0.0	0.9	1.6	0.0	0.1	1.7
30-35um	0.0	0.1	1.7	0.0	0.3	0.0	0.0	0.0	0.6	0.0	1.4	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.3	0.0
35-40um	0.5	0.0	2.5	0.3	1.3	0.0	0.0	0.0	0.6	1.6	0.0	0.0	0.1	0.0	0.0	1.5	0.0	0.0	0.3	0.5
40-45um	0.0	0.5	6.5	0.8	0.7	0.0	0.6	0.0	3.6	2.2	0.0	0.0	0.2	0.0	0.0	1.8	0.0	0.6	0.2	1.3
45-50um	0.0	0.0	2.0	0.0	1.3	0.4	1.5	0.2	4.5	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.4	0.0
50-55um	1.2	0.4	6.8	0.6	0.8	0.0	0.9	0.4	3.8	6.8	0.0	0.0	0.1	3.4	0.0	0.0	2.2	0.0	0.3	0.9
55-60um	1.4	1.2	10.9	1.3	1.2	0.0	0.0	0.5	9.6	4.1	0.0	0.0	0.1	0.0	12.6	7.1	2.2	0.0	2.2	1.1
60-65um	0.0	0.5	6.6	0.9	3.5	0.8	0.7	0.0	1.9	5.1	0.0	0.0	0.1	0.0	10.7	0.0	6.2	0.0	3.8	1.5
65-70um	0.0	1.8	0.0	1.0	3.0	1.9	0.9	0.7	4.3	0.0	0.0	0.0	0.6	11.1	12.7	0.0	3.6	1.6	1.8	4.6
70-75um	2.0	0.7	4.7	0.0	1.7	1.0	1.0	1.7	17.5	13.3	0.0	2.7	0.8	12.4	0.0	14.0	0.0	1.8	1.5	3.7
>75um	94.5	94.2	47.6	94.0	84.6	95.8	93.5	96.1	50.6	63.0	96.5	97.1	97.7	72.7	63.2	73.7	81.0	94.0	88.4	83.3
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

TIMA-X Analysis – Number of Monazite Grains as a Function of Size Class

Size Monazite / Product	R-11945c Sink	R-11947c Sink	R-11948c Sink	R-11949c Sink	R-11951c Sink	R-11953c Sink	R-11955c Sink	R-11956c Sink	R-11958c Sink	R-11960c Sink	R-11961c Sink	R-11962c Sink	R-11964c Sink	R-11965c Sink	R-11968c Sink	R-11969c Sink	R-11970c Sink	R-11971c Sink	R-12147c Sink	R-12149c Sink
<=3um	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-5um	3	5	2	4	3	1	1	3	0	5	4	10	16	0	6	6	8	13	13	5
5-10um	1	4	4	4	3	1	0	1	2	0	2	2	4	1	4	2	0	5	7	7
10-15um	2	5	6	0	2	4	3	2	2	1	3	1	3	0	4	4	0	9	8	2
15-20um	1	3	7	6	4	0	1	7	5	4	0	0	8	1	1	3	1	2	10	5
20-25um	1	4	9	3	5	0	4	1	6	0	0	0	5	0	0	1	1	3	6	2
25-30um	0	3	6	2	0	0	3	1	2	0	1	0	3	0	0	3	3	0	1	6
30-35um	0	1	3	0	1	0	0	0	1	0	1	0	1	0	0	0	3	0	3	0
35-40um	1	0	2	1	3	0	0	0	1	1	0	0	3	0	0	2	0	0	2	1
40-45um	0	2	5	2	2	0	2	0	4	1	0	0	3	0	0	2	0	1	1	2
45-50um	0	0	1	0	2	1	4	1	6	1	0	0	0	0	0	0	0	1	2	1
50-55um	2	1	3	1	1	0	2	2	3	2	0	0	2	1	0	0	1	0	1	1
55-60um	1	3	4	2	1	0	0	2	7	1	0	1	1	0	4	4	1	0	7	1
60-65um	0	1	2	1	4	1	1	0	1	1	0	0	1	0	4	0	2	0	10	1
65-70um	0	4	0	2	3	2	1	3	2	0	0	0	5	2	3	0	1	1	4	3
70-75um	1	1	1	0	1	1	2	4	7	2	0	1	6	2	0	5	0	1	3	2
>75um	31	51	14	43	28	33	39	64	17	9	18	14	152	10	12	19	18	35	59	28
Total	**44**	**88**	**69**	**71**	**63**	**44**	**63**	**91**	**66**	**28**	**29**	**29**	**213**	**17**	**38**	**51**	**39**	**71**	**137**	**67**

TIMA-X Analysis – Particle Classification

- It is possible to construct any expression using arithmetic operators. In this example, a category containing zircon grains with circularity is defined as second power of perimeter divided by 4* π * Area
- [(perimeter() ^ 2) /
(4 * 3.14159 * area_μm()) <1-7)].



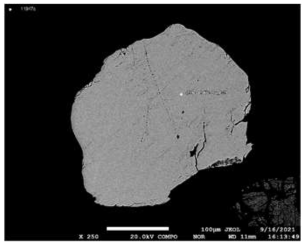
Mineral Chemistry by EPMA

- EPMA - Xenotime

SAMPLE	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	TOTAL
R-11964c Xenotime_002	0.46	0.00	34.78	48.37	0.09	0.00	0.04	0.00	0.16	0.17	1.42	0.28	3.67	3.49	0.17	93.10
R-11964c Xenotime_003	0.12	0.17	32.90	41.20	0.14	0.19	0.04	0.31	0.59	0.00	2.13	0.46	4.29	3.62	0.03	86.20
R-11964c Xenotime_003	1.17	3.08	31.38	39.43	0.21	0.00	0.06	0.30	0.62	0.85	1.96	0.42	3.97	3.14	0.09	86.68
R-11964c Xenotime_004	0.50	1.01	32.59	41.35	0.00	0.00	0.10	0.34	0.40	0.21	1.68	0.49	4.31	3.44	0.05	86.48
R-11964c Xenotime_004	0.99	2.20	31.58	39.88	0.06	0.03	0.00	0.31	0.55	0.55	1.66	0.41	4.37	2.99	0.02	85.60
R-11964c Xenotime_004	1.31	2.91	30.41	38.70	0.00	0.00	0.00	0.33	0.57	0.84	1.68	0.33	4.16	2.97	0.04	84.25
R-11964c Xenotime_005	0.12	0.00	33.35	43.65	0.00	0.00	0.00	0.29	0.53	0.00	1.80	0.33	4.58	3.37	0.00	88.04
R-11964c Xenotime_005	1.34	1.99	31.98	41.13	0.09	0.00	0.00	0.29	0.48	0.73	1.98	0.42	4.23	3.65	0.02	88.34
R-11964c Xenotime_006	0.11	0.15	32.60	40.81	0.07	0.00	0.12	0.34	0.57	0.00	1.98	0.46	4.49	3.56	0.00	85.27
R-11964c Xenotime_006	0.43	2.03	31.89	39.49	0.04	0.01	0.07	0.43	0.65	0.35	2.05	0.56	4.24	3.59	0.16	85.99
R-11964c Xenotime_006	0.82	4.12	31.32	38.08	0.03	0.20	0.00	0.44	0.66	0.96	1.98	0.50	4.17	3.51	0.15	86.96
R-11964c Xenotime_007	0.09	0.00	33.69	44.71	0.07	0.06	0.03	0.07	0.10	0.05	1.05	0.36	4.40	3.49	0.00	88.18
R-11964c Xenotime_007	0.39	1.52	32.27	40.81	0.08	0.09	0.04	0.36	0.60	0.32	1.92	0.57	4.58	3.72	0.06	87.33
R-11964c Xenotime_008	0.19	0.00	33.68	43.20	0.00	0.00	0.02	0.31	0.54	0.00	1.88	0.48	4.46	4.00	0.03	88.79
R-11964c Xenotime_008	0.28	1.20	32.93	41.16	0.21	0.04	0.13	0.25	0.68	0.24	1.96	0.53	4.02	4.21	0.08	87.93
R-11964c Xenotime_009	0.66	0.91	32.90	41.86	0.00	0.10	0.06	0.28	0.58	0.29	1.73	0.43	4.36	3.46	0.03	87.66
R-11964c Xenotime_009	1.65	3.95	30.80	39.72	0.00	0.00	0.00	0.36	0.52	1.32	1.68	0.45	4.09	3.44	0.05	88.04
Average	0.63	1.49	32.42	41.39	0.06	0.04	0.04	0.29	0.52	0.40	1.80	0.44	4.26	3.51	0.06	87.34
Maximum	1.65	4.12	34.78	48.37	0.21	0.20	0.13	0.44	0.68	1.32	2.13	0.57	4.58	4.21	0.17	93.10
Minimum	0.09	0.00	30.41	38.08	0.00	0.00	0.00	0.00	0.10	0.00	1.05	0.28	3.67	2.97	0.00	84.25
Std. Dev.	0.50	1.41	1.13	2.50	0.07	0.07	0.04	0.11	0.16	0.40	0.26	0.08	0.24	0.31	0.05	1.93

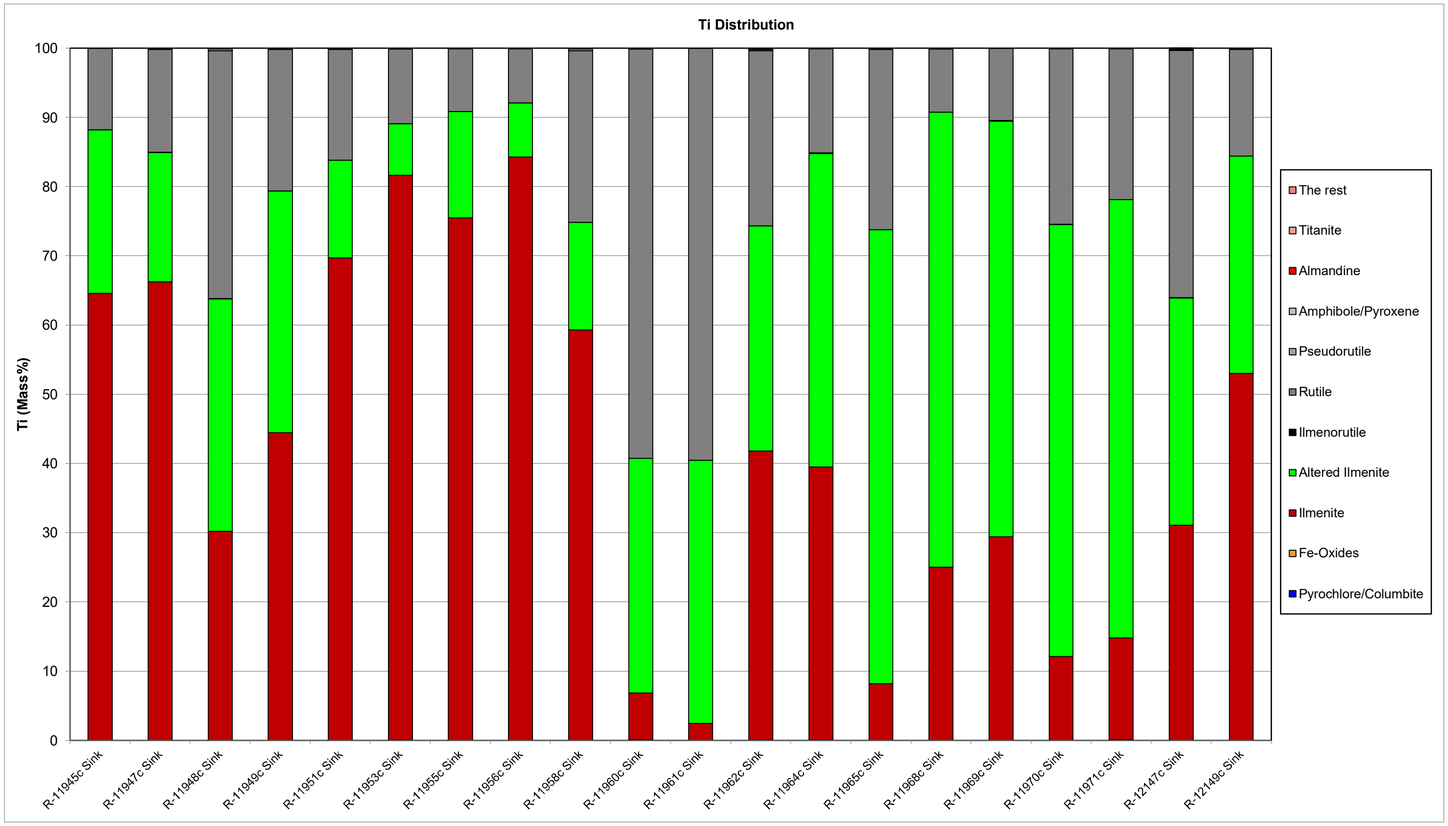
Mineral Chemistry by EPMA

- EPMA - Monazite



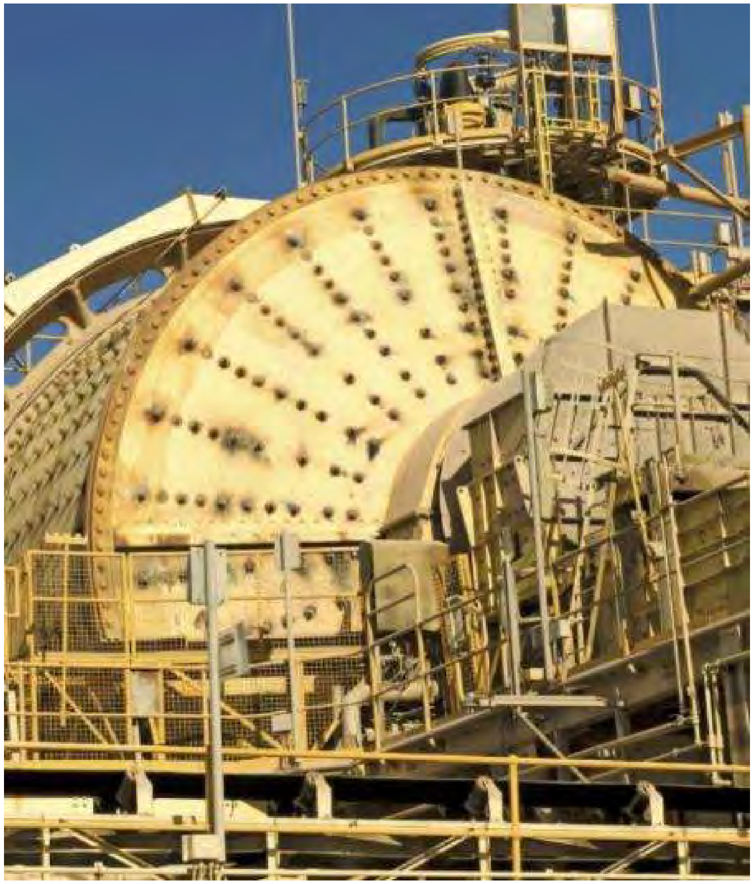
Sample	Oxide		ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO
	n=172	LOD	0.119	0.170	0.043	0.059	0.147	0.177	0.145	0.083	0.079	0.029	0.098	0.102	0.069	0.132	0.020
R-11947c	n=25	Average	6.26	0.18	29.46	1.22	27.79	13.45	3.06	11.94	1.96	0.52	1.24	0.07	0.09	0.32	1.11
		Maximum	11.27	1.85	30.52	2.91	30.47	16.48	3.47	14.01	2.46	1.98	1.89	0.18	0.29	0.74	1.92
		Minimum	0.69	-	27.18	0.08	25.66	11.50	2.77	10.74	1.25	0.03	0.55	-	-	-	0.56
		Std. Dev.	2.85	0.47	0.81	0.86	1.44	1.23	0.20	0.88	0.32	0.50	0.37	0.06	0.07	0.24	0.37
R-11955c	n=27	Average	8.23	0.20	28.54	1.01	27.38	13.25	2.96	11.52	1.88	1.12	1.18	0.05	0.07	0.23	1.03
		Maximum	19.34	1.27	30.20	2.76	30.79	16.72	3.37	14.00	2.59	3.78	2.12	0.19	0.21	0.57	2.40
		Minimum	3.01	-	24.37	0.15	20.39	9.61	2.51	9.23	1.09	0.07	0.41	-	-	-	0.40
		Std. Dev.	4.73	0.32	1.72	0.67	2.56	1.91	0.25	1.31	0.45	1.10	0.42	0.05	0.05	0.17	0.43
R-11956	n=32	Average	5.67	0.06	29.39	0.85	28.72	13.57	3.16	12.54	1.93	0.56	1.12	0.06	0.06	0.22	0.86
		Maximum	12.33	0.46	30.55	3.99	34.09	16.25	3.74	15.61	2.87	2.25	1.92	0.21	0.33	0.86	1.29
		Minimum	1.78	-	26.96	-	25.60	10.11	2.88	11.09	1.16	0.12	0.45	-	-	-	0.21
		Std. Dev.	2.18	0.13	0.86	0.89	1.63	1.53	0.19	1.13	0.43	0.52	0.44	0.06	0.07	0.21	0.24
R-11958c	n=24	Average	5.92	0.32	29.01	1.64	27.36	12.59	3.11	12.44	2.26	0.77	1.56	0.09	0.10	0.46	0.84
		Maximum	16.80	1.15	30.54	3.17	31.80	16.51	3.94	16.08	3.76	4.18	3.01	0.22	0.23	0.92	1.71
		Minimum	0.49	-	23.87	0.11	21.48	9.21	2.62	9.87	1.35	0.03	0.79	-	-	0.09	0.16
		Std. Dev.	4.77	0.38	1.88	1.00	2.58	2.01	0.33	1.47	0.49	1.24	0.50	0.07	0.06	0.25	0.43
R-11964c	n=35	Average	6.75	0.17	29.17	1.83	27.93	13.71	2.89	10.90	1.77	0.82	1.16	0.07	0.13	0.42	0.91
		Maximum	12.44	1.04	30.52	3.10	31.19	16.65	3.29	12.78	2.45	2.04	2.00	0.16	0.30	0.71	1.43
		Minimum	2.67	-	27.15	0.29	24.32	10.93	2.51	9.44	1.37	0.06	0.74	0.00	-	-	0.47
		Std. Dev.	2.27	0.25	0.89	0.64	1.71	1.17	0.21	0.85	0.27	0.51	0.29	0.05	0.06	0.17	0.29
R-12147c	n=29	Average	7.98	0.18	28.97	1.57	27.06	13.58	2.84	10.76	1.85	0.93	1.17	0.07	0.11	0.39	1.10
		Maximum	19.09	0.87	30.48	3.79	30.08	15.99	3.39	13.09	2.97	3.95	2.32	0.20	0.28	1.06	1.70
		Minimum	3.55	-	24.18	0.16	23.33	10.10	2.26	7.75	1.12	0.13	0.49	-	-	-	0.52
		Std. Dev.	3.01	0.23	1.32	1.04	1.97	1.62	0.24	1.22	0.49	0.82	0.50	0.05	0.08	0.27	0.32

Elemental Deportment – a Function of the Mass and Mineral Chemistry



Why TIMA-X and Automated Mineralogy

- TIMA-X is the latest state of the art mineralogical tool in the mining industry
  - Powerful software
  - Continuous development
- Automated mineralogy can provide quantitative mineralogical parameters
  - Mineral identification - especially REE minerals to define xenotime, monazite
  - liberation, association, exposure – provide limitations to mineral processing
  - grain size, shape factors - can be used for provenance evaluations
  - elemental distribution
  - EPMA – compare the chemistry of the minerals across samples with the source rocks
  - LA-ICP-MS - additional information on trace elements for minerals, e.g., zircon
  - It can explain the geochemical trends and elemental associations (Y-Th-P-REE), and thus avoid assumptions because ores are multi element systems, especially complicated for REE.



Thank you!

Do you have any questions?

tassos.grammatikopoulos@sgs.com

(01) 705 927 6281

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Session 5: Advanced technologies for heavy minerals identification, assessment, and monitoring

SHAH, A.K. – Geophysical approaches to imaging heavy mineral sand content in offshore environments (AShah.pdf)

Marine heavy mineral sands: Geophysical Approaches

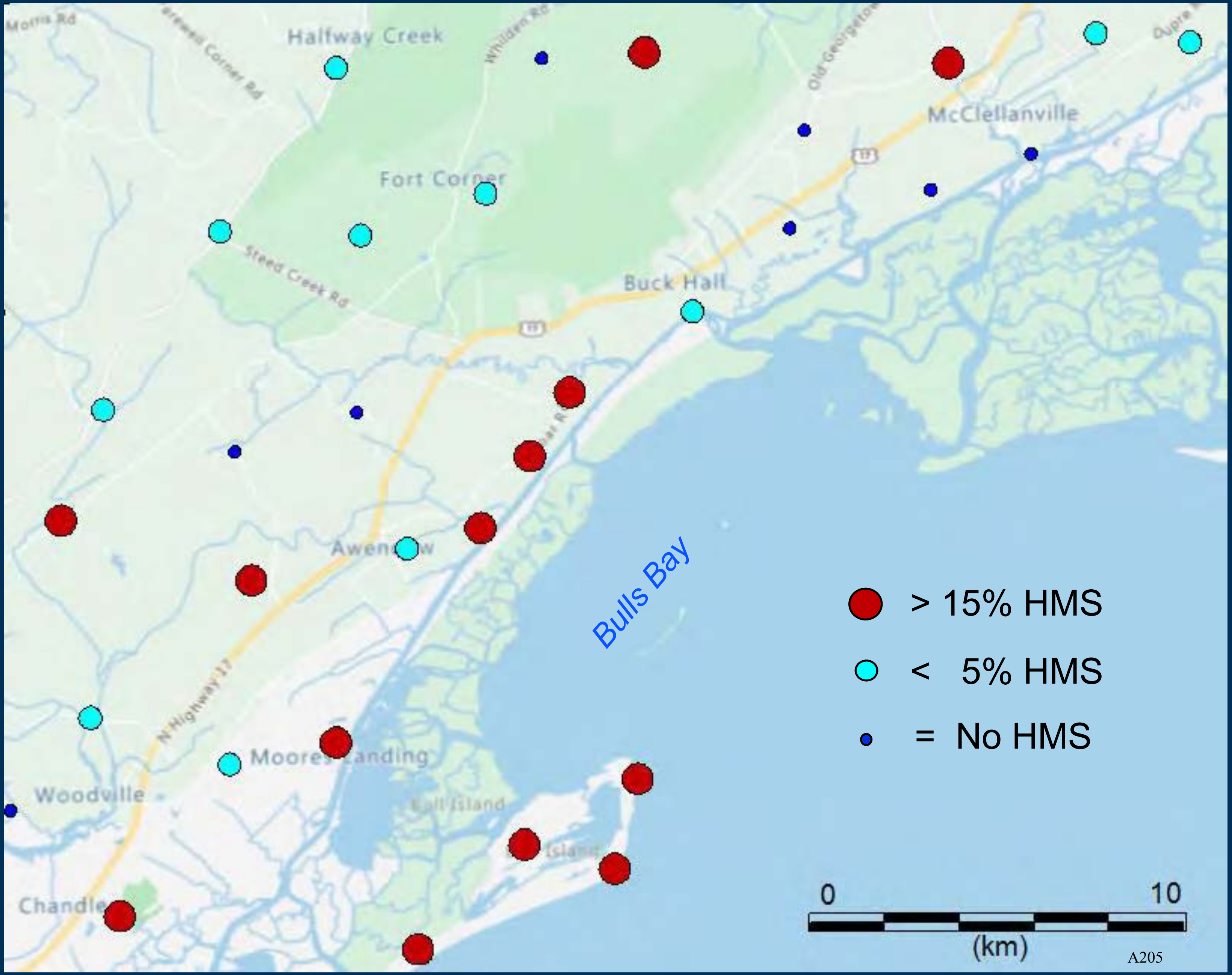
Anji Shah, USGS

U.S. Department of the Interior
U.S. Geological Survey

Why Geophysics?

Example from onshore South Carolina

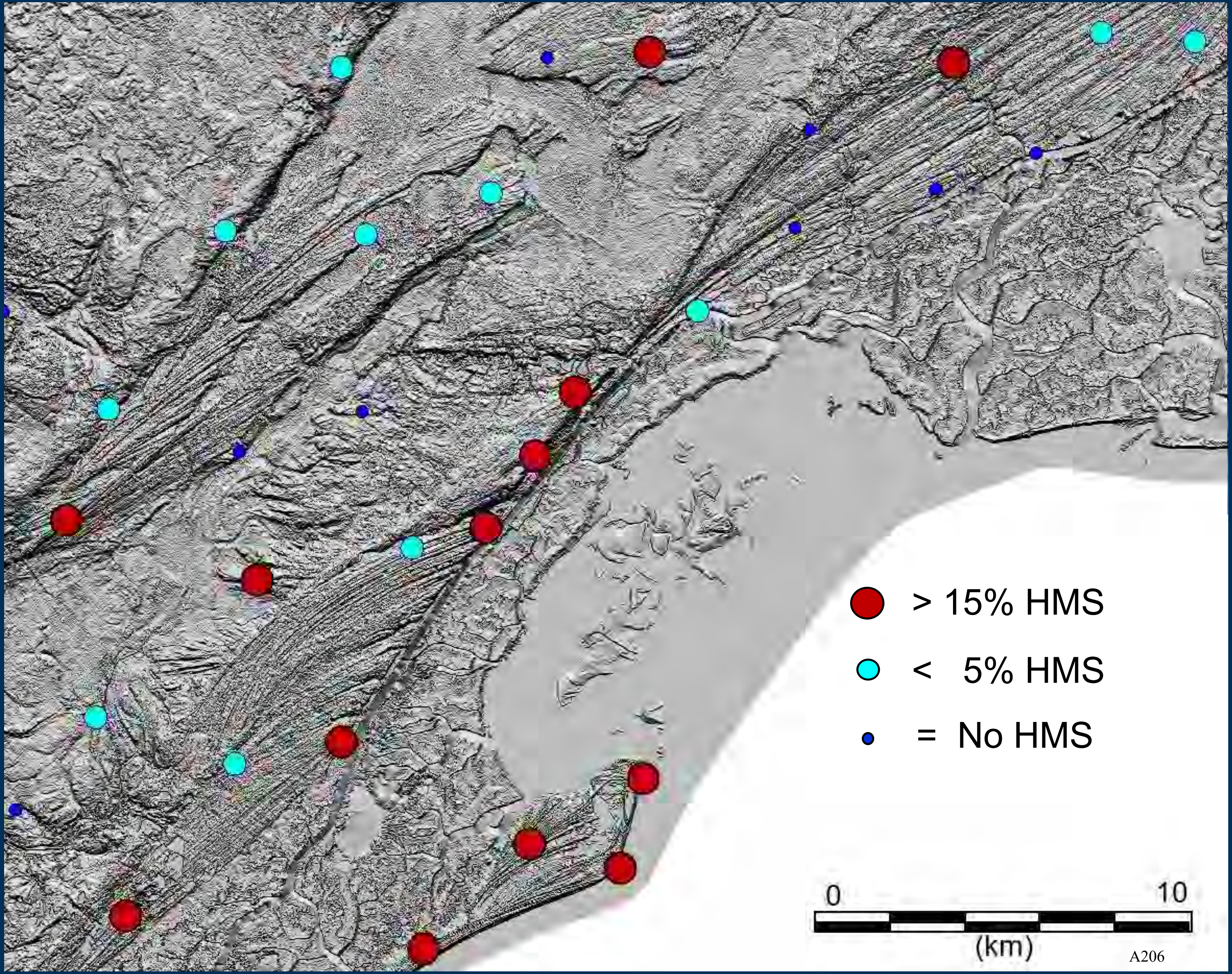
- **Auger sample data collected by R. Weems over several decades**



Why Geophysics?

Example from onshore South Carolina

- Auger sample data collected by R. Weems over several decades
- Lidar: analogous to sidescan sonar; provides grain size information
  HMS are in sands

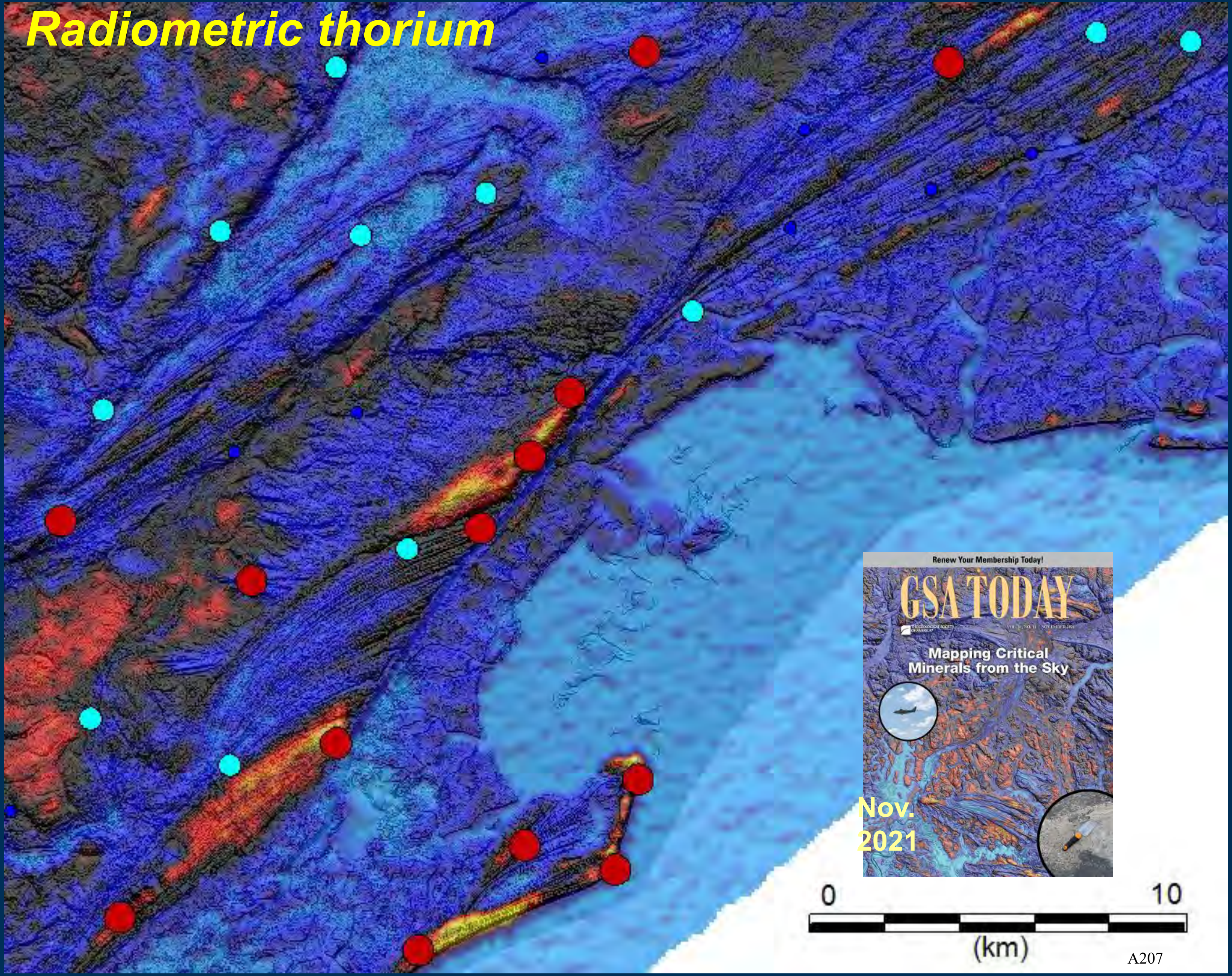


USGS

Why Geophysics?

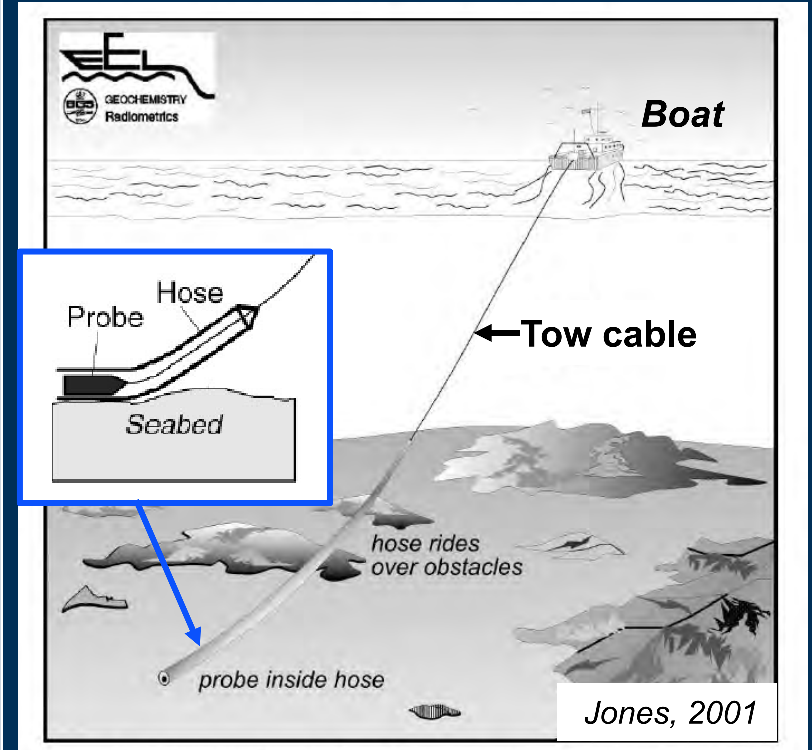
Example from onshore South Carolina

- **Auger sample data collected by R. Weems over several decades**
- **Lidar: analogous to sidescan sonar; provides grain size information**
  HMS are in sands
- **Radiometric data: (2019 airborne survey) Th monazite reflects compositional variation**
  HMS are in areas heavily reworked



Radiometric Methods

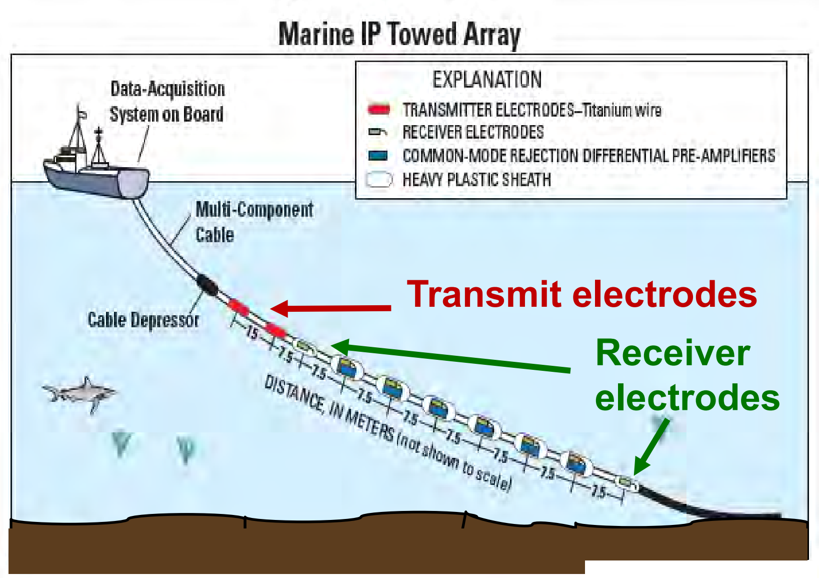
- *Gamma spec: K, U, Th*
- *Sensor must maintain contact with the seafloor*
- *Tow speed ~4 kts (up to 10 kts)*
- *Excellent likelihood of detection*
- *Operate with care*



Jones, 2001

Electrical Methods (IP)

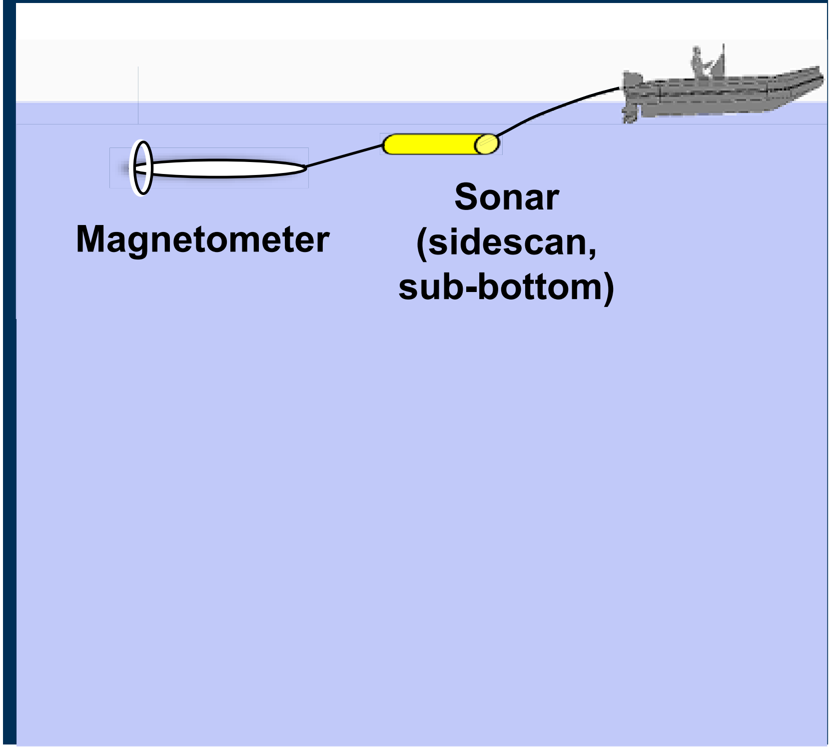
- *Electrical properties*
- *Sensor must maintain contact with the seafloor*
- *Tow speed ~3 kts*
- *Good detection, noise an issue*
- *Operate with care*



Wynn, 2008

Magnetic Methods

- *Magnetic minerals*
- *Sensor towed behind the boat; often in tandem with sonar*
- *Tow speed ~8 kts (up to 10 kts)*
- *Need to check mineralogy*
- *Need calmer waters, steady speed*



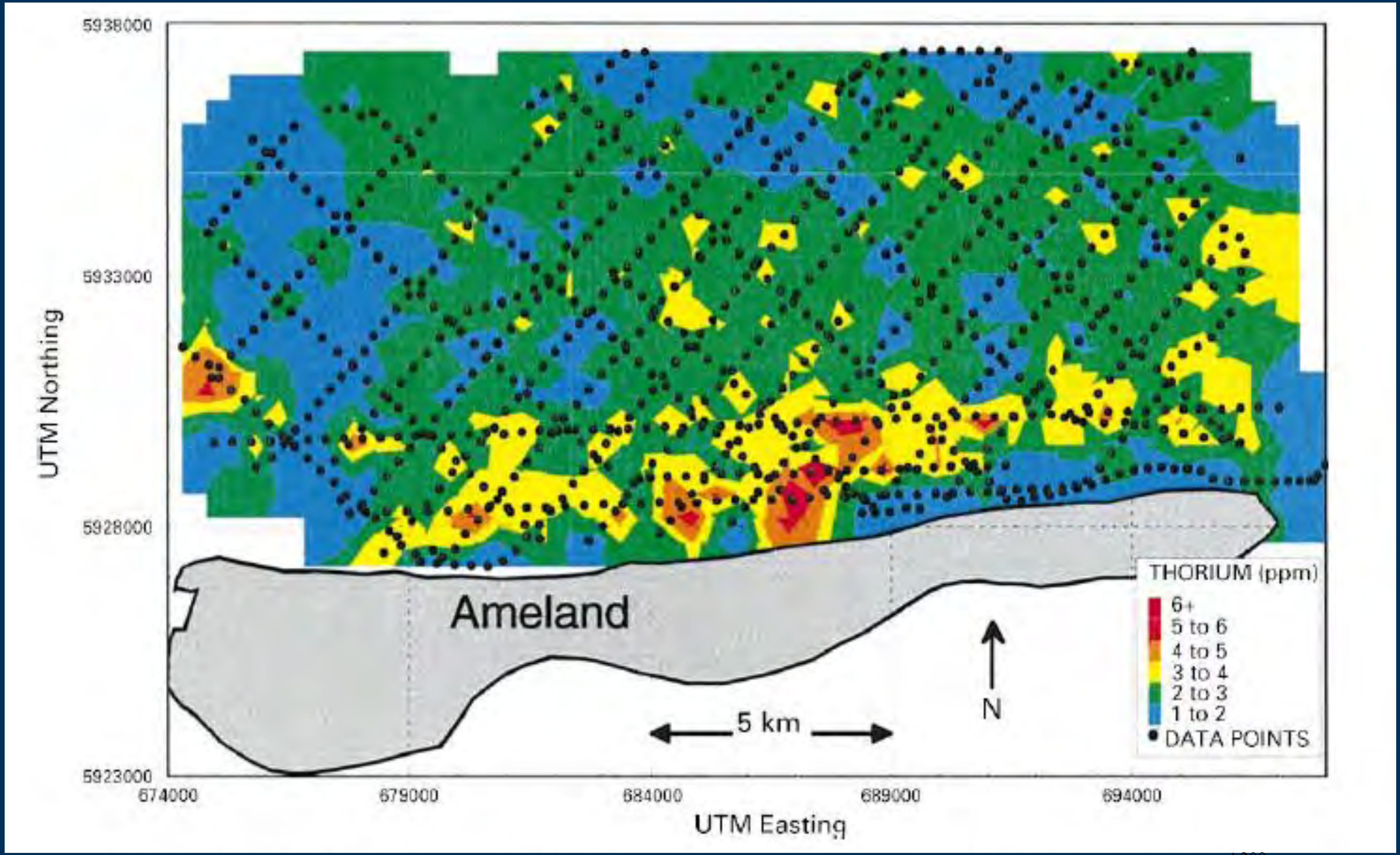
Offshore methods

Radiometric methods

Shallow water: Small boat (to 5 m depth); winch needed for deeper areas

Surveys have been conducted in up to 1600 m depth

Thorium measured off of Ameland in the Dutch Frisian Islands; Higher Th corresponds to heavy mineral sands containing monazite. Method "sees" the upper 50 cm

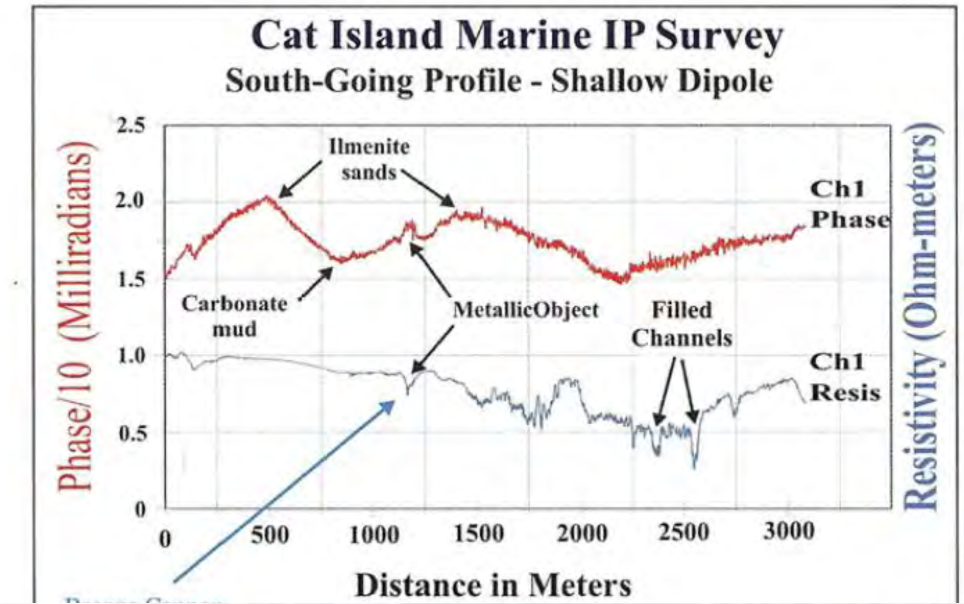


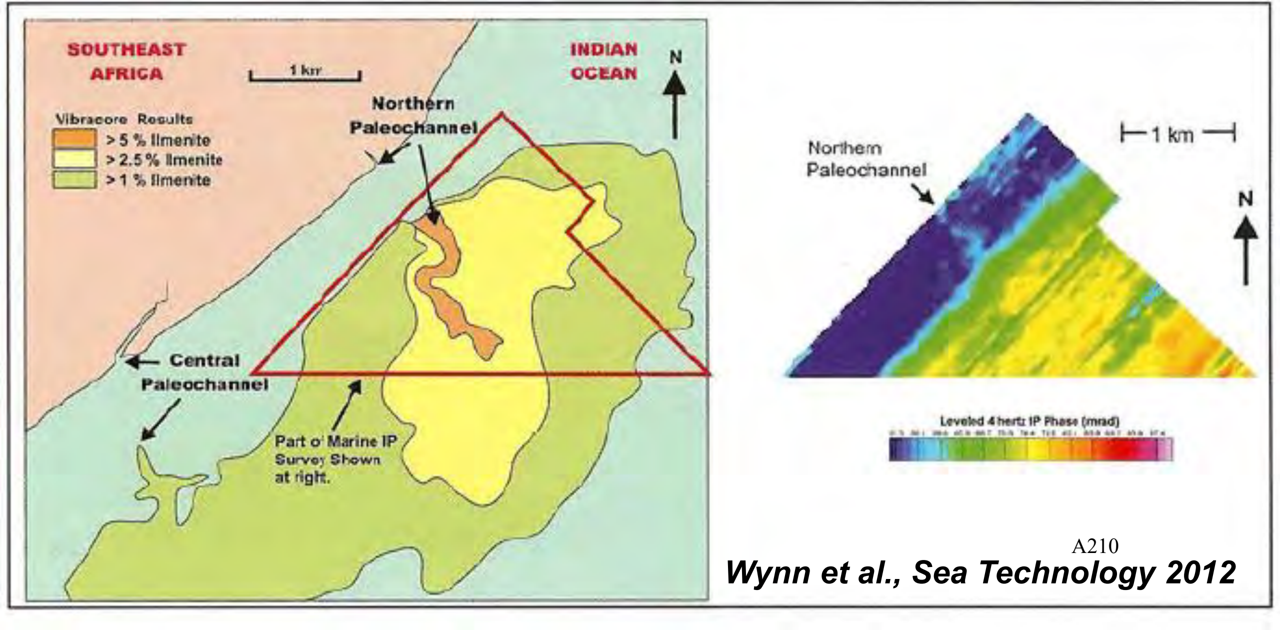
Jones, J. Environ Radioactivity, 2001

Electrical methods *(USGS)*

Phase changes (transmit vs received) respond to ilmenite. Resistivity may respond to manmade objects. Noise can be an issue.

Active signal needed. System is generally used with a larger boat to manage cables



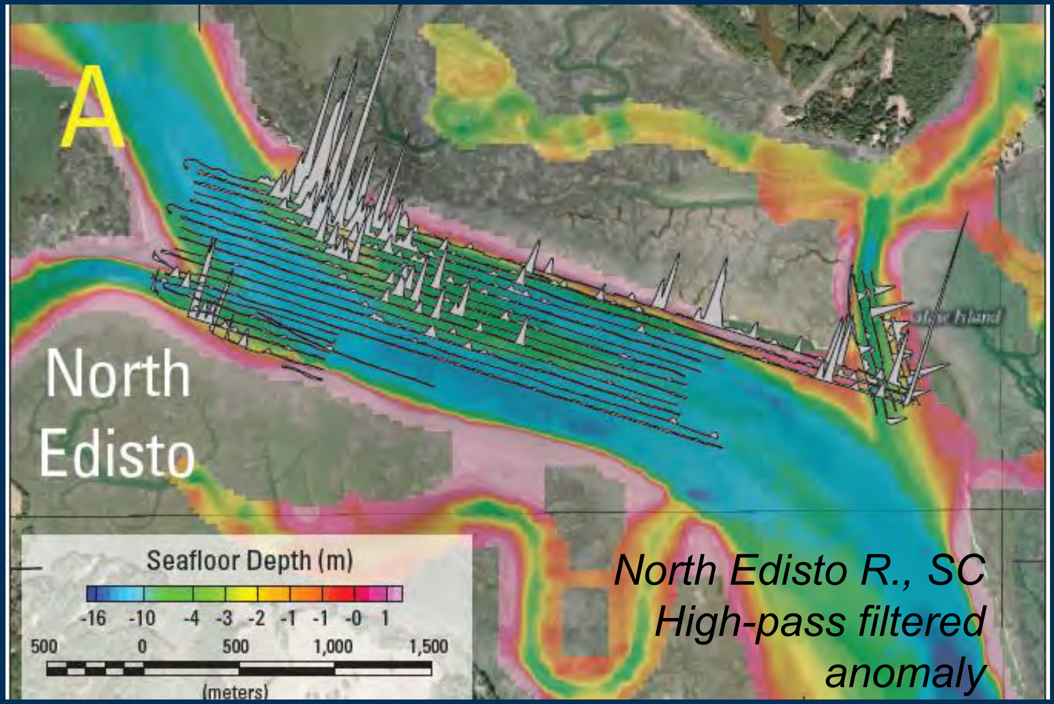


Wynn et al., Sea Technology 2012

Magnetic methods *(Many systems available)*

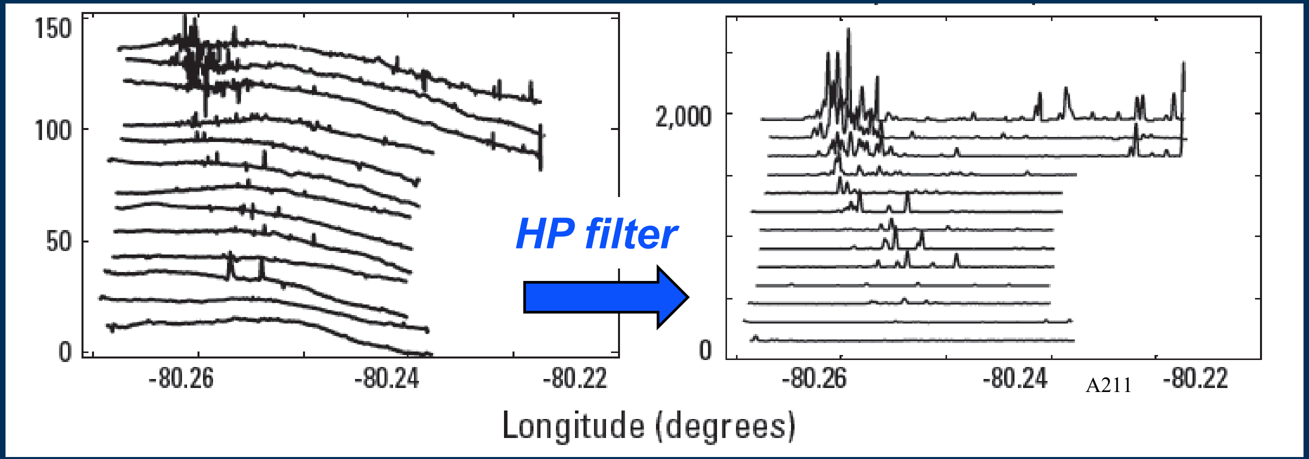
Filtered magnetic field responds to magnetite, maghemite, hematite, but also glauconite.

Can be used at any water depth;
the closer sensor is to the seafloor,
the better the detection (attenuation).
Sensor motion can introduce noise.



North Edisto R., SC
High-pass filtered anomaly

Longer wavelengths represent the basement, shorter wavelengths represent sources in sediments; filtering needed.

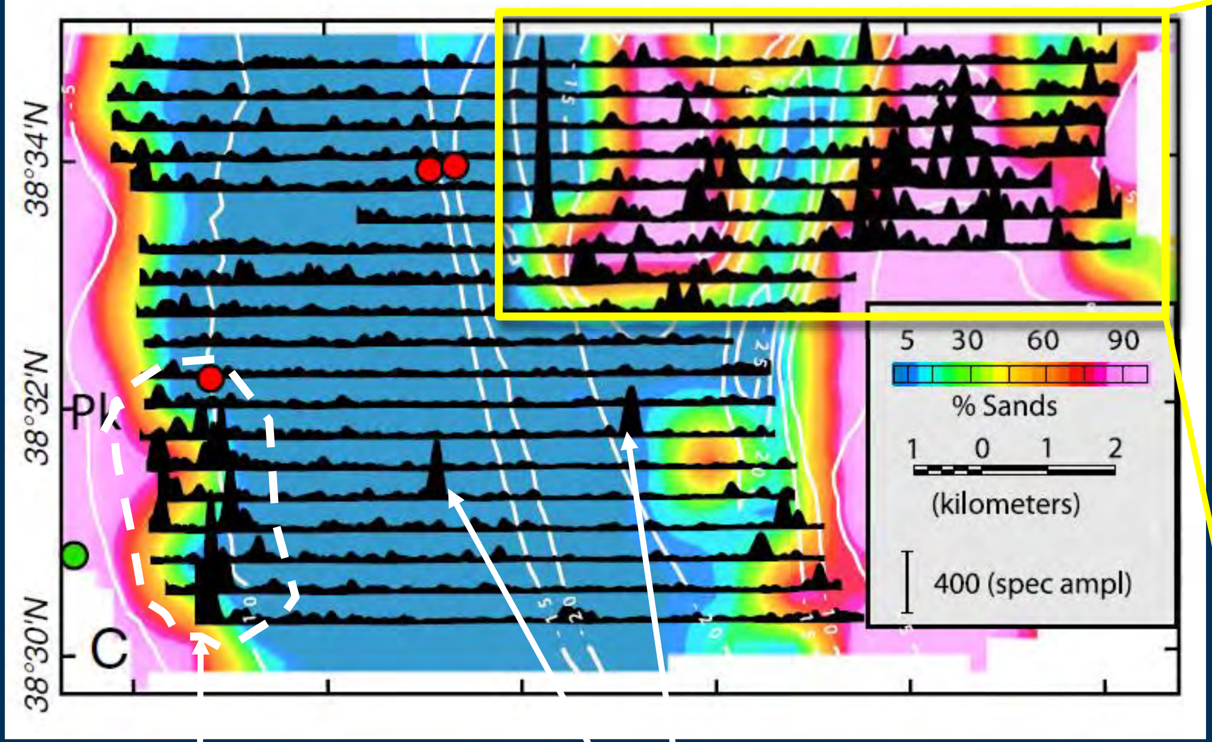


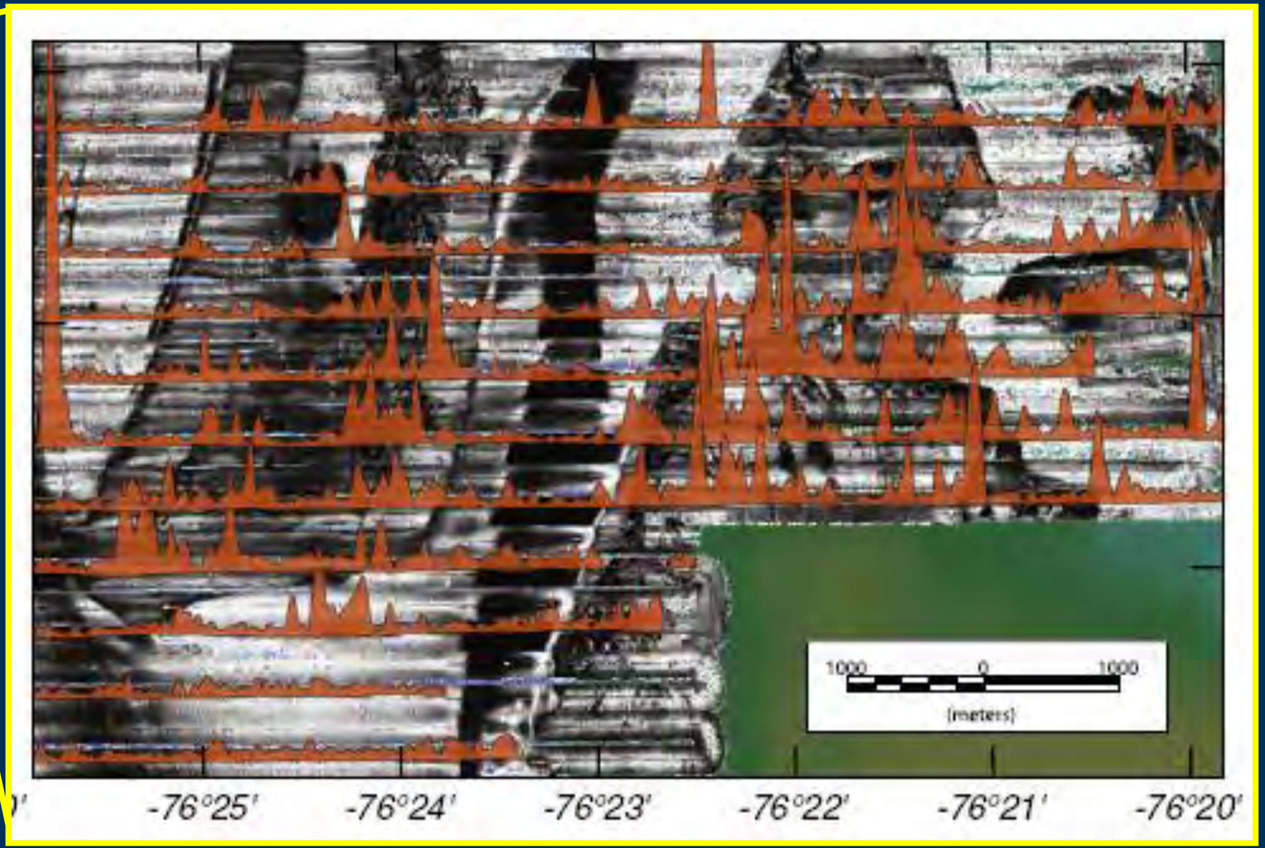
Shah and Harris, OFR 1112 2012;

Magnetic data with sidescan sonar data: Geologic context

Example from the Chesapeake Bay, MD

Pink = % sands





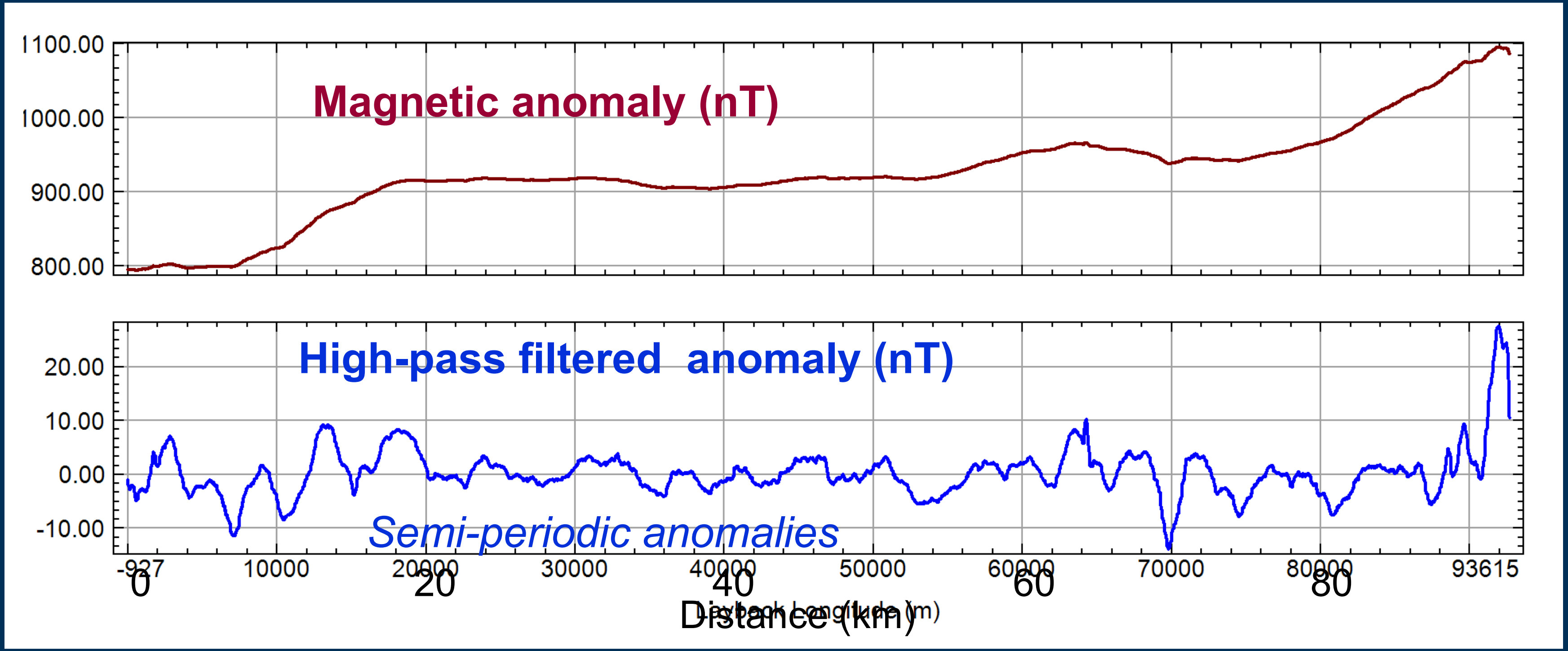
Parker's Creek

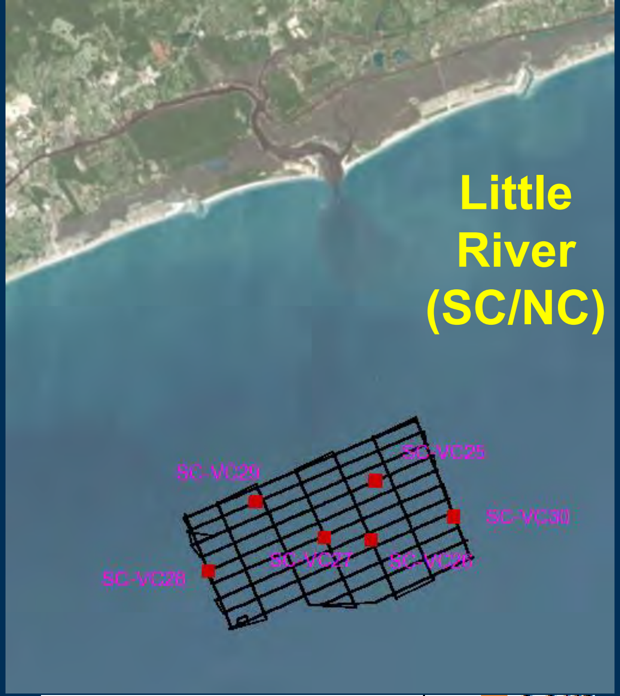
Metallic objects

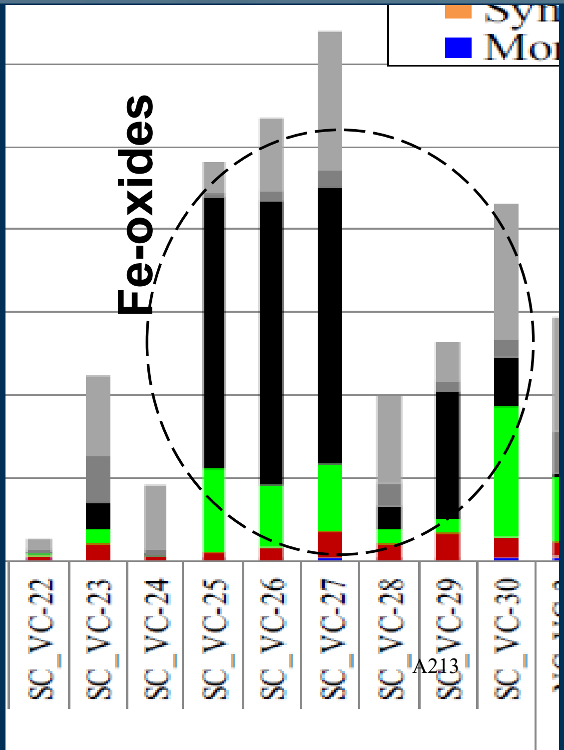
Shah et al., Marine Geology, 2012

Preliminary information-subject to revision.
Not for citation or distribution.

Smooth sailing…







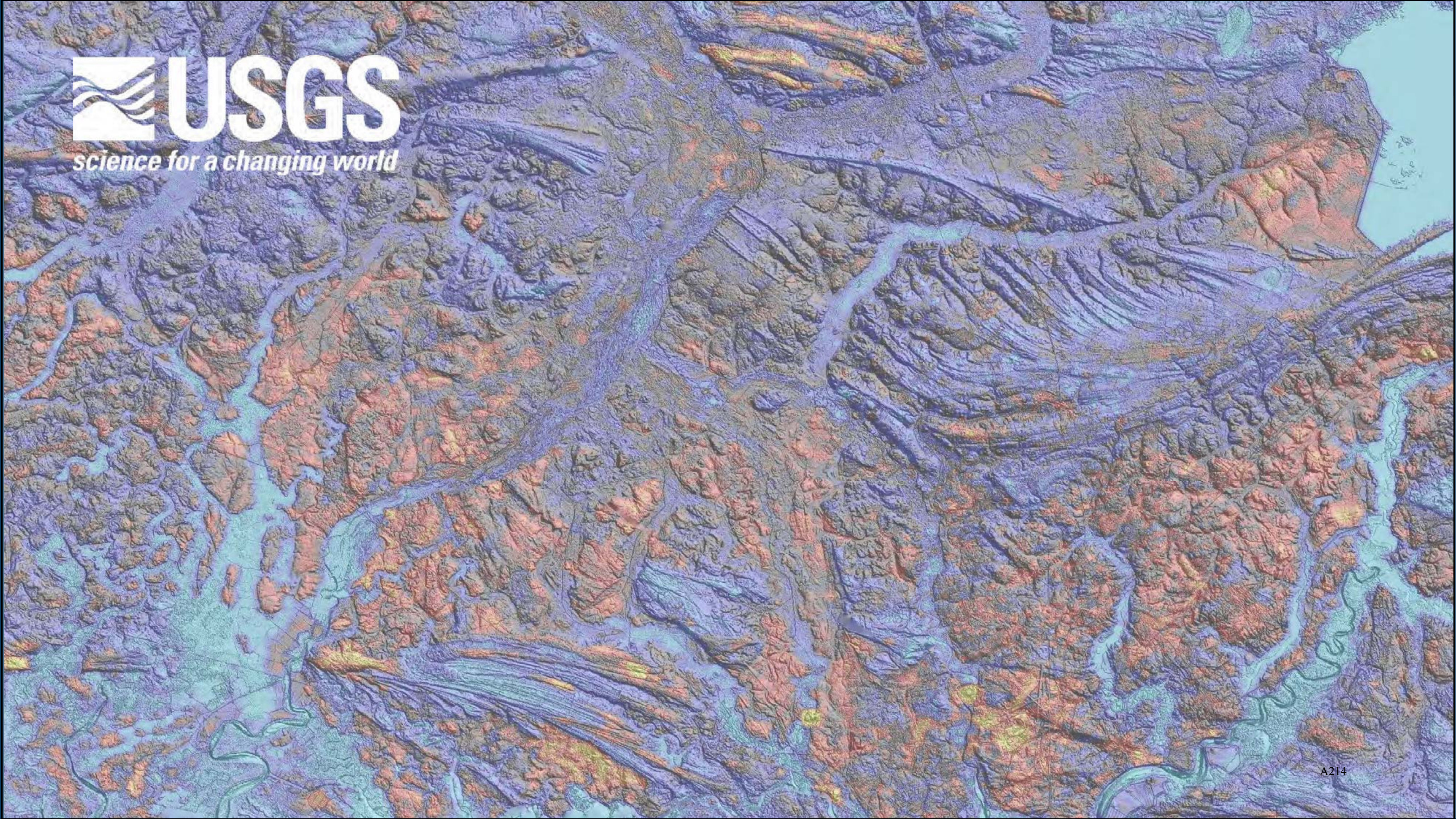
…is important

Motion of the sensor will be reflected in the data, obscuring more subtle anomalies. Towing deeper may or may not help.

USGS

Preliminary information-subject to revision.
Not for citation or distribution.

Grammatikopoulos et al.,
J. Geocehm Explo., 2020


USGS
science for a changing world

Session 5: Advanced technologies for heavy minerals identification, assessment, and monitoring

HAWKINS, D.W. and LASSETTER, W.L. – Field methods for assessment and monitoring of heavy mineral sands: Terrestrial and offshore insights (DHawkins_WLassetter.pdf)

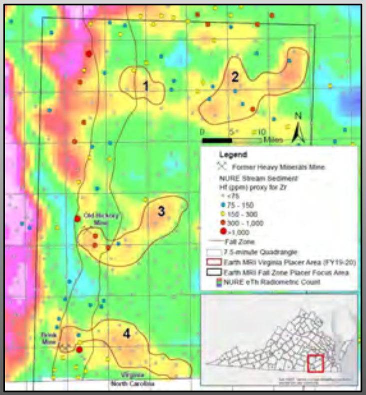
Field Methods for Assessment and Monitoring of Heavy Mineral Sands: Terrestrial and Offshore Insights

David W. Hawkins and William L. Lassetter

Virginia Department of Energy, Geology and Mineral Resources Program

VIRGINIA Energy

Reconnaissance-level Geology



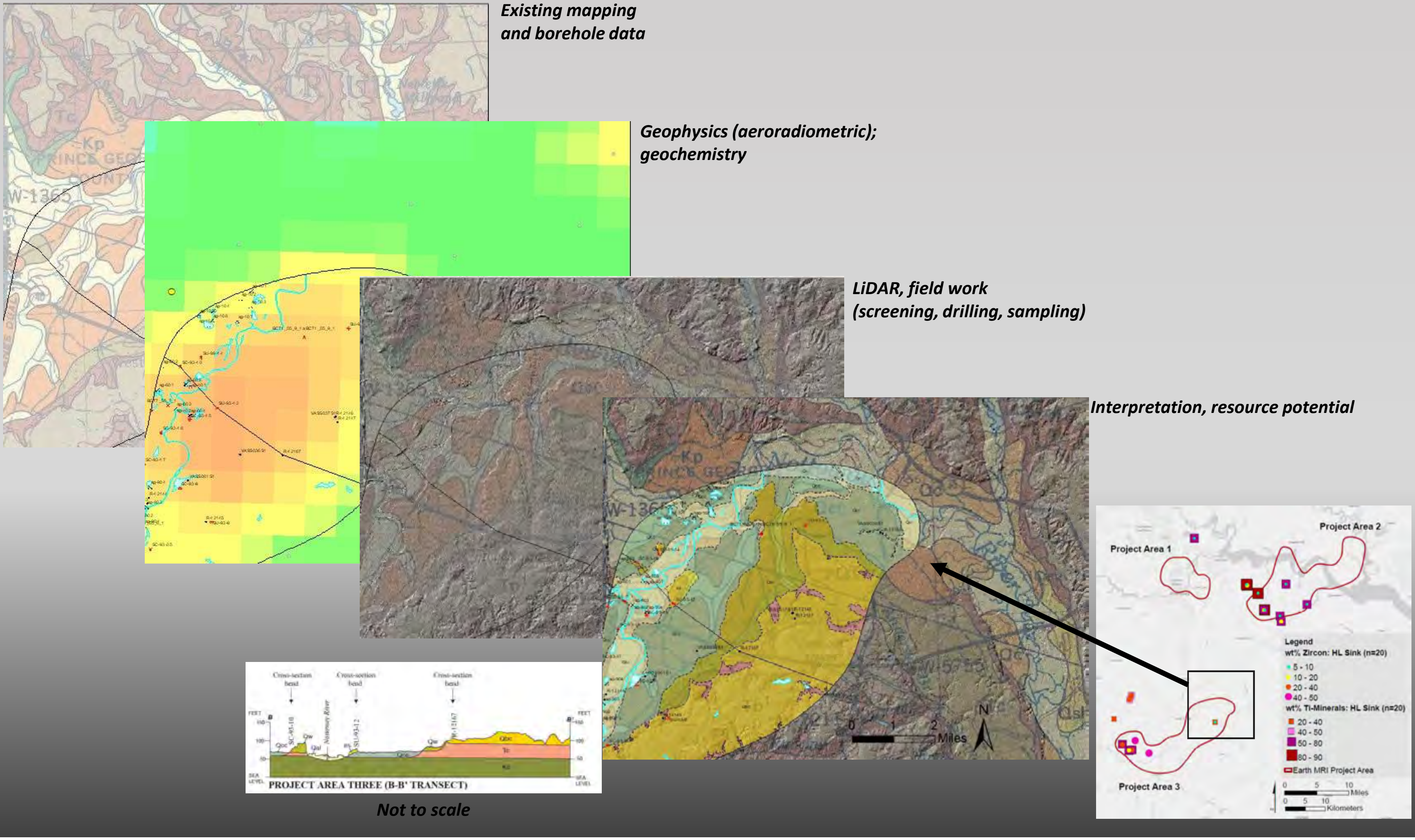
Field work

Sample processing

Analytical results

Data interpretation and <u>refinement</u> of methods

Big Picture



Existing mapping and borehole data

Geophysics (aeroradiometric); geochemistry

LiDAR, field work (screening, drilling, sampling)

Interpretation, resource potential

Not to scale

Target Area(s)

Regional-scale Data → Focus Areas

How can we apply land methods to the marine environment?

- Offshore geology and stratigraphy
- Seismic, other geophysics
- Lithology

→ Reconnaissance, geologic framework

- Sampling, screening, analysis

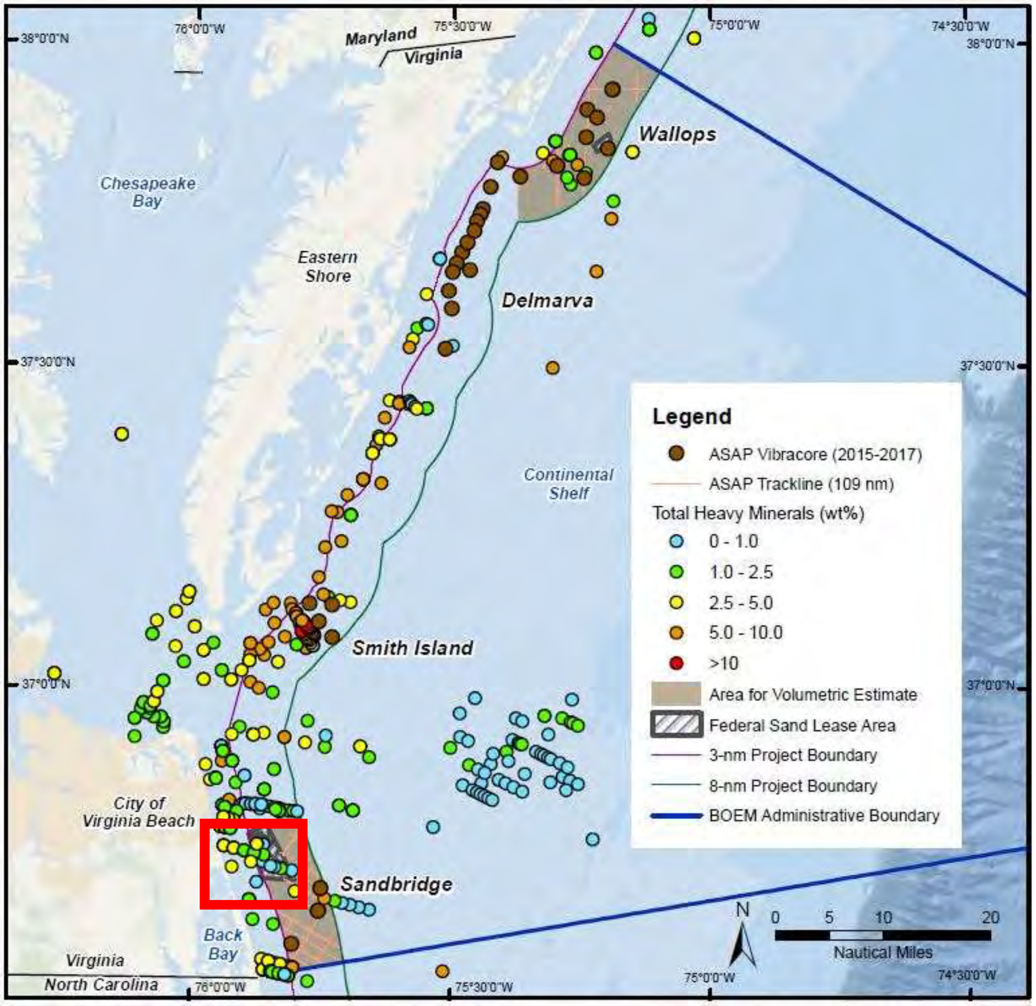
→ Field/lab applications

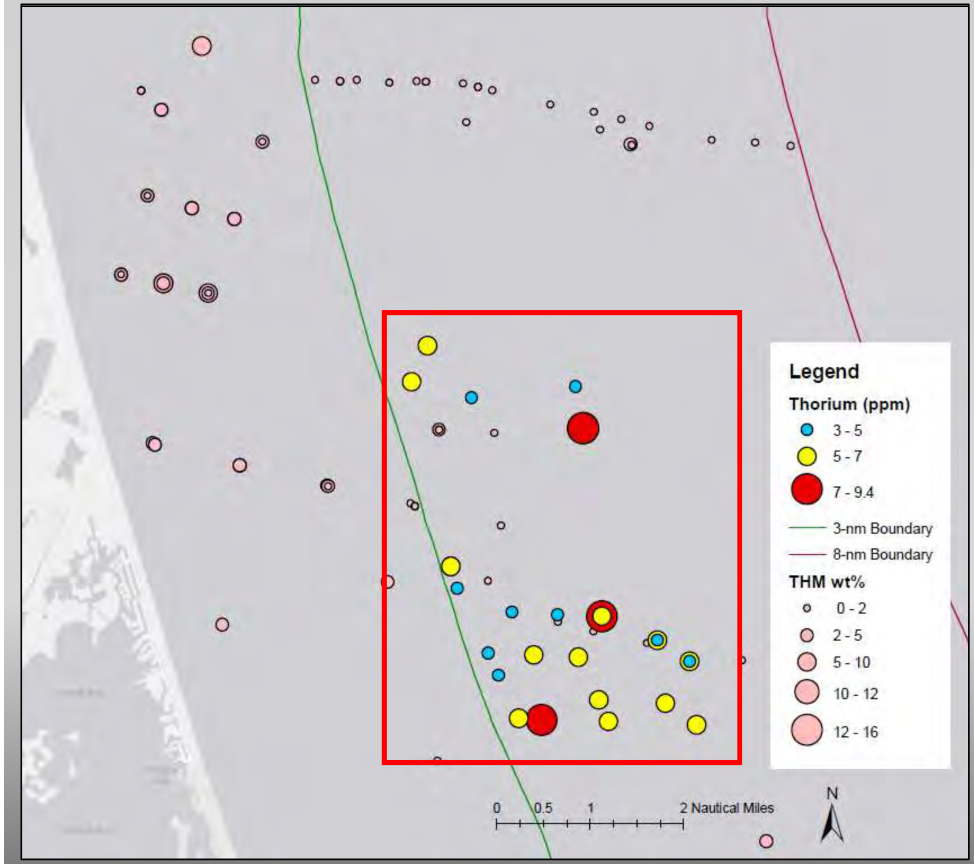
Geochemical Field/Lab Applications

<u>Gamma spectrometry:</u>
  - Heterogeneity (unconsolidated sediments)
  - Clay content
  - Error

- <u>X-ray fluorescence</u>
  - Heterogeneity (unconsolidated sediments)
  - Media preparation
  - Moisture content (what is the acceptable limit?)
  - Time
  - Error

- How can we obtain a reasonable estimate for the mineralogical composition of sediment based on elemental geochemistry from screening tools?



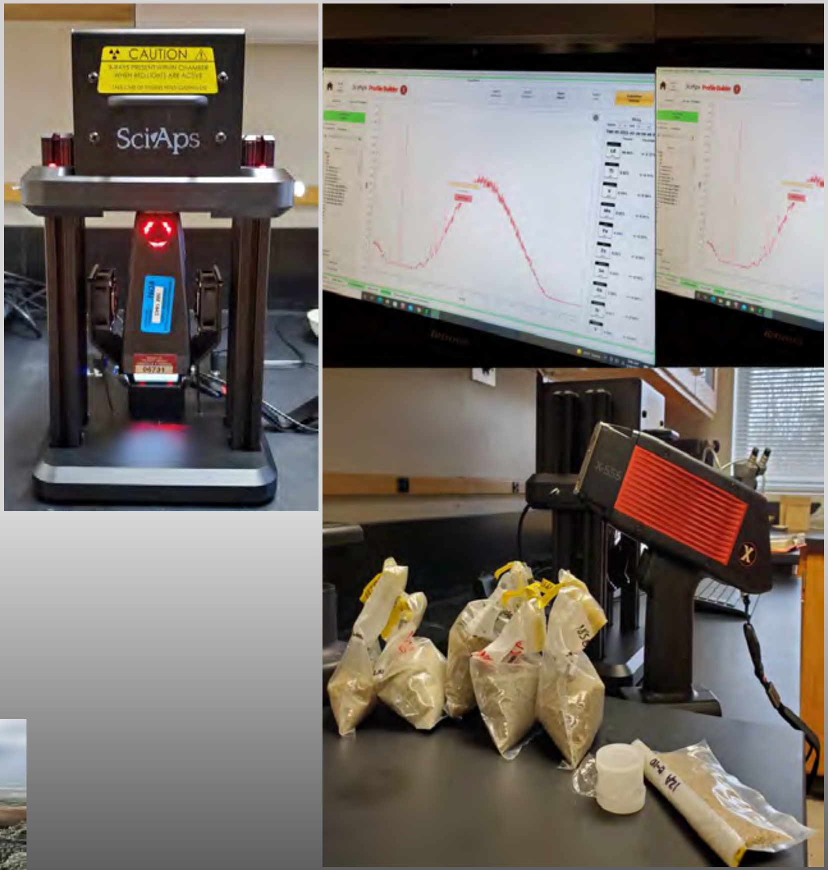


Screening data: Thorium is a proxy for monazite and heavy minerals (note: taken from bulk sample, this is not THM mineral data for new vibracores)

Gravity Separation (Pre-concentration)

Proposed Approach

- Develop a protocol to aide in rapid field assessment of minerals and/or potential contaminants
  - **Exploration, environmental, and regulatory uses**
- Utilize laboratory setting to refine testing methods (i.e.. time, media)
  - **Variations in grain-size, porosity, moisture content, etc.**
- Thoughts from other applications?



APPENDIX B

Offshore Virginia Heavy Mineral Sand Geodatabase

GEODATABASE

This geodatabase (M21AC00010_Geodatabase.gdb) was created for Cooperative Agreement M21AC00010 between VE and BOEM in an ESRI ArcGIS file geodatabase format with Federal Geographic Data Committee (FGDC) standard metadata. This database provides an updated record of heavy mineral samples located offshore of Virginia (Table B1). The polygon feature class (NewData_investigation_areas) contains the Sandbridge Borrow Lease Area managed by BOEM. This geodatabase consists of two point feature classes (M21AC00010_NewData and VA_Offshore_Previous_data) with total heavy mineral and modal mineralogy data on high-density sediments separated from offshore marine sand deposits, approximately > 2.9-3.2 g/cc. The data are projected in North American Datum (NAD) Universal Transverse Mercator Zone 18. Each point feature class has a related non-spatial table that contains extensive geochemical data (M21AC00010_NewData_additional_data_table and VA_Offshore_Previous_data_geochemical_table). The DataSources non-spatial table provides citations for the previous work dataset. This geodatabase serves as a digital archive that may be queried for total heavy mineral content, mineral composition, and distribution patterns of heavy minerals in marine sediments offshore of Virginia.

Table B1: Geodatabase Content

Name	Type
M21AC00010_NewData	File Geodatabase Point Feature Class
VA_Offshore_Previous_data	File Geodatabase Point Feature Class
NewData_investigation_areas	File Geodatabase Polygon Feature Class
M21AC00010_NewData_M21AC00010_NewData_additional_data_table	File Geodatabase Relationship Class
VA_Offshore_Previous_data_VA_Offshore_Previous_data_geochemical_table	File Geodatabase Relationship Class
DataSources	File Geodatabase Non-spatial Table
M21AC00010_NewData_additional_data_table	File Geodatabase Non-spatial Table
VA_Offshore_Previous_data_geochemical_table	File Geodatabase Non-spatial Table

Datum: NAD83
Projection: NAD83 UTM Zone 18

Data from Previous Work

The “VA_Offshore_Previous_data" feature class contains 620 grab and core sample points from previous studies spanning close to four decades (Table B2). The minimum sample depth is 0 ft (at the sediment-water interface), and the maximum sample depth is 27 ft below the interface. Sample collection and processing methods have evolved over the years from gravity and magnetic separators to include varying densities of heavy liquids. Mineral identification has also improved from the identification of minerals based on the degree and strength of magnetism and mineral point counting to high-resolution electron probe analysis and electron emission scanning. For example, Grosz et al. (1990) describes the recovery of heavy minerals from marine sediments through sieving to remove gravel, spiral/gravity concentration, heavy-liquid separation using acetylene tetrabromide ($C_2H_2Br_4$) at 2.96 g/cc, then magnetic separation. Mineral identification was performed using reflected and transmitted light through microscopes. The heavy-mineral composition of samples was determined by point counting individual mineral species present in each magnetic fraction. The product of the mineral percentage and fraction weight was used to estimate the abundance for each heavy mineral species. These were summed to calculate the total heavy mineral percentage for each sample.

This dataset provides reconnaissance information for Virginia and should help identify areas with heavy mineral potential. For example, Figure B1A displays wt% THM contours which are derived from all previous samples at the sediment-water interface (n=213). Hot spots of higher heavy mineral concentrations from this dataset align well with paleochannels (Brothers et al., 2020), modern inlets along the Eastern Shore, and are within 10 miles of the modern shorelines. Emery and Noakes (1968) estimated the median distance of heavy mineral sands from bedrock sources to be 8 km (Rona, 2008). Figure B1B displays two provenance-sensitivity indexes, which utilize mineral point count data and considers the stability of certain heavy minerals (Morton and Hallsworth, 1994). Detrital heavy minerals are known to be stable under deep burial conditions (high pore fluid temperatures), and therefore are expected to have similar chemical, mechanical and hydraulic behavior are apatite, rutile, zircon, and tourmaline. Index values presented in Figure B1B are: ATi, (percent of apatite divided by the sum of the percents of apatite and tourmaline), MZi (percent monazite divided by the sum of percents monazite and zircon), and RZi (percent rutile divided by the sum of percents rutile and zircon). Variations in these indices likely demonstrate that these minerals were derived from distinct bedrock sources in the region.

Figure B1B highlights the distinction between the clustered Sandbridge (green) and Smith Island (dark blue) provenance indices data. The offshore Wind Energy Area (WEA) (light blue) data is also distinguished from the major Sandbridge component and overlaps with values from Smith Island. The Wallops provenance index data (red) is scattered, and no pattern or distinction can be made. While it is not the scope of this assessment to identify the bedrock sources for offshore heavy minerals, the data do provide evidence that heavy minerals offshore of Virginia are variable in grade (wt% THM and mineralogy), potentially due to variable source areas. Figure B1C shows how well previous and new (white halo) wt% THM data compare in the Sandbridge and Atlantic Channel study areas. Yellow-filled circles represent higher total heavy mineral concentrations, while blue-filled circles represent <1 wt% THM. In general, these data are comparable for the Sandbridge borrow areas though overlap is minimal.

Early data from the Virginia Inner Continental Shelf (ICS) indicated average heavy mineral content of 8 wt% in the vicinity of Smith Island Shoal, Wachapreague Inlet, and Quinby Inlet (Berquist and Hobbs 1986). The uppermost Holocene surficial layer hosted the highest heavy mineral concentrations occurring in discontinuous lenses, although the minerals may have been sourced from the underlying strata through reworking (Berquist and Hobbs 1986). Where the surficial unit is thin or absent, heavy minerals such as zircon and monazite occur as lag deposits in troughs or in pre-Holocene units (Berquist 1990). Additional work offshore of Virginia Beach in the mouth of the Chesapeake Bay, and at other localities on the Outer Continental Shelf (OCS) yielded heavy mineral concentrations up to 14.7 wt%, with an average THM content of 3.5 wt% (Berquist and Hobbs 1988a; 1988b).

Berquist et al. (2016) evaluated heavy minerals in the Virginia WEA, which is substantially further offshore on the OCS in federal waters (20+ miles). Overall, THM content greater than 1.85 wt% correlated with higher percentages of very fine sand. Higher THM concentrations (i.e., >2 wt%) were closer to the shore within the three to eight nautical mile zone of the federal waters assessed (Berquist et al. 2016). Lassetter and Blanchette (2019) evaluated heavy minerals offshore Sandbridge Beach and Wallops Island. The data indicated that THM fractions were generally constrained to very fine to fine sand, with an average of 41 wt% of the THM fraction representing economic minerals (i.e., ilmenite, rutile, zircon, etc.). Based on the 63 sediment core and grab samples analyzed in the 2019 study, the THM fraction from surface and near surface samples averaged 0.60 wt% from those two localities (Lassetter and Blanchette 2019). Overall, grab samples and the upper few feet of sediment cores had higher THM concentrations relative to down-core samples (Lassetter and Blanchette 2019). However, the percentage of the economic minerals in the THM fraction was variable throughout the samples (i.e., grab and core). An analysis of the existing dataset of 620 samples indicates an average of 2.7 wt% THM from OCS samples (Hawkins and Lassetter 2022).

Table B2: Heavy mineral separation and mineral identification methods for 620 previous samples in geodatabase.

Number and type of samples	**Sample Collection Year** ***Mineral and/or Geochemical analysis year***	**Analysis Type**	**Investigating Entities**	**Separation Methods**	**Mineral Identification Method**	**Reference**
41 grab samples	1985 *1985*	**wt% THM** [n = 41] **Modal mineralogy** [n = 28]	• GMR • U.S. Minerals Management Service (MMS) • Virginia Institute of Marine • Science (VIMS) of the College of William and Mary	1. Sieving 2. Humphreys 3-turn spiral 3. Heavy liquid: bromoform at 2.85 g/cc 4. Frantz Isodynamic Magnetic Separator (FIMS)	Binocular microscope and X-ray analysis. Economic Heavy Minerals (EHM): Ilm, Rt, Sil, Lcx, Mnz, Zrn	Berquist Jr. and Hobbs III (1986)
283 vibracore samples 96 grab samples (379 samples total)	1970 (n=49) 1986 (n=128) 1987 (n=202) *1988 (n=379)*	**wt% THM** **Modal mineralogy** [n = 379]	• GMR • U.S. Minerals Management Service (MMS) • Virginia Institute of Marine • Science (VIMS) of the College of William and Mary	1. Sieving 2. Humphreys 3-turn spiral 3. Heavy liquid: acetylene tetrabromide ($C_2H_2Br_4$) at 2.96 g/cc 4. FIMS	Magnetic susceptibility, grain shape, color, cleavage, streak, fluorescence, solubility in acids, and optical properties. EHM: Ilm, Rt, Sil, Ky, Lcx, Mnz, Zrn	Berquist Jr. and Hobbs III (1988a, 1988b) Grosz et al. (1990) Berquist Jr. et al. (1990) *in* Berquist Jr. (1990) Meisburger (1972)

Table B2: Heavy mineral separation and mineral identification methods for 620 previous samples in geodatabase.

Number and type of samples	**Sample Collection Year** ***Mineral and/or Geochemical analysis year***	**Analysis Type**	**Investigating Entities**	**Separation Methods**	**Mineral Identification Method**	**Reference**
23 cores (72 samples total)	June 1985 *1990*	**wt% THM** **Modal mineralogy** [n = 72]	USGS	1. Sieving (remove < 62 micron) 2. Humphreys 3-turn spiral 3. Magnetic separation	Magnetic susceptibility, identification using binocular and petrographic microscopes, UV fluorescence, SEM and EDAX (select grains). EHM: Ilm, Lcx, Rt, Sil, Ky, Zrn, Mnz	Luepke (1990)
3 grab samples	August 2011 *2011*	**wt% THM** **Modal mineralogy** [n = 3]	BOEM, GMR and VIMS	1. Sieving to remove >2 mm 2. Humphreys 3-turn spiral 3. Heavy liquid: 2.89 g/cc (Activation Laboratories, Ontario)	Point count analysis of heavy-mineral concentrates with field emission scanning electron microscope. EHM: Ilm, Lcx, Rt, Zrn, Mnz	Berquist Jr. (2012)
60 grab samples	June-July 2013 *2015*	**wt% THM** **Modal mineralogy** [n = 60]	• BOEM, GMR and VIMS • Samples provided by: Fugro Consultants Inc.	1. Sieving 2. Humphreys 3-turn spiral 3. Heavy liquid: 2.89 g/cc (Activation Laboratories, Ontario)	Automated mineralogy with field emission gun quantitative evaluation of minerals by scanning electron microscopy (FEG QEMSCAN). EHM: Ilm, Rt, Lcx, Mag, Zrn, Mnz, Amp, St, Grt	Berquist Jr. et al. (2016)

Table B2: Heavy mineral separation and mineral identification methods for 620 previous samples in geodatabase.

Number and type of samples	**Sample Collection Year** ***Mineral and/or Geochemical analysis year***	**Analysis Type**	**Investigating Entities**	**Separation Methods**	**Mineral Identification Method**	**Reference**
65 samples total	June-July 2013 September 2015 August 2016 December 2017	**wt% THM** **Modal mineralogy** [n = 65]	• BOEM, GMR and VIMS • Samples provided by: Chicago Bridge and Ironworks Company and Tetra Tech, Inc. (TT) {BOEM Atlantic Sand Assessment Project (ASAP) 2015-2017}	1. Sieving to remove >2mm 2. Humphreys 3-turn spiral 3. Heavy liquid: 3.2 g/cc (Activation Laboratories, Ontario)	Automated mineralogy with field emission imaging FEG QEMSCAN scanning electron microscope Mineral Liberation Analysis method. EHM: Ilm, Rt, Zrn, Lcx, Ttn, Xtm, Mnz, Ap, Chr	Lassetter and Blanchette (2019)
13 grab samples (TT in 2013)	*2016 (n=13)*					
14 core samples (ASAP 2015)	*2017 (n=14)*					
15 core samples (TT in 2013)	*2017 (n=15)*					
23 core samples (ASAP 2015-2017)	*2018 (n=23)*					

New Data

SGS Canada Inc. prepared 20 sand and 3 mud subsamples for mineralogical and geochemical analysis (13 from SBB area A, 6 from SBB area B, and 4 from Atlantic Channel), to identify abundances of critical heavy minerals (Ti, Zr and REE-bearing minerals) using Tescan Integrated Mineral Analyzer (TIMA) technology. TIMA is used to quantify mineral speciation and distribution, grain size characteristics, and degree of liberation of the heavy mineral sand grains in the sink fraction (>2.9 g/cc density). At least two polished sections are prepared for each sample to ensure an adequate population of grains are present on the grain mounts. Electron Probe Micro Analysis (EPMA) was conducted on selected samples to determine the chemical composition of individual mineral grains. The sink fraction was also analyzed for bulk geochemical composition using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and ICP-Atomic Emission Spectrometry (ICP-AES). These analytical methods provide concentrations for 56 major and trace elements. Additionally, qualitative mineral identification by x-ray diffraction (XRD) analysis was performed on a selected number of samples to determine bulk crystalline mineralogy. XRD analysis of the selected sink samples (R-12225, R-12226, R-12227, R-12236) consist mainly of ilmenite, amphibole, garnet, with minor zircon, quartz, epidote, chlorite, hematite, rutile, and trace amounts of monazite, and davidite. The bulk and spiraled weights, total heavy mineral concentration from the spiral method, along with the full suite of geochemical data provided by SGS Canada Inc. are provided in Appendix C.

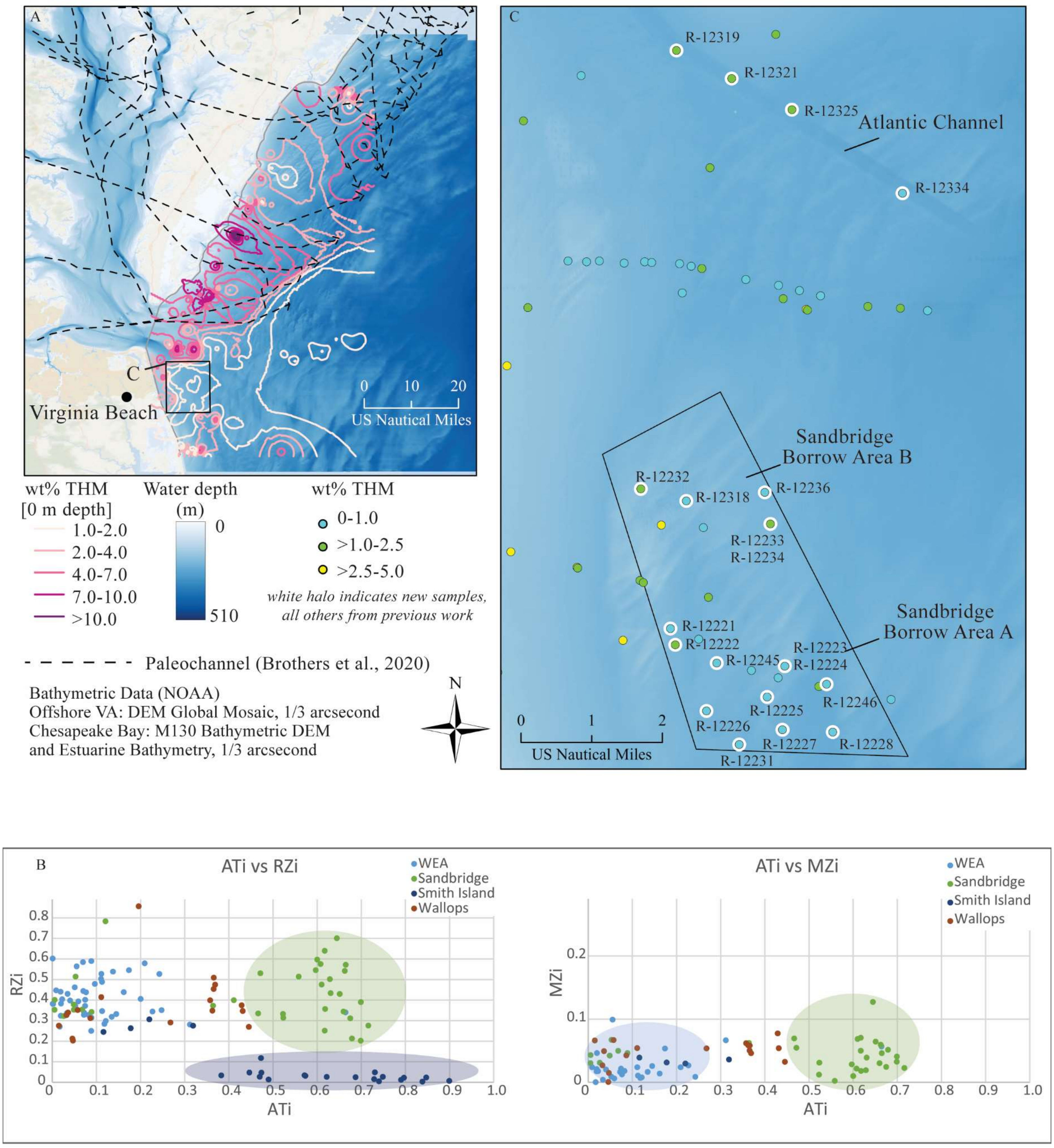


Figure B1: A) THM contours derived from previous sediment grab samples (i.e., samples from sediment water interface only, n=213). “Hot spots” with >7 wt% THM appear near paleochannel pathways (Brothers et al. 2020) and modern inlets. B) Provenance-sensitivity indices. ATi = wt% apatite divided by the sum of wt% apatite and wt% tourmaline, MZi = wt% monazite divided by the sum of wt% monazite and wt% zircon, and RZi = wt% rutile divided by the sum of wt% rutile and wt% zircon. Variations in these indices likely demonstrate that these minerals were derived from distinct bedrock sources in the region. C) Distribution of geodatabase point locations showing previous data and M21AC00010 project data (white halo, cores labeled) in the Atlantic Channel and Sandbridge Borrow Areas.

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APPENDIX C

Data Tables

Core data from Schnabel Engineering report data[1,2], and Virginia Energy total heavy mineral content from spiral and heavy liquid separation.

[1] Schnabel Engineering. 2018. Sandbridge Beach Renourishment Project: Sandbridge Shoal Borrow Site Areas A & B, Virginia Beach, Virginia. Blacksburg (VA): Schnabel Engineering. 15 p. and Appendices. Schnabel Reference 18C13103.

[2] Schnabel Engineering. 2019. Sandbridge Beach Renourishment Project: Atlantic Ocean Channel and Thimble Shoal Channel Atlantic Ocean, Virginia Beach, Virginia. Blacksburg (VA): Schnabel Engineering. 14 p. and Appendices. Schnabel Reference 18C13103.

SGS Analytical Report – An investigation by high definition mineralogy into twenty-three mineral sand samples from offshore of Virginia, USA: Project 17512-02 Final Report, May 31, 2023

*(**Note:** Appendix D and E of SGS report are not included but are available as Microsoft Excel spreadsheets upon request from Virginia Energy)*

Table C1. Sandbridge Shoal and Atlantic Ocean Channel Core Data.

Study Area	**VA GMR Rock Repository ID**	**Schnabel Core ID**	**Water Depth** [1] (ft)	**Latitude** [1] (NAD83)	**Longitude** [1] (NAD83)	**Grain-size Interval** [2] (ft)	**% Sand**	**% Mud**	**% Gravel**	**Lithology** [3]	**Heavy Mineral Sample Interval** (ft)	**% THM Fraction** [4] (Spiral)	**% THM Fraction** [4] (HL)
Sandbridge Shoal Area A	R-12227m	18SBB-46	54.2	36.70906858	-75.83645738	--	--	--	--		0-13, mud subsample	--	n/a
Sandbridge Shoal Area B	R-12236m	18SBB-71	51.8	36.76514284	-75.84223261	--	--	--	--		0-15, mud subsample	--	n/a
Sandbridge Shoal Area A	R-12245m	18SBB-08	50	36.72468946	-75.85588799	--	--	--	--	mud fraction from SP	2-11, mud subsample	--	n/a
Sandbridge Shoal Area A	R-12220	18SBB-02	45.3	36.73273461	-75.86956651	0-4.1	87.3	12.7	0	SM (SP)	0-5	6.9	--
Sandbridge Shoal Area A	R-12221	18SBB-02	45.3	36.73273461	-75.86956651	10-15	98.4	1.6	0	SP	10-15	2.9	0.6
Sandbridge Shoal Area A	R-12222	18SBB-04A	50	36.7288805	-75.86813657	0-5	93.2	6.4	0.4	SP-SM	0-5	18.2	1.9
Sandbridge Shoal Area A	R-12245	18SBB-08	50	36.72468946	-75.85588799	2.1-6.8	88.6	4.4	7	SP	2-11	2.4	0.8
Sandbridge Shoal Area A	R-12312	18SBB-10	50.7	36.72432195	-75.84582467	0.0-4.7	83.8	14.3	1.9	SP (SM, CH)	3-15	0.7	--
Sandbridge Shoal Area A	R-12223	18SBB-12A	41	36.72409684	-75.83589979	0-5	98	2	0	SP	0-10	1.8	0.4
Sandbridge Shoal Area A	R-12224	18SBB-12A	41	36.72409684	-75.83589979	10-15	97.8	2.1	0.1	SP, SP-SM	10-20	2.3	0.7
Sandbridge Shoal Area A	R-12313	18SBB-13	58.7	36.71989829	-75.82359247	0.0-3.5	93.7	1.9	4.4	SP	0-5.5	2.8	--

Study Area	**VA GMR Rock Repository ID**	**Schnabel Core ID**	**Water Depth** [1] (ft)	**Latitude** [1] (NAD83)	**Longitude** [1] (NAD83)	**Grain-size Interval** [2] (ft)	**% Sand**	**% Mud**	**% Gravel**	**Lithology** [3]	**Heavy Mineral Sample Interval** (ft)	**% THM Fraction** [4] (Spiral)	**% THM Fraction** [4] (HL)
Sandbridge Shoal Area A	R-12246	18SBB-13	58.7	36.71989829	-75.82359247	13.7-18.5	91	9	0	SP-SM (CH)	13.5-18.5	2.5	0.8
Sandbridge Shoal Area A	R-12314	18SBB-22	48.5	36.71734745	-75.86112305	0-5	94.5	3.4	2.1	SP (CH)	0-9	1.4	--
Sandbridge Shoal Area A	R-12315	18SBB-24	52	36.71707111	-75.85094147	0-3	95.7	2.3	2	SP	0-13	0.8	--
Sandbridge Shoal Area A	R-12225	18SBB-26	49.8	36.71675309	-75.84102079	0-5.1	92.4	7.6	0	SP-SM (SP)	0-12	1.8	1.0
Sandbridge Shoal Area A	R-12316	18SBB-31	50.4	36.71614536	-75.81640041	0-5	98.4	0.8	0.8	SP	0-10	1.6	--
Sandbridge Shoal Area A	R-12247	18SBB-31	50.4	36.71614536	-75.81640041	10-15	66.1	4.6	29.3	SP	10-15	2.7	--
Sandbridge Shoal Area A	R-12226	18SBB-41	47.9	36.71334307	-75.85876052	0-5	94.6	0.8	4.6	SP	0-11	0.9	0.6
Sandbridge Shoal Area A	R-12227	18SBB-46	54.2	36.70906858	-75.83645738	0-5	92.6	5.7	1.7	SP-SM (CL), SP, SP-SM	0-13	2.4	0.9
Sandbridge Shoal Area A	R-12228	18SBB-49	56.1	36.7086352	-75.82165833	0-4.5	89.6	10.4	0	(SP-SM), SM, (CH)	0-7.5	5.6	1.0
Sandbridge Shoal Area A	R-12229	18SBB-51	54.3	36.7048047	-75.81468515	0.0	98.4	1.5	0.1	SP	0-5	2.6	--
Sandbridge Shoal Area A	R-12230	18SBB-55A	56.3	36.70525061	-75.83421953	1.4-6.4	96.1	0.6	3.3	SP	1.5-9	1.5	--
Sandbridge Shoal Area A	R-12231	18SBB-58	55.4	36.70549153	-75.84908266	0-4.7	95	4.4	0.6	SP	0-3, 5-9	1.6	0.6

Study Area	**VA GMR Rock Repository ID**	**Schnabel Core ID**	**Water Depth**[1] (ft)	**Latitude**[1] (NAD83)	**Longitude**[1] (NAD83)	**Grain-size Interval**[2] (ft)	**% Sand**	**% Mud**	**% Gravel**	**Lithology**[3]	**Heavy Mineral Sample Interval** (ft)	**% THM Fraction**[4] (Spiral)	**% THM Fraction**[4] (HL)
Sandbridge Shoal Area A	R-12317	18SBB-59A	51.5	36.70575063	-75.85422647	1.2-2.4	95.5	2.1	2.4	SP (CL)	0-9	0.7	--
Sandbridge Shoal Area B	R-12232	18SBB-60.5	41.65	36.76567921	-75.8786468	0-4.6	98.8	1.2	0	SP	0-14	6.1	1.2
Sandbridge Shoal Area B	R-12318	18SBB-62	45.5	36.7629555	-75.86524463	0-4.6	98.3	1.5	0.2	SP (CH)	0-7	2.8	0.6
Sandbridge Shoal Area B	R-12233	18SBB-65	47.55	36.75766829	-75.84049994	0-4.5	98.6	1.2	0.2	SP (SC)	0-10	1.6	0.7
Sandbridge Shoal Area B	R-12234	18SBB-65	47.55	36.75766829	-75.84049994	9.6-14.6	96.3	3.7	0	SP, SP-SM	10-19.6	3.5	1.2
Sandbridge Shoal Area B	R-12235	18SBB-67	40.65	36.7721917	-75.87522852	0-4.6	99.1	0.7	0.2	SP (SM, SC)	0-9	1.9	--
Sandbridge Shoal Area B	R-12236	18SBB-71	51.8	36.76514284	-75.84223261	0-5	97.8	1.6	0.6	SP, SP-SM	0-15	1.4	0.7
Atlantic Ocean Channel	R-12319	18BS-01	57.6	36.86950339	-75.86936225	0-4.7	62.6	37.4	0	SM, SP-SM	0-4.7	5.6	1.4
Atlantic Ocean Channel	R-12320	18BS-01	57.6	36.86950339	-75.86936225	9.7-14.7	73.8	26.2	0	(SP-SM, CH) SM	9.7-19.7	1.0	--
Atlantic Ocean Channel	R-12321	18BC-02	57.7	36.86298571	-75.85302275	0-5	94	6	0	SP-SM, SP	0-10	2.8	1.1
Atlantic Ocean Channel	R-12322	18BC-02	57.7	36.86298571	-75.85302275	10-15	95.6	4.1	0.3	SP	10-15	1.2	--
Atlantic Ocean Channel	R-12323	18BC-03	59.9	36.85746737	-75.8419409	0-4.2	81.9	18.1	0	SM, SP	0-10	0.0	--

Study Area	**VA GMR Rock Repository ID**	**Schnabel Core ID**	**Water Depth**[1] (ft)	**Latitude**[1] (NAD83)	**Longitude**[1] (NAD83)	**Grain-size Interval**[2] (ft)	**% Sand**	**% Mud**	**% Gravel**	**Lithology**[3]	**Heavy Mineral Sample Interval** (ft)	**% THM Fraction**[4] (Spiral)	**% THM Fraction**[4] (HL)
Atlantic Ocean Channel	R-12324	18BC-03	59.9	36.85746737	-75.8419409	9.2-14.2	96.7	3.3	0	SP	10-19	1.1	--
Atlantic Ocean Channel	R-12325	18BN-03	62.5	36.8557422	-75.83523351	0-3.9	82.3	17.1	0.6	SM, SP	0-10	2.7	1.1
Atlantic Ocean Channel	R-12326	18BN-03	62.5	36.8557422	-75.83523351	8.9-13.9	97.3	2.4	0.3	SP	10-19	2.6	--
Atlantic Ocean Channel	R-12327	18BC-04	63	36.85194799	-75.83086067	0-2.5	93.3	3.8	2.9	SP	0-10	2.1	--
Atlantic Ocean Channel	R-12328	18BC-04	63	36.85194799	-75.83086067	12.5-17.5	97	1.5	1.5	SP	10-17.5	1.2	--
Atlantic Ocean Channel	R-12329	18BC-05	65.7	36.84642756	-75.81978204	0-4.3	97.8	2.2	0	SP (SP-SM)	0-10	0.8	--
Atlantic Ocean Channel	R-12330	18BC-05	65.7	36.84642756	-75.81978204	9.3-14.3	94	5.6	0.4	SP-SM, SP	10-19.3	0.9	--
Atlantic Ocean Channel	R-12331	18BN-05	68.6	36.84470113	-75.81307612	0-1.8	91.5	2.5	6	SP	0-16.8	0.5	--
Atlantic Ocean Channel	R-12332	18BC-06	65.4	36.84090609	-75.80870503	0-4.6	97.2	2.8	0	(SM, CH) SP	0-10	3.0	--
Atlantic Ocean Channel	R-12333	18BC-06	65.4	36.84090609	-75.80870503	9.6-14.6	95.7	4.3	0	SP (SM, CH)	10-18	0.6	--
Atlantic Ocean Channel	R-12334	18BS-07	64	36.83618756	-75.80248264	0-3.2	89	10.4	0.6	SP-SM, SP	0-10	2.0	0.7
Atlantic Ocean Channel	R-12335	18BS-07	64	36.83618756	-75.80248264	8.2-13.2	96.9	1.7	1.4	SP	10-18.2	0.8	--

Study Area													
Atlantic Ocean Channel	R-12336	18BN-07	68.6	36.83365587	-75.79092519	0-4.2	96.5	3.5	0	SP	0-19.2	0.6	--

[1] Core location data and MLLW water depth provided by Schnabel Engineering (2018, 2019).

[2] Grain-size data provided by Schnabel Engineering (2018, 2019). Schnabel Engineering followed ASTM D2487 for grain-size classification: https://www.astm.org/d2487-17.html.

[3] As described by Schnabel Engineering (2018, 2019), covering heavy mineral sample depth interval. Lithology in parentheses indicates minor component of sample. SM = silty sand, SP = poorly graded sand, SP-SM = poorly graded sand with silt, SC = clayey sand, CH = fat clay.

[4] Spiral: This THM fraction represents the initial estimate based on gravity and centrifugal separation using the three-turn Humphrey Spiral. HL: This fraction was obtained from laboratory analytical data from SGS using heavy liquid separation at 2.9 g/cc density.

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18BC-01	0.0 - 5.0	-56.2 - -61.2	36.868503	-75.86410622	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, gray	77.9	21.3	21.3	75.4	0.8
18BC-01	5.0- 10.0	-61.2 - -66.2	36.868503	-75.86410622	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, brownish gray	80.9	6.4	6.4	62.3	12.7
18BC-02	0.0 - 5.0	-56.6 - -61.6	36.86298571	-75.85302275	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, gray	94.0	6.0	6.0	89.8	0.0
18BC-02	5.0- 10.0	-61.6 - -66.6	36.86298571	-75.85302275	POORLY GRADED SAND (SP), fine to coarse grained sand, brownish gray	95.9	4.1	4.1	87.5	0.0
18BC-02	10.0 - 15.0	-66.6 - -71.6	36.86298571	-75.85302275	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, brownish gray	95.6	4.1	4.1	80.2	0.3
18BC-02	15.0 - 20.0	-71.6 - -76.6	36.86298571	-75.85302275	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, gray	89.6	8.8	8.8	89.0	1.6
18BC-03	0.0 - 4.2	-57.4- -61.6	36.85746737	-75.8419409	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, gray	81.9	18.1	18.1	89.7	0.0
18BC-03	4.2 - 9.2	-61.6 - -66.6	36.85746737	-75.8419409	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, brown	92.7	1.9	1.9	57.0	5.4
18BC-03	9.2 - 14.2	-66.6 - -71.6	36.85746737	-75.8419409	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	96.7	3.3	3.3	75.7	0.0
18BC-03	14.2- 19.2	-71.6 - -76.6	36.85746737	-75.8419409	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, brownish gray	96.0	3.5	3.5	82.0	0.5
18BC-04	0.0 - 2.5	-61.4 - -63.9	36.85194799	-75.83086067	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, gray	93.3	3.8	3.8	57.9	2.9
18BC-04	2.5 - 7.5	-63.9 - -68.9	36.85194799	-75.83086067	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, brown	95.2	1.4	1.4	59.9	3.4
18BC-04	7.5- 12.5	-68.9 - -73.9	36.85194799	-75.83086067	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, ray	98.3	1.3	1.3	75.3	0.4
18BC-04	12.5 - 17.5	-73.9 - -78.9	36.85194799	-75.83086067	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, ray	97.0	1.5	1.5	25.9	1.5
18BC-05	0.0- 4.3	-62.5 - -66.8	36.84642756	-75.81978204	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	97.8	2.2	2.2	67.3	0.0
18BC-05	4.3- 9.3	Bag	36.84642756	-75.81978204	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, light brown and gray	95.9	0.9	0.9	21.7	3.2
18BC-05	9.3 - 14.3	-71.8 - -76.8	36.84642756	-75.81978204	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, brown	94.0	5.6	5.6	98.4	0.4
18BC-05	14.3- 19.3	-76.8 - -81.8	36.84642756	-75.81978204	POORLY GRADED SAND (SP), fine to coarse grained sand, dark gray	97.0	3.0	3.0	85.0	0.0
18BC-06	0.0- 4.6	-62.5 - -67.1	36.84090609	-75.80870503	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	97.2	2.8	2.8	69.9	0.0
18BC-06	4.6- 9.6	-67.1 - -72.1	36.84090609	-75.80870503	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	96.2	3.6	3.6	68.5	0.2
18BC-06	9.6 - 14.6	-72.1 - -77.1	36.84090609	-75.80870503	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	95.7	4.3	4.3	97.6	0.0
18BC-07	0.0- 4.8	-65.2 - -70.0	36.83538357	-75.79762962	SILTY SAND (SM), fine to coarse grained sane, contains mica, trace shell fragments, dark gray	79.7	20.3	20.3	98.8	0.0

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18BC-07	4.8- 9.8	-70.0 - -75.0	36.83538357	-75.79762962	SILTY SAND (SM), fine to coarse grained sand, trace gravel, dark gray	86.0	13.5	13.5	91.2	0.5
18BC-07	9.8 - 14.8	-75.0 - -80.0	36.83538357	-75.79762962	POORLY GRADED SAND WITH SILT (SP-SM), fine to medium grained sand, dark gray	92.3	7.7	7.7	99.5	0.0
18BN-01	0.0 - 2.8	-52.7 - -55.5	36.86677909	-75.85739735	SILTY SAND (SM), fine to coarse grained sand, contains mica, shell fragments, trace gravel, dark gray	77.9	21.9	21.9	98.8	0.2
18BN-01	2.8 - 7.8	-55.5 - -60.5	36.86677909	-75.85739735	SILTY SAND (SM), fine to coarse grained sand, contains mica, trace shell fragments, dark gray	74.2	25.8	25.8	99.4	0.0
18BN-01	7.8 - 12.8	-60.5 - -65.5	36.86677909	-75.85739735	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, dark gray	95.1	4.3	4.3	61.9	0.6
18BN-01	12.8 - 17.8	-65.5 - -70.5	36.86677909	-75.85739735	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, tan-gray	96.1	2.4	2.4	56.0	1.5
18BN-02	0.0 - 2.9	-53.5 - -56.4	36.86053775	-75.84486191	SILTY SAND (SM), fine to coarse grained sand, contains mica, contains shell fragments, gray	79.5	20.4	20.4	99.2	0.1
18BN-02	2.9 - 7.9	-56.4 - -61.4	36.86053775	-75.84486191	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, gray	80.5	19.0	19.0	96.1	0.5
18BN-02	7.9- 12.9	-61.4 - -66.4	36.86053775	-75.84486191	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, gray	95.8	4.2	4.2	85.3	0.0
18BN-02	12.9- 17.9	-66.4 - -71.4	36.86053775	-75.84486191	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	97.4	1.8	1.8	61.6	0.8
18BN-03	0.0 - 3.9	-58.9 - -62.8	36.8557422	-75.83523351	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, gray	82.3	17.1	17.1	90.0	0.6
18BN-03	3.9 - 8.9	-62.8 - -67.8	36.8557422	-75.83523351	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	85.9	2.2	2.2	48.9	11.9
18BN-03	8.9 - 13.9	-67.8 - -72.8	36.8557422	-75.83523351	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	97.3	2.4	2.4	51.0	0.3
18BN-03	13.9- 18.9	-72.8 - -77.8	36.8557422	-75.83523351	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	88.8	1.7	1.7	25.1	9.5
18BN-04	5.5 - 9.2	-67.5 - -71.2	36.84949849	-75.82270172	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, brown and gray	96.8	1.4	1.4	29.6	1.8
18BN-04	9.2 - 14.2	-71.2 - -76.2	36.84949849	-75.82270172	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	98.2	1.8	1.8	30.1	0.0
18BN-04	14.2- 19.2	-76.2 - -81.2	36.84949849	-75.82270172	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	85.6	3.0	3.0	67.1	11.4
18BN-05	0.0 - 1.8	-65.0 - -66.8	36.84470113	-75.81307612	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	91.5	2.5	2.5	44.8	6.0
18BN-05	1.8 - 6.8	-66.8 - -71.8	36.84470113	-75.81307612	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	87.8	1.2	1.2	33.6	11.0
18BN-05	6.8 - 11.8	-71.8 - -76.8	36.84470113	-75.81307612	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	98.0	1.5	1.5	65.5	0.5
18BN-05	11.8 - 16.8	-76.8 - -81.8	36.84470113	-75.81307612	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	96.3	1.5	1.5	36.0	2.2
18BN-06	0.0 - 3.3	-65.5 - -68.8	36.83845505	-75.80054798	SILTY SAND (SM), fine to coarse grained sand, contains mica and shell fragments, dark gray	85.4	14.6	14.6	95.4	0.0
18BN-06	3.3 - 8.3	-68.8 - -73.8	36.83845505	-75.80054798	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	98.2	1.8	1.8	96.1	0.0

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18BN-06	8.3 - 13.3	-73.8 - -78.8	36.83845505	-75.80054798	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	93.0	0.7	0.7	14.6	6.3
18BN-07	0.0 - 4.2	-64.6 - -68.8	36.83365587	-75.79092519	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	96.5	3.5	3.5	87.9	0.0
18BN-07	4.2 - 9.2	-68.8 - -73.8	36.83365587	-75.79092519	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	91.8	1.1	1.1	22.5	7.1
18BN-07	9.2 - 14.2	-73.8 - -78.8	36.83365587	-75.79092519	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	94.5	1.5	1.5	23.9	4.0
18BN-07	14.2 - 19.2	-78.8 - -83.8	36.83365587	-75.79092519	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	97.7	1.1	1.1	43.9	1.2
18BS-01	0.0- 4.7	-54.4 - -59.1	36.86950339	-75.86936225	SILTY SAND (SM), fine to coarse grained sand, contains mica and shell fragments, dark gray	62.6	37.4	37.4	97.2	0.0
18BS-01	4.7 - 9.7	-59.1 - -64.1	36.86950339	-75.86936225	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, brown and gray	90.9	8.1	8.1	65.1	1.0
18BS-01	9.7 - 14.7	-64.1 - -69.1	36.86950339	-75.86936225	SILTY SAND (SM), fine to medium grained sand, dark gray	73.8	26.2	26.2	90.7	0.0
18BS-01	14.7- 19.7	-69.1 - -74.1	36.86950339	-75.86936225	SILTY SAND (SM), fine to coarse grained sand, dark gray	78.9	21.1	21.1	95.3	0.0
18BS-02	0.0 - 3.5	-55.3 - -58.8	36.86467665	-75.85966447	SILTY SAND (SM), fine to coarse grained sand, contains mica, trace shell fragments, dark gray	77.0	23.0	23.0	97.1	0.0
18BS-02	3.5 - 8.5	-58.8 - -63.8	36.86467665	-75.85966447	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, tan-gray	97.1	1.8	1.8	60.6	1.1
18BS-02	8.5 - 12.3	-63.8 - -67.6	36.86467665	-75.85966447	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	91.8	4.6	4.6	79.0	3.6
18BS-03	0.0 - 4.2	-55.9 - -60.1	36.85840234	-75.84706252	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, gray	79.2	20.7	20.7	98.9	0.1
18BS-03	4.2 - 9.2	-60.1 - -65.1	36.85840234	-75.84706252	SILTY SAND (SM), fine to coarse grained sand, gray	85.8	14.2	14.2	96.2	0.0
18BS-03	9.2 - 14.2	-65.1 - -70.1	36.85840234	-75.84706252	POORLY GRADED SAND (SP), fine to coarse grained sand, brown	96.4	3.6	3.6	76.3	0.0
18BS-03	14.2 - 19.2	-70.1 - -75.1	36.85840234	-75.84706252	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, brown	72.3	1.2	1.2	15.6	26.5
18BS-04	0.0 - 1.8	-58.2 - -60.0	36.85357377	-75.83736758	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, SM	81.0	19.0	19.0	99.3	0.0
18BS-04	1.8 - 6.8	-60.0 - -65.0	36.85357377	-75.83736758	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, gray	94.6	5.4	5.4	97.7	0.0
18BS-04	6.8 - 11.8	-65.0 - -70.0	36.85357377	-75.83736758	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, SM	79.9	20.1	20.1	98.5	0.0
18BS-04	11.8 - 16.8	-70.0 - -75.0	36.85357377	-75.83736758	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	97.3	2.7	2.7	74.7	0.0
18BS-05	0.0- 4.1	-60.3 - -64.4	36.84729707	-75.82476931	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	97.0	3.0	3.0	85.4	0.0
18BS-05	4.1 - 9.1	-64.4 - -69.4	36.84729707	-75.82476931	POORLY GRADED SAND (SP), fine to coarse grained sand, brown and gray	97.9	2.1	2.1	73.4	0.0
18BS-05	9.1 - 14.1	-69.4 - -74.4	36.84729707	-75.82476931	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	93.9	2.3	2.3	34.1	3.8
18BS-05	14.1 - 19.1	-74.4 - -79.4	36.84729707	-75.82476931	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	93.3	3.2	3.2	70.3	3.5

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18BS-06	0.0- 4.3	-63.8 - -68.1	36.84246665	-75.81507721	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse, trace gravel, dark gray	90.3	9.5	9.5	67.0	0.2
18BS-06	4.3- 9.3	-68.1 - -73.1	36.84246665	-75.81507721	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	87.6	1.7	1.7	48.1	10.7
18BS-06	9.3 - 14.3	-73.1 - -78.1	36.84246665	-75.81507721	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	98.6	0.6	0.6	26.7	0.8
18BS-07	0.0 - 3.2	-62.8 - -66.0	36.83618756	-75.80248264	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains mica and shell fragments, dark gray	89.0	10.4	10.4	97.0	0.6
18BS-07	3.2 - 8.2	-66.0- -71.0	36.83618756	-75.80248264	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, brown and gray	96.1	2.5	2.5	59.3	1.4
18BS-07	8.2 - 13.2	-71.0 - -76.0	36.83618756	-75.80248264	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, bown and gray	96.9	1.7	1.7	55.8	1.4
18BS-07	13.2 - 18.2	-76.0 - -81.0	36.83618756	-75.80248264	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, brown and gray	89.7	0.8	0.8	38.3	9.5

Notes:
1. Soil tests in general accordance with ASTM standards.
2. Soil classifications are in general accordance with ASTM D2487(as applicable), based on testing indicated and visual classification.
3. Key to abbreviations: NP=Non-Plastic; -- indicates no test performed

Project: Atlantic Ocean Channel
Offshore Virginia Beach, VA
Project Number: 18C13103.00

Schnabel ENGINEERING

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18SBB-01	0.0 - 3.9	-44.4 - -48.3	36.73594061	-75.87113509	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, dark gray	83.8	16.2	16.2	96.1	0.0
18SBB-01	6.4 - 10.0	-50.8 - -54.4	36.73594061	-75.87113509	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, light brown	97.9	1.9	1.9	51.2	0.2
18SBB-01	10.0 - 14.8	-54.4 - -59.2	36.73594061	-75.87113509	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, gray	87.0	2.6	2.6	30.8	10.4
18SBB-02	0.0 - 4.1	-44.2 - -48.3	36.73273461	-75.86956651	SILTY SAND (SM), fine to coarse grained sand, dark gray	87.3	12.7	12.7	95.7	0.0
18SBB-02	4.1 - 5.5	-48.3 - -49.7	36.73273461	-75.86956651	POORLY GRADED SAND WITH GRAVEL (SP), fine to coarse grained sand, contains shell fragments, gray	78.5	0.9	0.9	33.7	20.6
18SBB-02	5.5 - 10.0	-49.7 - -54.2	36.73273461	-75.86956651	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	96.3	1.0	1.0	52.7	2.7
18SBB-02	10.0 - 15.0	-54.2 - -59.2	36.73273461	-75.86956651	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	98.4	1.6	1.6	63.1	0.0
18SBB-02	15.0 - 16.4	-59.2 - -60.6	36.73273461	-75.86956651	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	96.7	3.3	3.3	65.8	0.0
18SBB-03	0.0 - 5.0	-50.3 - -55.3	36.73262416	-75.86464782	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	97.3	2.0	2.0	38.4	0.7
18SBB-03	5.0 - 5.8	-55.3 - -56.1	36.73262416	-75.86464782	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	94.0	4.5	4.5	38.4	1.5
18SBB-04	0.0 - 5.0	-46.7 - -51.7	36.7288805	-75.86813657	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, gray	93.2	6.4	6.4	77.6	0.4
18SBB-06	0.0 - 4.0	-48.6 - -52.6	36.72496024	-75.86584209	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, gray	96.3	3.3	3.3	64.4	0.4
18SBB-07	0.0 - 5.0	-49.0 - -54.0	36.72479897	-75.86074817	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, gray	94.8	1.9	1.9	51.5	3.3
18SBB-07	5.0 - 8.2	-54.0 - -57.2	36.72479897	-75.86074817	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	95.4	2.9	2.9	64.6	1.7
18SBB-08	0.0 - 1.2	-46.5 - -47.7	36.72468946	-75.85588799	POORLY GRADED SAND WITH SILT AND GRAVEL (SP), fine to coarse grained sand, contains shell fragments, gray	78.5	6.5	6.5	34.4	15.0
18SBB-08	2.1 - 6.8	-48.6 - -53.3	36.72468946	-75.85588799	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	88.6	4.4	4.4	68.5	7.0
18SBB-08	6.8 - 11.1	-53.3 - -57.6	36.72468946	-75.85588799	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	95.8	3.6	3.6	71.3	0.6
18SBB-09	0.0 - 2.1	-47.3 - -49.4	36.72457975	-75.85102782	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, light gray	97.2	2.3	2.3	59.5	0.5
18SBB-09	3.2 - 8.2	-50.5 - -55.5	36.72457975	-75.85102782	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light gray	95.0	4.2	4.2	84.3	0.8
18SBB-09	8.2 - 13.2	-55.5 - -60.5	36.72457975	-75.85102782	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light gray	98.2	1.8	1.8	51.4	0.0
18SBB-09	13.2 - 14.2	-60.5 - -61.5	36.72457975	-75.85102782	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, light gray	92.3	1.3	1.3	42.5	6.4
18SBB-10	0.0 - 4.7	-49.4 - -54.1	36.72432195	-75.84582467	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, light gray	83.8	14.3	14.3	78.3	1.9

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18SBB-10	4.7 - 9.7	-54.1 - -59.1	36.72432195	-75.84582467	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light gray	98.3	1.7	1.7	81.4	0.0
18SBB-10	9.7 - 14.5	-59.1 - -63.9	36.72432195	-75.84582467	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light gray	98.1	1.8	1.8	52.3	0.1
18SBB-11	0.0 - 5.0	-49.6 - -54.6	36.7240211	-75.84079372	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, contains shell fragments, gray	92.5	5.4	5.4	79.2	2.1
18SBB-11	5.0 - 10.0	-54.6 - -59.6	36.7240211	-75.84079372	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	97.4	1.2	1.2	49.5	1.4
18SBB-11	10.0 - 13.7	-59.6 - -63.3	36.7240211	-75.84079372	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	99.3	0.1	0.1	59.5	0.6
18SBB-12A	0.0 - 5.0	-39.7 - -44.7	36.72409684	-75.83589979	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, brown	98.0	2.0	2.0	90.5	0.0
18SBB-12A	5.0 - 10.0	-44.7 - -49.7	36.72409684	-75.83589979	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light brown	98.4	1.4	1.4	78.5	0.2
18SBB-12A	10.0 - 15.0	-49.7 - -54.7	36.72409684	-75.83589979	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light brown	97.8	2.1	2.1	94.4	0.1
18SBB-12A	15.0 - 20.0	-54.7 - -59.7	36.72409684	-75.83589979	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, light gray	94.1	5.2	5.2	84.3	0.7
18SBB-13	0.0 - 3.5	-55.2 - -58.7	36.71989829	-75.82359247	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	93.7	1.9	1.9	66.2	4.4
18SBB-13	3.5 - 8.5	-58.7 - -63.7	36.71989829	-75.82359247	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, dark gray	86.4	3.5	3.5	72.8	10.1
18SBB-13	13.7 - 18.5	-68.9 - -73.7	36.71989829	-75.82359247	POORLY GRADED SAND WITH SILT (SP-SM), fine to bedim grained sand, dark gray	91.0	9.0	9.0	99.8	0.0
18SBB-14	0.0 - 4.5	-55.2 - -59.7	36.72010256	-75.82845242	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, dark gray	92.4	4.7	4.7	80.0	2.9
18SBB-15	0.0 - 4.4	-51.5 - -55.9	36.72021585	-75.83342823	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, dark gray	89.6	7.9	7.9	87.7	2.5
18SBB-15	4.4 - 7.0	-55.9 - -58.5	36.72021585	-75.83342823	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	96.5	3.5	3.5	89.7	0.0
18SBB-16	0.0 - 4.9	-46.0 - -50.9	36.72051298	-75.83828155	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, dark gray	91.5	8.4	8.4	85.6	0.1
18SBB-16	4.9 - 9.9	-50.9 - -55.9	36.72051298	-75.83828155	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, dark gray	96.8	2.2	2.2	63.1	1.0
18SBB-16	9.9 - 13.6	-55.9 - -59.6	36.72051298	-75.83828155	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	96.6	1.3	1.3	31.6	2.1
18SBB-17	0.0 - 1.3	-47.4 - -48.7	36.7206726	-75.84325918	SILTY SAND (SM), fine to coarse grained sand, trace gravel, contains shell fragments, grayish brown	70.6	29.2	29.2	71.5	0.2

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18SBB-17	1.3 - 6.3	-48.7 - -53.7	36.7206726	-75.84325918	CLAYEY SAND (SC), fine to coarse grained sand, trace gravel, contains shell fragments brown {Visual}	64.9	29.2	29.2	75.9	5.9
18SBB-17	6.3 - 11.3	-53.7 - -58.7	36.7206726	-75.84325918	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	94.3	1.8	1.8	32.3	3.9
18SBB-17	11.3 - 16.3	-58.7 - -63.7	36.7206726	-75.84325918	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	85.8	0.9	0.9	27.4	13.3
18SBB-18	0.0 - 5.0	-49.3 - -54.3	36.7207412	-75.84835262	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, gray	91.3	8.7	8.7	83.0	0.0
18SBB-18	5.0 - 10.0	-54.3 - -59.3	36.7207412	-75.84835262	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	94.9	3.6	3.6	66.7	1.5
18SBB-19A	2.3 - 5.0	-49.1 - -51.8	36.72080958	-75.85344608	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	97.6	1.9	1.9	52.5	0.5
18SBB-19A	5.0 - 9.6	-51.8 - -56.4	36.72080958	-75.85344608	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, light brown and gray	98.5	1.2	1.2	56.2	0.3
18SBB-19A	11.1 - 14.5	-57.9 - -61.3	36.72080958	-75.85344608	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	89.5	3.4	3.4	68.6	7.1
18SBB-20	0.0 - 1.9	-47.5 - -49.4	36.7211072	-75.8583575	SILTY SAND WITH GRAVEL (SM), fine to coarse grained sand, contains shell fragments, dark gray	44.6	14.7	14.7	27.3	40.7
18SBB-20	1.9 - 5.0	-49.4 - -52.5	36.7211072	-75.8583575	POORLY GRADED SAND (SP), fine to coarse grained sand, dark gray	97.1	2.9	2.9	95.1	0.0
18SBB-20	5.0 - 9.5	-52.5 - -57.0	36.7211072	-75.8583575	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, light brown and gray	91.2	1.5	1.5	36.4	7.3
18SBB-21	0.0 - 5.0	-50.8 - -55.8	36.72122251	-75.86348007	POORLY GRADED SAND (SP), fine to coarse grained sand, light gray	95.7	2.3	2.3	82.1	2.0
18SBB-21	5.0 - 6.0	-55.8 - -56.8	36.72122251	-75.86348007	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light gray	95.9	3.7	3.7	86.9	0.4
18SBB-22	0.0 - 5.0	-46.6 - -51.6	36.71734745	-75.86112305	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light gray	94.5	3.4	3.4	60.4	2.1
18SBB-22	4.8 - 8.0	-51.4 - -54.6	36.71734745	-75.86112305	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, trace gravel, gray	96.7	2.1	2.1	51.2	1.2
18SBB-23	0.0 - 3.6	-47.9 - -51.5	36.71709663	-75.85621024	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, trace gravel, gray	96.2	1.4	1.4	62.4	2.4
18SBB-23	3.6 - 8.5	-51.5 - -56.4	36.71709663	-75.85621024	POORLY GRADED SAND (SP), fine to coarse grained sand, light gray	98.3	1.7	1.7	88.7	0.0
18SBB-24	0.0 - 3.0	-48.4 - -51.4	36.71707111	-75.85094147	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, gray	95.7	2.3	2.3	82.1	2.0
18SBB-24	3.0 - 8.0	-51.4 - -56.4	36.71707111	-75.85094147	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	98.4	1.0	1.0	43.1	0.6
18SBB-24	8.0 - 13.0	-56.4 - -61.4	36.71707111	-75.85094147	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	90.4	2.5	2.5	19.5	7.1
18SBB-24	13.0 - 13.9	-61.4 - -62.3	36.71707111	-75.85094147	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	62.9	4.2	4.2	24.3	32.9
18SBB-25	0.0 - 4.8	-48.3 - -53.1	36.71677319	-75.84603034	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	98.3	1.4	1.4	57.4	0.3

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering										
Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18SBB-25	4.8 - 9.5	-53.1 - -57.8	36.71677319	-75.84603034	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, gray	92.1	7.0	7.0	62.4	0.9
18SBB-26	0.0 - 5.1	-48.8 - -53.9	36.71675309	-75.84102079	POORLY GRADED SAND WITH SILT (SP-SM), fine to medium grained sand, dark gray	92.4	7.6	7.6	98.6	0.0
18SBB-26	5.1 - 10.1	-53.9 - -58.9	36.71675309	-75.84102079	POORLY GRADED SAND WITH SILT (SP-SM), fine to medium grained sand, dark gray	92.8	7.2	7.2	99.7	0.0
18SBB-26	10.1 - 13.0	-58.9 - -61.8	36.71675309	-75.84102079	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, dark gray	95.9	3.7	3.7	97.4	0.4
18SBB-27	0.0 - 4.4	-52.3 - -56.7	36.71659345	-75.83604683	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	96.8	2.1	2.1	67.7	1.1
18SBB-27	4.4 - 9.4	-56.7 - -61.7	36.71659345	-75.83604683	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	98.3	1.7	1.7	61.6	0.0
18SBB-27	9.4 - 11.8	-61.7 - -64.1	36.71659345	-75.83604683	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, gray	94.2	5.8	5.8	84.8	0.0
18SBB-27	12.7 - 14.4	-65.0 - -66.7	36.71659345	-75.83604683	CLAYEY SAND (SC), fine to coarse grained sand, dark gray {Visual}	68.1	31.9	31.9	92.8	0.0
18SBB-27	14.4 - 19.4	-66.7 - -71.7	36.71659345	-75.83604683	POORLY GRADED SAND WITH CLAY (SP-SC), fine to coarse grained sand, dark gray {Visual}	94.7	5.3	5.3	96.4	0.0
18SBB-28	0.0 - 4.2	-54.5 - -58.7	36.71644013	-75.83135936	SILTY SAND WITH GRAVEL (SM), fine to coarse grained sand, contains shell fragments, dark gray	54.2	23.2	23.2	42.0	22.6
18SBB-30	0.0 - 1.8	-54.0 - -55.8	36.71616183	-75.8212053	POORLY GRADED SAND (SP), fine to carse grained sand, contains shell fragments, dark gray	98.1	1.4	1.4	68.5	0.5
18SBB-30	2.7 - 4.7	-56.7 - -58.7	36.71616183	-75.8212053	POORLY GRADED SAND WITH SILT AND GRAVEL (SP-SM), fine to coarse grained sand, contains shell fragments, dark gray	71.1	9.7	9.7	35.1	19.2
18SBB-30	4.7 - 9.6	-58.7 - -63.6	36.71616183	-75.8212053	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, dark gray	94.8	5.2	5.2	62.4	0.0
18SBB-31	0.0 - 5.0	-47.1 - -52.1	36.71614536	-75.81640041	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, brownish gray	98.4	0.8	0.8	58.9	0.8
18SBB-31	5.0 - 10.0	-52.1 - -57.1	36.71614536	-75.81640041	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, brownish gray	97.3	2.4	2.4	97.0	0.3
18SBB-31	10.0 - 15.0	-57.1 - -62.1	36.71614536	-75.81640041	POORLY GRADED SAND WITH GRAVEL (SP), fine to coarse grained sand, contains shell fragments, gray	66.1	4.6	4.6	39.5	29.3
18SBB-31	15.0 - 20.0	-62.1 - -67.1	36.71614536	-75.81640041	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	97.3	2.7	2.7	81.0	0.0
18SBB-32	0.0 - 3.1	-53.3 - -56.4	36.71614536	-75.81640041	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, dark gray	94.8	3.7	3.7	92.4	1.5
18SBB-32	5.0 - 10.0	-58.3 - -63.3	36.71614536	-75.81640041	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, dark gray	88.0	9.2	9.2	65.8	2.8
18SBB-32	10.0 - 11.8	-63.3 - -65.1	36.71203864	-75.81417014	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, gray	77.2	9.9	9.9	58.2	12.9

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18SBB-33	0.0 - 5.1	-47.8 - -52.9	36.71228591	-75.81897004	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, dark brown	97.8	1.0	1.0	54.6	1.2
18SBB-33	5.1 - 10.1	-52.9 - -57.9	36.71228591	-75.81897004	SILTY SAND (SP), fine to coarse grained sand, contains shell fragments, brownish gray	80.5	18.6	18.6	75.5	0.9
18SBB-33	10.1 - 15.1	-57.9 - -62.9	36.71228591	-75.81897004	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, dark gray	80.1	17.8	17.8	87.6	2.1
18SBB-34	0.0 - 4.0	-56.2 - -60.2	36.71244759	-75.82400165	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	94.6	2.6	2.6	64.6	2.8
18SBB-34	14.0 - 19.8	-70.2 - -76.0	36.71244759	-75.82400165	SILTY SAND (SM), fine to coarse grained sand, dark gray	57.8	42.2	42.2	85.8	0.0
18SBB-35	0.0 - 5.0	-54.5 - -59.5	36.71255842	-75.828861	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, dark gray	88.8	2.8	2.8	47.1	8.4
18SBB-35	5.0 - 6.2	-59.5 - -60.7	36.71255842	-75.828861	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	91.1	3.0	3.0	71.0	5.9
18SBB-35	12.9 - 15.0	-67.4 - -69.5	36.71255842	-75.828861	SANDY LEAN CLAY (CL), dark gray {Visual}	49.7	50.3	50.3	98.7	0.0
18SBB-35	15.0 - 19.3	-69.5 - -73.8	36.71255842	-75.828861	LEAN CLAY WITH SAND (CL), dark gray {Visual}	27.2	72.8	72.8	98.9	0.0
18SBB-36	0.0 - 4.9	-53.0 - -57.9	36.71280915	-75.83371887	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, dark gray	85.0	5.2	5.2	60.9	9.8
18SBB-36	14.2 - 19.9	-67.2 - -72.9	36.71280915	-75.83371887	SILTY SAND (SM), fine to medium grained sand, dark gray	70.8	29.2	29.2	99.6	0.0
18SBB-37	0.0 - 3.3	-51.1 - -54.4	36.7127958	-75.83881467	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, dark gray	78.7	14.3	14.3	80.2	7.0
18SBB-37	12.1 - 13.4	-63.2 - -64.5	36.7127958	-75.83881467	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, contains shell fragments, gray	85.1	7.5	7.5	66.4	7.4
18SBB-38	0.0 - 3.3	-50.9 - -54.2	36.71305133	-75.84378161	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	82.0	4.6	4.6	56.4	13.4
18SBB-38	3.3 - 8.3	-54.2 - -59.2	36.71305133	-75.84378161	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	96.1	1.2	1.2	33.9	2.7
18SBB-39	0.0 - 4.2	-49.5 - -53.7	36.71320925	-75.84869396	POORLY GRADED SAND (SP), fine to coarse grained sand ,dark gray	98.5	1.5	1.5	35.5	0.0
18SBB-39	4.2 - 9.2	-53.7 - -58.7	36.71320925	-75.84869396	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, dark gray	98.1	1.3	1.3	21.8	0.6
18SBB-39	9.2 - 10.5	-58.7 - -60.0	36.71320925	-75.84869396	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, brown	97.1	2.0	2.0	18.2	0.9
18SBB-40A	4.6 - 9.6	-53.5 - -58.5	36.71323094	-75.85378854	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, dark gray	85.6	1.3	1.3	35.9	13.1
18SBB-40A	9.6 - 12.4	-58.5 - -61.3	36.71323094	-75.85378854	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	97.4	2.6	2.6	72.2	0.0
18SBB-41	0.0 - 5.0	-46.9 - -51.9	36.71334307	-75.85876052	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, trace gravel, gray	94.6	0.8	0.8	51.5	4.6

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18SBB-41	5.0 - 10.0	-51.9 - -56.9	36.71334307	-75.85876052	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, trace gravel, gray	98.3	1.5	1.5	66.0	0.2
18SBB-41	10.0 - 11.4	-56.9 - -58.3	36.71334307	-75.85876052	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, trace gravel, gray	96.7	2.1	2.1	47.7	1.2
18SBB-42	0.0	-50.8	36.70966693	-75.85657793	POORLY GRADED SAND (SP), fine to coarse grained sand, light brown	98.0	1.7	1.7	62.2	0.3
18SBB-42	5.0	-55.8	36.70966693	-75.85657793	POORLY GRADED SAND (SP), fine to coarse grained sand, light brown	98.6	1.1	1.1	54.5	0.3
18SBB-43	0.0 - 4.9	-49.9 - -54.8	36.70955602	-75.85166416	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, gray	95.7	3.5	3.5	91.0	0.8
18SBB-43	4.9 - 8.3	-54.8 - -58.2	36.70955602	-75.85166416	SILTY SAND (SM), fine to coarse grained sand, trace gravel, gray	85.7	11.0	11.0	64.4	3.3
18SBB-44	5.0	-55.8	36.70934622	-75.84651838	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	95.4	3.5	3.5	62.3	1.1
18SBB-45A	0.0 - 2.9	-49.1 - -52.0	36.7092362	-75.84166262	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, dark brown	95.0	3.9	3.9	47.7	1.1
18SBB-45A	3.8 - 8.1	-52.9 - -57.2	36.7092362	-75.84166262	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, brown	96.6	3.4	3.4	35.0	0.0
18SBB-45A	8.1 - 13.1	-57.2 - -62.2	36.7092362	-75.84166262	POORLY GRADED SAND (SP), fine to coarse grained sand, dark brown	97.6	2.4	2.4	46.1	0.0
18SBB-46	0.0 - 5.0	-51.3 - -56.3	36.70906858	-75.83645738	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, contains shell fragments, gray	92.6	5.7	5.7	89.6	1.7
18SBB-46	5.8 - 10.0	-57.1 - -61.3	36.70906858	-75.83645738	POORLY GRADED SAND (SP), fine to medium grained sand, gray and brown	97.0	3.0	3.0	81.9	0.0
18SBB-46	10.0 - 13.2	-61.3 - -64.5	36.70906858	-75.83645738	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, gray and brown	91.0	5.2	5.2	60.6	3.8
18SBB-47	0.0 - 3.4	-53.7 - -57.1	36.70890875	-75.83148394	SILTY SAND (SM), fine to medium grained sand, trace gravel, contains shell fragments, gray	73.7	25.0	25.0	97.6	1.3
18SBB-47	3.4 - 7.5	-57.1 - -61.2	36.70890875	-75.83148394	POORLY GRADED SAND (SP), fine to medium grained sand, light brown	96.9	3.1	3.1	99.8	0.0
18SBB-47	14.1 - 18.4	-67.8 - -72.1	36.70890875	-75.83148394	POORLY GRADED SAND WITH SILT (SP-SM), fine to medium grained sand, dark gray	93.4	6.6	6.6	97.5	0.0
18SBB-48	0.0	-53.3	36.70869937	-75.82651567	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, dark gray	91.5	8.0	8.0	79.9	0.5
18SBB-48	3.5	-56.8	36.70869937	-75.82651567	POORLY GRADED SAND (SP), fine to coarse grained sand, light gray	95.7	3.9	3.9	85.6	0.4
18SBB-48	13.8	-67.1	36.70869937	-75.82651567	POORLY GRADED SAND WITH SILT (SP-SM), fine to medium grained sand, contains wood fragments, dark gray	95.0	5.0	5.0	98.2	0.0
18SBB-49	0.0 - 4.5	-56.0 - -60.5	36.7086352	-75.82165833	POORLY GRADED SAND WITH SILT (SP-SM), fine to medium grained sand, grayish brown	89.6	10.4	10.4	93.6	0.0

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18SBB-49	4.5 - 6.9	-60.5 - -62.9	36.7086352	-75.82165833	SILTY SAND (SM), fine to coarse grained sand, trace gravel, contains shell fragments, grayish brown	83.5	15.2	15.2	58.6	1.3
18SBB-49	11.9 - 14.5	-67.9 - -70.5	36.7086352	-75.82165833	SANDY SILT (ML), contains mica, dark gray	31.7	68.3	68.3	97.9	0.0
18SBB-49	14.5 - 19.5	-70.5 - -75.5	36.7086352	-75.82165833	SILT WITH SAND (ML), contains mica and organic matter, dark gray	23.8	76.2	76.2	98.6	0.0
18SBB-50	0.0 - 5.0	-49.8 - -54.8	36.70842682	-75.81663204	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, gray	91.9	7.8	7.8	93.5	0.3
18SBB-50	5.0 - 7.3	-54.8 - -57.1	36.70842682	-75.81663204	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, gray	68.8	30.1	30.1	92.9	1.1
18SBB-50	8.9 - 10.0	-58.7 - -59.8	36.70842682	-75.81663204	SILTY SAND WITH GRAVEL (SM), fine to coarse grained sand, contains shell fragments, gray	61.9	19.0	19.0	53.5	19.1
18SBB-50	10.0 - 15.0	-59.8 - -64.8	36.70842682	-75.81663204	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, gray	92.1	6.4	6.4	61.1	1.5
18SBB-50	15.0 - 16.0	-64.8 - -65.8	36.70842682	-75.81663204	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, gray	91.5	7.0	7.0	59.3	1.5
18SBB-51	0.0	-50.5	36.7048047	-75.81468515	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light brown	98.4	1.5	1.5	89.7	0.1
18SBB-52A	0.0 - 3.0	-54.5 - -57.5	36.70481569	-75.81936668	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, brown	93.0	1.8	1.8	66.7	5.2
18SBB-52A	3.0 - 5.3	-57.5 - -59.8	36.70481569	-75.81936668	SILTY SAND WITH GRAVEL (SM), fine to coarse grained sand, contains shell fragments, dark gray	32.5	33.3	33.3	38.8	34.2
18SBB-53	11.9 - 15.0	-68.7 - -71.8	36.70483319	-75.82434144	SILTY SAND (SM), fine grained sand, contains mica, dark gray	54.5	45.5	45.5	99.5	0.0
18SBB-54	0.0	-53.7	36.70513604	-75.82918674	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, light gray	88.8	10.9	10.9	82.4	0.3
18SBB-55	0.0 - 2.3	-52.8 - -55.1	36.70525061	-75.83421953	POORLY GRADED SAND WITH SILT AND GRAVEL (SP), fine to coarse grained sand, contains shell fragments, gray	62.1	6.9	6.9	29.6	31.0
18SBB-55	2.3 - 7.3	-55.1 - -60.1	36.70525061	-75.83421953	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	95.4	0.4	0.4	23.8	4.2
18SBB-55	7.3 - 9.8	-60.1 - -62.6	36.70525061	-75.83421953	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	98.5	1.1	1.1	29.8	0.4
18SBB-55A	0.0 - 1.4	-53.0 - -54.4	36.70525061	-75.83421953	SILTY SAND (SM), fine to coarse grained sand, contains shell fragments, dark gray	73.4	26.4	26.4	89.6	0.2
18SBB-55A	1.4 - 6.4	-54.4 - -59.4	36.70525061	-75.83421953	POORLY GRADED SAND WITH GRAVEL (SP), fine to coarse grained sand, grayish brown	96.1	0.6	0.6	23.4	3.3
18SBB-56	5.9	-56.6	36.70541163	-75.8392507	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, gray	94.7	5.3	5.3	73.8	0.0
18SBB-56	10.0	-60.7	36.70541163	-75.8392507	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light gray	88.6	1.3	1.3	32.7	10.1
18SBB-57	0.0 - 4.7	-50.9 - -55.6	36.70542829	-75.84422551	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, contains shell fragments, brownish gray	88.2	7.5	7.5	65.9	4.3

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18SBB-57	4.7 - 9.0	-55.6 - -59.9	36.70542829	-75.84422551	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, light brownish gray	88.5	2.3	2.3	59.3	9.2
18SBB-58	0.0 - 4.7	-51.7 - -56.4	36.70549153	-75.84908266	POORLY GRADED SAND WITH GRAVEL (SP), fine to coarse grained sand, gray	95.0	4.4	4.4	90.6	0.6
18SBB-58	5.6 - 8.9	-57.3 - -60.6	36.70549153	-75.84908266	POORLY GRADED SAND WITH GRAVEL (SP), fine to coarse grained sand, contains shell fragments, gray	81.9	1.5	1.5	30.2	16.6
18SBB-59A	1.2 - 2.4	-50.7 - -51.9	36.70575063	-75.85422647	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	95.5	2.1	2.1	26.7	2.4
18SBB-59A	2.4 - 7.4	-51.9 - -56.9	36.70575063	-75.85422647	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	97.9	0.6	0.6	19.4	1.5
18SBB-59A	7.4 - 9.3	-56.9 - -58.8	36.70575063	-75.85422647	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, gray	96.0	2.0	2.0	77.1	2.0
18SBB-60	0.0 - 4.6	-40.8 - -45.4	36.76647926	-75.88174407	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, gray	93.8	5.7	5.7	95.1	0.5
18SBB-60	4.6 - 9.3	-45.4 - -50.1	36.76647926	-75.88174407	SILTY SAND (SM), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	78.1	21.7	21.7	78.5	0.2
18SBB-60.5	0.0 - 4.6	-37.9 - -42.5	36.76567921	-75.8786468	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, dark gray	98.8	1.2	1.2	89.1	0.0
18SBB-60.5	4.6 - 9.6	-42.5 - -47.5	36.76567921	-75.8786468	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, contains shell fragments, gray	92.7	6.7	6.7	89.5	0.6
18SBB-60.5	9.6 - 14.0	-47.5 - -51.9	36.76567921	-75.8786468	SILTY SAND (SM), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	76.2	23.5	23.5	89.8	0.3
18SBB-61	0.0 - 4.5	-41.9 - -46.4	36.76471771	-75.87349587	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	97.3	2.7	2.7	98.5	0.0
18SBB-61	4.5 - 8.8	-46.4 - -50.7	36.76471771	-75.87349587	CLAYEY SAND (SC), fine to coarse grained sand, contains shell fragments, gray	75.5	22.8	22.8	69.7	1.7
18SBB-61	15.4 - 19.5	-57.3 - -61.4	36.76471771	-75.87349587	CLAYEY SAND (SC), fine to coarse grained sand, gray	84.3	15.7	15.7	98.4	0.0
18SBB-62	0.0 - 4.6	-44.9 - -49.5	36.7629555	-75.86524463	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, brown	98.3	1.5	1.5	77.1	0.2
18SBB-62	4.6 - 6.7	-49.5 - -51.6	36.7629555	-75.86524463	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	94.8	5.1	5.1	93.3	0.1
18SBB-62	9.6 - 14.6	-54.5 - -59.5	36.7629555	-75.86524463	SILTY SAND (SM), fine to coarse grained sand, contains mica, dark gray	78.0	22.0	22.0	99.7	0.0
18SBB-62	14.6 - 19.6	-59.5 - -64.5	36.7629555	-75.86524463	SILTY SAND (SM), fine to medium grained sand, dark gray	84.9	15.1	15.1	99.7	0.0
18SBB-63	0.0 - 4.5	-44.8 - -49.3	36.76119553	-75.85699709	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	95.8	3.3	3.3	79.0	0.9
18SBB-63	9.5 - 14.5	-54.3 - -59.3	36.76119553	-75.85699709	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, contains shell fragments, gray	83.5	10.4	10.4	48.2	6.1

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18SBB-63	14.5 - 19.5	-59.3 - -64.3	36.76119553	-75.85699709	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	97.5	2.2	2.2	90.7	0.3
18SBB-64	0.0 - 3.2	-43.6 - -46.8	36.75943224	-75.84875003	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, light brown	97.5	0.9	0.9	61.9	1.6
18SBB-64	3.2 - 6.0	-46.8 - -49.6	36.75943224	-75.84875003	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, gray	97.9	1.9	1.9	83.2	0.2
18SBB-64	10.1 - 13.2	-53.7 - -56.8	36.75943224	-75.84875003	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, light gray	96.7	3.1	3.1	90.7	0.2
18SBB-64	13.2 - 18.2	-56.8 - -61.8	36.75943224	-75.84875003	POORLY GRADED SAND (SP), fine to medium grained sand, gray	96.2	3.8	3.8	99.3	0.0
18SBB-65	0.0 - 4.5	-45.3 - -49.8	36.75766829	-75.84049994	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, brown	98.6	1.2	1.2	71.2	0.2
18SBB-65	4.6 - 9.6	-49.9 - -54.9	36.75766829	-75.84049994	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, gray	97.7	2.1	2.1	96.7	0.2
18SBB-65	9.6 - 14.6	-54.9 - -59.9	36.75766829	-75.84049994	POORLY GRADED SAND (SP), fine to coarse grained sand, gray	96.3	3.7	3.7	99.4	0.0
18SBB-65	14.6 - 19.6	-59.9 - -64.9	36.75766829	-75.84049994	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, gray	95.0	5.0	5.0	99.6	0.0
18SBB-66	0.0 - 4.6	-43.4 - -48.0	36.77395313	-75.88347758		85.2	14.7	14.7	85.8	0.1
18SBB-67	0.0 - 4.6	-39.2 - -43.8	36.7721917	-75.87522852	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	99.1	0.7	0.7	81.5	0.2
18SBB-67	4.6 - 8.8	-43.8 - -48.0	36.7721917	-75.87522852	SILTY SAND (SM), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	87.2	11.6	11.6	89.5	1.2
18SBB-67	17.6 - 19.6	-56.8 - -58.8	36.7721917	-75.87522852	SILTY SAND (SM), fine to medium grained sand, dark gray	82.3	17.7	17.7	99.8	0.0
18SBB-68	0.0 - 4.4	-44.6 - -49.0	36.77042969	-75.86697985	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, contains shell fragments, dark gray	93.2	6.8	6.8	93.6	0.0
18SBB-68	4.4 - 5.9	-49.0 - -50.5	36.77042969	-75.86697985	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	90.5	6.7	6.7	87.2	2.8
18SBB-68	10.8 - 14.4	-55.4 - -59.0	36.77042969	-75.86697985	SILTY SAND (SM), fine to coarse grained sand, trace gravel, dark gray	86.5	13.0	13.0	98.8	0.5
18SBB-68	14.4 - 19.4	-59.0 - -64.0	36.77042969	-75.86697985	POORLY GRADED SAND WITH SILT (SP-SM), fine to medium grained sand, contains mica, dark gray	90.1	9.9	9.9	99.8	0.0
18SBB-69	0.0 - 2.6	-42.4 - -45.0	36.76866976	-75.85872804	POORLY GRADED SAND (SP), fine to coarse grained sand, contains shell fragments, brown	99.0	1.0	1.0	68.6	0.0
18SBB-69	2.6 - 6.0	-45.0 - -48.4	36.76866976	-75.85872804	POORLY GRADED SAND (SP), fine to coarse grained sand, brown	99.1	0.9	0.9	68.0	0.0
18SBB-69	12.6 - 17.6	-55.0 - -60.0	36.76866976	-75.85872804	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, dark gray	94.8	1.7	1.7	95.5	3.5

Summary Of Laboratory Tests for samples from Unit A submitted by Schnabel Engineering

Boring No.	Sample Depth ft	Elevation ft	Lat (NAD 83)	Long (NAD 83)	Description of Soil Specimen	Percent Sand (75-2000 µm)	Percent Fines (<75 µm)	% Passing No. 200 Sieve (<75 µm)	% Passing No. 40 Sieve (<425 µm)	Percent Gravel (> 2mm)
18SBB-70	8.0 - 13.0	-55.2 - -60.2	36.76690659	-75.85048013	SILTY SAND (SM), fine to coarse grained sand, trace gravel, contains shell fragments, dark gray	82.5	15.7	15.7	80.8	1.8
18SBB-70	13.0 - 18.0	-60.2 - -65.2	36.76690659	-75.85048013	SILTY SAND (SM), fine to medium grained sand, gray	82.8	17.2	17.2	99.8	0.0
18SBB-71	0.0 - 5.0	-47.6 - -52.6	36.76514284	-75.84223261	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, gray	97.8	1.6	1.6	70.8	0.6
18SBB-71	5.0 - 10.0	-52.6 - -57.6	36.76514284	-75.84223261	POORLY GRADED SAND (SP), fine to coarse grained sand, trace gravel, contains shell fragments, gray	96.3	2.9	2.9	85.5	0.8
18SBB-71	10.0 - 15.0	-57.6 - -62.6	36.76514284	-75.84223261	POORLY GRADED SAND WITH SILT (SP-SM), fine to coarse grained sand, trace gravel, contains shell fragments, gray	89.4	10.4	10.4	97.1	0.2
18SBB-71	15.0 - 20.0	-62.6 - -67.6	36.76514284	-75.84223261	POORLY GRADED SAND WITH SILT (SP-SM), fine to medium grained sand, dark gray	90.0	10.0	10.0	98.8	0.0

Notes:
1. Soil tests in general accordance with ASTM standards.
2. Soil classifications are in general accordance with ASTM D2487(as applicable), based on testing indicated and visual classification.
3. Key to abbreviations: NP=Non-Plastic; -- indicates no test performed

Project: Sandbridge Borrow Area
Offshore Virginia Beach, VA
Project Number: 18C13103.00

Schnabel
ENGINEERING

An Investigation by High Definition Mineralogy into

TWENTY-THREE MINERAL SAND SAMPLES FROM OFFSHORE OF VIRGINIA, USA

prepared for

VIRGINIA DEPARTMENT OF ENERGY, GEOLOGY, AND MINERAL RESOURCES PROGRAM

Project 17512-02 – Final Report
May 31, 2023

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Table of Contents

List of Tables

List of Figures

Executive Summary

Twenty-three (23) mineral sand samples were submitted to the Advanced Mineralogy Facility at SGS Canada Inc., by Mr. William L. Lassetter from the Virginia Department of Energy, Geology and Mineral Resources Program, for mineralogical analysis.

The purpose of this test program was to determine the overall mineral assemblage of the samples, with an emphasis on the REE minerals (REM) and their occurrence. The testwork was conducted with TIMA-X technology (Tescan Integrated Mineral Analyzer), X-ray diffraction (XRD) analysis, geochemical assays, electron probe micro-analyses (EPMA), and laser ablation inductively coupled plasma mass spectroscopy (LA-ICP-MS).

Sample Preparation

- Each sample was submitted for heavy liquid separation (HLS) at a specific gravity (S.G.) of 2.9 g/cc^3 to generate a sink (heavy mineral concentrate) and float fraction (light minerals).
- From each sink fraction, a 2-5 g subsample was obtained to complete the following chemical assays:
    - sodium peroxide fusion ICP-MS analysis (IMS93A) for REE, Th, U, Cs, Ga, In, Nb, Rb and Ta;
    - sodium peroxide fusion ICP-AES analysis (ICP93A) for Al, Ca, Cr, Fe, K, Mg, Mn, Si, Ti and V, Sc, and Zr;
    - strong acid digest / ICP-AES (ICP42C) for 30 elements
    - ICM90A for As, Ge, and Hf
- A 1-2 g aliquot from each of the Sink and Float fraction was used to prepare graphite impregnated polished sections. Two randomly oriented graphite-impregnated polished sections were prepared from each Sink fraction and one from each Float and submitted for TIMA-X analysis using the Tescan High Resolution Mineral (THRM) analysis mode of operation.
- A 9 g subsample was also riffled from the R-12225c Sink, R-12226c Sink, R-12227c Sink, and R-12236c Sink for qualitative XRD.

Mineralogical Results

X-Ray Diffraction (XRD) Results

XRD analysis of the selected sink samples indicates that they consist mainly of ilmenite, amphibole, garnet, zircon, quartz, epidote, chlorite, hematite, rutile, and tentatively identified trace amounts of monazite, and davidite.

TIMA-X Results of the Sink Fractions

The results below refer to the Sink fractions. Additional data for the Float and calculated heads are given in the main body of the report.

Modal Mineralogy

Table I and Figure I illustrate the mineral mass of the Sink fractions. Rare Earth Minerals (REM) include mainly monazite and lesser amounts of xenotime. Monazite ranges from 0.05 to 1.48% and avg. 0.31%, and xenotime from nil to 0.14% and avg. 0.02%. The remainder of the mass includes ilmenite ranging from 12.6% to 56.3% and avg. 33.7%, altered Ilmenite from 2.3% to 10.8% and avg. 6.3%, rutile from 2.6% to 7.4% and avg. 4.5%, zircon from 2.2% to 22.1% and avg. 6.4%, amphibole/pyroxene from 5.7% to 36.6% and avg. 19.8%, epidote from 2.3% to 19.0% and avg. 8.6%, staurolite from 0.6% to 5.2% and avg. 2.8%, kyanite from 0.8% to 5.8% and avg. 2.9%, chlorite from 0.7% to 9.2% and avg. 3.8%, quartz from 0.7% to 19.3% and avg. 3.1%, while other minerals average less than 1%.

Table I: Mineral Mass% of the Sink Fractions

Sample/Product	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
HLS Sink wt%	**21.40**	**10.61**	**62.87**	**54.19**	**36.91**	**17.07**	**19.31**	**34.33**	**47.07**	**33.30**	**30.41**	**0.14**	**21.74**	**31.25**	**37.90**	**43.55**	**21.58**	**24.76**	**39.22**	**33.59**	**41.81**	**0.13**	**0.20**
Monazite	0.20	0.18	0.30	0.16	0.15	0.23	0.09	0.24	0.16	0.20	0.36	1.46	0.05	0.17	0.12	0.16	0.17	0.21	0.26	0.20	0.26	0.23	1.48
Xenotime	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.02	0.14	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.08
Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Allanite	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.02	0.01	0.01
Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12
Gorceixite	0.01	0.02	0.00	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.00	0.02
Chromite	0.07	0.10	0.18	0.19	0.16	0.28	0.08	0.22	0.24	0.04	0.19	0.17	0.07	0.10	0.20	0.10	0.11	0.13	0.12	0.07	0.11	0.10	0.17
Spinel	0.01	0.10	0.05	0.08	0.13	0.18	0.09	0.09	0.05	0.04	0.05	0.01	0.08	0.05	0.05	0.12	0.09	0.03	0.06	0.04	0.06	0.05	0.01
Gahnite	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.05
Fe-Oxides	0.02	0.11	0.00	0.04	2.01	2.28	0.44	0.02	0.49	0.01	1.08	3.33	0.41	0.68	4.61	0.83	1.57	6.24	1.04	3.75	3.11	0.94	2.81
Goethite	0.01	0.05	0.03	0.01	0.52	0.22	0.23	0.01	0.12	0.01	1.16	4.76	0.05	0.01	0.03	0.12	0.05	0.28	0.01	0.16	0.08	4.25	2.47
Ilmenite	51.2	40.3	56.3	28.1	29.5	32.4	19.9	40.2	30.9	45.2	40.2	23.8	20.7	42.1	51.2	38.5	29.3	20.2	35.7	31.1	28.9	12.6	26.9
Altered Ilmenite	6.64	5.72	7.40	6.36	6.19	5.63	5.09	7.62	7.50	6.96	10.7	3.72	6.95	9.39	6.41	7.57	6.13	3.83	7.76	5.77	6.38	2.32	3.43
Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rutile	5.04	4.72	5.10	4.31	4.11	3.63	3.92	4.50	3.64	5.83	7.41	3.75	5.49	6.02	4.15	4.37	4.08	4.05	4.87	3.95	4.92	2.55	3.52
Pseudorutile	0.03	0.02	0.02	0.02	0.03	0.02	0.03	0.01	0.02	0.03	0.03	0.02	0.06	0.05	0.03	0.04	0.05	0.03	0.03	0.02	0.04	0.05	0.04
Zircon	5.61	5.30	7.33	4.57	4.85	5.23	2.45	5.60	4.95	5.51	8.34	22.1	2.22	5.31	5.84	5.22	3.64	3.81	5.27	4.63	5.06	3.68	19.79
Baddeleyite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thorite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluorite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.09	0.03
Anhydrite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphibole/Pyroxene	8.44	14.1	5.68	31.0	25.9	25.1	36.6	25.0	30.8	10.1	11.9	12.1	26.8	11.8	8.55	15.8	22.9	34.2	17.5	22.3	22.9	26.8	9.2
Garnets	0.36	0.60	0.31	1.32	1.39	1.43	1.14	0.72	1.31	0.39	0.50	1.40	1.16	0.83	1.50	1.25	1.40	2.00	1.29	1.42	1.53	0.95	1.33
Staurolite	3.41	5.21	1.66	2.05	3.52	2.94	4.90	1.71	2.97	3.80	1.85	0.58	4.73	3.06	2.25	4.06	4.65	1.50	3.43	2.71	2.27	1.14	0.55
Kyanite	3.14	4.77	1.85	2.30	2.54	2.54	4.42	2.62	2.07	4.01	2.09	0.81	5.79	2.53	1.69	3.63	4.55	2.30	3.48	3.21	3.20	1.32	1.30
Biotite	0.01	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.01	0.04	0.07	0.01	0.02	0.00	0.01	0.01	0.03	0.01	0.03	0.02	0.14	0.11
Chlorite	0.83	1.98	0.75	9.23	9.18	7.37	4.81	2.55	6.03	0.95	0.74	1.46	2.61	2.17	5.86	3.93	4.84	4.01	4.33	5.50	4.82	2.60	1.65
Quartz	3.01	1.53	2.87	1.59	1.36	0.98	0.96	0.87	0.69	1.26	1.19	7.27	1.52	2.58	1.29	1.40	1.80	3.41	1.66	3.00	2.72	19.26	9.06
Orthoclase	0.09	0.08	0.05	0.04	0.06	0.06	0.04	0.03	0.05	0.02	0.04	0.43	0.11	0.22	0.06	0.10	0.13	0.32	0.12	0.25	0.30	4.12	1.41
Plagioclase	0.22	0.28	0.19	0.53	0.48	0.38	0.49	0.63	0.42	0.19	0.34	1.58	0.38	0.67	0.20	0.37	0.41	1.21	0.43	1.02	0.85	4.74	4.54
Muscovite	0.06	0.07	0.05	0.09	0.09	0.06	0.07	0.05	0.05	0.06	0.12	0.78	0.12	0.10	0.06	0.12	0.08	0.26	0.12	0.15	0.19	1.47	1.30
Clays	0.05	0.05	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.05	0.02	0.09	0.02	0.02	0.03	0.02	0.01	0.02	0.04	0.03	0.03	0.08	0.11
Epidote	10.1	13.1	8.40	5.11	5.55	7.10	11.5	4.89	4.74	13.5	8.06	2.26	19.0	10.7	4.98	10.7	12.5	7.57	10.7	8.07	9.54	4.00	4.55
Ti Silicates	0.96	0.78	0.94	1.01	0.93	0.77	0.86	0.84	0.81	1.03	1.67	1.19	0.55	0.42	0.32	0.47	0.41	0.45	0.36	0.32	0.35	0.33	0.41
Olivine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00
Apatite	0.03	0.08	0.00	0.33	0.09	0.06	0.40	0.53	0.48	0.06	0.08	0.33	0.04	0.05	0.03	0.08	0.06	1.07	0.22	0.45	0.64	0.41	0.27
Titanite	0.31	0.46	0.17	0.93	0.49	0.50	0.82	0.65	0.79	0.42	0.48	0.39	0.57	0.49	0.27	0.49	0.41	1.23	0.81	0.95	0.95	0.66	0.35
Carbonates	0.00	0.02	0.00	0.00	0.18	0.04	0.03	0.00	0.02	0.00	0.01	0.49	0.05	0.10	0.00	0.02	0.05	0.55	0.10	0.40	0.24	0.68	0.29
Sulphides	0.00	0.07	0.01	0.15	0.13	0.14	0.03	0.05	0.25	0.05	0.91	3.61	0.01	0.05	0.01	0.01	0.03	0.08	0.02	0.02	0.07	3.17	0.62
Ni-(Cu-Co) Alloy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marshite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Gibbsite	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.03	0.01	0.07	0.03	0.02	0.04	0.01	0.05	0.05	0.01	0.03	0.00	0.01
Tin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.02	0.01	0.03	0.02	0.07	0.26
Wollastonite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Schorl	0.13	0.18	0.13	0.29	0.30	0.32	0.44	0.15	0.26	0.17	0.25	1.86	0.34	0.22	0.19	0.41	0.42	0.85	0.22	0.35	0.30	1.04	1.47
Other	0.01	0.01	0.10	0.03	0.05	0.03	0.08	0.05	0.03	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.03	0.01	0.02	0.02	0.02	0.06	0.18
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

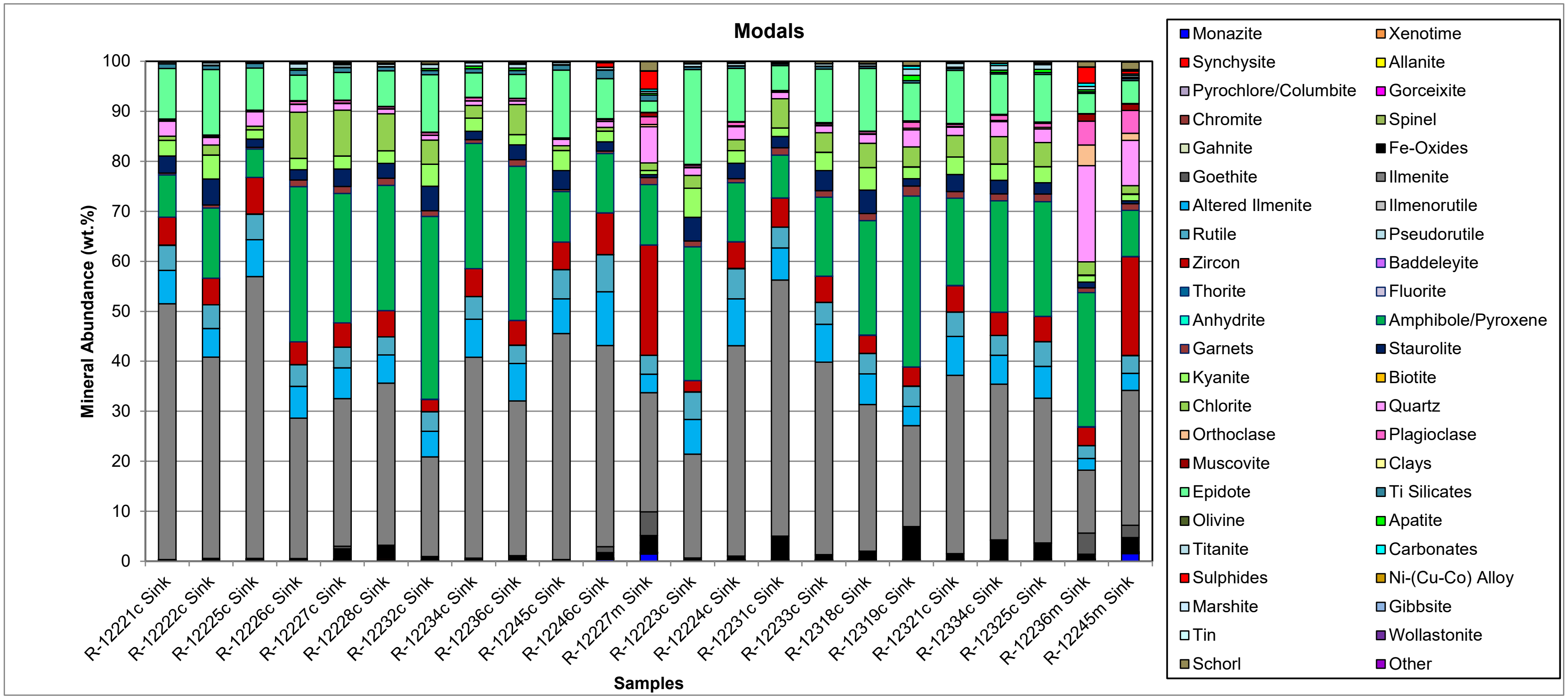

Figure I: Graphical Illustration of a Summary of Mineral Mass% of the Sink Fractions

Mineral Liberation

The liberation (>80% liberated) of monazite, zircon, rutile, and apatite is shown in Table II. Liberation in all samples ranges for:

- monazite from 71% to 97% and avg. 87%.
- zircon from 89% to 96% and avg. 93%.
- rutile from 49% to 72% and avg. 59%.
- ilmenite from 90% to 96% and avg. 93%.

Table II: Monazite, Zircon, Rutile, and Ilmenite Liberation and Association of the Sink Fractions

Association/Range	**Min**	**Max**	**Avg.**
Pure Monazite	15.3	52.2	32.2
Free Monazite	26.9	69.1	47.5
Lib Monazite	0.0	14.6	7.7
Mnz:Xenotime	0.0	0.0	0.0
Mnz:Synchysite	0.0	0.1	0.0
Mnz:Pyrochlore/Columbite	0.0	0.0	0.0
Mnz:Spinel	0.0	1.4	0.1
Mnz:Ilmenite	0.0	27.5	3.7
Mnz:Ilmenorutile	0.0	0.0	0.0
Mnz:Rutile	0.0	4.1	0.4
Mnz:Zircon	0.0	1.8	0.4
Mnz:Amph/Pyr/Grt	0.0	9.1	1.3
Mnz:Staurolite	0.0	8.6	0.5
Mnz:Kyanite	0.0	9.3	0.5
Mnz:Quartz/Feldspars	0.0	2.8	0.5
Mnz:Other Minerals	0.0	8.1	1.9
Complex	0.0	9.9	3.2
Liberated	71.3	96.6	87.4

Association/Range	**Min**	**Max**	**Avg.**
Pure Zircon	29.8	60.7	39.4
Free Zircon	28.2	58.5	47.9
Lib Zircon	3.3	9.1	5.8
Zrn:Monazite	0.0	0.7	0.1
Zrn:Xenotime	0.0	0.0	0.0
Zrn:Synchysite	0.0	0.0	0.0
Zrn:Pyrochlore/Columbite	0.0	0.0	0.0
Zrn:Spinel	0.0	0.5	0.1
Zrn:Ilmenite	0.3	6.9	3.2
Zrn:Ilmenorutile	0.0	0.0	0.0
Zrn:Rutile	0.0	0.5	0.1
Zrn:Amph/Pyr/Grt	0.2	3.3	1.2
Zrn:Staurolite	0.0	0.4	0.1
Zrn:Kyanite	0.0	0.8	0.2
Zrn:Quartz/Feldpars	0.0	1.4	0.3
Zrn:Other Minerals	0.4	1.9	0.9
Complex	0.4	1.7	0.8
Liberated	89.3	96.2	93.0

Association/Range	**Min**	**Max**	**Avg.**
Pure Rutile	9.3	23.7	14.7
Free Rutile	18.1	31.8	26.0
Lib Rutile	14.3	24.4	18.0
Rt:Monazite	0.0	0.4	0.0
Rt:Xenotime	0.0	0.0	0.0
Rt:Synchysite	0.0	0.0	0.0
Rt:Pyrochlore/Columbite	0.0	0.0	0.0
Rt:Spinel	0.0	0.3	0.1
Rt:Ilmenite	4.5	27.4	15.4
Rt:Ilmenorutile	0.0	0.0	0.0
Rt:Zircon	0.0	1.0	0.2
Rt:Amph/Pyr/Grt	0.0	1.0	0.4
Rt:Staurolite	0.0	0.1	0.0
Rt:Kyanite	0.0	0.2	0.0
Rt:Quartz/Feldpars	0.1	1.1	0.5
Rt:Other Minerals	3.2	9.3	6.1
Complex	11.9	27.6	18.6
Liberated	49.2	71.7	58.7

Association/Range	**Min**	**Max**	**Avg.**
Pure Ilmenite	30.5	51.0	37.4
Free Ilmenite	36.7	55.0	45.4
Lib Ilmenite	6.1	17.4	10.2
Ilm:Monazite	0.0	0.1	0.0
Ilm:Xenotime	0.0	0.0	0.0
Ilm:Synchysite	0.0	0.0	0.0
Ilm:Pyrochlore/Columbite	0.0	0.0	0.0
Ilm:Spinel	0.0	2.9	0.9
Ilm:Ilmenorutile	0.0	0.0	0.0
Ilm:Rutile	0.5	3.2	1.6
Ilm:Zircon	0.0	1.1	0.4
Ilm:Amph/Pyr/Grt	0.2	1.7	0.7
Ilm:Staurolite	0.0	0.2	0.1
Ilm:Kyanite	0.0	0.2	0.0
Ilm:Quartz/Feldspars	0.0	0.4	0.1
Ilm:Other Minerals	0.4	1.3	0.8
Complex	1.2	3.9	2.4
Liberated	90.0	95.5	93.0

Mineral Chemistry

Selected samples from the Sink products were submitted for EPMA to determine the quantitative mineral compositions of monazite, xenotime, zircon, rutile, and ilmenite.

Monazite is Ce_2O_3, La_2O_3, and Nd_2O_3 rich (Table III). The average concentrations of the major oxides including La_2O_3, Ce_2O_3, Pr_2O_3, Nd_2O_3, and Sm_2O_3 in the monazite analyzed are similar among the samples. Note that thorium varies widely but the average ThO_2 concentrations range from 4.48 wt% to 7.34 wt% and UO_2 from 0.29 wt% to 0.71 wt%. Average Y_2O_3 ranges from 0.95 wt% to 1.49 wt%.

Table III: Average Mineral Chemistry of Monazite from the EPMA

Sample/Oxide	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
LOD	n=226	0.0498	0.0527	0.0065	0.0177	0.0516	0.0625	0.0501	0.0269	0.0263	0.0051	0.0354	0.0344	0.0260	0.0462	0.0070	0.0706	
R-12221c	n=22	6.67	0.71	28.91	1.31	27.93	13.16	3.09	11.49	1.94	0.91	1.17	0.13	0.06	0.39	0.99	0.14	99.00
R-12222c	n=22	6.55	0.58	28.62	0.95	28.37	13.86	3.10	11.49	1.92	0.87	1.11	0.11	0.03	0.28	0.89	0.10	98.84
R-12225c	n=21	5.11	0.59	28.95	1.24	29.02	13.87	3.17	11.70	1.94	0.58	1.21	0.13	0.05	0.37	0.80	0.18	98.88
R-12234c	n=25	4.85	0.53	29.23	1.31	28.24	12.49	3.37	13.43	2.21	0.73	1.22	0.14	0.06	0.38	0.79	0.15	99.14
R-12246c	n=26	4.52	0.59	28.97	1.29	28.82	13.70	3.24	12.38	2.08	0.63	1.23	0.14	0.06	0.40	0.74	0.16	98.96
R-12321c	n=26	7.34	0.63	28.23	1.45	27.61	12.90	3.13	11.97	1.98	1.19	1.21	0.12	0.10	0.45	0.87	0.29	99.47
R-12334c	n=13	4.53	0.33	29.70	1.37	29.14	13.64	3.25	12.49	2.18	0.28	1.26	0.13	0.10	0.44	1.07	0.05	99.95
R-12224c	n=22	5.09	0.29	29.03	1.49	29.11	12.87	3.30	12.91	1.99	0.67	1.14	0.12	0.10	0.43	0.77	0.16	99.45
R-12319c	n=19	4.48	0.31	28.94	1.35	29.27	13.76	3.30	12.61	2.00	0.51	1.03	0.12	0.10	0.43	0.61	0.06	98.87
R-12325c	n=30	5.38	0.35	28.99	1.29	28.42	13.96	3.18	12.30	2.07	0.67	1.14	0.14	0.10	0.44	0.71	0.07	99.20

Xenotime is characterized by average Y_2O_3 which ranges from 38.87 wt% to 43.03 wt%, Gd_2O_3 avg. from 1.31% to 2.90%, Er_2O_3 from 3.73% to 4.80% and Dy_2O_3 from 5.06% to 7.15% (Table IV). Note the presence of ThO_2 which ranges from 0.03% to 0.45%, and UO_2 from 0.35% to 1.77%. Other REE are below the detection limit (LOD) of the instrument or very low (<1%) in concentration.

Table IV: Average Mineral Chemistry of Xenotime from the EPMA

Sample/Oxide	Xenotime	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
LOD	n=30	0.0498	0.0527	0.0065	0.0177	0.0516	0.0625	0.0501	0.0269	0.0263	0.0051	0.0354	0.0344	0.0260	0.0462	0.0070	0.0706	
R-12221c	n=1	0.05	1.77	32.23	38.87	0.09	0.04	0.07	0.40	0.67	0.40	2.05	0.54	4.56	5.38	0.10	0.52	87.76
R-12222c	n=4	0.14	1.53	33.11	41.85	0.16	0.03	0.05	0.44	0.73	0.41	2.67	0.78	3.73	6.28	0.10	0.26	92.27
R-12225c	n=2	0.05	0.59	33.06	41.25	0.11	0.03	0.04	0.50	0.85	0.14	2.90	0.76	4.22	6.17	0.05	0.29	90.99
R-12234c	n=4	0.45	0.37	33.06	42.40	0.05	0.01	0.02	0.16	0.27	0.31	1.31	0.45	4.64	4.71	0.03	0.44	88.69
R-12246c	n=4	0.09	0.68	32.69	40.72	0.09	0.05	0.03	0.36	0.47	0.18	1.63	0.52	4.80	5.06	0.06	0.44	87.86
R-12334c	n=2	0.04	0.35	34.38	43.03	0.02	0.01	0.02	0.04	0.25	0.29	2.29	0.80	4.13	7.15	0.01	0.22	93.01
R-12224c	n=3	0.16	1.34	33.08	39.64	0.10	0.03	0.08	0.47	0.68	0.30	2.06	0.61	4.45	5.51	0.10	0.25	88.87
R-12319c	n=5	0.03	0.71	34.00	42.16	0.08	0.02	0.08	0.28	0.40	0.26	1.76	0.57	4.46	5.68	0.05	0.36	90.89
R-12325c	n=5	0.07	0.37	34.27	42.86	0.03	0.03	0.08	0.19	0.34	0.20	1.55	0.52	4.66	5.06	0.00	0.28	90.51

For zircon, the average concentration of ZrO_2 ranges from 65.37 wt% to 66.58 wt% and HfO_2 from 1.20 wt% to 1.42 wt%. Y_2O_3 ranges from 0.01 wt% to 0.16 wt%, while other analyzed rare earth elements and uranium are near or below the detection limits of the instrument (Table V).

Table V: Average Mineral Chemistry for Zircon from the EPMA

Sample/Oxide	Zircon	UO2	Y2O3	Ce2O3	La2O3	Nd2O3	SiO2	ZrO2	HfO2	Dy2O3	CaO	P2O5	TOTAL
LOD	n=297	0.0366	0.0119	0.0361	0.0430	0.0186	0.0030	0.0160	0.0143	0.0176	0.0049	0.0036	
R-12221c	n=27	0.05	0.01	0.00	0.01	0.01	32.52	65.88	1.25	0.00	0.00	0.09	99.82
R-12222c	n=27	0.08	0.03	0.00	0.01	0.00	32.52	65.90	1.28	0.00	0.00	0.12	99.95
R-12225c	n=29	0.06	0.04	0.00	0.02	0.01	32.66	65.95	1.27	0.01	0.00	0.10	100.13
R-12234c	n=28	0.04	0.05	0.00	0.01	0.00	32.54	66.21	1.31	0.01	0.00	0.11	100.29
R-12246c	n=30	0.05	0.09	0.00	0.02	0.00	32.67	66.58	1.27	0.01	0.00	0.14	100.83
R-12321c	n=25	0.01	0.14	0.00	0.01	0.01	32.72	65.50	1.26	0.06	0.01	0.12	99.84
R-12334c	n=33	0.02	0.15	0.00	0.01	0.01	32.69	65.77	1.20	0.06	0.00	0.10	100.03
R-12224c	n=26	0.07	0.15	0.00	0.01	0.01	32.46	65.37	1.42	0.06	0.01	0.13	99.70
R-12319c	n=36	0.01	0.16	0.01	0.01	0.01	32.85	66.29	1.30	0.07	0.00	0.11	100.82
R-12325c	n=36	0.02	0.16	0.01	0.01	0.01	32.92	66.29	1.27	0.06	0.02	0.12	100.90

For rutile, the TiO_2 concentration ranges from 97.97 wt% to 100.07 wt% and Nb_2O_5 from 0.06 wt% to 0.50 wt%. The FeO is between 0.23 wt% and 0.61 wt% (Table VI).

Table VI: Average Mineral Chemistry for Rutile from the EPMA

Sample/Oxide	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
LOD	n=98	0.01902	0.0029	0.0167	0.0102	0.0056	0.0056	0.0084	0.0041	0.0157	0.0039	0.0100	
R-12221c	n=10	0.29	0.04	98.46	0.04	0.23	0.09	0.00	0.00	0.00	0.01	0.00	99.16
R-12222c	n=11	0.26	0.04	99.74	0.00	0.28	0.07	0.00	-	0.00	0.01	0.01	100.41
R-12225c	n=11	0.25	0.04	99.88	0.01	0.23	0.08	0.00	-	0.00	0.01	0.01	100.51
R-12234c	n=10	0.26	0.07	98.94	0.00	0.23	0.06	-	-	0.00	0.01	-	99.58
R-12246c	n=11	0.50	0.05	98.89	0.09	0.61	0.09	0.00	-	0.00	0.02	-	100.26
R-12321c	n=11	0.36	0.04	99.59	0.01	0.48	0.09	-	0.00	0.02	0.01	-	100.60
R-12334c	n=11	0.47	0.05	100.07	0.01	0.36	0.10	0.00	0.02	0.04	0.01	0.00	101.12
R-12224c	n=12	0.44	0.05	99.62	0.01	0.37	0.10	0.00	0.03	0.02	0.01	-	100.64
R-12319c	n=7	0.20	0.09	97.97	0.01	0.46	0.11	0.02	0.02	0.02	0.04	0.01	98.94
R-12325c	n=4	0.06	0.04	99.41	0.00	0.28	0.05	-	-	0.00	0.01	-	99.86

For ilmenite, the TiO_2 concentration ranges from 49.53 wt% to 60.43 wt%, FeO from 35.79 wt% to 47.7 wt%, and Nb_2O_5 from 0.01 wt% to 0.69 wt% (Table VI).

Table VII: Average Mineral Chemistry for Ilmenite from the EPMA

Sample/Oxide	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
LOD	n=132	0.01902	0.0029	0.0167	0.0102	0.0056	0.0056	0.0084	0.0041	0.0157	0.0039	0.0100	
R-12221c	n=11	0.04	0.00	50.67	0.01	45.92	0.08	1.90	0.03	-	0.01	0.03	98.97
R-12222c	n=8	0.69	0.01	60.43	0.11	35.79	0.05	0.81	0.00	0.05	0.01	0.02	98.24
R-12225c	n=8	0.04	0.00	49.98	0.01	46.16	0.01	2.08	-	-	0.01	0.02	98.67
R-12234c	n=10	0.05	0.00	50.57	0.01	45.01	0.00	3.09	-	-	0.01	-	99.06
R-12246c	n=9	0.06	0.00	49.76	0.01	47.08	0.00	1.50	-	-	0.01	-	98.85
R-12321c	n=16	0.01	0.06	51.45	0.01	46.82	0.01	1.49	0.00	0.01	0.02	0.02	100.14
R-12334c	n=18	0.01	0.05	50.95	0.01	47.38	0.05	1.43	0.00	0.01	0.02	0.03	100.29
R-12224c	n=18	0.01	0.05	50.27	0.01	46.33	0.01	2.32	0.00	0.00	0.01	0.03	99.47
R-12319c	n=18	0.03	0.05	49.83	0.01	47.70	0.02	1.34	0.00	0.01	0.01	0.01	99.48
R-12325c	n=16	-	0.04	49.53	0.01	47.52	0.02	1.53	0.00	0.00	0.01	0.01	99.19

Introduction

This report describes a mineralogical test program using High Definition Mineralogy, including TIMA-X technology (Tescan Integrated Mineral Analyzer), X-ray diffraction (XRD) analysis, geochemical analyses, and electron probe micro-analyses, and laser ablation inductively coupled plasma mass spectroscopy (LA-ICP-MS) on twenty-three mineral sand samples.

The samples were submitted by Mr. William L. Lassetter from the Virginia Department of Energy, Geology and Mineral Resources Program, for mineralogical analysis. The purpose of this test program was to determine the overall mineral assemblage of the samples, with an emphasis on the REE minerals (REM) occurrence.

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Testwork Summary

1. Sample Receipt and Preparation

Twenty-three (23) mineral sand samples (Table 1), collected from marine sediments were submitted to the Advanced Mineralogy Facility at SGS Canada Inc., Lakefield site by the Virginia Department of Energy, Geology and Mineral Resources Program for mineralogical analysis. The project number 17512-02 was assigned to the testwork.

Table 1: Sample Inventory and Identifications

No	Sample ID
1	R-12221c
2	R-12222c
3	R-12225c
4	R-12226c
5	R-12227m
6	R-12227c
7	R-12228c
8	R-12232c
9	R-12234c
10	R-12236c
11	R-12245c
12	R-12246c
13	R-12321c
14	R-12334c
15	R-12231c
16	R-12236m
17	R-12318c
18	R-12224c
19	R-12233c
20	R-12223c
21	R-12319c
22	R-12325c
23	R-12245m

Each sample was submitted for heavy liquid separation (HLS) at a specific gravity (S.G.) of 2.9 g/cc^3 to generate a sink (heavy mineral concentrate) and float fraction (light minerals).

From each sink fraction, a 2-5 g subsample was obtained to complete the following chemical assays:

- sodium peroxide fusion ICP-MS analysis (IMS93A) for REE, Th, U, Cs, Ga, In, Nb, Rb and Ta;
- sodium peroxide fusion ICP-AES analysis (ICP93A) for Al, Ca, Cr, Fe, K, Mg, Mn, Si, Ti and V, Sc, and Zr;
- strong acid digest / ICP-AES (ICP42C) for 30 elements
- ICM90A for As, Ge, and Hf.

- A 1-2 g aliquot from each of the Sink and Float fraction was used to prepare graphite impregnated polished sections. Two randomly oriented graphite-impregnated polished sections were prepared from each Sink fraction and one from each Float fraction and submitted for TIMA-X analysis using the Tescan High Resolution Mineral (THRM) analysis mode of operation.
- A 9 g subsample was also riffled from the R-12225c, R-12226c, R-12227c, and R-12236c HLS Sink for qualitative XRD.

The XRD report is presented in Appendix A, the Certificate of Analysis in Appendix B, the TIMA-X data are presented in Appendix C, the results from the EPMA in Appendix D, and the LA-ICP-MS in Appendix E.

2. Heavy Liquid Separation

The initial HLS weight, Sink and Float fraction weight, and wt% distribution are given in Table 2 and graphically illustrated in Figure 1. The Sink fraction accounts for 0.1% to 62.9% of the total mass in all samples.

Table 2: HLS, Sink, and Float Weight

No	Sample ID	HLS Initial wt/g	HLS Sink wt/g	HLS Float wt/g	Loss wt/g	HLS Sink wt%	HLS Float wt%
1	R-12221c	104.6	22.3	81.9	0.5	21.4	78.6
2	R-12222c	270.0	28.6	240.7	0.7	10.6	89.4
3	R-12225c	117.2	73.6	43.4	0.2	62.9	37.1
4	R-12226c	243.6	131.7	111.4	0.5	54.2	45.8
5	R-12227m	173.9	0.3	172.7	0.9	0.1	99.9
6	R-12227c	204.6	75.3	128.7	0.7	36.9	63.1
7	R-12228c	217.2	37.0	179.8	0.4	17.1	82.9
8	R-12232c	235.1	45.3	189.4	0.4	19.3	80.7
9	R-12234c	224.9	77.1	147.6	0.2	34.3	65.7
10	R-12236c	229.1	107.7	121.1	0.4	47.1	52.9
11	R-12245c	273.9	91.1	182.4	0.4	33.3	66.7
12	R-12246c	110.7	33.5	76.7	0.4	30.4	69.6
13	R-12321c	299.2	117.0	181.3	0.8	39.2	60.8
14	R-12334c	219.0	73.3	145.0	0.7	33.6	66.4
15	R-12231c	98.9	37.3	61.1	0.5	37.9	62.1
16	R-12236m	96.5	0.1	95.1	1.3	0.1	99.9
17	R-12318c	179.0	38.6	140.2	0.3	21.6	78.4
18	R-12224c	149.4	46.6	102.5	0.3	31.3	68.7
19	R-12233c	99.1	43.1	55.9	0.1	43.6	56.4
20	R-12223c	200.2	43.4	156.2	0.7	21.7	78.3
21	R-12319c	299.4	74.0	224.9	0.5	24.8	75.2
22	R-12325c	250.8	104.3	145.1	1.4	41.8	58.2
23	R-12245m	70.9	0.1	69.1	1.6	0.2	99.8

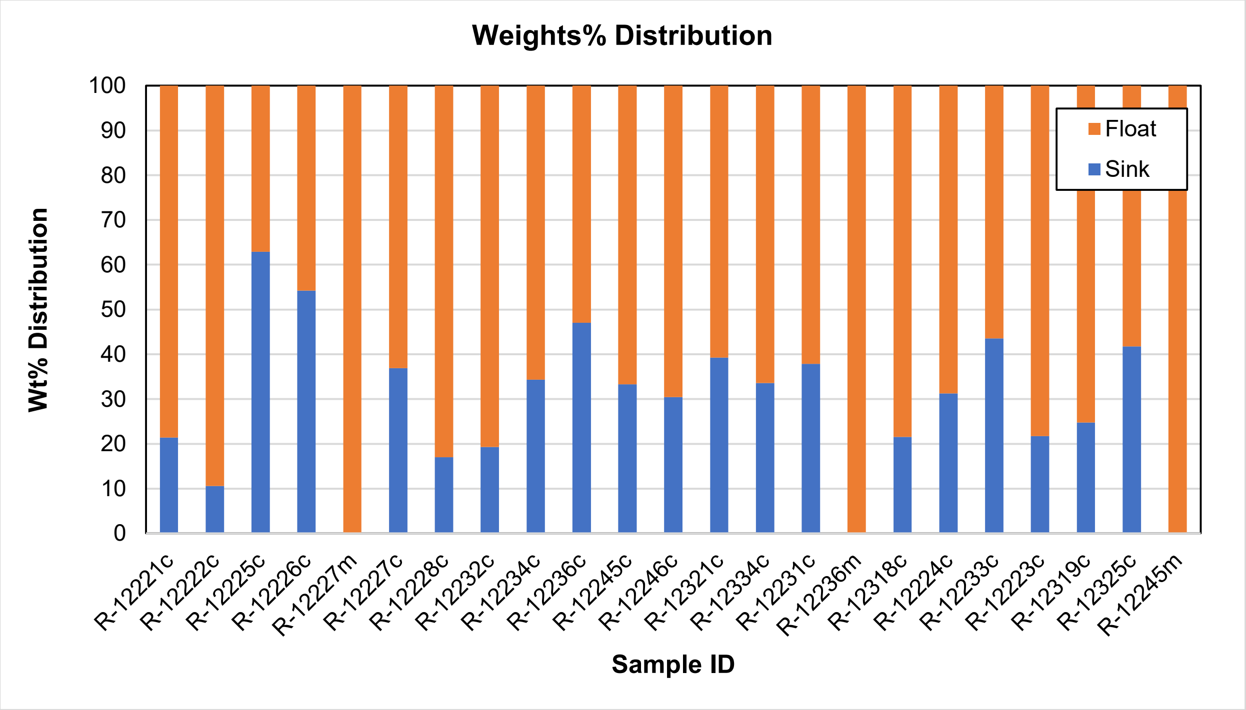


Figure 1: Weight % Distribution of the Sink and Float Fraction for Each Sample

3. X-Ray Diffraction (XRD) Analysis

Qualitative XRD analysis was conducted on the R-12225c, R-12226c, R-12227c, and R-12236c HLS Sink for data validation purposes and TIMA-X analysis set-up. The summary of XRD results is given in Table 3 and the complete report in Appendix A.

XRD analysis of the selected sink samples consist mainly of ilmenite, amphibole, garnet, with minor zircon, quartz, epidote, chlorite, hematite, rutile, and tentatively identified trace amounts of monazite, and davidite.

Table 3: XRD Results

Sample ID	Major	Moderate	Minor	Trace
(1) R-12225c Sink	ilmenite	-	quartz, zircon, epidote, chlorite, hematite, rutile, amphibole	*monazite, *davidite
(2) R-12226c Sink	amphibole	ilmenite garnet	quartz, zircon, epidote	*monazite, *davidite *hematite, *rutile, *chlorite
(3) R-12227c Sink	amphibole	ilmenite garnet	quartz, zircon, epidote	*monazite, *davidite *hematite, *rutile, *chlorite
(4) R-12236c Sink	amphibole	ilmenite, garnet	zircon, epidote	*monazite, *davidite *hematite, *rutile, *quartz, *chlorite

4. TIMA-X Operational Modes and Quality Control

4.1. Operational Modes

TIMA-X is an acronym for TESCAN Integrated Mineral Analyzer. It is based on four Energy Dispersive X-Ray (EDX) silicon drift detectors (SDD) attached to a TESCAN MIRA (field-emission gun – FEG) platform which also includes a backscattered electron (BSE) and secondary electron (SE) detectors. The TIMA system utilizes both the EDX and BSE signals to identify minerals at each measurement point, and it is optimized to deal with rapidly acquired low-count spectra. These EDX (and BSE) spectra (and BSE data) are compared to entries in a mineral library on a first match principle to identify the mineral phase, where this mineral library is based on theoretical mineral/phase composition or created by the user based from BSE, X-ray spectral window counts, and/or ratios. TIMA-X has four X-ray analysis scanning modes to identify mineral/compounds including the High-Resolution Mapping (THRM) mode. The THRM collects a BSE signal and an X-ray spectrum at a set resolution to map the particles, and collect modal and textural information (i.e., liberation, exposure).

4.2. Operational Modes and Quality Control

The mode of TIMA-X analysis used for this project was High-Resolution Mapping (THRM) mode. The THRM scans the entire polished section and provides a statistically robust population of mineral identifications based on X-ray chemistry of minerals. It should be noted that the energy dispersive X-ray characteristics for magnetite and hematite are nearly identical and that these two minerals cannot reliably be distinguished by TIMA-X. Light elements such as lithium, boron, carbon, beryllium, oxygen, and hydrogen cannot be discriminated by the TIMA-X analysis.

The THRM is a two-dimensional mapping analysis aimed at resolving liberation and locking characteristics of a generic set of particles. A pre-defined number of particles are mapped at a point spacing selected to spatially resolve and describe mineral textures and associations.

4.3. TIMA-X Assay Reconciliation

Each polished section was submitted for mineralogical analyses with TIMA-X using THRM mode. All data was processed with the TIMA-X software version 2.5.1. A mineral list developed for the analyzed sample is shown in Table 4.

Key TIMA-X mineralogically calculated assays have been regressed with the chemical assays for the samples, as presented in Table 5 and Figure 2. Elemental deviation between the calculated TIMA-X assays and actual assays are attributed to the low mass of the Sink fractions.

Table 4: Mineral List and Formulas

Mineral	**Mineral Formula**
Almandine	$Fe_3Al_2(SiO_4)_3$
Altered Ilmenite	$FeTiO_3$
Amphibole	$(Na,K)Ca_2(Fe,Mg)_5(Al,Si)_8O_{22}(OH)_2$
Anhydrite	$CaSO_4$
Apatite	$Fe^{2+}{}_3Al_2(SiO_4)_3$
Baddeleyite	ZrO_2
Biotite	$K(Mg,Fe)Al_2Si_3AlO_{10}(OH)_2$
Carbonates, i.e., clacite	$CaCO_3$
Chlorite	$(Fe,(Mg,Mn)_5,Al)(Si_3Al)O_{10}(OH)_8$
Chromite	$Fe^{2+}Cr_2O_4$
Clays, i.e., kaolinite	$Al_2Si_2O_5(OH)_4$
Columbite	$FeNb_2O_6$
Epidote	$Ca_2(Al,Fe)Al_2O(SiO_4)(Si_2O_7)(OH)$
Fe-Oxides, i.e., magnetite	Fe_3O_4
Fluorite	CaF_2
Gahnite	$ZnAl_2O_4$
Gibbsite	$Al(OH)_3$
Goethite	$\alpha FeO \cdot OH$
Gorceixite	$BaAl_3(PO_4)(PO_3OH)(OH)_6$
Ilmenite	$FeTiO_3$
Ilmenorutile	$Ti_{0.7}Nb_{0.2}Fe^{2+}{}_{0.2}O_2$
Kyanite	Al_2SiO_5
Marshite	CuI
Monazite	$(Ce,La,Nd,Th)PO_4$
Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$
Ni-(Cu-Co) Alloy	Ni-(Cu-Co)
Olivine	$(Mg,Fe)_2SiO_4$
Orthoclase	$KAlSi_3O_8$
Plagioclase	$(NaSi,CaAl)AlSi_2O_8$
Pseudorutile	$Fe^{3+}{}_2Ti_3O_9$
Pyrite	FeS_2
Pyrochlore	$(Ca,Na)_2(Nb,Ta)_2O_6(O,OH,F)$
Pyroxene	$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$
Quartz	SiO_2
Rutile	TiO_2
Schorl, i.e., dravite	$NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$
Sphalerite	$(Fe,Zn)S$
Spinel	$MgAl_2O_4$
Staurolite	$(Fe,Mg)_2Al_9(Si,Al)_4O_{20}(O,OH)_4$
Synchysite	$Ca(Ce,Nd,La)(CO_3)_2F$
Thorite	$ThSiO_4$
Ti Silicates	Ti-Silicate mixtures
Tin	Sn
Titanite	$CaTiSiO_5$
Wollastonite	$CaSiO_3$
Xenotime	$Y(HREE)PO_4$
Zircon	$ZrSiO_4$

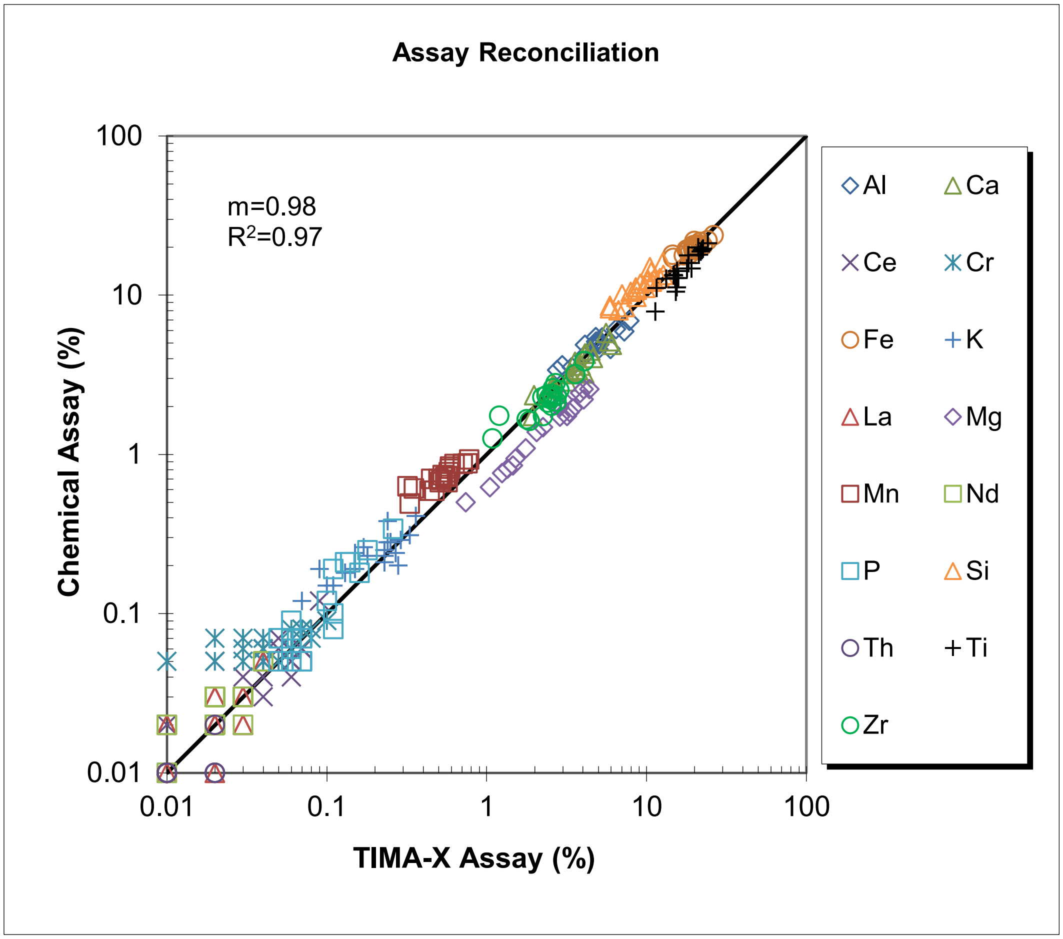


Figure 2: Graphical Illustration of TIMA-X Calculated and Direct Chemical Assay Reconciliation

Table 5: TIMA-X Calculated and Direct Chemical Assay Reconciliation

Sample	**R-12221c**	**R-12222c**	**R-12225c**	**R-12226c**	**R-12227c**	**R-12228c**	**R-12232c**	**R-12234c**	**R-12236c**	**R-12245c**
Al (TIMA)	4.08	5.97	2.76	4.83	5.08	4.96	7.29	4.13	4.84	5.00
Al (Chemical)	4.14	4.60	3.38	5.45	4.90	5.01	5.93	4.88	5.10	4.57
Ca (TIMA)	2.60	3.73	1.98	4.09	3.62	3.82	5.86	3.57	4.18	3.36
Ca (Chemical)	2.74	3.37	2.35	3.22	3.27	3.24	5.12	3.82	4.28	3.18
Ce (TIMA)	0.05	0.04	0.07	0.04	0.04	0.06	0.02	0.06	0.04	0.05
Ce (Chemical)	0.06	0.06	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.07
Cr (TIMA)	0.02	0.04	0.06	0.07	0.06	0.10	0.03	0.08	0.08	0.01
Cr (Chemical)	0.05	0.05	0.06	0.08	0.08	0.09	0.07	0.08	0.07	0.05
Fe (TIMA)	22.5	19.6	24.1	17.9	19.7	19.9	14.6	19.67	18.4	21.1
Fe (Chemical)	20.4	20.6	22.1	19.3	20.2	21.9	17.9	19.6	19.6	20.8
K (TIMA)	0.10	0.15	0.07	0.28	0.24	0.23	0.33	0.23	0.29	0.11
K (Chemical)	0.15	0.19	0.12	0.20	0.28	0.21	0.31	0.23	0.29	0.15
La (TIMA)	0.02	0.02	0.03	0.02	0.02	0.03	0.01	0.03	0.02	0.02
La (Chemical)	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Mg (TIMA)	1.05	1.76	0.74	4.05	3.47	3.31	4.40	3.01	3.85	1.25
Mg (Chemical)	0.62	1.09	0.50	2.21	1.94	1.84	2.56	2.19	2.43	0.76
Mn (TIMA)	0.71	0.59	0.78	0.50	0.51	0.55	0.35	0.57	0.52	0.63
Mn (Chemical)	0.87	0.84	0.93	0.70	0.67	0.72	0.61	0.67	0.69	0.87
Nd (TIMA)	0.02	0.02	0.03	0.02	0.02	0.02	0.01	0.03	0.02	0.02
Nd (Chemical)	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03
P (TIMA)	0.06	0.07	0.07	0.11	0.06	0.07	0.11	0.16	0.13	0.07
P (Chemical)	0.05	0.05	0.05	0.10	0.09	0.07	0.19	0.18	0.21	0.07
Si (TIMA)	7.04	8.68	5.90	11.1	10.3	9.86	12.8	8.6	10.2	7.35
Si (Chemical)	10.1	9.75	8.24	12.5	12.5	11.1	13.4	11.2	12.2	8.42
Th (TIMA)	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Th (Chemical)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ti (TIMA)	22.3	18.3	24.2	14.89	15.2	15.5	11.6	19.18	15.9	21.1
Ti (Chemical)	19.2	17.8	21.2	13.3	12.8	14.2	11.1	14.7	12.8	19.9
Zr (TIMA)	2.75	2.60	3.59	2.24	2.37	2.56	1.20	2.74	2.42	2.70
Zr (Chemical)	2.33	2.60	3.18	2.29	2.35	2.39	1.75	2.14	2.11	2.80

Table 6: TIMA-X Calculated and Direct Chemical Assay Reconciliation (cont'd)

Sample	**R-12246c**	**R-12223c**	**R-12224c**	**R-12231c**	**R-12233c**	**R-12318c**	**R-12319c**	**R-12321c**	**R-12334c**	**R-12325c**
Al (TIMA)	3.42	7.83	4.24	2.97	5.29	6.44	5.16	5.15	4.95	5.03
Al (Chemical)	3.53	6.89	4.30	3.63	5.41	6.12	5.12	5.14	5.11	5.03
Ca (TIMA)	2.60	6.07	3.17	1.95	3.60	4.63	5.60	3.89	4.12	4.46
Ca (Chemical)	2.56	4.88	2.86	1.74	3.40	4.03	5.78	3.61	4.30	4.48
Ce (TIMA)	0.09	0.01	0.04	0.03	0.04	0.04	0.06	0.07	0.06	0.07
Ce (Chemical)	0.12	0.02	0.05	0.04	0.03	0.04	0.05	0.06	0.04	0.06
Cr (TIMA)	0.07	0.03	0.03	0.07	0.04	0.04	0.05	0.04	0.02	0.04
Cr (Chemical)	0.08	0.05	0.06	0.08	0.07	0.06	0.05	0.06	0.07	0.05
Fe (TIMA)	21.68	14.72	21.13	26.26	20.42	18.15	17.16	19.67	19.67	18.58
Fe (Chemical)	21.60	17.10	20.20	23.80	20.00	18.90	17.80	19.40	19.20	18.20
K (TIMA)	0.13	0.27	0.15	0.09	0.17	0.23	0.36	0.18	0.24	0.25
K (Chemical)	0.18	0.24	0.24	0.19	0.26	0.25	0.41	0.23	0.38	0.28
La (TIMA)	0.04	0.01	0.02	0.01	0.02	0.02	0.03	0.03	0.02	0.03
La (Chemical)	0.05	0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.02	0.03
Mg (TIMA)	1.46	3.19	1.52	1.35	2.06	2.88	4.05	2.26	2.85	2.86
Mg (Chemical)	0.85	1.74	0.94	0.81	1.38	1.72	2.56	1.48	2.04	1.97
Mn (TIMA)	0.57	0.32	0.59	0.76	0.58	0.45	0.33	0.53	0.47	0.44
Mn (Chemical)	0.73	0.63	0.81	0.88	0.77	0.70	0.49	0.74	0.59	0.59
Nd (TIMA)	0.04	0.01	0.02	0.01	0.02	0.02	0.02	0.03	0.02	0.03
Nd (Chemical)	0.05	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.03
P (TIMA)	0.11	0.05	0.06	0.05	0.06	0.06	0.26	0.10	0.14	0.18
P (Chemical)	0.08	0.07	0.07	0.05	0.07	0.06	0.34	0.12	0.21	0.25
Si (TIMA)	6.71	12.13	7.96	5.91	8.71	10.79	12.72	9.16	10.54	10.70
Si (Chemical)	8.02	12.80	10.50	8.55	10.80	12.10	16.10	11.80	15.00	14.00
Th (TIMA)	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02
Th (Chemical)	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ti (TIMA)	22.55	13.33	21.25	21.86	18.39	14.78	11.36	17.98	15.29	15.50
Ti (Chemical)	19.60	12.70	17.90	18.80	15.90	13.40	7.87	14.70	10.50	11.20
Zr (TIMA)	4.08	1.09	2.60	2.85	2.55	1.78	1.86	2.58	2.26	2.47
Zr (Chemical)	3.85	1.26	2.30	2.53	2.02	1.66	1.62	2.26	1.74	2.27

4.4. Mineralogical Data

4.4.1. Mineral Classification

The mineral classification was designed based on the TIMA-X analyses, coupled with the EPMA and XRD.

It is critical to note that light elements (Be, Li, B) cannot be detected. REM are identified based on the major element oxide. For example, Figure 3 and Figure 4 illustrate back scattered electron (BSE) image, a pseudo-colour image, and X-ray maps of Ce and P, and Figure 5 a representative spectrum of a monazite grain. Figure 6 illustrates a back scattered electron (BSE) image, a pseudo-colour image, and X-ray maps of Y and P, and Figure 7 the corresponding spectrum of a xenotime grain. Xenotime was identified based mainly on the yttrium and phosphorus concentrations.

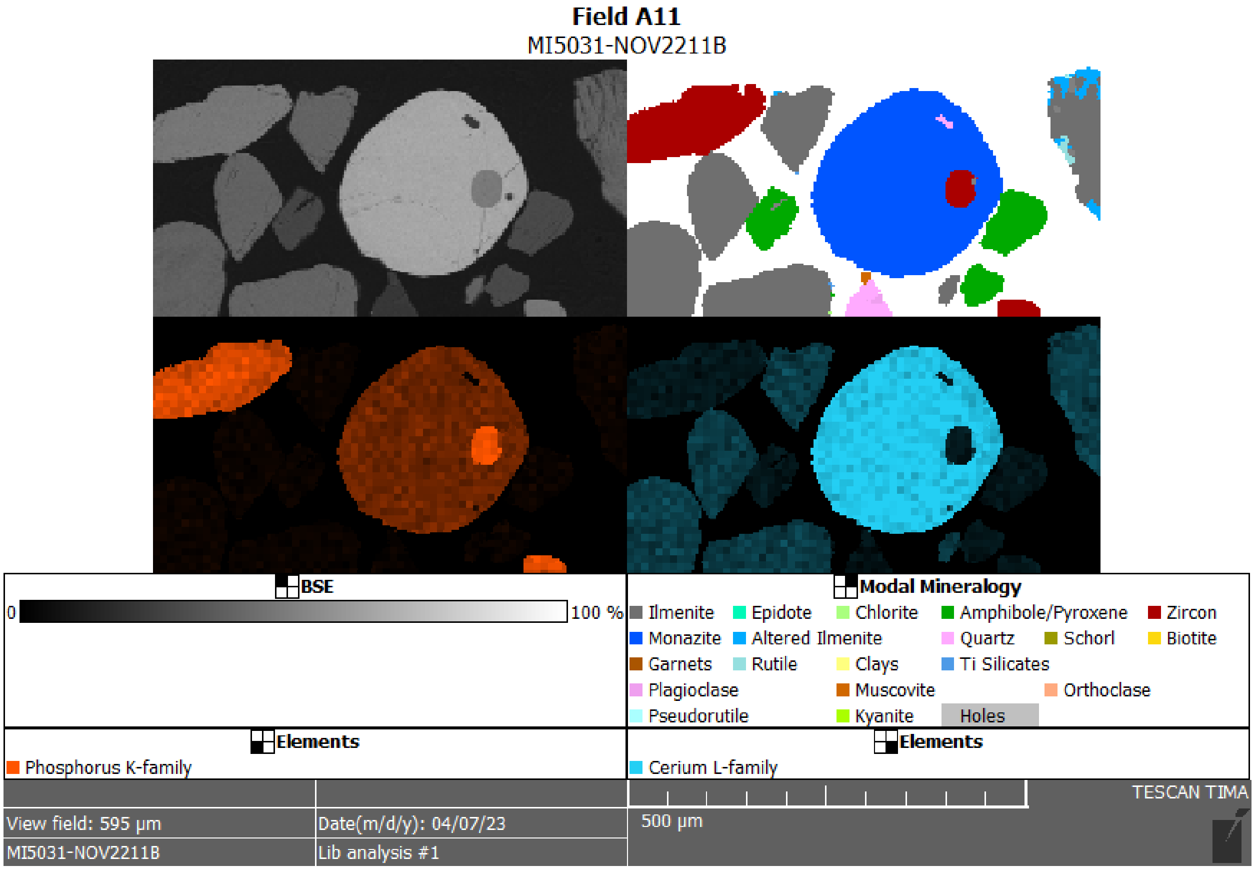
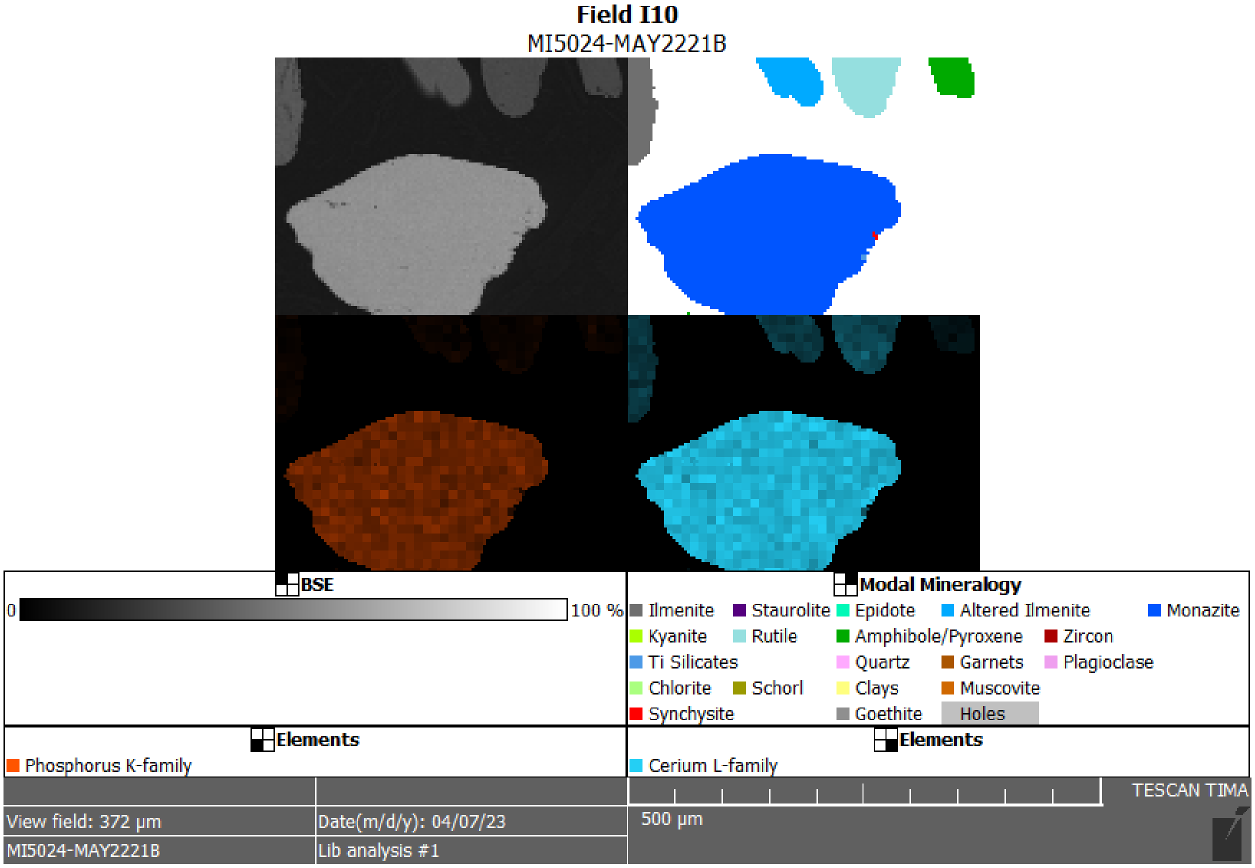


Figure 3: Clockwise: A Back Scatterred Electron (BSE) Image, a Pseudo-Colour Image, and X-ray Maps of Ce and P of a Monazite Grain



View field: 372 µm
Date(m/d/y): 04/07/23
MI5024-MAY2221B
Lib analysis #1

Figure 4: Clockwise: A Back Scattered Electron (BSE) Image, a Pseudo-Colour Image, and X-ray Maps of Ce and P of a Monazite Grain

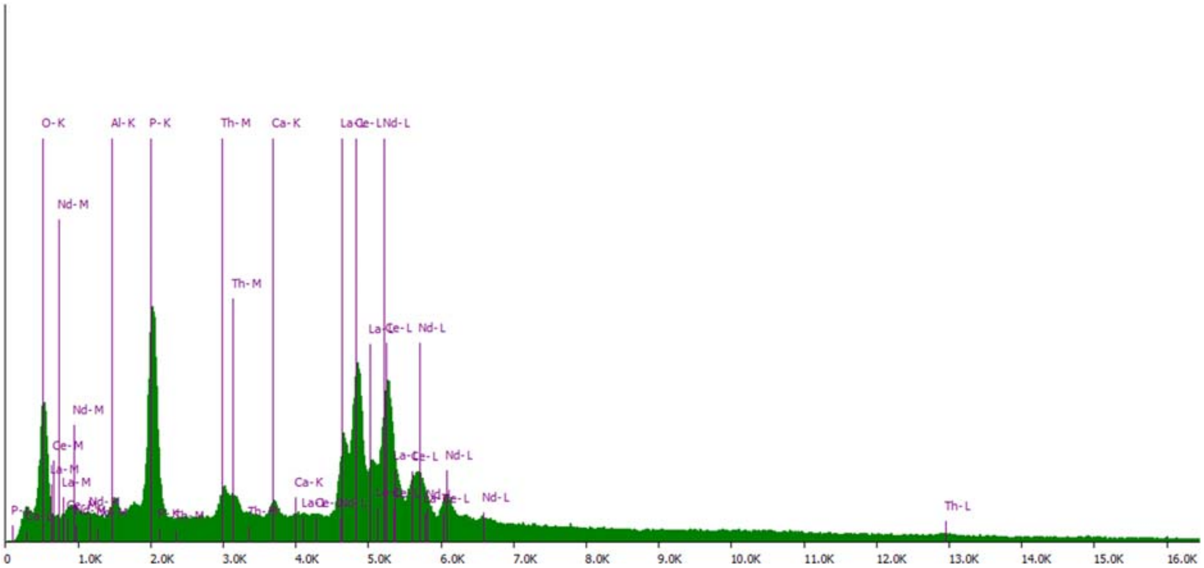


Figure 5: A Representative Spectrum of Monazite Grain

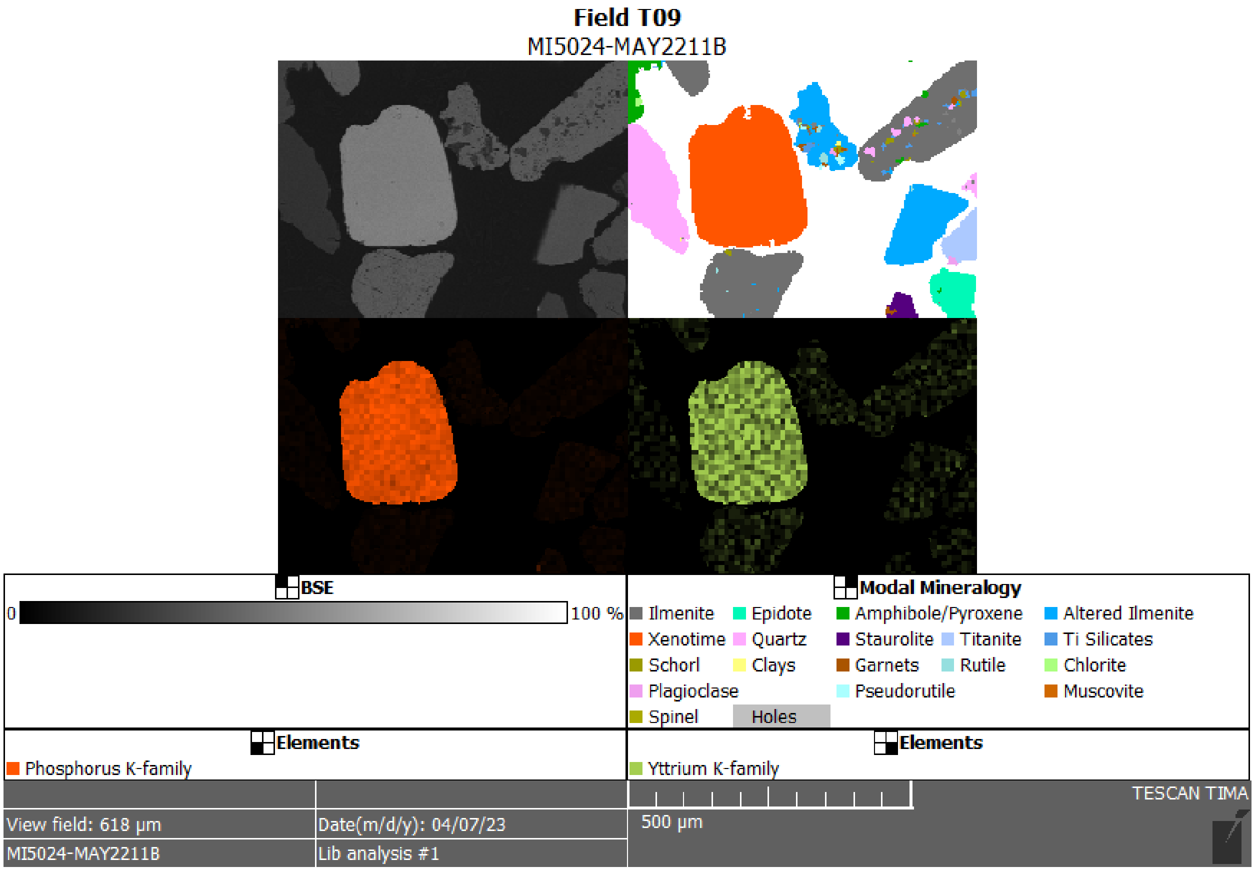


Figure 6: Clockwise: A Back Scattered Electron (BSE) Image, a Pseudo-Colour Image, and X-ray Maps of Y and P of a Xenotime Grain

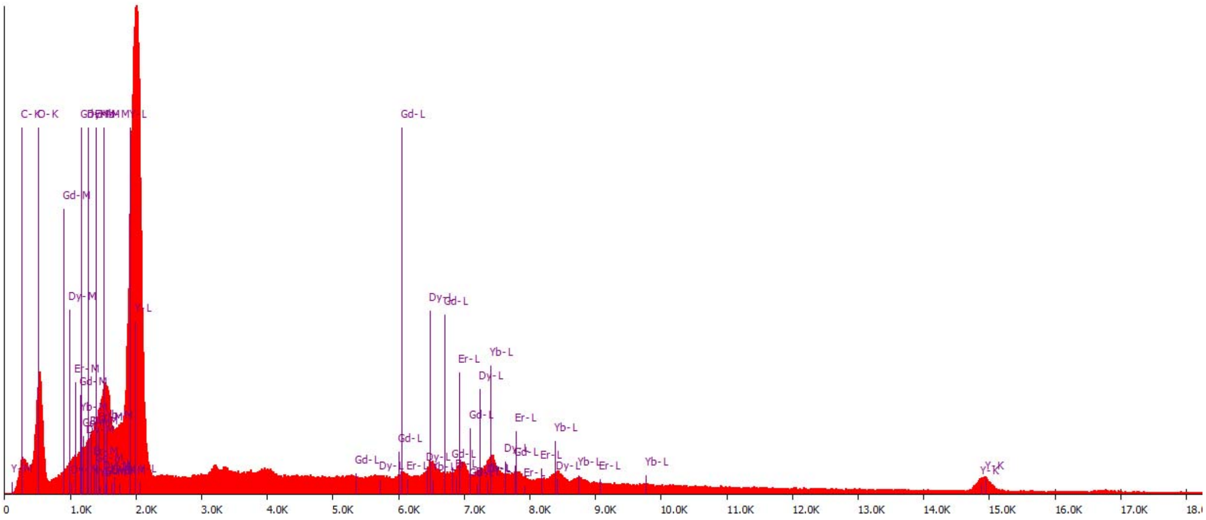


Figure 7: A representative Spectrum of Xenotime Grain

Epidote is also identified based on the main elemental concentration. The particle maps in Figure 8 and Figure 9 illustrate epidote (coloured images) and X-ray maps of Ce to indicate the lack of REE, except for a single allanite grain (yellow) colour, whose corresponding spectrum is shown in Figure 10 to contrast the epidote.

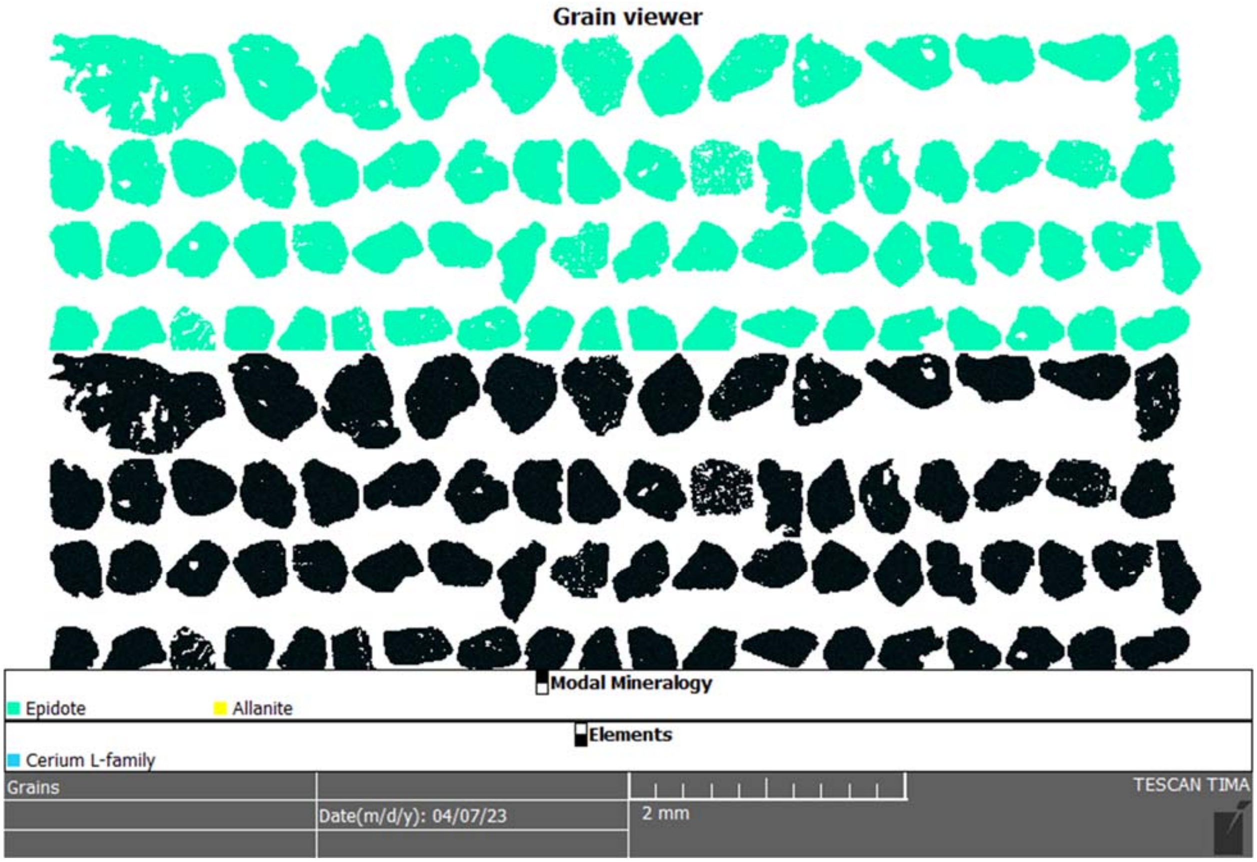
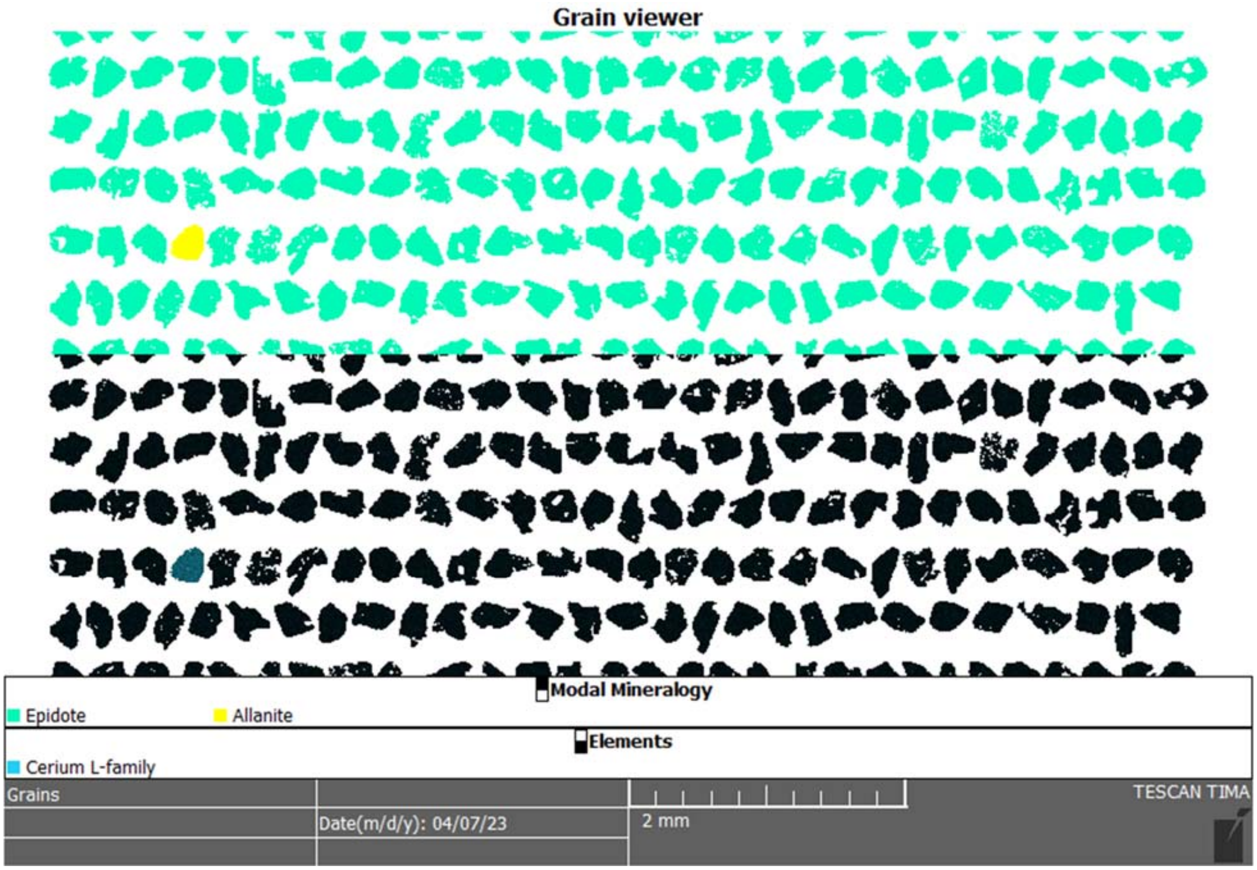


Figure 8: Pseudo-Colour Images of Epidote Grains (above) and X-ray Maps of Ce (below)



Date(m/d/y): 04/07/23

Figure 9: Pseudo-Colour Images of Epidote Grains (above) and X-ray Maps of Ce (below)

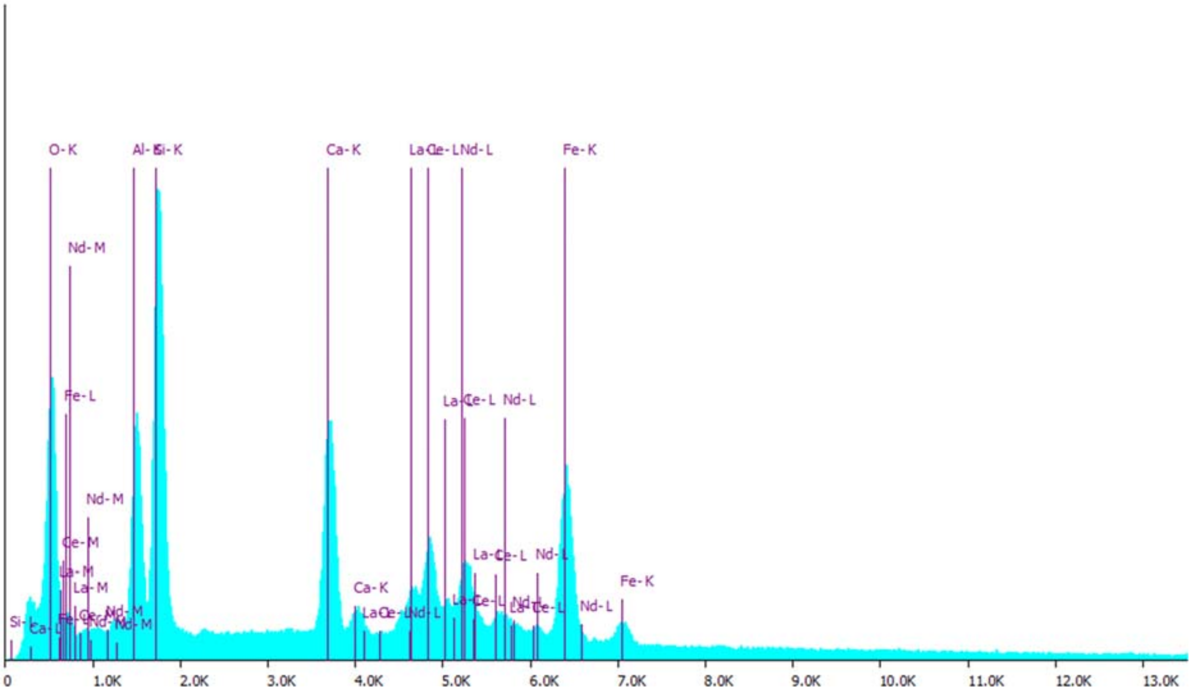


Figure 10: A Representative Spectrum of an Allanite Grain

Differentiation of ilmenite and altered ilmenite is based on the Fe and Ti peak intensities. For example, Figure 11 shows a representative spectrum of ilmenite and Figure 12 that of an altered ilmenite (lower Fe compared to the ilmenite). The semi-quantitative analyses of the two grains are given in Table 7.

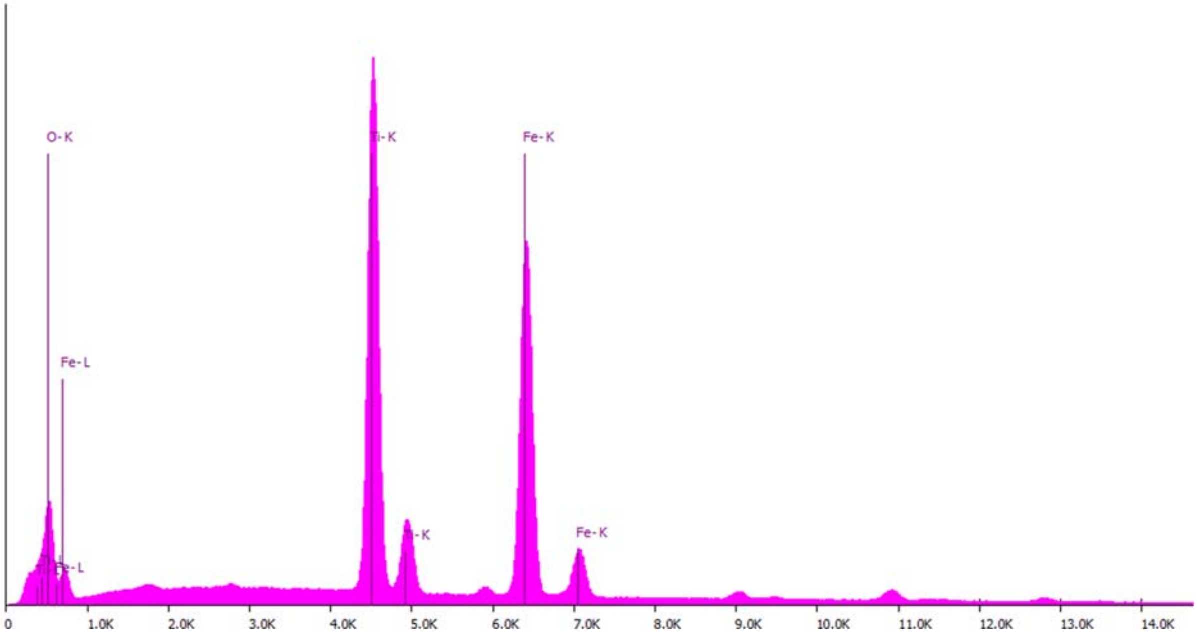


Figure 11: A Representative Spectrum of an Ilmenite Grain

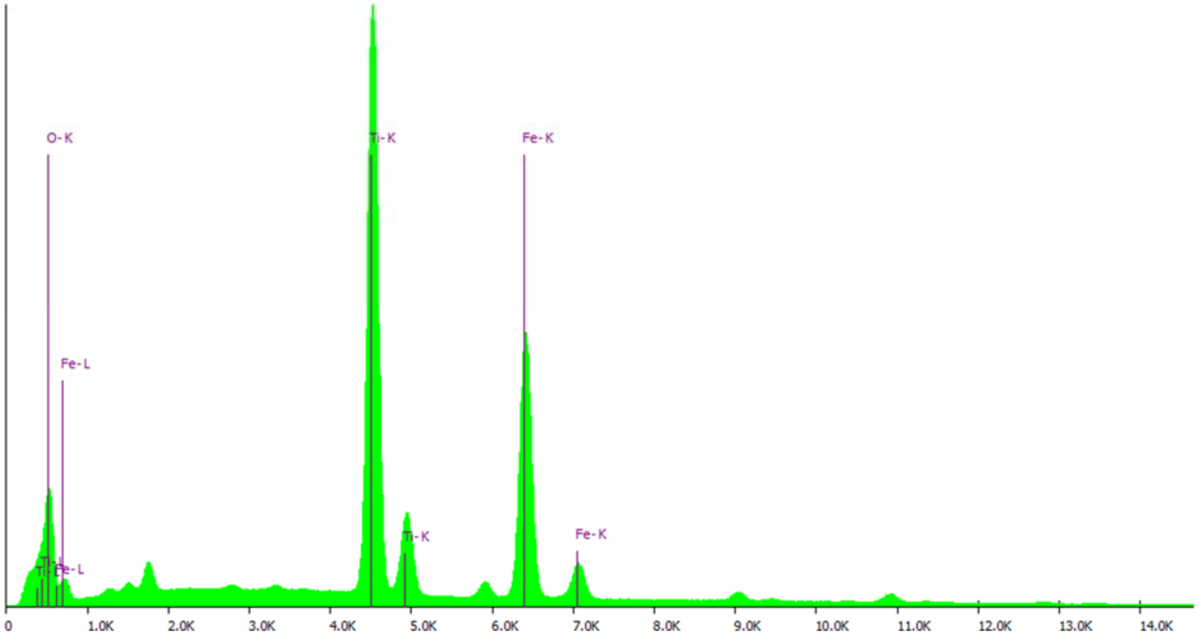


Figure 12: A Representative Spectrum of an Altered Ilmenite Grain

Table 7: Semi-Quantitative Analyses of Ilmenite and Altered Ilmenite

Element	Ilmenite	Altered Ilmenite
	weight %	
Ti	38.2	40.9
Fe	34.6	25.5
O	25.6	30.1
Mn	1.0	1.6
Si	0.4	1.4
Al	0.3	0.7
Total	100	100

4.4.2. Modal Mineralogy

The mineral distributions (in wt%) for the Sinks and Floats is given in Table 8 and Table 9 and graphically illustrated in Figure 13 and Figure 14. Table 10 and Table 11 show the complete and condensed mineralogy distributions for the Sink fractions only, and Table 12 and Table 13 the minimum, maximum, and average values. Note that the Float fraction was analyzed only from five sample to illustrate the recovery of the heavy minerals.

Rare Earth Minerals (REM) include mainly monazite and lesser amounts of xenotime. Monazite ranges from 0.05 to 1.48% and avg. 0.31%, and xenotime from nil to 0.14% and avg. 0.02%, ilmenite from 12.6% to 56.3% and avg. 33.7%, altered Ilmenite from 2.3% to 10.8% and avg. 6.3%, rutile from 2.6% to 7.4% and avg. 4.5%, zircon from 2.2% to 22.1% and avg. 6.4%, amphibole/pyroxene from 5.7% to 36.6% and avg. 19.8%, epidote from 2.3% to 19.0% and avg. 8.6%, staurolite from 0.6% to 5.2% and avg. 2.8%, kyanite from 0.8% to 5.8% and avg. 2.9%, chlorite from 0.7% to 9.2% and avg. 3.8%, quartz from 0.7% to 19.3% and avg. 3.1%, while other minerals average less than 1%.

Table 8: Modal Mineralogy Calculated for the Sinks and Floats (n=5) for Each Sample

Sample/Product	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12226c Float	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12234c Float	R-12236c Sink	R-12245c Sink	R-12246c Sink	R-12227m Sink	R-12227m Float	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12318c Float	R-12319c Sink	R-12319c Float	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Monazite	0.20	0.18	0.30	0.16	0.00	0.15	0.23	0.09	0.24	0.01	0.16	0.20	0.36	1.46	0.01	0.05	0.17	0.12	0.16	0.17	0.00	0.21	0.02	0.26	0.20	0.26	0.23	1.48
Xenotime	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.14	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.02	0.02	0.08
Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Allanite	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.02	0.01	0.01
Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12
Gorceixite	0.01	0.02	0.00	0.02	0.03	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.03	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.02
Chromite	0.07	0.10	0.18	0.19	0.00	0.16	0.28	0.08	0.22	0.00	0.24	0.04	0.19	0.17	0.00	0.07	0.10	0.20	0.10	0.11	0.00	0.13	0.02	0.12	0.07	0.11	0.10	0.17
Spinel	0.01	0.10	0.05	0.08	0.00	0.13	0.18	0.09	0.09	0.00	0.05	0.04	0.05	0.01	0.00	0.08	0.05	0.05	0.12	0.09	0.00	0.03	0.00	0.06	0.04	0.06	0.05	0.01
Gahnite	0.02	0.02	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.05
Fe-Oxides	0.02	0.11	0.00	0.04	0.00	2.01	2.28	0.44	0.02	0.00	0.49	0.01	1.08	3.33	0.04	0.41	0.68	4.61	0.83	1.57	0.05	6.24	0.52	1.04	3.75	3.11	0.94	2.81
Goethite	0.01	0.05	0.03	0.01	0.00	0.52	0.22	0.23	0.01	0.00	0.12	0.01	1.16	4.76	0.39	0.05	0.01	0.03	0.12	0.05	0.01	0.28	0.03	0.01	0.16	0.08	4.25	2.47
Ilmenite	51.2	40.3	56.3	28.1	0.43	29.5	32.4	19.9	40.2	0.08	30.9	45.2	40.2	23.8	0.28	20.7	42.1	51.2	38.5	29.3	0.31	20.2	1.30	35.7	31.1	28.9	12.6	26.9
Altered Ilmenite	6.64	5.72	7.40	6.36	0.15	6.19	5.63	5.09	7.62	0.04	7.50	6.96	10.7	3.72	0.05	6.95	9.39	6.41	7.57	6.13	0.16	3.83	0.26	7.76	5.77	6.38	2.32	3.43
Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rutile	5.04	4.72	5.10	4.31	0.72	4.11	3.63	3.92	4.50	0.13	3.64	5.83	7.41	3.75	0.42	5.49	6.02	4.15	4.37	4.08	0.29	4.05	0.75	4.87	3.95	4.92	2.55	3.52
Pseudorutile	0.03	0.02	0.02	0.02	0.00	0.03	0.02	0.03	0.01	0.00	0.02	0.03	0.03	0.02	0.00	0.06	0.05	0.03	0.04	0.05	0.02	0.03	0.02	0.03	0.02	0.04	0.05	0.04
Zircon	5.61	5.30	7.33	4.57	0.18	4.85	5.23	2.45	5.60	0.02	4.95	5.51	8.34	22.1	0.22	2.22	5.31	5.84	5.22	3.64	0.06	3.81	0.30	5.27	4.63	5.06	3.68	19.79
Baddeleyite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thorite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluorite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.21	0.01	0.01	0.00	0.01	0.01	0.02	0.01	0.04	0.01	0.01	0.01	0.09	0.03
Anhydrite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphibole/Pyroxene	8.44	14.1	5.68	31.0	9.21	25.9	25.1	36.6	25.0	3.92	30.8	10.1	11.9	12.1	9.69	26.8	11.8	8.55	15.8	22.9	8.44	34.2	14.4	17.5	22.3	22.9	26.8	9.2
Garnets	0.36	0.60	0.31	1.32	0.12	1.39	1.43	1.14	0.72	0.03	1.31	0.39	0.50	1.40	3.51	1.16	0.83	1.50	1.25	1.40	0.09	2.00	0.53	1.29	1.42	1.53	0.95	1.33
Staurolite	3.41	5.21	1.66	2.05	0.04	3.52	2.94	4.90	1.71	0.02	2.97	3.80	1.85	0.58	0.01	4.73	3.06	2.25	4.06	4.65	0.15	1.50	0.14	3.43	2.71	2.27	1.14	0.55
Kyanite	3.14	4.77	1.85	2.30	0.48	2.54	2.54	4.42	2.62	0.08	2.07	4.01	2.09	0.81	0.04	5.79	2.53	1.69	3.63	4.55	0.52	2.30	0.40	3.48	3.21	3.20	1.32	1.30
Biotite	0.01	0.00	0.00	0.01	0.10	0.02	0.01	0.00	0.00	0.08	0.00	0.01	0.04	0.07	0.29	0.01	0.02	0.00	0.01	0.01	0.23	0.03	0.44	0.01	0.03	0.02	0.14	0.11
Chlorite	0.83	1.98	0.75	9.23	0.30	9.18	7.37	4.81	2.55	0.13	6.03	0.95	0.74	1.46	1.41	2.61	2.17	5.86	3.93	4.84	0.34	4.01	0.90	4.33	5.50	4.82	2.60	1.65
Quartz	3.01	1.53	2.87	1.59	75.9	1.36	0.98	0.96	0.87	68.1	0.69	1.26	1.19	7.27	37.6	1.52	2.58	1.29	1.40	1.80	72.7	3.41	49.7	1.66	3.00	2.72	19.26	9.06
Orthoclase	0.09	0.08	0.05	0.04	2.46	0.06	0.06	0.04	0.03	7.19	0.05	0.02	0.04	0.43	2.77	0.11	0.22	0.06	0.10	0.13	4.44	0.32	5.57	0.12	0.25	0.30	4.12	1.41
Plagioclase	0.22	0.28	0.19	0.53	6.52	0.48	0.38	0.49	0.63	19.0	0.42	0.19	0.34	1.58	9.00	0.38	0.67	0.20	0.37	0.41	9.25	1.21	15.4	0.43	1.02	0.85	4.74	4.54
Muscovite	0.06	0.07	0.05	0.09	0.80	0.09	0.06	0.07	0.05	0.39	0.05	0.06	0.12	0.78	10.9	0.12	0.10	0.06	0.12	0.08	0.56	0.26	1.31	0.12	0.15	0.19	1.47	1.30
Clays	0.05	0.05	0.04	0.03	0.08	0.03	0.03	0.03	0.02	0.03	0.02	0.05	0.02	0.09	0.55	0.02	0.02	0.03	0.02	0.01	0.02	0.02	0.03	0.04	0.03	0.03	0.08	0.11
Epidote	10.1	13.1	8.40	5.11	1.16	5.55	7.10	11.5	4.89	0.25	4.74	13.5	8.06	2.26	0.28	19.0	10.7	4.98	10.7	12.5	1.29	7.57	1.88	10.7	8.07	9.54	4.00	4.55
Ti Silicates	0.96	0.78	0.94	1.01	0.42	0.93	0.77	0.86	0.84	0.11	0.81	1.03	1.67	1.19	0.46	0.55	0.42	0.32	0.47	0.41	0.12	0.45	0.20	0.36	0.32	0.35	0.33	0.41
Olivine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00
Apatite	0.03	0.08	0.00	0.33	0.24	0.09	0.06	0.40	0.53	0.16	0.48	0.06	0.08	0.33	0.06	0.04	0.05	0.03	0.08	0.06	0.08	1.07	1.06	0.22	0.45	0.64	0.41	0.27
Titanite	0.31	0.46	0.17	0.93	0.09	0.49	0.50	0.82	0.65	0.02	0.79	0.42	0.48	0.39	0.09	0.57	0.49	0.27	0.49	0.41	0.09	1.23	0.41	0.81	0.95	0.95	0.66	0.35
Carbonates	0.00	0.02	0.00	0.00	0.00	0.18	0.04	0.03	0.00	0.03	0.02	0.00	0.01	0.49	0.73	0.05	0.10	0.00	0.02	0.05	0.37	0.55	3.67	0.10	0.40	0.24	0.68	0.29
Sulphides	0.00	0.07	0.01	0.15	0.14	0.13	0.14	0.03	0.05	0.02	0.25	0.05	0.91	3.61	2.19	0.01	0.05	0.01	0.01	0.03	0.03	0.08	0.03	0.02	0.02	0.07	3.17	0.62
Ni-(Cu-Co) Alloy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marshite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Gibbsite	0.02	0.03	0.03	0.04	0.00	0.04	0.04	0.03	0.03	0.00	0.02	0.02	0.03	0.01	0.00	0.07	0.03	0.02	0.04	0.01	0.01	0.05	0.00	0.05	0.01	0.03	0.00	0.01
Tin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.03	0.03	0.00	0.01	0.00	0.00	0.00	0.01	0.02	0.06	0.01	0.03	0.02	0.07	0.26
Wollastonite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Schorl	0.13	0.18	0.13	0.29	0.38	0.30	0.32	0.44	0.15	0.20	0.26	0.17	0.25	1.86	18.7	0.34	0.22	0.19	0.41	0.42	0.36	0.85	0.63	0.22	0.35	0.30	1.04	1.47
Other	0.01	0.01	0.10	0.03	0.01	0.05	0.03	0.08	0.05	0.00	0.03	0.02	0.02	0.03	0.10	0.03	0.01	0.01	0.01	0.03	0.00	0.01	0.01	0.02	0.02	0.02	0.06	0.18
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

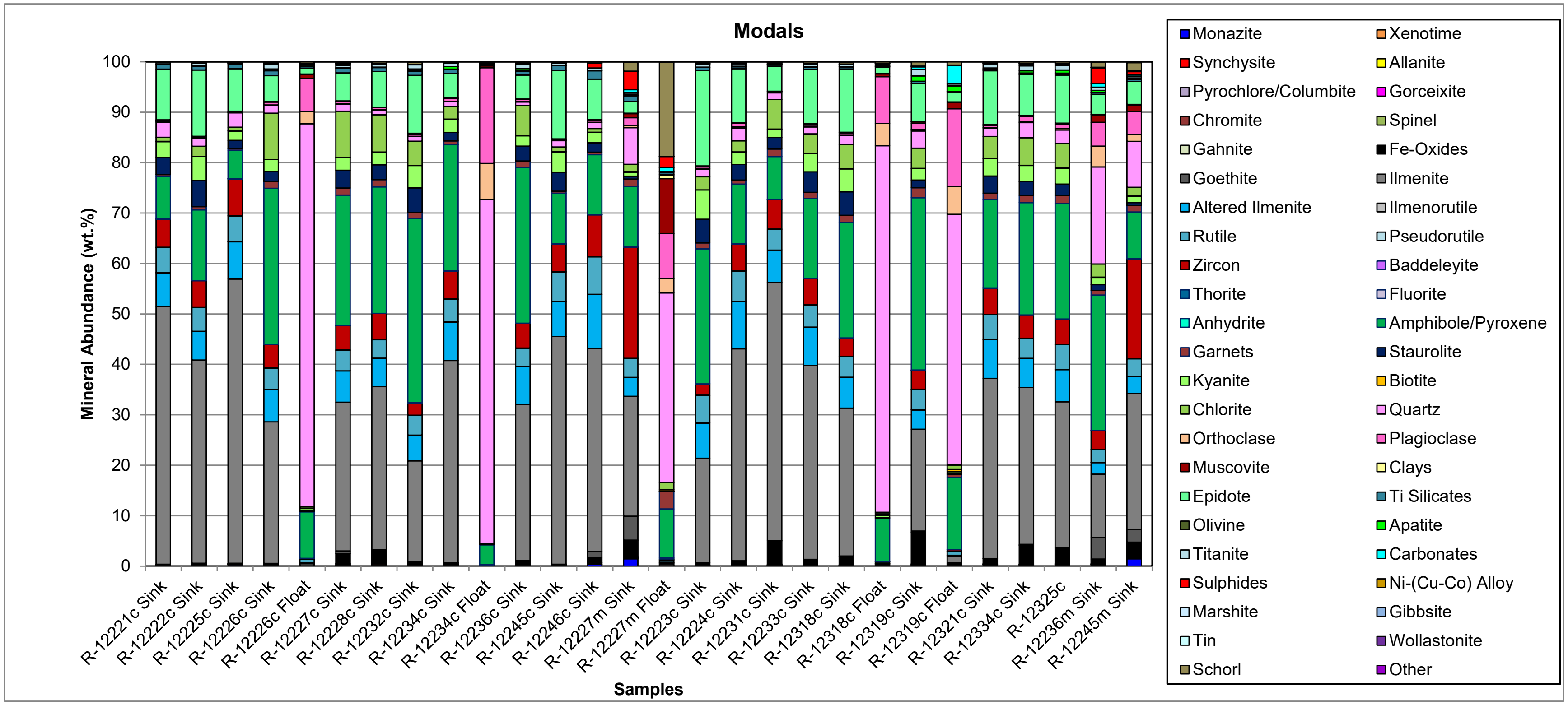


Figure 13: Illustration of Modal Mineralogy for the Sink and Floats for Each Sample

Table 9: Condensed Modal Mineralogy Calculated for the Sink and Float Fractions (n=5) for Each Sample

Sample/Product	**R-12221c Sink**	**R-12222c Sink**	**R-12225c Sink**	**R-12226c Sink**	**R-12226c Float**	**R-12227c Sink**	**R-12228c Sink**	**R-12232c Sink**	**R-12234c Sink**	**R-12234c Float**	**R-12236c Sink**	**R-12245c Sink**	**R-12246c Sink**	**R-12227m Sink**	**R-12227m Float**	**R-12223c Sink**	**R-12224c Sink**	**R-12231c Sink**	**R-12233c Sink**	**R-12318c Sink**	**R-12318c Float**	**R-12319c Sink**	**R-12319c Float**	**R-12321c Sink**	**R-12334c Sink**	**R-12325c Sink**	**R-12236m Sink**	**R-12245m Sink**
Monazite	0.20	0.18	0.30	0.16	0.00	0.15	0.23	0.09	0.24	0.01	0.16	0.20	0.36	1.46	0.01	0.05	0.17	0.12	0.16	0.17	0.00	0.21	0.02	0.26	0.20	0.26	0.23	1.48
Xenotime	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.14	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.02	0.02	0.08
Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12
Gorceixite	0.00	0.02	0.00	0.02	0.02	0.00	0.02	0.01	0.02	0.02	0.01	0.00	0.03	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.02
Spinel	0.13	0.38	0.27	0.33	0.01	2.82	2.97	0.84	0.36	0.01	0.92	0.12	2.49	8.27	0.44	0.61	0.86	4.90	1.17	1.83	0.06	6.69	0.57	1.23	4.03	3.37	5.31	5.51
Ilmenite	57.8	46.0	63.7	34.5	0.58	35.7	38.0	25.0	47.8	0.11	38.4	52.1	51.0	27.5	0.33	27.7	51.5	57.6	46.1	35.4	0.47	24.0	1.56	43.4	36.9	35.3	14.9	30.4
Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rutile	5.07	4.74	5.12	4.33	0.72	4.14	3.65	3.96	4.52	0.13	3.66	5.85	7.44	3.77	0.42	5.55	6.07	4.18	4.42	4.13	0.31	4.08	0.77	4.90	3.98	4.96	2.60	3.56
Zircon	5.61	5.30	7.33	4.57	0.18	4.85	5.24	2.45	5.60	0.02	4.95	5.52	8.34	22.1	0.22	2.22	5.31	5.84	5.22	3.64	0.06	3.81	0.30	5.27	4.63	5.06	3.69	19.79
Amphibole/Pyroxene	8.44	14.0	5.67	30.7	9.08	25.5	24.7	35.8	24.9	3.91	30.5	10.1	11.8	11.9	9.67	26.4	11.7	8.46	15.6	22.5	8.35	33.6	14.2	17.3	21.9	22.6	26.5	9.1
Garnets	0.36	0.60	0.31	1.32	0.12	1.39	1.43	1.14	0.72	0.03	1.31	0.39	0.50	1.40	3.51	1.16	0.83	1.50	1.25	1.40	0.09	2.00	0.53	1.29	1.42	1.53	0.95	1.33
Staurolite	3.41	5.21	1.66	2.05	0.04	3.52	2.94	4.90	1.71	0.02	2.97	3.80	1.85	0.58	0.01	4.73	3.06	2.25	4.06	4.65	0.15	1.50	0.14	3.43	2.71	2.27	1.14	0.55
Kyanite	3.14	4.77	1.85	2.30	0.48	2.54	2.54	4.42	2.62	0.08	2.07	4.01	2.09	0.81	0.04	5.79	2.53	1.69	3.63	4.55	0.52	2.30	0.40	3.48	3.21	3.20	1.32	1.30
Quartz	3.01	1.53	2.87	1.59	75.9	1.36	0.98	0.96	0.87	68.1	0.69	1.26	1.19	7.27	37.6	1.52	2.58	1.29	1.40	1.80	72.7	3.41	49.7	1.66	3.00	2.72	19.26	9.06
Feldspars	0.31	0.36	0.24	0.57	8.99	0.54	0.44	0.52	0.66	26.2	0.47	0.21	0.38	2.01	11.8	0.49	0.89	0.26	0.47	0.54	13.7	1.54	20.9	0.54	1.26	1.15	8.86	5.94
Epidote	10.1	13.1	8.40	5.11	1.16	5.55	7.10	11.5	4.89	0.25	4.74	13.5	8.06	2.26	0.28	19.0	10.7	4.98	10.7	12.5	1.29	7.57	1.88	10.7	8.07	9.54	4.00	4.55
Ti Silicates	0.96	0.78	0.94	1.01	0.42	0.93	0.77	0.86	0.84	0.11	0.81	1.03	1.67	1.19	0.46	0.55	0.42	0.32	0.47	0.41	0.12	0.45	0.20	0.36	0.32	0.35	0.33	0.41
Schorl	0.13	0.18	0.13	0.29	0.38	0.30	0.32	0.44	0.15	0.20	0.26	0.17	0.25	1.86	18.7	0.34	0.22	0.19	0.41	0.42	0.36	0.85	0.63	0.22	0.35	0.30	1.04	1.47
Other	1.34	2.82	1.16	11.2	1.90	10.7	8.69	7.09	4.15	0.86	7.99	1.66	2.51	7.53	16.6	3.90	3.17	6.40	4.92	5.99	1.86	7.94	8.14	5.91	7.94	7.39	9.79	5.38
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

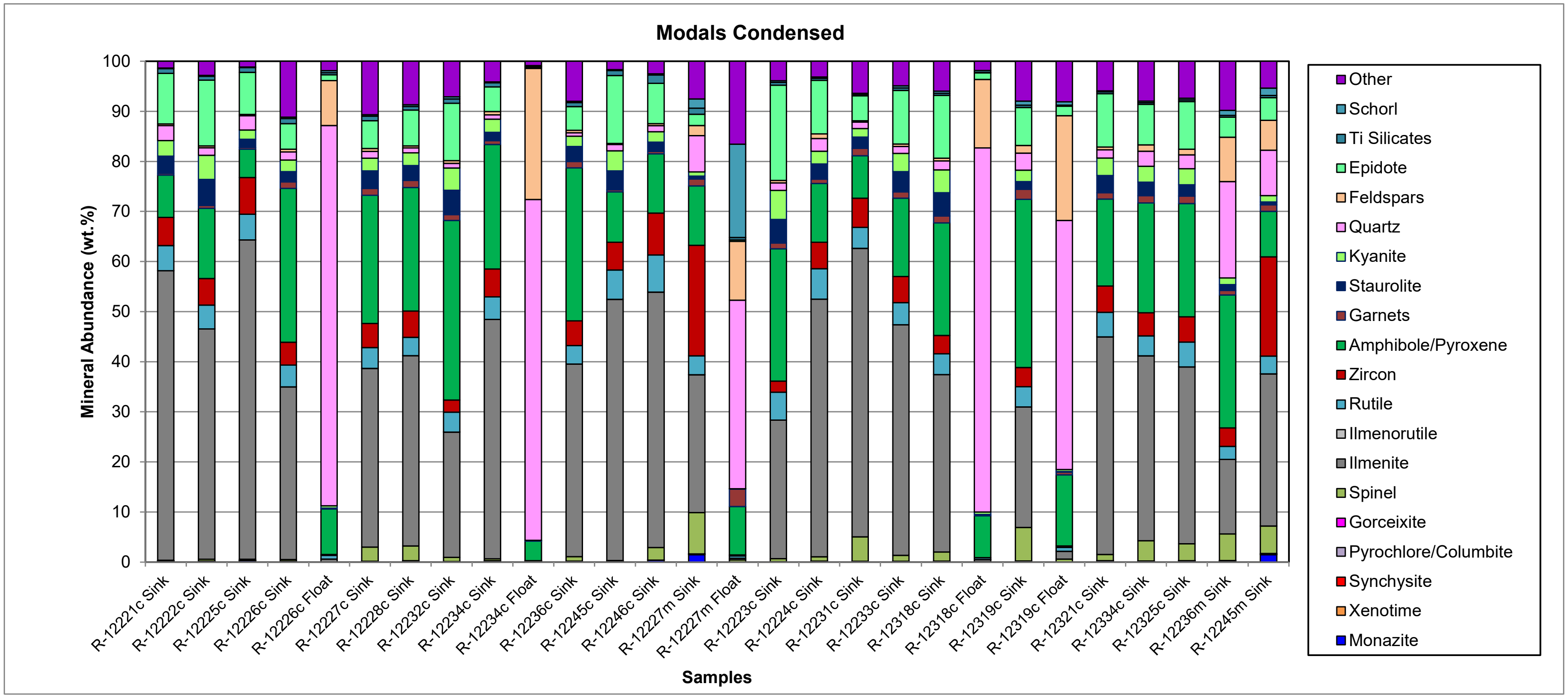


Figure 14: Illustration of Condensed Modal Mineralogy for the Sink and Floats for Each Sample

Table 10: Modal Mineralogy Calculated for the Sink Fraction for Each Sample

Sample/Product	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Monazite	0.20	0.18	0.30	0.16	0.15	0.23	0.09	0.24	0.16	0.20	0.36	1.46	0.05	0.17	0.12	0.16	0.17	0.21	0.26	0.20	0.26	0.23	1.48
Xenotime	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.02	0.14	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.08
Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Allanite	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.02	0.01	0.01
Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12
Gorceixite	0.01	0.02	0.00	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.00	0.02
Chromite	0.07	0.10	0.18	0.19	0.16	0.28	0.08	0.22	0.24	0.04	0.19	0.17	0.07	0.10	0.20	0.10	0.11	0.13	0.12	0.07	0.11	0.10	0.17
Spinel	0.01	0.10	0.05	0.08	0.13	0.18	0.09	0.09	0.05	0.04	0.05	0.01	0.08	0.05	0.05	0.12	0.09	0.03	0.06	0.04	0.06	0.05	0.01
Gahnite	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.05
Fe-Oxides	0.02	0.11	0.00	0.04	2.01	2.28	0.44	0.02	0.49	0.01	1.08	3.33	0.41	0.68	4.61	0.83	1.57	6.24	1.04	3.75	3.11	0.94	2.81
Goethite	0.01	0.05	0.03	0.01	0.52	0.22	0.23	0.01	0.12	0.01	1.16	4.76	0.05	0.01	0.03	0.12	0.05	0.28	0.01	0.16	0.08	4.25	2.47
Ilmenite	51.2	40.3	56.3	28.1	29.5	32.4	19.9	40.2	30.9	45.2	40.2	23.8	20.7	42.1	51.2	38.5	29.3	20.2	35.7	31.1	28.9	12.6	26.9
Altered Ilmenite	6.64	5.72	7.40	6.36	6.19	5.63	5.09	7.62	7.50	6.96	10.7	3.72	6.95	9.39	6.41	7.57	6.13	3.83	7.76	5.77	6.38	2.32	3.43
Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rutile	5.04	4.72	5.10	4.31	4.11	3.63	3.92	4.50	3.64	5.83	7.41	3.75	5.49	6.02	4.15	4.37	4.08	4.05	4.87	3.95	4.92	2.55	3.52
Pseudorutile	0.03	0.02	0.02	0.02	0.03	0.02	0.03	0.01	0.02	0.03	0.03	0.02	0.06	0.05	0.03	0.04	0.05	0.03	0.03	0.02	0.04	0.05	0.04
Zircon	5.61	5.30	7.33	4.57	4.85	5.23	2.45	5.60	4.95	5.51	8.34	22.1	2.22	5.31	5.84	5.22	3.64	3.81	5.27	4.63	5.06	3.68	19.79
Baddeleyite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thorite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluorite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.09	0.03
Anhydrite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphibole/Pyroxene	8.44	14.1	5.68	31.0	25.9	25.1	36.6	25.0	30.8	10.1	11.9	12.1	26.8	11.8	8.55	15.8	22.9	34.2	17.5	22.3	22.9	26.8	9.2
Garnets	0.36	0.60	0.31	1.32	1.39	1.43	1.14	0.72	1.31	0.39	0.50	1.40	1.16	0.83	1.50	1.25	1.40	2.00	1.29	1.42	1.53	0.95	1.33
Staurolite	3.41	5.21	1.66	2.05	3.52	2.94	4.90	1.71	2.97	3.80	1.85	0.58	4.73	3.06	2.25	4.06	4.65	1.50	3.43	2.71	2.27	1.14	0.55
Kyanite	3.14	4.77	1.85	2.30	2.54	2.54	4.42	2.62	2.07	4.01	2.09	0.81	5.79	2.53	1.69	3.63	4.55	2.30	3.48	3.21	3.20	1.32	1.30
Biotite	0.01	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.01	0.04	0.07	0.01	0.02	0.00	0.01	0.01	0.03	0.01	0.03	0.02	0.14	0.11
Chlorite	0.83	1.98	0.75	9.23	9.18	7.37	4.81	2.55	6.03	0.95	0.74	1.46	2.61	2.17	5.86	3.93	4.84	4.01	4.33	5.50	4.82	2.60	1.65
Quartz	3.01	1.53	2.87	1.59	1.36	0.98	0.96	0.87	0.69	1.26	1.19	7.27	1.52	2.58	1.29	1.40	1.80	3.41	1.66	3.00	2.72	19.26	9.06
Orthoclase	0.09	0.08	0.05	0.04	0.06	0.06	0.04	0.03	0.05	0.02	0.04	0.43	0.11	0.22	0.06	0.10	0.13	0.32	0.12	0.25	0.30	4.12	1.41
Plagioclase	0.22	0.28	0.19	0.53	0.48	0.38	0.49	0.63	0.42	0.19	0.34	1.58	0.38	0.67	0.20	0.37	0.41	1.21	0.43	1.02	0.85	4.74	4.54
Muscovite	0.06	0.07	0.05	0.09	0.09	0.06	0.07	0.05	0.05	0.06	0.12	0.78	0.12	0.10	0.06	0.12	0.08	0.26	0.12	0.15	0.19	1.47	1.30
Clays	0.05	0.05	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.05	0.02	0.09	0.02	0.02	0.03	0.02	0.01	0.02	0.04	0.03	0.03	0.08	0.11
Epidote	10.1	13.1	8.40	5.11	5.55	7.10	11.5	4.89	4.74	13.5	8.06	2.26	19.0	10.7	4.98	10.7	12.5	7.57	10.7	8.07	9.54	4.00	4.55
Ti Silicates	0.96	0.78	0.94	1.01	0.93	0.77	0.86	0.84	0.81	1.03	1.67	1.19	0.55	0.42	0.32	0.47	0.41	0.45	0.36	0.32	0.35	0.33	0.41
Olivine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00
Apatite	0.03	0.08	0.00	0.33	0.09	0.06	0.40	0.53	0.48	0.06	0.08	0.33	0.04	0.05	0.03	0.08	0.06	1.07	0.22	0.45	0.64	0.41	0.27
Titanite	0.31	0.46	0.17	0.93	0.49	0.50	0.82	0.65	0.79	0.42	0.48	0.39	0.57	0.49	0.27	0.49	0.41	1.23	0.81	0.95	0.95	0.66	0.35
Carbonates	0.00	0.02	0.00	0.00	0.18	0.04	0.03	0.00	0.02	0.00	0.01	0.49	0.05	0.10	0.00	0.02	0.05	0.55	0.10	0.40	0.24	0.68	0.29
Sulphides	0.00	0.07	0.01	0.15	0.13	0.14	0.03	0.05	0.25	0.05	0.91	3.61	0.01	0.05	0.01	0.01	0.03	0.08	0.02	0.02	0.07	3.17	0.62
Ni-(Cu-Co) Alloy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marshite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Gibbsite	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.03	0.01	0.07	0.03	0.02	0.04	0.01	0.05	0.05	0.01	0.03	0.00	0.01
Tin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.02	0.01	0.03	0.02	0.07	0.26
Wollastonite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Schorl	0.13	0.18	0.13	0.29	0.30	0.32	0.44	0.15	0.26	0.17	0.25	1.86	0.34	0.22	0.19	0.41	0.42	0.85	0.22	0.35	0.30	1.04	1.47
Other	0.01	0.01	0.10	0.03	0.05	0.03	0.08	0.05	0.03	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.03	0.01	0.02	0.02	0.02	0.06	0.18
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 11: Condensed Modal Mineralogy Calculated for the Sink Fraction for Each Sample

Sample/Product	**R-12221c Sink**	**R-12222c Sink**	**R-12225c Sink**	**R-12226c Sink**	**R-12227c Sink**	**R-12228c Sink**	**R-12232c Sink**	**R-12234c Sink**	**R-12236c Sink**	**R-12245c Sink**	**R-12246c Sink**	**R-12227m Sink**	**R-12223c Sink**	**R-12224c Sink**	**R-12231c Sink**	**R-12233c Sink**	**R-12318c Sink**	**R-12319c Sink**	**R-12321c Sink**	**R-12334c Sink**	**R-12325c Sink**	**R-12236m Sink**	**R-12245m Sink**
Monazite	0.20	0.18	0.30	0.16	0.15	0.23	0.09	0.24	0.16	0.20	0.36	1.46	0.05	0.17	0.12	0.16	0.17	0.21	0.26	0.20	0.26	0.23	1.48
Xenotime	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.02	0.14	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.08
Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12
Gorceixite	0.00	0.02	0.00	0.02	0.00	0.02	0.01	0.02	0.01	0.00	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.00	0.02
Spinel	0.13	0.38	0.27	0.33	2.82	2.97	0.84	0.36	0.92	0.12	2.49	8.27	0.61	0.86	4.90	1.17	1.83	6.69	1.23	4.03	3.37	5.31	5.51
Ilmenite	57.8	46.0	63.7	34.5	35.7	38.0	25.0	47.8	38.4	52.1	51.0	27.5	27.7	51.5	57.6	46.1	35.4	24.0	43.4	36.9	35.3	14.9	30.4
Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rutile	5.07	4.74	5.12	4.33	4.14	3.65	3.96	4.52	3.66	5.85	7.44	3.77	5.55	6.07	4.18	4.42	4.13	4.08	4.90	3.98	4.96	2.60	3.56
Zircon	5.61	5.30	7.33	4.57	4.85	5.24	2.45	5.60	4.95	5.52	8.34	22.1	2.22	5.31	5.84	5.22	3.64	3.81	5.27	4.63	5.06	3.69	19.79
Amphibole/Pyroxene	8.44	14.0	5.67	30.7	25.5	24.7	35.8	24.9	30.5	10.1	11.8	11.9	26.4	11.7	8.46	15.6	22.5	33.6	17.3	21.9	22.6	26.5	9.1
Garnets	0.36	0.60	0.31	1.32	1.39	1.43	1.14	0.72	1.31	0.39	0.50	1.40	1.16	0.83	1.50	1.25	1.40	2.00	1.29	1.42	1.53	0.95	1.33
Staurolite	3.41	5.21	1.66	2.05	3.52	2.94	4.90	1.71	2.97	3.80	1.85	0.58	4.73	3.06	2.25	4.06	4.65	1.50	3.43	2.71	2.27	1.14	0.55
Kyanite	3.14	4.77	1.85	2.30	2.54	2.54	4.42	2.62	2.07	4.01	2.09	0.81	5.79	2.53	1.69	3.63	4.55	2.30	3.48	3.21	3.20	1.32	1.30
Quartz	3.01	1.53	2.87	1.59	1.36	0.98	0.96	0.87	0.69	1.26	1.19	7.27	1.52	2.58	1.29	1.40	1.80	3.41	1.66	3.00	2.72	19.26	9.06
Feldspars	0.31	0.36	0.24	0.57	0.54	0.44	0.52	0.66	0.47	0.21	0.38	2.01	0.49	0.89	0.26	0.47	0.54	1.54	0.54	1.26	1.15	8.86	5.94
Epidote	10.1	13.1	8.40	5.11	5.55	7.10	11.5	4.89	4.74	13.5	8.06	2.26	19.0	10.7	4.98	10.7	12.5	7.57	10.7	8.07	9.54	4.00	4.55
Ti Silicates	0.96	0.78	0.94	1.01	0.93	0.77	0.86	0.84	0.81	1.03	1.67	1.19	0.55	0.42	0.32	0.47	0.41	0.45	0.36	0.32	0.35	0.33	0.41
Schorl	0.13	0.18	0.13	0.29	0.30	0.32	0.44	0.15	0.26	0.17	0.25	1.86	0.34	0.22	0.19	0.41	0.42	0.85	0.22	0.35	0.30	1.04	1.47
Other	1.34	2.82	1.16	11.2	10.7	8.69	7.09	4.15	7.99	1.66	2.51	7.53	3.90	3.17	6.40	4.92	5.99	7.94	5.91	7.94	7.39	9.79	5.38
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 12: Range of Modal Mineralogy of the Sink Fractions from Each Sample

Sample/Product	Min	Max	Avg.
Monazite	0.05	1.48	0.31
Xenotime	0.00	0.14	0.02
Synchysite	0.00	0.01	0.00
Allanite	0.00	0.02	0.01
Pyrochlore/Columbite	0.00	0.12	0.01
Gorceixite	0.00	0.03	0.01
Chromite	0.04	0.28	0.14
Spinel	0.01	0.18	0.07
Gahnite	0.00	0.05	0.01
Fe-Oxides	0.00	6.24	1.56
Goethite	0.01	4.76	0.64
Ilmenite	12.57	56.34	33.71
Altered Ilmenite	2.32	10.75	6.33
Ilmenorutile	0.00	0.01	0.00
Rutile	2.55	7.41	4.52
Pseudorutile	0.01	0.06	0.03
Zircon	2.22	22.06	6.36
Baddeleyite	0.00	0.00	0.00
Thorite	0.00	0.00	0.00
Fluorite	0.00	0.09	0.01
Anhydrite	0.00	0.00	0.00
Amphibole/Pyroxene	5.68	36.59	19.80
Garnets	0.31	2.00	1.11
Staurolite	0.55	5.21	2.82
Kyanite	0.81	5.79	2.88
Biotite	0.00	0.14	0.02
Chlorite	0.74	9.23	3.83
Quartz	0.69	19.26	3.10
Orthoclase	0.02	4.12	0.35
Plagioclase	0.19	4.74	0.89
Muscovite	0.05	1.47	0.24
Clays	0.01	0.11	0.04
Epidote	2.26	18.99	8.55
Ti Silicates	0.32	1.67	0.70
Olivine	0.00	0.01	0.00
Apatite	0.00	1.07	0.25
Titanite	0.17	1.23	0.59
Carbonates	0.00	0.68	0.14
Sulphides	0.00	3.61	0.41
Ni-(Cu-Co) Alloy	0.00	0.00	0.00
Marshite	0.00	0.01	0.00
Gibbsite	0.00	0.07	0.03
Tin	0.00	0.26	0.02
Wollastonite	0.00	0.01	0.00
Schorl	0.13	1.86	0.45
Other	0.01	0.18	0.04

Table 13: Range of Condensed Modal Mineralogy of the Sink Fractions from Each Sample

Sample/Product	Min	Max	Avg.
Monazite	0.05	1.48	0.31
Xenotime	0.00	0.14	0.02
Synchysite	0.00	0.01	0.00
Pyrochlore/Columbite	0.00	0.12	0.01
Gorceixite	0.00	0.03	0.01
Spinel	0.12	8.27	2.41
Ilmenite	14.89	63.75	40.03
Ilmenorutile	0.00	0.01	0.00
Rutile	2.60	7.44	4.55
Zircon	2.22	22.06	6.36
Amphibole/Pyroxene	5.67	35.83	19.56
Garnets	0.31	2.00	1.11
Staurolite	0.55	5.21	2.82
Kyanite	0.81	5.79	2.88
Quartz	0.69	19.26	3.10
Feldspars	0.21	8.86	1.25
Epidote	2.26	18.99	8.55
Ti Silicates	0.32	1.67	0.70
Schorl	0.13	1.86	0.45
Other	1.16	11.15	5.89

4.5. Mineral Characteristics of the Sink Fractions

The data below refer to the Sink fractions.

4.5.1. Cumulative Grain Size Distribution

The grain size distribution for selected minerals is given in Appendix C. The grain size report serves to study the distribution of the grain size of a specific phase, within the TIMA software; it is defined as equivalent circle diameter (*d*). It is the diameter of a circle that has the same area (*A*) as the particle (or grain). The diameter is defined in pixels and then multiplied by pixel spacing (*Ps*) to obtain size in micrometres. The precise definition is described in the following formula: $d = 2 \cdot \sqrt{A / \pi} \cdot Ps$.

The P_{80} (80% passing, in µm) for selected minerals and the entire particle population from each Sink fraction is presented in Table 14. The P_{80} ranges from 82 µm to 255 µm for the particle, from 68 µm to 199 µm for the monazite, and from 39 µm to 234 µm for the xenotime.

Table 14: Median and P_{80} for Specific Minerals and all Particles for the Sink Fractions from Each Sample

Sample	Grain Size [µm]	Monazite	Xenotime	Synchysite	Pyrochlore/ Columbite	Spinel	Ilmenite	Ilmenorutile	Rutile	Zircon	Amphibole/ Pyroxene/ Garnets	Staurolite	Kyanite	Quartz/ Feldspars	Other	Particle
R-12221c Sink	Median	131	234	8	9	172	163	14	147	158	195	210	220	130	184	174
	P80	164	234	12	10	209	204	26	209	200	255	278	298	165	236	226
R-12222c Sink	Median	128	123	8	9	153	155	12	141	154	201	290	301	85	204	181
	P80	199	123	10	12	293	204	20	220	233	295	461	474	148	292	270
R-12225c Sink	Median	120	79	8	11	187	146	47	121	143	141	159	151	125	138	148
	P80	158	102	10	11	235	196	52	170	202	185	222	199	157	176	197
R-12226c Sink	Median	86	146	10	14	140	126	10	111	115	154	183	178	84	150	144
	P80	144	146	14	26	173	166	14	164	155	199	271	232	129	198	194
R-12227c Sink	Median	99	84	10	45	130	149	10	132	143	178	235	223	76	182	173
	P80	149	89	14	45	190	218	12	215	230	252	320	319	118	260	255
R-12228c Sink	Median	122	39	9	82	126	142	9	134	139	192	240	215	77	188	170
	P80	177	39	12	82	180	190	11	204	199	261	317	303	134	255	246
R-12232c Sink	Median	138	56	10	10	129	150	105	136	135	174	247	220	66	188	178
	P80	184	70	14	10	173	202	105	228	197	262	341	360	125	265	262
R-12234c Sink	Median	93	76	9	12	121	116	11	113	108	125	141	148	95	120	123
	P80	115	91	13	14	168	144	16	149	130	166	182	186	136	157	158
R-12236c Sink	Median	116	57	8	13	126	140	113	121	131	141	185	174	73	146	147
	P80	149	62	14	26	188	186	113	173	184	205	256	259	129	207	205
R-12245c Sink	Median	100	88	9	8	115	146	10	125	132	156	205	198	87	166	157
	P80	146	127	10	11	177	193	26	189	179	221	263	284	128	228	214
R-12246c Sink	Median	69	57	9	86	70	90	115	79	81	102	100	110	54	87	93
	P80	87	79	12	86	96	119	115	110	106	137	136	151	86	121	125
R-12227m Sink	Median	56	61	10	56	52	59	40	55	61	64	119	183	41	46	59
	P80	68	68	49	56	67	75	40	73	76	145	289	237	58	64	82
R-12223c Sink	Median	107	9	6	6	117	142	9	141	130	189	189	202	76	175	174
	P80	122	15	11	6	151	179	17	195	164	240	232	261	109	215	224
R-12224c Sink	Median	97	88	9	9	104	128	79	122	120	149	150	168	83	148	137
	P80	124	111	16	9	139	160	79	161	150	191	192	213	107	186	177
R-12231c Sink	Median	119	165	9	7	138	153	17	128	150	176	175	207	77	171	163
	P80	137	165	13	7	179	197	23	181	202	227	222	281	109	214	211
R-12233c Sink	Median	119	93	10	10	129	147	26	134	145	178	190	208	86	185	165
	P80	186	93	14	11	174	185	43	191	193	246	253	276	120	237	224
R-12318c Sink	Median	124	89	10	68	128	148	10	139	141	198	211	239	79	188	176
	P80	149	89	14	68	167	185	12	189	178	256	289	312	119	239	237
R-12319c Sink	Median	81	53	10	7	77	111	11	84	79	92	179	186	64	88	101
	P80	114	87	15	7	142	173	19	164	144	196	284	281	83	188	190
R-12321c Sink	Median	121	134	8	7	88	135	67	127	126	177	202	218	70	164	154
	P80	178	134	11	7	138	179	67	185	173	257	336	316	91	226	216
R-12334c Sink	Median	148	71	12	-	83	151	11	122	134	159	199	227	75	166	157
	P80	190	90	16	-	118	200	14	189	182	236	262	306	93	226	218
R-12325 Sink	Median	90	85	10	10	83	119	14	97	97	129	204	220	71	134	126
	P80	131	115	14	14	128	174	36	161	151	216	282	339	91	210	198
R-12236m Sink	Median	56	117	10	46	178	88	15	83	64	69	253	202	45	47	63
	P80	81	117	11	79	334	159	21	167	110	178	350	309	62	135	163
R-12245m Sink	Median	66	72	9	59	117	71	46	66	69	76	148	166	58	58	72
	P80	77	83	12	72	187	124	46	124	83	172	267	210	96	145	129

4.6. Liberation and Association of Monazite, Zircon, Ilmenite, and Rutile

The liberation and association characteristics of monazite, zircon, rutile, and ilmenite were examined. For the purposes of this analysis, particle liberation is defined based on 2D particle area percent and mass of a mineral. Particles are classified in the following groups (in descending order) based on mineral-of-interest area percent: pure (100% of the total particle area), free (≥95% of the total particle area) and liberated (≥80%). The non-liberated grains have been classified according to association characteristics, where binary association groups refer to particle area percent greater than or equal to 95% of the two minerals or mineral groups. The complex groups refer to particles with ternary, quaternary, and greater mineral associations including the mineral of interest.

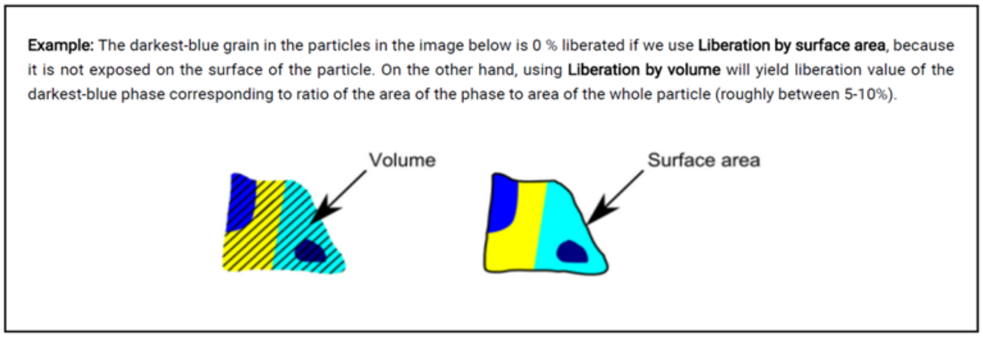
Association classes are defined (as an example for monazite and similarly for the other minerals):

- Barren – a particle that has 0% of monazite
- Pure monazite - a particle that has 100% of monazite
- Free monazite - a particle that has ≥95% of monazite
- Liberated monazite - a particle that has ≤95% to ≥80% of monazite
- Binary monazite: xenotime - a particle that has ≥95 area% of monazite: xenotime
- Binary monazite: synchysite - a particle that has ≥95 area% of monazite: synchysite
- Binary monazite: pyrochlore/columbite - a particle that has ≥95 area% of monazite: pyrochlore/columbite
- Binary monazite: spinel - a particle that has ≥95 area% of monazite: spinel
- Binary monazite: ilmenorutile - a particle that has ≥95 area% of monazite: ilmenorutile
- Binary monazite: rutile - a particle that has ≥95 area% of monazite: rutile
- Binary monazite: zircon - a particle that has ≥95 area% of monazite: zircon
- Binary/ternary monazite: amphibole/pyroxene/garnet (Amph/Pyr/Grt) - a particle that has ≥95 area% monazite: amphibole/pyroxene/garnet
- Binary monazite: staurolite - a particle that has ≥95 area% monazite: staurolite
- Binary monazite: kyanite - a particle that has ≥95 area% monazite: kyanite
- Binary/ternary monazite: quartz/feldspars - a particle that has ≥95 area% monazite: quartz/feldspars
- Binary monazite: other minerals - a particle that has ≥95 area% of monazite: other minerals
- Monazite complex - particles that do not fall into the above categories

Note: the complex category refers to ternary and quaternary particles and does not necessarily reflect the complexity of the middling particles.

Association classes were defined the same way for other minerals.

The liberation and association of the minerals is calculated based on their volume as a function of their mass%, and the exposure based on the free surface (Figure 15).



Example: The darkest-blue grain in the particles in the image below is 0 % liberated if we use **Liberation by surface area**, because it is not exposed on the surface of the particle. On the other hand, using **Liberation by volume** will yield liberation value of the darkest-blue phase corresponding to ratio of the area of the phase to area of the whole particle (roughly between 5-10%).

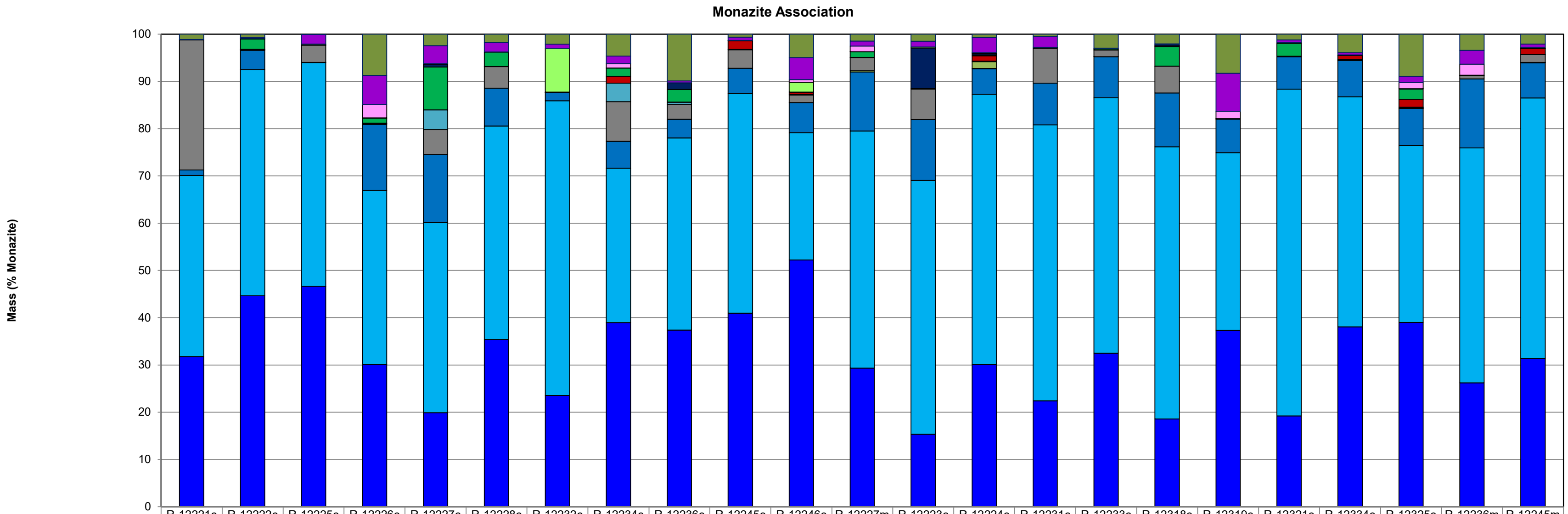
Figure 15: Liberation by Free Surface and Volume of a Mineral

4.6.1. Liberation and Association of Monazite

Pure, free, and liberated monazite ranges from 71% to 97% and avg. 87% in the Sink fractions (Table 15, Figure 16). The non-liberated grains occur as middling particles with ilmenite (nil to 28% and avg. 4%), and minor associations (average <2%) with other minerals. Image grids and particle maps for each group of selected samples are presented in Figure 17.

Table 15: Minimum, Maximum, and Range of Liberation and Association of Monazite

Association/Range	Min	Max	Avg.
Pure Monazite	15.3	52.2	32.2
Free Monazite	26.9	69.1	47.5
Lib Monazite	0.0	14.6	7.7
Mnz:Xenotime	0.0	0.0	0.0
Mnz:Synchysite	0.0	0.1	0.0
Mnz:Pyrochlore/Columbite	0.0	0.0	0.0
Mnz:Spinel	0.0	1.4	0.1
Mnz:Ilmenite	0.0	27.5	3.7
Mnz:Ilmenorutile	0.0	0.0	0.0
Mnz:Rutile	0.0	4.1	0.4
Mnz:Zircon	0.0	1.8	0.4
Mnz:Amph/Pyr/Grt	0.0	9.1	1.3
Mnz:Staurolite	0.0	8.6	0.5
Mnz:Kyanite	0.0	9.3	0.5
Mnz:Quartz/Feldspars	0.0	2.8	0.5
Mnz:Other Minerals	0.0	8.1	1.9
Complex	0.0	9.9	3.2
Liberated	71.3	96.6	87.4



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■ Complex	1.13	0.66	0.04	8.72	2.43	1.81	2.11	4.65	9.88	0.64	4.95	1.47	1.50	0.72	0.54	2.96	2.08	8.27	1.21	3.91	8.88	3.41	2.10
■ Mnz:Other Minerals	0.03	0.24	2.06	6.21	3.79	1.95	0.88	1.57	0.40	0.66	4.68	1.07	1.23	3.20	2.23	0.04	0.18	8.06	0.50	0.47	1.38	2.96	0.68
■ Mnz:Quartz/Feldspars	0.00	0.00	0.00	2.78	0.00	0.00	0.00	0.93	0.00	0.00	0.55	1.19	0.00	0.01	0.02	0.01	0.00	1.53	0.13	0.05	1.27	2.32	0.30
■ Mnz:Kyanite	0.00	0.04	0.19	0.00	0.12	0.00	9.28	0.00	0.00	0.10	2.08	0.00	0.18	0.21	0.00	0.00	0.08	0.03	0.05	0.03	0.01	0.00	0.00
■ Mnz:Staurolite	0.03	0.09	0.02	0.09	0.59	0.04	0.03	0.02	1.42	0.03	0.00	0.00	8.61	0.25	0.03	0.00	0.28	0.01	0.03	0.00	0.05	0.00	0.00
■ Mnz:Amph/Pyr/Grt	0.00	2.16	0.00	1.04	9.08	3.06	0.01	1.73	2.69	0.00	0.01	1.20	0.05	0.17	0.08	0.28	4.12	0.00	2.76	0.03	2.22	0.06	0.00
■ Mnz:Zircon	0.04	0.01	0.02	0.04	0.02	0.01	0.01	1.44	0.00	1.78	0.53	0.01	0.04	1.15	0.01	0.04	0.02	0.01	0.06	0.84	1.66	0.01	1.22
■ Mnz:Rutile	0.00	0.13	0.00	0.05	4.13	0.00	0.01	3.92	0.55	0.08	0.08	0.00	0.02	0.02	0.04	0.02	0.02	0.04	0.04	0.06	0.03	0.00	0.00
■ Mnz:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Ilmenite	27.5	0.08	3.65	0.16	5.28	4.53	0.04	8.41	3.06	3.91	1.58	2.79	6.42	0.11	7.40	1.42	5.65	0.02	0.00	0.15	0.14	0.69	1.66
■ Mnz:Spinel	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.27	0.00	1.41	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01
■ Mnz:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Synchysite	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.02	0.07	0.01	0.07
■ Mnz:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Lib Monazite	1.18	4.08	0.03	14.0	14.4	8.04	1.71	5.70	3.96	5.34	6.40	12.5	12.9	5.40	8.84	8.69	11.4	7.10	6.86	7.70	7.90	14.64	7.46
■ Free Monazite	38.3	47.9	47.3	36.8	40.3	45.2	62.4	32.7	40.6	46.5	26.9	50.1	53.7	57.2	58.4	54.1	57.6	37.6	69.1	48.7	37.4	49.7	55.1
■ Pure Monazite	31.8	44.6	46.7	30.1	19.9	35.4	23.6	39.0	37.4	40.9	52.2	29.3	15.3	30.1	22.4	32.5	18.6	37.3	19.2	38.1	39.0	26.2	31.4

Figure 16: Liberation and Association of Monazite (Mass%) for the Sink Fractions

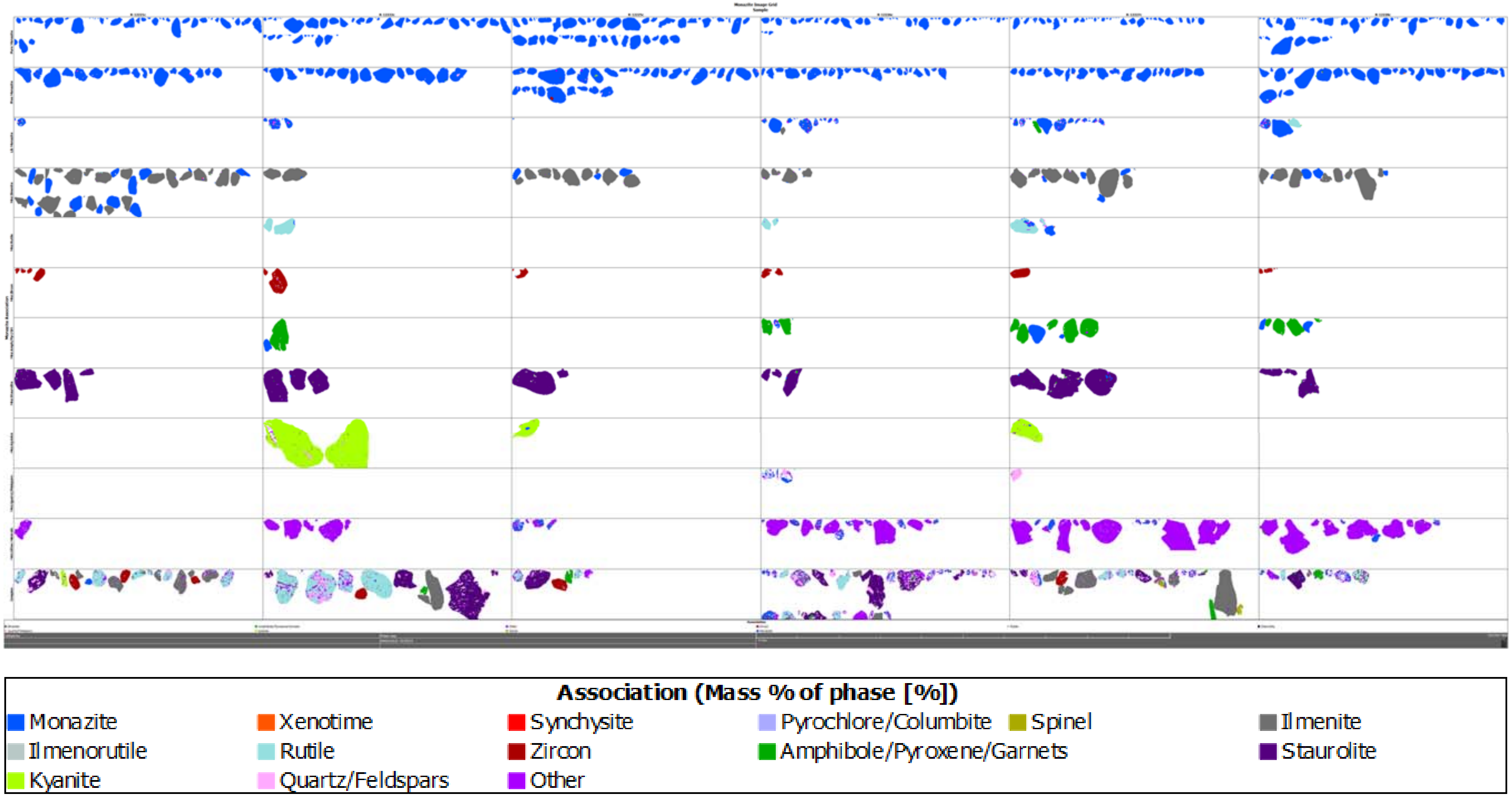


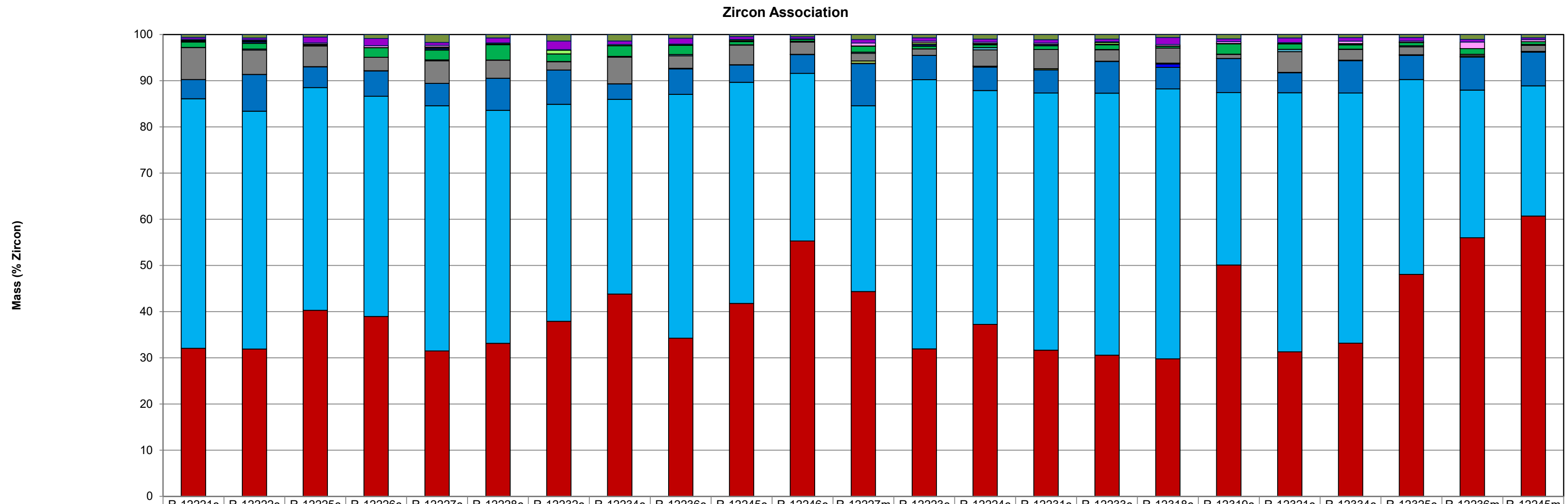
Figure 17: Image Grid and Particle Maps of Monazite Associations for Selected Sink Fractions

4.6.2. Liberation and Association of Zircon

Free and liberated zircon ranges from 89% to 96% and avg. 93% in the Sink fractions (Table 16, Figure 18). The remainder occurs as middling particles with ilmenite (0.3% to 7% and avg. 3%), while other associations average less than 1%. Image grids and particle maps for each group of selected samples are presented in Figure 19.

Table 16: Minimum, Maximum, and Range of Liberation and Association of Zircon

Association/Range	Min	Max	Avg.
Pure Zircon	29.8	60.7	39.4
Free Zircon	28.2	58.5	47.9
Lib Zircon	3.3	9.1	5.8
Zrn:Monazite	0.0	0.7	0.1
Zrn:Xenotime	0.0	0.0	0.0
Zrn:Synchysite	0.0	0.0	0.0
Zrn:Pyrochlore/Columbite	0.0	0.0	0.0
Zrn:Spinel	0.0	0.5	0.1
Zrn:Ilmenite	0.3	6.9	3.2
Zrn:Ilmenorutile	0.0	0.0	0.0
Zrn:Rutile	0.0	0.5	0.1
Zrn:Amph/Pyr/Grt	0.2	3.3	1.2
Zrn:Staurolite	0.0	0.4	0.1
Zrn:Kyanite	0.0	0.8	0.2
Zrn:Quartz/Feldpars	0.0	1.4	0.3
Zrn:Other Minerals	0.4	1.9	0.9
Complex	0.4	1.7	0.8
Liberated	89.3	96.2	93.0



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■ Complex	0.59	0.69	0.52	0.85	1.71	0.70	1.36	1.37	0.79	0.42	0.46	1.06	0.67	0.97	1.10	0.97	0.60	0.92	0.70	0.65	0.60	1.04	0.67
■ Zrn:Other Minerals	0.41	0.44	1.26	1.56	0.62	1.08	1.90	0.77	1.23	0.61	0.46	0.75	0.77	0.67	0.71	0.59	1.54	0.62	1.02	0.79	0.77	0.56	0.43
■ Zrn:Quartz/Feldpars	0.23	0.13	0.27	0.39	0.33	0.11	0.10	0.02	0.02	0.13	0.03	0.64	0.33	0.28	0.28	0.13	0.33	0.37	0.21	0.51	0.30	1.42	0.45
■ Zrn:Kyanite	0.19	0.23	0.01	0.07	0.24	0.20	0.80	0.22	0.12	0.21	0.02	0.08	0.33	0.13	0.01	0.36	0.03	0.06	0.03	0.18	0.02	0.01	0.00
■ Zrn:Staurolite	0.20	0.39	0.12	0.00	0.43	0.08	0.02	0.06	0.19	0.17	0.05	0.00	0.42	0.17	0.33	0.16	0.02	0.00	0.06	0.12	0.01	0.00	0.00
■ Zrn:Amph/Pyr/Grt	1.14	1.25	0.22	2.02	2.15	3.33	1.65	2.29	1.98	0.67	0.43	1.28	0.57	0.58	0.78	1.01	0.40	2.27	1.17	0.93	0.74	1.25	0.60
■ Zrn:Rutile	0.05	0.20	0.04	0.00	0.17	0.01	0.08	0.13	0.26	0.09	0.18	0.23	0.01	0.52	0.00	0.06	0.01	0.04	0.52	0.01	0.21	0.00	0.16
■ Zrn:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
■ Zrn:Ilmenite	6.94	5.28	4.49	2.96	4.89	3.92	1.77	5.82	2.70	4.25	2.64	1.66	1.40	3.52	4.15	2.49	3.24	0.89	4.46	2.34	1.73	0.32	1.31
■ Zrn:Spinel	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.14	0.00	0.05	0.54	0.00	0.00	0.24	0.08	0.19	0.02	0.08	0.09	0.02	0.21	0.02
■ Zrn:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
■ Zrn:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Xenotime	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03
■ Zrn:Monazite	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.03	0.00	0.04	0.02	0.01	0.01	0.17	0.00	0.00	0.72	0.00	0.01	0.02	0.07	0.00	0.09
■ Lib Zircon	4.16	7.96	4.51	5.49	4.86	6.93	7.43	3.33	5.52	3.74	4.05	9.15	5.26	5.11	5.01	6.83	4.68	7.37	4.32	7.03	5.23	7.19	7.30
■ Free Zircon	54.0	51.5	48.2	47.7	53.1	50.5	47.0	42.2	52.8	47.9	36.3	40.2	58.3	50.7	55.7	56.8	58.5	37.4	56.1	54.2	42.2	32.0	28.2
■ Pure Zircon	32.1	31.9	40.3	39.0	31.5	33.1	37.9	43.8	34.2	41.8	55.3	44.4	31.9	37.2	31.6	30.6	29.8	50.1	31.3	33.2	48.1	56.0	60.7

Figure 18: Liberation and Association of Zircon (Mass%) for the Sink Fractions

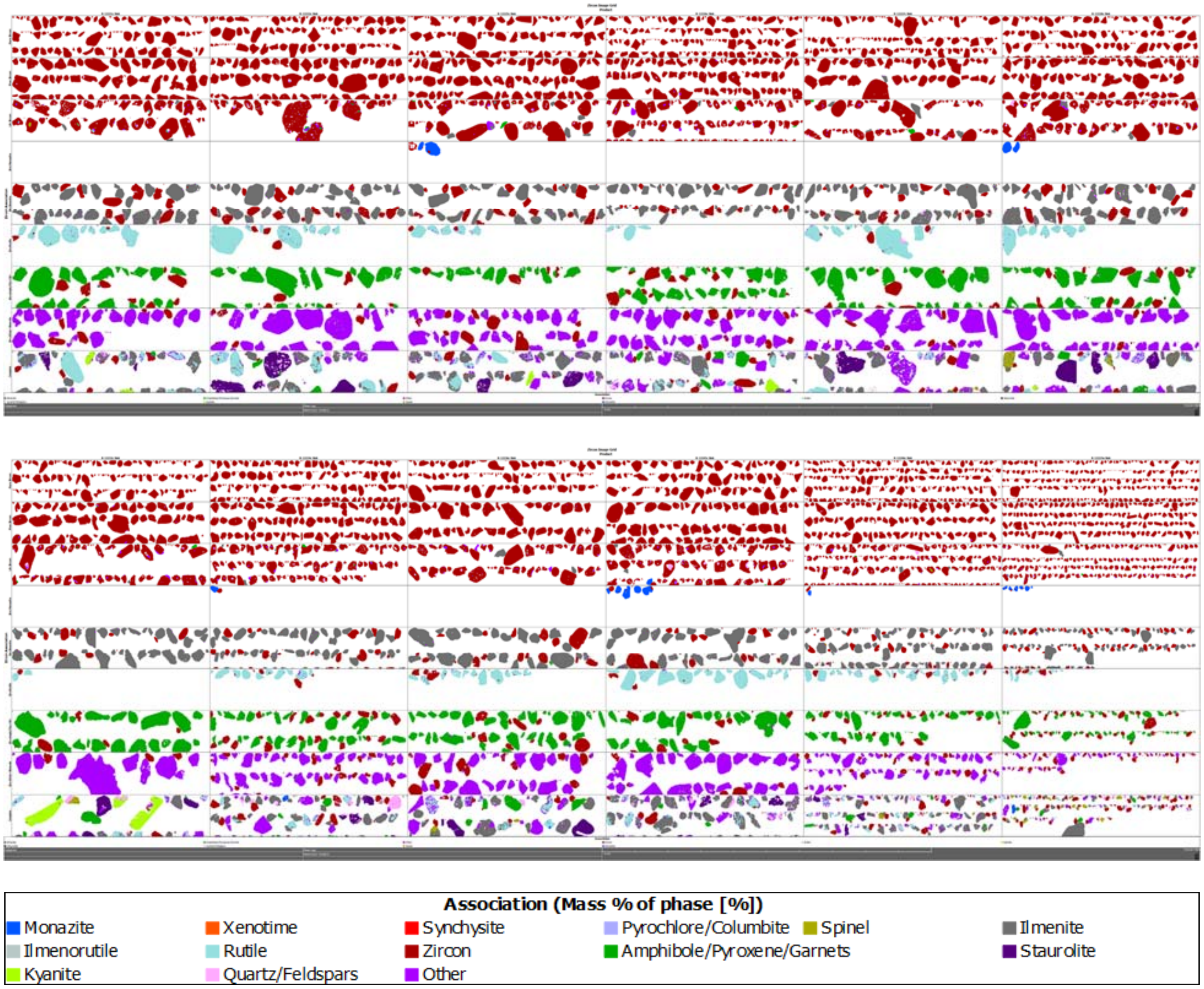


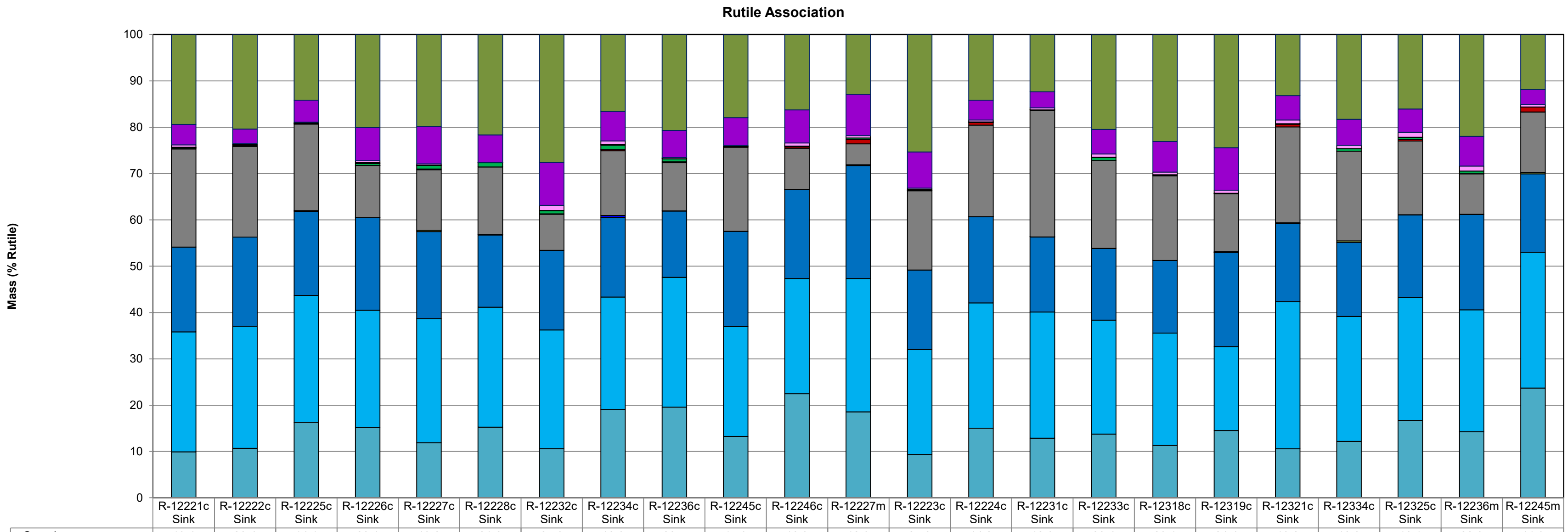
Figure 19: Image Grid and Particle Maps of Zircon Liberation and Association for Selected Sink Fractions

4.6.3. Liberation and Association of Rutile

Free and liberated rutile ranges from 49% to 72% and avg. 59% in the Sink fractions (Table 17, Figure 20). The remainder occurs as middling particles with ilmenite (<5% to 27% and avg. 15%), other minerals (3% to 9% and avg. 6%) and complex particles (12% to 27% and avg. 19%). Image grids for selected Sink fractions are presented in Figure 21.

Table 17: Minimum, Maximum, and Range of Liberation and Association of Rutile

Association/Range	Min	Max	Avg.
Pure Rutile	9.3	23.7	14.7
Free Rutile	18.1	31.8	26.0
Lib Rutile	14.3	24.4	18.0
Rt:Monazite	0.0	0.4	0.0
Rt:Xenotime	0.0	0.0	0.0
Rt:Synchysite	0.0	0.0	0.0
Rt:Pyrochlore/Columbite	0.0	0.0	0.0
Rt:Spinel	0.0	0.3	0.1
Rt:Ilmenite	4.5	27.4	15.4
Rt:Ilmenorutile	0.0	0.0	0.0
Rt:Zircon	0.0	1.0	0.2
Rt:Amph/Pyr/Grt	0.0	1.0	0.4
Rt:Staurolite	0.0	0.1	0.0
Rt:Kyanite	0.0	0.2	0.0
Rt:Quartz/Feldpars	0.1	1.1	0.5
Rt:Other Minerals	3.2	9.3	6.1
Complex	11.9	27.6	18.6
Liberated	49.2	71.7	58.7



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Complex	19.4	20.4	14.1	20.1	19.8	21.6	27.6	16.6	20.7	17.9	16.3	12.9	25.3	14.2	12.3	20.4	23.1	24.4	13.2	18.3	16.1	22.0	11.9
Rt:Other Minerals	4.41	3.16	4.75	7.14	8.13	5.92	9.26	6.30	5.84	6.00	7.14	8.89	7.80	4.30	3.47	5.33	6.59	9.18	5.31	5.62	5.02	6.42	3.29
Rt:Quartz/Feldpars	0.51	0.18	0.15	0.40	0.27	0.06	1.09	0.81	0.26	0.24	0.64	0.52	0.35	0.38	0.43	0.70	0.56	0.66	0.78	0.69	1.07	1.07	0.49
Rt:Kyanite	0.07	0.08	0.11	0.18	0.02	0.05	0.03	0.08	0.01	0.02	0.01	0.00	0.18	0.01	0.02	0.02	0.03	0.00	0.02	0.03	0.03	0.00	0.00
Rt:Staurolite	0.01	0.07	0.08	0.02	0.01	0.00	0.01	0.00	0.00	0.06	0.00	0.00	0.00	0.09	0.00	0.02	0.00	0.00	0.01	0.01	0.02	0.00	0.00
Rt:Amph/Pyr/Grt	0.22	0.21	0.01	0.40	0.83	0.91	0.71	1.01	0.64	0.02	0.17	0.38	0.04	0.05	0.01	0.69	0.22	0.11	0.07	0.54	0.48	0.55	0.02
Rt:Zircon	0.09	0.08	0.11	0.01	0.12	0.00	0.07	0.24	0.20	0.05	0.33	0.90	0.00	0.57	0.00	0.00	0.01	0.01	0.60	0.00	0.31	0.03	1.03
Rt:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Rt:Ilmenite	21.2	19.5	18.7	11.3	13.1	14.5	7.78	14.0	10.4	18.2	8.93	4.47	17.1	19.7	27.4	18.9	18.3	12.5	20.7	19.3	15.9	8.7	13.0
Rt:Spinel	0.00	0.00	0.00	0.00	0.30	0.07	0.00	0.00	0.01	0.00	0.01	0.19	0.01	0.01	0.03	0.01	0.00	0.17	0.07	0.33	0.08	0.03	0.31
Rt:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Monazite	0.00	0.00	0.13	0.00	0.00	0.10	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lib Rutile	18.3	19.3	18.2	20.0	18.8	15.6	17.2	17.2	14.3	20.6	19.2	24.4	17.2	18.6	16.2	15.5	15.7	20.3	16.9	16.0	17.8	20.6	16.9
Free Rutile	25.9	26.4	27.4	25.2	26.8	25.9	25.6	24.3	28.0	23.7	24.9	28.8	22.7	27.0	27.3	24.6	24.3	18.1	31.8	27.0	26.5	26.4	29.3
Pure Rutile	9.92	10.7	16.3	15.2	11.9	15.2	10.6	19.1	19.6	13.2	22.5	18.5	9.34	15.1	12.9	13.8	11.3	14.5	10.6	12.2	16.7	14.2	23.7

Figure 20: Liberation and Association of Rutile (Mass%) for the Sink Fractions

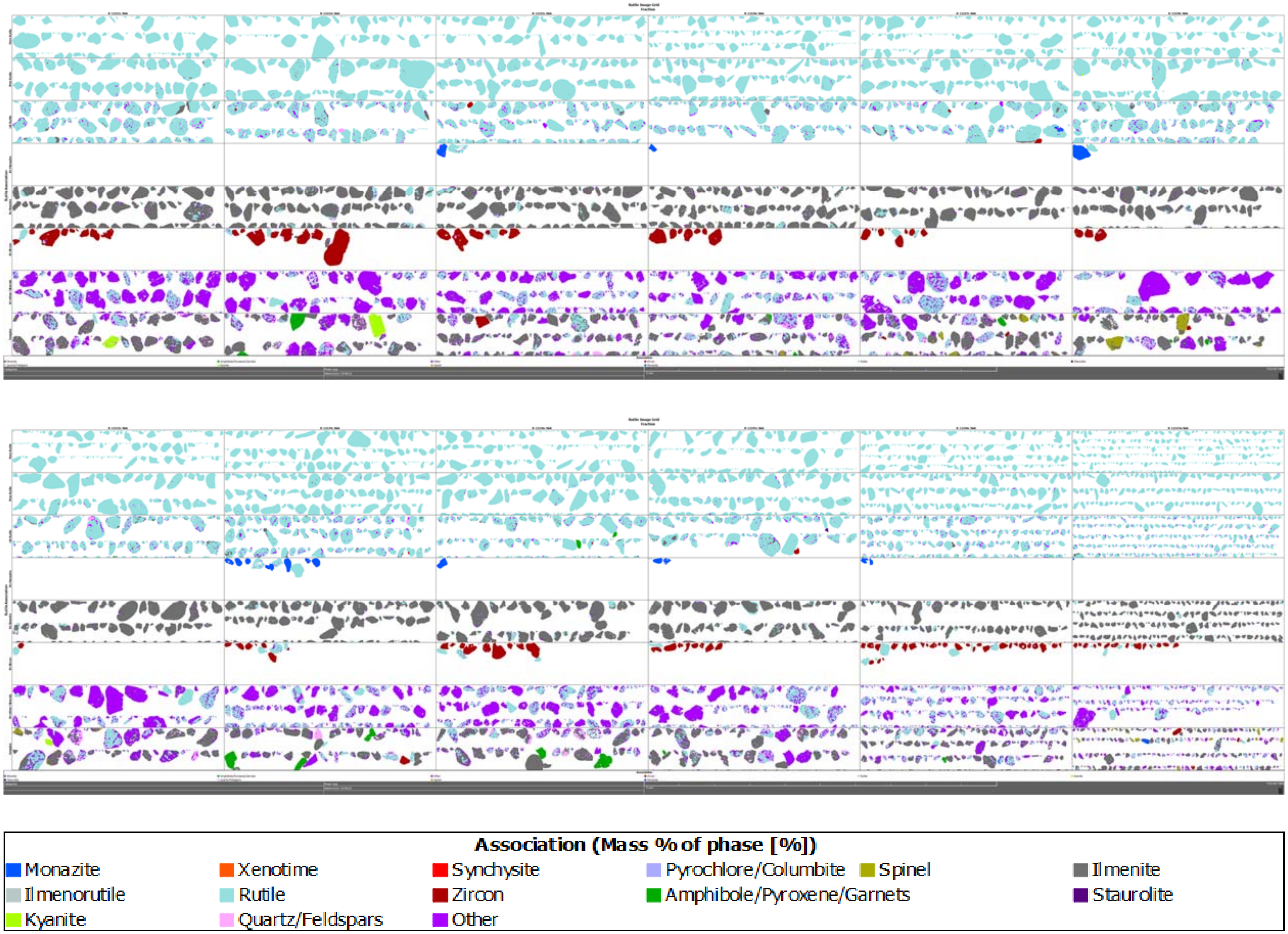


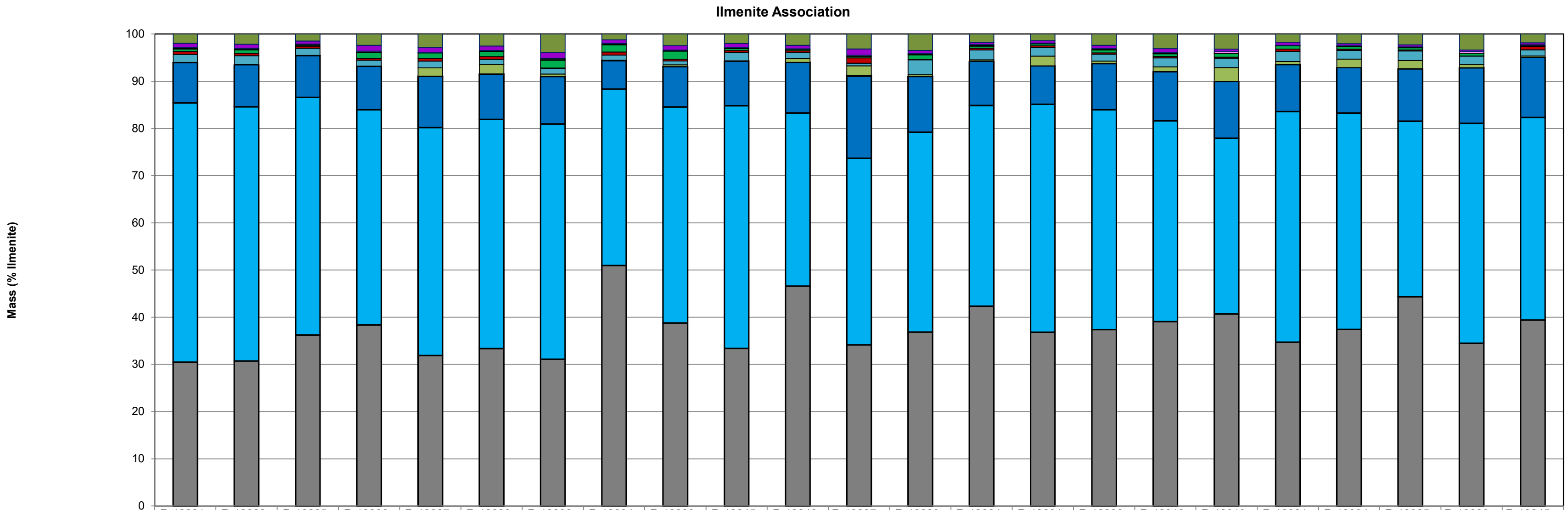
Figure 21: Image Grid of Rutile Liberation and Association for Selected Samples for the Sink Fractions

4.6.4. Liberation and Association of Ilmenite

Free and liberated ilmenite ranges from 90% to 96% and avg. 93% in all Sink fractions (Table 18, Figure 20). The remainder of the ilmenite occurs as complex middling particles (1% to 4% and avg. 2%), while other associations are minor and average <1%. An image grid for selected Sink fractions is presented in Figure 22.

Table 18: Minimum, Maximum, and Range of Liberation and Association of Ilmenite

Association/Range	Min	Max	Avg.
Pure Ilmenite	30.5	51.0	37.4
Free Ilmenite	36.7	55.0	45.4
Lib Ilmenite	6.1	17.4	10.2
Ilm:Monazite	0.0	0.1	0.0
Ilm:Xenotime	0.0	0.0	0.0
Ilm:Synchysite	0.0	0.0	0.0
Ilm:Pyrochlore/Columbite	0.0	0.0	0.0
Ilm:Spinel	0.0	2.9	0.9
Ilm:Ilmenorutile	0.0	0.0	0.0
Ilm:Rutile	0.5	3.2	1.6
Ilm:Zircon	0.0	1.1	0.4
Ilm:Amph/Pyr/Grt	0.2	1.7	0.7
Ilm:Staurolite	0.0	0.2	0.1
Ilm:Kyanite	0.0	0.2	0.0
Ilm:Quartz/Feldspars	0.0	0.4	0.1
Ilm:Other Minerals	0.4	1.3	0.8
Complex	1.2	3.9	2.4
Liberated	90.0	95.5	93.0



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■ Complex	1.99	2.15	1.50	2.37	2.80	2.54	3.86	1.24	2.42	2.03	2.37	3.17	3.46	1.76	1.40	2.36	3.11	3.19	1.72	2.04	2.28	3.37	1.83
■ Ilm:Other Minerals	0.82	0.82	0.62	1.27	1.07	0.90	1.26	0.75	0.98	0.83	0.78	1.32	0.64	0.46	0.51	0.75	0.80	0.57	0.64	0.41	0.45	0.35	0.43
■ Ilm:Quartz/Feldspars	0.14	0.07	0.14	0.21	0.04	0.08	0.09	0.08	0.06	0.09	0.05	0.23	0.15	0.17	0.07	0.11	0.12	0.39	0.06	0.15	0.13	0.33	0.20
■ Ilm:Kyanite	0.09	0.10	0.05	0.03	0.04	0.10	0.21	0.12	0.00	0.06	0.02	0.00	0.08	0.07	0.03	0.05	0.06	0.01	0.02	0.01	0.01	0.01	0.00
■ Ilm:Staurolite	0.16	0.19	0.04	0.02	0.04	0.08	0.11	0.08	0.18	0.09	0.02	0.00	0.06	0.11	0.09	0.12	0.09	0.00	0.09	0.01	0.02	0.00	0.01
■ Ilm:Amph/Pyr/Grt	0.52	0.72	0.24	1.28	1.23	1.08	1.65	1.55	1.71	0.37	0.29	0.32	0.95	0.42	0.44	0.62	0.58	0.74	0.68	0.59	0.48	0.60	0.17
■ Ilm:Zircon	0.61	0.52	0.45	0.38	0.54	0.59	0.15	0.65	0.34	0.43	0.45	1.12	0.12	0.38	0.35	0.28	0.29	0.20	0.47	0.26	0.21	0.04	0.71
■ Ilm:Rutile	1.66	1.86	1.47	1.22	1.41	1.05	1.14	1.07	0.84	1.77	1.19	0.55	3.18	2.09	1.82	1.45	1.90	2.00	2.15	1.83	2.02	1.72	1.29
■ Ilm:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Spinel	0.01	0.05	0.01	0.05	1.73	2.03	0.55	0.03	0.37	0.01	0.82	2.03	0.29	0.26	2.00	0.56	1.00	2.93	0.64	1.81	1.76	0.70	0.26
■ Ilm:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
■ Ilm:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Monazite	0.08	0.00	0.02	0.00	0.02	0.03	0.00	0.03	0.00	0.00	0.01	0.12	0.02	0.00	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.05
■ Lib Ilmenite	8.50	8.91	8.90	9.21	10.9	9.58	10.0	6.08	8.57	9.50	10.7	17.4	11.8	9.39	8.13	9.76	10.4	12.0	9.97	9.64	11.1	11.79	12.7
■ Free Ilmenite	55.0	53.9	50.3	45.6	48.3	48.6	49.9	37.3	45.7	51.4	36.7	39.5	42.4	42.6	48.3	46.6	42.5	37.3	48.8	45.8	37.2	46.6	42.9
■ Pure Ilmenite	30.5	30.7	36.2	38.4	31.9	33.4	31.1	51.0	38.8	33.4	46.6	34.2	36.9	42.3	36.8	37.4	39.1	40.7	34.7	37.4	44.3	34.5	39.4

Figure 22: Liberation and Association of Ilmenite (Mass%) for the Sink Fractions

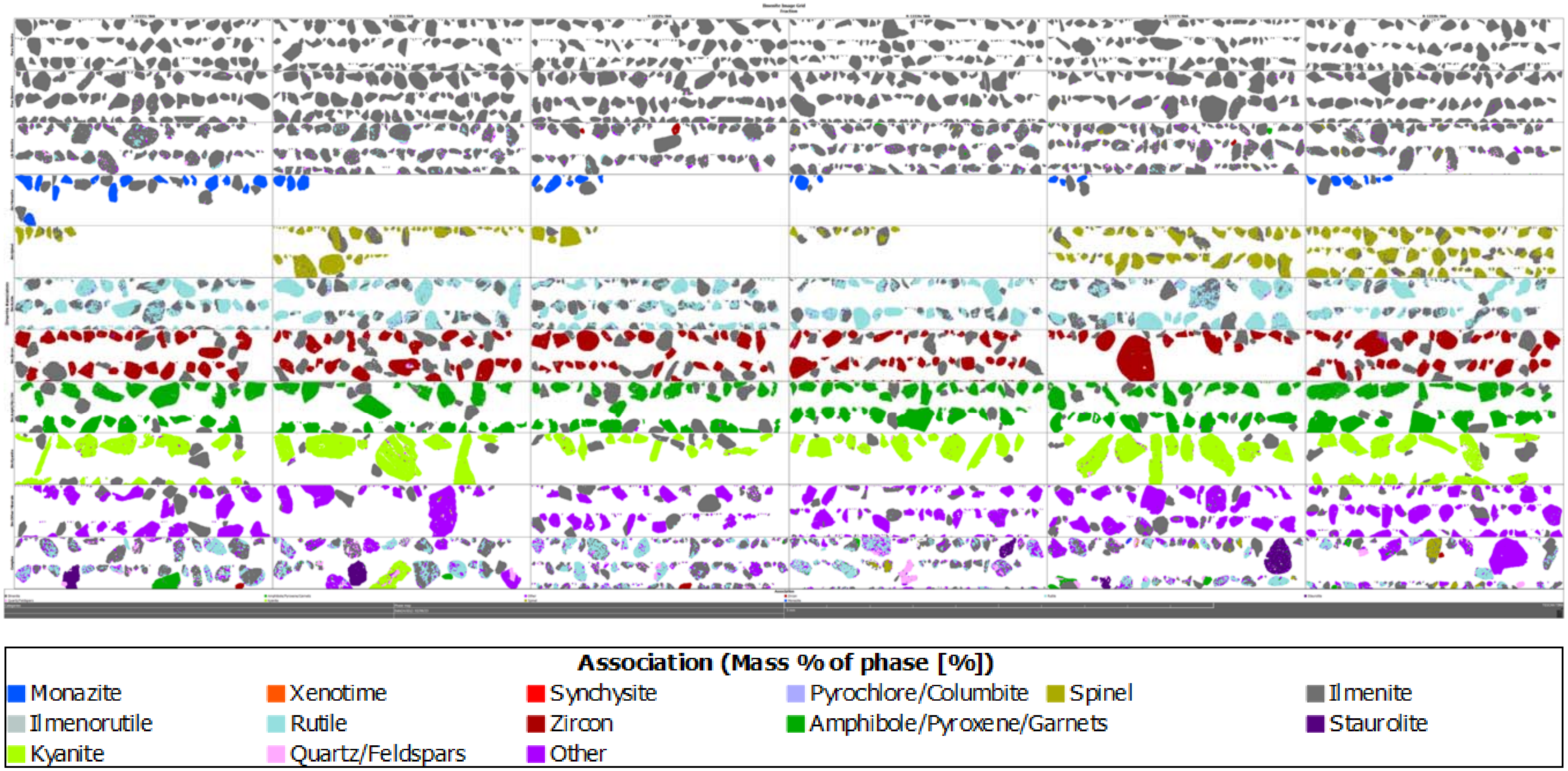
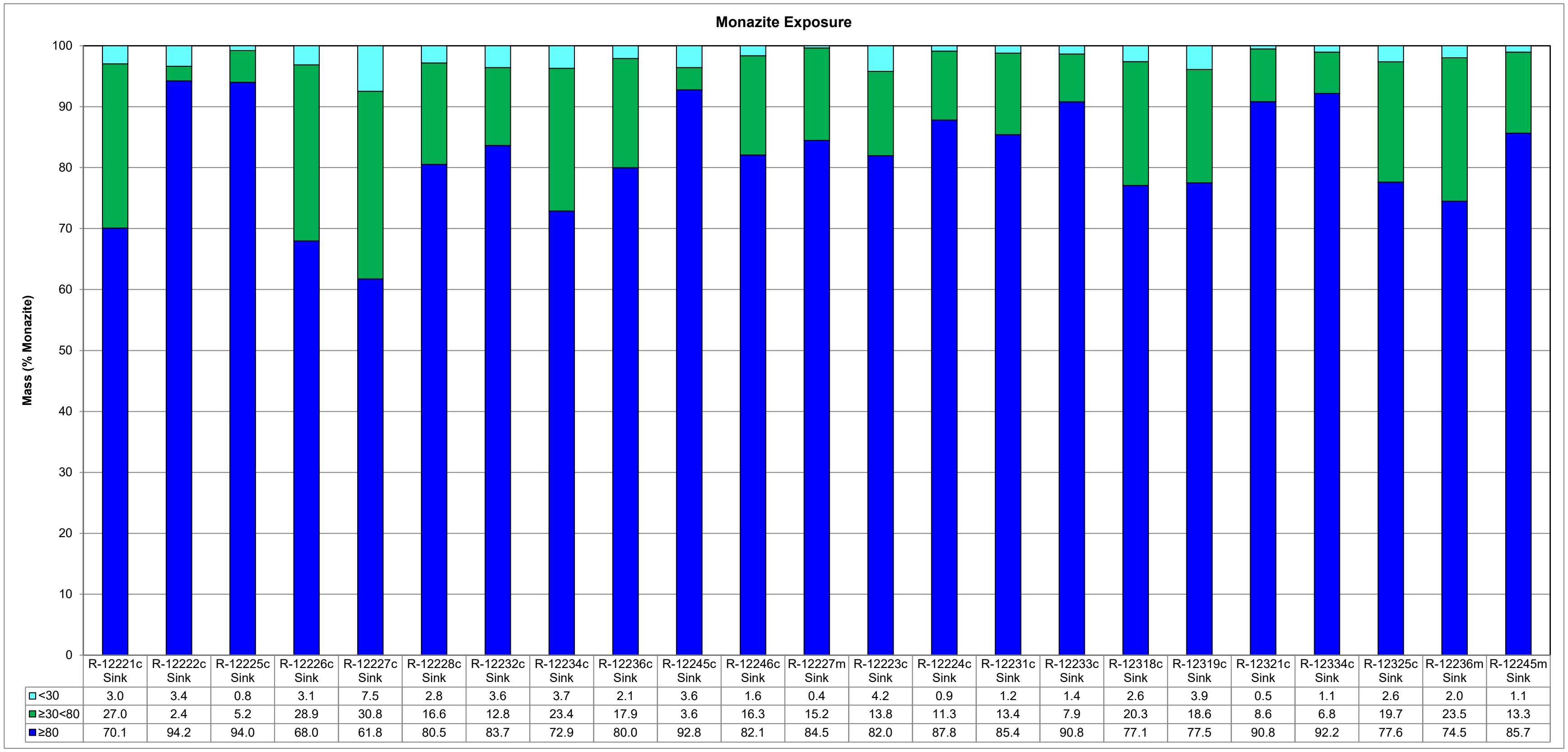


Figure 23: Image Grid Image Grid of Ilmenite Liberation and Association for Selected Samples for the Sink Fractions

4.7. Exposure of Monazite and Xenotime of the Sink Fractions

The exposure characteristics of monazite (Figure 24) illustrate that well-exposed monazite (≥80% exposure) accounts for 62% to 94% and avg. 82%; ≥30<80% exposed monazite for 2% to 31% and avg. 16%, and poorly-exposed monazite (<30% exposure) accounts for <0.5% to 7% and avg. 2%. Note that 30% exposure is empirically defined as the cut-off point for which particles can be recovered (e.g., by flotation and/or possibly gravity).



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
□<30	3.0	3.4	0.8	3.1	7.5	2.8	3.6	3.7	2.1	3.6	1.6	0.4	4.2	0.9	1.2	1.4	2.6	3.9	0.5	1.1	2.6	2.0	1.1
■≥30<80	27.0	2.4	5.2	28.9	30.8	16.6	12.8	23.4	17.9	3.6	16.3	15.2	13.8	11.3	13.4	7.9	20.3	18.6	8.6	6.8	19.7	23.5	13.3
■≥80	70.1	94.2	94.0	68.0	61.8	80.5	83.7	72.9	80.0	92.8	82.1	84.5	82.0	87.8	85.4	90.8	77.1	77.5	90.8	92.2	77.6	74.5	85.7

Figure 24: Exposure of Monazite (Mass%) for the Sink Fractions

5. REE Geochemistry of the Sink Fractions

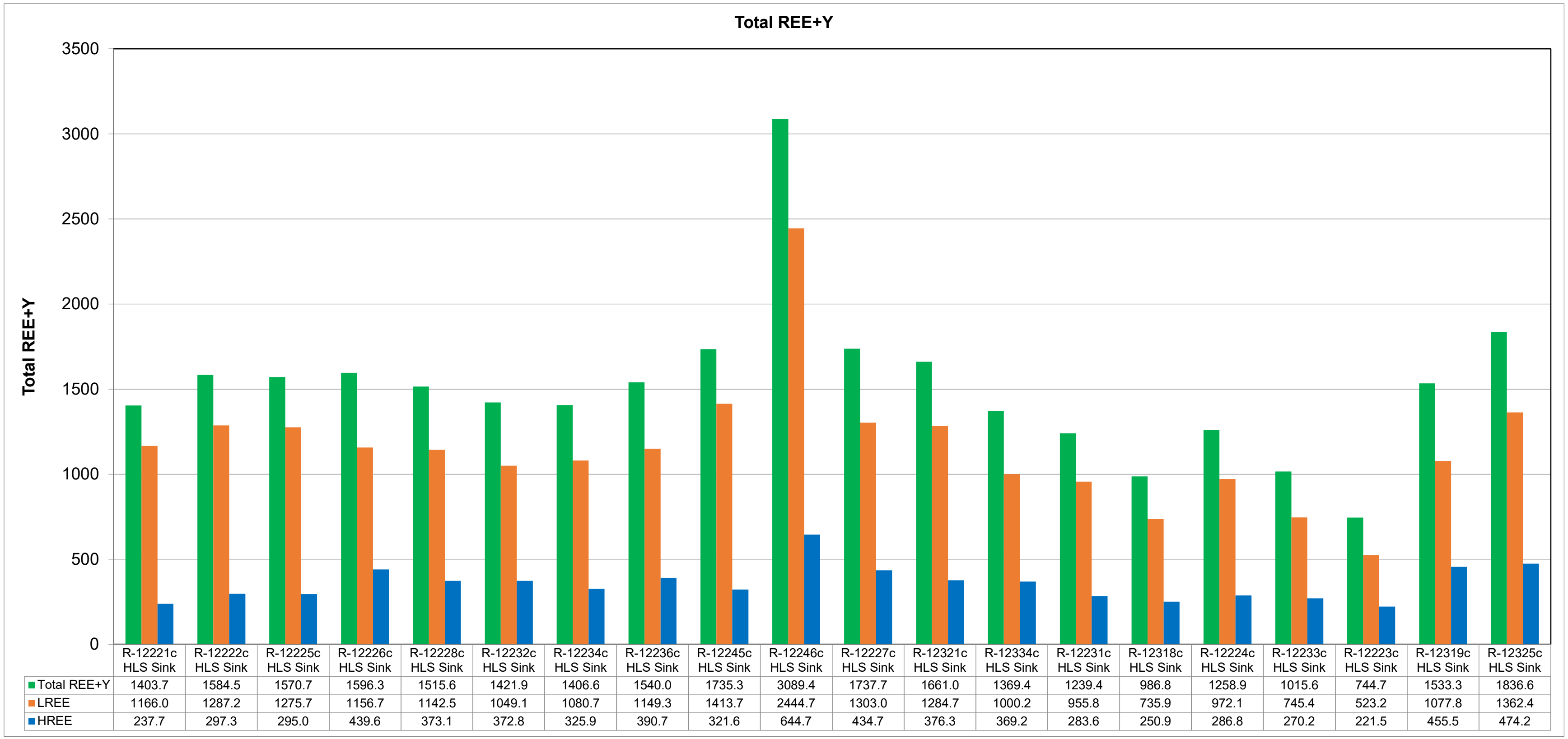
5.1. REE Geochemistry of the Sink Fractions

Table 19 shows the REE and Y concentrations, total REE+Y, LREE, HREE, and LREE/HREE ratios.

Figure 25 illustrates the distribution of total REE+Y, LREE, and HREE. Sample R-12223c yields the lowest total REE+Y at 744.7 ppm, and R-12246c the highest at 3,089.4 ppm, while the rest of the samples yield a total REE+Y below 1,836.6 ppm for the Sink fractions.

Table 19: REE Concentrations (g/t) in the Sink Fractions

Sample ID/Element	La g/t	Ce g/t	Pr g/t	Nd g/t	Sm g/t	Eu g/t	Gd g/t	Tb g/t	Dy g/t	Ho g/t	Er g/t	Tm g/t	Yb g/t	Lu g/t	Y g/t	Total REE+Y	LREE	HREE	LREE/ HREE	U g/t	Th g/t
R-12221c HLS Sink	261	555	64.9	239	46.1	3.4	28.5	3.7	24.2	4.4	16.7	2.8	23.6	4.4	126	1403.7	1166.0	237.7	4.9	24.6	116
R-12222c HLS Sink	275	638	70.3	257	46.9	4.9	31.4	4.4	33.8	5.7	19.7	3.6	26.2	4.6	163	1584.5	1287.2	297.3	4.3	31.9	115
R-12225c HLS Sink	286	606	72	268	43.7	4.1	34	4.6	25.6	6.1	18.8	3.3	27	4.5	167	1570.7	1275.7	295.0	4.3	30.1	123
R-12226c HLS Sink	244	535	63.8	264	49.9	6.5	39.9	6.1	40	10.3	29.9	5.5	39.3	7.1	255	1596.3	1156.7	439.6	2.6	23.9	75.4
R-12228c HLS Sink	245	538	64.3	250	45.2	5.6	41.9	5.5	32.5	7.9	26.3	4.7	30.7	6	212	1515.6	1142.5	373.1	3.1	24.3	89.7
R-12232c HLS Sink	225	490	58.8	232	43.3	6.6	39.6	6	34.8	7.8	26	4.2	32.3	5.5	210	1421.9	1049.1	372.8	2.8	22.2	71.5
R-12234c HLS Sink	217	531	58.9	234	39.8	5.8	33.6	4.8	35.6	6.9	21.4	3.5	26.1	5.2	183	1406.6	1080.7	325.9	3.3	22.5	64.8
R-12236c HLS Sink	233	557	62.4	249	47.9	6.6	38.8	6.3	41.9	8.4	25.5	4.8	34.6	5.8	218	1540.0	1149.3	390.7	2.9	23.9	77.9
R-12245c HLS Sink	303	697	78.3	283	52.4	4.6	38.2	5.3	32.1	6.6	20.9	3.6	25.7	4.6	180	1735.3	1413.7	321.6	4.4	33.8	125
R-12246c HLS Sink	522	1180	133	522	87.7	10.3	72.1	10.1	61.5	14.5	46.5	7.6	55.8	9.3	357	3089.4	2444.7	644.7	3.8	48.9	170
R-12227c HLS Sink	267	639	69.7	279	48.3	6.3	41.3	6.9	47.1	9.5	30.8	5.7	36.1	7	244	1737.7	1303.0	434.7	3.0	26.4	82.1
R-12321c HLS Sink	319	560	73.3	288	44.4	5.7	38.8	11.6	36.6	8.2	23.9	4	30.6	4.9	212	1661.0	1284.7	376.3	3.4	25.8	104
R-12334c HLS Sink	200	446	62.4	248	43.8	5.4	34.3	5.6	36.6	7.9	25.1	4	30.6	4.7	215	1369.4	1000.2	369.2	2.7	20.8	78.5
R-12231c HLS Sink	194	447	61.1	214	39.7	3.1	29.4	4.6	27.1	6.2	20	3.5	25.1	4.6	160	1239.4	955.8	283.6	3.4	21	102
R-12318c HLS Sink	131	361	44	170	29.9	3.9	24.9	3.7	28.2	5.7	15.5	3.1	22.9	4	139	986.8	735.9	250.9	2.9	15.8	70.6
R-12224c HLS Sink	191	452	61.1	223	45	4.7	31.3	4.2	29.2	6	19.3	3.7	25.7	4.7	158	1258.9	972.1	286.8	3.4	24.8	98
R-12233c HLS Sink	140	340	47	185	33.4	3.2	30.6	4.3	24.1	6.1	19.7	3.5	22.7	4	152	1015.6	745.4	270.2	2.8	19	73.3
R-12223c HLS Sink	89	232	36.3	141	24.9	4	19.6	3.1	21.6	5.2	15.6	2.6	19.7	3.1	127	744.7	523.2	221.5	2.4	13.3	49.5
R-12319c HLS Sink	187	509	66.6	267	48.2	6	42.3	7.3	50.1	9.5	31.3	5.3	33.7	6	264	1533.3	1077.8	455.5	2.4	21.1	58.3
R-12325c HLS Sink	254	647	82.3	323	56.1	7.1	45.2	7.7	51.2	10.2	33	5.6	38.4	6.8	269	1836.6	1362.4	474.2	2.9	29.9	96.9



	R-12221c HLS Sink	R-12222c HLS Sink	R-12225c HLS Sink	R-12226c HLS Sink	R-12228c HLS Sink	R-12232c HLS Sink	R-12234c HLS Sink	R-12236c HLS Sink	R-12245c HLS Sink	R-12246c HLS Sink
🟩 Total REE+Y	1403.7	1584.5	1570.7	1596.3	1515.6	1421.9	1406.6	1540.0	1735.3	3089.4
🟧 LREE	1166.0	1287.2	1275.7	1156.7	1142.5	1049.1	1080.7	1149.3	1413.7	2444.7
🟦 HREE	237.7	297.3	295.0	439.6	373.1	372.8	325.9	390.7	321.6	644.7

	R-12227c HLS Sink	R-12321c HLS Sink	R-12334c HLS Sink	R-12231c HLS Sink	R-12318c HLS Sink	R-12224c HLS Sink	R-12233c HLS Sink	R-12223c HLS Sink	R-12319c HLS Sink	R-12325c HLS Sink
🟩 Total REE+Y	1737.7	1661.0	1369.4	1239.4	986.8	1258.9	1015.6	744.7	1533.3	1836.6
🟧 LREE	1303.0	1284.7	1000.2	955.8	735.9	972.1	745.4	523.2	1077.8	1362.4
🟦 HREE	434.7	376.3	369.2	283.6	250.9	286.8	270.2	221.5	455.5	474.2

Figure 25: Total REE+Y, LREE, and HREE for the Sink Fractions

Chondrite normalized plots (REE+Y) are shown for all the Sink fractions in Figure 26. All the samples show enriched LREE and lower but flat HREE, lower Y, and a pronounced negative europium anomaly.

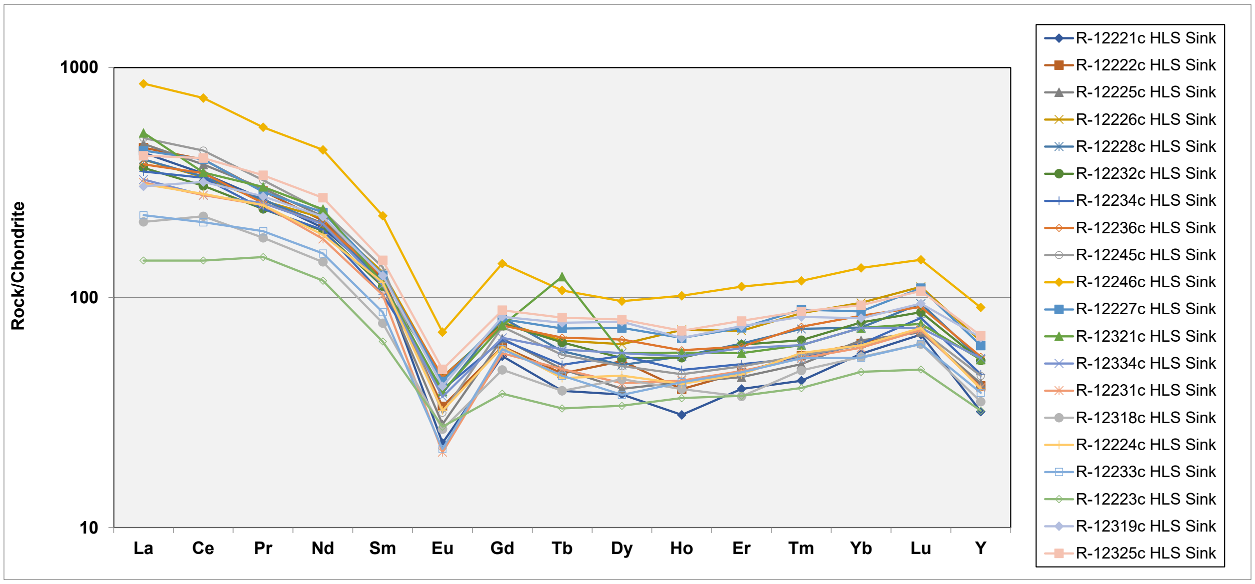


Figure 26: Primitive Mantle-Normalized Spider Diagram for the Sink Fractions

Primitive mantle composition is from Hofmann (1988)

5.2. Bulk Geochemistry of the Sink Fractions

Table 20 shows some of the major elements in the Sink fractions. Iron and titanium illustrate the presence of ilmenite and rutile, and zirconium that of zircon. Silicon is mainly below 16% in all samples. This indicates the presence of various silicate minerals as either attachments or as heavy silicates above the density split point of 2.9 g/cc.

Table 20: Selected Elemental Concentrations in the Sink Fractions

Sample ID	Zr g/t	Nb g/t	Ta g/t	Al g/t	Ca g/t	Cr g/t	Fe g/t	K g/t	Mg g/t	Mn g/t	Si g/t	Ti g/t	V g/t	Zn g/t	Sc g/t	Na g/t	P g/t
R-12221c HLS Sink	23300	615	34	41400	27400	453	204000	1540	6190	8670	101000	192000	392	468	45	2200	523
R-12222c HLS Sink	26000	544	31	46000	33700	531	206000	1870	10900	8390	97500	178000	415	447	48	1740	469
R-12225c HLS Sink	31800	625	34	33800	23500	563	221000	1190	4980	9270	82400	212000	439	472	46	1800	469
R-12226c HLS Sink	22900	400	22	54500	32200	828	193000	1980	22100	7040	125000	133000	358	322	59	2680	972
R-12228c HLS Sink	23900	387	21	50100	32400	858	219000	2060	18400	7210	111000	142000	431	339	55	2680	736
R-12232c HLS Sink	17500	331	18	59300	51200	668	179000	3120	25600	6110	134000	111000	372	317	57	3860	1860
R-12234c HLS Sink	21400	440	20	48800	38200	762	196000	2320	21900	6680	112000	147000	391	316	53	3490	1800
R-12236c HLS Sink	21100	364	18	51000	42800	702	196000	2920	24300	6870	122000	128000	373	331	58	3470	2110
R-12245c HLS Sink	28000	602	33	45700	31800	494	208000	1500	7570	8720	84200	199000	430	518	49	2160	700
R-12246c HLS Sink	38500	557	32	35300	25600	769	216000	1760	8530	7260	80200	196000	490	433	71	2180	788
R-12227c HLS Sink	23500	392	22	49000	32700	842	202000	2850	19400	6700	125000	128000	390	332	69	2690	947
R-12321c HLS Sink	22600	375	32	51400	36100	621	194000	2330	14800	7370	118000	147000	420	404	49	2960	1200
R-12334c HLS Sink	17400	275	22	51100	43000	651	192000	3800	20400	5870	150000	105000	368	< 300	44	5190	2080
R-12231c HLS Sink	25300	493	35	36300	17400	751	238000	1860	8120	8770	85500	188000	462	406	44	2700	472
R-12318c HLS Sink	16600	363	26	61200	40300	620	189000	2470	17200	7050	121000	134000	391	374	53	2880	556
R-12224c HLS Sink	23000	448	33	43000	28600	560	202000	2360	9420	8050	105000	179000	420	436	44	3290	681
R-12233c HLS Sink	20200	403	< 10	54100	34000	675	200000	2600	13800	7680	108000	159000	420	403	48	3410	743
R-12223c HLS Sink	12600	334	24	68900	48800	474	171000	2380	17400	6330	128000	127000	407	389	54	3220	659
R-12319c HLS Sink	16200	203	16	51200	57800	511	178000	4130	25600	4910	161000	78700	331	< 300	46	5220	3430
R-12325c HLS Sink	22700	288	22	50300	44800	548	182000	2850	19700	5930	140000	112000	369	307	50	3610	2540

6. Mineral Chemistry by Electron Probe Micro-Analyses (EPMA)

EPMA were conducted on monazite, xenotime, zircon, ilmenite, and rutile in selected Sink products. The complete results along with representative back-scattered electron images are given in Appendix D.

6.1. Monazite

The detections limits, average mineral chemistry, and minimum (Min) and maximum (Max) oxide concentrations of monazite from the EPMA are shown in Table 21 and Table 22. Monazite is Ce_2O_3, La_2O_3, and Nd_2O_3 rich. The average concentrations of the major oxides including La_2O_3, Ce_2O_3, Pr_2O_3, Nd_2O_3, and Sm_2O_3 in the monazite analyzed are similar among the samples. Note that thorium varies widely but the average ThO_2 concentrations range from 4.48 wt% to 7.34 wt% and UO_2 from 0.29 wt% to 0.71 wt%. Average Y_2O_3 ranges from 0.95 wt% to 1.49 wt%.

Table 21: Average Mineral Chemistry of Monazite from the EPMA

Sample/Oxide	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
LOD	n=226	0.0498	0.0527	0.0065	0.0177	0.0516	0.0625	0.0501	0.0269	0.0263	0.0051	0.0354	0.0344	0.0260	0.0462	0.0070	0.0706	
R-12221c	n=22	6.67	0.71	28.91	1.31	27.93	13.16	3.09	11.49	1.94	0.91	1.17	0.13	0.06	0.39	0.99	0.14	99.00
R-12222c	n=22	6.55	0.58	28.62	0.95	28.37	13.86	3.10	11.49	1.92	0.87	1.11	0.11	0.03	0.28	0.89	0.10	98.84
R-12225c	n=21	5.11	0.59	28.95	1.24	29.02	13.87	3.17	11.70	1.94	0.58	1.21	0.13	0.05	0.37	0.80	0.18	98.88
R-12234c	n=25	4.85	0.53	29.23	1.31	28.24	12.49	3.37	13.43	2.21	0.73	1.22	0.14	0.06	0.38	0.79	0.15	99.14
R-12246c	n=26	4.52	0.59	28.97	1.29	28.82	13.70	3.24	12.38	2.08	0.63	1.23	0.14	0.06	0.40	0.74	0.16	98.96
R-12321c	n=26	7.34	0.63	28.23	1.45	27.61	12.90	3.13	11.97	1.98	1.19	1.21	0.12	0.10	0.45	0.87	0.29	99.47
R-12334c	n=13	4.53	0.33	29.70	1.37	29.14	13.64	3.25	12.49	2.18	0.28	1.26	0.13	0.10	0.44	1.07	0.05	99.95
R-12224c	n=22	5.09	0.29	29.03	1.49	29.11	12.87	3.30	12.91	1.99	0.67	1.14	0.12	0.10	0.43	0.77	0.16	99.45
R-12319c	n=19	4.48	0.31	28.94	1.35	29.27	13.76	3.30	12.61	2.00	0.51	1.03	0.12	0.10	0.43	0.61	0.06	98.87
R-12325c	n=30	5.38	0.35	28.99	1.29	28.42	13.96	3.18	12.30	2.07	0.67	1.14	0.14	0.10	0.44	0.71	0.07	99.20

Table 22: Average Mineral Chemistry of Monazite from the EPMA

n=22	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
R-12221c	Average	6.67	0.71	28.91	1.31	27.93	13.16	3.09	11.49	1.94	0.91	1.17	0.13	0.06	0.39	0.99	0.14	99.00
	StdDev	2.94	0.25	1.17	1.06	1.79	2.07	0.35	1.89	0.56	0.74	0.53	0.07	0.07	0.33	0.36	0.16	0.66
	StdErr	0.63	0.05	0.25	0.23	0.38	0.44	0.07	0.40	0.12	0.16	0.11	0.01	0.01	0.07	0.08	0.03	0.14
	Minimum	0.64	0.24	26.20	0.14	23.85	8.26	2.50	7.60	0.75	0.07	0.32	0.00	-	0.00	0.17	-	97.91
	Maximum	14.24	1.18	30.77	3.58	31.45	17.18	4.20	16.95	3.25	2.41	1.94	0.27	0.18	1.08	1.64	0.63	100.22

n=22	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
R-12222c	Average	6.55	0.58	28.62	0.95	28.37	13.86	3.10	11.49	1.92	0.87	1.11	0.11	0.03	0.28	0.89	0.10	98.84
	StdDev	3.96	0.31	1.39	0.71	2.30	2.39	0.35	2.09	0.62	0.80	0.52	0.06	0.04	0.23	0.48	0.09	0.61
	StdErr	0.84	0.07	0.30	0.15	0.49	0.51	0.07	0.45	0.13	0.17	0.11	0.01	0.01	0.05	0.10	0.02	0.13
	Minimum	0.33	0.03	23.64	0.19	21.10	9.48	2.50	8.83	0.99	0.06	0.45	0.02	-	0.03	0.06	-	97.61
	Maximum	20.64	1.40	30.24	2.82	32.33	18.21	3.84	16.60	4.05	3.87	3.04	0.30	0.13	1.01	2.13	0.29	99.91

n=21	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
R-12225c	Average	5.11	0.59	28.95	1.24	29.02	13.87	3.17	11.70	1.94	0.58	1.21	0.13	0.05	0.37	0.80	0.18	98.88
	Std.Dev.	1.99	0.35	0.84	0.90	1.35	1.11	0.16	1.08	0.43	0.49	0.41	0.05	0.05	0.24	0.27	0.16	0.51
	Std. Err.	0.44	0.08	0.18	0.20	0.29	0.24	0.04	0.24	0.09	0.11	0.09	0.01	0.01	0.05	0.06	0.03	0.11
	Minimum	1.58	0.22	27.24	0.16	26.62	12.32	2.90	9.95	1.14	0.12	0.64	0.05	-	0.06	0.35	0.00	98.08
	Maximum	8.94	1.91	29.96	3.25	31.99	16.50	3.44	13.29	2.64	1.70	1.78	0.22	0.17	0.89	1.34	0.61	99.84

n=25	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
R-12234c	Average	4.85	0.53	29.23	1.31	28.24	12.49	3.37	13.43	2.21	0.73	1.22	0.14	0.06	0.38	0.79	0.15	99.14
	StdDev	3.41	0.34	1.07	0.98	1.91	2.87	0.58	3.53	0.92	0.78	0.61	0.08	0.07	0.27	0.47	0.15	0.55
	StdErr	0.70	0.07	0.22	0.20	0.39	0.59	0.12	0.72	0.19	0.16	0.12	0.02	0.01	0.06	0.10	0.03	0.11
	Minimum	0.14	-	25.99	0.02	23.18	5.38	2.54	8.86	1.12	0.01	0.25	-	-	-	0.11	-	97.93
	Maximum	14.54	1.36	30.45	3.96	31.69	17.36	4.86	23.81	5.25	2.78	2.32	0.28	0.26	0.97	1.62	0.61	100.09

n=26	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
R-12246c	Average	4.52	0.59	28.97	1.29	28.82	13.70	3.24	12.38	2.08	0.63	1.23	0.14	0.06	0.40	0.74	0.16	98.96
	StdDev	2.99	0.39	0.94	1.25	2.05	1.76	0.20	1.33	0.55	0.63	0.48	0.06	0.09	0.31	0.43	0.16	0.57
	StdErr	0.59	0.08	0.18	0.24	0.40	0.34	0.04	0.26	0.11	0.12	0.09	0.01	0.02	0.06	0.08	0.03	0.11
	Minimum	0.09	0.02	26.80	0.08	24.68	11.52	2.81	9.94	0.95	-	0.30	0.05	-	0.00	0.06	-	98.00
	Maximum	11.10	1.54	30.10	5.02	33.87	19.35	3.62	15.49	3.36	2.02	2.01	0.24	0.33	1.05	1.83	0.50	100.13

n=26	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
R-12321c	Average	7.34	0.63	28.23	1.45	27.61	12.90	3.13	11.97	1.98	1.19	1.21	0.12	0.10	0.45	0.87	0.29	99.47
	Std.Dev.	3.41	0.48	1.72	1.40	2.85	2.52	0.33	1.66	0.54	1.08	0.61	0.08	0.09	0.39	0.34	0.27	0.73
	Std. Err.	0.67	0.09	0.34	0.28	0.56	0.49	0.06	0.33	0.11	0.21	0.12	0.02	0.02	0.08	0.07	0.05	0.14
	Minimum	2.00	0.02	24.74	0.22	21.77	7.51	2.18	6.52	0.58	0.12	0.20	0.01	-	0.06	0.18	0.01	98.02
	Maximum	15.24	1.70	30.28	4.75	32.50	17.95	3.61	14.71	3.10	3.56	2.61	0.32	0.29	1.42	1.67	0.77	100.81

n=13	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
R-12334c	Average	4.53	0.33	29.70	1.37	29.14	13.64	3.25	12.49	2.18	0.28	1.26	0.13	0.10	0.44	1.07	0.05	99.95
	StdDev	2.24	0.19	0.45	1.10	1.70	1.09	0.27	1.71	0.48	0.26	0.42	0.05	0.08	0.28	0.59	0.05	0.74
	StdErr	0.62	0.05	0.13	0.30	0.47	0.30	0.07	0.47	0.13	0.07	0.12	0.01	0.02	0.08	0.16	0.01	0.21
	Minimum	0.47	0.04	28.67	0.34	26.43	11.88	2.82	10.23	1.38	0.01	0.41	0.03	0.02	0.10	0.27	-	98.68
	Maximum	7.56	0.57	30.38	3.43	32.04	15.83	3.68	15.28	2.87	0.94	1.91	0.22	0.28	0.93	2.31	0.13	101.34

n=22	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
R-12224c	Average	5.09	0.29	29.03	1.49	29.11	12.87	3.30	12.91	1.99	0.67	1.14	0.12	0.10	0.43	0.77	0.16	99.45
	Std.Dev.	3.29	0.27	1.28	1.01	2.82	2.65	0.34	1.84	0.57	0.82	0.51	0.06	0.07	0.27	0.29	0.18	0.62
	Std. Err.	0.72	0.06	0.28	0.22	0.62	0.58	0.07	0.40	0.12	0.18	0.11	0.01	0.01	0.06	0.06	0.04	0.13
	Minimum	0.27	-	24.76	0.28	22.70	6.80	2.79	10.08	1.11	-	0.37	0.03	0.00	0.09	0.07	-	98.53
	Maximum	15.86	1.10	30.26	3.13	34.42	17.89	4.11	18.45	3.62	3.52	2.15	0.24	0.20	0.98	1.25	0.74	100.68

n=19	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
R-12319c	Average	4.48	0.31	28.94	1.35	29.27	13.76	3.30	12.61	2.00	0.51	1.03	0.12	0.10	0.43	0.61	0.06	98.87
	StdDev	2.13	0.21	0.73	0.99	1.45	1.39	0.21	1.25	0.43	0.45	0.38	0.06	0.07	0.24	0.27	0.08	0.46
	StdErr	0.50	0.05	0.17	0.23	0.34	0.33	0.05	0.29	0.10	0.11	0.09	0.01	0.02	0.06	0.06	0.02	0.11
	Minimum	0.10	-	27.79	0.34	26.49	11.77	2.86	9.53	0.95	0.00	0.14	0.04	0.02	0.09	0.07	-	98.21
	Maximum	8.02	0.80	29.81	3.60	33.35	17.98	3.84	14.43	2.67	1.39	1.63	0.24	0.28	1.00	1.08	0.25	99.74

n=30	Monazite	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
R-12325c	Average	5.38	0.35	28.99	1.29	28.42	13.96	3.18	12.30	2.07	0.67	1.14	0.14	0.10	0.44	0.71	0.07	99.20
	StdDev	3.39	0.31	1.16	0.81	1.95	1.98	0.23	1.51	0.51	0.73	0.48	0.08	0.07	0.26	0.30	0.11	0.51
	StdErr	0.64	0.06	0.22	0.15	0.37	0.37	0.04	0.28	0.10	0.14	0.09	0.01	0.01	0.05	0.06	0.02	0.10
	Minimum	0.62	-	24.85	0.28	22.77	8.46	2.76	9.81	1.30	-	0.52	0.02	0.02	0.08	0.11	-	98.08
	Maximum	18.08	1.25	30.38	3.33	32.39	18.37	3.73	17.05	3.55	3.44	2.34	0.34	0.28	1.04	1.56	0.37	100.34

6.2. Xenotime

The range of mineral chemistry from the EPMA of xenotime are shown in Table 23 and Table 24. The average Y_2O_3 ranges from 38.87 wt% to 43.03 wt%, Gd_2O_3 avg. from 1.31% to 2.90%, Er_2O_3 from 3.73% to 4.80% and Dy_2O_3 from 5.06% to 7.15%. Note the presence of ThO_2 which ranges from 0.03% to 0.45%, and UO_2 from 0.37% to 1.77%. Other REE are below the detection limit (LOD) of the instrument or very low (<1%) in concentration.

Table 23: Average Mineral Chemistry and Detection Limits (LOD) in Oxide wt% for Xenotime from the EPMA

Sample/Oxide	Xenotime	ThO2	UO2	P2O5	Y2O3	Ce2O3	La2O3	Pr2O3	Nd2O3	Sm2O3	SiO2	Gd2O3	Tb2O3	Er2O3	Dy2O3	CaO	PbO	TOTAL
LOD	n=30	0.0498	0.0527	0.0065	0.0177	0.0516	0.0625	0.0501	0.0269	0.0263	0.0051	0.0354	0.0344	0.0260	0.0462	0.0070	0.0706	
R-12221c	n=1	0.05	1.77	32.23	38.87	0.09	0.04	0.07	0.40	0.67	0.40	2.05	0.54	4.56	5.38	0.10	0.52	87.76
R-12222c	n=4	0.14	1.53	33.11	41.85	0.16	0.03	0.05	0.44	0.73	0.41	2.67	0.78	3.73	6.28	0.10	0.26	92.27
R-12225c	n=2	0.05	0.59	33.06	41.25	0.11	0.03	0.04	0.50	0.85	0.14	2.90	0.76	4.22	6.17	0.05	0.29	90.99
R-12234c	n=4	0.45	0.37	33.06	42.40	0.05	0.01	0.02	0.16	0.27	0.31	1.31	0.45	4.64	4.71	0.03	0.44	88.69
R-12246c	n=4	0.09	0.68	32.69	40.72	0.09	0.05	0.03	0.36	0.47	0.18	1.63	0.52	4.80	5.06	0.06	0.44	87.86
R-12334c	n=2	0.04	0.35	34.38	43.03	0.02	0.01	0.02	0.04	0.25	0.29	2.29	0.80	4.13	7.15	0.01	0.22	93.01
R-12224c	n=3	0.16	1.34	33.08	39.64	0.10	0.03	0.08	0.47	0.68	0.30	2.06	0.61	4.45	5.51	0.10	0.25	88.87
R-12319c	n=5	0.03	0.71	34.00	42.16	0.08	0.02	0.08	0.28	0.40	0.26	1.76	0.57	4.46	5.68	0.05	0.36	90.89
R-12325c	n=5	0.07	0.37	34.27	42.86	0.03	0.03	0.08	0.19	0.34	0.20	1.55	0.52	4.66	5.06	0.00	0.28	90.51

Table 24: Range of Mineral Chemistry and Detection Limits (LOD) in Oxide wt% for Xenotime from the EPMA

n=1	Xenotime	ThO_2	UO_2	P_2O_5	Y_2O_3	Ce_2O_3	La_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	SiO_2	Gd_2O_3	Tb_2O_3	Er_2O_3	Dy_2O_3	CaO	PbO	TOTAL
R-12221c	1	0.05	1.77	32.23	38.87	0.09	0.04	0.07	0.40	0.67	0.40	2.05	0.54	4.56	5.38	0.10	0.52	87.76

n=4	Xenotime	ThO_2	UO_2	P_2O_5	Y_2O_3	Ce_2O_3	La_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	SiO_2	Gd_2O_3	Tb_2O_3	Er_2O_3	Dy_2O_3	CaO	PbO	TOTAL
R-12222c	Average	0.14	1.53	33.11	41.85	0.16	0.03	0.05	0.44	0.73	0.41	2.67	0.78	3.73	6.28	0.10	0.26	92.27
	StdDev	0.16	1.78	1.03	1.51	0.05	0.02	0.04	0.04	0.09	0.29	0.41	0.05	0.35	0.52	0.12	0.30	0.41
	StdErr	0.08	0.89	0.51	0.75	0.03	0.01	0.02	0.02	0.04	0.15	0.21	0.03	0.17	0.26	0.06	0.15	0.20
	Minimum	-	-	32.02	40.33	0.09	0.02	0.03	0.41	0.65	0.10	2.33	0.74	3.21	6.00	-	-	91.86
	Maximum	0.31	3.40	34.15	43.62	0.21	0.05	0.11	0.50	0.85	0.74	3.24	0.85	3.91	7.06	0.23	0.55	92.64

n=2	Xenotime	ThO_2	UO_2	P_2O_5	Y_2O_3	Ce_2O_3	La_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	SiO_2	Gd_2O_3	Tb_2O_3	Er_2O_3	Dy_2O_3	CaO	PbO	TOTAL
R-12225c	Average	0.05	0.59	33.06	41.25	0.11	0.03	0.04	0.50	0.85	0.14	2.90	0.76	4.22	6.17	0.05	0.29	90.99
	StdDev	0.07	0.22	0.16	0.39	0.00	0.04	0.02	0.01	0.03	0.01	0.02	0.01	0.08	0.05	0.02	0.02	0.22
	StdErr	0.05	0.16	0.11	0.27	0.00	0.03	0.01	0.01	0.02	0.01	0.01	0.01	0.06	0.04	0.01	0.01	0.16
	Minimum	-	0.43	32.94	40.98	0.11	-	0.03	0.49	0.83	0.13	2.88	0.75	4.16	6.13	0.04	0.27	90.84
	Maximum	0.11	0.75	33.17	41.52	0.11	0.06	0.06	0.50	0.87	0.15	2.91	0.76	4.27	6.20	0.07	0.30	91.15

n=4	Xenotime	ThO_2	UO_2	P_2O_5	Y_2O_3	Ce_2O_3	La_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	SiO_2	Gd_2O_3	Tb_2O_3	Er_2O_3	Dy_2O_3	CaO	PbO	TOTAL
R-12234c	Average	0.45	0.37	33.06	42.40	0.05	0.01	0.02	0.16	0.27	0.31	1.31	0.45	4.64	4.71	0.03	0.44	88.69
	StdDev	0.17	0.20	0.80	2.88	0.05	0.01	0.03	0.22	0.19	0.11	0.55	0.14	0.44	0.83	0.01	0.09	2.15
	StdErr	0.09	0.10	0.40	1.44	0.02	0.00	0.01	0.11	0.09	0.06	0.28	0.07	0.22	0.42	0.01	0.05	1.08
	Minimum	0.19	0.08	32.06	39.82	-	0.00	-	0.02	0.07	0.19	0.51	0.23	4.22	3.49	0.01	0.34	85.46
	Maximum	0.56	0.54	33.96	46.38	0.11	0.02	0.06	0.49	0.52	0.45	1.78	0.53	5.24	5.26	0.04	0.53	89.91

n=4	Xenotime	ThO_2	UO_2	P_2O_5	Y_2O_3	Ce_2O_3	La_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	SiO_2	Gd_2O_3	Tb_2O_3	Er_2O_3	Dy_2O_3	CaO	PbO	TOTAL
R-12246c	Average	0.09	0.68	32.69	40.72	0.09	0.05	0.03	0.36	0.47	0.18	1.63	0.52	4.80	5.06	0.06	0.44	87.86
	Std.Dev.	0.04	0.42	0.44	1.11	0.06	0.03	0.01	0.22	0.27	0.05	0.78	0.20	0.53	1.16	0.04	0.03	3.12
	Std. Err.	0.02	0.21	0.22	0.55	0.03	0.02	0.00	0.11	0.13	0.03	0.39	0.10	0.26	0.58	0.02	0.02	1.56
	Minimum	0.04	0.14	32.13	39.38	0.03	0.01	0.02	0.04	0.08	0.14	0.46	0.22	4.17	3.34	0.01	0.39	83.34
	Maximum	0.12	1.16	33.05	42.09	0.17	0.08	0.04	0.54	0.67	0.25	2.13	0.65	5.46	5.84	0.09	0.47	90.42

n=2	Xenotime	ThO_2	UO_2	P_2O_5	Y_2O_3	Ce_2O_3	La_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	SiO_2	Gd_2O_3	Tb_2O_3	Er_2O_3	Dy_2O_3	CaO	PbO	TOTAL
R-12334c	Average	0.04	0.35	34.38	43.03	0.02	0.01	0.02	0.04	0.25	0.29	2.29	0.80	4.13	7.15	0.01	0.22	93.01
	StdDev	0.05	0.20	0.29	0.39	0.02	0.01	0.02	0.02	0.04	0.19	0.02	0.04	0.10	0.24	0.01	0.00	0.58
	StdErr	0.04	0.14	0.20	0.28	0.02	0.01	0.02	0.02	0.03	0.13	0.01	0.03	0.07	0.17	0.01	0.00	0.41
	Minimum	-	0.21	34.17	42.75	-	-	-	0.03	0.22	0.16	2.28	0.77	4.06	6.98	0.01	0.22	92.61
	Maximum	0.08	0.49	34.58	43.31	0.03	0.02	0.03	0.06	0.27	0.42	2.30	0.83	4.20	7.32	0.02	0.22	93.42

n=3	Xenotime	ThO_2	UO_2	P_2O_5	Y_2O_3	Ce_2O_3	La_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	SiO_2	Gd_2O_3	Tb_2O_3	Er_2O_3	Dy_2O_3	CaO	PbO	TOTAL
R-12224c	Average	0.16	1.34	33.08	39.64	0.10	0.03	0.08	0.47	0.68	0.30	2.06	0.61	4.45	5.51	0.10	0.25	88.87
	StdDev	0.09	0.87	0.35	0.52	0.07	0.03	0.01	0.03	0.01	0.20	0.08	0.01	0.19	0.10	0.04	0.05	0.33
	StdErr	0.05	0.50	0.20	0.30	0.04	0.02	0.00	0.02	0.01	0.12	0.05	0.01	0.11	0.06	0.03	0.03	0.19
	Minimum	0.07	0.38	32.85	39.22	0.05	-	0.07	0.44	0.67	0.09	1.98	0.60	4.24	5.40	0.05	0.20	88.56
	Maximum	0.25	2.08	33.48	40.23	0.18	0.06	0.08	0.50	0.70	0.48	2.14	0.63	4.61	5.61	0.13	0.29	89.23

n=5	Xenotime	ThO_2	UO_2	P_2O_5	Y_2O_3	Ce_2O_3	La_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	SiO_2	Gd_2O_3	Tb_2O_3	Er_2O_3	Dy_2O_3	CaO	PbO	TOTAL
R-12319c	Average	0.03	0.71	34.00	42.16	0.08	0.02	0.08	0.28	0.40	0.26	1.76	0.57	4.46	5.68	0.05	0.36	90.89
	StdDev	0.06	0.36	0.23	1.17	0.07	0.03	0.05	0.23	0.24	0.13	0.28	0.05	0.26	0.51	0.03	0.11	0.56
	StdErr	0.02	0.16	0.10	0.52	0.03	0.01	0.02	0.10	0.11	0.06	0.12	0.02	0.12	0.23	0.02	0.05	0.25
	Minimum	-	0.34	33.72	40.89	-	-	0.01	0.05	0.13	0.16	1.27	0.51	4.04	5.18	-	0.25	89.92
	Maximum	0.13	1.17	34.35	43.91	0.16	0.06	0.12	0.54	0.64	0.49	1.95	0.64	4.69	6.44	0.08	0.52	91.34

n=5	Xenotime	ThO_2	UO_2	P_2O_5	Y_2O_3	Ce_2O_3	La_2O_3	Pr_2O_3	Nd_2O_3	Sm_2O_3	SiO_2	Gd_2O_3	Tb_2O_3	Er_2O_3	Dy_2O_3	CaO	PbO	TOTAL
R-12325c	Average	0.07	0.37	34.27	42.86	0.03	0.03	0.08	0.19	0.34	0.20	1.55	0.52	4.66	5.06	0.00	0.28	90.51
	Std.Dev.	0.08	0.10	0.60	2.11	0.04	0.04	0.03	0.10	0.16	0.07	0.69	0.16	0.15	0.90	0.00	0.05	1.46
	Std. Err.	0.03	0.05	0.27	0.94	0.02	0.02	0.01	0.04	0.07	0.03	0.31	0.07	0.07	0.40	0.00	0.02	0.65
	Minimum	-	0.24	33.35	41.20	-	-	0.04	0.05	0.08	0.13	0.56	0.26	4.45	3.57	-	0.21	88.46
	Maximum	0.18	0.52	34.91	46.34	0.09	0.09	0.13	0.29	0.51	0.32	2.38	0.72	4.85	5.86	0.00	0.33	91.72

6.3. Zircon

The detections limits and minimum, maximum, and average oxide concentrations from the EPMA of zircon are shown in Table 25 and Table 26. The average concentration of ZrO_2 ranges from 65.37 wt% to 66.58 wt% and HfO_2 from 1.20 wt% to 1.42 wt%. Y_2O_3 ranges from 0.01 wt% to 0.16 wt%, while other analyzed rare earth elements and uranium are near or below the detection limits of the instrument.

Table 25: Average Mineral Chemistry and Detection Limits (LOD) in Oxide wt% for Zircon from the EPMA

Sample/Oxide	Zircon	UO2	Y2O3	Ce2O3	La2O3	Nd2O3	SiO2	ZrO2	HfO2	Dy2O3	CaO	P2O5	TOTAL
LOD	n=297	0.0366	0.0119	0.0361	0.0430	0.0186	0.0030	0.0160	0.0143	0.0176	0.0049	0.0036	
R-12221c	n=27	0.05	0.01	0.00	0.01	0.01	32.52	65.88	1.25	0.00	0.00	0.09	99.82
R-12222c	n=27	0.08	0.03	0.00	0.01	0.00	32.52	65.90	1.28	0.00	0.00	0.12	99.95
R-12225c	n=29	0.06	0.04	0.00	0.02	0.01	32.66	65.95	1.27	0.01	0.00	0.10	100.13
R-12234c	n=28	0.04	0.05	0.00	0.01	0.00	32.54	66.21	1.31	0.01	0.00	0.11	100.29
R-12246c	n=30	0.05	0.09	0.00	0.02	0.00	32.67	66.58	1.27	0.01	0.00	0.14	100.83
R-12321c	n=25	0.01	0.14	0.00	0.01	0.01	32.72	65.50	1.26	0.06	0.01	0.12	99.84
R-12334c	n=33	0.02	0.15	0.00	0.01	0.01	32.69	65.77	1.20	0.06	0.00	0.10	100.03
R-12224c	n=26	0.07	0.15	0.00	0.01	0.01	32.46	65.37	1.42	0.06	0.01	0.13	99.70
R-12319c	n=36	0.01	0.16	0.01	0.01	0.01	32.85	66.29	1.30	0.07	0.00	0.11	100.82
R-12325c	n=36	0.02	0.16	0.01	0.01	0.01	32.92	66.29	1.27	0.06	0.02	0.12	100.90

Table 26: Range of Mineral Chemistry and Detection Limits (LOD) in Oxide wt% for Zircon from the EPMA

n=27	Zircon	UO_2	Y_2O_3	Ce_2O_3	La_2O_3	Nd_2O_3	SiO_2	ZrO_2	HfO_2	Dy_2O_3	CaO	P_2O_5	TOTAL
R-12221c	Average	0.05	0.01	0.00	0.01	0.01	32.52	65.88	1.25	0.00	0.00	0.09	99.82
	StdDev	0.03	0.02	0.01	0.01	0.01	0.10	0.51	0.16	0.00	0.01	0.02	0.63
	StdErr	0.01	0.00	0.00	0.00	0.00	0.02	0.10	0.03	0.00	0.00	0.00	0.12
	Minimum	-	-	-	-	-	32.26	64.36	1.00	-	-	0.05	98.16
	Maximum	0.09	0.07	0.03	0.05	0.04	32.71	66.64	1.62	0.01	0.02	0.13	100.71

n=27	Zircon	UO_2	Y_2O_3	Ce_2O_3	La_2O_3	Nd_2O_3	SiO_2	ZrO_2	HfO_2	Dy_2O_3	CaO	P_2O_5	TOTAL
R-12222c	Average	0.08	0.03	0.00	0.01	0.00	32.52	65.90	1.28	0.00	0.00	0.12	99.95
	StdDev	0.05	0.05	0.01	0.02	0.01	0.13	0.47	0.22	0.00	0.00	0.04	0.53
	StdErr	0.01	0.01	0.00	0.00	0.00	0.03	0.09	0.04	0.00	0.00	0.01	0.10
	Minimum	0.03	-	-	-	-	32.13	64.87	0.76	-	-	0.08	98.78
	Maximum	0.28	0.22	0.03	0.05	0.02	32.69	66.73	2.00	0.01	0.01	0.19	100.98

n=29	Zircon	UO_2	Y_2O_3	Ce_2O_3	La_2O_3	Nd_2O_3	SiO_2	ZrO_2	HfO_2	Dy_2O_3	CaO	P_2O_5	TOTAL
R-12225c	Average	0.06	0.04	0.00	0.02	0.01	32.66	65.95	1.27	0.01	0.00	0.10	100.13
	StdDev	0.03	0.07	0.01	0.02	0.01	0.13	0.61	0.16	0.01	0.01	0.04	0.73
	StdErr	0.01	0.01	0.00	0.00	0.00	0.02	0.11	0.03	0.00	0.00	0.01	0.14
	Minimum	0.01	-	-	-	-	32.36	64.76	0.88	-	-	0.05	98.60
	Maximum	0.16	0.30	0.03	0.06	0.02	32.90	67.05	1.60	0.03	0.03	0.23	101.39

n=28	Zircon	UO_2	Y_2O_3	Ce_2O_3	La_2O_3	Nd_2O_3	SiO_2	ZrO_2	HfO_2	Dy_2O_3	CaO	P_2O_5	TOTAL
R-12234c	Average	0.04	0.05	0.00	0.01	0.00	32.54	66.21	1.31	0.01	0.00	0.11	100.29
	StdDev	0.05	0.09	0.01	0.02	0.00	0.16	0.61	0.16	0.01	0.01	0.04	0.62
	StdErr	0.01	0.02	0.00	0.00	0.00	0.03	0.12	0.03	0.00	0.00	0.01	0.12
	Minimum	-	-	-	-	-	31.94	65.05	1.03	-	-	0.05	98.91
	Maximum	0.24	0.47	0.04	0.08	0.02	32.75	67.17	1.74	0.04	0.05	0.24	101.15

n=30	Zircon	UO_2	Y_2O_3	Ce_2O_3	La_2O_3	Nd_2O_3	SiO_2	ZrO_2	HfO_2	Dy_2O_3	CaO	P_2O_5	TOTAL
R-12246c	Average	0.05	0.09	0.00	0.02	0.00	32.67	66.58	1.27	0.01	0.00	0.14	100.83
	StdDev	0.04	0.12	0.01	0.02	0.01	0.16	0.52	0.11	0.01	0.01	0.10	0.47
	StdErr	0.01	0.02	0.00	0.00	0.00	0.03	0.09	0.02	0.00	0.00	0.02	0.09
	Minimum	-	-	-	-	-	32.13	65.17	1.02	-	-	0.07	99.38
	Maximum	0.14	0.49	0.02	0.06	0.02	32.86	67.45	1.52	0.03	0.04	0.57	101.53

n=25	Zircon	UO_2	Y_2O_3	Ce_2O_3	La_2O_3	Nd_2O_3	SiO_2	ZrO_2	HfO_2	Dy_2O_3	CaO	P_2O_5	TOTAL
R-12321c	Average	0.01	0.14	0.00	0.01	0.01	32.72	65.50	1.26	0.06	0.01	0.12	99.84
	StdDev	0.03	0.02	0.01	0.01	0.01	0.16	0.93	0.16	0.01	0.01	0.03	0.88
	StdErr	0.01	0.00	0.00	0.00	0.00	0.03	0.19	0.03	0.00	0.00	0.01	0.18
	Minimum	-	0.10	-	-	-	32.30	63.70	0.92	0.04	-	0.07	98.08
	Maximum	0.14	0.19	0.05	0.04	0.03	32.93	67.26	1.60	0.08	0.04	0.19	101.29

n=33	Zircon	UO_2	Y_2O_3	Ce_2O_3	La_2O_3	Nd_2O_3	SiO_2	ZrO_2	HfO_2	Dy_2O_3	CaO	P_2O_5	TOTAL
R-12334c	Average	0.02	0.15	0.00	0.01	0.01	32.69	65.77	1.20	0.06	0.00	0.10	100.03
	StdDev	0.03	0.03	0.01	0.01	0.01	0.21	1.05	0.19	0.02	0.01	0.02	0.91
	StdErr	0.01	0.01	0.00	0.00	0.00	0.04	0.18	0.03	0.00	0.00	0.00	0.16
	Minimum	-	0.10	-	-	-	31.78	63.96	0.87	0.04	-	0.06	98.15
	Maximum	0.11	0.28	0.02	0.04	0.04	32.99	68.52	1.56	0.10	0.02	0.15	101.84

n=26	Zircon	UO_2	Y_2O_3	Ce_2O_3	La_2O_3	Nd_2O_3	SiO_2	ZrO_2	HfO_2	Dy_2O_3	CaO	P_2O_5	TOTAL
R-12224c	Average	0.07	0.15	0.00	0.01	0.01	32.46	65.37	1.42	0.06	0.01	0.13	99.70
	StdDev	0.17	0.05	0.01	0.01	0.01	0.23	1.26	0.52	0.01	0.02	0.08	0.90
	StdErr	0.03	0.01	0.00	0.00	0.00	0.04	0.25	0.10	0.00	0.00	0.02	0.18
	Minimum	-	0.11	-	-	-	31.67	62.69	0.87	0.03	-	0.06	98.31
	Maximum	0.79	0.34	0.06	0.06	0.04	32.80	67.28	3.06	0.09	0.09	0.50	101.25

n=36	Zircon	UO_2	Y_2O_3	Ce_2O_3	La_2O_3	Nd_2O_3	SiO_2	ZrO_2	HfO_2	Dy_2O_3	CaO	P_2O_5	TOTAL
R-12319c	Average	0.01	0.16	0.01	0.01	0.01	32.85	66.29	1.30	0.07	0.00	0.11	100.82
	StdDev	0.05	0.07	0.01	0.01	0.01	0.15	1.02	0.23	0.02	0.00	0.04	0.84
	StdErr	0.01	0.01	0.00	0.00	0.00	0.03	0.17	0.04	0.00	0.00	0.01	0.14
	Minimum	-	0.12	-	-	-	32.37	62.87	0.71	0.04	-	0.06	98.54
	Maximum	0.28	0.57	0.04	0.04	0.03	33.02	67.88	2.00	0.16	0.00	0.27	101.94

n=36	Zircon	UO_2	Y_2O_3	Ce_2O_3	La_2O_3	Nd_2O_3	SiO_2	ZrO_2	HfO_2	Dy_2O_3	CaO	P_2O_5	TOTAL
R-12325c	Average	0.02	0.16	0.01	0.01	0.01	32.92	66.29	1.27	0.06	0.02	0.12	100.90
	StdDev	0.04	0.03	0.01	0.02	0.01	0.12	0.65	0.21	0.02	0.09	0.08	0.55
	StdErr	0.01	0.00	0.00	0.00	0.00	0.02	0.11	0.03	0.00	0.01	0.01	0.09
	Minimum	-	0.11	-	-	-	32.52	64.70	0.86	0.03	-	0.05	99.35
	Maximum	0.17	0.22	0.03	0.06	0.04	33.08	67.63	2.11	0.10	0.40	0.45	101.93

6.4. Rutile

The detections limits, minimum, maximum, and average mineral chemistry concentrations from the EPMA of rutile are shown in Table 27 and Table 28. The TiO_2 concentration ranges from 97.97 wt% to 100.07 wt% and Nb_2O_5 from 0.06 wt% to 0.50 wt%. The FeO is between 0.23 wt% and 0.61 wt%.

Table 27: Average Mineral Chemistry and Detection Limits (LOD) in Oxide wt% for Rutile from the EPMA

Sample/Oxide	Rutile	Nb_2O_5	SiO_2	TiO_2	SnO_2	FeO	Cr_2O_3	MnO	Al_2O_3	Ta_2O_5	CaO	Na_2O	TOTAL
LOD	n=98	0.01902	0.0029	0.0167	0.0102	0.0056	0.0056	0.0084	0.0041	0.0157	0.0039	0.0100	
R-12221c	n=10	0.29	0.04	98.46	0.04	0.23	0.09	0.00	0.00	0.00	0.01	0.00	99.16
R-12222c	n=11	0.26	0.04	99.74	0.00	0.28	0.07	0.00	-	0.00	0.01	0.01	100.41
R-12225c	n=11	0.25	0.04	99.88	0.01	0.23	0.08	0.00	-	0.00	0.01	0.01	100.51
R-12234c	n=10	0.26	0.07	98.94	0.00	0.23	0.06	-	-	0.00	0.01	-	99.58
R-12246c	n=11	0.50	0.05	98.89	0.09	0.61	0.09	0.00	-	0.00	0.02	-	100.26
R-12321c	n=11	0.36	0.04	99.59	0.01	0.48	0.09	-	0.00	0.02	0.01	-	100.60
R-12334c	n=11	0.47	0.05	100.07	0.01	0.36	0.10	0.00	0.02	0.04	0.01	0.00	101.12
R-12224c	n=12	0.44	0.05	99.62	0.01	0.37	0.10	0.00	0.03	0.02	0.01	-	100.64
R-12319c	n=7	0.20	0.09	97.97	0.01	0.46	0.11	0.02	0.02	0.02	0.04	0.01	98.94
R-12325c	n=4	0.06	0.04	99.41	0.00	0.28	0.05	-	-	0.00	0.01	-	99.86

Table 28: Range of Mineral Chemistry and Detection Limits (LOD) in Oxide wt% for Rutile from the EPMA

n=10	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12221c	Average	0.29	0.04	98.46	0.04	0.23	0.09	0.00	0.00	0.00	0.01	0.00	99.16
	StdDev	0.33	0.00	0.61	0.07	0.18	0.03	0.00	0.00	0.01	0.00	0.01	0.79
	StdErr	0.11	0.00	0.19	0.02	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.25
	Minimum	0.05	0.04	97.63	-	0.05	0.05	-	-	-	0.00	-	98.26
	Maximum	1.20	0.04	99.58	0.18	0.65	0.14	0.00	0.01	0.04	0.02	0.02	100.47

n=11	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12222c	Average	0.26	0.04	99.74	0.00	0.28	0.07	0.00	-	0.00	0.01	0.01	100.41
	StdDev	0.25	0.00	0.79	0.00	0.06	0.03	0.00	-	0.01	0.00	0.01	0.77
	StdErr	0.07	0.00	0.24	0.00	0.02	0.01	0.00	-	0.00	0.00	0.00	0.23
	Minimum	0.07	0.03	98.54	-	0.16	0.03	-	-	-	-	-	99.38
	Maximum	0.90	0.04	100.93	0.00	0.36	0.11	0.01	-	0.04	0.02	0.04	101.80

n=11	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12225c	Average	0.25	0.04	99.88	0.01	0.23	0.08	0.00	-	0.00	0.01	0.01	100.51
	StdDev	0.18	0.00	0.67	0.01	0.14	0.05	0.00	-	0.01	0.01	0.02	0.72
	StdErr	0.06	0.00	0.20	0.00	0.04	0.02	0.00	-	0.00	0.00	0.00	0.22
	Minimum	-	0.04	98.89	-	0.05	-	-	-	-	-	-	99.63
	Maximum	0.47	0.05	101.26	0.04	0.50	0.14	0.01	-	0.02	0.02	0.05	101.84

n=10	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12234c	Average	0.26	0.07	98.94	0.00	0.23	0.06	-	-	0.00	0.01	-	99.58
	StdDev	0.29	0.07	0.81	0.00	0.19	0.04	-	-	0.00	0.01	-	0.65
	StdErr	0.09	0.02	0.26	0.00	0.06	0.01	-	-	0.00	0.00	-	0.21
	Minimum	0.03	0.03	97.63	-	0.07	-	-	-	-	-	-	98.52
	Maximum	0.97	0.25	99.83	0.01	0.67	0.11	-	-	0.00	0.04	-	100.23

n=11	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12246c	Average	0.50	0.05	98.89	0.09	0.61	0.09	0.00	-	0.00	0.02	-	100.26
	Std.Dev.	0.41	0.02	1.51	0.20	0.55	0.12	0.00	-	0.01	0.02	-	0.48
	Std. Err.	0.12	0.01	0.46	0.06	0.17	0.04	0.00	-	0.00	0.00	-	0.14
	Minimum	-	0.04	94.93	-	0.21	-	-	-	-	0.01	-	99.13
	Maximum	1.43	0.10	100.34	0.60	2.07	0.40	0.01	-	0.03	0.04	-	100.97

n=11	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12321c	Average	0.36	0.04	99.59	0.01	0.48	0.09	-	0.00	0.02	0.01	-	100.60
	StdDev	0.59	0.01	1.32	0.01	0.33	0.07	-	0.00	0.05	0.01	-	0.57
	StdErr	0.18	0.00	0.40	0.00	0.10	0.02	-	0.00	0.01	0.00	-	0.17
	Minimum	-	0.03	96.35	-	0.11	0.01	-	-	-	0.00	-	99.42
	Maximum	1.68	0.05	100.92	0.02	1.15	0.23	-	0.00	0.15	0.05	-	101.41

n=11	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12334c	Average	0.47	0.05	100.07	0.01	0.36	0.10	0.00	0.02	0.04	0.01	0.00	101.12
	StdDev	0.57	0.01	1.35	0.03	0.18	0.05	0.00	0.04	0.08	0.01	0.00	0.59
	StdErr	0.17	0.00	0.41	0.01	0.06	0.02	0.00	0.01	0.02	0.00	0.00	0.18
	Minimum	-	0.04	96.32	-	0.19	0.02	-	-	-	0.00	-	99.72
	Maximum	2.04	0.09	101.38	0.10	0.80	0.18	0.01	0.09	0.27	0.03	0.00	101.99

n=12	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12224c	Average	0.44	0.05	99.62	0.01	0.37	0.10	0.00	0.03	0.02	0.01	-	100.64
	StdDev	0.55	0.02	1.05	0.01	0.22	0.08	0.00	0.07	0.04	0.01	-	0.52
	StdErr	0.16	0.01	0.30	0.00	0.06	0.02	0.00	0.02	0.01	0.00	-	0.15
	Minimum	-	0.03	97.32	-	0.12	0.02	-	-	-	0.00	-	99.74
	Maximum	1.83	0.12	101.45	0.02	0.73	0.33	0.00	0.26	0.13	0.03	-	101.83

n=7	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12319c	Average	0.20	0.09	97.97	0.01	0.46	0.11	0.02	0.02	0.02	0.04	0.01	98.94
	StdDev	0.32	0.09	1.85	0.01	0.54	0.11	0.04	0.03	0.04	0.08	0.01	0.99
	StdErr	0.12	0.03	0.70	0.01	0.20	0.04	0.01	0.01	0.02	0.03	0.01	0.38
	Minimum	-	0.04	93.90	-	0.12	0.00	-	-	-	0.00	-	97.15
	Maximum	0.87	0.27	99.28	0.04	1.59	0.32	0.08	0.07	0.11	0.22	0.04	100.31

n=4	Rutile	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12325c	Average	0.06	0.04	99.41	0.00	0.28	0.05	-	-	0.00	0.01	-	99.86
	Std.Dev.	0.07	0.00	1.19	0.00	0.16	0.04	-	-	0.00	0.01	-	1.34
	Std. Err.	0.03	0.00	0.60	0.00	0.08	0.02	-	-	0.00	0.01	-	0.67
	Minimum	-	0.04	98.05	-	0.18	0.01	-	-	-	0.00	-	98.31
	Maximum	0.14	0.04	100.82	0.00	0.51	0.10	-	-	0.00	0.03	-	101.46

6.5. Ilmenite

The detections limits, minimum, maximum, and average mineral chemistry concentrations from the EPMA of ilmenite are shown in Table 29. The TiO_2 concentration ranges from 49.53 wt% to 60.43 wt%, FeO from 35.79 wt% to 47.7 wt%, and Nb_2O_5 from 0.01 wt% to 0.69 wt%.

Table 29: Average Mineral Chemistry and Detection Limits (LOD) in Oxide wt% for Ilmenite from the EPMA

Sample/Oxide	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
LOD	n=132	0.01902	0.0029	0.0167	0.0102	0.0056	0.0056	0.0084	0.0041	0.0157	0.0039	0.0100	
R-12221c	n=11	0.04	0.00	50.67	0.01	45.92	0.08	1.90	0.03	-	0.01	0.03	98.97
R-12222c	n=8	0.69	0.01	60.43	0.11	35.79	0.05	0.81	0.00	0.05	0.01	0.02	98.24
R-12225c	n=8	0.04	0.00	49.98	0.01	46.16	0.01	2.08	-	-	0.01	0.02	98.67
R-12234c	n=10	0.05	0.00	50.57	0.01	45.01	0.00	3.09	-	-	0.01	-	99.06
R-12246c	n=9	0.06	0.00	49.76	0.01	47.08	0.00	1.50	-	-	0.01	-	98.85
R-12321c	n=16	0.01	0.06	51.45	0.01	46.82	0.01	1.49	0.00	0.01	0.02	0.02	100.14
R-12334c	n=18	0.01	0.05	50.95	0.01	47.38	0.05	1.43	0.00	0.01	0.02	0.03	100.29
R-12224c	n=18	0.01	0.05	50.27	0.01	46.33	0.01	2.32	0.00	0.00	0.01	0.03	99.47
R-12319c	n=18	0.03	0.05	49.83	0.01	47.70	0.02	1.34	0.00	0.01	0.01	0.01	99.48
R-12325c	n=16	-	0.04	49.53	0.01	47.52	0.02	1.53	0.00	0.00	0.01	0.01	99.19

Table 30: Range of Mineral Chemistry and Detection Limits (LOD) in Oxide wt% for Ilmenite from the EPMA

n=11	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12221c	Average	0.04	0.00	50.67	0.01	45.92	0.08	1.90	0.03	-	0.01	0.03	98.97
	StdDev	0.05	0.00	1.73	0.00	2.00	0.19	0.89	0.11	-	0.00	0.05	0.38
	StdErr	0.02	0.00	0.52	0.00	0.60	0.06	0.27	0.03	-	0.00	0.01	0.12
	Minimum	-	-	46.18	-	42.98	-	0.31	-	-	0.00	-	98.33
	Maximum	0.15	0.01	52.64	0.01	50.43	0.65	3.34	0.36	-	0.02	0.16	99.54

n=8	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12222c	Average	0.69	0.01	60.43	0.11	35.79	0.05	0.81	0.00	0.05	0.01	0.02	98.24
	StdDev	1.36	0.02	19.56	0.19	20.53	0.13	1.07	0.01	0.13	0.01	0.03	0.88
	StdErr	0.48	0.01	6.92	0.07	7.26	0.05	0.38	0.00	0.04	0.00	0.01	0.31
	Minimum	-	-	45.65	0.00	1.73	-	-	-	-	0.00	-	97.00
	Maximum	3.83	0.04	95.02	0.44	49.83	0.38	3.09	0.03	0.36	0.02	0.08	99.18

n=8	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12225c	Average	0.04	0.00	49.98	0.01	46.16	0.01	2.08	-	-	0.01	0.02	98.67
	Std.Dev.	0.06	0.00	0.98	0.01	0.70	0.02	1.10	-	-	0.00	0.03	0.60
	Std. Err.	0.02	0.00	0.35	0.00	0.25	0.01	0.39	-	-	0.00	0.01	0.21
	Minimum	-	-	48.44	-	45.38	-	0.44	-	-	0.00	-	98.12
	Maximum	0.17	0.01	51.54	0.02	47.51	0.06	3.59	-	-	0.01	0.08	99.96

n=10	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12234c	Average	0.05	0.00	50.57	0.01	45.01	0.00	3.09	-	-	0.01	-	99.06
	StdDev	0.08	0.00	1.56	0.00	7.15	0.00	6.65	-	-	0.00	-	0.40
	StdErr	0.02	0.00	0.49	0.00	2.26	0.00	2.10	-	-	0.00	-	0.13
	Minimum	-	-	48.44	0.00	25.01	-	0.49	-	-	0.00	-	98.56
	Maximum	0.23	0.00	52.81	0.02	48.98	0.01	22.00	-	-	0.01	-	99.91

n=9	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12246c	Average	0.06	0.00	49.76	0.01	47.08	0.00	1.50	-	-	0.01	-	98.85
	Std.Dev.	0.10	0.00	1.54	0.00	2.00	0.00	1.37	-	-	0.01	-	0.42
	Std. Err.	0.03	0.00	0.51	0.00	0.67	0.00	0.46	-	-	0.00	-	0.14
	Minimum	-	-	47.63	-	43.75	-	0.18	-	-	0.00	-	98.39
	Maximum	0.28	0.01	52.06	0.01	49.64	0.01	4.87	-	-	0.02	-	99.70

n=16	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12321c	Average	0.01	0.06	51.45	0.01	46.82	0.01	1.49	0.00	0.01	0.02	0.02	100.138
	StdDev	0.03	0.02	1.43	0.01	1.56	0.01	0.72	0.00	0.01	0.02	0.03	0.54891
	StdErr	0.01	0.01	0.36	0.00	0.39	0.00	0.18	0.00	0.00	0.01	0.01	0.13723
	Minimum	-	0.04	48.23	-	44.41	0.00	0.35	-	-	0.01	-	99.0582
	Maximum	0.13	0.13	53.21	0.02	49.84	0.06	2.92	0.02	0.03	0.10	0.10	101.131

n=18	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12334c	Average	0.01	0.05	50.95	0.01	47.38	0.05	1.43	0.00	0.01	0.02	0.03	100.285
	StdDev	0.03	0.01	1.93	0.01	1.70	0.11	0.90	0.00	0.01	0.01	0.05	0.75167
	StdErr	0.01	0.00	0.45	0.00	0.40	0.03	0.21	0.00	0.00	0.00	0.01	0.17717
	Minimum	-	0.05	46.25	-	44.00	0.00	0.26	-	-	0.00	-	98.5277
	Maximum	0.12	0.07	53.55	0.02	50.02	0.48	3.67	0.01	0.04	0.04	0.20	101.509

n=18	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12224c	Average	0.01	0.05	50.27	0.01	46.33	0.01	2.32	0.00	0.00	0.01	0.03	99.4741
	Std.Dev.	0.03	0.01	2.14	0.01	3.12	0.01	1.96	0.00	0.01	0.01	0.06	0.6494
	Std. Err.	0.01	0.00	0.50	0.00	0.73	0.00	0.46	0.00	0.00	0.00	0.01	0.15306
	Minimum	-	0.04	45.90	-	37.85	0.00	0.61	-	-	0.00	-	98.1727
	Maximum	0.09	0.07	53.63	0.02	50.49	0.03	9.58	0.02	0.02	0.04	0.20	100.145

n=18	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12319c	Average	0.03	0.05	49.83	0.01	47.70	0.02	1.34	0.00	0.01	0.01	0.01	99.48
	StdDev	0.09	0.01	2.52	0.01	2.59	0.01	0.81	0.02	0.01	0.01	0.01	0.77
	StdErr	0.02	0.00	0.59	0.00	0.61	0.00	0.19	0.00	0.00	0.00	0.00	0.18
	Minimum	-	0.04	45.68	0.00	43.50	0.00	0.12	-	-	0.00	-	98.07
	Maximum	0.39	0.06	53.01	0.02	51.55	0.05	2.67	0.06	0.02	0.02	0.03	100.95

n=16	Ilmenite	Nb2O5	SiO2	TiO2	SnO2	FeO	Cr2O3	MnO	Al2O3	Ta2O5	CaO	Na2O	TOTAL
R-12325c	Average	-	0.04	49.53	0.01	47.52	0.02	1.53	0.00	0.00	0.01	0.01	99.19
	Std.Dev.	-	0.00	1.84	0.01	2.01	0.03	1.43	0.00	0.00	0.01	0.02	0.57
	Std. Err.	-	0.00	0.46	0.00	0.50	0.01	0.36	0.00	0.00	0.00	0.01	0.14
	Minimum	-	0.04	46.95	-	44.94	0.00	0.24	-	-	-	-	98.11
	Maximum	-	0.05	52.36	0.02	50.26	0.09	4.94	0.01	0.01	0.02	0.09	100.10

6.6. Iron (Fe) and Titanium (Ti) Deportment

The iron and titanium deportment were calculated based on the mineral mass as determined by TIMA-X and the EPMA for rutile and ilmenite. Theoretical or calculated compositions are used for other Fe and Ti-bearing phases (e.g., amphibole, garnets, etc.).

In the Sink fractions, iron is hosted mainly by ilmenite (35% to 83%), altered ilmenite (5% to 15%), Fe-oxides (nil to 23%), goethite (nil to 18%), amphiboles/pyroxenes (1% to 14%). Chlorite (1% to 16%), epidote (1% to 15%), sulphides (nil to 12%), staurolite (<0.5% to ca. 3%) host the remaining iron, while other minerals account for minor amounts (averaging <1-2%) (Table 31, Figure 27).

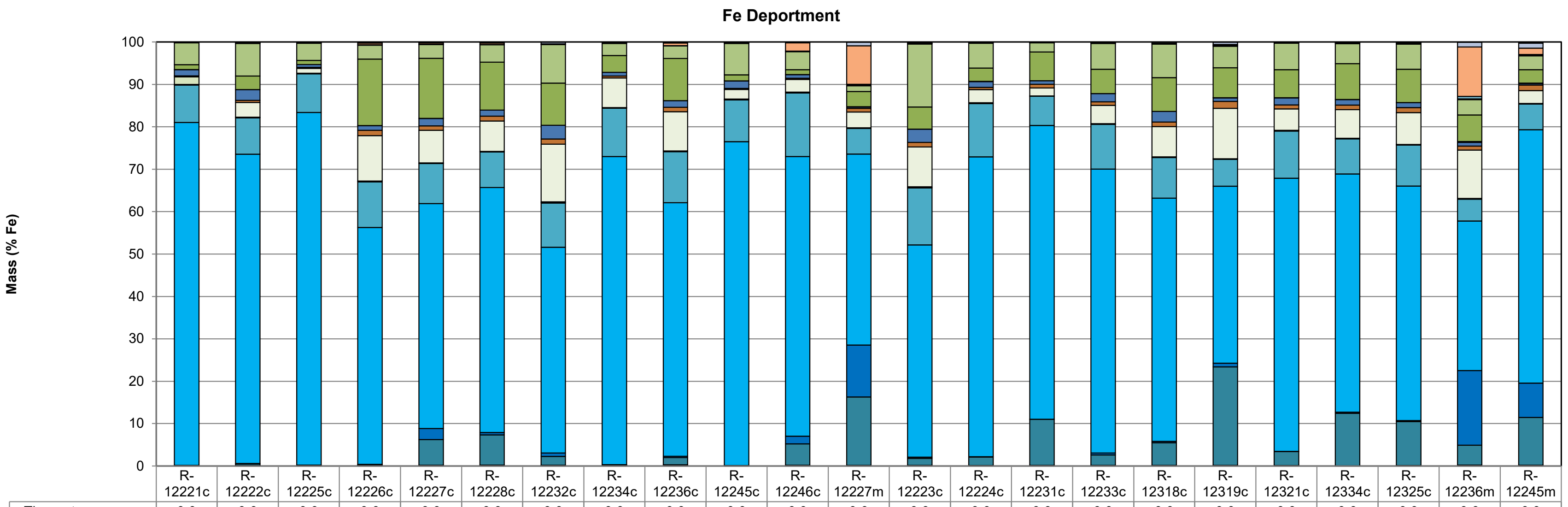
Table 31: Range of Iron Deportment for the Sink Fractions

Modal Mineralogy / Sample	Min	Max	Avg.
Chromite	0.0	0.2	0.1
Spinel	0.0	0.1	0.0
Gahnite	0.0	0.0	0.0
Fe-Oxides	0.0	23.2	5.5
Goethite	0.0	17.6	2.0
Ilmenite	35.3	83.2	60.8
Altered Ilmenite	5.2	15.0	9.6
Rutile	0.0	0.1	0.1
Pseudorutile	0.0	0.2	0.1
Amphibole/Pyroxene	1.2	13.6	6.2
Garnets	0.2	1.6	0.9
Staurolite	0.3	3.2	1.4
Biotite	0.0	0.2	0.0
Chlorite	1.0	15.7	6.3
Epidote	1.4	14.9	5.3
Ti Silicates	0.1	0.2	0.1
Carbonates	0.0	0.6	0.1
Sulphides	0.0	11.7	1.2
Schorl	0.1	1.2	0.3
Other	0.0	0.2	0.0
The rest	0.0	0.0	0.0

Table 32: Range of Titanium Deportment for the Sink Fractions

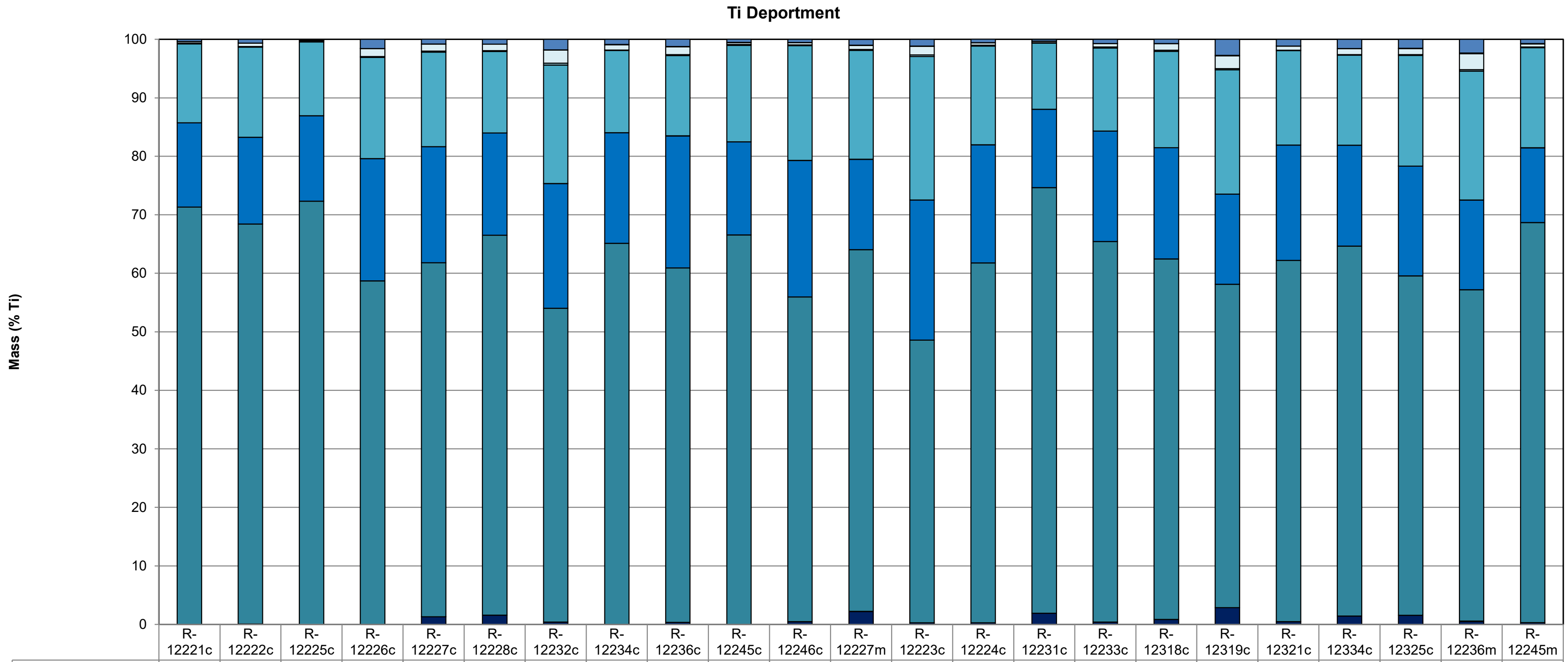
Modal Mineralogy / Sample	Min	Max	Avg.
Spinel	0.0	0.0	0.0
Fe-Oxides	0.0	2.9	0.7
Goethite	0.0	0.1	0.0
Ilmenite	48.3	72.8	62.2
Altered Ilmenite	12.8	23.9	18.0
Ilmenorutile	0.0	0.0	0.0
Rutile	11.3	24.6	16.8
Pseudorutile	0.1	0.3	0.2
Amphibole/Pyroxene	0.2	2.7	1.0
Garnets	0.0	0.1	0.0
Clays	0.0	0.0	0.0
Titanite	0.2	2.8	1.0
The rest	0.0	0.0	0.0

Titanium is hosted mainly by ilmenite (48% to 73%), altered ilmenite (13% to 24%), and rutile (11% to 25%) while other minerals account for minor amounts (averaging <1%) (Table 32, Figure 28).



	R-12221c	R-12222c	R-12225c	R-12226c	R-12227c	R-12228c	R-12232c	R-12234c	R-12236c	R-12245c	R-12246c	R-12227m	R-12223c	R-12224c	R-12231c	R-12233c	R-12318c	R-12319c	R-12321c	R-12334c	R-12325c	R-12236m	R-12245m
▢ The rest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
▢ Other	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
▢ Schorl	0.1	0.1	0.1	0.2	0.2	0.2	0.4	0.1	0.2	0.1	0.2	0.9	0.3	0.1	0.1	0.2	0.3	0.6	0.1	0.2	0.2	1.1	1.2
▢ Sulphides	0.0	0.2	0.0	0.4	0.3	0.3	0.1	0.1	0.6	0.1	2.0	9.0	0.0	0.1	0.0	0.0	0.1	0.2	0.1	0.1	0.2	11.7	1.5
▢ Carbonates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.6	0.2
▢ Ti Silicates	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
▢ Epidote	5.2	7.7	4.0	3.3	3.2	4.1	9.1	2.9	3.0	7.4	4.3	1.4	14.9	5.8	2.2	6.1	8.0	5.1	6.2	4.7	5.9	3.6	3.3
▢ Chlorite	1.2	3.2	1.0	15.7	14.2	11.3	10.0	4.0	10.0	1.4	1.1	3.6	5.2	3.2	6.8	5.8	7.9	7.1	6.6	8.4	7.9	6.3	3.1
▢ Biotite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
▢ Staurolite	1.5	2.6	0.7	1.1	1.7	1.4	3.2	0.8	1.6	1.7	0.8	0.3	3.1	1.4	0.8	1.9	2.5	0.8	1.7	1.3	1.2	0.9	0.3
▢ Garnets	0.2	0.5	0.2	1.3	1.1	1.2	1.2	0.5	1.1	0.3	0.3	0.9	1.1	0.5	0.9	0.9	1.1	1.6	0.9	1.1	1.2	0.9	1.3
▢ Amphibole/Pyroxene	1.8	3.5	1.2	10.7	7.7	7.1	13.6	7.0	9.3	2.3	3.0	3.7	9.4	3.1	1.9	4.3	7.1	11.9	5.0	6.8	7.5	11.4	3.0
▢ Pseudorutile	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
▢ Rutile	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
▢ Altered Ilmenite	8.8	8.6	9.1	10.8	9.4	8.4	10.5	11.4	12.1	9.9	15.0	6.1	13.4	12.6	6.9	10.5	9.6	6.3	11.2	8.3	9.7	5.2	6.0
▢ Ilmenite	80.9	72.9	83.2	55.9	53.0	57.8	48.6	72.7	59.8	76.4	66.0	45.0	50.1	70.7	69.3	67.0	57.4	41.8	64.5	56.2	55.3	35.3	59.8
▢ Goethite	0.0	0.1	0.0	0.0	2.6	0.6	0.8	0.0	0.3	0.0	1.8	12.3	0.3	0.0	0.1	0.5	0.3	0.9	0.0	0.3	0.3	17.6	8.1
▢ Fe-Oxides	0.1	0.4	0.1	0.1	6.1	7.1	2.1	0.1	1.7	0.0	5.1	16.1	1.7	2.1	10.9	2.5	5.4	23.2	3.3	12.4	10.4	4.7	11.3
■ Gahnite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ Spinel	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0
■ Chromite	0.0	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2

Figure 27: Graphical Illustration of Iron Deportment for the Sink Fractions



	R-12221c	R-12222c	R-12225c	R-12226c	R-12227c	R-12228c	R-12232c	R-12234c	R-12236c	R-12245c	R-12246c	R-12227m	R-12223c	R-12224c	R-12231c	R-12233c	R-12318c	R-12319c	R-12321c	R-12334c	R-12325c	R-12236m	R-12245m
■ The rest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ Titanite	0.4	0.6	0.2	1.6	0.8	0.8	1.8	0.9	1.3	0.5	0.6	1.0	1.2	0.6	0.3	0.7	0.7	2.8	1.1	1.6	1.6	2.4	0.7
■ Clays	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
□ Garnets	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0
□ Amphibole/Pyroxene	0.3	0.6	0.2	1.4	1.2	1.1	2.3	0.9	1.4	0.4	0.4	0.7	1.5	0.4	0.3	0.6	1.1	2.2	0.7	1.0	1.1	2.7	0.6
■ Pseudorutile	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.3	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.3	0.1
■ Rutile	13.5	15.4	12.6	17.3	16.2	13.9	20.3	14.0	13.7	16.5	19.6	18.6	24.6	16.9	11.3	14.2	16.5	21.2	16.1	15.4	18.9	22.0	17.1
■ Ilmenorutile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ Altered Ilmenite	14.4	14.9	14.6	20.9	19.9	17.5	21.3	18.9	22.6	15.9	23.3	15.4	23.9	20.2	13.4	18.9	19.0	15.4	19.7	17.2	18.8	15.3	12.8
■ Ilmenite	71.3	68.3	72.3	58.7	60.5	64.9	53.6	65.1	60.6	66.6	55.5	61.8	48.3	61.5	72.8	65.0	61.6	55.2	61.7	63.2	58.0	56.6	68.4
■ Goethite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
■ Fe-Oxides	0.0	0.1	0.0	0.0	1.3	1.6	0.4	0.0	0.3	0.0	0.5	2.2	0.3	0.3	1.9	0.4	0.8	2.9	0.5	1.4	1.6	0.5	0.3
■ Spinel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 28: Graphical Illustration of Titanium Deportment for the Sink Fractions

7. Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)

Samples were analyzed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the University of Ottawa Laser Ablation Lab. The analyses were conducted with:

- A Photon Machines Analyte Excite 193 nm excimer laser, Agilent 7700x ICP-MS
- Data Reduction Software used was LADR v1.1.06
- Gas flow:
    - He carrier gas: 1L/min
    - Ar make up gas: 0.75L/min

Laser Parameters are shown in Table 33.

Table 33: Laser Parameters

Laser Parameters	
Repetition rate (Hz)	15
Spot size (um)	32
Energy (J/cm2)	6.5
Ablation sequence (s) (background – ablation – flush)	20-40-30

Quantification schemes were conducted with internal standard: 29Si, and internal value used: 15.3 wt% Si; primary standard was NIST612; secondary standard was GSE-1G; Zircon 91500.

7.1. Zircon Chemistry

The complete data is presented in Appendix E. The average Y concentration ranges from 560 ppm in R-12221c to 1,341 ppm in R-12246c, Yb 140 ppm in R-12221c to 374 ppm in R-12246c, and Er 81 ppm in R-12221c to 206 ppm in R-12246c (**Table 34**, **Table 35**). LREE are generally below 40 ppm. Th ranges from 55 ppm in R-12321c and R-12319c to 124 ppm in R-12246c, U from 129 ppm in R-12321c to 370 ppm in R-12224c, and Hf from 9,115 ppm in R-12221c to 10,953 ppm in R-12325c.

Chondrite normalized plots (REE+Y) are shown for analyzed zircon grains (Figure 29 to Figure 38). All the samples show depleted LREE and increased HREE and Y.

Box plots for selected elements (U, Th, Hf, and TREE+Y) are shown in Figure 39 to Figure 42. These figures indicate varied differences of the elements across the samples. A linear positive correlation is observed in the plot of Y vs. Dy and Tb (Figure 43 to Figure 44).

The significance of these correlations is not dealt herein but they have to be further explored for petrogenetic and provenance purposes.

Table 34: Average Chemistry from the EPMA (wt%) and from the LA-ICP-MS (ppm) of Zircon

	EPMA (wt%)											
Sample	**Range**	**UO2**	**Y2O3**	**Ce2O3**	**La2O3**	**Nd2O3**	**SiO2**	**ZrO2**	**HfO2**	**Dy2O3**	**CaO**	**P2O5**	**TOTAL**
R-12221c, n=22	Min	0.0	0.0	0.0	0.0	0.0	32.3	64.4	1.0	0.0	0.0	0.1	98.2
	Max	0.1	0.1	0.0	0.1	0.0	32.7	66.6	1.6	0.0	0.0	0.1	100.7
	Avg.	0.0	0.0	0.0	0.0	0.0	32.5	65.9	1.2	0.0	0.0	0.1	99.8
R-12222c, n=21	Min	0.0	0.0	0.0	0.0	0.0	32.2	65.2	1.0	0.0	0.0	0.1	99.3
	Max	0.3	0.2	0.0	0.0	0.0	32.7	66.7	2.0	0.0	0.0	0.2	101.0
	Avg.	0.1	0.0	0.0	0.0	0.0	32.6	66.0	1.3	0.0	0.0	0.1	100.1
R-12225c, n=29	Min	0.0	0.0	0.0	0.0	0.0	32.4	64.8	0.9	0.0	0.0	0.1	98.6
	Max	0.2	0.3	0.0	0.1	0.0	32.9	67.0	1.6	0.0	0.0	0.2	101.4
	Avg.	0.1	0.0	0.0	0.0	0.0	32.7	66.0	1.3	0.0	0.0	0.1	100.1
R-12234c, n=27	Min	0.0	0.0	0.0	0.0	0.0	19.9	43.9	1.0	0.0	0.0	0.0	64.9
	Max	0.2	0.2	0.0	0.1	0.0	32.8	67.2	1.7	0.0	0.0	0.2	101.1
	Avg.	0.0	0.0	0.0	0.0	0.0	32.1	65.4	1.3	0.0	0.0	0.1	99.0
R-12246c, n=28	Min	0.0	0.0	0.0	0.0	0.0	32.1	65.2	1.1	0.0	0.0	0.1	99.4
	Max	0.1	0.5	0.0	0.1	0.0	32.9	67.3	1.5	0.0	0.0	0.6	101.5
	Avg.	0.1	0.1	0.0	0.0	0.0	32.7	66.5	1.3	0.0	0.0	0.1	100.8
R-12224c, n=20	Min	0.0	0.1	0.0	0.0	0.0	32.2	62.7	0.9	0.0	0.0	0.1	98.3
	Max	0.4	0.2	0.1	0.0	0.0	32.8	67.3	3.0	0.1	0.1	0.2	101.3
	Avg.	0.0	0.1	0.0	0.0	0.0	32.5	65.4	1.3	0.1	0.0	0.1	99.6
R-12334c, n=28	Min	0.0	0.1	0.0	0.0	0.0	32.4	64.0	0.9	0.0	0.0	0.1	98.4
	Max	0.1	0.3	0.0	0.0	0.0	33.0	67.0	1.6	0.1	0.0	0.1	101.3
	Avg.	0.0	0.2	0.0	0.0	0.0	32.7	65.8	1.2	0.1	0.0	0.1	100.0
R-12321c, n=20	Min	0.0	0.1	0.0	0.0	0.0	32.3	63.7	0.9	0.0	0.0	0.1	98.1
	Max	0.1	0.2	0.0	0.0	0.0	32.9	67.3	1.5	0.1	0.0	0.2	101.3
	Avg.	0.0	0.1	0.0	0.0	0.0	32.7	65.6	1.3	0.1	0.0	0.1	99.9
R-12319c, n=19	Min	0.0	0.1	0.0	0.0	0.0	32.5	65.1	0.7	0.0	0.0	0.1	99.7
	Max	0.1	0.2	0.0	0.0	0.0	33.0	67.9	1.6	0.1	0.0	0.3	101.9
	Avg.	0.0	0.1	0.0	0.0	0.0	32.8	66.6	1.3	0.1	0.0	0.1	101.0
R-12325c, n=27	Min	0.0	0.1	0.0	0.0	0.0	32.5	64.7	1.0	0.0	0.0	0.1	100.1
	Max	0.2	0.2	0.0	0.1	0.0	33.1	67.6	2.1	0.1	0.4	0.5	101.9
	Avg.	0.0	0.2	0.0	0.0	0.0	32.9	66.3	1.3	0.1	0.0	0.1	101.0

Table 35: Average Chemistry from the EPMA (wt%) and from the LA-ICP-MS (ppm) of Zircon (cont'd)

	LA-ICP-MS Concentration (ppm)																												
Sample	**27Al**	**29Si**	**31P**	**42Ca**	**49Ti**	**57Fe**	**88Sr**	**89Y**	**91Zr**	**93Nb**	**97Mo**	**139La**	**140Ce**	**141Pr**	**146Nd**	**147Sm**	**151Eu**	**157Gd**	**159Tb**	**163Dy**	**165Ho**	**167Er**	**169Tm**	**173Yb**	**175Lu**	**177Hf**	**208Pb**	**232Th**	**238U**
R-12221c, n=22	1.8	153000	220.9	335.9	4.2	4.6	0.2	286.7	414990	1.1	0.9	0.0	2.2	0.0	0.8	0.9	0.1	4.3	1.7	21.8	9.5	27.8	4.1	27.7	5.1	7369.1	1.8	15.3	17.3
	11099.9	153000	1441.7	335.9	2891.0	4379.6	1.6	931.1	508397	5.3	2.3	1.0	22.0	1.1	9.0	10.4	1.9	38.2	10.8	103.0	32.6	135.9	25.8	223.0	42.3	11848.3	33.9	327.5	354.0
	739.1	153000	582.2	335.9	158.0	566.1	0.4	559.7	460439	2.8	1.6	0.1	9.7	0.3	3.3	4.9	0.7	19.2	5.9	58.4	18.9	80.8	16.0	139.8	27.2	9114.8	7.4	73.6	138.6
R-12222c, n=21	1.5	153000	144.3	233.6	6.8	3.2	0.3	291.5	430177	1.3	0.8	0.0	0.5	0.0	0.7	1.6	0.0	7.9	2.5	29.0	10.0	46.0	9.6	81.3	15.3	7687.0	0.5	6.0	9.5
	553.4	153000	1633.7	233.6	180.6	111.3	3.9	1709.8	527243	10.8	2.3	9.8	108.0	15.7	87.7	65.4	23.9	105.3	30.8	259.1	62.1	252.0	46.7	421.3	83.5	14124.8	13.3	157.2	1629.4
	87.3	153000	520.9	233.6	28.2	30.2	0.5	700.5	465293	2.6	1.2	1.0	16.8	1.1	7.4	7.7	1.7	23.2	6.9	73.2	23.8	102.7	20.1	179.7	34.9	9943.7	6.8	79.7	258.8
R-12225c, n=29	3.7	153000	82.7	0.0	6.8	4.1	0.3	52.8	407895	1.0	0.3	0.0	1.1	0.0	0.1	0.1	0.1	0.6	0.2	3.5	2.0	10.0	2.6	32.3	9.5	6661.9	0.7	2.0	21.0
	1723.7	153000	1841.9	0.0	37937.2	767.7	4.6	1668.9	523944	187.5	4.3	1.8	19.2	0.9	12.3	16.6	2.5	61.6	17.1	163.0	57.9	268.6	53.4	472.6	90.8	11683.2	38.8	333.5	971.0
	318.0	153000	485.7	-	1431.5	112.9	0.7	737.3	469586	9.4	1.2	0.3	10.1	0.3	3.5	5.2	0.7	21.5	6.8	72.7	25.6	113.1	22.6	206.1	40.0	9391.1	8.4	74.5	179.5
R-12234c, n=27	4.2	153000	50.0	377.5	2.6	7.4	0.2	240.6	437737	1.0	0.7	0.0	2.1	0.0	0.3	1.2	0.1	7.5	1.9	19.7	7.4	34.4	6.7	54.9	12.0	7936.2	1.2	12.0	24.1
	434.1	153000	616.7	1846.4	1121.7	972.8	45.2	1993.6	544785	18.9	2.4	17.9	103.4	13.1	61.4	27.8	4.8	54.7	17.2	196.6	70.3	311.8	67.4	633.6	120.5	13601.0	44.0	590.7	2029.2
	69.0	153000	231.1	1112.0	69.0	180.5	2.1	789.5	489449	3.8	1.3	1.5	16.7	0.8	4.6	5.1	1.0	20.0	6.5	75.7	27.2	124.2	25.2	229.0	45.2	10295.4	9.5	99.6	228.7
R-12246c, n=28	2.9	153000	69.2	187.8	3.8	5.9	0.2	201.3	389948	0.8	0.3	0.0	1.0	0.0	0.6	0.8	0.0	3.9	1.3	16.6	6.4	33.8	7.3	70.7	15.9	7201.3	0.8	7.5	12.8
	699.4	153000	2042.3	2072.4	166.6	244.5	8.8	4835.7	599138	13.1	1.5	35.9	254.0	42.4	209.1	63.2	15.9	126.3	38.6	447.8	166.6	771.8	162.9	1583.5	273.9	13332.5	53.7	493.2	1363.2
	108.7	153000	464.9	896.3	23.1	58.5	1.1	1340.6	473823	3.8	0.7	3.2	30.9	2.9	18.3	11.8	2.0	36.0	11.4	126.4	45.3	205.6	41.6	374.0	71.1	10108.5	13.3	124.0	246.5
R-12224c, n=20	1.6	153000	192.3	836.8	1.6	5.3	0.2	194.9	216636	0.8	0.4	0.0	2.7	0.0	0.2	1.1	0.1	3.8	1.3	20.2	6.1	30.5	7.6	53.0	8.4	3946.2	1.0	9.4	30.3
	18288.4	153000	816.1	1256.1	69.6	1329.6	26.4	1136.7	583789	71.9	4.4	9.7	61.5	4.3	26.9	13.3	11.1	41.3	12.3	140.9	44.2	212.8	57.8	915.7	279.3	18396.7	40.7	407.7	3248.1
	2066.6	153000	380.7	1046.5	17.4	245.4	1.8	691.3	488132	10.2	0.9	1.3	16.8	0.5	4.6	4.5	1.2	17.3	5.5	66.6	24.0	114.3	25.5	255.4	53.2	9793.7	9.6	105.8	369.7
R-12334c, n=28	2.5	153000	95.0	0.0	1.6	9.5	0.3	300.6	374392	0.8	0.4	0.0	3.1	0.0	0.4	0.8	0.1	5.3	2.1	26.2	9.9	54.1	11.8	104.4	18.7	6729.0	0.5	5.7	7.0
	605.0	153000	497.6	0.0	100.3	441.9	1.7	3432.0	602861	135.5	1.3	2.4	63.0	5.4	40.6	24.1	3.6	77.5	28.3	338.5	124.6	498.9	101.5	779.4	114.2	12776.1	36.0	346.3	469.3
	99.9	153000	257.0	-	26.1	99.2	0.5	847.7	522508	10.7	0.8	0.4	16.3	0.6	5.7	6.3	0.7	24.5	8.0	86.4	30.2	128.2	26.0	231.6	40.6	9361.8	6.7	69.5	147.5
R-12321c, n=20	2.0	153000	169.6	0.0	5.6	98.6	0.2	217.3	433335	1.1	0.7	0.0	3.9	0.0	0.4	0.7	0.1	4.3	1.5	19.1	7.2	35.5	8.4	87.9	14.6	8435.5	0.5	4.0	11.4
	281.6	153000	913.7	0.0	59.0	118.3	0.7	1509.5	618449	9.5	1.4	0.3	24.7	0.8	12.2	14.9	5.6	50.4	13.2	149.4	52.4	277.4	63.3	622.7	128.1	13758.6	14.2	141.5	345.0
	61.3	153000	393.2	-	23.0	108.5	0.4	785.5	510360	3.1	1.0	0.1	10.5	0.2	2.9	4.9	0.8	21.6	7.0	79.5	27.8	125.1	25.7	241.7	44.1	10874.0	5.9	55.2	129.1
R-12319c, n=19	1.8	153000	80.9	0.0	1.7	4.5	0.2	166.3	422351	1.1	0.9	0.0	0.3	0.0	0.5	0.2	0.1	1.7	0.9	16.4	5.6	12.8	1.8	11.8	1.6	4854.3	0.5	6.4	14.1
	118.8	153000	440.7	0.0	40.2	43.6	1.7	1624.9	579529	17.1	1.9	2.7	50.4	3.0	15.4	10.7	2.8	39.9	12.4	148.8	57.1	258.9	55.9	529.9	99.1	12439.3	23.5	190.7	839.8
	30.3	153000	297.3	-	15.1	19.3	0.4	647.9	504712	3.9	1.3	0.3	14.7	0.3	2.8	4.0	0.8	18.2	5.7	63.5	22.6	100.6	21.2	210.4	36.6	9658.4	5.5	54.8	188.9
R-12325c, n=27	1.5	153000	107.9	225.6	2.0	5.3	0.3	245.2	368965	1.4	1.0	0.0	3.3	0.0	0.7	0.8	0.1	2.8	1.0	14.4	6.8	40.9	10.8	118.0	22.1	8351.7	0.6	7.4	8.8
	1538.6	153000	1437.6	1253.6	130.6	229.1	2.8	2159.7	593136	39.1	4.1	8.1	80.8	10.8	65.2	42.2	10.9	71.7	22.6	251.7	92.3	400.0	74.3	840.7	154.2	19073.1	30.5	359.9	2217.4
	173.0	153000	378.3	739.6	22.7	76.6	0.6	936.2	513573	4.7	2.1	0.9	16.3	0.9	7.0	7.3	1.2	26.5	8.5	93.9	33.6	152.6	31.3	282.8	50.8	10953.2	7.6	87.9	317.6

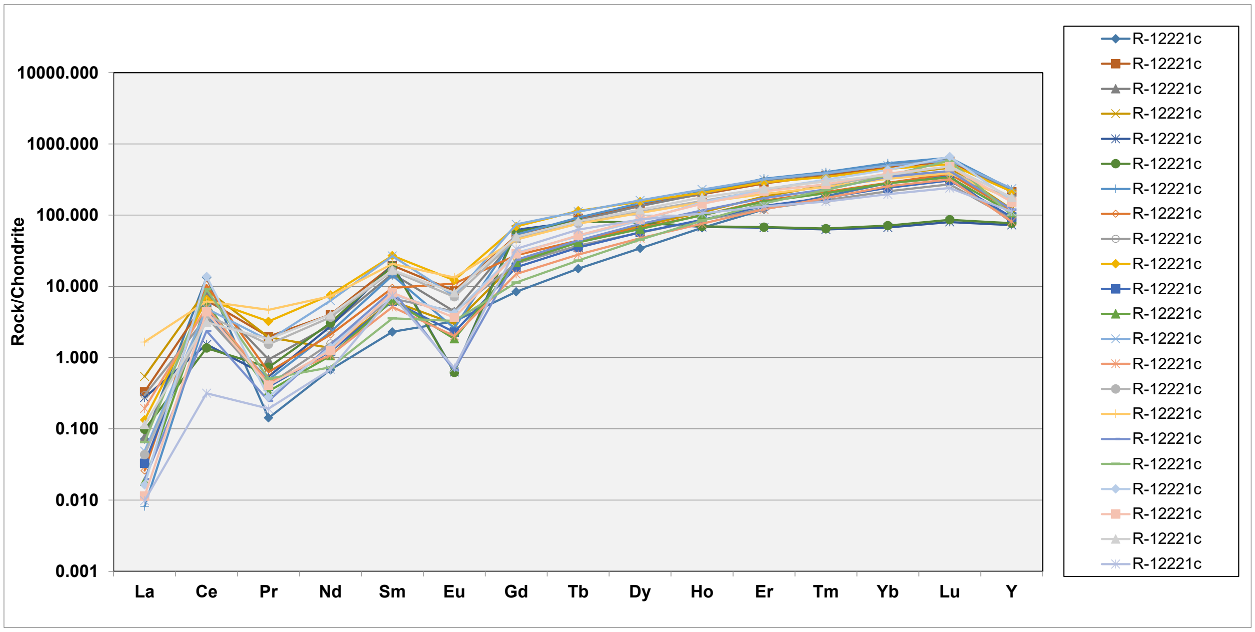


Figure 29: Primitive Mantle-Normalized Spider Diagram for Zircon

Primitive mantle composition is from Hofmann (1988)

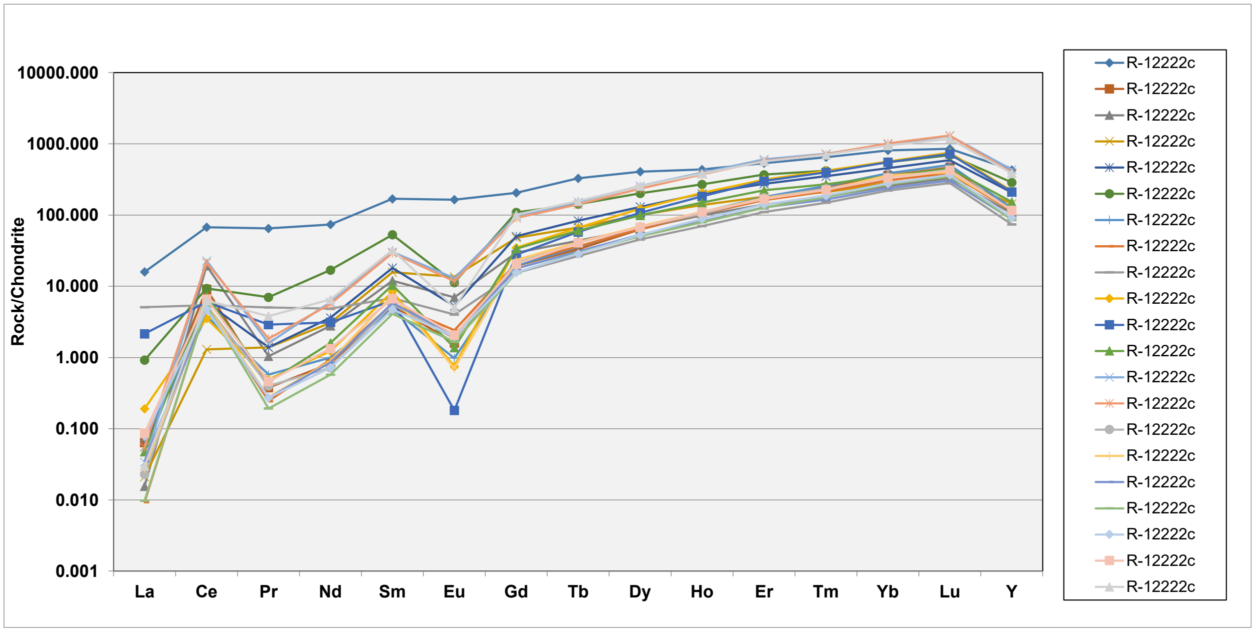


Figure 30: Primitive Mantle-Normalized Spider Diagram for Zircon

Primitive mantle composition is from Hofmann (1988)

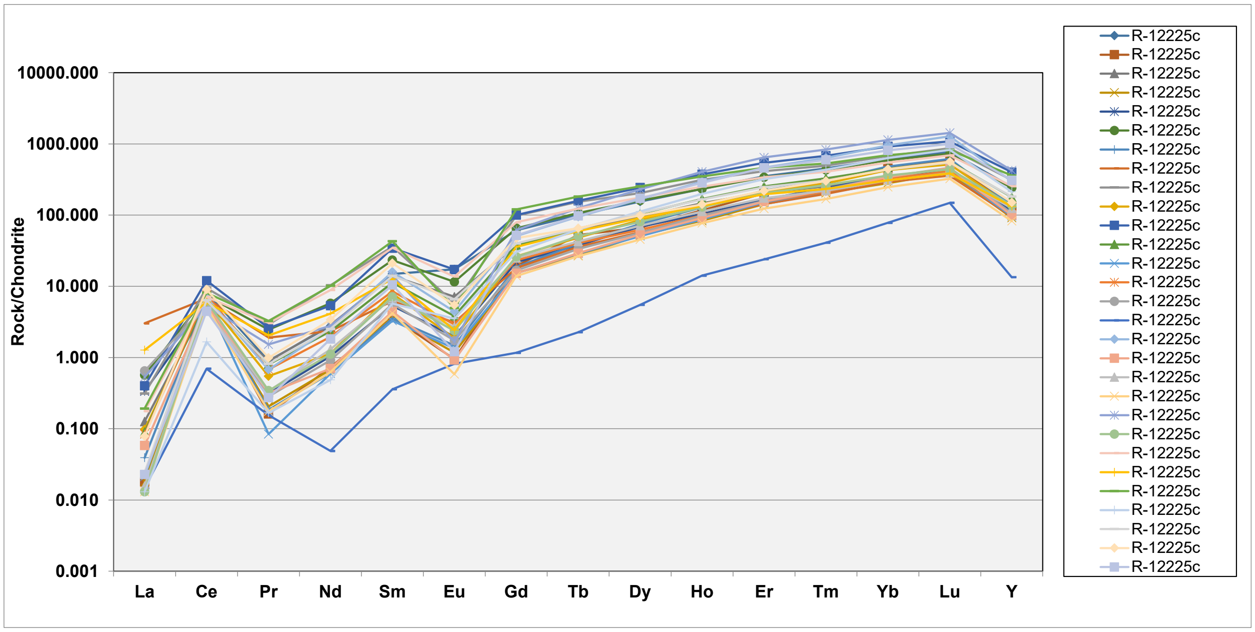


Figure 31: Primitive Mantle-Normalized Spider Diagram for Zircon

Primitive mantle composition is from Hofmann (1988)

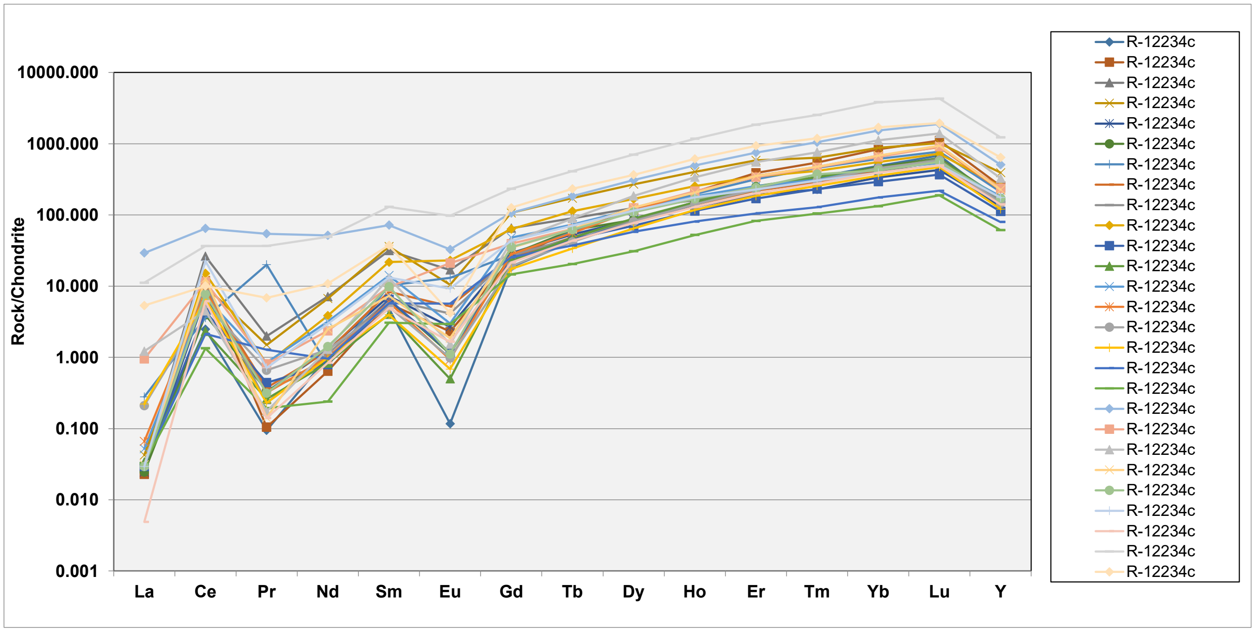


Figure 32: Primitive Mantle-Normalized Spider Diagram for Zircon

Primitive mantle composition is from Hofmann (1988)

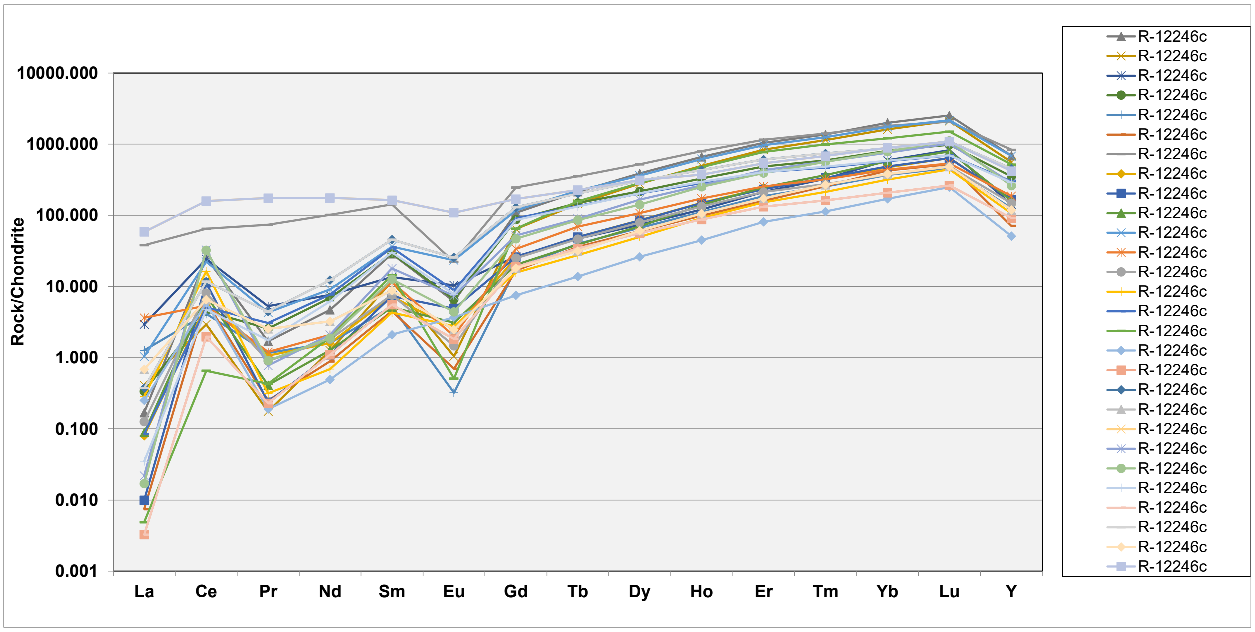


Figure 33: Primitive Mantle-Normalized Spider Diagram for Zircon

Primitive mantle composition is from Hofmann (1988)

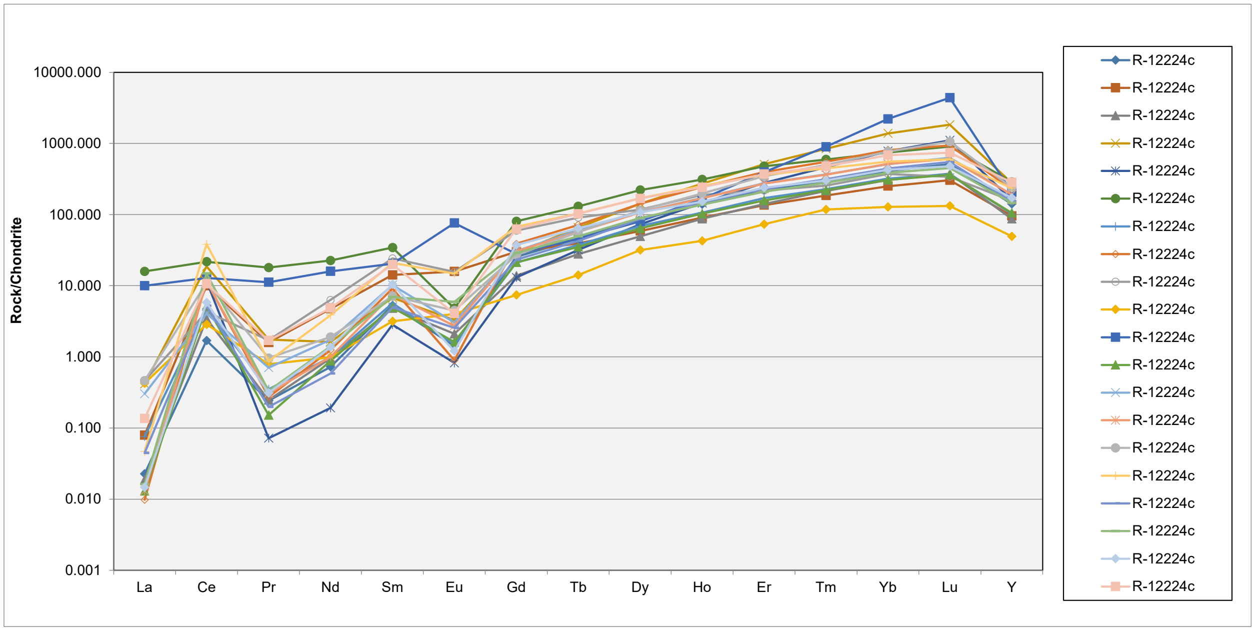


Figure 34: Primitive Mantle-Normalized Spider Diagram for Zircon

Primitive mantle composition is from Hofmann (1988)

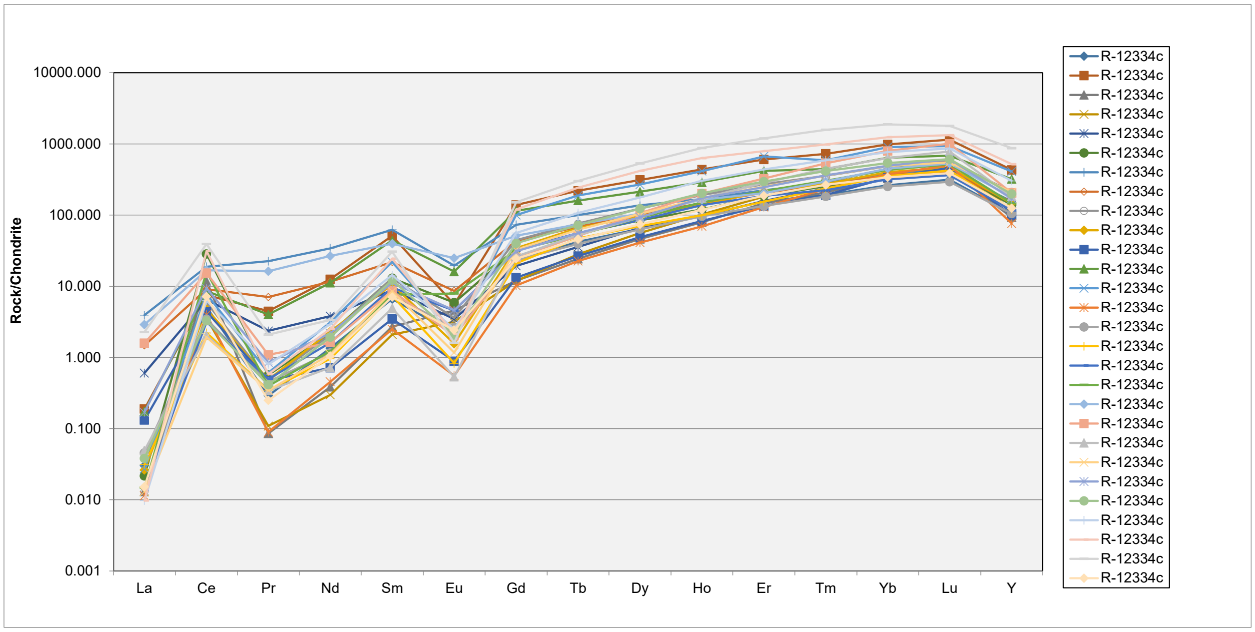


Figure 35: Primitive Mantle-Normalized Spider Diagram for Zircon

Primitive mantle composition is from Hofmann (1988)

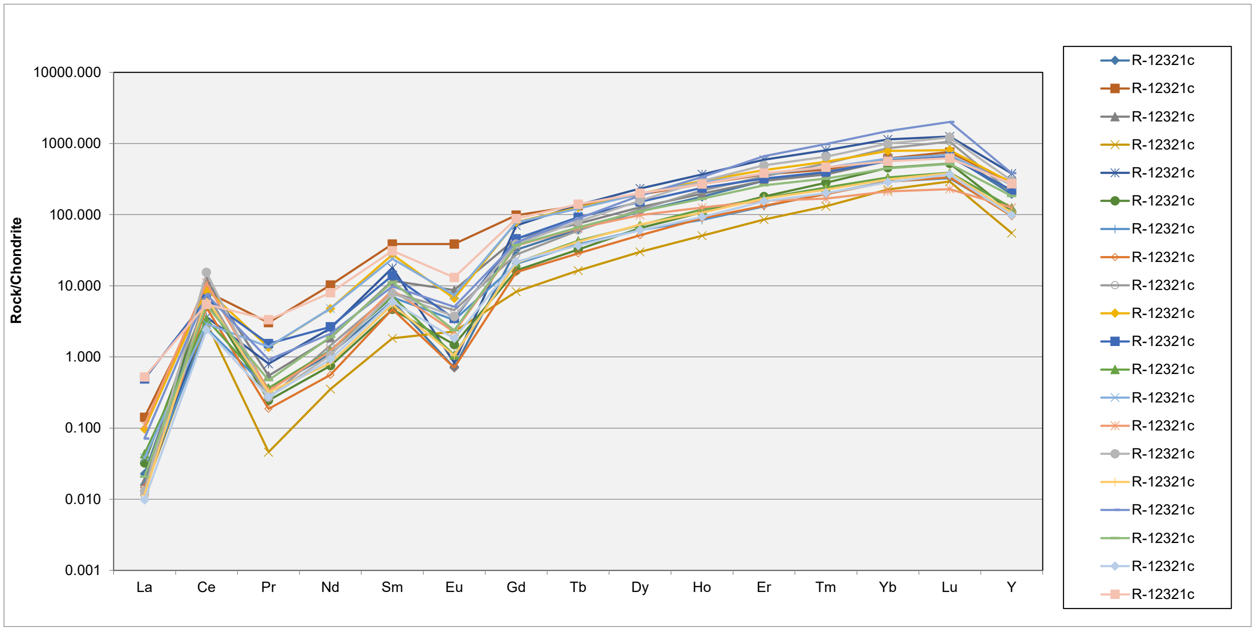


Figure 36: Primitive Mantle-Normalized Spider Diagram for Zircon

Primitive mantle composition is from Hofmann (1988)

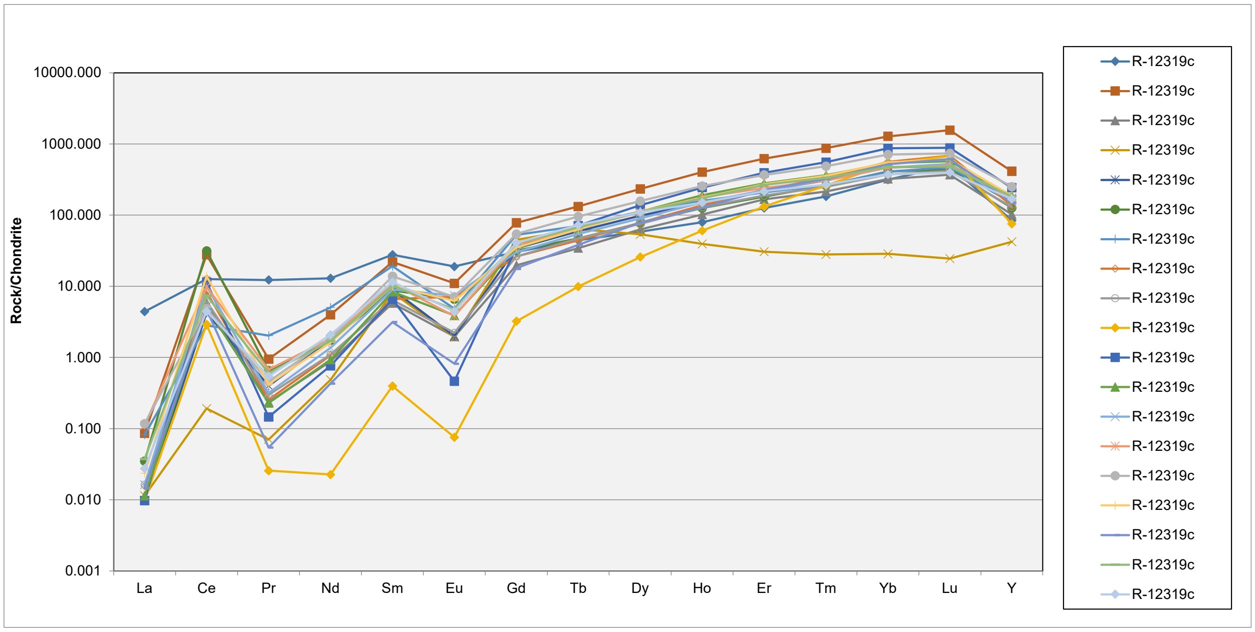


Figure 37: Primitive Mantle-Normalized Spider Diagram for Zircon

Primitive mantle composition is from Hofmann (1988)

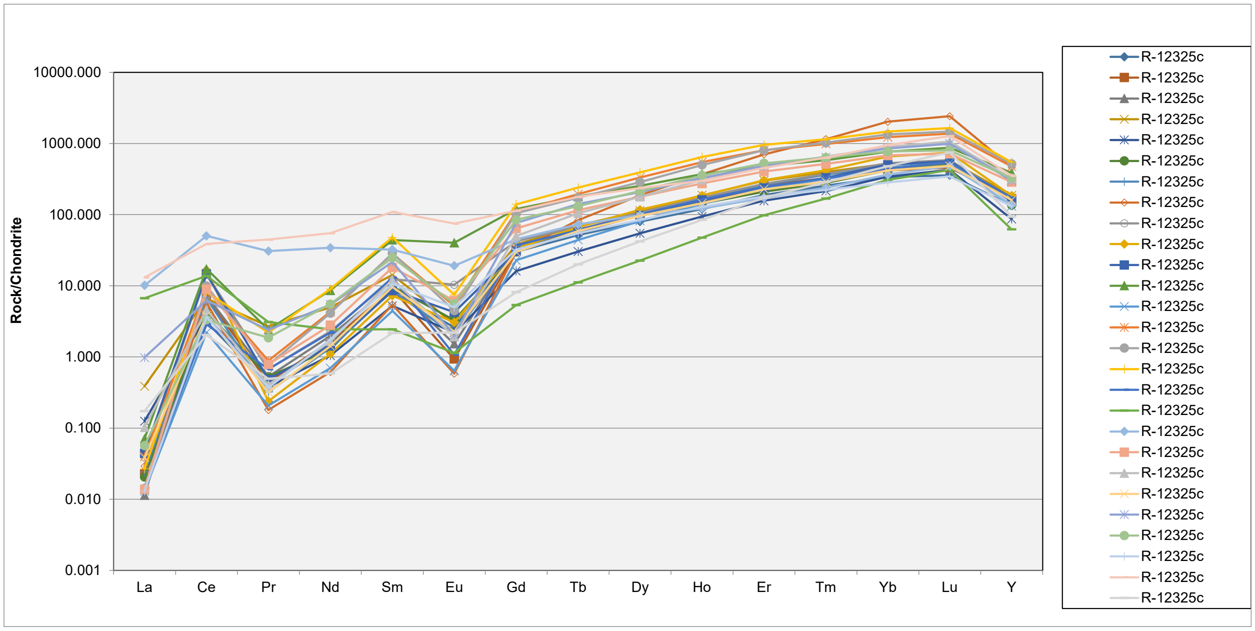


Figure 38: Primitive Mantle-Normalized Spider Diagram for Zircon

Primitive mantle composition is from Hofmann (1988)

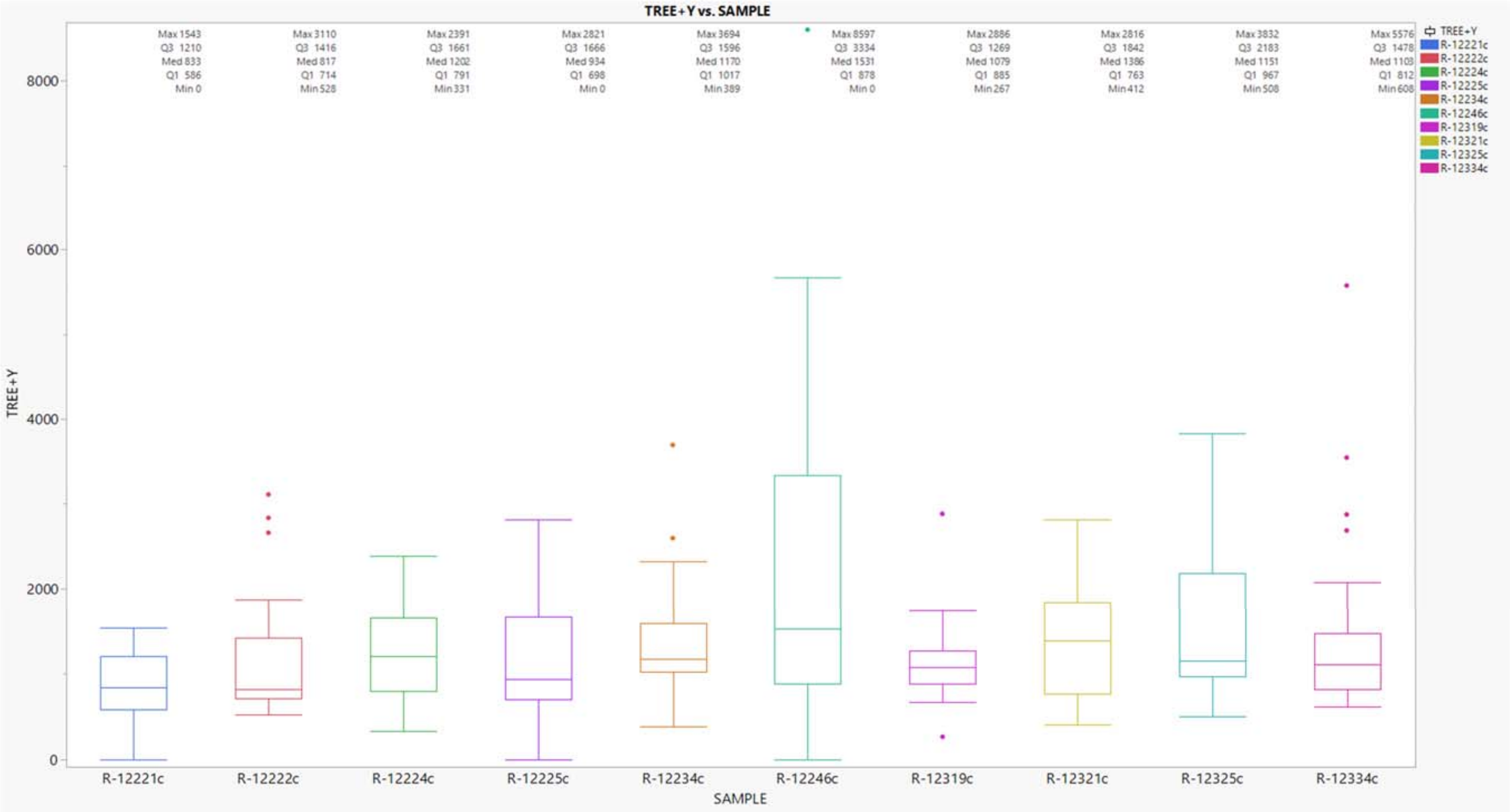


Figure 39: Box Plot for TREE+Y (ppm) for the Analyzed Zircon Grains

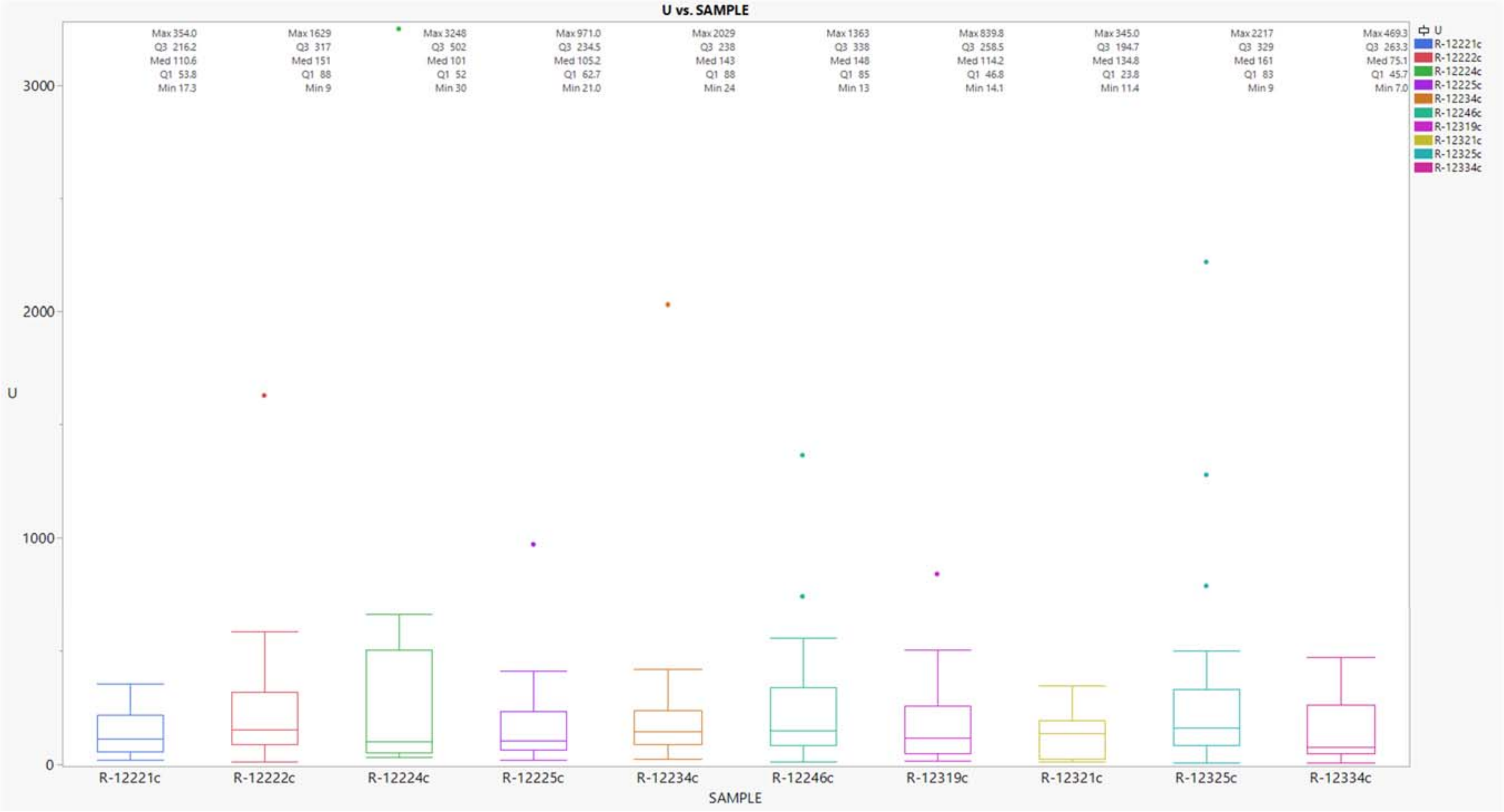


Figure 40: Box Plot for U (ppm) for the Analyzed Zircon Grains

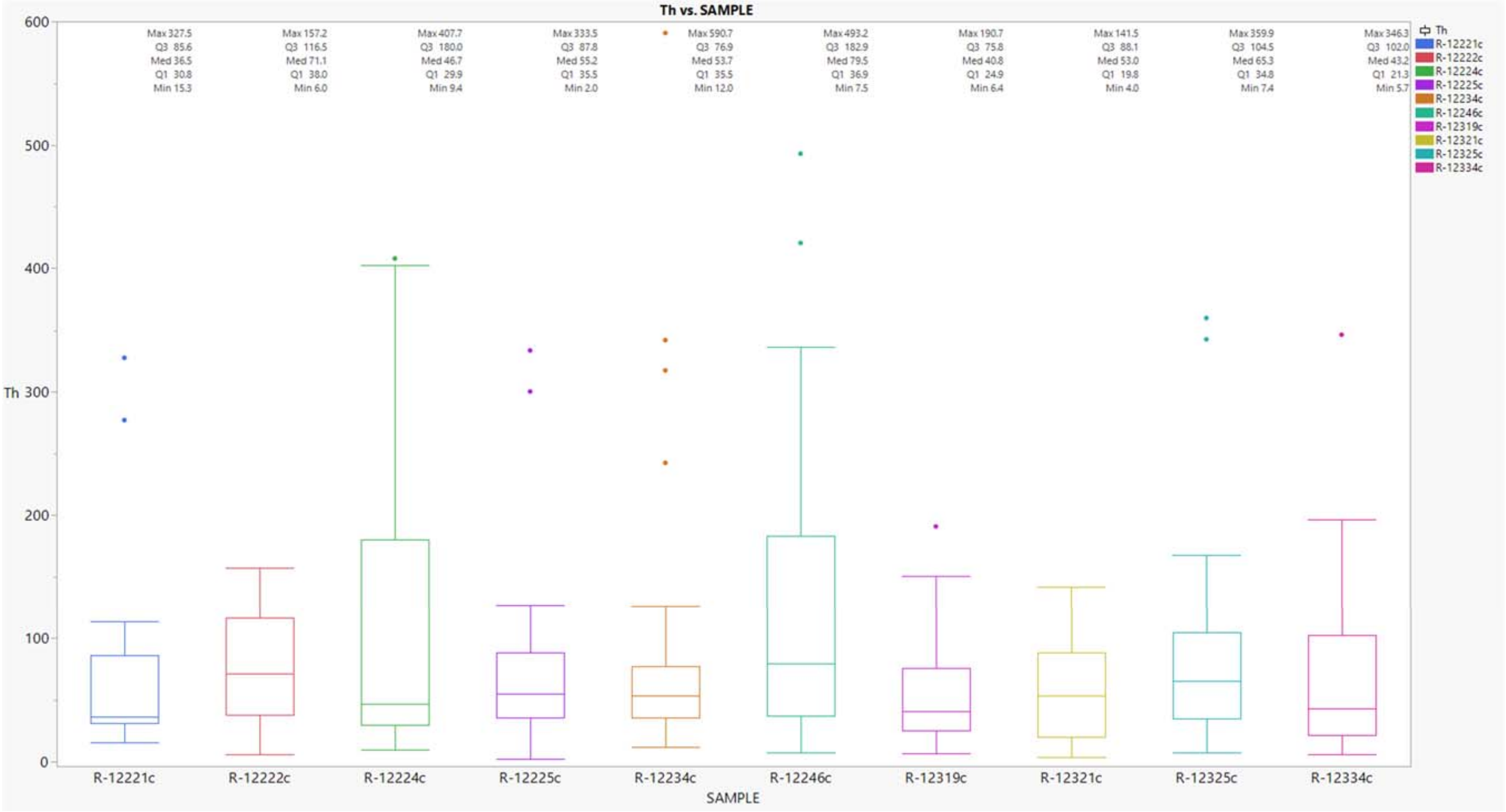


Figure 41: Box Plot for Th (ppm) for the Analyzed Zircon Grains

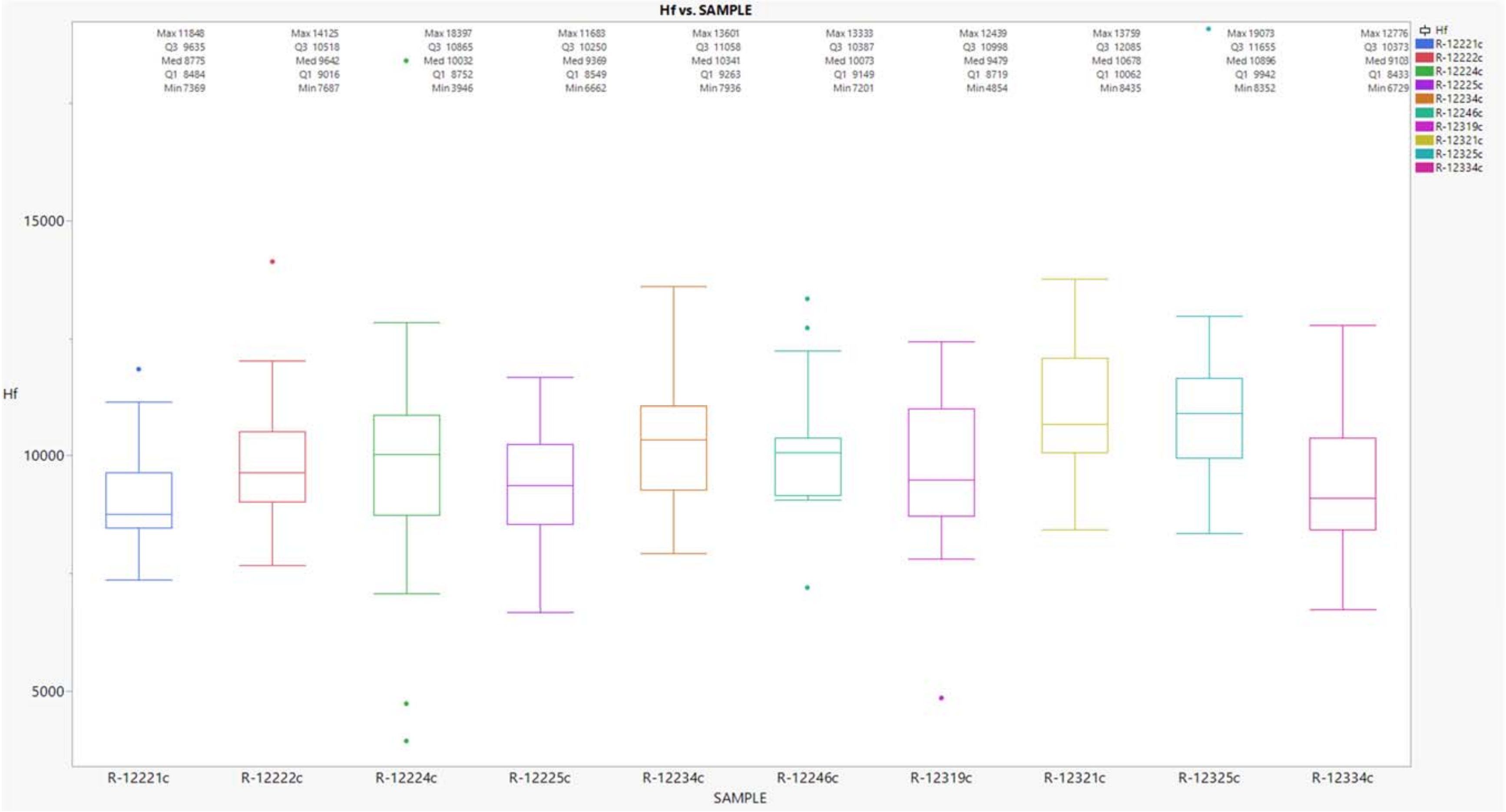


Figure 42: Box Plot for Hf (ppm) for the Analyzed Zircon Grains

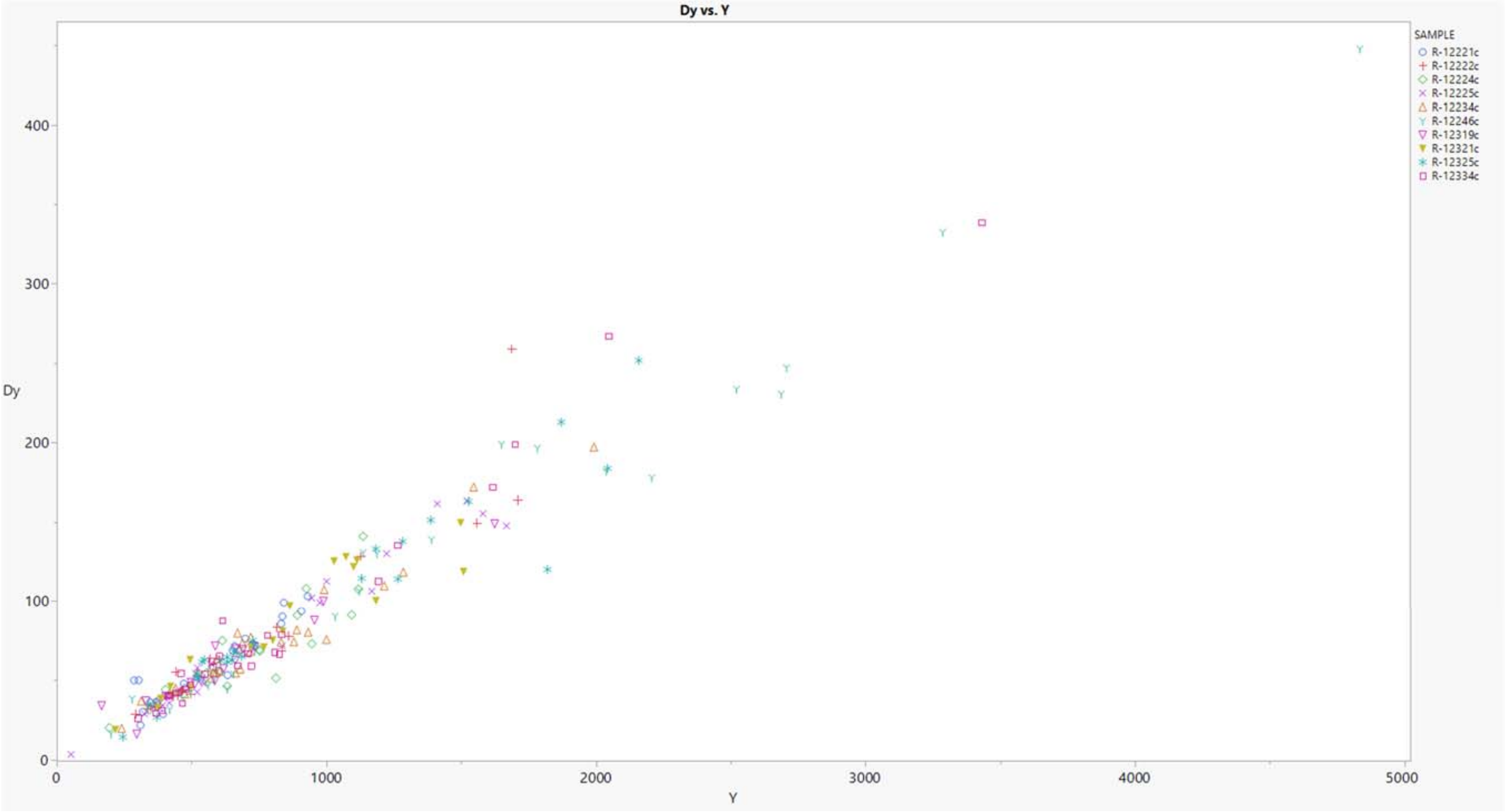


Figure 43: Y vs. Dy for the Analyzed Zircon Grains

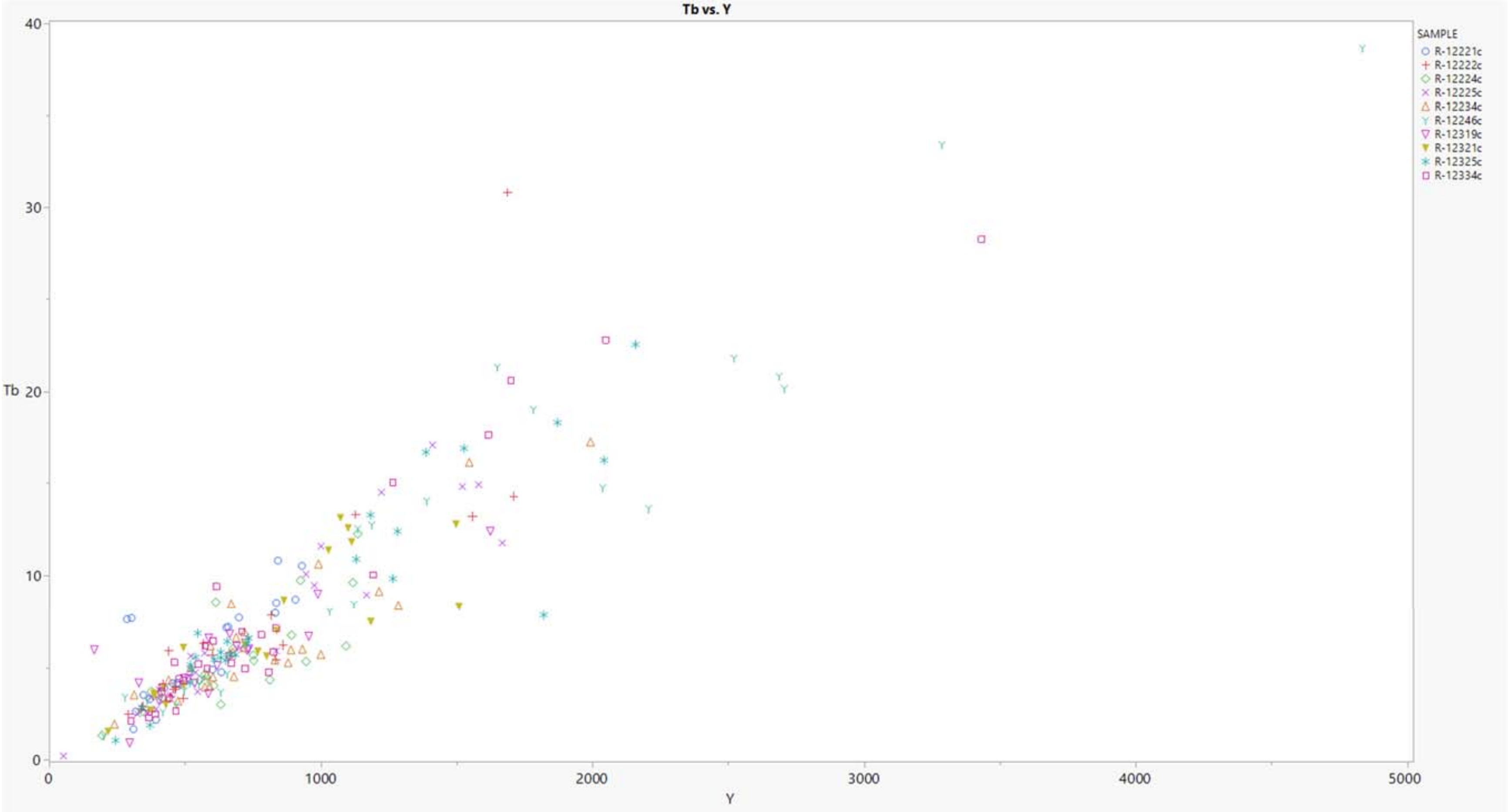


Figure 44: Y vs. Tb for the Analyzed Zircon Grains

Conclusions and Recommendations

- Heavy liquid separation of the samples indicates that the Sink (heavy) fractions account for 0.1% to 62.9% of the total mass of all samples.
- The total REE+Y ranges from <745 ppm to 3,089 ppm, reflecting mainly monazite and less commonly xenotime, and allanite.
- Mineralogical analysis shows that monazite (source of REE, Y, Th, U), zircon, ilmenite, and rutile (Ti, Nb) are the main economic minerals. Allanite is a trace mineral and an insignificant REE carrier.
- The monazite chemistry also shows that a REE concentrate will be radioactive (due to the thorium and lesser uranium) in the matrix of the mineral.
- Gravity methods should be efficient to separate the minerals. However, additional metallurgical testwork is required to determine the potential separation and concentration of monazite, zircon, and rutile and ilmenite.

Appendix A – XRD Results

SGS

Qualitative X-Ray Diffraction

Report Prepared for:	*Department of Mines Minerals and Energy*
Project Number/ LIMS No.	*17512-02/MI4507-APR23*
Sample Receipt:	*April 5, 2023*
Sample Analysis:	*April 19, 2023*
Reporting Date:	*May 4, 2023*

Instrument:	BRUKER AXS D8 Advance Diffractometer
Test Conditions:	Co radiation, 35 kV, 40 mA; Detector: LYNXEYE Regular Scanning: Step: 0.02°, Step time:0.2s, 2θ range: 6-70°
Interpretations :	PDF2/PDF4 powder diffraction databases issued by the International Center for Diffraction Data (ICDD). DiffracPlus Eva software.
Detection Limit :	0.5-2%. Strongly dependent on crystallinity.

Contents:

1) Method Summary
2) Summary of Mineral Asemblages
3) XRD Pattern(s)

Kim Gibbs

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Senior Mineralogist

Huyun Zhou

Huyun Zhou, Ph.D., P.Geo.
Senior Mineralogist

ACCREDITATION: SGS Natural Resources Lakefield is accredited to the requirements of ISO/IEC 17025 for specific tests as listed on our scope of accreditation, including geochemical, mineralogical and trade mineral tests. To view a list of the accredited methods, please visit the following website and search SGS Canada Inc. - Minerals: https://www.scc.ca/en/search/palcan.

Method Summary

The Qualitative Mineral Identification By XRD (ME-LR-MIN-MET-MN-D01) method used by SGS Natural Resources is accredited to the requirements of ISO/IEC 17025.

Mineral Identification and Interpretation:

Mineral identification and interpretation involve matching the diffraction pattern of an unknown test sample to patterns of single-phase reference materials. The reference patterns are compiled by the Joint Committee on Powder Diffraction Standards - International Center for Diffraction Data (JCPDS-ICDD) and released on software as a database of Powder Diffraction Files (PDF).

Interpretations do not reflect the presence of non-crystalline and/or amorphous compounds. Mineral proportions are based on relative peak heights and may be strongly influenced by crystallinity, structural group or preferred orientations. Interpretations and relative proportions should be accompanied by supporting petrographic and geochemical data (Whole Rock Analysis, Inductively Coupled Plasma - Optical Emission Spectroscopy, etc.).

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WARNING: The sample(s) to which the findings recorded herein (the "Findings") relate was(were) drawn and / or provided by the Client or by a third party acting at the Client's direction. The Findings constitute no warranty of the sample's representativeness of any goods and strictly relate to the sample(s). The Company accepts no liability with regard to the origin or source from which the sample(s) is/are said to be extracted.

Summary of Qualitative X-Ray Diffraction Results

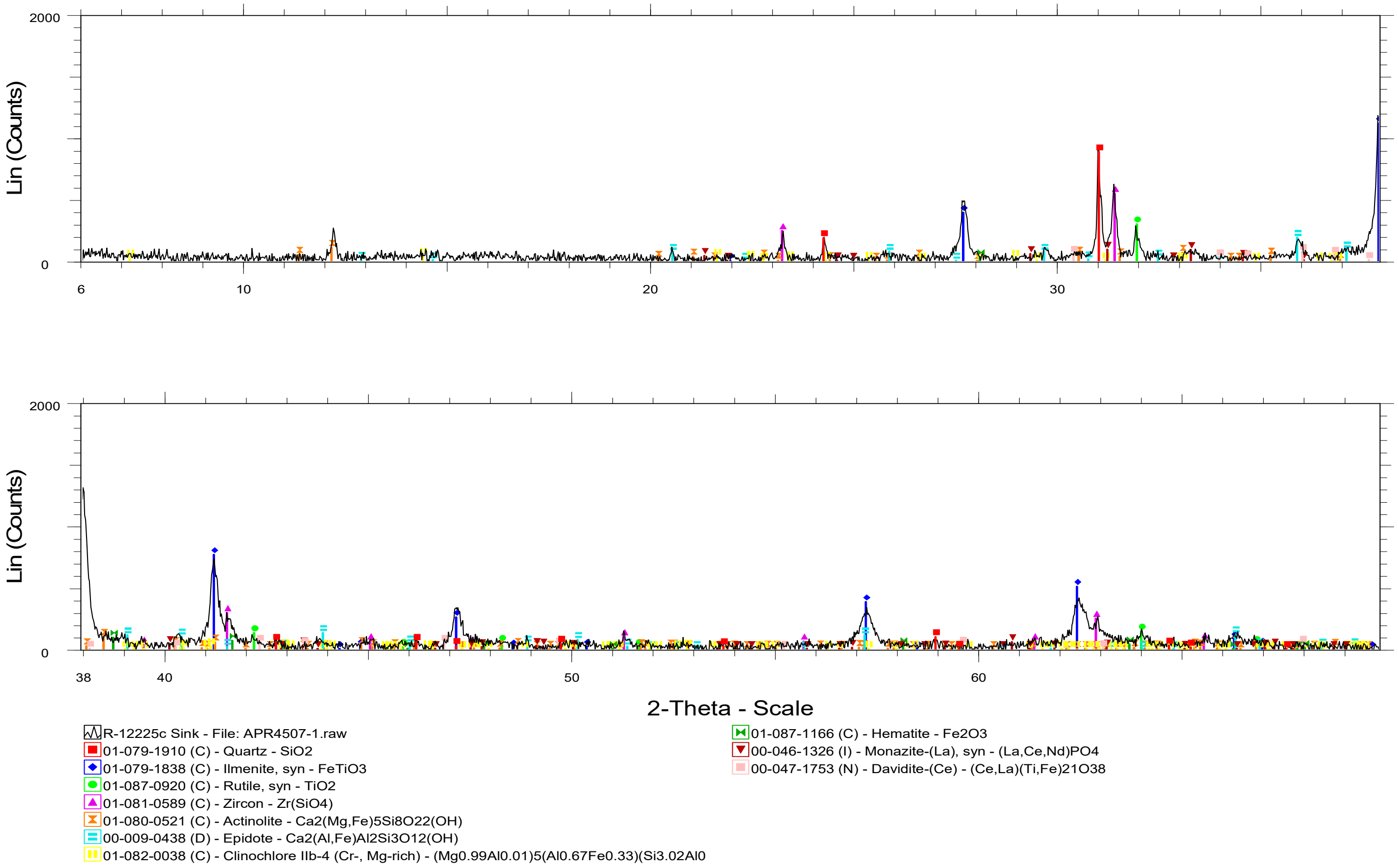
Crystalline Mineral Assemblage (relative proportions based on peak height)

Sample ID	Major	Moderate	Minor	Trace
(1) R-12225c Sink	ilmenite	-	quartz, zircon, epidote, chlorite, hematite, rutile, amphibole	*monazite, *davidite
(2) R-12226c Sink	amphibole	ilmenite garnet	quartz, zircon, epidote	*monazite, *davidite *hematite, *rutile, *chlorite
(3) R-12227c Sink	amphibole	ilmenite garnet	quartz, zircon, epidote	*monazite, *davidite *hematite, *rutile, *chlorite
(4) R-12236c Sink	amphibole	ilmenite, garnet	zircon, epidote	*monazite, *davidite *hematite, *rutile, *quartz, *chlorite

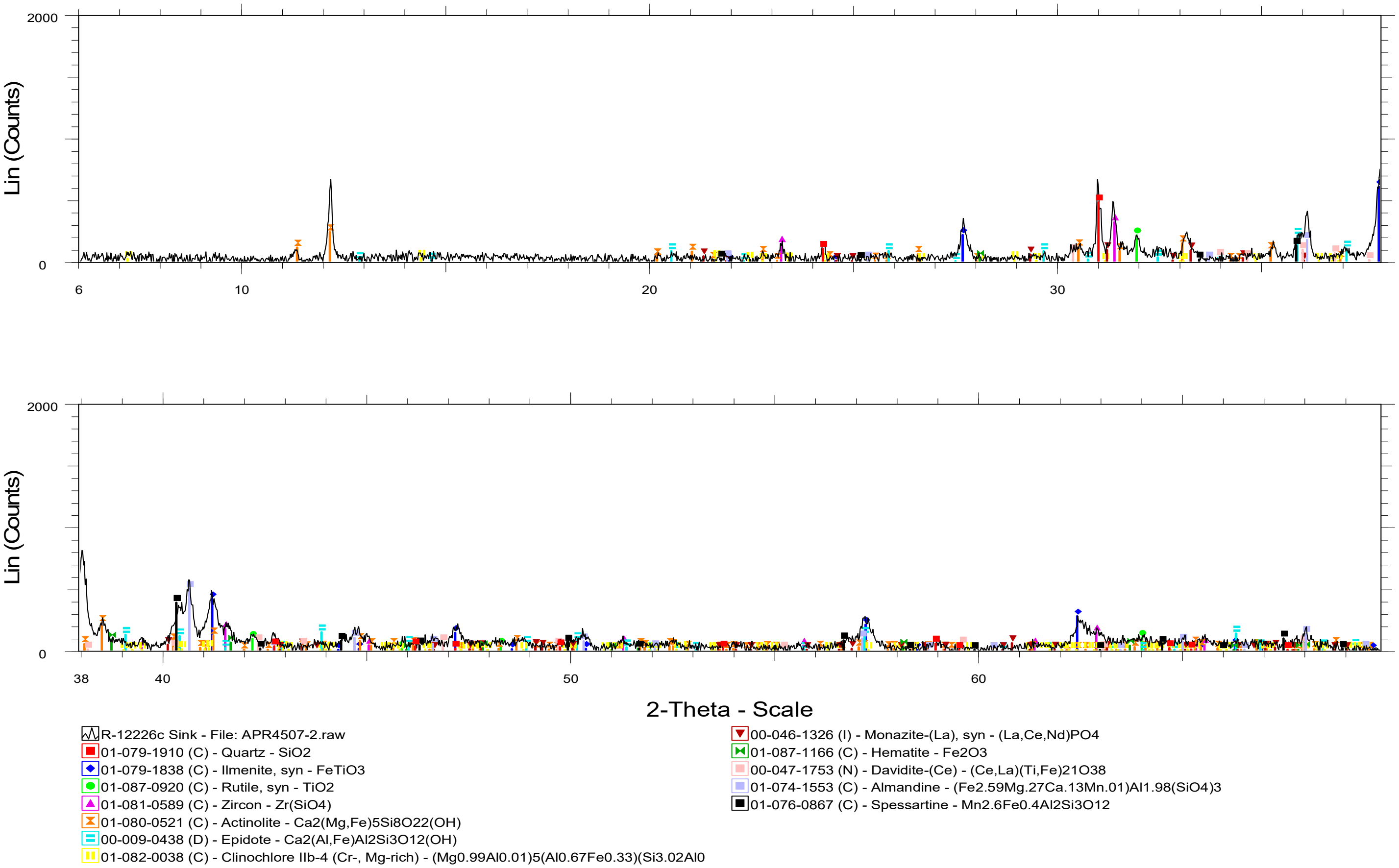
** tentative identification due to low concentrations, diffraction line overlap or poor crystallinity*

Mineral	Composition
Amphibole	$(Na,K)Ca_2(Fe,Mg)_5(Al,Si)_8O_{22}(OH)_2$
Chlorite	$(Fe,(Mg,Mn)_5,Al)(Si_3Al)O_{10}(OH)_8$
Davidite-Ce	$(Ce,La)(Ti,Fe)_{21}O_{38}$
Epidote	$Ca_2(Al,Fe)Al_2O(SiO_4)(Si_2O_7)(OH)$
Garnet	$(Ca,Mg,Mn^{2+})_3(V,Al, Fe^{3+})_2(SiO_4)_3$
Hematite	Fe_2O_3
Ilmenite	$FeTiO_3$
Monazite	$(Ce,La,Y,Th)PO_4$
Quartz	SiO_2
Rutile	TiO_2
Zircon	$Zr(SiO_4)$

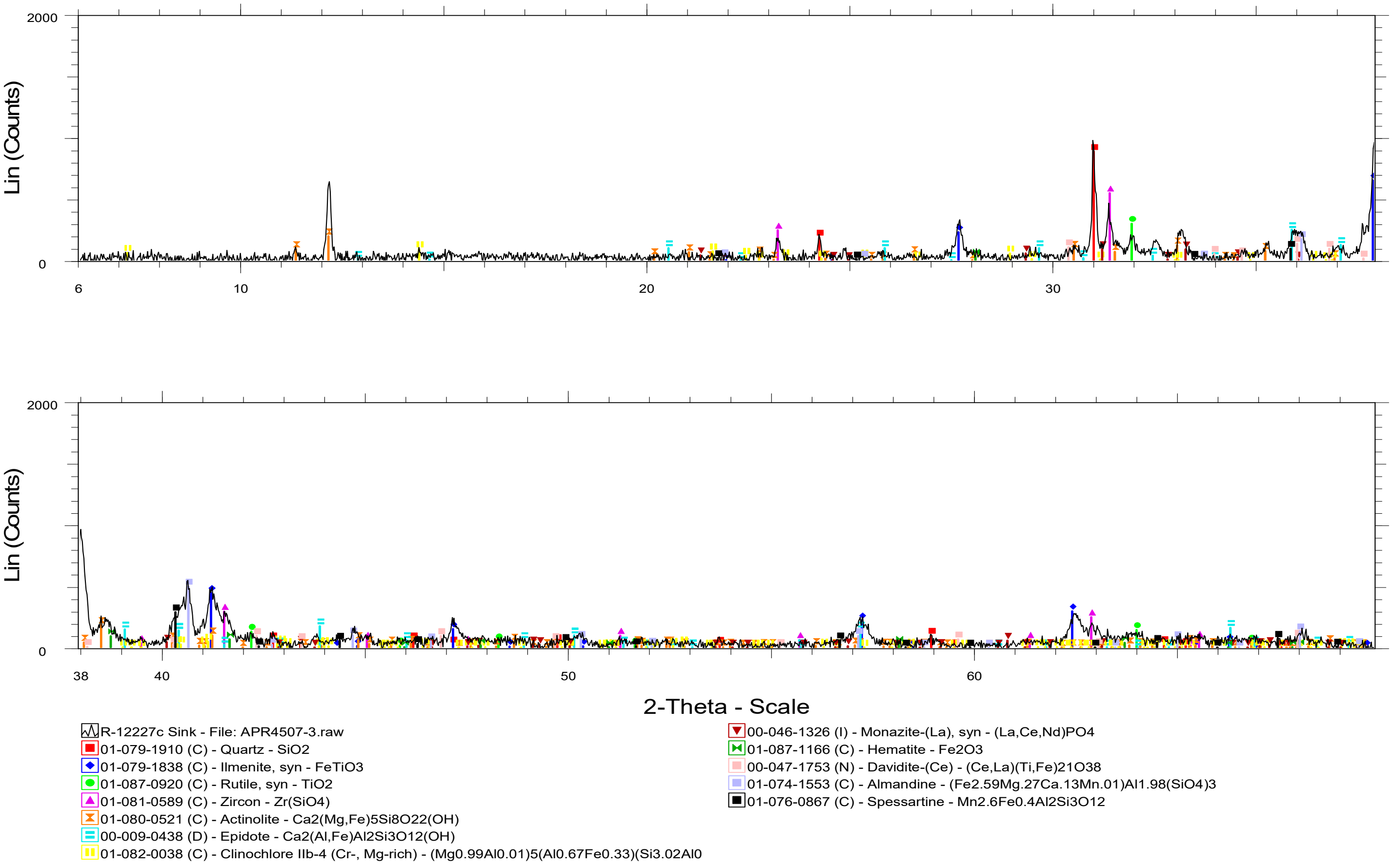
R-12225c Sink



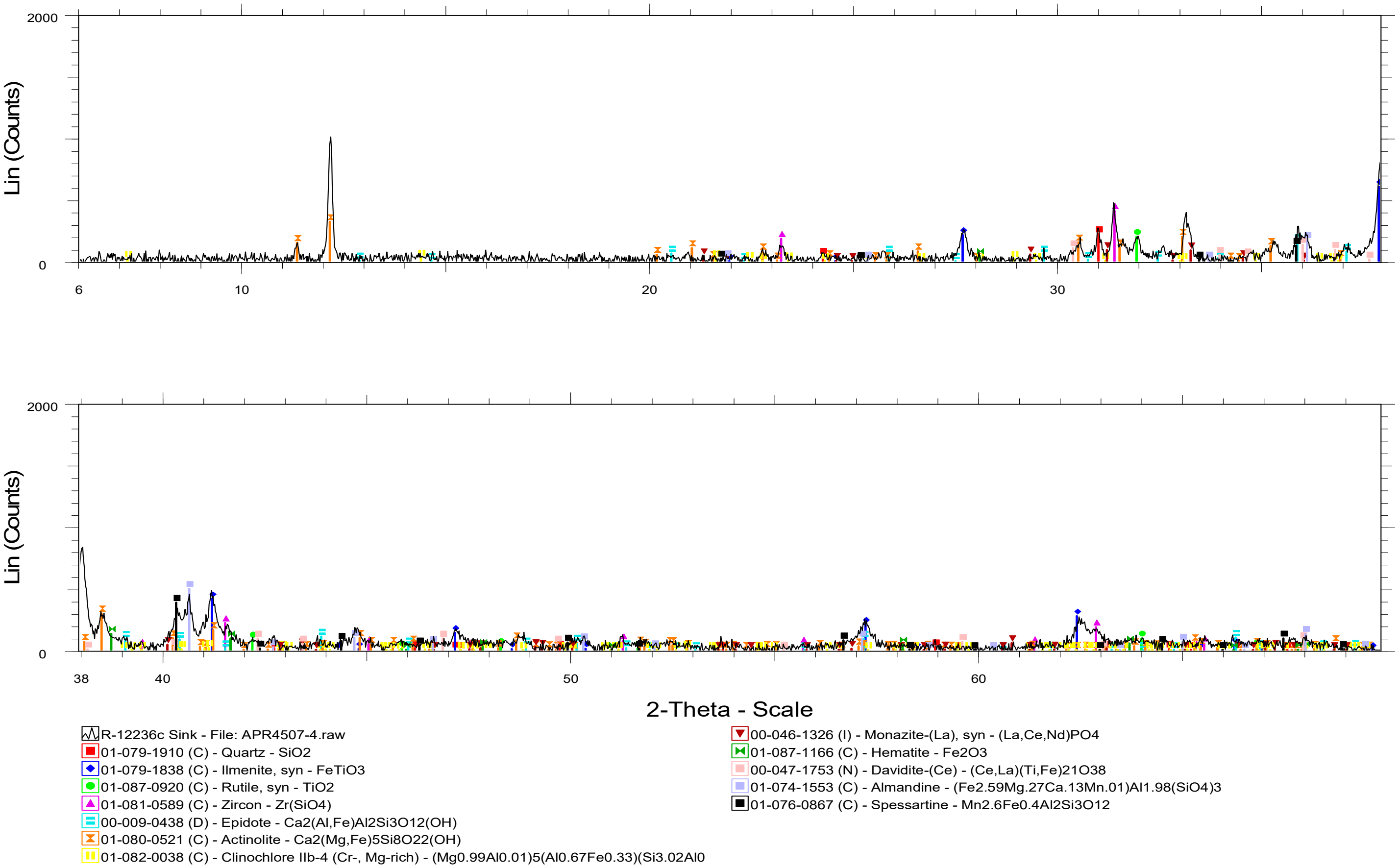
R-12226c Sink



R-12227c Sink



R-12236c Sink



Appendix B – Certificates of Analyses

SGS Canada Inc.
P.O. Box 4300 - 185 Concession St.
Lakefield - Ontario - KOL 2HO
Phone: 705-652-2000 FAX: 705-652-6365

LR Internal Dept 14
Attn : Tassos Grammatikopoulos

31-January-2023

Date Rec. : 08 June 2022
LR Report : **CA02129-JUN22**
Project : CA20I-00000-110-17512-02
Client Ref : MI5024-MAY22

CERTIFICATE OF ANALYSIS

Final Report

Sample ID	La g/t	Ce g/t	Pr g/t	Nd g/t	Sm g/t	Eu g/t	Gd g/t	Tb g/t	Dy g/t	Ho g/t	Er g/t
1: R-12221c HLS Sink	261	555	64.9	239	46.1	3.4	28.5	3.7	24.2	4.4	16.7
2: R-12222c HLS Sink	275	638	70.3	257	46.9	4.9	31.4	4.4	33.8	5.7	19.7
3: R-12225c HLS Sink	286	606	72.0	268	43.7	4.1	34.0	4.6	25.6	6.1	18.8

Sample ID	Tm g/t	Yb g/t	Lu g/t	U g/t	Th g/t	Cs g/t	Ga g/t	In g/t	Nb g/t	Rb g/t	Ta g/t
1: R-12221c HLS Sink	2.8	23.6	4.4	24.6	116	< 10	27	< 3	615	< 10	34
2: R-12222c HLS Sink	3.6	26.2	4.6	31.9	115	< 10	26	< 3	544	< 10	31
3: R-12225c HLS Sink	3.3	27.0	4.5	30.1	123	< 10	14	< 3	625	< 10	34

Sample ID	Al g/t	Ba g/t	Be g/t	Bi g/t	Ca g/t	Cd g/t	Co g/t	Cr g/t	Cu g/t	Fe g/t	K g/t
1: R-12221c HLS Sink	41400	45	< 3	< 400	27400	< 40	< 200	453	< 40	204000	1540
2: R-12222c HLS Sink	46000	54	< 3	< 400	33700	< 40	< 200	531	< 40	206000	1870
3: R-12225c HLS Sink	33800	34	< 3	< 400	23500	< 40	< 200	563	< 40	221000	1190

Sample ID	Li g/t	Mg g/t	Mn g/t	Mo g/t	Ni g/t	Pb g/t	Sb g/t	Se g/t	Si g/t	Sn g/t	Sr g/t
1: R-12221c HLS Sink	< 800	6190	8670	< 300	< 300	< 800	< 400	< 2000	101000	< 800	153
2: R-12222c HLS Sink	< 800	10900	8390	< 300	< 300	< 800	< 400	< 2000	97500	< 800	166
3: R-12225c HLS Sink	< 800	4980	9270	< 300	< 300	< 800	< 400	< 2000	82400	< 800	147

Sample ID	Ti g/t	Tl g/t	U g/t	V g/t	Y g/t	Zn g/t	Sc g/t	Zr g/t	Ag g/t	Na g/t	P g/t	As ppm	Ge ppm
1: R-12221c HLS Sink	192000	< 2000	< 800	392	126	468	45	23300	< 9	2200	523	15	2
2: R-12222c HLS Sink	178000	< 2000	< 800	415	163	447	48	26000	< 9	1740	469	< 5	2
3: R-12225c HLS Sink	212000	< 2000	< 800	439	167	472	46	31800	< 9	1800	469	13	2

Sample ID	**La g/t**	**Ce g/t**	**Pr g/t**	**Nd g/t**	**Sm g/t**	**Eu g/t**	**Gd g/t**	**Tb g/t**	**Dy g/t**	**Ho g/t**	**Er g/t**
4: R-12226c HLS Sink	244	535	63.8	264	49.9	6.5	39.9	6.1	40.0	10.3	29.9
5: R-12228c HLS Sink	245	538	64.3	250	45.2	5.6	41.9	5.5	32.5	7.9	26.3
6: R-12232c HLS Sink	225	490	58.8	232	43.3	6.6	39.6	6.0	34.8	7.8	26.0
7: R-12234c HLS Sink	217	531	58.9	234	39.8	5.8	33.6	4.8	35.6	6.9	21.4
8: R-12236c HLS Sink	233	557	62.4	249	47.9	6.6	38.8	6.3	41.9	8.4	25.5
9: R-12245c HLS Sink	303	697	78.3	283	52.4	4.6	38.2	5.3	32.1	6.6	20.9

Sample ID	**Tm g/t**	**Yb g/t**	**Lu g/t**	**U g/t**	**Th g/t**	**Cs g/t**	**Ga g/t**	**In g/t**	**Nb g/t**	**Rb g/t**	**Ta g/t**
4: R-12226c HLS Sink	5.5	39.3	7.1	23.9	75.4	< 10	21	< 3	400	< 10	22
5: R-12228c HLS Sink	4.7	30.7	6.0	24.3	89.7	< 10	24	< 3	387	< 10	21
6: R-12232c HLS Sink	4.2	32.3	5.5	22.2	71.5	< 10	20	< 3	331	< 10	18
7: R-12234c HLS Sink	3.5	26.1	5.2	22.5	64.8	< 10	36	< 3	440	< 10	20
8: R-12236c HLS Sink	4.8	34.6	5.8	23.9	77.9	< 10	27	< 3	364	< 10	18
9: R-12245c HLS Sink	3.6	25.7	4.6	33.8	125	< 10	24	< 3	602	< 10	33

Sample ID	**Al g/t**	**Ba g/t**	**Be g/t**	**Bi g/t**	**Ca g/t**	**Cd g/t**	**Co g/t**	**Cr g/t**	**Cu g/t**	**Fe g/t**	**K g/t**
4: R-12226c HLS Sink	54500	49	< 3	< 400	32200	< 40	< 200	828	< 40	193000	1980
5: R-12228c HLS Sink	50100	44	< 3	< 400	32400	< 40	< 200	858	< 40	219000	2060
6: R-12232c HLS Sink	59300	63	< 3	< 400	51200	< 40	< 200	668	< 40	179000	3120
7: R-12234c HLS Sink	48800	61	< 3	< 400	38200	< 40	< 200	762	< 40	196000	2320
8: R-12236c HLS Sink	51000	52	< 3	< 400	42800	< 40	< 200	702	< 40	196000	2920
9: R-12245c HLS Sink	45700	41	< 3	< 400	31800	< 40	< 200	494	< 40	208000	1500

Sample ID	**Li g/t**	**Mg g/t**	**Mn g/t**	**Mo g/t**	**Ni g/t**	**Pb g/t**	**Sb g/t**	**Se g/t**	**Si g/t**	**Sn g/t**	**Sr g/t**
4: R-12226c HLS Sink	< 800	22100	7040	< 300	< 300	< 800	< 400	< 2000	125000	< 800	119
5: R-12228c HLS Sink	< 800	18400	7210	< 300	< 300	< 800	< 400	< 2000	111000	< 800	130
6: R-12232c HLS Sink	< 800	25600	6110	< 300	< 300	< 800	< 400	< 2000	134000	< 800	179
7: R-12234c HLS Sink	< 800	21900	6680	< 300	< 300	< 800	< 400	< 2000	112000	< 800	152
8: R-12236c HLS Sink	< 800	24300	6870	< 300	< 300	< 800	< 400	< 2000	122000	< 800	143
9: R-12245c HLS Sink	< 800	7570	8720	< 300	< 300	< 800	< 400	< 2000	84200	< 800	180

Sample ID	**Ti g/t**	**Tl g/t**	**U g/t**	**V g/t**	**Y g/t**	**Zn g/t**	**Sc g/t**	**Zr g/t**	**Ag g/t**	**Na g/t**	**P g/t**	**As ppm**	**Ge ppm**
4: R-12226c HLS Sink	133000	< 2000	< 800	358	255	322	59	22900	< 9	2680	972	7	3
5: R-12228c HLS Sink	142000	< 2000	< 800	431	212	339	55	23900	< 9	2680	736	< 5	3
6: R-12232c HLS Sink	111000	< 2000	< 800	372	210	317	57	17500	< 9	3860	1860	< 5	3
7: R-12234c HLS Sink	147000	< 2000	< 800	391	183	316	53	21400	< 9	3490	1800	5	2
8: R-12236c HLS Sink	128000	< 2000	< 800	373	218	331	58	21100	< 9	3470	2110	10	3
9: R-12245c HLS Sink	199000	< 2000	< 800	430	180	518	49	28000	< 9	2160	700	13	2

C119

Sample ID	La g/t	Ce g/t	Pr g/t	Nd g/t	Sm g/t	Eu g/t	Gd g/t	Tb g/t	Dy g/t	Ho g/t	Er g/t
10: R-12246c HLS Sink	522	1180	133	522	87.7	10.3	72.1	10.1	61.5	14.5	46.5
11: R-12227c HLS Sink	267	639	69.7	279	48.3	6.3	41.3	6.9	47.1	9.5	30.8

Sample ID	Tm g/t	Yb g/t	Lu g/t	U g/t	Th g/t	Cs g/t	Ga g/t	In g/t	Nb g/t	Rb g/t	Ta g/t
10: R-12246c HLS Sink	7.6	55.8	9.3	48.9	170	< 10	29	< 3	557	< 10	32
11: R-12227c HLS Sink	5.7	36.1	7.0	26.4	82.1	< 10	31	< 3	392	< 10	22

Sample ID	Al g/t	Ba g/t	Be g/t	Bi g/t	Ca g/t	Cd g/t	Co g/t	Cr g/t	Cu g/t	Fe g/t	K g/t
10: R-12246c HLS Sink	35300	71	< 3	< 400	25600	< 40	< 200	769	< 40	216000	1760
11: R-12227c HLS Sink	49000	62	< 3	< 400	32700	< 40	< 200	842	< 40	202000	2850

Sample ID	Li g/t	Mg g/t	Mn g/t	Mo g/t	Ni g/t	Pb g/t	Sb g/t	Se g/t	Si g/t	Sn g/t	Sr g/t
10: R-12246c HLS Sink	< 800	8530	7260	< 300	< 300	< 800	< 400	< 2000	80200	< 800	183
11: R-12227c HLS Sink	< 800	19400	6700	< 300	< 300	< 800	< 400	< 2000	125000	< 800	131

Sample ID	Ti g/t	Tl g/t	U g/t	V g/t	Y g/t	Zn g/t	Sc g/t	Zr g/t	Ag g/t	Na g/t	P g/t	As ppm	Ge ppm
10: R-12246c HLS Sink	196000	< 2000	< 800	490	357	433	71	38500	< 9	2180	788	< 5	2
11: R-12227c HLS Sink	128000	< 2000	< 800	390	244	332	69	23500	< 9	2690	947	5	3

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Control Quality Assay
Not Suitable for Commercial Exchange
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Sarah Thyret-Arbour

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OnLine LIMS

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C120

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Lakefield - Ontario - KOL 2HO
Phone: 705-652-2000 FAX: 705-652-6365

LR Internal Dept 14
Attn : T. Grammatikopoulos

10-May-2023

Date Rec. : 31 January 2023
LR Report : **CA02373-JAN23**
Project : CA20I-00000-110-17512-02
Client Ref : MI5031-NOV22

CERTIFICATE OF ANALYSIS

Final Report

Sample ID	Al g/t	As g/t	Ba g/t	Be g/t	Bi g/t	Ca g/t	Cd g/t	Co g/t	Cr g/t	Cu g/t	Fe g/t	K g/t
1: R-12321c HLS Sink	51400	< 200	61	< 3	< 400	36100	< 40	< 200	621	< 40	194000	2330
2: R-12334c HLS Sink	51100	< 200	78	< 3	< 400	43000	< 40	< 200	651	< 40	192000	3800
3: R-12231c HLS Sink	36300	< 200	58	< 3	< 400	17400	< 40	< 200	751	< 40	238000	1860

Sample ID	Li g/t	Mg g/t	Mn g/t	Mo g/t	Ni g/t	Pb g/t	Sb g/t	Se g/t	Si g/t	Sn g/t	Sr g/t
1: R-12321c HLS Sink	< 800	14800	7370	< 300	< 300	< 800	< 400	< 2000	118000	< 800	156
2: R-12334c HLS Sink	< 800	20400	5870	< 300	< 300	< 800	< 400	< 2000	150000	< 800	158
3: R-12231c HLS Sink	< 800	8120	8770	< 300	< 300	< 800	< 400	< 2000	85500	< 800	89

Sample ID	Ti g/t	Tl g/t	V g/t	Y g/t	Zn g/t	Sc g/t	Zr g/t	La g/t	Ce g/t	Pr g/t	Nd g/t	Sm g/t
1: R-12321c HLS Sink	147000	< 2000	420	212	404	49	22600	319	560	73.3	288	44.4
2: R-12334c HLS Sink	105000	< 2000	368	215	< 300	44	17400	200	446	62.4	248	43.8
3: R-12231c HLS Sink	188000	< 2000	462	160	406	44	25300	194	447	61.1	214	39.7

Sample ID	Eu g/t	Gd g/t	Tb g/t	Dy g/t	Ho g/t	Er g/t	Tm g/t	Yb g/t	Lu g/t	U g/t	Th g/t	Ge g/t	Ag g/t	Na g/t
1: R-12321c HLS Sink	5.7	38.8	11.6	36.6	8.2	23.9	4.0	30.6	4.9	25.8	104	17	< 20	2960
2: R-12334c HLS Sink	5.4	34.3	5.6	36.6	7.9	25.1	4.0	30.6	4.7	20.8	78.5	14	< 20	5190
3: R-12231c HLS Sink	3.1	29.4	4.6	27.1	6.2	20.0	3.5	25.1	4.6	21.0	102	16	< 20	2700

Sample ID	P g/t
1: R-12321c HLS Sink	1200
2: R-12334c HLS Sink	2080
3: R-12231c HLS Sink	472

OnLine LIMS

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C121

Sample ID	Al g/t	As g/t	Ba g/t	Be g/t	Bi g/t	Ca g/t	Cd g/t	Co g/t	Cr g/t	Cu g/t	Fe g/t	K g/t
4: R-12236m HLS Sink	---	---	---	---	---	---	---	---	---	---	---	---
5: R-12318c HLS Sink	61200	< 200	62	< 3	< 400	40300	< 40	< 200	620	< 40	189000	2470
6: R-12224c HLS Sink	43000	< 200	72	< 3	< 400	28600	< 40	< 200	560	< 40	202000	2360
7: R-12233c HLS Sink	54100	< 200	60	< 3	< 400	34000	< 40	< 200	675	< 40	200000	2600
8: R-12223c HLS Sink	68900	< 200	65	< 3	< 400	48800	< 40	< 200	474	< 40	171000	2380
9: R-12319c HLS Sink	51200	< 200	78	< 3	< 400	57800	< 40	< 200	511	< 40	178000	4130

Sample ID	Li g/t	Mg g/t	Mn g/t	Mo g/t	Ni g/t	Pb g/t	Sb g/t	Se g/t	Si g/t	Sn g/t	Sr g/t
4: R-12236m HLS Sink	---	---	---	---	---	---	---	---	---	---	---
5: R-12318c HLS Sink	< 800	17200	7050	< 300	< 300	< 800	< 400	< 2000	121000	< 800	178
6: R-12224c HLS Sink	< 800	9420	8050	< 300	< 300	< 800	< 400	< 2000	105000	< 800	157
7: R-12233c HLS Sink	< 800	13800	7680	< 300	< 300	< 800	< 400	< 2000	108000	< 800	169
8: R-12223c HLS Sink	< 800	17400	6330	< 300	< 300	< 800	< 400	< 2000	128000	< 800	238
9: R-12319c HLS Sink	< 800	25600	4910	< 300	< 300	< 800	< 400	< 2000	161000	< 800	187

Sample ID	Ti g/t	Tl g/t	V g/t	Y g/t	Zn g/t	Sc g/t	Zr g/t	La g/t	Ce g/t	Pr g/t	Nd g/t	Sm g/t
4: R-12236m HLS Sink	---	---	---	---	---	---	---	---	---	---	---	---
5: R-12318c HLS Sink	134000	< 2000	391	139	374	53	16600	131	361	44.0	170	29.9
6: R-12224c HLS Sink	179000	< 2000	420	158	436	44	23000	191	452	61.1	223	45.0
7: R-12233c HLS Sink	159000	< 2000	420	152	403	48	20200	140	340	47.0	185	33.4
8: R-12223c HLS Sink	127000	< 2000	407	127	389	54	12600	89	232	36.3	141	24.9
9: R-12319c HLS Sink	78700	< 2000	331	264	< 300	46	16200	187	509	66.6	267	48.2

Sample ID	Eu g/t	Gd g/t	Tb g/t	Dy g/t	Ho g/t	Er g/t	Tm g/t	Yb g/t	Lu g/t	U g/t	Th g/t	Ge g/t	Ag g/t	Na g/t
4: R-12236m HLS Sink	---	---	---	---	---	---	---	---	---	---	---	---	---	---
5: R-12318c HLS Sink	3.9	24.9	3.7	28.2	5.7	15.5	3.1	22.9	4.0	15.8	70.6	14	< 20	2880
6: R-12224c HLS Sink	4.7	31.3	4.2	29.2	6.0	19.3	3.7	25.7	4.7	24.8	98.0	17	< 20	3290
7: R-12233c HLS Sink	3.2	30.6	4.3	24.1	6.1	19.7	3.5	22.7	4.0	19.0	73.3	17	< 20	3410
8: R-12223c HLS Sink	4.0	19.6	3.1	21.6	5.2	15.6	2.6	19.7	3.1	13.3	49.5	17	< 20	3220
9: R-12319c HLS Sink	6.0	42.3	7.3	50.1	9.5	31.3	5.3	33.7	6.0	21.1	58.3	12	< 20	5220

Sample ID	P g/t
4: R-12236m HLS Sink	---
5: R-12318c HLS Sink	556
6: R-12224c HLS Sink	681
7: R-12233c HLS Sink	743
8: R-12223c HLS Sink	659
9: R-12319c HLS Sink	3430

Sample ID	Al g/t	As g/t	Ba g/t	Be g/t	Bi g/t	Ca g/t	Cd g/t	Co g/t	Cr g/t	Cu g/t	Fe g/t	K g/t
10: R-12325c HLS Sink	50300	< 200	69	< 3	< 400	44800	< 40	< 200	548	< 40	182000	2850

Sample ID	Li g/t	Mg g/t	Mn g/t	Mo g/t	Ni g/t	Pb g/t	Sb g/t	Se g/t	Si g/t	Sn g/t	Sr g/t
10: R-12325c HLS Sink	< 800	19700	5930	< 300	< 300	< 800	< 400	< 2000	140000	< 800	180

Sample ID	Ti g/t	Tl g/t	V g/t	Y g/t	Zn g/t	Sc g/t	Zr g/t	La g/t	Ce g/t	Pr g/t	Nd g/t	Sm g/t
10: R-12325c HLS Sink	112000	< 2000	369	269	307	50	22700	254	647	82.3	323	56.1

Sample ID	Eu g/t	Gd g/t	Tb g/t	Dy g/t	Ho g/t	Er g/t	Tm g/t	Yb g/t	Lu g/t	U g/t	Th g/t	Ge g/t	Ag g/t	Na g/t
10: R-12325c HLS Sink	7.1	45.2	7.7	51.2	10.2	33.0	5.6	38.4	6.8	29.9	96.9	18	< 20	3610

Sample ID	P g/t
10: R-12325c HLS Sink	2540

Sarah Thyret-Arbour

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LR Internal Dept 14
Attn : T. Grammatikopoulos

31-May-2023

Date Rec. : 03 May 2023
LR Report : **CA02063-MAY23**
Project : CA20I-00000-110-17512-02
Client Ref : MI5031-NOV22

CERTIFICATE OF ANALYSIS

Final Report

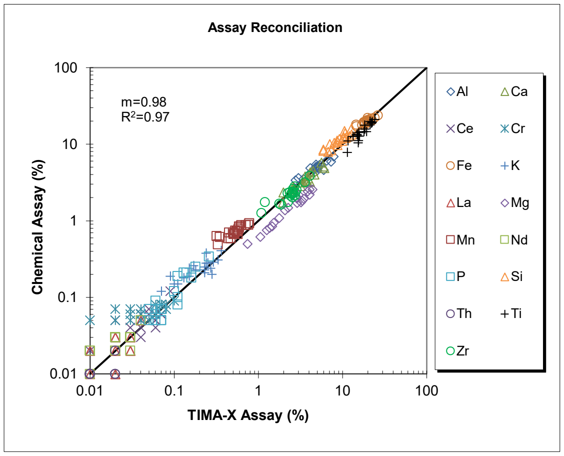
Sample ID	Cs g/t	Ga g/t	In g/t	Nb g/t	Rb g/t	Ta g/t
1: R-12321c HLS Sink	< 10	28	< 3	375	< 10	32
2: R-12334c HLS Sink	< 10	27	< 3	275	10	22
3: R-12231c HLS Sink	< 10	25	< 3	493	< 10	35
4: R-12318c HLS Sink	< 10	30	< 3	363	< 10	26
5: R-12224c HLS Sink	< 10	27	< 3	448	< 10	33
6: R-12233c HLS Sink	< 10	27	< 3	403	< 10	< 10
7: R-12223c HLS Sink	< 10	34	< 3	334	< 10	24
8: R-12319c HLS Sink	< 10	28	< 3	203	10	16
9: R-12325c HLS Sink	< 10	28	< 3	288	< 10	22

Control Quality Assays not suitable for commercial exchange

Jordan Graham
Client Rep

Appendix C – TIMA-X Data

Assay Reconciliation



Sample	R-12221c	R-12222c	R-12225c	R-12226c	R-12227c	R-12228c	R-12232c	R-12234c	R-12236c	R-12245c
Al (TIMA)	4.08	5.97	2.76	4.83	5.08	4.96	7.29	4.13	4.84	5.00
Al (Chemical)	4.14	4.60	3.38	5.45	4.90	5.01	5.93	4.88	5.10	4.57
Ca (TIMA)	2.60	3.73	1.98	4.09	3.62	3.82	5.86	3.57	4.18	3.36
Ca (Chemical)	2.74	3.37	2.35	3.22	3.27	3.24	5.12	3.82	4.28	3.18
Ce (TIMA)	0.05	0.04	0.07	0.04	0.04	0.06	0.02	0.06	0.04	0.05
Ce (Chemical)	0.06	0.06	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.07
Cr (TIMA)	0.02	0.04	0.06	0.07	0.06	0.10	0.03	0.08	0.08	0.01
Cr (Chemical)	0.05	0.05	0.06	0.08	0.08	0.09	0.07	0.08	0.07	0.05
Fe (TIMA)	22.5	19.6	24.1	17.9	19.7	19.9	14.6	19.67	18.4	21.1
Fe (Chemical)	20.4	20.6	22.1	19.3	20.2	21.9	17.9	19.6	19.6	20.8
K (TIMA)	0.10	0.15	0.07	0.28	0.24	0.23	0.33	0.23	0.29	0.11
K (Chemical)	0.15	0.19	0.12	0.20	0.28	0.21	0.31	0.23	0.29	0.15
La (TIMA)	0.02	0.02	0.03	0.02	0.02	0.03	0.01	0.03	0.02	0.02
La (Chemical)	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Mg (TIMA)	1.05	1.76	0.74	4.05	3.47	3.31	4.40	3.01	3.85	1.25
Mg (Chemical)	0.62	1.09	0.50	2.21	1.94	1.84	2.56	2.19	2.43	0.76
Mn (TIMA)	0.71	0.59	0.78	0.50	0.51	0.55	0.35	0.57	0.52	0.63
Mn (Chemical)	0.87	0.84	0.93	0.70	0.67	0.72	0.61	0.67	0.69	0.87
Nd (TIMA)	0.02	0.02	0.03	0.02	0.02	0.02	0.01	0.03	0.02	0.02
Nd (Chemical)	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03
P (TIMA)	0.06	0.07	0.07	0.11	0.06	0.07	0.11	0.16	0.13	0.07
P (Chemical)	0.05	0.05	0.05	0.10	0.09	0.07	0.19	0.18	0.21	0.07
Si (TIMA)	7.04	8.68	5.90	11.1	10.3	9.86	12.8	8.6	10.2	7.35
Si (Chemical)	10.1	9.75	8.24	12.5	12.5	11.1	13.4	11.2	12.2	8.42
Th (TIMA)	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Th (Chemical)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ti (TIMA)	22.3	18.3	24.2	14.89	15.2	15.5	11.6	19.18	15.9	21.1
Ti (Chemical)	19.2	17.8	21.2	13.3	12.8	14.2	11.1	14.7	12.8	19.9
Zr (TIMA)	2.75	2.60	3.59	2.24	2.37	2.56	1.20	2.74	2.42	2.70
Zr (Chemical)	2.33	2.60	3.18	2.29	2.35	2.39	1.75	2.14	2.11	2.80

Sample	R-12246c	R-12223c	R-12224c	R-12231c	R-12233c	R-12318c	R-12319c	R-12321c	R-12334c	R-12325c
Al (TIMA)	3.42	7.83	4.24	2.97	5.29	6.44	5.16	5.15	4.95	5.03
Al (Chemical)	3.53	6.89	4.30	3.63	5.41	6.12	5.12	5.14	5.11	5.03
Ca (TIMA)	2.60	6.07	3.17	1.95	3.60	4.63	5.60	3.89	4.12	4.46
Ca (Chemical)	2.56	4.88	2.86	1.74	3.40	4.03	5.78	3.61	4.30	4.48
Ce (TIMA)	0.09	0.01	0.04	0.03	0.04	0.04	0.06	0.07	0.06	0.07
Ce (Chemical)	0.12	0.02	0.05	0.04	0.03	0.04	0.05	0.06	0.04	0.06
Cr (TIMA)	0.07	0.03	0.03	0.07	0.04	0.04	0.05	0.04	0.02	0.04
Cr (Chemical)	0.08	0.05	0.06	0.08	0.07	0.06	0.05	0.06	0.07	0.05
Fe (TIMA)	21.68	14.72	21.13	26.26	20.42	18.15	17.16	19.67	19.67	18.58
Fe (Chemical)	21.60	17.10	20.20	23.80	20.00	18.90	17.80	19.40	19.20	18.20
K (TIMA)	0.13	0.27	0.15	0.09	0.17	0.23	0.36	0.18	0.24	0.25
K (Chemical)	0.18	0.24	0.24	0.19	0.26	0.25	0.41	0.23	0.38	0.28
La (TIMA)	0.04	0.01	0.02	0.01	0.02	0.02	0.03	0.03	0.02	0.03
La (Chemical)	0.05	0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.02	0.03
Mg (TIMA)	1.46	3.19	1.52	1.35	2.06	2.88	4.05	2.26	2.85	2.86
Mg (Chemical)	0.85	1.74	0.94	0.81	1.38	1.72	2.56	1.48	2.04	1.97
Mn (TIMA)	0.57	0.32	0.59	0.76	0.58	0.45	0.33	0.53	0.47	0.44
Mn (Chemical)	0.73	0.63	0.81	0.88	0.77	0.70	0.49	0.74	0.59	0.59
Nd (TIMA)	0.04	0.01	0.02	0.01	0.02	0.02	0.02	0.03	0.02	0.03
Nd (Chemical)	0.05	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.03
P (TIMA)	0.11	0.05	0.06	0.05	0.06	0.06	0.26	0.10	0.14	0.18
P (Chemical)	0.08	0.07	0.07	0.05	0.07	0.06	0.34	0.12	0.21	0.25
Si (TIMA)	6.71	12.13	7.96	5.91	8.71	10.79	12.72	9.16	10.54	10.70
Si (Chemical)	8.02	12.80	10.50	8.55	10.80	12.10	16.10	11.80	15.00	14.00
Th (TIMA)	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02
Th (Chemical)	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ti (TIMA)	22.55	13.33	21.25	21.86	18.39	14.78	11.36	17.98	15.29	15.50
Ti (Chemical)	19.60	12.70	17.90	18.80	15.90	13.40	7.87	14.70	10.50	11.20
Zr (TIMA)	4.08	1.09	2.60	2.85	2.55	1.78	1.86	2.58	2.26	2.47
Zr (Chemical)	3.85	1.26	2.30	2.53	2.02	1.66	1.62	2.26	1.74	2.27

Modals

Survey		**CALR-17512-02 / MI5024-MAY22 & MI5031-NOV22**														
Project		**Virginia Department of Mines Minerals and Energy**														
Sample		**R-12221c**	**R-12222c**	**R-12225c**	**R-12226c**			**R-12227c**	**R-12228c**	**R-12232c**	**R-12234c**			**R-12236c**	**R-12245c**	**R-12246c**
Fraction		**Sink**	**Sink**	**Sink**	**Combined**	**Sink**	**Float**	**Sink**	**Sink**	**Sink**	**Combined**	**Sink**	**Float**	**Sink**	**Sink**	**Sink**
Mass Size Distribution (%)		100.0	100.0	100.0	100.0	54.2	45.8	100.0	100.0	100.0	100.0	34.3	65.7	100.0	100.0	100.0
Mineral Mass (%)	Monazite	0.20	0.18	0.30	0.09	0.16	0.00	0.15	0.23	0.09	0.09	0.24	0.01	0.16	0.20	0.36
	Xenotime	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02
	Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Allanite	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.02	0.01
	Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Gorceixite	0.01	0.02	0.00	0.02	0.02	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.03
	Chromite	0.07	0.10	0.18	0.10	0.19	0.00	0.16	0.28	0.08	0.08	0.22	0.00	0.24	0.04	0.19
	Spinel	0.01	0.10	0.05	0.04	0.08	0.00	0.13	0.18	0.09	0.03	0.09	0.00	0.05	0.04	0.05
	Gahnite	0.02	0.02	0.01	0.01	0.02	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.02	0.02	0.01
	Fe-Oxides	0.02	0.11	0.00	0.02	0.04	0.00	2.01	2.28	0.44	0.01	0.02	0.00	0.49	0.01	1.08
	Goethite	0.01	0.05	0.03	0.00	0.01	0.00	0.52	0.22	0.23	0.01	0.01	0.00	0.12	0.01	1.16
	Ilmenite	51.2	40.3	56.3	15.4	28.1	0.43	29.5	32.4	19.9	13.8	40.2	0.08	30.9	45.2	40.2
	Altered Ilmenite	6.64	5.72	7.40	3.52	6.36	0.15	6.19	5.63	5.09	2.64	7.62	0.04	7.50	6.96	10.7
	Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
	Rutile	5.04	4.72	5.10	2.67	4.31	0.72	4.11	3.63	3.92	1.63	4.50	0.13	3.64	5.83	7.41
	Pseudorutile	0.03	0.02	0.02	0.01	0.02	0.00	0.03	0.02	0.03	0.00	0.01	0.00	0.02	0.03	0.03
	Zircon	5.61	5.30	7.33	2.56	4.57	0.18	4.85	5.23	2.45	1.93	5.60	0.02	4.95	5.51	8.34
	Baddeleyite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Thorite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluorite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Anhydrite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Amphibole/Pyroxene	8.44	14.1	5.68	21.0	31.0	9.21	25.9	25.1	36.6	11.2	25.0	3.92	30.8	10.1	11.9
	Garnets	0.36	0.60	0.31	0.77	1.32	0.12	1.39	1.43	1.14	0.27	0.72	0.03	1.31	0.39	0.50
	Staurolite	3.41	5.21	1.66	1.13	2.05	0.04	3.52	2.94	4.90	0.60	1.71	0.02	2.97	3.80	1.85
	Kyanite	3.14	4.77	1.85	1.47	2.30	0.48	2.54	2.54	4.42	0.95	2.62	0.08	2.07	4.01	2.09
	Biotite	0.01	0.00	0.00	0.05	0.01	0.10	0.02	0.01	0.00	0.05	0.00	0.08	0.00	0.01	0.04
	Chlorite	0.83	1.98	0.75	5.14	9.23	0.30	9.18	7.37	4.81	0.96	2.55	0.13	6.03	0.95	0.74
	Quartz	3.01	1.53	2.87	35.6	1.59	75.9	1.36	0.98	0.96	45.0	0.87	68.1	0.69	1.26	1.19
	Orthoclase	0.09	0.08	0.05	1.15	0.04	2.46	0.06	0.06	0.04	4.73	0.03	7.19	0.05	0.02	0.04
	Plagioclase	0.22	0.28	0.19	3.28	0.53	6.52	0.48	0.38	0.49	12.7	0.63	19.0	0.42	0.19	0.34
	Muscovite	0.06	0.07	0.05	0.42	0.09	0.80	0.09	0.06	0.07	0.27	0.05	0.39	0.05	0.06	0.12
	Clays	0.05	0.05	0.04	0.05	0.03	0.08	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.05	0.02
	Epidote	10.1	13.1	8.40	3.30	5.11	1.16	5.55	7.10	11.5	1.84	4.89	0.25	4.74	13.5	8.06
	Ti Silicates	0.96	0.78	0.94	0.74	1.01	0.42	0.93	0.77	0.86	0.36	0.84	0.11	0.81	1.03	1.67
	Olivine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Apatite	0.03	0.08	0.00	0.29	0.33	0.24	0.09	0.06	0.40	0.28	0.53	0.16	0.48	0.06	0.08
	Titanite	0.31	0.46	0.17	0.54	0.93	0.09	0.49	0.50	0.82	0.24	0.65	0.02	0.79	0.42	0.48
	Carbonates	0.00	0.02	0.00	0.00	0.00	0.00	0.18	0.04	0.03	0.02	0.00	0.03	0.02	0.00	0.01
	Sulphides	0.00	0.07	0.01	0.14	0.15	0.14	0.13	0.14	0.03	0.03	0.05	0.02	0.25	0.05	0.91
	Ni-(Cu-Co) Alloy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Marshite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Gibbsite	0.02	0.03	0.03	0.02	0.04	0.00	0.04	0.04	0.03	0.01	0.03	0.00	0.02	0.02	0.03
	Tin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
	Wollastonite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Schorl	0.13	0.18	0.13	0.33	0.29	0.38	0.30	0.32	0.44	0.19	0.15	0.20	0.26	0.17	0.25
	Other	0.01	0.01	0.10	0.02	0.03	0.01	0.05	0.03	0.08	0.02	0.05	0.00	0.03	0.02	0.02
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Virginia Department of Energy, Geology and Mineral Resources Progran
CALR-17512-02
MI5024-MAY22 & MI5031-NOV22

Modals

Survey		**CALR-17512-02 / MI5024-MAY22 & MI5031-NOV22**																	
Project		**Virginia Department of Mines Minerals and Energy**																	
Sample		**R-12227m**			**R-12223c**	**R-12224c**	**R-12231c**	**R-12233c**	**R-12318c**			**R-12319c**			**R-12321c**	**R-12334c**	**R-12325c**	**R-12236m**	**R-12245m**
Fraction		**Combined**	**Sink**	**Float**	**Sink**	**Sink**	**Sink**	**Sink**	**Combined**	**Sink**	**Float**	**Combined**	**Sink**	**Float**	**Sink**	**Sink**	**Sink**	**Sink**	**Sink**
Mass Size Distribution (%)		100.0	0.01	100.0	100.0	100.0	100.0	100.0	100.0	21.6	78.4	100.0	24.8	75.2	100.0	100.0	100.0	100.0	100.0
Mineral Mass (%)	Monazite	0.01	1.46	0.01	0.05	0.17	0.12	0.16	0.04	0.17	0.00	0.07	0.21	0.02	0.26	0.20	0.26	0.23	1.48
	Xenotime	0.00	0.14	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.02	0.02	0.08
	Synchysite	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Allanite	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.02	0.01	0.01
	Pyrochlore/Columbite	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12
	Gorceixite	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.02
	Chromite	0.00	0.17	0.00	0.07	0.10	0.20	0.10	0.02	0.11	0.00	0.05	0.13	0.02	0.12	0.07	0.11	0.10	0.17
	Spinel	0.00	0.01	0.00	0.08	0.05	0.05	0.12	0.02	0.09	0.00	0.01	0.03	0.00	0.06	0.04	0.06	0.05	0.01
	Gahnite	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.05
	Fe-Oxides	0.04	3.33	0.04	0.41	0.68	4.61	0.83	0.38	1.57	0.05	1.94	6.24	0.52	1.04	3.75	3.11	0.94	2.81
	Goethite	0.39	4.76	0.39	0.05	0.01	0.03	0.12	0.02	0.05	0.01	0.09	0.28	0.03	0.01	0.16	0.08	4.25	2.47
	Ilmenite	0.28	23.8	0.28	20.7	42.1	51.2	38.5	6.57	29.3	0.31	5.99	20.2	1.30	35.7	31.1	28.9	12.6	26.9
	Altered Ilmenite	0.05	3.72	0.05	6.95	9.39	6.41	7.57	1.45	6.13	0.16	1.15	3.83	0.26	7.76	5.77	6.38	2.32	3.43
	Ilmenorutile	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Rutile	0.42	3.75	0.42	5.49	6.02	4.15	4.37	1.11	4.08	0.29	1.57	4.05	0.75	4.87	3.95	4.92	2.55	3.52
	Pseudorutile	0.00	0.02	0.00	0.06	0.05	0.03	0.04	0.03	0.05	0.02	0.02	0.03	0.02	0.03	0.02	0.04	0.05	0.04
	Zircon	0.22	22.1	0.22	2.22	5.31	5.84	5.22	0.84	3.64	0.06	1.17	3.81	0.30	5.27	4.63	5.06	3.68	19.79
	Baddeleyite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Thorite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluorite	0.21	0.02	0.21	0.01	0.01	0.00	0.01	0.01	0.01	0.02	0.03	0.01	0.04	0.01	0.01	0.01	0.09	0.03
	Anhydrite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Amphibole/Pyroxene	9.69	12.1	9.69	26.8	11.8	8.55	15.8	11.6	22.9	8.44	19.3	34.2	14.4	17.5	22.3	22.9	26.8	9.21
	Garnets	3.51	1.40	3.51	1.16	0.83	1.50	1.25	0.38	1.40	0.09	0.89	2.00	0.53	1.29	1.42	1.53	0.95	1.33
	Staurolite	0.01	0.58	0.01	4.73	3.06	2.25	4.06	1.12	4.65	0.15	0.48	1.50	0.14	3.43	2.71	2.27	1.14	0.55
	Kyanite	0.04	0.81	0.04	5.79	2.53	1.69	3.63	1.39	4.55	0.52	0.87	2.30	0.40	3.48	3.21	3.20	1.32	1.30
	Biotite	0.29	0.07	0.29	0.01	0.02	0.00	0.01	0.18	0.01	0.23	0.34	0.03	0.44	0.01	0.03	0.02	0.14	0.11
	Chlorite	1.41	1.46	1.41	2.61	2.17	5.86	3.93	1.31	4.84	0.34	1.67	4.01	0.90	4.33	5.50	4.82	2.60	1.65
	Quartz	37.6	7.27	37.6	1.52	2.58	1.29	1.40	57.4	1.80	72.7	38.2	3.41	49.7	1.66	3.00	2.72	19.26	9.06
	Orthoclase	2.77	0.43	2.77	0.11	0.22	0.06	0.10	3.51	0.13	4.44	4.27	0.32	5.57	0.12	0.25	0.30	4.12	1.41
	Plagioclase	9.00	1.58	9.00	0.38	0.67	0.20	0.37	7.34	0.41	9.25	11.9	1.21	15.4	0.43	1.02	0.85	4.74	4.54
	Muscovite	10.9	0.78	10.9	0.12	0.10	0.06	0.12	0.46	0.08	0.56	1.05	0.26	1.31	0.12	0.15	0.19	1.47	1.30
	Clays	0.55	0.09	0.55	0.02	0.02	0.03	0.02	0.02	0.01	0.02	0.03	0.02	0.03	0.04	0.03	0.03	0.08	0.11
	Epidote	0.28	2.26	0.28	19.0	10.7	4.98	10.7	3.72	12.5	1.29	3.29	7.57	1.88	10.7	8.07	9.54	4.00	4.55
	Ti Silicates	0.46	1.19	0.46	0.55	0.42	0.32	0.47	0.18	0.41	0.12	0.26	0.45	0.20	0.36	0.32	0.35	0.33	0.41
	Olivine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00
	Apatite	0.06	0.33	0.06	0.04	0.05	0.03	0.08	0.07	0.06	0.08	1.06	1.07	1.06	0.22	0.45	0.64	0.41	0.27
	Titanite	0.09	0.39	0.09	0.57	0.49	0.27	0.49	0.16	0.41	0.09	0.61	1.23	0.41	0.81	0.95	0.95	0.66	0.35
	Carbonates	0.73	0.49	0.73	0.05	0.10	0.00	0.02	0.30	0.05	0.37	2.90	0.55	3.67	0.10	0.40	0.24	0.68	0.29
	Sulphides	2.19	3.61	2.19	0.01	0.05	0.01	0.01	0.03	0.03	0.03	0.04	0.08	0.03	0.02	0.02	0.07	3.17	0.62
	Ni-(Cu-Co) Alloy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Marshite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	Gibbsite	0.00	0.01	0.00	0.07	0.03	0.02	0.04	0.01	0.01	0.01	0.01	0.05	0.00	0.05	0.01	0.03	0.00	0.01
	Tin	0.03	0.03	0.03	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.05	0.02	0.06	0.01	0.03	0.02	0.07	0.26
	Wollastonite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Schorl	18.7	1.86	18.7	0.34	0.22	0.19	0.41	0.37	0.42	0.36	0.68	0.85	0.63	0.22	0.35	0.30	1.04	1.47
	Other	0.10	0.03	0.10	0.03	0.01	0.01	0.01	0.01	0.03	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.06	0.18
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

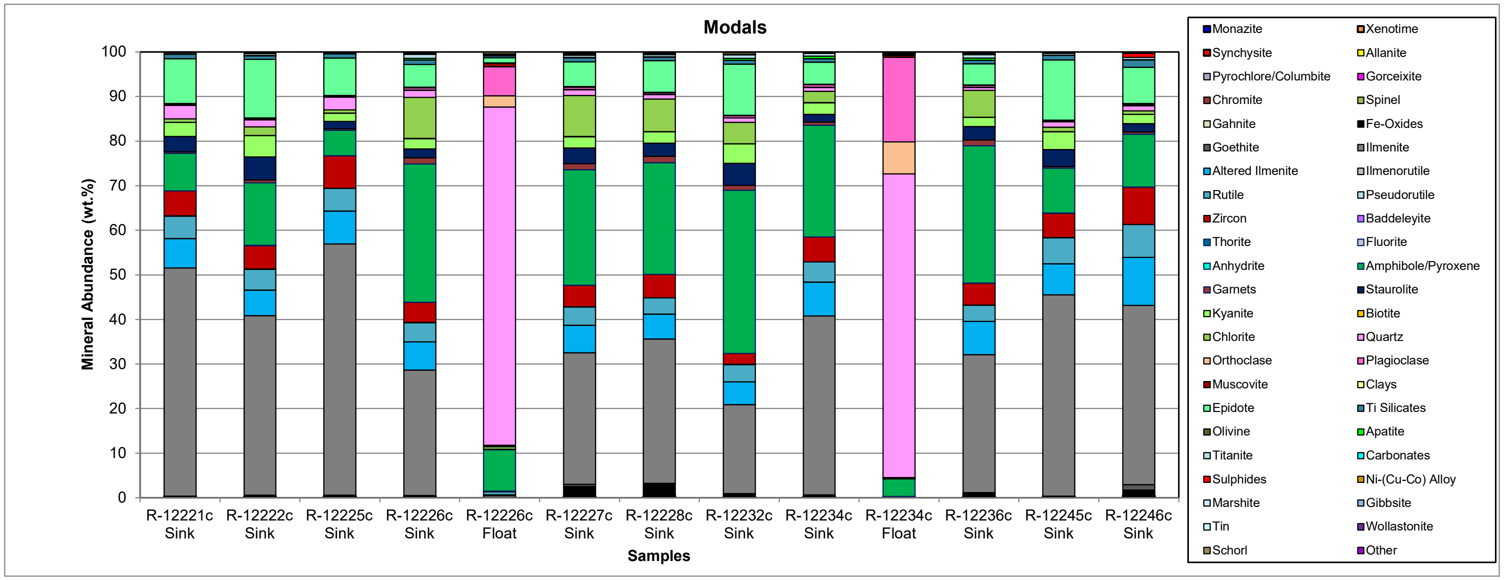
Modals-Condensed

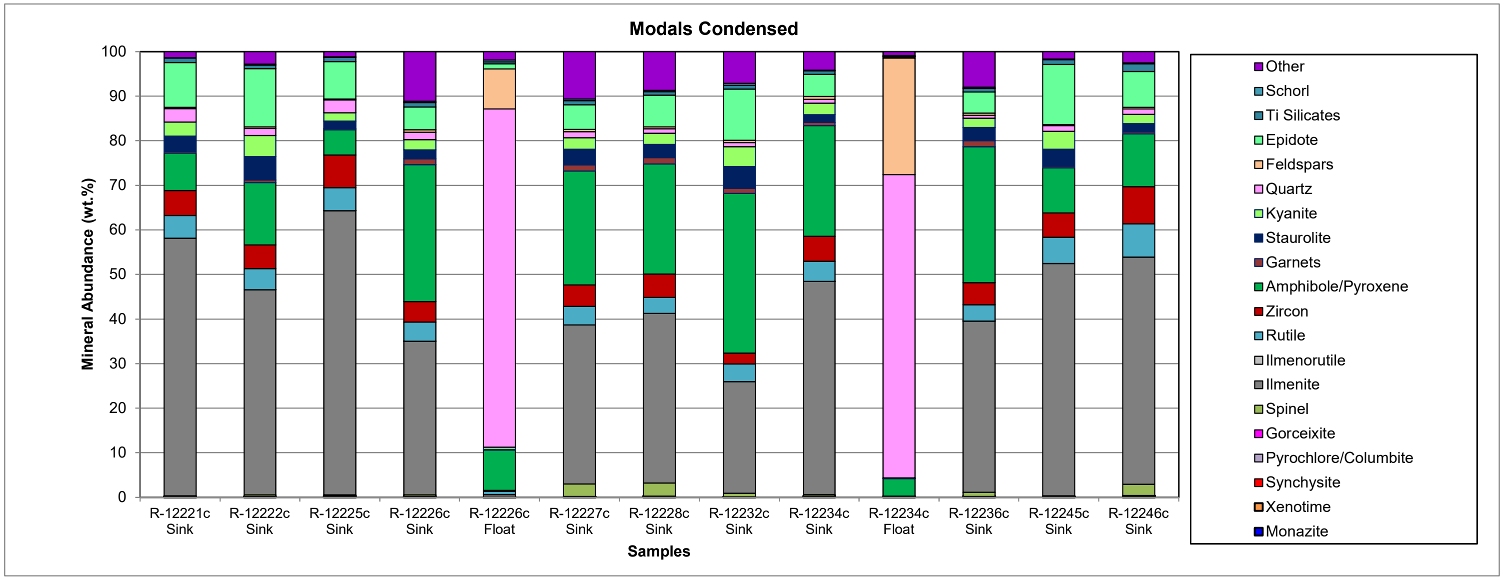
Survey		CALR-17512-02 / MI5024-MAY22 & MI5031-NOV22														
Project		Virginia Department of Mines Minerals and Energy														
Sample		R-12221c	R-12222c	R-12225c	R-12226c			R-12227c	R-12228c	R-12232c	R-12234c			R-12236c	R-12245c	R-12246c
Fraction		Sink	Sink	Sink	Combined	Sink	Float	Sink	Sink	Sink	Combined	Sink	Float	Sink	Sink	Sink
Mass Size Distribution (%)		100.0	100.0	100.0	100.0	54.2	45.8	100.0	100.0	100.0	100.0	34.3	65.7	100.0	100.0	100.0
Mineral Mass (%)	Monazite	0.20	0.18	0.30	0.09	0.16	0.00	0.15	0.23	0.09	0.09	0.24	0.01	0.16	0.20	0.36
	Xenotime	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02
	Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Gorceixite	0.00	0.02	0.00	0.02	0.02	0.02	0.00	0.02	0.01	0.02	0.02	0.02	0.01	0.00	0.03
	Spinel	0.13	0.38	0.27	0.18	0.33	0.01	2.82	2.97	0.84	0.13	0.36	0.01	0.92	0.12	2.49
	Ilmenite	57.8	46.0	63.7	18.9	34.5	0.58	35.7	38.0	25.0	16.5	47.8	0.11	38.4	52.1	51.0
	Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
	Rutile	5.07	4.74	5.12	2.68	4.33	0.72	4.14	3.65	3.96	1.64	4.52	0.13	3.66	5.85	7.44
	Zircon	5.61	5.30	7.33	2.56	4.57	0.18	4.85	5.24	2.45	1.93	5.60	0.02	4.95	5.52	8.34
	Amphibole/Pyroxene	8.44	14.0	5.67	20.8	30.7	9.08	25.5	24.7	35.8	11.1	24.9	3.91	30.5	10.1	11.8
	Garnets	0.36	0.60	0.31	0.77	1.32	0.12	1.39	1.43	1.14	0.27	0.72	0.03	1.31	0.39	0.50
	Staurolite	3.41	5.21	1.66	1.13	2.05	0.04	3.52	2.94	4.90	0.60	1.71	0.02	2.97	3.80	1.85
	Kyanite	3.14	4.77	1.85	1.47	2.30	0.48	2.54	2.54	4.42	0.95	2.62	0.08	2.07	4.01	2.09
	Quartz	3.01	1.53	2.87	35.6	1.59	75.9	1.36	0.98	0.96	45.0	0.87	68.1	0.69	1.26	1.19
	Feldspars	0.31	0.36	0.24	4.43	0.57	8.99	0.54	0.44	0.52	17.4	0.66	26.2	0.47	0.21	0.38
	Epidote	10.1	13.1	8.40	3.30	5.11	1.16	5.55	7.10	11.5	1.84	4.89	0.25	4.74	13.5	8.06
	Ti Silicates	0.96	0.78	0.94	0.74	1.01	0.42	0.93	0.77	0.86	0.36	0.84	0.11	0.81	1.03	1.67
	Schorl	0.13	0.18	0.13	0.33	0.29	0.38	0.30	0.32	0.44	0.19	0.15	0.20	0.26	0.17	0.25
	Other	1.34	2.82	1.16	6.92	11.2	1.90	10.7	8.69	7.09	1.99	4.15	0.86	7.99	1.66	2.51
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Survey		CALR-17512-02 / MI5024-MAY22 & MI5031-NOV22																	
Project		Virginia Department of Mines Minerals and Energy																	
Sample		R-12227m			R-12223c	R-12224c	R-12231c	R-12233c	R-12318c			R-12319c			R-12321c	R-12334c	R-12325c	R-12236m	R-12245m
Fraction		Combined	Sink	Float	Sink	Sink	Sink	Sink	Combined	Sink	Float	Combined	Sink	Float	Sink	Sink	Sink	Sink	Sink
Mass Size Distribution (%)		100.0	0.01	100.0	100.0	100.0	100.0	100.0	100.0	21.6	78.4	100.0	24.8	75.2	100.0	100.0	100.0	100.0	100.0
Mineral Mass (%)	Monazite	0.01	1.46	0.01	0.05	0.17	0.12	0.16	0.04	0.17	0.00	0.07	0.21	0.02	0.26	0.20	0.26	0.23	1.48
	Xenotime	0.00	0.14	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.02	0.02	0.08
	Synchysite	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Pyrochlore/Columbite	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.12
	Gorceixite	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.02
	Spinel	0.44	8.27	0.44	0.61	0.86	4.90	1.17	0.44	1.83	0.06	2.09	6.69	0.57	1.23	4.03	3.37	5.31	5.51
	Ilmenite	0.33	27.5	0.33	27.7	51.5	57.6	46.1	8.02	35.4	0.47	7.13	24.0	1.56	43.4	36.9	35.3	14.9	30.4
	Ilmenorutile	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Rutile	0.42	3.77	0.42	5.55	6.07	4.18	4.42	1.14	4.13	0.31	1.59	4.08	0.77	4.90	3.98	4.96	2.60	3.56
	Zircon	0.22	22.1	0.22	2.22	5.31	5.84	5.22	0.84	3.64	0.06	1.17	3.81	0.30	5.27	4.63	5.06	3.69	19.79
	Amphibole/Pyroxene	9.67	11.9	9.67	26.4	11.7	8.46	15.6	11.4	22.5	8.35	19.0	33.6	14.2	17.3	21.9	22.6	26.5	9.1
	Garnets	3.51	1.40	3.51	1.16	0.83	1.50	1.25	0.38	1.40	0.09	0.89	2.00	0.53	1.29	1.42	1.53	0.95	1.33
	Staurolite	0.01	0.58	0.01	4.73	3.06	2.25	4.06	1.12	4.65	0.15	0.48	1.50	0.14	3.43	2.71	2.27	1.14	0.55
	Kyanite	0.04	0.81	0.04	5.79	2.53	1.69	3.63	1.39	4.55	0.52	0.87	2.30	0.40	3.48	3.21	3.20	1.32	1.30
	Quartz	37.6	7.27	37.6	1.52	2.58	1.29	1.40	57.4	1.80	72.7	38.2	3.41	49.7	1.66	3.00	2.72	19.26	9.06
	Feldspars	11.8	2.01	11.8	0.49	0.89	0.26	0.47	10.8	0.54	13.7	16.1	1.54	20.9	0.54	1.26	1.15	8.86	5.94
	Epidote	0.28	2.26	0.28	19.0	10.7	4.98	10.7	3.72	12.5	1.29	3.29	7.57	1.88	10.7	8.07	9.54	4.00	4.55
	Ti Silicates	0.46	1.19	0.46	0.55	0.42	0.32	0.47	0.18	0.41	0.12	0.26	0.45	0.20	0.36	0.32	0.35	0.33	0.41
	Schorl	18.7	1.86	18.7	0.34	0.22	0.19	0.41	0.37	0.42	0.36	0.68	0.85	0.63	0.22	0.35	0.30	1.04	1.47
	Other	16.5	7.53	16.6	3.90	3.17	6.40	4.92	2.76	5.99	1.86	8.09	7.94	8.14	5.91	7.94	7.39	9.79	5.38
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Virginia Department of Energy, Geology and Mineral Resources Program
CALR-17512-02
MI5024-MAY22 & MI5031-NOV22

Modal Chart





Virginia Department of Mines Minerals and Energy
CALR-17512-02
MI5024-MAY22 & MI5031-NOV22

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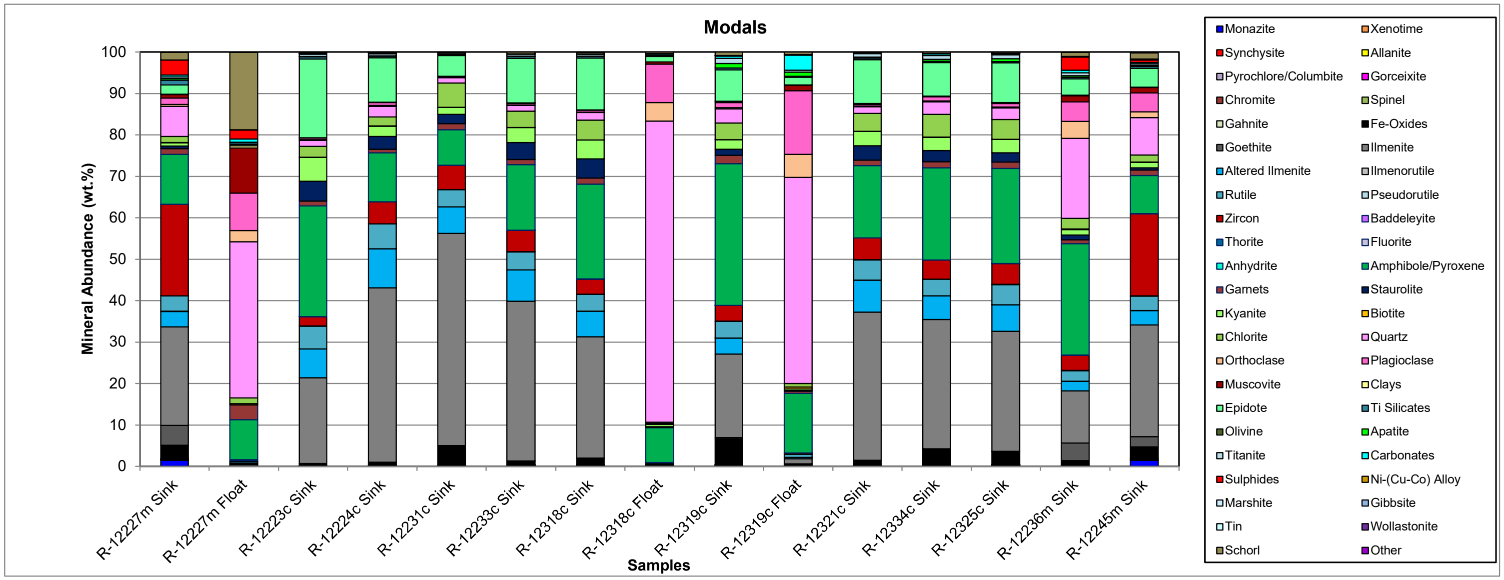

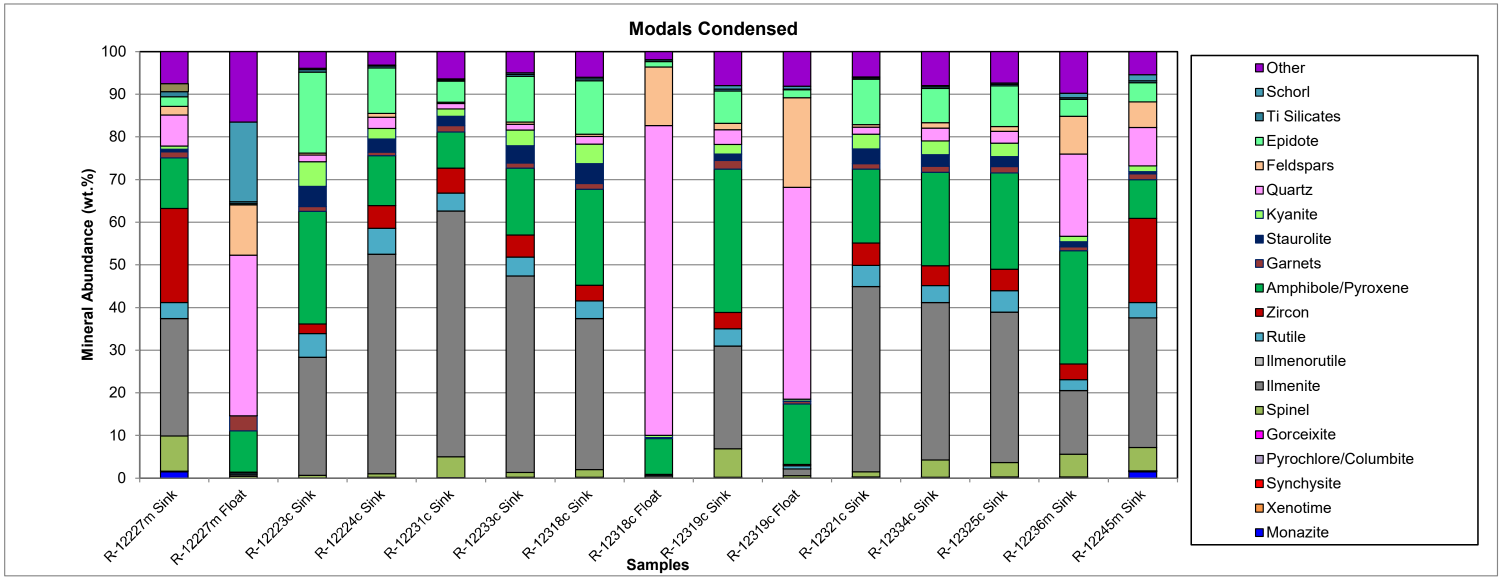

Virginia Department of Mines Minerals and Energy
CALR-17512-02
MI5024-MAY22 & MI5031-NOV22

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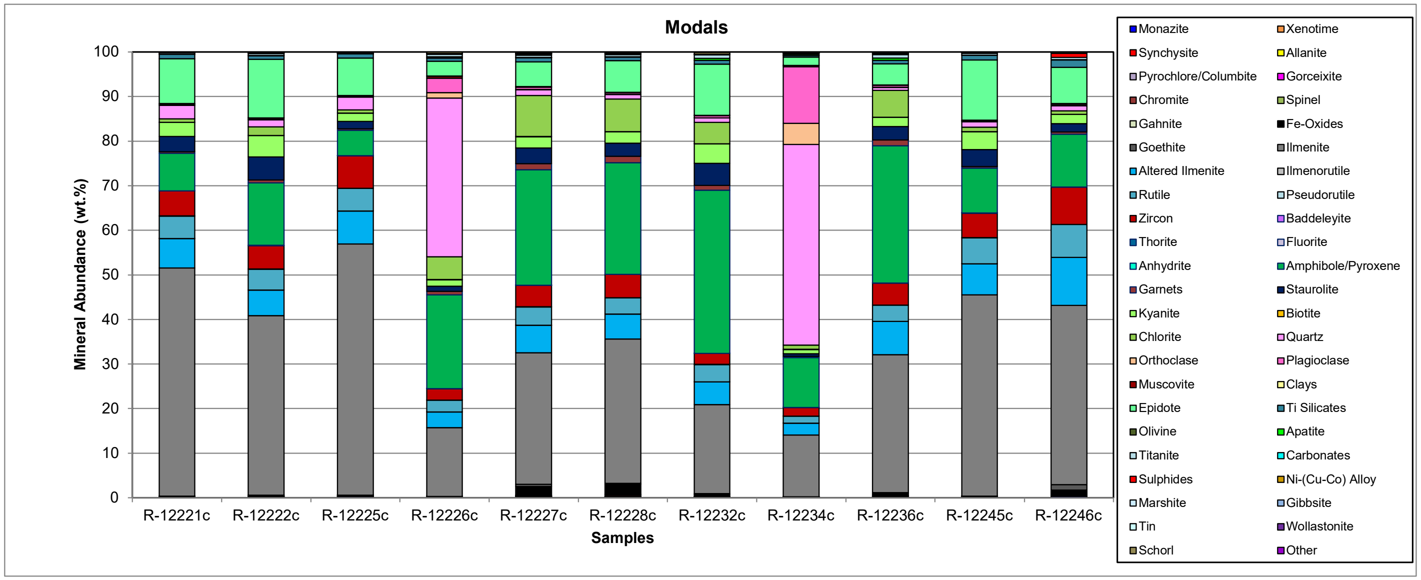

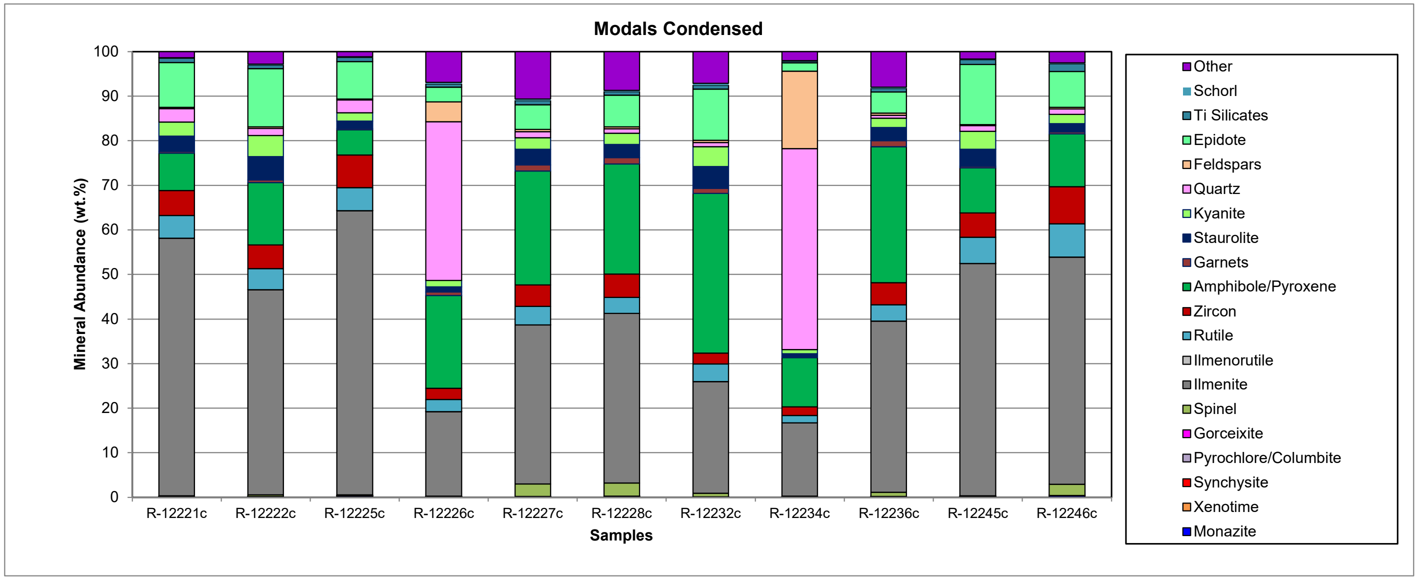

Virginia Department of Mines Minerals and Energy
CALR-17512-02
MI5024-MAY22 & MI5031-NOV22

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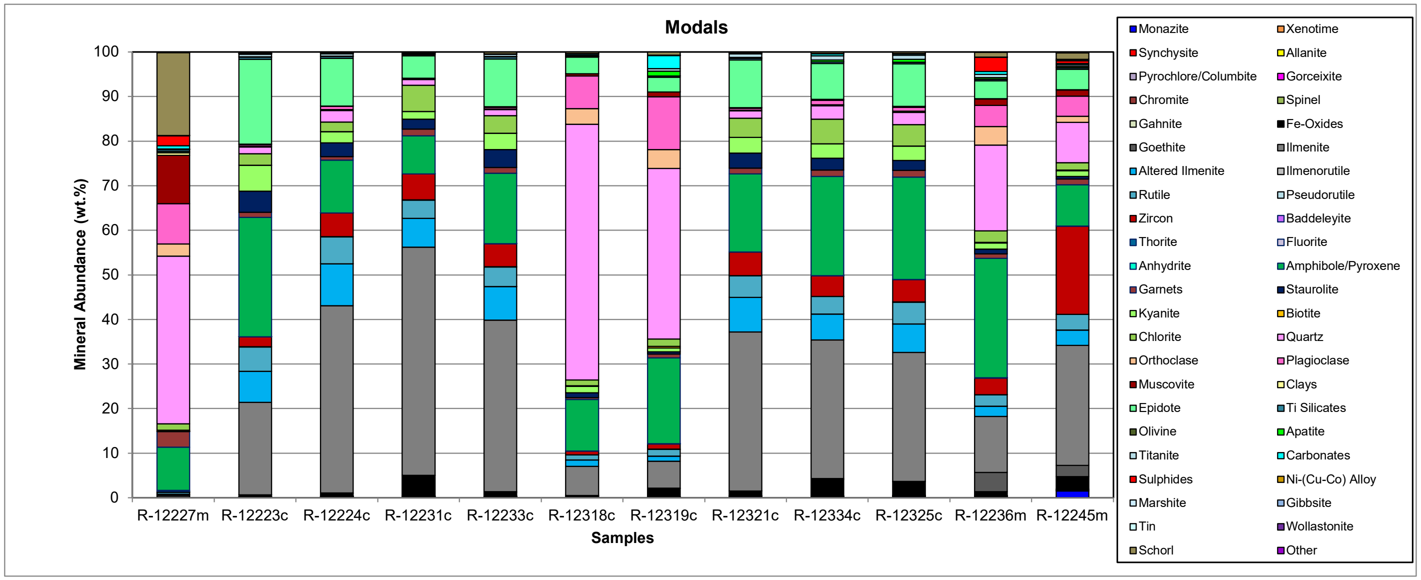

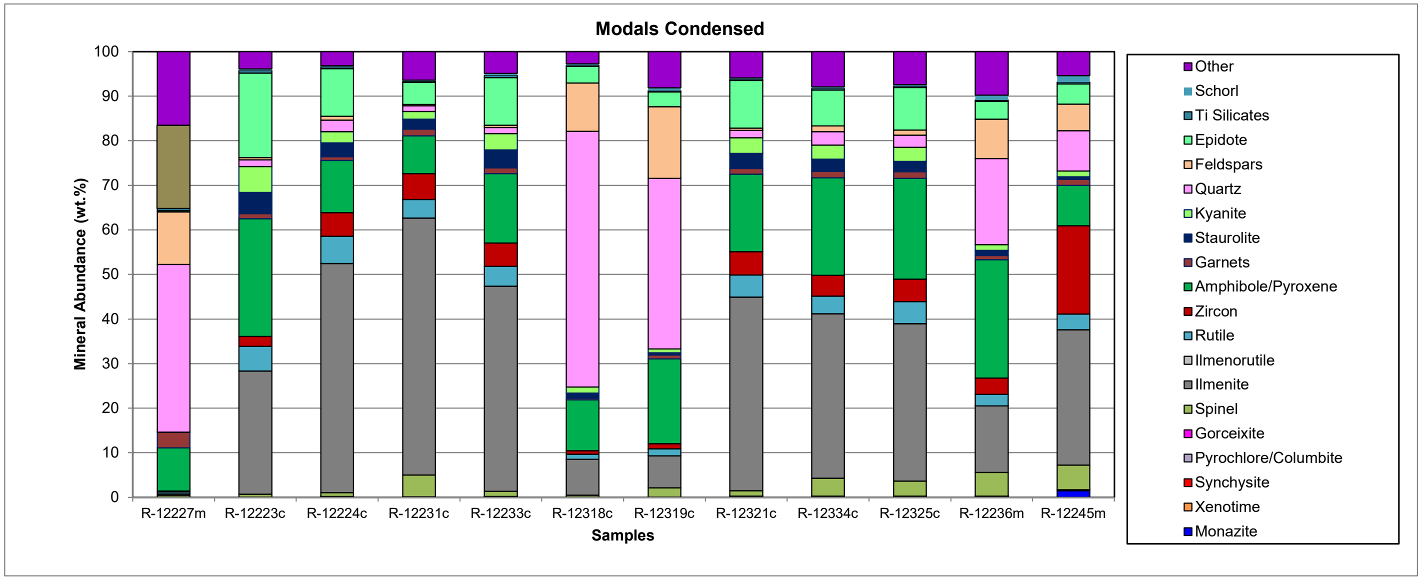

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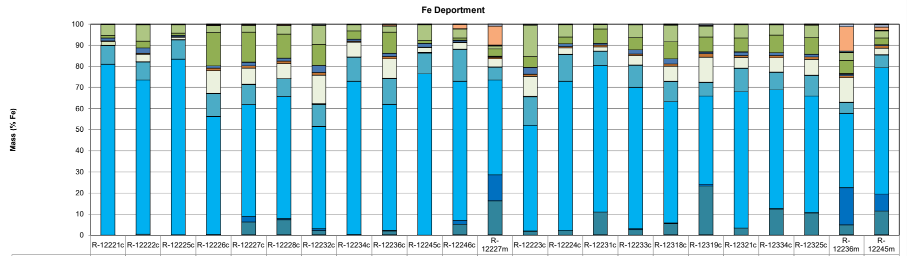


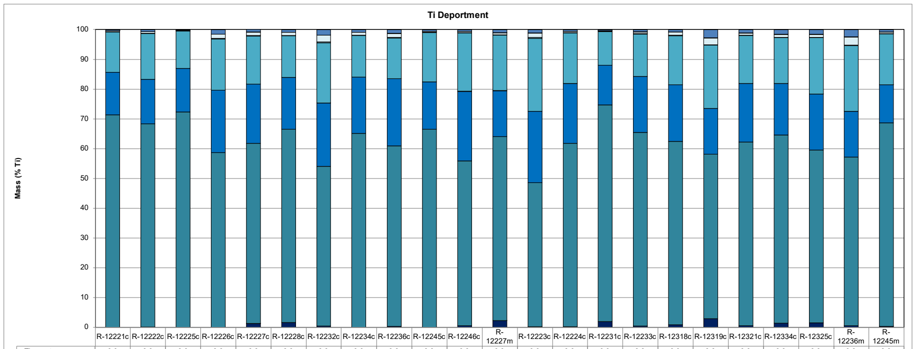
	R-12221c	R-12222c	R-12225c	R-12226c	R-12227c	R-12228c	R-12232c	R-12234c	R-12236c	R-12245c	R-12246c	R-12227m	R-12223c	R-12224c	R-12231c	R-12233c	R-12318c	R-12319c	R-12321c	R-12334c	R-12325c	R-12236m	R-12245m
The rest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
Schorl	0.1	0.1	0.1	0.2	0.2	0.2	0.4	0.1	0.2	0.1	0.2	0.9	0.3	0.1	0.1	0.2	0.3	0.6	0.1	0.2	0.2	1.1	1.2
Sulphides	0.0	0.2	0.0	0.4	0.3	0.3	0.1	0.1	0.6	0.1	2.0	9.0	0.0	0.1	0.0	0.0	0.1	0.2	0.1	0.1	0.2	11.7	1.5
Carbonates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.6	0.2
Ti Silicates	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Epidote	5.2	7.7	4.0	3.3	3.2	4.1	9.1	2.9	3.0	7.4	4.3	1.4	14.9	5.8	2.2	6.1	8.0	5.1	6.2	4.7	5.9	3.6	3.3
Chlorite	1.2	3.2	1.0	15.7	14.2	11.3	10.0	4.0	10.0	1.4	1.1	3.6	5.2	3.2	6.8	5.8	7.9	7.1	6.6	8.4	7.9	6.3	3.1
Biotite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
Staurolite	1.5	2.6	0.7	1.1	1.7	1.4	3.2	0.8	1.6	1.7	0.8	0.3	3.1	1.4	0.8	1.9	2.5	0.8	1.7	1.3	1.2	0.9	0.3
Garnets	0.2	0.5	0.2	1.3	1.1	1.2	1.2	0.5	1.1	0.3	0.3	0.9	1.1	0.5	0.9	0.9	1.1	1.6	0.9	1.1	1.2	0.9	1.3
Amphibole/Pyroxene	1.8	3.5	1.2	10.7	7.7	7.1	13.6	7.0	9.3	2.3	3.0	3.7	9.4	3.1	1.9	4.3	7.1	11.9	5.0	6.8	7.5	11.4	3.0
Pseudorutile	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Rutile	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Altered Ilmenite	8.8	8.6	9.1	10.8	9.4	8.4	10.5	11.4	12.1	9.9	15.0	6.1	13.4	12.6	6.9	10.5	9.6	6.3	11.2	8.3	9.7	5.2	6.0
Ilmenite	80.9	72.9	83.2	55.9	53.0	57.8	48.6	72.7	59.8	76.4	66.0	45.0	50.1	70.7	69.3	67.0	57.4	41.8	64.5	56.2	55.3	35.3	59.8
Goethite	0.0	0.1	0.0	0.0	2.6	0.6	0.8	0.0	0.3	0.0	1.8	12.3	0.3	0.0	0.1	0.5	0.3	0.9	0.0	0.3	0.3	17.6	8.1
Fe-Oxides	0.1	0.4	0.1	0.1	6.1	7.1	2.1	0.1	1.7	0.0	5.1	16.1	1.7	2.1	10.9	2.5	5.4	23.2	3.3	12.4	10.4	4.7	11.3
Gahnite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spinel	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0
Chromite	0.0	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2

Modal Mineralogy / Mass % of Iron in phase [%]

Mass % of Iron in phase [%]

Modal Mineralogy / Sample	R-12221c	R-12222c	R-12225c	R-12226c	R-12227c	R-12228c	R-12232c	R-12234c	R-12236c	R-12245c	R-12246c	R-12227m	R-12223c	R-12224c	R-12231c	R-12233c	R-12318c	R-12319c	R-12321c	R-12334c	R-12325c	R-12236m	R-12245m
Chromite	0.0	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Spinel	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0
Gahnite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe-Oxides	0.1	0.4	0.1	0.1	6.1	7.1	2.1	0.1	1.7	0.0	5.1	16.1	1.7	2.1	10.9	2.5	5.4	23.2	3.3	12.4	10.4	4.7	11.3
Goethite	0.0	0.1	0.0	0.0	2.6	0.6	0.8	0.0	0.3	0.0	1.8	12.3	0.3	0.0	0.1	0.5	0.3	0.9	0.0	0.3	0.3	17.6	8.1
Ilmenite	80.9	72.9	83.2	55.9	53.0	57.8	48.6	72.7	59.8	76.4	66.0	45.0	50.1	70.7	69.3	67.0	57.4	41.8	64.5	56.2	55.3	35.3	59.8
Altered Ilmenite	8.8	8.6	9.1	10.8	9.4	8.4	10.5	11.4	12.1	9.9	15.0	6.1	13.4	12.6	6.9	10.5	9.6	6.3	11.2	8.3	9.7	5.2	6.0
Rutile	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pseudorutile	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Amphibole/Pyroxene	1.8	3.5	1.2	10.7	7.7	7.1	13.6	7.0	9.3	2.3	3.0	3.7	9.4	3.1	1.9	4.3	7.1	11.9	5.0	6.8	7.5	11.4	3.0
Garnets	0.2	0.5	0.2	1.3	1.1	1.2	1.2	0.5	1.1	0.3	0.3	0.9	1.1	0.5	0.9	0.9	1.1	1.6	0.9	1.1	1.2	0.9	1.3
Staurolite	1.5	2.6	0.7	1.1	1.7	1.4	3.2	0.8	1.6	1.7	0.8	0.3	3.1	1.4	0.8	1.9	2.5	0.8	1.7	1.3	1.2	0.9	0.3
Biotite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
Chlorite	1.2	3.2	1.0	15.7	14.2	11.3	10.0	4.0	10.0	1.4	1.1	3.6	5.2	3.2	6.8	5.8	7.9	7.1	6.6	8.4	7.9	6.3	3.1
Epidote	5.2	7.7	4.0	3.3	3.2	4.1	9.1	2.9	3.0	7.4	4.3	1.4	14.9	5.8	2.2	6.1	8.0	5.1	6.2	4.7	5.9	3.6	3.3
Ti Silicates	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Carbonates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.6	0.2
Sulphides	0.0	0.2	0.0	0.4	0.3	0.3	0.1	0.1	0.6	0.1	2.0	9.0	0.0	0.1	0.0	0.0	0.1	0.2	0.1	0.1	0.2	11.7	1.5
Schorl	0.1	0.1	0.1	0.2	0.2	0.2	0.4	0.1	0.2	0.1	0.2	0.9	0.3	0.1	0.1	0.2	0.3	0.6	0.1	0.2	0.2	1.1	1.2
Other	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
The rest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Fe Deportment


Ti Deportment

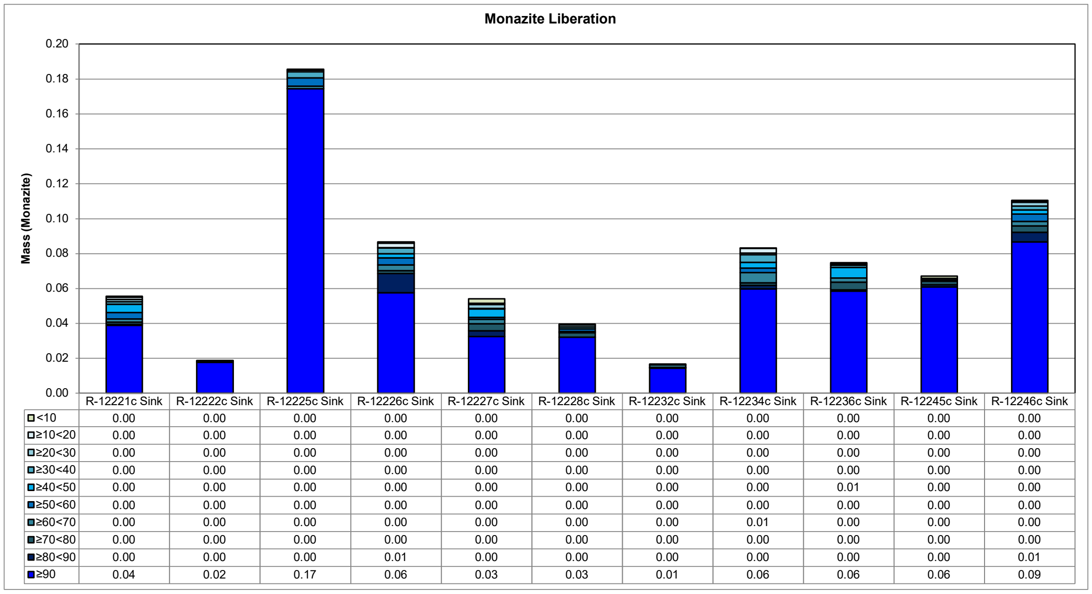
	R-12221c	R-12222c	R-12225c	R-12226c	R-12227c	R-12228c	R-12232c	R-12234c	R-12236c	R-12245c	R-12246c	R-12227m	R-12223c	R-12224c	R-12231c	R-12233c	R-12318c	R-12319c	R-12321c	R-12334c	R-12325c	R-12236m	R-12245m
■ The rest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ Titanite	0.4	0.6	0.2	1.6	0.8	0.8	1.8	0.9	1.3	0.5	0.6	1.0	1.2	0.6	0.3	0.7	0.7	2.8	1.1	1.6	1.6	2.4	0.7
■ Clays	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
□ Garnets	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0
□ Amphibole/Pyroxene	0.3	0.6	0.2	1.4	1.2	1.1	2.3	0.9	1.4	0.4	0.4	0.7	1.5	0.4	0.3	0.6	1.1	2.2	0.7	1.0	1.1	2.7	0.6
□ Pseudorutile	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.3	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.3	0.1
■ Rutile	13.5	15.4	12.6	17.3	16.2	13.9	20.3	14.0	13.7	16.5	19.6	18.6	24.6	16.9	11.3	14.2	16.5	21.2	16.1	15.4	18.9	22.0	17.1
■ Ilmenorutile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ Altered Ilmenite	14.4	14.9	14.6	20.9	19.9	17.5	21.3	18.9	22.6	15.9	23.3	15.4	23.9	20.2	13.4	18.9	19.0	15.4	19.7	17.2	18.8	15.3	12.8
■ Ilmenite	71.3	68.3	72.3	58.7	60.5	64.9	53.6	65.1	60.6	66.6	55.5	61.8	48.3	61.5	72.8	65.0	61.6	55.2	61.7	63.2	58.0	56.6	68.4
■ Goethite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
■ Fe-Oxides	0.0	0.1	0.0	0.0	1.3	1.6	0.4	0.0	0.3	0.0	0.5	2.2	0.3	0.3	1.9	0.4	0.8	2.9	0.5	1.4	1.6	0.5	0.3
■ Spinel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Modal Mineralogy / Mass % of Titanium in phase [%]

Mass % of Titanium in phase [%]

Modal Mineralogy / Sample	R-12221c	R-12222c	R-12225c	R-12226c	R-12227c	R-12228c	R-12232c	R-12234c	R-12236c	R-12245c	R-12246c	R-12227m	R-12223c	R-12224c	R-12231c	R-12233c	R-12318c	R-12319c	R-12321c	R-12334c	R-12325c	R-12236m	R-12245m
Spinel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe-Oxides	0.0	0.1	0.0	0.0	1.3	1.6	0.4	0.0	0.3	0.0	0.5	2.2	0.3	0.3	1.9	0.4	0.8	2.9	0.5	1.4	1.6	0.5	0.3
Goethite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Ilmenite	71.3	68.3	72.3	58.7	60.5	64.9	53.6	65.1	60.6	66.6	55.5	61.8	48.3	61.5	72.8	65.0	61.6	55.2	61.7	63.2	58.0	56.6	68.4
Altered Ilmenite	14.4	14.9	14.6	20.9	19.9	17.5	21.3	18.9	22.6	15.9	23.3	15.4	23.9	20.2	13.4	18.9	19.0	15.4	19.7	17.2	18.8	15.3	12.8
Ilmenorutile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rutile	13.5	15.4	12.6	17.3	16.2	13.9	20.3	14.0	13.7	16.5	19.6	18.6	24.6	16.9	11.3	14.2	16.5	21.2	16.1	15.4	18.9	22.0	17.1
Pseudorutile	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.3	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.3	0.1
Amphibole/Pyroxene	0.3	0.6	0.2	1.4	1.2	1.1	2.3	0.9	1.4	0.4	0.4	0.7	1.5	0.4	0.3	0.6	1.1	2.2	0.7	1.0	1.1	2.7	0.6
Garnets	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0
Clays	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Titanite	0.4	0.6	0.2	1.6	0.8	0.8	1.8	0.9	1.3	0.5	0.6	1.0	1.2	0.6	0.3	0.7	0.7	2.8	1.1	1.6	1.6	2.4	0.7
The rest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

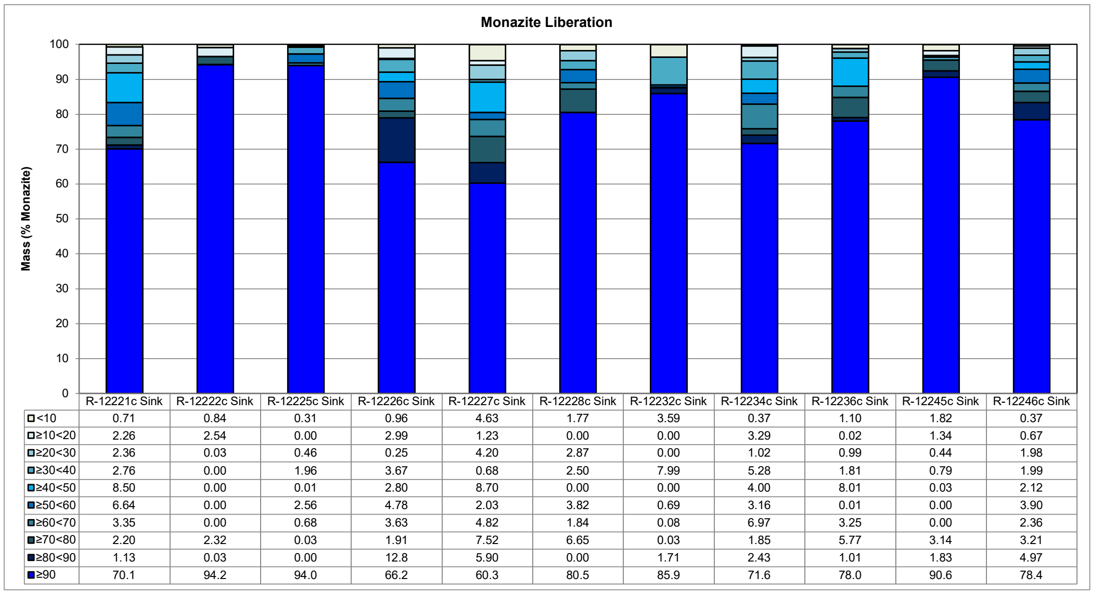
Monazite Liberation



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥10<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥20<30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥30<40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥40<50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
≥50<60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥60<70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
≥70<80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥80<90	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
≥90	0.04	0.02	0.17	0.06	0.03	0.03	0.01	0.06	0.06	0.06	0.09

Absolute Mass of Monazite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	0.04	0.02	0.17	0.06	0.03	0.03	0.01	0.06	0.06	0.06	0.09
≥80<90	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
≥70<80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥60<70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
≥50<60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥40<50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
≥30<40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥20<30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥10<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.06	0.02	0.19	0.09	0.05	0.04	0.02	0.08	0.07	0.07	0.11

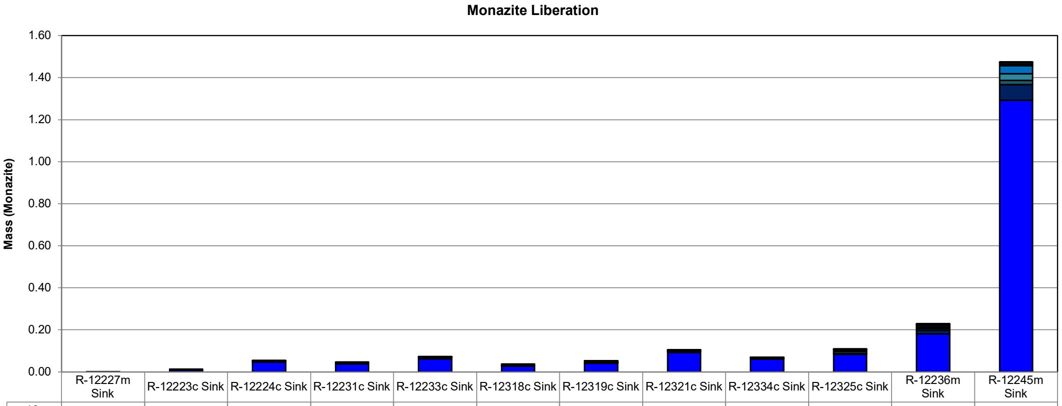


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
<10	0.71	0.84	0.31	0.96	4.63	1.77	3.59	0.37	1.10	1.82	0.37
≥10<20	2.26	2.54	0.00	2.99	1.23	0.00	0.00	3.29	0.02	1.34	0.67
≥20<30	2.36	0.03	0.46	0.25	4.20	2.87	0.00	1.02	0.99	0.44	1.98
≥30<40	2.76	0.00	1.96	3.67	0.68	2.50	7.99	5.28	1.81	0.79	1.99
≥40<50	8.50	0.00	0.01	2.80	8.70	0.00	0.00	4.00	8.01	0.03	2.12
≥50<60	6.64	0.00	2.56	4.78	2.03	3.82	0.69	3.16	0.01	0.00	3.90
≥60<70	3.35	0.00	0.68	3.63	4.82	1.84	0.08	6.97	3.25	0.00	2.36
≥70<80	2.20	2.32	0.03	1.91	7.52	6.65	0.03	1.85	5.77	3.14	3.21
≥80<90	1.13	0.03	0.00	12.8	5.90	0.00	1.71	2.43	1.01	1.83	4.97
≥90	70.1	94.2	94.0	66.2	60.3	80.5	85.9	71.6	78.0	90.6	78.4

Normalized Mass of Monazite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	70.1	94.2	94.0	66.2	60.3	80.5	85.9	71.6	78.0	90.6	78.4
≥80<90	1.13	0.03	0.00	12.8	5.90	0.00	1.71	2.43	1.01	1.83	4.97
≥70<80	2.20	2.32	0.03	1.91	7.52	6.65	0.03	1.85	5.77	3.14	3.21
≥60<70	3.35	0.00	0.68	3.63	4.82	1.84	0.08	6.97	3.25	0.00	2.36
≥50<60	6.64	0.00	2.56	4.78	2.03	3.82	0.69	3.16	0.01	0.00	3.90
≥40<50	8.50	0.00	0.01	2.80	8.70	0.00	0.00	4.00	8.01	0.03	2.12
≥30<40	2.76	0.00	1.96	3.67	0.68	2.50	7.99	5.28	1.81	0.79	1.99
≥20<30	2.36	0.03	0.46	0.25	4.20	2.87	0.00	1.02	0.99	0.44	1.98
≥10<20	2.26	2.54	0.00	2.99	1.23	0.00	0.00	3.29	0.02	1.34	0.67
<10	0.71	0.84	0.31	0.96	4.63	1.77	3.59	0.37	1.10	1.82	0.37
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

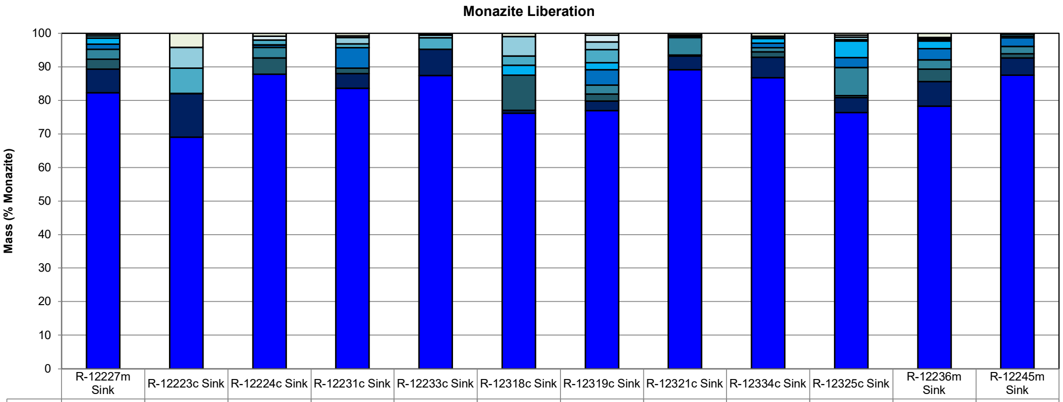
Monazite Liberation



	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■≥10<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■≥20<30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■≥30<40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
■≥40<50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
■≥50<60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04
■≥60<70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.03
■≥70<80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
■≥80<90	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.08
■≥90	0.00	0.01	0.05	0.04	0.06	0.03	0.04	0.09	0.06	0.08	0.18	1.29

Absolute Mass of Monazite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	0.00	0.01	0.05	0.04	0.06	0.03	0.04	0.09	0.06	0.08	0.18	1.29
≥80<90	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.08
≥70<80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
≥60<70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.03
≥50<60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04
≥40<50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
≥30<40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
≥20<30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥10<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.00	0.01	0.05	0.05	0.07	0.04	0.05	0.10	0.07	0.11	0.23	1.48

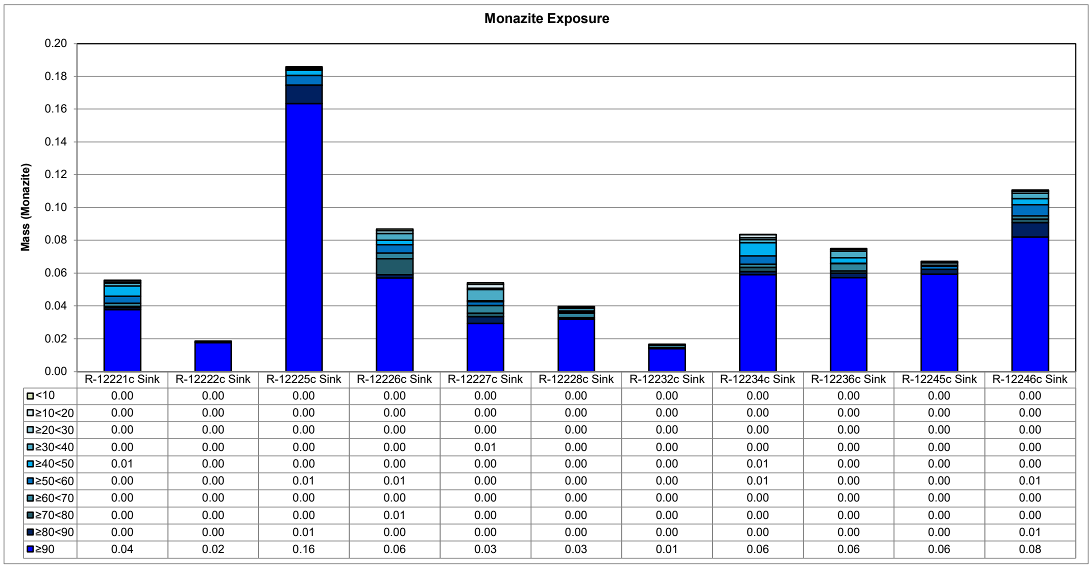


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■<10	0.13	4.19	0.88	0.74	0.29	0.95	0.59	0.44	0.85	0.53	1.21	0.10
■≥10<20	0.09	0.00	1.15	0.47	0.28	0.00	1.95	0.38	0.00	0.58	0.43	0.17
■≥20<30	0.54	6.22	0.00	1.89	0.80	5.84	2.34	0.09	0.20	0.79	0.34	0.01
■≥30<40	0.64	7.52	1.41	1.14	3.41	2.72	3.93	0.25	0.51	0.38	0.26	0.55
■≥40<50	1.83	0.00	0.06	0.06	0.00	2.93	2.07	0.11	1.42	4.95	2.36	0.46
■≥50<60	1.53	0.11	0.67	6.05	0.00	0.00	4.54	0.01	1.34	2.98	3.27	2.59
■≥60<70	2.99	0.00	3.15	0.00	0.00	0.00	2.67	5.23	1.25	8.32	2.80	2.17
■≥70<80	2.95	0.00	4.91	1.64	0.00	10.5	2.07	0.29	1.60	0.66	3.73	1.24
■≥80<90	7.05	12.9	0.00	4.43	7.79	0.86	2.89	4.10	6.11	4.41	7.35	5.14
■≥90	82.2	69.0	87.8	83.6	87.4	76.2	77.0	89.1	86.7	76.4	78.2	87.5

Normalized Mass of Monazite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	82.2	69.0	87.8	83.6	87.4	76.2	77.0	89.1	86.7	76.4	78.2	87.5
≥80<90	7.05	12.9	0.00	4.43	7.79	0.86	2.89	4.10	6.11	4.41	7.35	5.14
≥70<80	2.95	0.00	4.91	1.64	0.00	10.5	2.07	0.29	1.60	0.66	3.73	1.24
≥60<70	2.99	0.00	3.15	0.00	0.00	0.00	2.67	5.23	1.25	8.32	2.80	2.17
≥50<60	1.53	0.11	0.67	6.05	0.00	0.00	4.54	0.01	1.34	2.98	3.27	2.59
≥40<50	1.83	0.00	0.06	0.06	0.00	2.93	2.07	0.11	1.42	4.95	2.36	0.46
≥30<40	0.64	7.52	1.41	1.14	3.41	2.72	3.93	0.25	0.51	0.38	0.26	0.55
≥20<30	0.54	6.22	0.00	1.89	0.80	5.84	2.34	0.09	0.20	0.79	0.34	0.01
≥10<20	0.09	0.00	1.15	0.47	0.28	0.00	1.95	0.38	0.00	0.58	0.43	0.17
<10	0.13	4.19	0.88	0.74	0.29	0.95	0.59	0.44	0.85	0.53	1.21	0.10
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

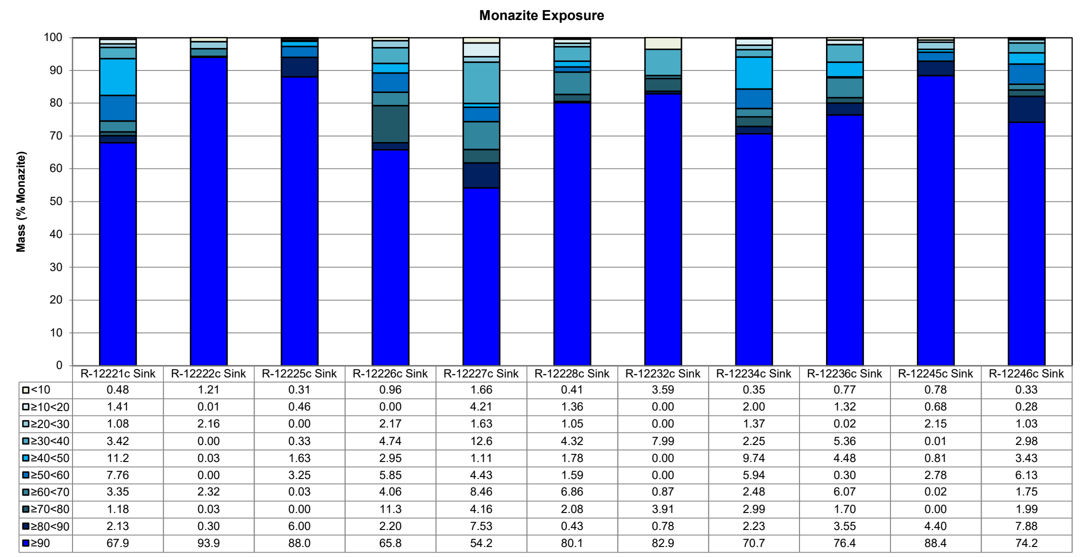
Monazite Exposure



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥10<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥20<30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥30<40	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
≥40<50	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
≥50<60	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01
≥60<70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥70<80	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥80<90	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
≥90	0.04	0.02	0.16	0.06	0.03	0.03	0.01	0.06	0.06	0.06	0.08

Absolute Mass of Monazite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	0.04	0.02	0.16	0.06	0.03	0.03	0.01	0.06	0.06	0.06	0.08
≥80<90	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
≥70<80	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥60<70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥50<60	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01
≥40<50	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
≥30<40	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
≥20<30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥10<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.06	0.02	0.19	0.09	0.05	0.04	0.02	0.08	0.07	0.07	0.11

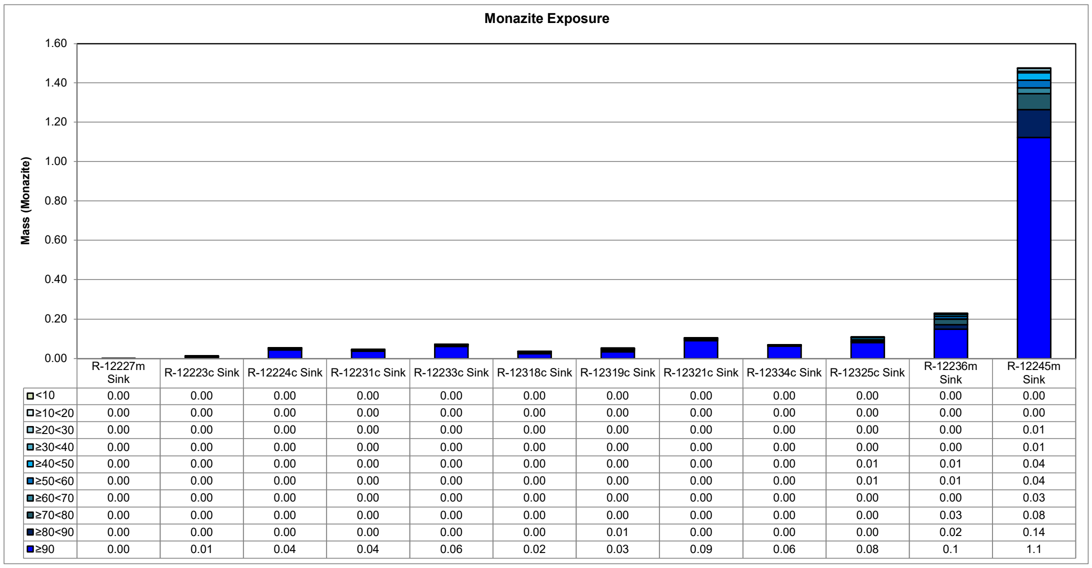


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
<10	0.48	1.21	0.31	0.96	1.66	0.41	3.59	0.35	0.77	0.78	0.33
≥10<20	1.41	0.01	0.46	0.00	4.21	1.36	0.00	2.00	1.32	0.68	0.28
≥20<30	1.08	2.16	0.00	2.17	1.63	1.05	0.00	1.37	0.02	2.15	1.03
≥30<40	3.42	0.00	0.33	4.74	12.6	4.32	7.99	2.25	5.36	0.01	2.98
≥40<50	11.2	0.03	1.63	2.95	1.11	1.78	0.00	9.74	4.48	0.81	3.43
≥50<60	7.76	0.00	3.25	5.85	4.43	1.59	0.00	5.94	0.30	2.78	6.13
≥60<70	3.35	2.32	0.03	4.06	8.46	6.86	0.87	2.48	6.07	0.02	1.75
≥70<80	1.18	0.03	0.00	11.3	4.16	2.08	3.91	2.99	1.70	0.00	1.99
≥80<90	2.13	0.30	6.00	2.20	7.53	0.43	0.78	2.23	3.55	4.40	7.88
≥90	67.9	93.9	88.0	65.8	54.2	80.1	82.9	70.7	76.4	88.4	74.2

Normalized Mass of Monazite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	67.9	93.9	88.0	65.8	54.2	80.1	82.9	70.7	76.4	88.4	74.2
≥80<90	2.13	0.30	6.00	2.20	7.53	0.43	0.78	2.23	3.55	4.40	7.88
≥70<80	1.18	0.03	0.00	11.3	4.16	2.08	3.91	2.99	1.70	0.00	1.99
≥60<70	3.35	2.32	0.03	4.06	8.46	6.86	0.87	2.48	6.07	0.02	1.75
≥50<60	7.76	0.00	3.25	5.85	4.43	1.59	0.00	5.94	0.30	2.78	6.13
≥40<50	11.2	0.03	1.63	2.95	1.11	1.78	0.00	9.74	4.48	0.81	3.43
≥30<40	3.42	0.00	0.33	4.74	12.6	4.32	7.99	2.25	5.36	0.01	2.98
≥20<30	1.08	2.16	0.00	2.17	1.63	1.05	0.00	1.37	0.02	2.15	1.03
≥10<20	1.41	0.01	0.46	0.00	4.21	1.36	0.00	2.00	1.32	0.68	0.28
<10	0.48	1.21	0.31	0.96	1.66	0.41	3.59	0.35	0.77	0.78	0.33
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

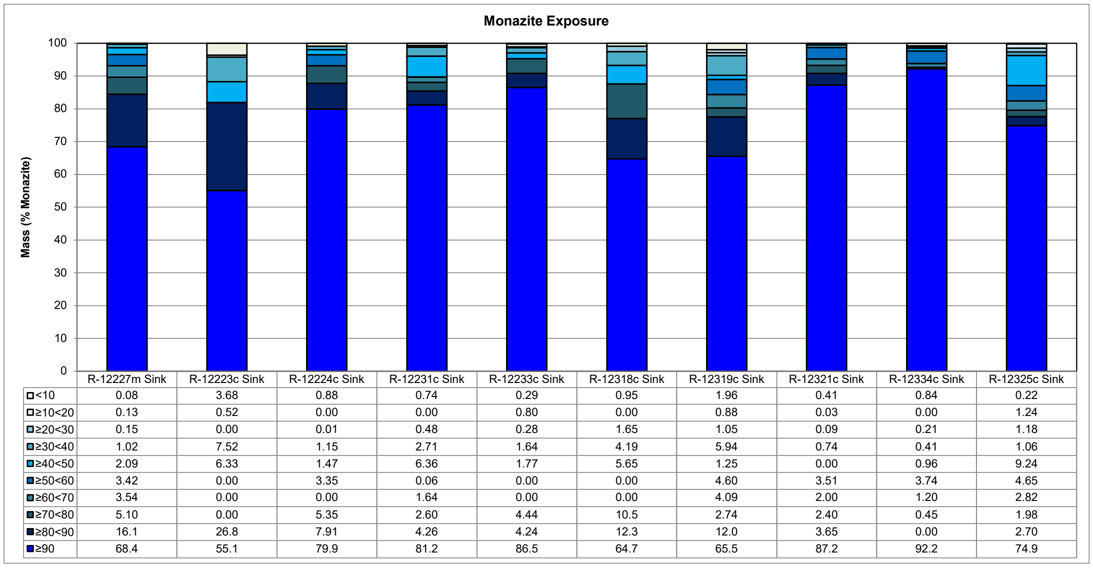
Monazite Exposure



	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■≥10<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■≥20<30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
■≥30<40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
■≥40<50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04
■≥50<60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04
■≥60<70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
■≥70<80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08
■≥80<90	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.14
■≥90	0.00	0.01	0.04	0.04	0.06	0.02	0.03	0.09	0.06	0.08	0.1	1.1

Absolute Mass of Monazite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	0.00	0.01	0.04	0.04	0.06	0.02	0.03	0.09	0.06	0.08	0.1	1.1
≥80<90	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.14
≥70<80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08
≥60<70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
≥50<60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04
≥40<50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04
≥30<40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
≥20<30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
≥10<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.00	0.01	0.05	0.05	0.07	0.04	0.05	0.10	0.07	0.11	0.2	1.5

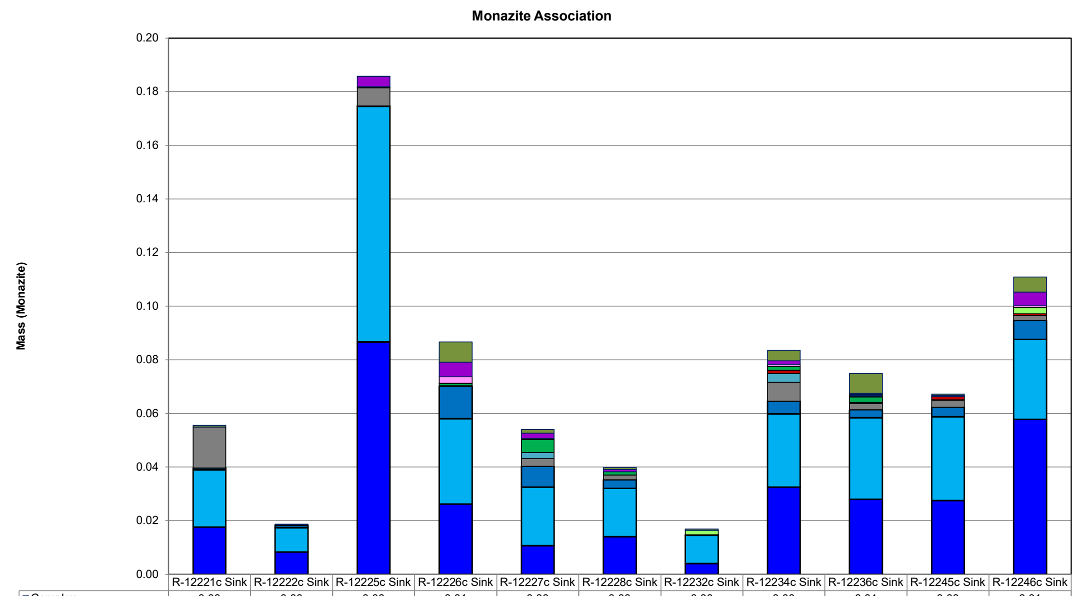


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink
■<10	0.08	3.68	0.88	0.74	0.29	0.95	1.96	0.41	0.84	0.22
■≥10<20	0.13	0.52	0.00	0.00	0.80	0.00	0.88	0.03	0.00	1.24
■≥20<30	0.15	0.00	0.01	0.48	0.28	1.65	1.05	0.09	0.21	1.18
■≥30<40	1.02	7.52	1.15	2.71	1.64	4.19	5.94	0.74	0.41	1.06
■≥40<50	2.09	6.33	1.47	6.36	1.77	5.65	1.25	0.00	0.96	9.24
■≥50<60	3.42	0.00	3.35	0.06	0.00	0.00	4.60	3.51	3.74	4.65
■≥60<70	3.54	0.00	0.00	1.64	0.00	0.00	4.09	2.00	1.20	2.82
■≥70<80	5.10	0.00	5.35	2.60	4.44	10.5	2.74	2.40	0.45	1.98
■≥80<90	16.1	26.8	7.91	4.26	4.24	12.3	12.0	3.65	0.00	2.70
■≥90	68.4	55.1	79.9	81.2	86.5	64.7	65.5	87.2	92.2	74.9

Normalized Mass of Monazite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	68.4	55.1	79.9	81.2	86.5	64.7	65.5	87.2	92.2	74.9	64.7	76.0
≥80<90	16.1	26.8	7.91	4.26	4.24	12.3	12.0	3.65	0.00	2.70	9.75	9.61
≥70<80	5.10	0.00	5.35	2.60	4.44	10.5	2.74	2.40	0.45	1.98	12.05	5.50
≥60<70	3.54	0.00	0.00	1.64	0.00	0.00	4.09	2.00	1.20	2.82	1.06	2.01
≥50<60	3.42	0.00	3.35	0.06	0.00	0.00	4.60	3.51	3.74	4.65	5.29	2.66
≥40<50	2.09	6.33	1.47	6.36	1.77	5.65	1.25	0.00	0.96	9.24	4.19	2.54
≥30<40	1.02	7.52	1.15	2.71	1.64	4.19	5.94	0.74	0.41	1.06	0.94	0.58
≥20<30	0.15	0.00	0.01	0.48	0.28	1.65	1.05	0.09	0.21	1.18	0.35	0.95
≥10<20	0.13	0.52	0.00	0.00	0.80	0.00	0.88	0.03	0.00	1.24	0.72	0.03
<10	0.08	3.68	0.88	0.74	0.29	0.95	1.96	0.41	0.84	0.22	0.92	0.08
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Monazite Associatior

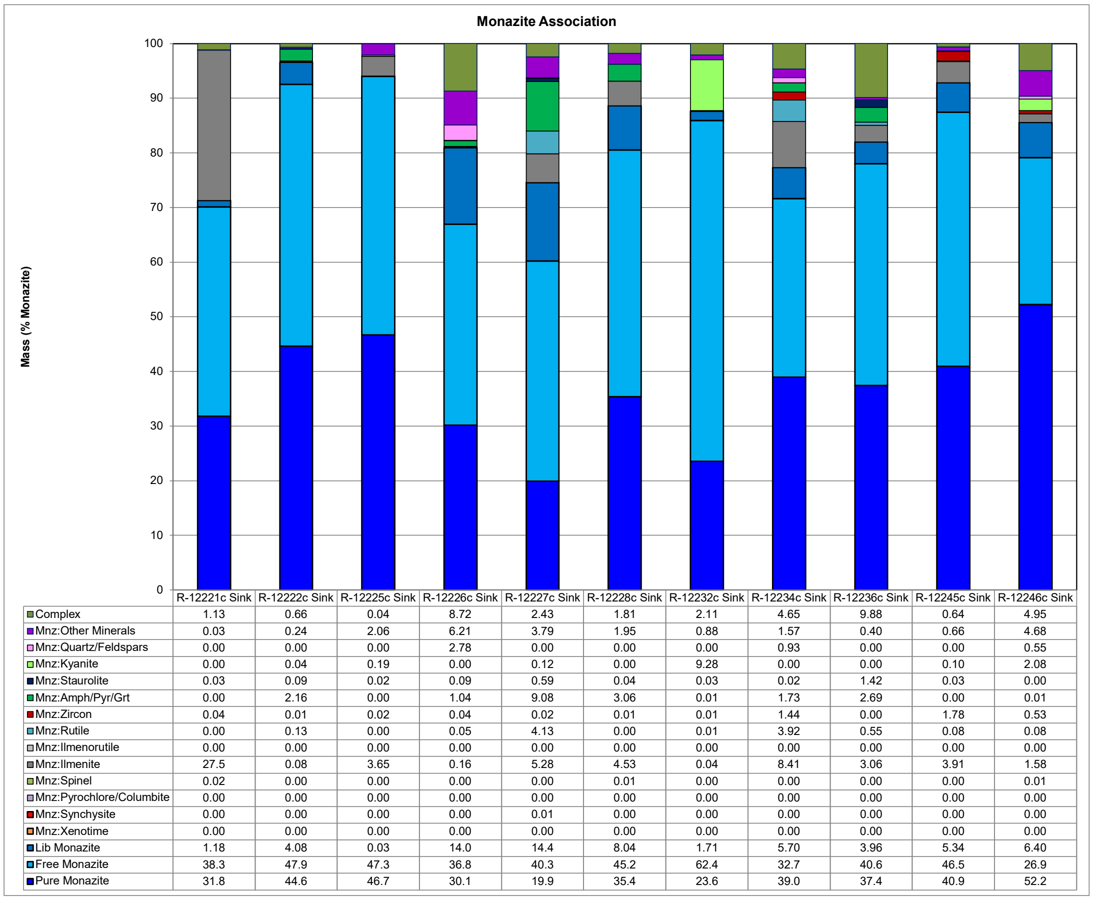


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
■ Complex	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01
■ Mnz:Other Minerals	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
■ Mnz:Quartz/Feldspars	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Staurolite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Amph/Pyr/Grt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Zircon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Rutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Ilmenite	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
■ Mnz:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Lib Monazite	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
■ Free Monazite	0.02	0.01	0.09	0.03	0.02	0.02	0.01	0.03	0.03	0.03	0.03
■ Pure Monazite	0.02	0.01	0.09	0.03	0.01	0.01	0.00	0.03	0.03	0.03	0.06

Absolute Mass of Monazite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
Pure Monazite	0.02	0.01	0.09	0.03	0.01	0.01	0.00	0.03	0.03	0.03	0.06
Free Monazite	0.02	0.01	0.09	0.03	0.02	0.02	0.01	0.03	0.03	0.03	0.03
Lib Monazite	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
Mnz:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Ilmenite	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Mnz:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Rutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Zircon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Amph/Pyr/Grt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Staurolite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Quartz/Feldspars	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Other Minerals	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Complex	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Total	0.06	0.02	0.19	0.09	0.05	0.04	0.02	0.08	0.07	0.07	0.11

Monazite Associatior

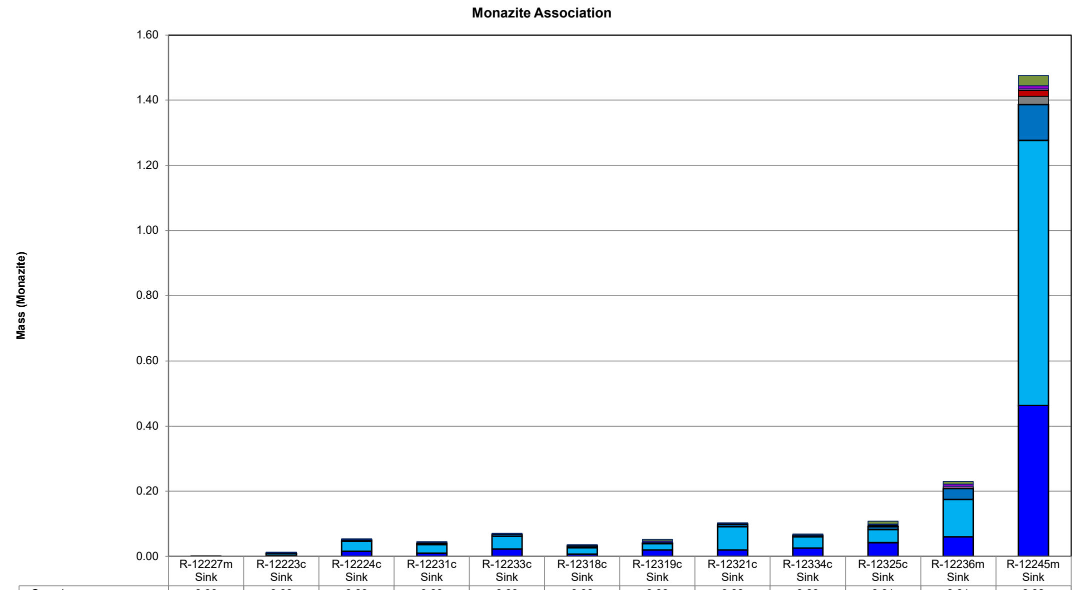


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
Complex	1.13	0.66	0.04	8.72	2.43	1.81	2.11	4.65	9.88	0.64	4.95
Mnz:Other Minerals	0.03	0.24	2.06	6.21	3.79	1.95	0.88	1.57	0.40	0.66	4.68
Mnz:Quartz/Feldspars	0.00	0.00	0.00	2.78	0.00	0.00	0.00	0.93	0.00	0.00	0.55
Mnz:Kyanite	0.00	0.04	0.19	0.00	0.12	0.00	9.28	0.00	0.00	0.10	2.08
Mnz:Staurolite	0.03	0.09	0.02	0.09	0.59	0.04	0.03	0.02	1.42	0.03	0.00
Mnz:Amph/Pyr/Grt	0.00	2.16	0.00	1.04	9.08	3.06	0.01	1.73	2.69	0.00	0.01
Mnz:Zircon	0.04	0.01	0.02	0.04	0.02	0.01	0.01	1.44	0.00	1.78	0.53
Mnz:Rutile	0.00	0.13	0.00	0.05	4.13	0.00	0.01	3.92	0.55	0.08	0.08
Mnz:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Ilmenite	27.5	0.08	3.65	0.16	5.28	4.53	0.04	8.41	3.06	3.91	1.58
Mnz:Spinel	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Mnz:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Synchysite	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lib Monazite	1.18	4.08	0.03	14.0	14.4	8.04	1.71	5.70	3.96	5.34	6.40
Free Monazite	38.3	47.9	47.3	36.8	40.3	45.2	62.4	32.7	40.6	46.5	26.9
Pure Monazite	31.8	44.6	46.7	30.1	19.9	35.4	23.6	39.0	37.4	40.9	52.2

Normalized Mass of Monazite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
Pure Monazite	31.8	44.6	46.7	30.1	19.9	35.4	23.6	39.0	37.4	40.9	52.2
Free Monazite	38.3	47.9	47.3	36.8	40.3	45.2	62.4	32.7	40.6	46.5	26.9
Lib Monazite	1.18	4.08	0.03	14.0	14.4	8.04	1.71	5.70	3.96	5.34	6.40
Mnz:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Synchysite	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Spinel	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Mnz:Ilmenite	27.5	0.08	3.65	0.16	5.28	4.53	0.04	8.41	3.06	3.91	1.58
Mnz:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Rutile	0.00	0.13	0.00	0.05	4.13	0.00	0.01	3.92	0.55	0.08	0.08
Mnz:Zircon	0.04	0.01	0.02	0.04	0.02	0.01	0.01	1.44	0.00	1.78	0.53
Mnz:Amph/Pyr/Grt	0.00	2.16	0.00	1.04	9.08	3.06	0.01	1.73	2.69	0.00	0.01
Mnz:Staurolite	0.03	0.09	0.02	0.09	0.59	0.04	0.03	0.02	1.42	0.03	0.00
Mnz:Kyanite	0.00	0.04	0.19	0.00	0.12	0.00	9.28	0.00	0.00	0.10	2.08
Mnz:Quartz/Feldspars	0.00	0.00	0.00	2.78	0.00	0.00	0.00	0.93	0.00	0.00	0.55
Mnz:Other Minerals	0.03	0.24	2.06	6.21	3.79	1.95	0.88	1.57	0.40	0.66	4.68
Complex	1.13	0.66	0.04	8.72	2.43	1.81	2.11	4.65	9.88	0.64	4.95
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Liberated	71.3	96.6	94.0	80.9	74.5	88.6	87.6	77.3	82.0	92.8	85.5

Monazite Associatior

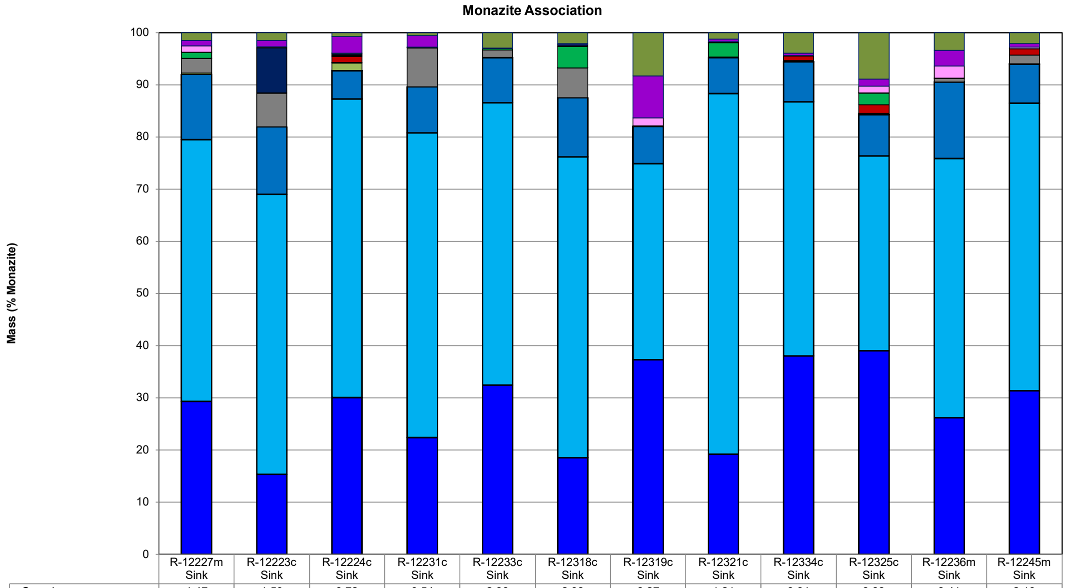


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■ Complex	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03
■ Mnz:Other Minerals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
■ Mnz:Quartz/Feldspars	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
■ Mnz:Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Staurolite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Amph/Pyr/Grt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Zircon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
■ Mnz:Rutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Ilmenite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
■ Mnz:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Lib Monazite	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.03	0.11
■ Free Monazite	0.00	0.01	0.03	0.03	0.04	0.02	0.02	0.07	0.03	0.04	0.1	0.8
■ Pure Monazite	0.00	0.00	0.02	0.01	0.02	0.01	0.02	0.02	0.03	0.04	0.1	0.5

Absolute Mass of Monazite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Pure Monazite	0.00	0.00	0.02	0.01	0.02	0.01	0.02	0.02	0.03	0.04	0.1	0.5
Free Monazite	0.00	0.01	0.03	0.03	0.04	0.02	0.02	0.07	0.03	0.04	0.1	0.8
Lib Monazite	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.03	0.11
Mnz:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Ilmenite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Mnz:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Rutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Zircon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Mnz:Amph/Pyr/Grt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Staurolite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Quartz/Feldspars	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Mnz:Other Minerals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Complex	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.03
Total	0.00	0.01	0.05	0.05	0.07	0.04	0.05	0.10	0.07	0.11	0.2	1.5

Monazite Associatior



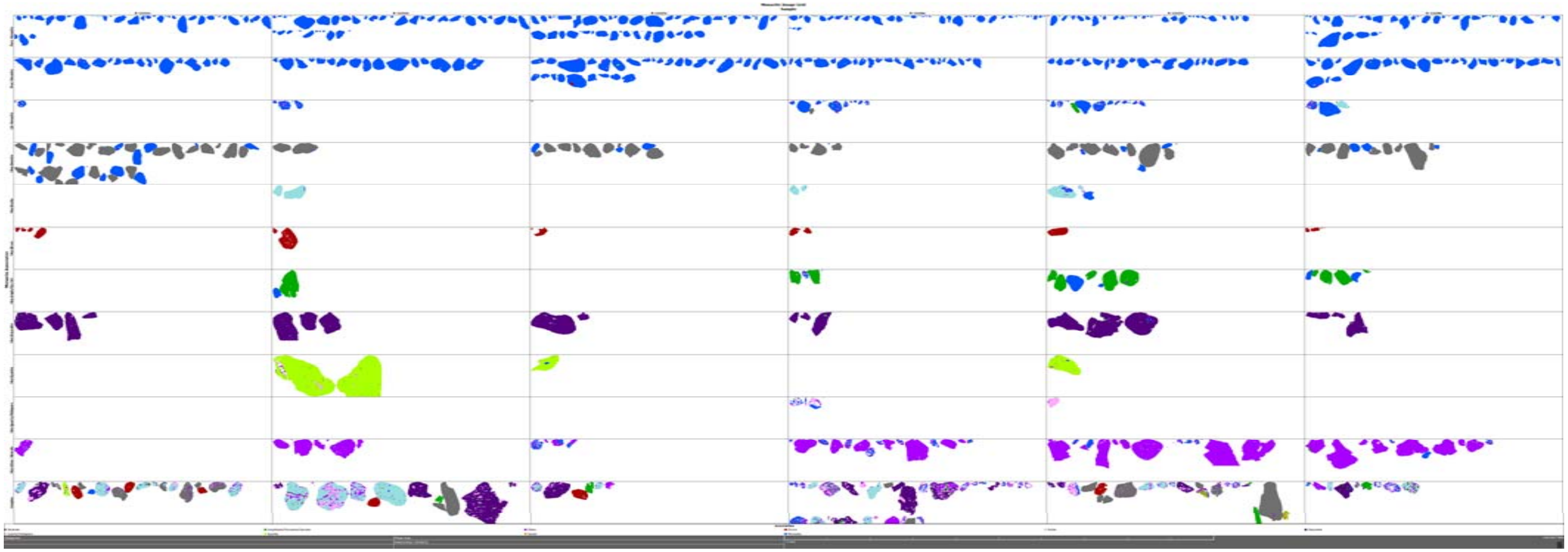
	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■ Complex	1.47	1.50	0.72	0.54	2.96	2.08	8.27	1.21	3.91	8.88	3.41	2.10
■ Mnz:Other Minerals	1.07	1.23	3.20	2.23	0.04	0.18	8.06	0.50	0.47	1.38	2.96	0.68
■ Mnz:Quartz/Feldspars	1.19	0.00	0.01	0.02	0.01	0.00	1.53	0.13	0.05	1.27	2.32	0.30
■ Mnz:Kyanite	0.00	0.18	0.21	0.00	0.00	0.08	0.03	0.05	0.03	0.01	0.00	0.00
■ Mnz:Staurolite	0.00	8.61	0.25	0.03	0.00	0.28	0.01	0.03	0.00	0.05	0.00	0.00
■ Mnz:Amph/Pyr/Grt	1.20	0.05	0.17	0.08	0.28	4.12	0.00	2.76	0.03	2.22	0.06	0.00
■ Mnz:Zircon	0.01	0.04	1.15	0.01	0.04	0.02	0.01	0.06	0.84	1.66	0.01	1.22
■ Mnz:Rutile	0.00	0.02	0.02	0.04	0.02	0.02	0.04	0.04	0.06	0.03	0.00	0.00
■ Mnz:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Ilmenite	2.79	6.42	0.11	7.40	1.42	5.65	0.02	0.00	0.15	0.14	0.69	1.66
■ Mnz:Spinel	0.27	0.00	1.41	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01
■ Mnz:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Mnz:Synchysite	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.02	0.07	0.01	0.07
■ Mnz:Xenotime	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Lib Monazite	12.5	12.9	5.40	8.84	8.69	11.4	7.10	6.86	7.70	7.90	14.64	7.46
■ Free Monazite	50.1	53.7	57.2	58.4	54.1	57.6	37.6	69.1	48.7	37.4	49.7	55.1
■ Pure Monazite	29.3	15.3	30.1	22.4	32.5	18.6	37.3	19.2	38.1	39.0	26.2	31.4

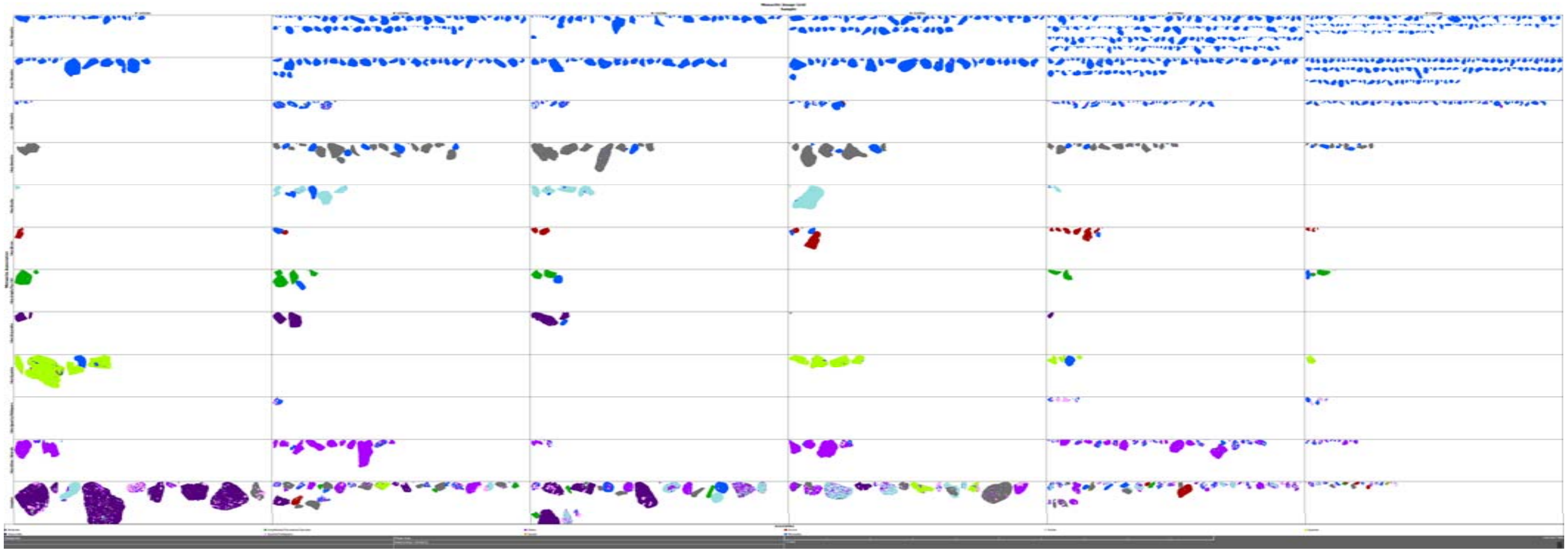
Normalized Mass of Monazite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Pure Monazite	29.3	15.3	30.1	22.4	32.5	18.6	37.3	19.2	38.1	39.0	26.2	31.4
Free Monazite	50.1	53.7	57.2	58.4	54.1	57.6	37.6	69.1	48.7	37.4	49.7	55.1
Lib Monazite	12.5	12.9	5.40	8.84	8.69	11.4	7.10	6.86	7.70	7.90	14.64	7.46
Mnz:Xenotime	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Synchysite	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.02	0.07	0.01	0.07
Mnz:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Spinel	0.27	0.00	1.41	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01
Mnz:Ilmenite	2.79	6.42	0.11	7.40	1.42	5.65	0.02	0.00	0.15	0.14	0.69	1.66
Mnz:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mnz:Rutile	0.00	0.02	0.02	0.04	0.02	0.02	0.04	0.04	0.06	0.03	0.00	0.00
Mnz:Zircon	0.01	0.04	1.15	0.01	0.04	0.02	0.01	0.06	0.84	1.66	0.01	1.22
Mnz:Amph/Pyr/Grt	1.20	0.05	0.17	0.08	0.28	4.12	0.00	2.76	0.03	2.22	0.06	0.00
Mnz:Staurolite	0.00	8.61	0.25	0.03	0.00	0.28	0.01	0.03	0.00	0.05	0.00	0.00
Mnz:Kyanite	0.00	0.18	0.21	0.00	0.00	0.08	0.03	0.05	0.03	0.01	0.00	0.00
Mnz:Quartz/Feldspars	1.19	0.00	0.01	0.02	0.01	0.00	1.53	0.13	0.05	1.27	2.32	0.30
Mnz:Other Minerals	1.07	1.23	3.20	2.23	0.04	0.18	8.06	0.50	0.47	1.38	2.96	0.68
Complex	1.47	1.50	0.72	0.54	2.96	2.08	8.27	1.21	3.91	8.88	3.41	2.10
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Liberated	92.0	82.0	92.7	89.6	95.2	87.6	82.0	95.2	94.4	84.3	90.5	94.0

Virginia Department of Energy, Geology and Mineral Resources Program
CALR-17512-02
MI5024-MAY22 & MI5031-NOV22

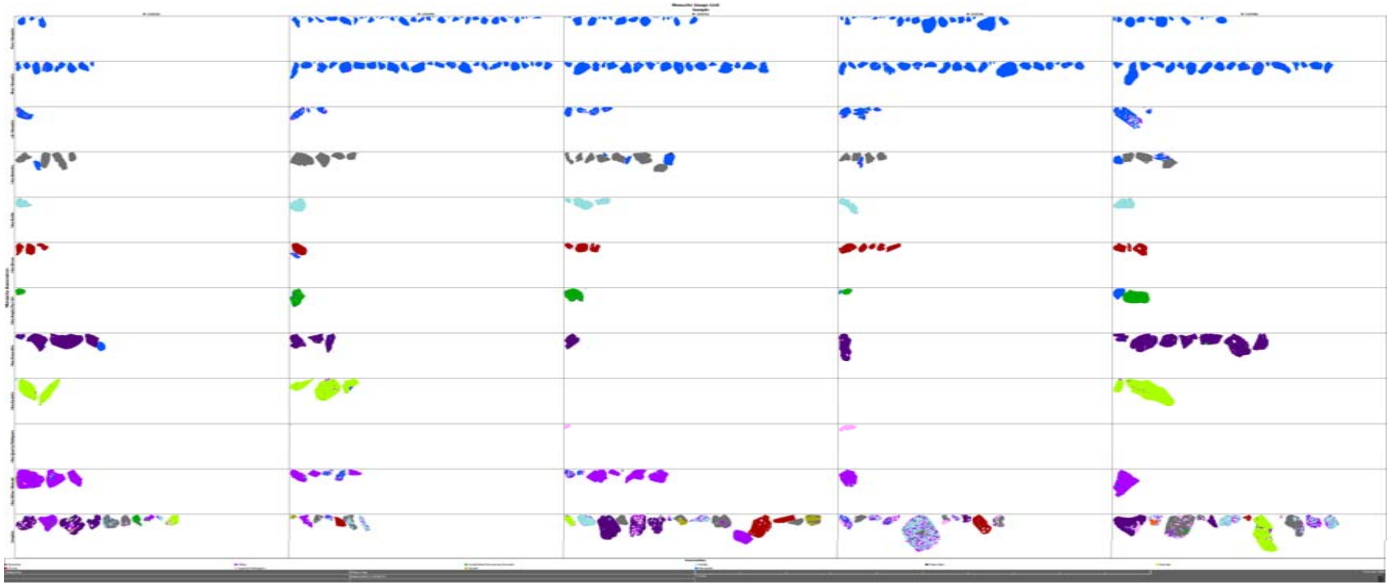
Image Grid of Monazite Association

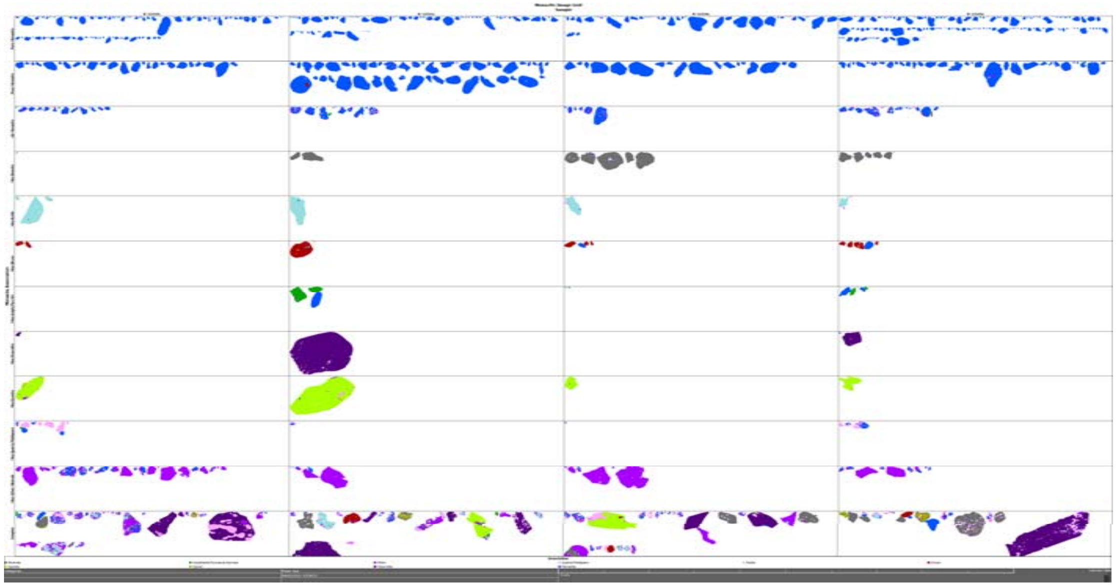




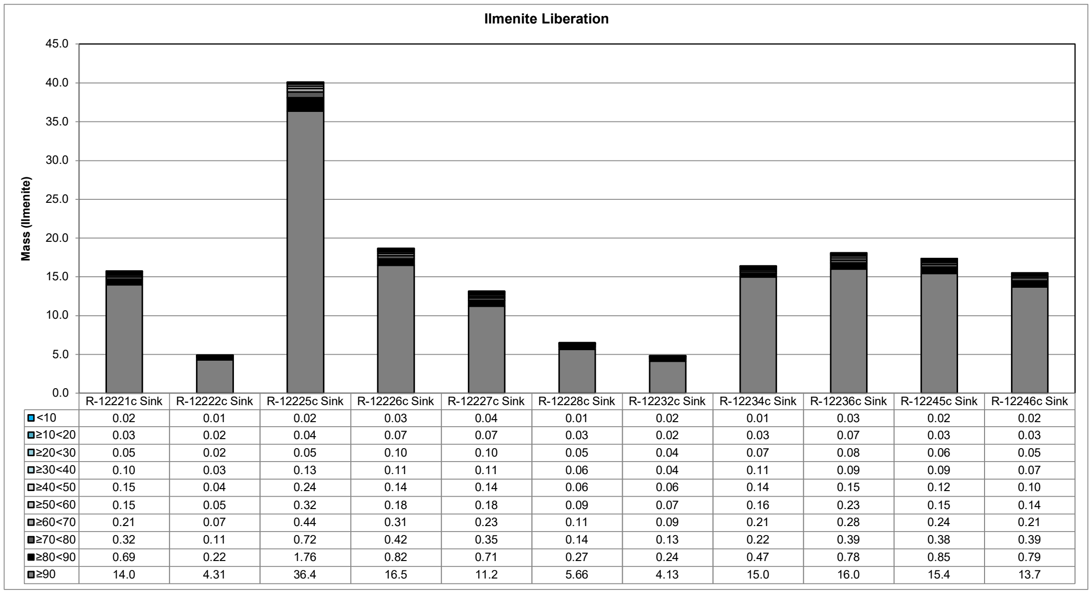
Virginia Department of Energy, Geology and Mineral Resources Program
CALR-17512-02
MI5024-MAY22 & MI5031-NOV22

Image Grid of Monazite Association





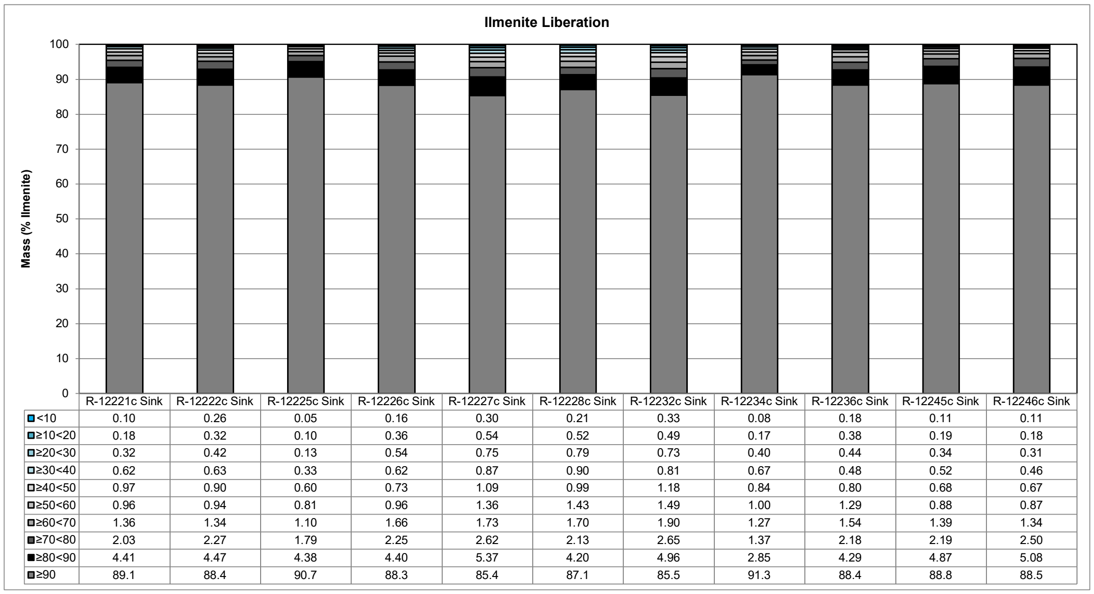
Ilmenite Liberation



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
<10	0.02	0.01	0.02	0.03	0.04	0.01	0.02	0.01	0.03	0.02	0.02
≥10<20	0.03	0.02	0.04	0.07	0.07	0.03	0.02	0.03	0.07	0.03	0.03
≥20<30	0.05	0.02	0.05	0.10	0.10	0.05	0.04	0.07	0.08	0.06	0.05
≥30<40	0.10	0.03	0.13	0.11	0.11	0.06	0.04	0.11	0.09	0.09	0.07
≥40<50	0.15	0.04	0.24	0.14	0.14	0.06	0.06	0.14	0.15	0.12	0.10
≥50<60	0.15	0.05	0.32	0.18	0.18	0.09	0.07	0.16	0.23	0.15	0.14
≥60<70	0.21	0.07	0.44	0.31	0.23	0.11	0.09	0.21	0.28	0.24	0.21
≥70<80	0.32	0.11	0.72	0.42	0.35	0.14	0.13	0.22	0.39	0.38	0.39
≥80<90	0.69	0.22	1.76	0.82	0.71	0.27	0.24	0.47	0.78	0.85	0.79
≥90	14.0	4.31	36.4	16.5	11.2	5.66	4.13	15.0	16.0	15.4	13.7

Absolute Mass of Ilmenite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	14.0	4.31	36.4	16.5	11.2	5.66	4.13	15.0	16.0	15.4	13.7
≥80<90	0.69	0.22	1.76	0.82	0.71	0.27	0.24	0.47	0.78	0.85	0.79
≥70<80	0.32	0.11	0.72	0.42	0.35	0.14	0.13	0.22	0.39	0.38	0.39
≥60<70	0.21	0.07	0.44	0.31	0.23	0.11	0.09	0.21	0.28	0.24	0.21
≥50<60	0.15	0.05	0.32	0.18	0.18	0.09	0.07	0.16	0.23	0.15	0.14
≥40<50	0.15	0.04	0.24	0.14	0.14	0.06	0.06	0.14	0.15	0.12	0.10
≥30<40	0.10	0.03	0.13	0.11	0.11	0.06	0.04	0.11	0.09	0.09	0.07
≥20<30	0.05	0.02	0.05	0.10	0.10	0.05	0.04	0.07	0.08	0.06	0.05
≥10<20	0.03	0.02	0.04	0.07	0.07	0.03	0.02	0.03	0.07	0.03	0.03
<10	0.02	0.01	0.02	0.03	0.04	0.01	0.02	0.01	0.03	0.02	0.02
Total	15.7	4.87	40.1	18.7	13.2	6.50	4.83	16.4	18.1	17.4	15.5

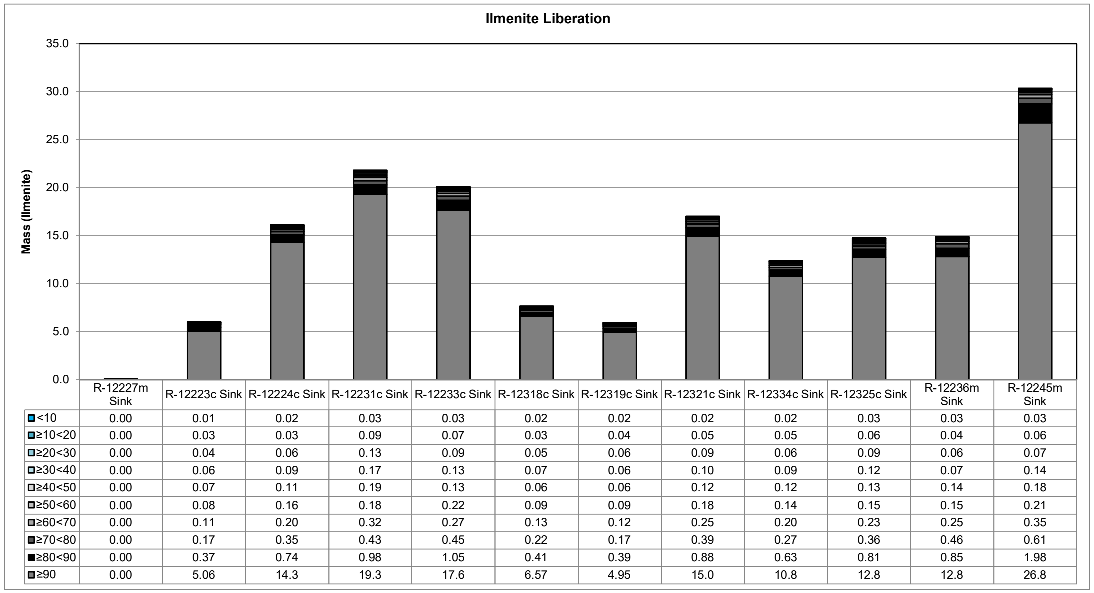


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
<10	0.10	0.26	0.05	0.16	0.30	0.21	0.33	0.08	0.18	0.11	0.11
≥10<20	0.18	0.32	0.10	0.36	0.54	0.52	0.49	0.17	0.38	0.19	0.18
≥20<30	0.32	0.42	0.13	0.54	0.75	0.79	0.73	0.40	0.44	0.34	0.31
≥30<40	0.62	0.63	0.33	0.62	0.87	0.90	0.81	0.67	0.48	0.52	0.46
≥40<50	0.97	0.90	0.60	0.73	1.09	0.99	1.18	0.84	0.80	0.68	0.67
≥50<60	0.96	0.94	0.81	0.96	1.36	1.43	1.49	1.00	1.29	0.88	0.87
≥60<70	1.36	1.34	1.10	1.66	1.73	1.70	1.90	1.27	1.54	1.39	1.34
≥70<80	2.03	2.27	1.79	2.25	2.62	2.13	2.65	1.37	2.18	2.19	2.50
≥80<90	4.41	4.47	4.38	4.40	5.37	4.20	4.96	2.85	4.29	4.87	5.08
≥90	89.1	88.4	90.7	88.3	85.4	87.1	85.5	91.3	88.4	88.8	88.5

Normalized Mass of Ilmenite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	89.1	88.4	90.7	88.3	85.4	87.1	85.5	91.3	88.4	88.8	88.5
≥80<90	4.41	4.47	4.38	4.40	5.37	4.20	4.96	2.85	4.29	4.87	5.08
≥70<80	2.03	2.27	1.79	2.25	2.62	2.13	2.65	1.37	2.18	2.19	2.50
≥60<70	1.36	1.34	1.10	1.66	1.73	1.70	1.90	1.27	1.54	1.39	1.34
≥50<60	0.96	0.94	0.81	0.96	1.36	1.43	1.49	1.00	1.29	0.88	0.87
≥40<50	0.97	0.90	0.60	0.73	1.09	0.99	1.18	0.84	0.80	0.68	0.67
≥30<40	0.62	0.63	0.33	0.62	0.87	0.90	0.81	0.67	0.48	0.52	0.46
≥20<30	0.32	0.42	0.13	0.54	0.75	0.79	0.73	0.40	0.44	0.34	0.31
≥10<20	0.18	0.32	0.10	0.36	0.54	0.52	0.49	0.17	0.38	0.19	0.18
<10	0.10	0.26	0.05	0.16	0.30	0.21	0.33	0.08	0.18	0.11	0.11
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

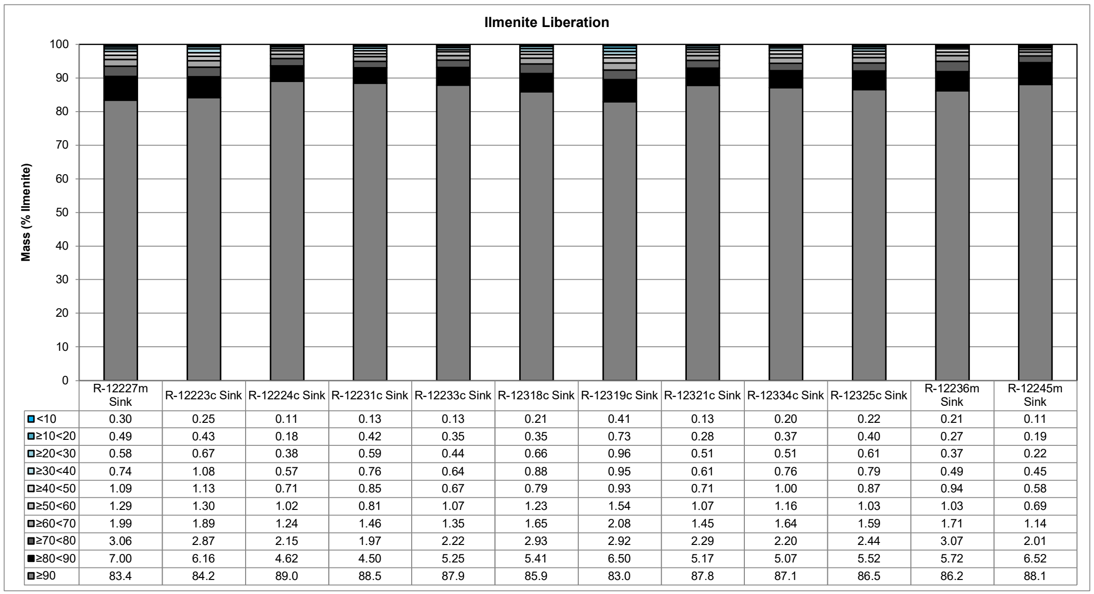
Ilmenite Liberation



	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■<10	0.00	0.01	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.03
■≥10<20	0.00	0.03	0.03	0.09	0.07	0.03	0.04	0.05	0.05	0.06	0.04	0.06
■≥20<30	0.00	0.04	0.06	0.13	0.09	0.05	0.06	0.09	0.06	0.09	0.06	0.07
■≥30<40	0.00	0.06	0.09	0.17	0.13	0.07	0.06	0.10	0.09	0.12	0.07	0.14
■≥40<50	0.00	0.07	0.11	0.19	0.13	0.06	0.06	0.12	0.12	0.13	0.14	0.18
■≥50<60	0.00	0.08	0.16	0.18	0.22	0.09	0.09	0.18	0.14	0.15	0.15	0.21
■≥60<70	0.00	0.11	0.20	0.32	0.27	0.13	0.12	0.25	0.20	0.23	0.25	0.35
■≥70<80	0.00	0.17	0.35	0.43	0.45	0.22	0.17	0.39	0.27	0.36	0.46	0.61
■≥80<90	0.00	0.37	0.74	0.98	1.05	0.41	0.39	0.88	0.63	0.81	0.85	1.98
■≥90	0.00	5.06	14.3	19.3	17.6	6.57	4.95	15.0	10.8	12.8	12.8	26.8

Absolute Mass of Ilmenite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	0.00	5.06	14.3	19.3	17.6	6.57	4.95	15.0	10.8	12.8	12.8	26.8
≥80<90	0.00	0.37	0.74	0.98	1.05	0.41	0.39	0.88	0.63	0.81	0.85	1.98
≥70<80	0.00	0.17	0.35	0.43	0.45	0.22	0.17	0.39	0.27	0.36	0.46	0.61
≥60<70	0.00	0.11	0.20	0.32	0.27	0.13	0.12	0.25	0.20	0.23	0.25	0.35
≥50<60	0.00	0.08	0.16	0.18	0.22	0.09	0.09	0.18	0.14	0.15	0.15	0.21
≥40<50	0.00	0.07	0.11	0.19	0.13	0.06	0.06	0.12	0.12	0.13	0.14	0.18
≥30<40	0.00	0.06	0.09	0.17	0.13	0.07	0.06	0.10	0.09	0.12	0.07	0.14
≥20<30	0.00	0.04	0.06	0.13	0.09	0.05	0.06	0.09	0.06	0.09	0.06	0.07
≥10<20	0.00	0.03	0.03	0.09	0.07	0.03	0.04	0.05	0.05	0.06	0.04	0.06
<10	0.00	0.01	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.03
Total	0.00	6.01	16.1	21.8	20.1	7.66	5.96	17.0	12.4	14.8	14.9	30.4

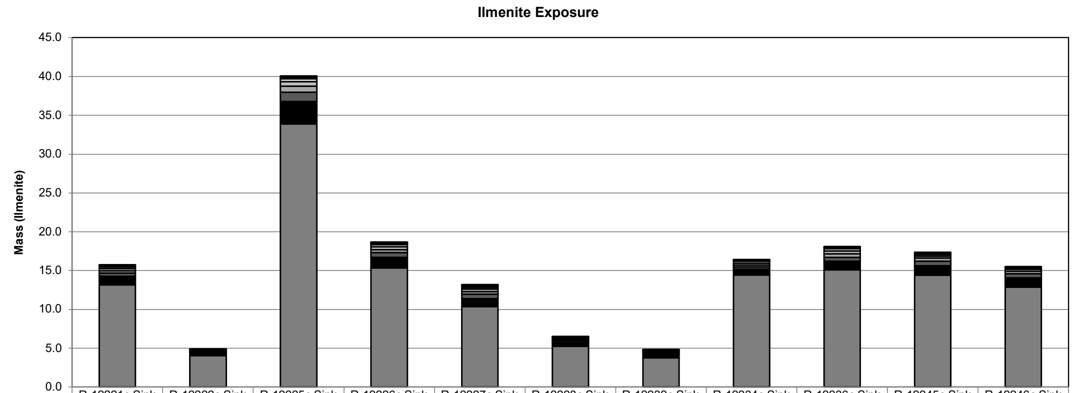


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■<10	0.30	0.25	0.11	0.13	0.13	0.21	0.41	0.13	0.20	0.22	0.21	0.11
■≥10<20	0.49	0.43	0.18	0.42	0.35	0.35	0.73	0.28	0.37	0.40	0.27	0.19
■≥20<30	0.58	0.67	0.38	0.59	0.44	0.66	0.96	0.51	0.51	0.61	0.37	0.22
■≥30<40	0.74	1.08	0.57	0.76	0.64	0.88	0.95	0.61	0.76	0.79	0.49	0.45
■≥40<50	1.09	1.13	0.71	0.85	0.67	0.79	0.93	0.71	1.00	0.87	0.94	0.58
■≥50<60	1.29	1.30	1.02	0.81	1.07	1.23	1.54	1.07	1.16	1.03	1.03	0.69
■≥60<70	1.99	1.89	1.24	1.46	1.35	1.65	2.08	1.45	1.64	1.59	1.71	1.14
■≥70<80	3.06	2.87	2.15	1.97	2.22	2.93	2.92	2.29	2.20	2.44	3.07	2.01
■≥80<90	7.00	6.16	4.62	4.50	5.25	5.41	6.50	5.17	5.07	5.52	5.72	6.52
■≥90	83.4	84.2	89.0	88.5	87.9	85.9	83.0	87.8	87.1	86.5	86.2	88.1

Normalized Mass of Ilmenite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	83.4	84.2	89.0	88.5	87.9	85.9	83.0	87.8	87.1	86.5	86.2	88.1
≥80<90	7.00	6.16	4.62	4.50	5.25	5.41	6.50	5.17	5.07	5.52	5.72	6.52
≥70<80	3.06	2.87	2.15	1.97	2.22	2.93	2.92	2.29	2.20	2.44	3.07	2.01
≥60<70	1.99	1.89	1.24	1.46	1.35	1.65	2.08	1.45	1.64	1.59	1.71	1.14
≥50<60	1.29	1.30	1.02	0.81	1.07	1.23	1.54	1.07	1.16	1.03	1.03	0.69
≥40<50	1.09	1.13	0.71	0.85	0.67	0.79	0.93	0.71	1.00	0.87	0.94	0.58
≥30<40	0.74	1.08	0.57	0.76	0.64	0.88	0.95	0.61	0.76	0.79	0.49	0.45
≥20<30	0.58	0.67	0.38	0.59	0.44	0.66	0.96	0.51	0.51	0.61	0.37	0.22
≥10<20	0.49	0.43	0.18	0.42	0.35	0.35	0.73	0.28	0.37	0.40	0.27	0.19
<10	0.30	0.25	0.11	0.13	0.13	0.21	0.41	0.13	0.20	0.22	0.21	0.11
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

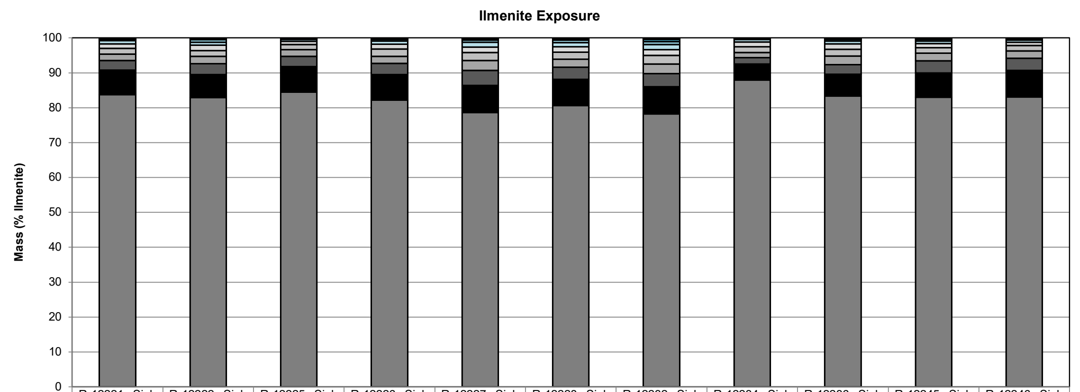
Ilmenite Exposure



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
■<10	0.02	0.01	0.04	0.03	0.03	0.01	0.02	0.01	0.03	0.03	0.01
■≥10<20	0.04	0.02	0.04	0.04	0.06	0.03	0.03	0.01	0.04	0.04	0.03
■≥20<30	0.06	0.03	0.09	0.09	0.09	0.05	0.04	0.04	0.09	0.08	0.05
■≥30<40	0.15	0.04	0.23	0.17	0.17	0.08	0.07	0.12	0.14	0.14	0.10
■≥40<50	0.20	0.07	0.37	0.26	0.21	0.10	0.08	0.22	0.29	0.20	0.15
■≥50<60	0.26	0.08	0.57	0.39	0.30	0.13	0.12	0.27	0.35	0.27	0.23
■≥60<70	0.29	0.10	0.78	0.37	0.36	0.15	0.13	0.24	0.44	0.39	0.34
■≥70<80	0.43	0.15	1.18	0.60	0.58	0.22	0.18	0.30	0.50	0.59	0.53
■≥80<90	1.11	0.32	2.91	1.36	1.02	0.49	0.38	0.75	1.12	1.21	1.19
■≥90	13.2	4.04	33.9	15.4	10.4	5.24	3.78	14.4	15.1	14.4	12.9

Absolute Mass of Ilmenite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	13.2	4.04	33.9	15.4	10.4	5.24	3.78	14.4	15.1	14.4	12.9
≥80<90	1.11	0.32	2.91	1.36	1.02	0.49	0.38	0.75	1.12	1.21	1.19
≥70<80	0.43	0.15	1.18	0.60	0.58	0.22	0.18	0.30	0.50	0.59	0.53
≥60<70	0.29	0.10	0.78	0.37	0.36	0.15	0.13	0.24	0.44	0.39	0.34
≥50<60	0.26	0.08	0.57	0.39	0.30	0.13	0.12	0.27	0.35	0.27	0.23
≥40<50	0.20	0.07	0.37	0.26	0.21	0.10	0.08	0.22	0.29	0.20	0.15
≥30<40	0.15	0.04	0.23	0.17	0.17	0.08	0.07	0.12	0.14	0.14	0.10
≥20<30	0.06	0.03	0.09	0.09	0.09	0.05	0.04	0.04	0.09	0.08	0.05
≥10<20	0.04	0.02	0.04	0.04	0.06	0.03	0.03	0.01	0.04	0.04	0.03
<10	0.02	0.01	0.04	0.03	0.03	0.01	0.02	0.01	0.03	0.03	0.01
Total	15.7	4.87	40.1	18.7	13.2	6.50	4.83	16.4	18.1	17.4	15.5

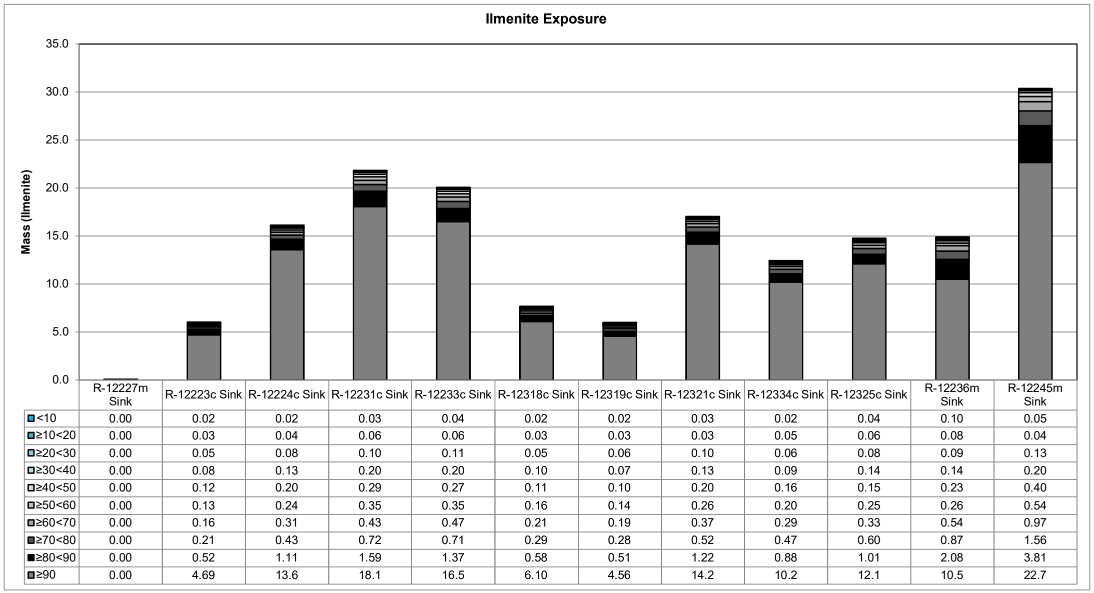


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
■<10	0.14	0.22	0.10	0.18	0.19	0.18	0.41	0.07	0.14	0.16	0.09
■≥10<20	0.24	0.31	0.10	0.21	0.42	0.39	0.65	0.09	0.22	0.23	0.18
■≥20<30	0.35	0.67	0.22	0.50	0.65	0.75	0.77	0.24	0.50	0.43	0.30
■≥30<40	0.93	0.89	0.57	0.91	1.30	1.19	1.54	0.76	0.79	0.79	0.63
■≥40<50	1.28	1.53	0.92	1.39	1.62	1.60	1.62	1.33	1.62	1.18	0.96
■≥50<60	1.67	1.60	1.41	2.11	2.30	2.03	2.50	1.67	1.93	1.55	1.50
■≥60<70	1.84	2.14	1.95	2.00	2.76	2.28	2.75	1.48	2.43	2.24	2.18
■≥70<80	2.71	3.10	2.95	3.23	4.37	3.44	3.72	1.82	2.78	3.42	3.44
■≥80<90	7.06	6.65	7.26	7.28	7.78	7.56	7.80	4.55	6.17	7.00	7.65
■≥90	83.8	82.9	84.5	82.2	78.6	80.6	78.2	88.0	83.4	83.0	83.1

Normalized Mass of Ilmenite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	83.8	82.9	84.5	82.2	78.6	80.6	78.2	88.0	83.4	83.0	83.1
≥80<90	7.06	6.65	7.26	7.28	7.78	7.56	7.80	4.55	6.17	7.00	7.65
≥70<80	2.71	3.10	2.95	3.23	4.37	3.44	3.72	1.82	2.78	3.42	3.44
≥60<70	1.84	2.14	1.95	2.00	2.76	2.28	2.75	1.48	2.43	2.24	2.18
≥50<60	1.67	1.60	1.41	2.11	2.30	2.03	2.50	1.67	1.93	1.55	1.50
≥40<50	1.28	1.53	0.92	1.39	1.62	1.60	1.62	1.33	1.62	1.18	0.96
≥30<40	0.93	0.89	0.57	0.91	1.30	1.19	1.54	0.76	0.79	0.79	0.63
≥20<30	0.35	0.67	0.22	0.50	0.65	0.75	0.77	0.24	0.50	0.43	0.30
≥10<20	0.24	0.31	0.10	0.21	0.42	0.39	0.65	0.09	0.22	0.23	0.18
<10	0.14	0.22	0.10	0.18	0.19	0.18	0.41	0.07	0.14	0.16	0.09
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

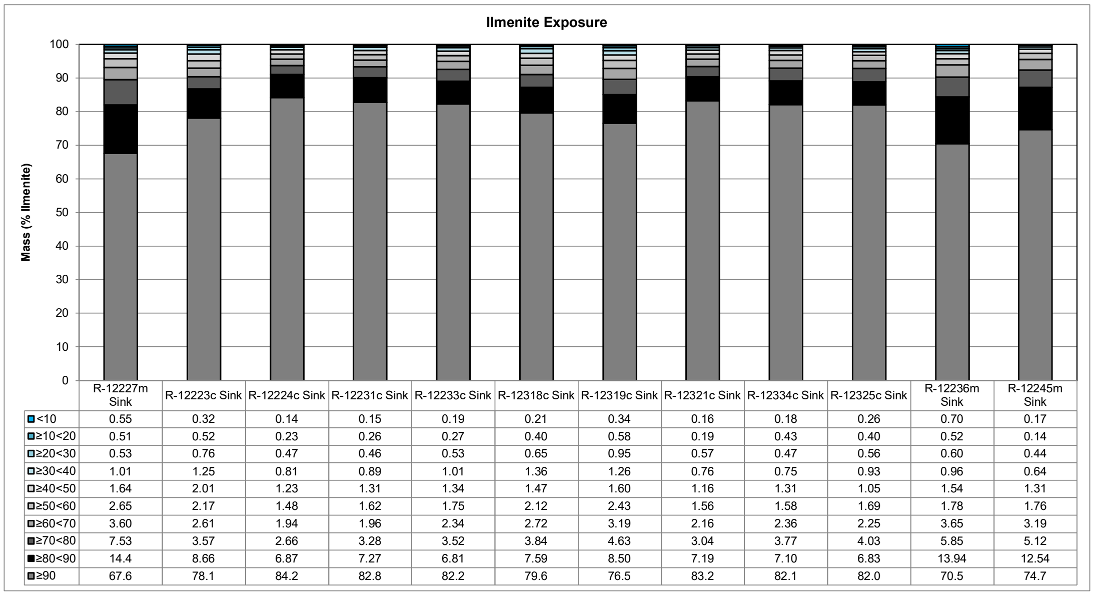
Ilmenite Exposure



	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
<10	0.00	0.02	0.02	0.03	0.04	0.02	0.02	0.03	0.02	0.04	0.10	0.05
≥10<20	0.00	0.03	0.04	0.06	0.06	0.03	0.03	0.03	0.05	0.06	0.08	0.04
≥20<30	0.00	0.05	0.08	0.10	0.11	0.05	0.06	0.10	0.06	0.08	0.09	0.13
≥30<40	0.00	0.08	0.13	0.20	0.20	0.10	0.07	0.13	0.09	0.14	0.14	0.20
≥40<50	0.00	0.12	0.20	0.29	0.27	0.11	0.10	0.20	0.16	0.15	0.23	0.40
≥50<60	0.00	0.13	0.24	0.35	0.35	0.16	0.14	0.26	0.20	0.25	0.26	0.54
≥60<70	0.00	0.16	0.31	0.43	0.47	0.21	0.19	0.37	0.29	0.33	0.54	0.97
≥70<80	0.00	0.21	0.43	0.72	0.71	0.29	0.28	0.52	0.47	0.60	0.87	1.56
≥80<90	0.00	0.52	1.11	1.59	1.37	0.58	0.51	1.22	0.88	1.01	2.08	3.81
≥90	0.00	4.69	13.6	18.1	16.5	6.10	4.56	14.2	10.2	12.1	10.5	22.7

Absolute Mass of Ilmenite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	0.00	4.69	13.6	18.1	16.5	6.10	4.56	14.2	10.2	12.1	10.5	22.7
≥80<90	0.00	0.52	1.11	1.59	1.37	0.58	0.51	1.22	0.88	1.01	2.08	3.81
≥70<80	0.00	0.21	0.43	0.72	0.71	0.29	0.28	0.52	0.47	0.60	0.87	1.56
≥60<70	0.00	0.16	0.31	0.43	0.47	0.21	0.19	0.37	0.29	0.33	0.54	0.97
≥50<60	0.00	0.13	0.24	0.35	0.35	0.16	0.14	0.26	0.20	0.25	0.26	0.54
≥40<50	0.00	0.12	0.20	0.29	0.27	0.11	0.10	0.20	0.16	0.15	0.23	0.40
≥30<40	0.00	0.08	0.13	0.20	0.20	0.10	0.07	0.13	0.09	0.14	0.14	0.20
≥20<30	0.00	0.05	0.08	0.10	0.11	0.05	0.06	0.10	0.06	0.08	0.09	0.13
≥10<20	0.00	0.03	0.04	0.06	0.06	0.03	0.03	0.03	0.05	0.06	0.08	0.04
<10	0.00	0.02	0.02	0.03	0.04	0.02	0.02	0.03	0.02	0.04	0.10	0.05
Total	0.00	6.01	16.1	21.8	20.1	7.66	5.96	17.0	12.4	14.8	14.9	30.4

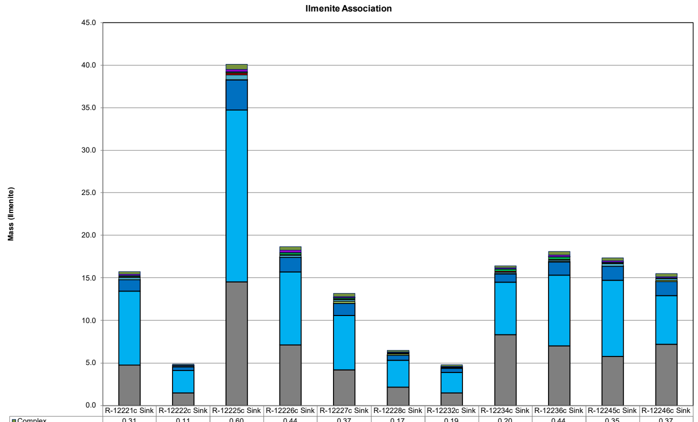


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
<10	0.55	0.32	0.14	0.15	0.19	0.21	0.34	0.16	0.18	0.26	0.70	0.17
≥10<20	0.51	0.52	0.23	0.26	0.27	0.40	0.58	0.19	0.43	0.40	0.52	0.14
≥20<30	0.53	0.76	0.47	0.46	0.53	0.65	0.95	0.57	0.47	0.56	0.60	0.44
≥30<40	1.01	1.25	0.81	0.89	1.01	1.36	1.26	0.76	0.75	0.93	0.96	0.64
≥40<50	1.64	2.01	1.23	1.31	1.34	1.47	1.60	1.16	1.31	1.05	1.54	1.31
≥50<60	2.65	2.17	1.48	1.62	1.75	2.12	2.43	1.56	1.58	1.69	1.78	1.76
≥60<70	3.60	2.61	1.94	1.96	2.34	2.72	3.19	2.16	2.36	2.25	3.65	3.19
≥70<80	7.53	3.57	2.66	3.28	3.52	3.84	4.63	3.04	3.77	4.03	5.85	5.12
≥80<90	14.4	8.66	6.87	7.27	6.81	7.59	8.50	7.19	7.10	6.83	13.94	12.54
≥90	67.6	78.1	84.2	82.8	82.2	79.6	76.5	83.2	82.1	82.0	70.5	74.7

Normalized Mass of Ilmenite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	67.6	78.1	84.2	82.8	82.2	79.6	76.5	83.2	82.1	82.0	70.5	74.7
≥80<90	14.4	8.66	6.87	7.27	6.81	7.59	8.50	7.19	7.10	6.83	13.94	12.54
≥70<80	7.53	3.57	2.66	3.28	3.52	3.84	4.63	3.04	3.77	4.03	5.85	5.12
≥60<70	3.60	2.61	1.94	1.96	2.34	2.72	3.19	2.16	2.36	2.25	3.65	3.19
≥50<60	2.65	2.17	1.48	1.62	1.75	2.12	2.43	1.56	1.58	1.69	1.78	1.76
≥40<50	1.64	2.01	1.23	1.31	1.34	1.47	1.60	1.16	1.31	1.05	1.54	1.31
≥30<40	1.01	1.25	0.81	0.89	1.01	1.36	1.26	0.76	0.75	0.93	0.96	0.64
≥20<30	0.53	0.76	0.47	0.46	0.53	0.65	0.95	0.57	0.47	0.56	0.60	0.44
≥10<20	0.51	0.52	0.23	0.26	0.27	0.40	0.58	0.19	0.43	0.40	0.52	0.14
<10	0.55	0.32	0.14	0.15	0.19	0.21	0.34	0.16	0.18	0.26	0.70	0.17
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Ilmenite Association



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
■ Complex	0.31	0.11	0.60	0.44	0.37	0.17	0.19	0.20	0.44	0.35	0.37
■ Ilm:Other Minerals	0.13	0.04	0.25	0.24	0.14	0.06	0.06	0.12	0.18	0.14	0.12
■ Ilm:Quartz/Feldspars	0.02	0.00	0.06	0.04	0.01	0.01	0.00	0.01	0.01	0.02	0.01
■ Ilm:Kyanite	0.01	0.00	0.02	0.01	0.00	0.01	0.01	0.02	0.00	0.01	0.00
■ Ilm:Staurolite	0.03	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.03	0.02	0.00
■ Ilm:Amph/Pyr/Grt	0.08	0.03	0.09	0.24	0.16	0.07	0.08	0.25	0.31	0.07	0.04
■ Ilm:Zircon	0.10	0.03	0.18	0.07	0.07	0.04	0.01	0.11	0.06	0.07	0.07
■ Ilm:Rutile	0.26	0.09	0.59	0.23	0.19	0.07	0.06	0.17	0.15	0.31	0.18
■ Ilm:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Spinel	0.00	0.00	0.00	0.01	0.23	0.13	0.03	0.00	0.07	0.00	0.13
■ Ilm:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Monazite	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
■ Lib Ilmenite	1.34	0.43	3.57	1.72	1.44	0.62	0.48	1.00	1.55	1.65	1.66
■ Free Ilmenite	8.64	2.63	20.2	8.52	6.36	3.16	2.41	6.12	8.28	8.93	5.69
■ Pure Ilmenite	4.79	1.50	14.5	7.16	4.20	2.17	1.50	8.36	7.03	5.80	7.22

Absolute Mass of Ilmenite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
Pure Ilmenite	4.79	1.50	14.5	7.16	4.20	2.17	1.50	8.36	7.03	5.80	7.22
Free Ilmenite	8.64	2.63	20.2	8.52	6.36	3.16	2.41	6.12	8.28	8.93	5.69
Lib Ilmenite	1.34	0.43	3.57	1.72	1.44	0.62	0.48	1.00	1.55	1.65	1.66
Ilm:Monazite	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Ilm:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Spinel	0.00	0.00	0.00	0.01	0.23	0.13	0.03	0.00	0.07	0.00	0.13
Ilm:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Rutile	0.26	0.09	0.59	0.23	0.19	0.07	0.06	0.17	0.15	0.31	0.18
Ilm:Zircon	0.10	0.03	0.18	0.07	0.07	0.04	0.01	0.11	0.06	0.07	0.07
Ilm:Amph/Pyr/Grt	0.08	0.03	0.09	0.24	0.16	0.07	0.08	0.25	0.31	0.07	0.04
Ilm:Staurolite	0.03	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.03	0.02	0.00
Ilm:Kyanite	0.01	0.00	0.02	0.01	0.00	0.01	0.01	0.02	0.00	0.01	0.00
Ilm:Quartz/Feldspars	0.02	0.00	0.06	0.04	0.01	0.01	0.00	0.01	0.01	0.02	0.01
Ilm:Other Minerals	0.13	0.04	0.25	0.24	0.14	0.06	0.06	0.12	0.18	0.14	0.12
Complex	0.31	0.11	0.60	0.44	0.37	0.17	0.19	0.20	0.44	0.35	0.37
Total	15.7	4.87	40.1	18.7	13.2	6.50	4.83	16.4	18.1	17.4	15.5

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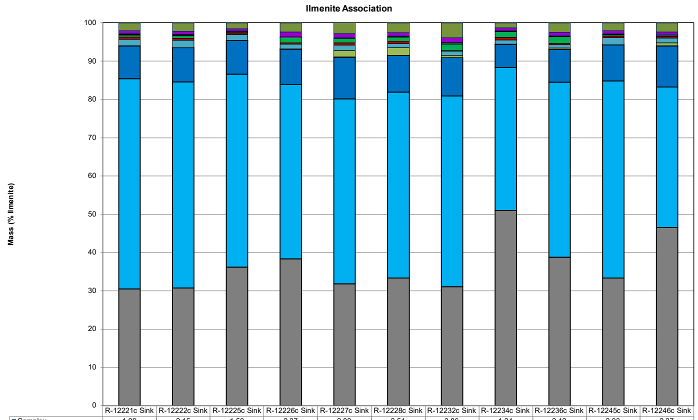
Ilmenite Association

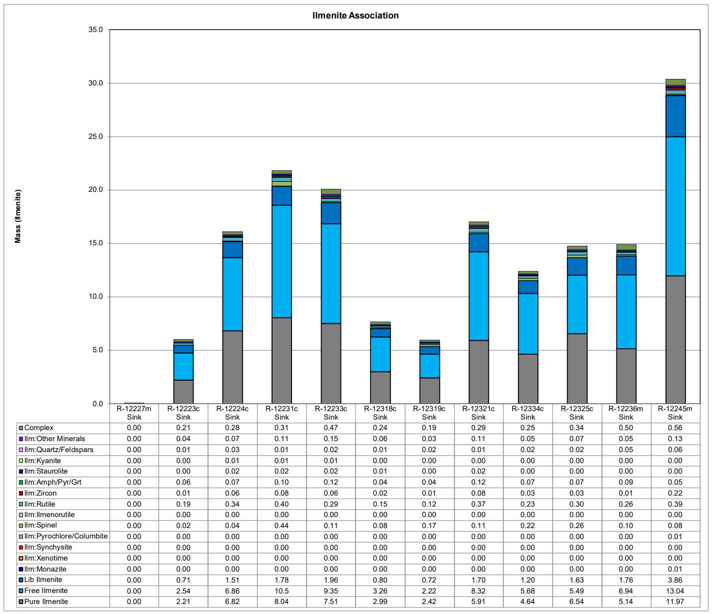


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
■ Complex	1.99	2.15	1.50	2.37	2.80	2.54	3.86	1.24	2.42	2.03	2.37
■ Ilm:Other Minerals	0.82	0.82	0.62	1.27	1.07	0.90	1.26	0.75	0.98	0.83	0.78
■ Ilm:Quartz/Feldspars	0.14	0.07	0.14	0.21	0.04	0.08	0.09	0.08	0.06	0.09	0.05
■ Ilm:Kyanite	0.09	0.10	0.05	0.03	0.04	0.10	0.21	0.12	0.00	0.06	0.02
■ Ilm:Staurolite	0.16	0.19	0.04	0.02	0.04	0.08	0.11	0.08	0.18	0.09	0.02
■ Ilm:Amph/Pyr/Grt	0.52	0.72	0.24	1.28	1.23	1.08	1.65	1.55	1.71	0.37	0.29
■ Ilm:Zircon	0.61	0.52	0.45	0.38	0.54	0.59	0.15	0.65	0.34	0.43	0.45
■ Ilm:Rutile	1.66	1.86	1.47	1.22	1.41	1.05	1.14	1.07	0.84	1.77	1.19
■ Ilm:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Spinel	0.01	0.05	0.01	0.05	1.73	2.03	0.55	0.03	0.37	0.01	0.82
■ Ilm:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Monazite	0.08	0.00	0.02	0.00	0.02	0.03	0.00	0.03	0.00	0.00	0.01
■ Lib Ilmenite	8.50	8.91	8.90	9.21	10.9	9.58	10.0	6.08	8.57	9.50	10.7
■ Free Ilmenite	55.0	53.9	50.3	45.6	48.3	48.6	49.9	37.3	45.7	51.4	36.7
■ Pure Ilmenite	30.5	30.7	36.2	38.4	31.9	33.4	31.1	51.0	38.8	33.4	46.6

Normalized Mass of Ilmenite Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
Pure Ilmenite	30.5	30.7	36.2	38.4	31.9	33.4	31.1	51.0	38.8	33.4	46.6
Free Ilmenite	55.0	53.9	50.3	45.6	48.3	48.6	49.9	37.3	45.7	51.4	36.7
Lib Ilmenite	8.50	8.91	8.90	9.21	10.9	9.58	10.0	6.08	8.57	9.50	10.7
Ilm:Monazite	0.08	0.00	0.02	0.00	0.02	0.03	0.00	0.03	0.00	0.00	0.01
Ilm:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Spinel	0.01	0.05	0.01	0.05	1.73	2.03	0.55	0.03	0.37	0.01	0.82
Ilm:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Rutile	1.66	1.86	1.47	1.22	1.41	1.05	1.14	1.07	0.84	1.77	1.19
Ilm:Zircon	0.61	0.52	0.45	0.38	0.54	0.59	0.15	0.65	0.34	0.43	0.45
Ilm:Amph/Pyr/Grt	0.52	0.72	0.24	1.28	1.23	1.08	1.65	1.55	1.71	0.37	0.29
Ilm:Staurolite	0.16	0.19	0.04	0.02	0.04	0.08	0.11	0.08	0.18	0.09	0.02
Ilm:Kyanite	0.09	0.10	0.05	0.03	0.04	0.10	0.21	0.12	0.00	0.06	0.02
Ilm:Quartz/Feldspars	0.14	0.07	0.14	0.21	0.04	0.08	0.09	0.08	0.06	0.09	0.05
Ilm:Other Minerals	0.82	0.82	0.62	1.27	1.07	0.90	1.26	0.75	0.98	0.83	0.78
Complex	1.99	2.15	1.50	2.37	2.80	2.54	3.86	1.24	2.42	2.03	2.37
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Liberated	93.9	93.5	95.5	93.2	91.1	91.5	91.0	94.4	93.1	94.3	94.0

Ilmenite Association

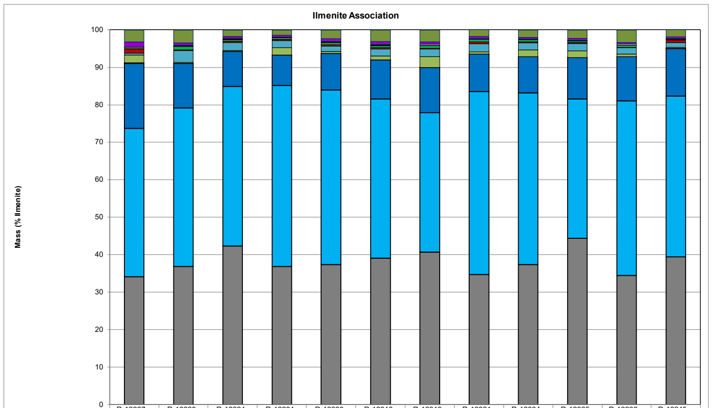


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■ Complex	0.00	0.21	0.28	0.31	0.47	0.24	0.19	0.29	0.25	0.34	0.50	0.56
■ Ilm:Other Minerals	0.00	0.04	0.07	0.11	0.15	0.06	0.03	0.11	0.05	0.07	0.05	0.13
■ Ilm:Quartz/Feldspars	0.00	0.01	0.03	0.01	0.02	0.01	0.02	0.01	0.02	0.02	0.05	0.06
■ Ilm:Kyanite	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Staurolite	0.00	0.00	0.02	0.02	0.02	0.01	0.00	0.02	0.00	0.00	0.00	0.00
■ Ilm:Amph/Pyr/Grt	0.00	0.06	0.07	0.10	0.12	0.04	0.04	0.12	0.07	0.07	0.09	0.05
■ Ilm:Zircon	0.00	0.01	0.06	0.08	0.06	0.02	0.01	0.08	0.03	0.03	0.01	0.22
■ Ilm:Rutile	0.00	0.19	0.34	0.40	0.29	0.15	0.12	0.37	0.23	0.30	0.26	0.39
■ Ilm:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Spinel	0.00	0.02	0.04	0.44	0.11	0.08	0.17	0.11	0.22	0.26	0.10	0.08
■ Ilm:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
■ Ilm:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Ilm:Monazite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
■ Lib Ilmenite	0.00	0.71	1.51	1.78	1.96	0.80	0.72	1.70	1.20	1.63	1.76	3.86
■ Free Ilmenite	0.00	2.54	6.86	10.5	9.35	3.26	2.22	8.32	5.68	5.49	6.94	13.04
■ Pure Ilmenite	0.00	2.21	6.82	8.04	7.51	2.99	2.42	5.91	4.64	6.54	5.14	11.97

Absolute Mass of Ilmenite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Pure Ilmenite	0.00	2.21	6.82	8.04	7.51	2.99	2.42	5.91	4.64	6.54	5.14	11.97
Free Ilmenite	0.00	2.54	6.86	10.5	9.35	3.26	2.22	8.32	5.68	5.49	6.94	13.04
Lib Ilmenite	0.00	0.71	1.51	1.78	1.96	0.80	0.72	1.70	1.20	1.63	1.76	3.86
Ilm:Monazite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ilm:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ilm:Spinel	0.00	0.02	0.04	0.44	0.11	0.08	0.17	0.11	0.22	0.26	0.10	0.08
Ilm:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Rutile	0.00	0.19	0.34	0.40	0.29	0.15	0.12	0.37	0.23	0.30	0.26	0.39
Ilm:Zircon	0.00	0.01	0.06	0.08	0.06	0.02	0.01	0.08	0.03	0.03	0.01	0.22
Ilm:Amph/Pyr/Grt	0.00	0.06	0.07	0.10	0.12	0.04	0.04	0.12	0.07	0.07	0.09	0.05
Ilm:Staurolite	0.00	0.00	0.02	0.02	0.02	0.01	0.00	0.02	0.00	0.00	0.00	0.00
Ilm:Kyanite	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Quartz/Feldspars	0.00	0.01	0.03	0.01	0.02	0.01	0.02	0.01	0.02	0.02	0.05	0.06
Ilm:Other Minerals	0.00	0.04	0.07	0.11	0.15	0.06	0.03	0.11	0.05	0.07	0.05	0.13
Complex	0.00	0.21	0.28	0.31	0.47	0.24	0.19	0.29	0.25	0.34	0.50	0.56
Total	0.00	6.01	16.1	21.8	20.1	7.66	5.96	17.0	12.4	14.8	14.9	30.4

Ilmenite Association



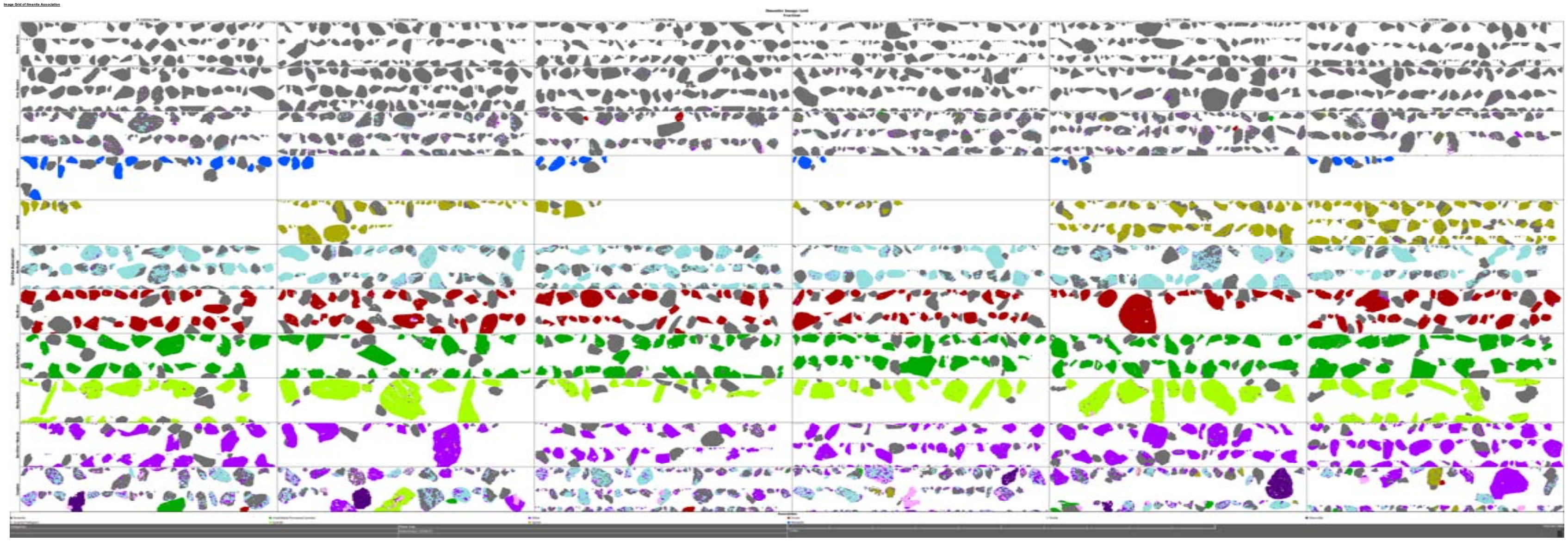
	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Complex	3.17	3.46	1.76	1.40	2.36	3.11	3.19	1.72	2.04	2.28	3.37	1.83
Ilm:Other Minerals	1.32	0.64	0.46	0.51	0.75	0.80	0.57	0.64	0.41	0.45	0.35	0.43
Ilm:Quartz/Feldspars	0.23	0.15	0.17	0.07	0.11	0.12	0.39	0.06	0.15	0.13	0.33	0.20
Ilm:Kyanite	0.00	0.08	0.07	0.03	0.05	0.06	0.01	0.02	0.01	0.01	0.01	0.00
Ilm:Staurolite	0.00	0.06	0.11	0.09	0.12	0.09	0.00	0.09	0.01	0.02	0.00	0.01
Ilm:Amph/Pyr/Grt	0.32	0.95	0.42	0.44	0.62	0.58	0.74	0.68	0.59	0.48	0.60	0.17
Ilm:Zircon	1.12	0.12	0.38	0.35	0.28	0.29	0.20	0.47	0.26	0.21	0.04	0.71
Ilm:Rutile	0.55	3.18	2.09	1.82	1.45	1.90	2.00	2.15	1.83	2.02	1.72	1.29
Ilm:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Spinel	2.03	0.29	0.26	2.00	0.56	1.00	2.93	0.64	1.81	1.76	0.70	0.26
Ilm:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Ilm:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Xenotime	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Monazite	0.12	0.02	0.00	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.05
Lib Ilmenite	17.4	11.8	9.39	8.13	9.76	10.4	12.0	9.97	9.64	11.1	11.79	12.7
Free Ilmenite	39.5	42.4	42.6	48.3	46.6	42.5	37.3	48.8	45.8	37.2	46.6	42.9
Pure Ilmenite	34.2	36.9	42.3	36.8	37.4	39.1	40.7	34.7	37.4	44.3	34.5	39.4

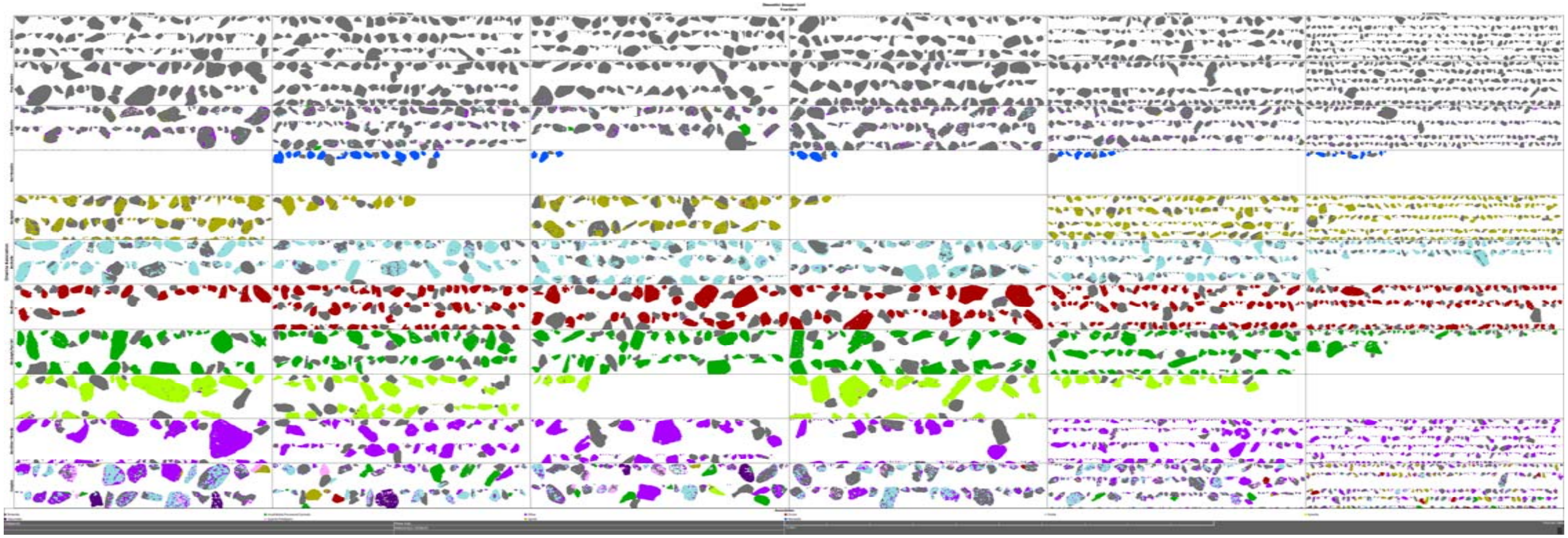
Normalized Mass of Ilmenite Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Pure Ilmenite	34.2	36.9	42.3	36.8	37.4	39.1	40.7	34.7	37.4	44.3	34.5	39.4
Free Ilmenite	39.5	42.4	42.6	48.3	46.6	42.5	37.3	48.8	45.8	37.2	46.6	42.9
Lib Ilmenite	17.4	11.8	9.39	8.13	9.76	10.4	12.0	9.97	9.64	11.1	11.79	12.7
Ilm:Monazite	0.12	0.02	0.00	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.05
Ilm:Xenotime	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Ilm:Spinel	2.03	0.29	0.26	2.00	0.56	1.00	2.93	0.64	1.81	1.76	0.70	0.26
Ilm:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilm:Rutile	0.55	3.18	2.09	1.82	1.45	1.90	2.00	2.15	1.83	2.02	1.72	1.29
Ilm:Zircon	1.12	0.12	0.38	0.35	0.28	0.29	0.20	0.47	0.26	0.21	0.04	0.71
Ilm:Amph/Pyr/Grt	0.32	0.95	0.42	0.44	0.62	0.58	0.74	0.68	0.59	0.48	0.60	0.17
Ilm:Staurolite	0.00	0.06	0.11	0.09	0.12	0.09	0.00	0.09	0.01	0.02	0.00	0.01
Ilm:Kyanite	0.00	0.08	0.07	0.03	0.05	0.06	0.01	0.02	0.01	0.01	0.01	0.00
Ilm:Quartz/Feldspars	0.23	0.15	0.17	0.07	0.11	0.12	0.39	0.06	0.15	0.13	0.33	0.20
Ilm:Other Minerals	1.32	0.64	0.46	0.51	0.75	0.80	0.57	0.64	0.41	0.45	0.35	0.43
Complex	3.17	3.46	1.76	1.40	2.36	3.11	3.19	1.72	2.04	2.28	3.37	1.83
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Liberated	91.1	91.0	94.3	93.3	93.7	92.0	90.0	93.5	92.9	92.6	92.9	95.0

Virginia Department of Energy, Geology and Mineral Resources Program
CALR-17512-02
MI6024-MAY22 & MI6031-NOV22

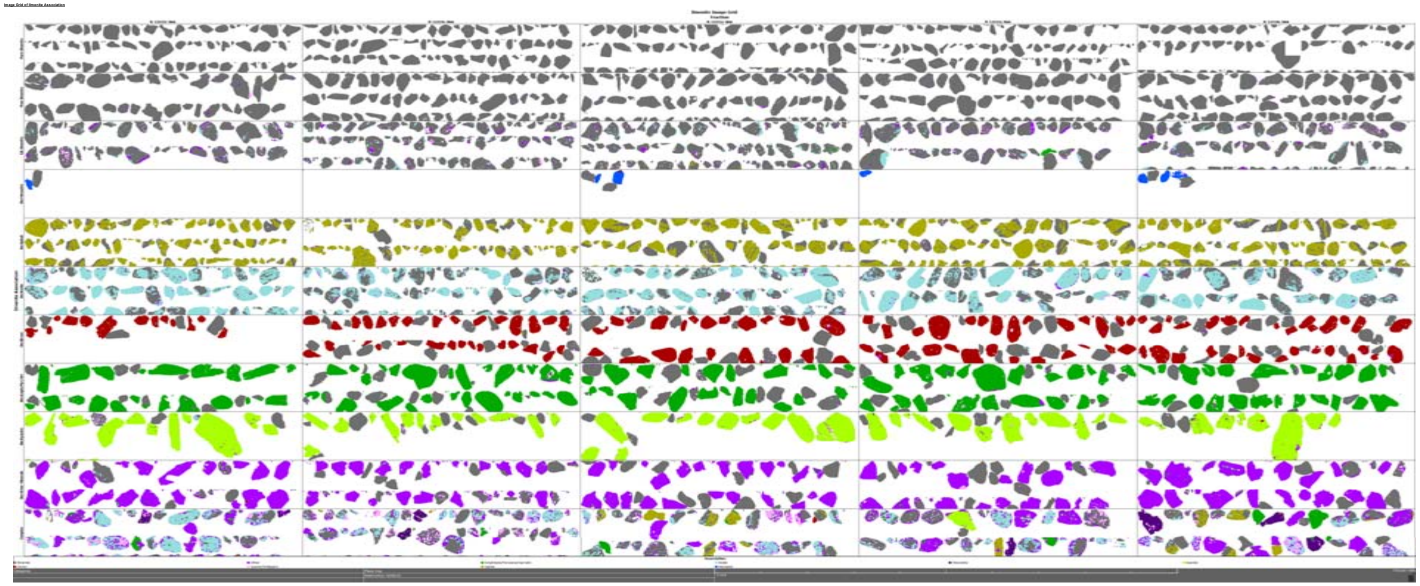
Image Grid of Ilmenite Association

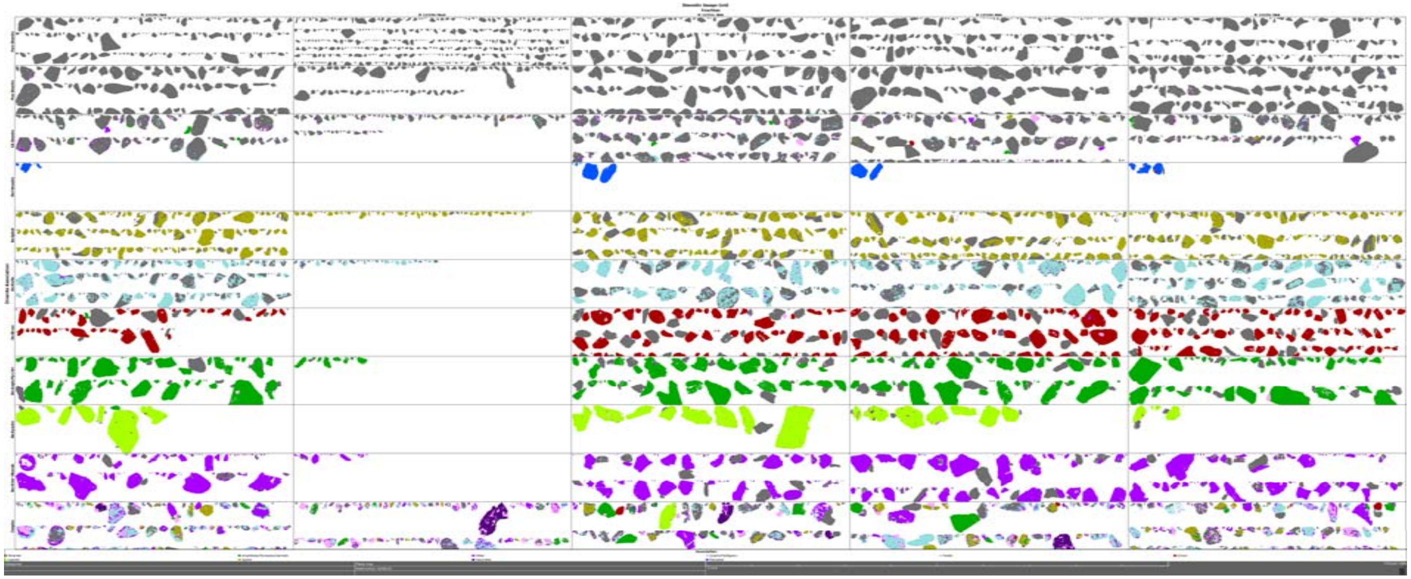




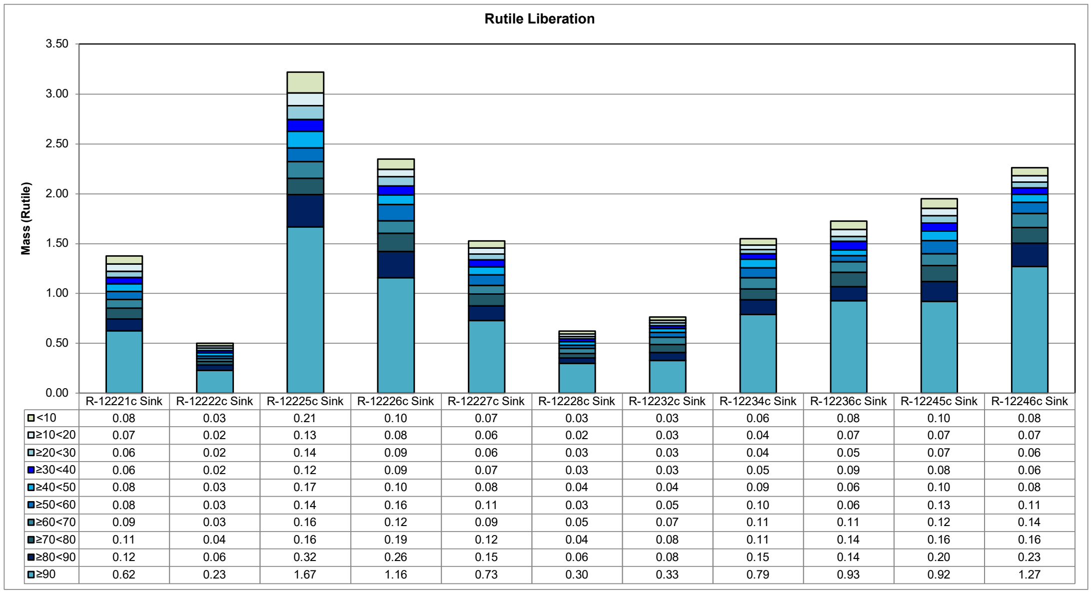
Virginia Department of Energy, Geology and Mineral Resources Program
CALR-17512-02
MI6024-MAY22 & MI6031-NOV22

Image Grid of Ilmenite Association





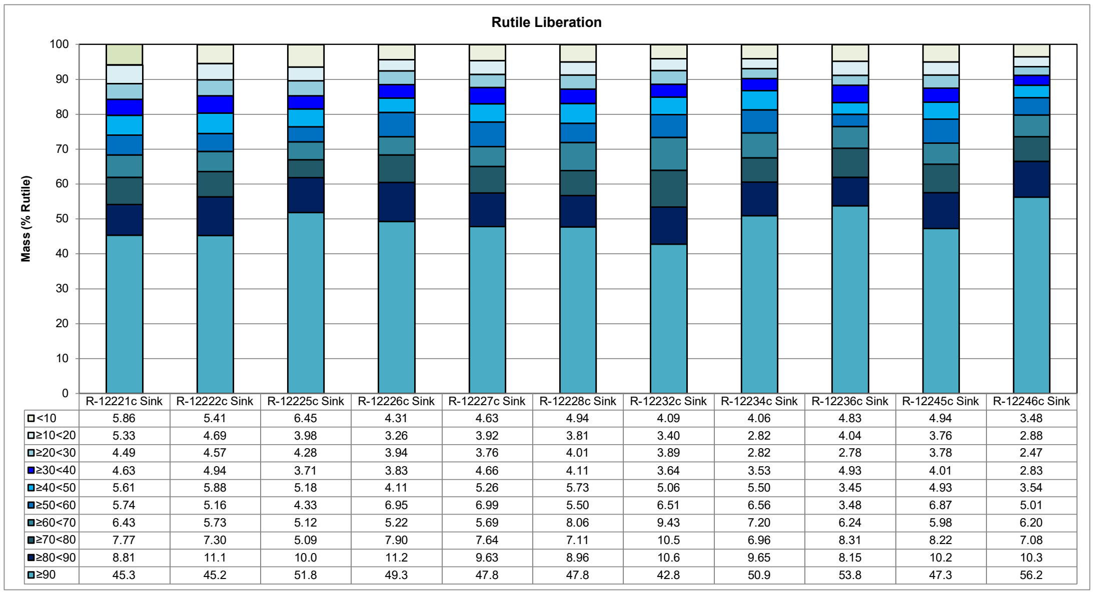
Rutile Liberation



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
<10	0.08	0.03	0.21	0.10	0.07	0.03	0.03	0.06	0.08	0.10	0.08
≥10<20	0.07	0.02	0.13	0.08	0.06	0.02	0.03	0.04	0.07	0.07	0.07
≥20<30	0.06	0.02	0.14	0.09	0.06	0.03	0.03	0.04	0.05	0.07	0.06
≥30<40	0.06	0.02	0.12	0.09	0.07	0.03	0.03	0.05	0.09	0.08	0.06
≥40<50	0.08	0.03	0.17	0.10	0.08	0.04	0.04	0.09	0.06	0.10	0.08
≥50<60	0.08	0.03	0.14	0.16	0.11	0.03	0.05	0.10	0.06	0.13	0.11
≥60<70	0.09	0.03	0.16	0.12	0.09	0.05	0.07	0.11	0.11	0.12	0.14
≥70<80	0.11	0.04	0.16	0.19	0.12	0.04	0.08	0.11	0.14	0.16	0.16
≥80<90	0.12	0.06	0.32	0.26	0.15	0.06	0.08	0.15	0.14	0.20	0.23
≥90	0.62	0.23	1.67	1.16	0.73	0.30	0.33	0.79	0.93	0.92	1.27

Absolute Mass of Rutile Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	0.62	0.23	1.67	1.16	0.73	0.30	0.33	0.79	0.93	0.92	1.27
≥80<90	0.12	0.06	0.32	0.26	0.15	0.06	0.08	0.15	0.14	0.20	0.23
≥70<80	0.11	0.04	0.16	0.19	0.12	0.04	0.08	0.11	0.14	0.16	0.16
≥60<70	0.09	0.03	0.16	0.12	0.09	0.05	0.07	0.11	0.11	0.12	0.14
≥50<60	0.08	0.03	0.14	0.16	0.11	0.03	0.05	0.10	0.06	0.13	0.11
≥40<50	0.08	0.03	0.17	0.10	0.08	0.04	0.04	0.09	0.06	0.10	0.08
≥30<40	0.06	0.02	0.12	0.09	0.07	0.03	0.03	0.05	0.09	0.08	0.06
≥20<30	0.06	0.02	0.14	0.09	0.06	0.03	0.03	0.04	0.05	0.07	0.06
≥10<20	0.07	0.02	0.13	0.08	0.06	0.02	0.03	0.04	0.07	0.07	0.07
<10	0.08	0.03	0.21	0.10	0.07	0.03	0.03	0.06	0.08	0.10	0.08
Total	1.38	0.50	3.22	2.35	1.53	0.62	0.76	1.55	1.73	1.95	2.26

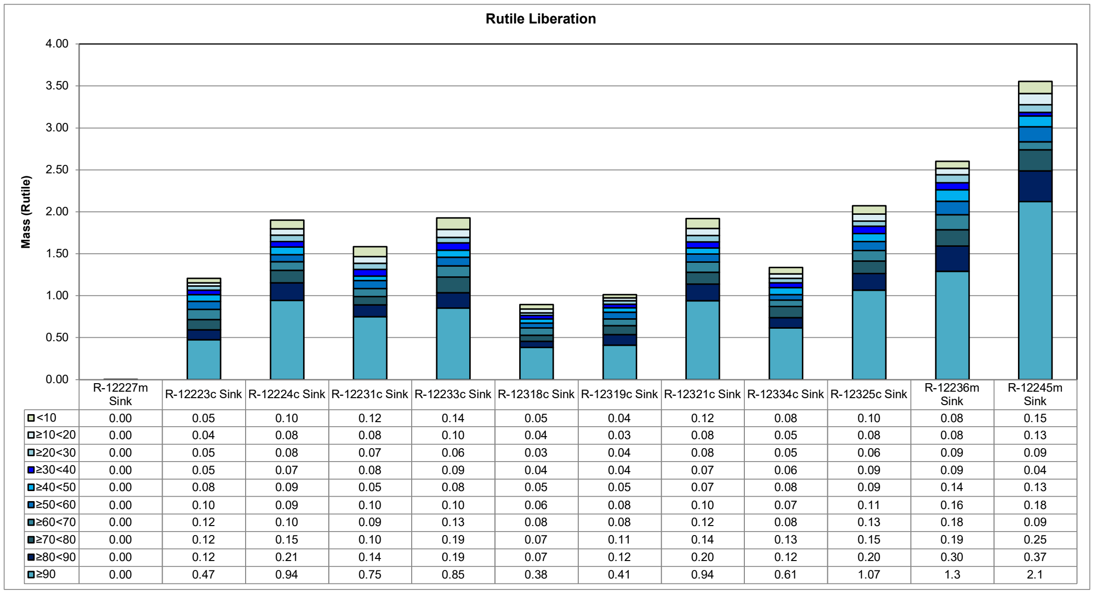


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
<10	5.86	5.41	6.45	4.31	4.63	4.94	4.09	4.06	4.83	4.94	3.48
≥10<20	5.33	4.69	3.98	3.26	3.92	3.81	3.40	2.82	4.04	3.76	2.88
≥20<30	4.49	4.57	4.28	3.94	3.76	4.01	3.89	2.82	2.78	3.78	2.47
≥30<40	4.63	4.94	3.71	3.83	4.66	4.11	3.64	3.53	4.93	4.01	2.83
≥40<50	5.61	5.88	5.18	4.11	5.26	5.73	5.06	5.50	3.45	4.93	3.54
≥50<60	5.74	5.16	4.33	6.95	6.99	5.50	6.51	6.56	3.48	6.87	5.01
≥60<70	6.43	5.73	5.12	5.22	5.69	8.06	9.43	7.20	6.24	5.98	6.20
≥70<80	7.77	7.30	5.09	7.90	7.64	7.11	10.5	6.96	8.31	8.22	7.08
≥80<90	8.81	11.1	10.0	11.2	9.63	8.96	10.6	9.65	8.15	10.2	10.3
≥90	45.3	45.2	51.8	49.3	47.8	47.8	42.8	50.9	53.8	47.3	56.2

Normalized Mass of Rutile Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	45.3	45.2	51.8	49.3	47.8	47.8	42.8	50.9	53.8	47.3	56.2
≥80<90	8.81	11.1	10.0	11.2	9.63	8.96	10.6	9.65	8.15	10.2	10.3
≥70<80	7.77	7.30	5.09	7.90	7.64	7.11	10.5	6.96	8.31	8.22	7.08
≥60<70	6.43	5.73	5.12	5.22	5.69	8.06	9.43	7.20	6.24	5.98	6.20
≥50<60	5.74	5.16	4.33	6.95	6.99	5.50	6.51	6.56	3.48	6.87	5.01
≥40<50	5.61	5.88	5.18	4.11	5.26	5.73	5.06	5.50	3.45	4.93	3.54
≥30<40	4.63	4.94	3.71	3.83	4.66	4.11	3.64	3.53	4.93	4.01	2.83
≥20<30	4.49	4.57	4.28	3.94	3.76	4.01	3.89	2.82	2.78	3.78	2.47
≥10<20	5.33	4.69	3.98	3.26	3.92	3.81	3.40	2.82	4.04	3.76	2.88
<10	5.86	5.41	6.45	4.31	4.63	4.94	4.09	4.06	4.83	4.94	3.48
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

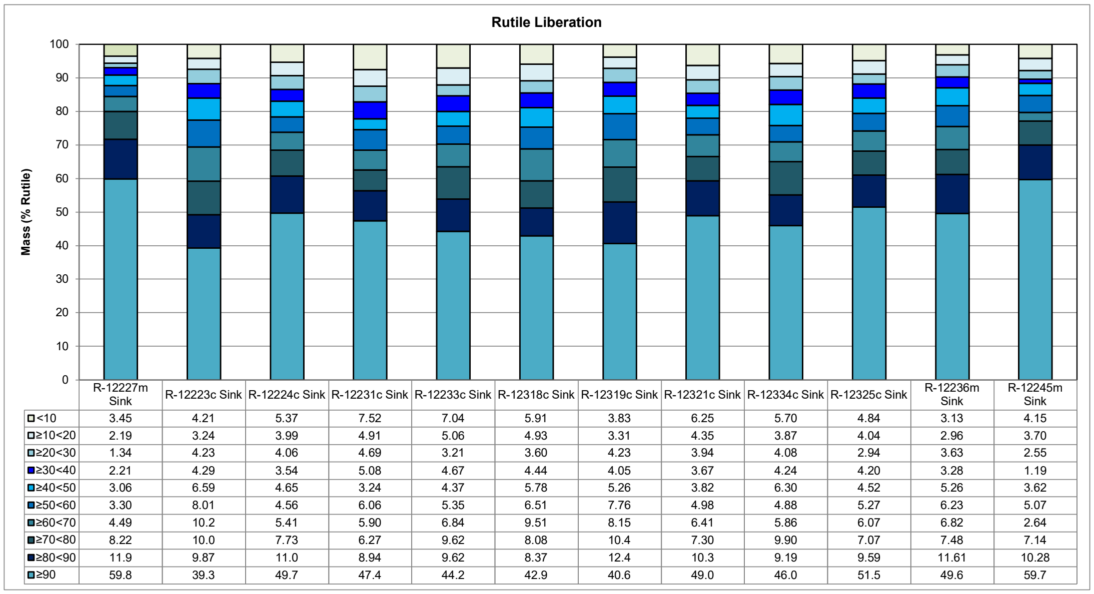
Rutile Liberation



	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
<10	0.00	0.05	0.10	0.12	0.14	0.05	0.04	0.12	0.08	0.10	0.08	0.15
≥10<20	0.00	0.04	0.08	0.08	0.10	0.04	0.03	0.08	0.05	0.08	0.08	0.13
≥20<30	0.00	0.05	0.08	0.07	0.06	0.03	0.04	0.08	0.05	0.06	0.09	0.09
≥30<40	0.00	0.05	0.07	0.08	0.09	0.04	0.04	0.07	0.06	0.09	0.09	0.04
≥40<50	0.00	0.08	0.09	0.05	0.08	0.05	0.05	0.07	0.08	0.09	0.14	0.13
≥50<60	0.00	0.10	0.09	0.10	0.10	0.06	0.08	0.10	0.07	0.11	0.16	0.18
≥60<70	0.00	0.12	0.10	0.09	0.13	0.08	0.08	0.12	0.08	0.13	0.18	0.09
≥70<80	0.00	0.12	0.15	0.10	0.19	0.07	0.11	0.14	0.13	0.15	0.19	0.25
≥80<90	0.00	0.12	0.21	0.14	0.19	0.07	0.12	0.20	0.12	0.20	0.30	0.37
≥90	0.00	0.47	0.94	0.75	0.85	0.38	0.41	0.94	0.61	1.07	1.3	2.1

Absolute Mass of Rutile Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	0.00	0.47	0.94	0.75	0.85	0.38	0.41	0.94	0.61	1.07	1.3	2.1
≥80<90	0.00	0.12	0.21	0.14	0.19	0.07	0.12	0.20	0.12	0.20	0.30	0.37
≥70<80	0.00	0.12	0.15	0.10	0.19	0.07	0.11	0.14	0.13	0.15	0.19	0.25
≥60<70	0.00	0.12	0.10	0.09	0.13	0.08	0.08	0.12	0.08	0.13	0.18	0.09
≥50<60	0.00	0.10	0.09	0.10	0.10	0.06	0.08	0.10	0.07	0.11	0.16	0.18
≥40<50	0.00	0.08	0.09	0.05	0.08	0.05	0.05	0.07	0.08	0.09	0.14	0.13
≥30<40	0.00	0.05	0.07	0.08	0.09	0.04	0.04	0.07	0.06	0.09	0.09	0.04
≥20<30	0.00	0.05	0.08	0.07	0.06	0.03	0.04	0.08	0.05	0.06	0.09	0.09
≥10<20	0.00	0.04	0.08	0.08	0.10	0.04	0.03	0.08	0.05	0.08	0.08	0.13
<10	0.00	0.05	0.10	0.12	0.14	0.05	0.04	0.12	0.08	0.10	0.08	0.15
Total	0.00	1.20	1.90	1.58	1.93	0.89	1.01	1.92	1.34	2.07	2.6	3.6

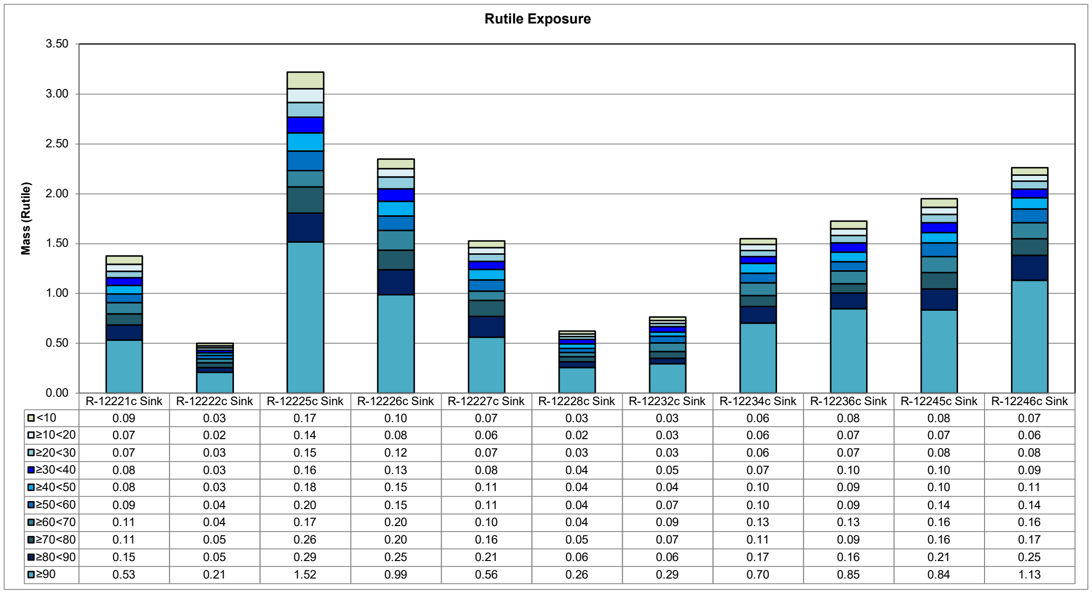


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
<10	3.45	4.21	5.37	7.52	7.04	5.91	3.83	6.25	5.70	4.84	3.13	4.15
≥10<20	2.19	3.24	3.99	4.91	5.06	4.93	3.31	4.35	3.87	4.04	2.96	3.70
≥20<30	1.34	4.23	4.06	4.69	3.21	3.60	4.23	3.94	4.08	2.94	3.63	2.55
≥30<40	2.21	4.29	3.54	5.08	4.67	4.44	4.05	3.67	4.24	4.20	3.28	1.19
≥40<50	3.06	6.59	4.65	3.24	4.37	5.78	5.26	3.82	6.30	4.52	5.26	3.62
≥50<60	3.30	8.01	4.56	6.06	5.35	6.51	7.76	4.98	4.88	5.27	6.23	5.07
≥60<70	4.49	10.2	5.41	5.90	6.84	9.51	8.15	6.41	5.86	6.07	6.82	2.64
≥70<80	8.22	10.0	7.73	6.27	9.62	8.08	10.4	7.30	9.90	7.07	7.48	7.14
≥80<90	11.9	9.87	11.0	8.94	9.62	8.37	12.4	10.3	9.19	9.59	11.61	10.28
≥90	59.8	39.3	49.7	47.4	44.2	42.9	40.6	49.0	46.0	51.5	49.6	59.7

Normalized Mass of Rutile Across Samples

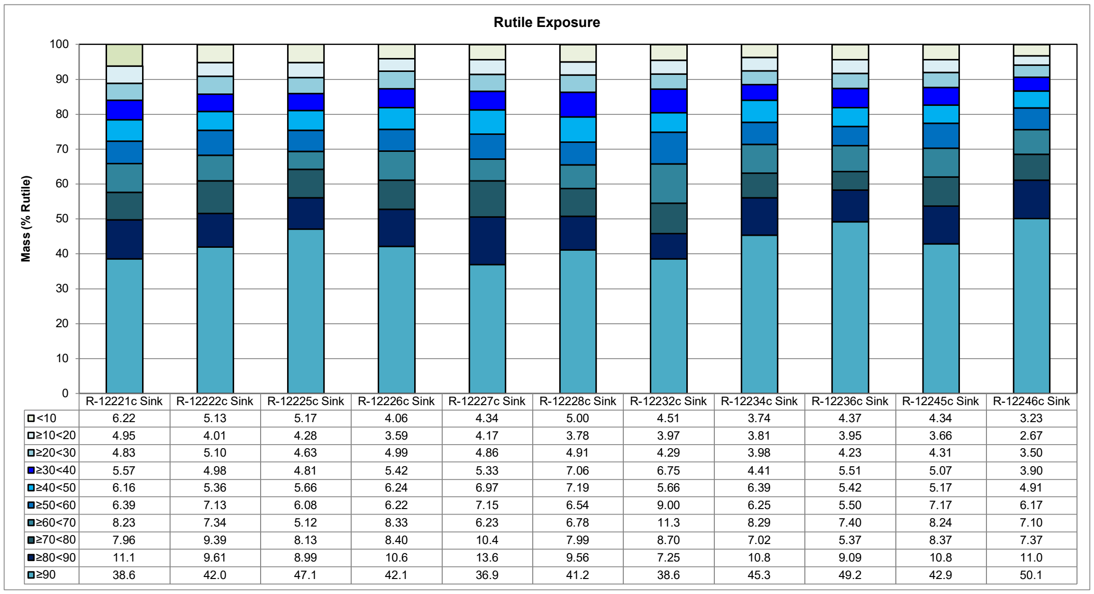
Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	59.8	39.3	49.7	47.4	44.2	42.9	40.6	49.0	46.0	51.5	49.6	59.7
≥80<90	11.9	9.87	11.0	8.94	9.62	8.37	12.4	10.3	9.19	9.59	11.61	10.28
≥70<80	8.22	10.0	7.73	6.27	9.62	8.08	10.4	7.30	9.90	7.07	7.48	7.14
≥60<70	4.49	10.2	5.41	5.90	6.84	9.51	8.15	6.41	5.86	6.07	6.82	2.64
≥50<60	3.30	8.01	4.56	6.06	5.35	6.51	7.76	4.98	4.88	5.27	6.23	5.07
≥40<50	3.06	6.59	4.65	3.24	4.37	5.78	5.26	3.82	6.30	4.52	5.26	3.62
≥30<40	2.21	4.29	3.54	5.08	4.67	4.44	4.05	3.67	4.24	4.20	3.28	1.19
≥20<30	1.34	4.23	4.06	4.69	3.21	3.60	4.23	3.94	4.08	2.94	3.63	2.55
≥10<20	2.19	3.24	3.99	4.91	5.06	4.93	3.31	4.35	3.87	4.04	2.96	3.70
<10	3.45	4.21	5.37	7.52	7.04	5.91	3.83	6.25	5.70	4.84	3.13	4.15
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Rutile Exposure



Absolute Mass of Rutile Across Samples

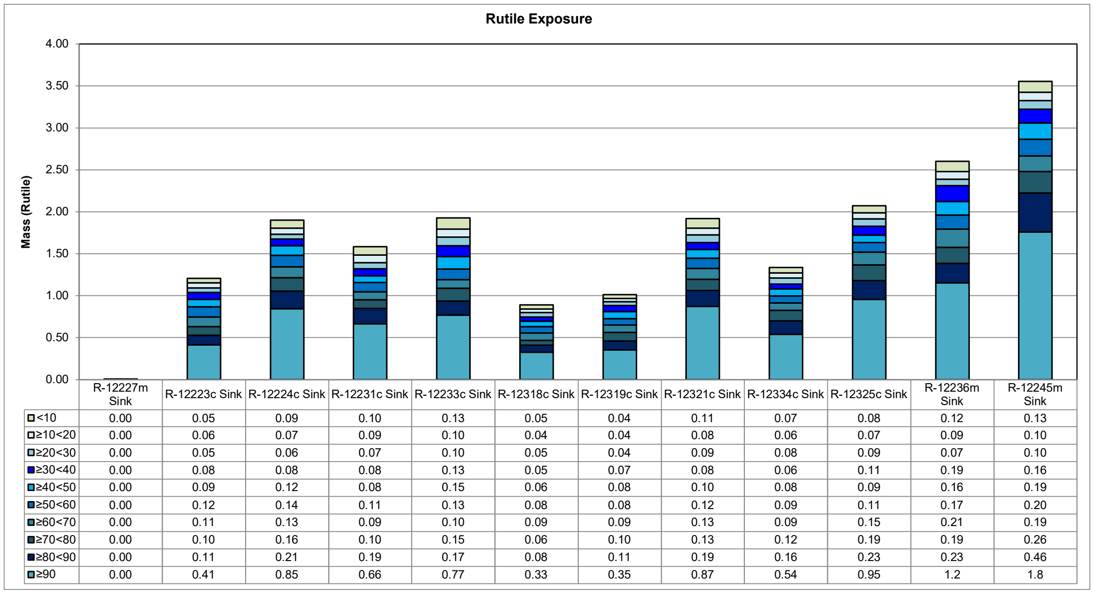
Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	0.53	0.21	1.52	0.99	0.56	0.26	0.29	0.70	0.85	0.84	1.13
≥80<90	0.15	0.05	0.29	0.25	0.21	0.06	0.06	0.17	0.16	0.21	0.25
≥70<80	0.11	0.05	0.26	0.20	0.16	0.05	0.07	0.11	0.09	0.16	0.17
≥60<70	0.11	0.04	0.17	0.20	0.10	0.04	0.09	0.13	0.13	0.16	0.16
≥50<60	0.09	0.04	0.20	0.15	0.11	0.04	0.07	0.10	0.09	0.14	0.14
≥40<50	0.08	0.03	0.18	0.15	0.11	0.04	0.04	0.10	0.09	0.10	0.11
≥30<40	0.08	0.03	0.16	0.13	0.08	0.04	0.05	0.07	0.10	0.10	0.09
≥20<30	0.07	0.03	0.15	0.12	0.07	0.03	0.03	0.06	0.07	0.08	0.08
≥10<20	0.07	0.02	0.14	0.08	0.06	0.02	0.03	0.06	0.07	0.07	0.06
<10	0.09	0.03	0.17	0.10	0.07	0.03	0.03	0.06	0.08	0.08	0.07
Total	1.38	0.50	3.22	2.35	1.53	0.62	0.76	1.55	1.73	1.95	2.26



Normalized Mass of Rutile Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	38.6	42.0	47.1	42.1	36.9	41.2	38.6	45.3	49.2	42.9	50.1
≥80<90	11.1	9.61	8.99	10.6	13.6	9.56	7.25	10.8	9.09	10.8	11.0
≥70<80	7.96	9.39	8.13	8.40	10.4	7.99	8.70	7.02	5.37	8.37	7.37
≥60<70	8.23	7.34	5.12	8.33	6.23	6.78	11.3	8.29	7.40	8.24	7.10
≥50<60	6.39	7.13	6.08	6.22	7.15	6.54	9.00	6.25	5.50	7.17	6.17
≥40<50	6.16	5.36	5.66	6.24	6.97	7.19	5.66	6.39	5.42	5.17	4.91
≥30<40	5.57	4.98	4.81	5.42	5.33	7.06	6.75	4.41	5.51	5.07	3.90
≥20<30	4.83	5.10	4.63	4.99	4.86	4.91	4.29	3.98	4.23	4.31	3.50
≥10<20	4.95	4.01	4.28	3.59	4.17	3.78	3.97	3.81	3.95	3.66	2.67
<10	6.22	5.13	5.17	4.06	4.34	5.00	4.51	3.74	4.37	4.34	3.23
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

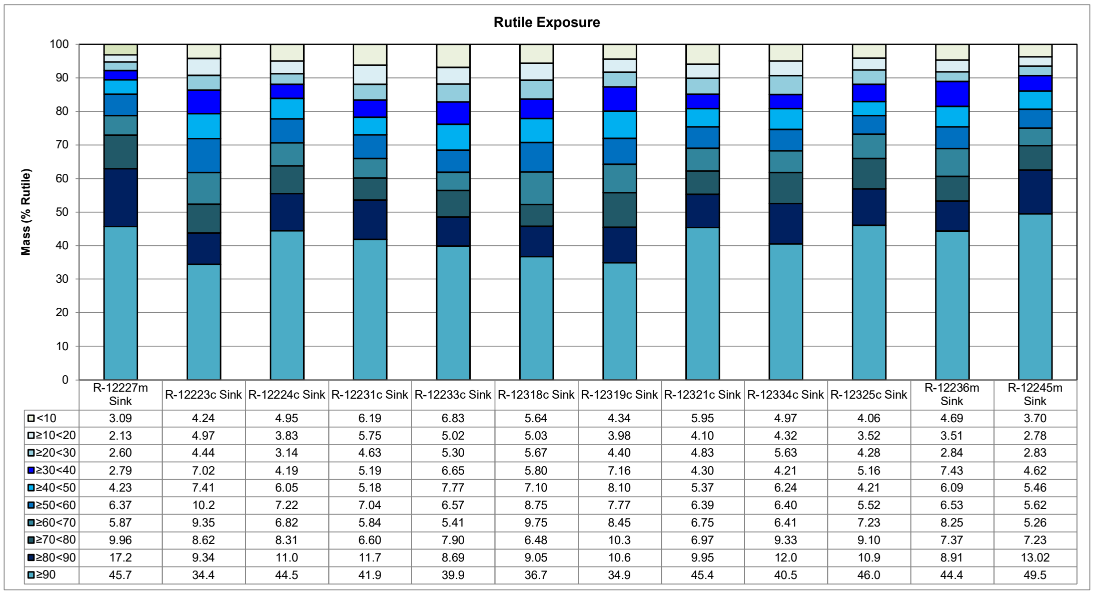
Rutile Exposure



	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■<10	0.00	0.05	0.09	0.10	0.13	0.05	0.04	0.11	0.07	0.08	0.12	0.13
■≥10<20	0.00	0.06	0.07	0.09	0.10	0.04	0.04	0.08	0.06	0.07	0.09	0.10
■≥20<30	0.00	0.05	0.06	0.07	0.10	0.05	0.04	0.09	0.08	0.09	0.07	0.10
■≥30<40	0.00	0.08	0.08	0.08	0.13	0.05	0.07	0.08	0.06	0.11	0.19	0.16
■≥40<50	0.00	0.09	0.12	0.08	0.15	0.06	0.08	0.10	0.08	0.09	0.16	0.19
■≥50<60	0.00	0.12	0.14	0.11	0.13	0.08	0.08	0.12	0.09	0.11	0.17	0.20
■≥60<70	0.00	0.11	0.13	0.09	0.10	0.09	0.09	0.13	0.09	0.15	0.21	0.19
■≥70<80	0.00	0.10	0.16	0.10	0.15	0.06	0.10	0.13	0.12	0.19	0.19	0.26
■≥80<90	0.00	0.11	0.21	0.19	0.17	0.08	0.11	0.19	0.16	0.23	0.23	0.46
■≥90	0.00	0.41	0.85	0.66	0.77	0.33	0.35	0.87	0.54	0.95	1.2	1.8

Absolute Mass of Rutile Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	0.00	0.41	0.85	0.66	0.77	0.33	0.35	0.87	0.54	0.95	1.2	1.8
≥80<90	0.00	0.11	0.21	0.19	0.17	0.08	0.11	0.19	0.16	0.23	0.23	0.46
≥70<80	0.00	0.10	0.16	0.10	0.15	0.06	0.10	0.13	0.12	0.19	0.19	0.26
≥60<70	0.00	0.11	0.13	0.09	0.10	0.09	0.09	0.13	0.09	0.15	0.21	0.19
≥50<60	0.00	0.12	0.14	0.11	0.13	0.08	0.08	0.12	0.09	0.11	0.17	0.20
≥40<50	0.00	0.09	0.12	0.08	0.15	0.06	0.08	0.10	0.08	0.09	0.16	0.19
≥30<40	0.00	0.08	0.08	0.08	0.13	0.05	0.07	0.08	0.06	0.11	0.19	0.16
≥20<30	0.00	0.05	0.06	0.07	0.10	0.05	0.04	0.09	0.08	0.09	0.07	0.10
≥10<20	0.00	0.06	0.07	0.09	0.10	0.04	0.04	0.08	0.06	0.07	0.09	0.10
<10	0.00	0.05	0.09	0.10	0.13	0.05	0.04	0.11	0.07	0.08	0.12	0.13
Total	0.00	1.20	1.90	1.58	1.93	0.89	1.01	1.92	1.34	2.07	2.6	3.6

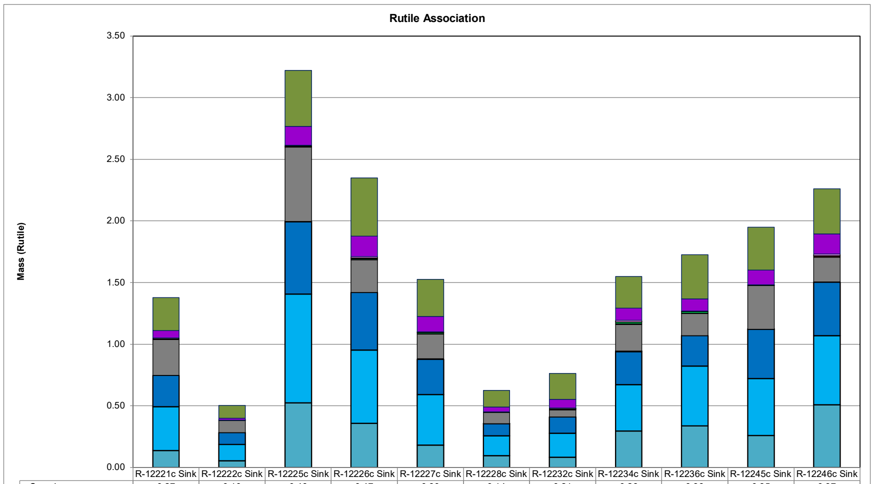


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■<10	3.09	4.24	4.95	6.19	6.83	5.64	4.34	5.95	4.97	4.06	4.69	3.70
■≥10<20	2.13	4.97	3.83	5.75	5.02	5.03	3.98	4.10	4.32	3.52	3.51	2.78
■≥20<30	2.60	4.44	3.14	4.63	5.30	5.67	4.40	4.83	5.63	4.28	2.84	2.83
■≥30<40	2.79	7.02	4.19	5.19	6.65	5.80	7.16	4.30	4.21	5.16	7.43	4.62
■≥40<50	4.23	7.41	6.05	5.18	7.77	7.10	8.10	5.37	6.24	4.21	6.09	5.46
■≥50<60	6.37	10.2	7.22	7.04	6.57	8.75	7.77	6.39	6.40	5.52	6.53	5.62
■≥60<70	5.87	9.35	6.82	5.84	5.41	9.75	8.45	6.75	6.41	7.23	8.25	5.26
■≥70<80	9.96	8.62	8.31	6.60	7.90	6.48	10.3	6.97	9.33	9.10	7.37	7.23
■≥80<90	17.2	9.34	11.0	11.7	8.69	9.05	10.6	9.95	12.0	10.9	8.91	13.02
■≥90	45.7	34.4	44.5	41.9	39.9	36.7	34.9	45.4	40.5	46.0	44.4	49.5

Normalized Mass of Rutile Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	45.7	34.4	44.5	41.9	39.9	36.7	34.9	45.4	40.5	46.0	44.4	49.5
≥80<90	17.2	9.34	11.0	11.7	8.69	9.05	10.6	9.95	12.0	10.9	8.91	13.02
≥70<80	9.96	8.62	8.31	6.60	7.90	6.48	10.3	6.97	9.33	9.10	7.37	7.23
≥60<70	5.87	9.35	6.82	5.84	5.41	9.75	8.45	6.75	6.41	7.23	8.25	5.26
≥50<60	6.37	10.2	7.22	7.04	6.57	8.75	7.77	6.39	6.40	5.52	6.53	5.62
≥40<50	4.23	7.41	6.05	5.18	7.77	7.10	8.10	5.37	6.24	4.21	6.09	5.46
≥30<40	2.79	7.02	4.19	5.19	6.65	5.80	7.16	4.30	4.21	5.16	7.43	4.62
≥20<30	2.60	4.44	3.14	4.63	5.30	5.67	4.40	4.83	5.63	4.28	2.84	2.83
≥10<20	2.13	4.97	3.83	5.75	5.02	5.03	3.98	4.10	4.32	3.52	3.51	2.78
<10	3.09	4.24	4.95	6.19	6.83	5.64	4.34	5.95	4.97	4.06	4.69	3.70
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Rutile Association

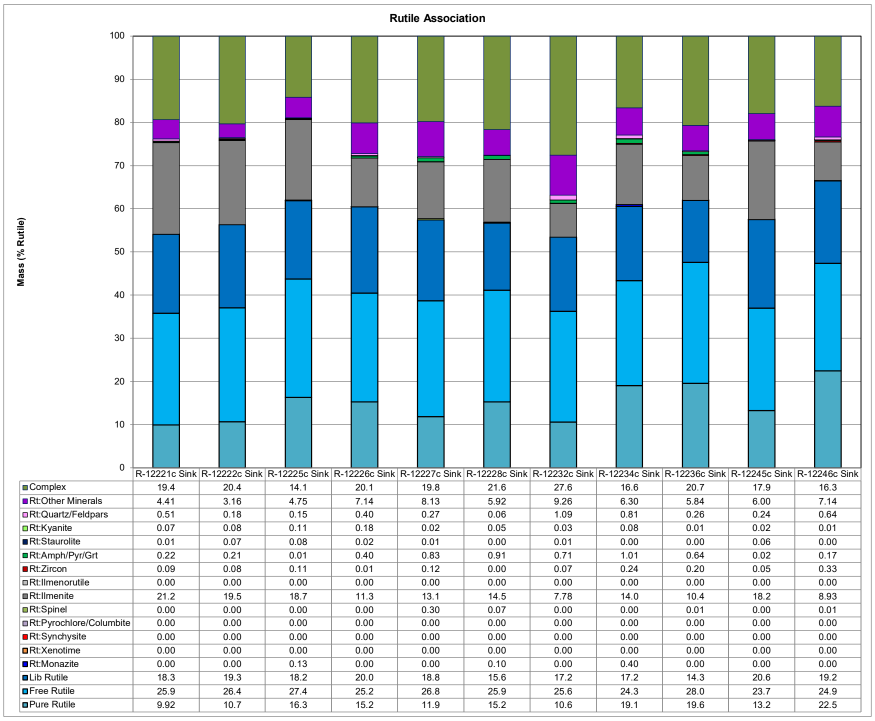


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
■ Complex	0.27	0.10	0.46	0.47	0.30	0.14	0.21	0.26	0.36	0.35	0.37
■ Rt:Other Minerals	0.06	0.02	0.15	0.17	0.12	0.04	0.07	0.10	0.10	0.12	0.16
■ Rt:Quartz/Feldpars	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01
■ Rt:Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Staurolite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Amph/Pyr/Grt	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0.00
■ Rt:Zircon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
■ Rt:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Ilmenite	0.29	0.10	0.60	0.27	0.20	0.09	0.06	0.22	0.18	0.35	0.20
■ Rt:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Monazite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
■ Lib Rutile	0.25	0.10	0.59	0.47	0.29	0.10	0.13	0.27	0.25	0.40	0.43
■ Free Rutile	0.36	0.13	0.88	0.59	0.41	0.16	0.20	0.38	0.48	0.46	0.56
■ Pure Rutile	0.14	0.05	0.52	0.36	0.18	0.10	0.08	0.30	0.34	0.26	0.51

Absolute Mass of Rutile Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
Pure Rutile	0.14	0.05	0.52	0.36	0.18	0.10	0.08	0.30	0.34	0.26	0.51
Free Rutile	0.36	0.13	0.88	0.59	0.41	0.16	0.20	0.38	0.48	0.46	0.56
Lib Rutile	0.25	0.10	0.59	0.47	0.29	0.10	0.13	0.27	0.25	0.40	0.43
Rt:Monazite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Rt:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Ilmenite	0.29	0.10	0.60	0.27	0.20	0.09	0.06	0.22	0.18	0.35	0.20
Rt:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Zircon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Rt:Amph/Pyr/Grt	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0.00
Rt:Staurolite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Quartz/Feldpars	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01
Rt:Other Minerals	0.06	0.02	0.15	0.17	0.12	0.04	0.07	0.10	0.10	0.12	0.16
Complex	0.27	0.10	0.46	0.47	0.30	0.14	0.21	0.26	0.36	0.35	0.37
Total	1.38	0.50	3.22	2.35	1.53	0.62	0.76	1.55	1.73	1.95	2.26

Rutile Association

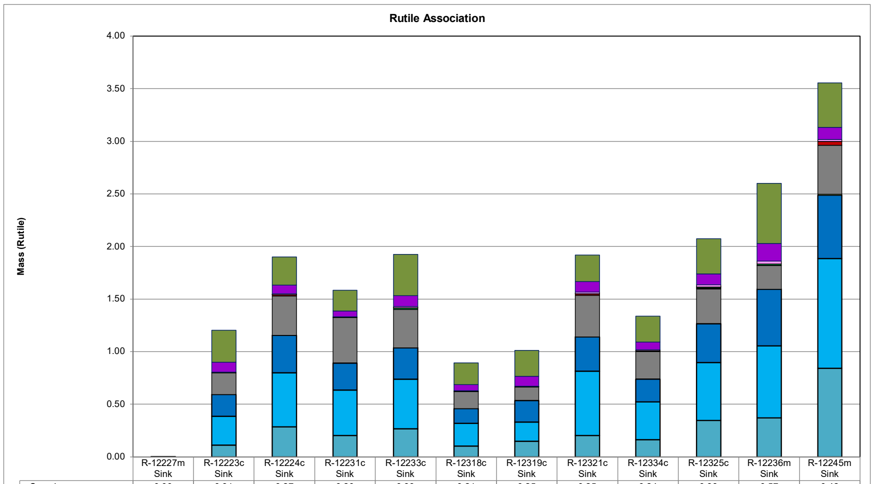


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
■ Complex	19.4	20.4	14.1	20.1	19.8	21.6	27.6	16.6	20.7	17.9	16.3
■ Rt:Other Minerals	4.41	3.16	4.75	7.14	8.13	5.92	9.26	6.30	5.84	6.00	7.14
■ Rt:Quartz/Feldpars	0.51	0.18	0.15	0.40	0.27	0.06	1.09	0.81	0.26	0.24	0.64
■ Rt:Kyanite	0.07	0.08	0.11	0.18	0.02	0.05	0.03	0.08	0.01	0.02	0.01
■ Rt:Staurolite	0.01	0.07	0.08	0.02	0.01	0.00	0.01	0.00	0.00	0.06	0.00
■ Rt:Amph/Pyr/Grt	0.22	0.21	0.01	0.40	0.83	0.91	0.71	1.01	0.64	0.02	0.17
■ Rt:Zircon	0.09	0.08	0.11	0.01	0.12	0.00	0.07	0.24	0.20	0.05	0.33
■ Rt:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Ilmenite	21.2	19.5	18.7	11.3	13.1	14.5	7.78	14.0	10.4	18.2	8.93
■ Rt:Spinel	0.00	0.00	0.00	0.00	0.30	0.07	0.00	0.00	0.01	0.00	0.01
■ Rt:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Rt:Monazite	0.00	0.00	0.13	0.00	0.00	0.10	0.00	0.40	0.00	0.00	0.00
■ Lib Rutile	18.3	19.3	18.2	20.0	18.8	15.6	17.2	17.2	14.3	20.6	19.2
■ Free Rutile	25.9	26.4	27.4	25.2	26.8	25.9	25.6	24.3	28.0	23.7	24.9
■ Pure Rutile	9.92	10.7	16.3	15.2	11.9	15.2	10.6	19.1	19.6	13.2	22.5

Normalized Mass of Rutile Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
Pure Rutile	9.92	10.7	16.3	15.2	11.9	15.2	10.6	19.1	19.6	13.2	22.5
Free Rutile	25.9	26.4	27.4	25.2	26.8	25.9	25.6	24.3	28.0	23.7	24.9
Lib Rutile	18.3	19.3	18.2	20.0	18.8	15.6	17.2	17.2	14.3	20.6	19.2
Rt:Monazite	0.00	0.00	0.13	0.00	0.00	0.10	0.00	0.40	0.00	0.00	0.00
Rt:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Spinel	0.00	0.00	0.00	0.00	0.30	0.07	0.00	0.00	0.01	0.00	0.01
Rt:Ilmenite	21.2	19.5	18.7	11.3	13.1	14.5	7.78	14.0	10.4	18.2	8.93
Rt:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Zircon	0.09	0.08	0.11	0.01	0.12	0.00	0.07	0.24	0.20	0.05	0.33
Rt:Amph/Pyr/Grt	0.22	0.21	0.01	0.40	0.83	0.91	0.71	1.01	0.64	0.02	0.17
Rt:Staurolite	0.01	0.07	0.08	0.02	0.01	0.00	0.01	0.00	0.00	0.06	0.00
Rt:Kyanite	0.07	0.08	0.11	0.18	0.02	0.05	0.03	0.08	0.01	0.02	0.01
Rt:Quartz/Feldpars	0.51	0.18	0.15	0.40	0.27	0.06	1.09	0.81	0.26	0.24	0.64
Rt:Other Minerals	4.41	3.16	4.75	7.14	8.13	5.92	9.26	6.30	5.84	6.00	7.14
Complex	19.4	20.4	14.1	20.1	19.8	21.6	27.6	16.6	20.7	17.9	16.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Liberated	54.1	56.3	61.9	60.5	57.4	56.7	53.4	60.6	61.9	57.5	66.5

Rutile Association

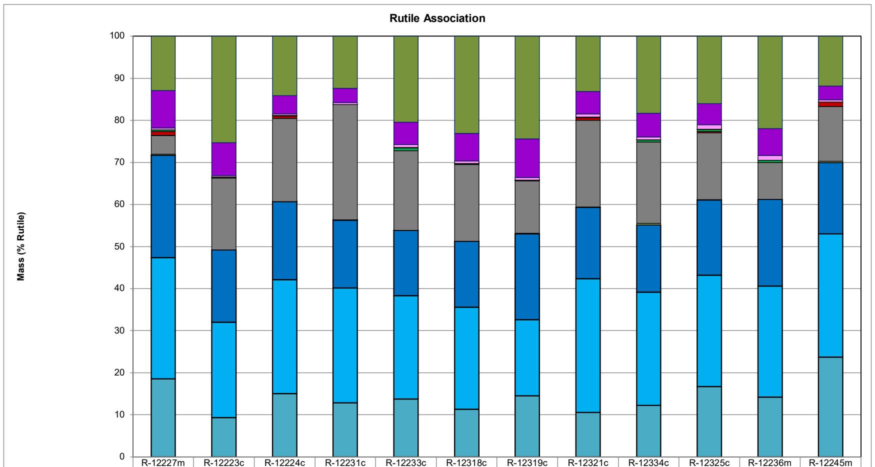


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■Complex	0.00	0.31	0.27	0.20	0.39	0.21	0.25	0.25	0.24	0.33	0.57	0.42
■Rt:Other Minerals	0.00	0.09	0.08	0.05	0.10	0.06	0.09	0.10	0.08	0.10	0.17	0.12
■Rt:Quartz/Feldpars	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.03	0.02
■Rt:Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■Rt:Staurolite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■Rt:Amph/Pyr/Grt	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00
■Rt:Zircon	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.04
■Rt:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■Rt:Ilmenite	0.00	0.21	0.38	0.43	0.36	0.16	0.13	0.40	0.26	0.33	0.23	0.46
■Rt:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
■Rt:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■Rt:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■Rt:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■Rt:Monazite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■Lib Rutile	0.00	0.21	0.35	0.26	0.30	0.14	0.21	0.33	0.21	0.37	0.54	0.60
■Free Rutile	0.00	0.27	0.51	0.43	0.47	0.22	0.18	0.61	0.36	0.55	0.69	1.04
■Pure Rutile	0.00	0.11	0.29	0.20	0.27	0.10	0.15	0.20	0.16	0.35	0.37	0.84

Absolute Mass of Rutile Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Pure Rutile	0.00	0.11	0.29	0.20	0.27	0.10	0.15	0.20	0.16	0.35	0.37	0.84
Free Rutile	0.00	0.27	0.51	0.43	0.47	0.22	0.18	0.61	0.36	0.55	0.69	1.04
Lib Rutile	0.00	0.21	0.35	0.26	0.30	0.14	0.21	0.33	0.21	0.37	0.54	0.60
Rt:Monazite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Rt:Ilmenite	0.00	0.21	0.38	0.43	0.36	0.16	0.13	0.40	0.26	0.33	0.23	0.46
Rt:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Zircon	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.04
Rt:Amph/Pyr/Grt	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00
Rt:Staurolite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Quartz/Feldpars	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.03	0.02
Rt:Other Minerals	0.00	0.09	0.08	0.05	0.10	0.06	0.09	0.10	0.08	0.10	0.17	0.12
Complex	0.00	0.31	0.27	0.20	0.39	0.21	0.25	0.25	0.24	0.33	0.57	0.42
Total	0.00	1.20	1.90	1.58	1.93	0.89	1.01	1.92	1.34	2.07	2.60	3.56

Rutile Association



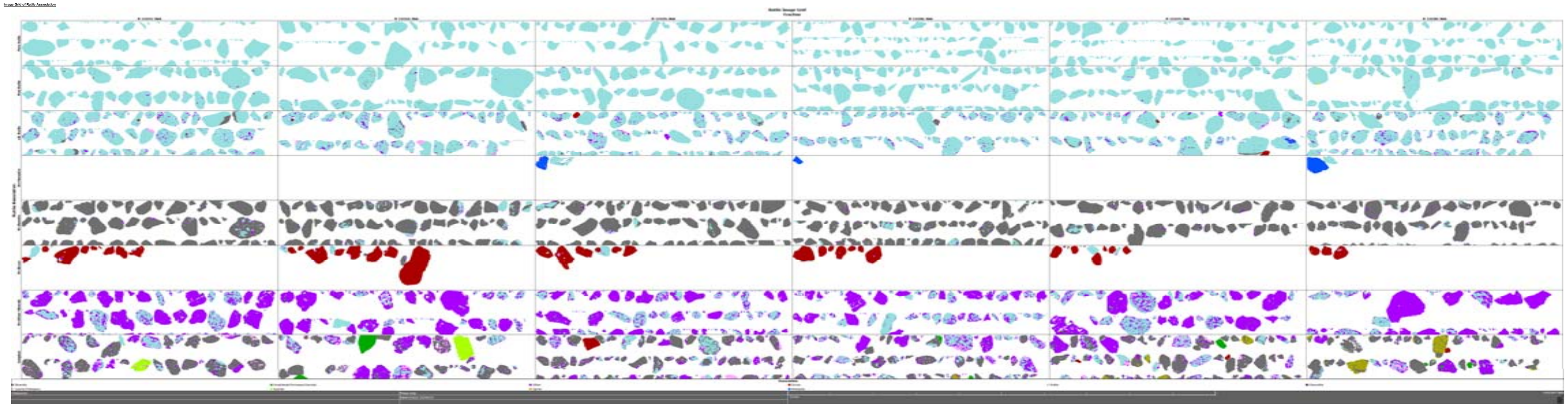
	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Complex	12.9	25.3	14.2	12.3	20.4	23.1	24.4	13.2	18.3	16.1	22.0	11.9
Rt:Other Minerals	8.89	7.80	4.30	3.47	5.33	6.59	9.18	5.31	5.62	5.02	6.42	3.29
Rt:Quartz/Feldpars	0.52	0.35	0.38	0.43	0.70	0.56	0.66	0.78	0.69	1.07	1.07	0.49
Rt:Kyanite	0.00	0.18	0.01	0.02	0.02	0.03	0.00	0.02	0.03	0.03	0.00	0.00
Rt:Staurolite	0.00	0.00	0.09	0.00	0.02	0.00	0.00	0.01	0.01	0.02	0.00	0.00
Rt:Amph/Pyr/Grt	0.38	0.04	0.05	0.01	0.69	0.22	0.11	0.07	0.54	0.48	0.55	0.02
Rt:Zircon	0.90	0.00	0.57	0.00	0.00	0.01	0.01	0.60	0.00	0.31	0.03	1.03
Rt:Ilmenorutile	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Rt:Ilmenite	4.47	17.1	19.7	27.4	18.9	18.3	12.5	20.7	19.3	15.9	8.7	13.0
Rt:Spinel	0.19	0.01	0.01	0.03	0.01	0.00	0.17	0.07	0.33	0.08	0.03	0.31
Rt:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Monazite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lib Rutile	24.4	17.2	18.6	16.2	15.5	15.7	20.3	16.9	16.0	17.8	20.6	16.9
Free Rutile	28.8	22.7	27.0	27.3	24.6	24.3	18.1	31.8	27.0	26.5	26.4	29.3
Pure Rutile	18.5	9.34	15.1	12.9	13.8	11.3	14.5	10.6	12.2	16.7	14.2	23.7

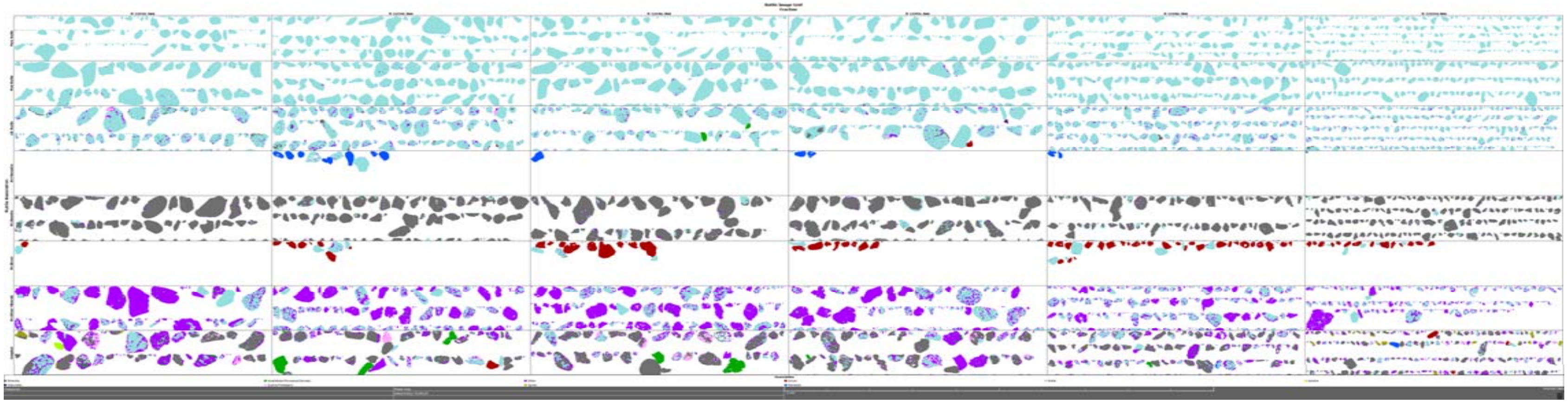
Normalized Mass of Rutile Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Pure Rutile	18.5	9.34	15.1	12.9	13.8	11.3	14.5	10.6	12.2	16.7	14.2	23.7
Free Rutile	28.8	22.7	27.0	27.3	24.6	24.3	18.1	31.8	27.0	26.5	26.4	29.3
Lib Rutile	24.4	17.2	18.6	16.2	15.5	15.7	20.3	16.9	16.0	17.8	20.6	16.9
Rt:Monazite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt:Spinel	0.19	0.01	0.01	0.03	0.01	0.00	0.17	0.07	0.33	0.08	0.03	0.31
Rt:Ilmenite	4.47	17.1	19.7	27.4	18.9	18.3	12.5	20.7	19.3	15.9	8.7	13.0
Rt:Ilmenorutile	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Rt:Zircon	0.90	0.00	0.57	0.00	0.00	0.01	0.01	0.60	0.00	0.31	0.03	1.03
Rt:Amph/Pyr/Grt	0.38	0.04	0.05	0.01	0.69	0.22	0.11	0.07	0.54	0.48	0.55	0.02
Rt:Staurolite	0.00	0.00	0.09	0.00	0.02	0.00	0.00	0.01	0.01	0.02	0.00	0.00
Rt:Kyanite	0.00	0.18	0.01	0.02	0.02	0.03	0.00	0.02	0.03	0.03	0.00	0.00
Rt:Quartz/Feldpars	0.52	0.35	0.38	0.43	0.70	0.56	0.66	0.78	0.69	1.07	1.07	0.49
Rt:Other Minerals	8.89	7.80	4.30	3.47	5.33	6.59	9.18	5.31	5.62	5.02	6.42	3.29
Complex	12.9	25.3	14.2	12.3	20.4	23.1	24.4	13.2	18.3	16.1	22.0	11.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Liberated	71.7	49.2	60.7	56.3	53.8	51.2	53.0	59.3	55.2	61.1	61.2	69.9

C163

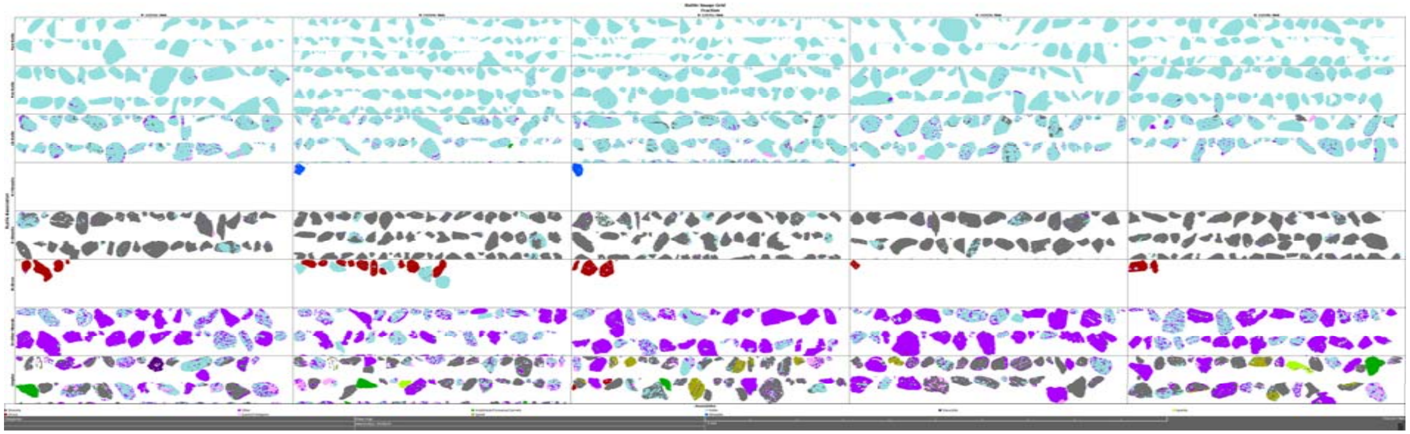
Image Grid of Rutile Association

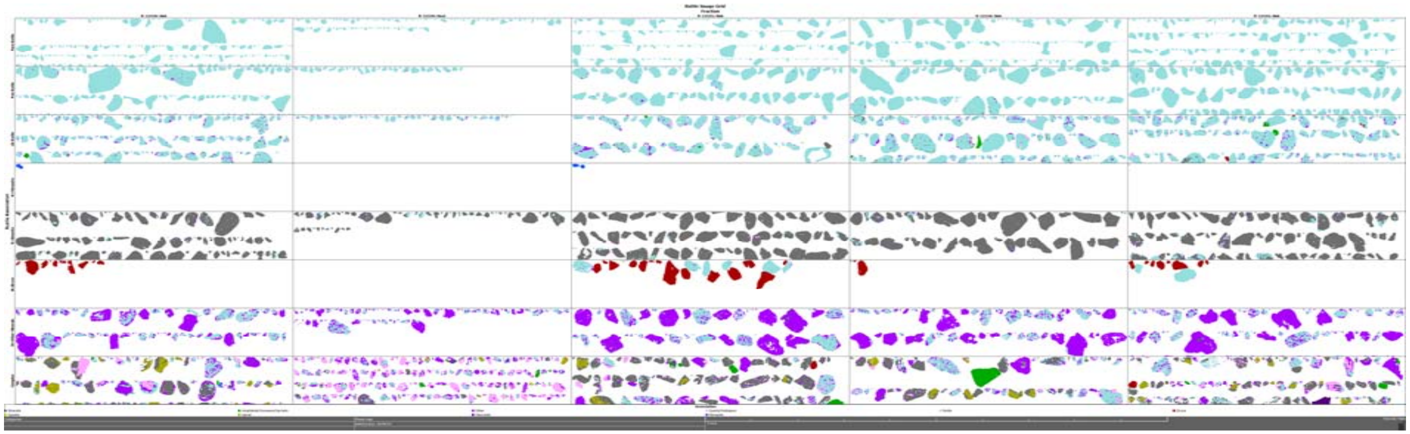




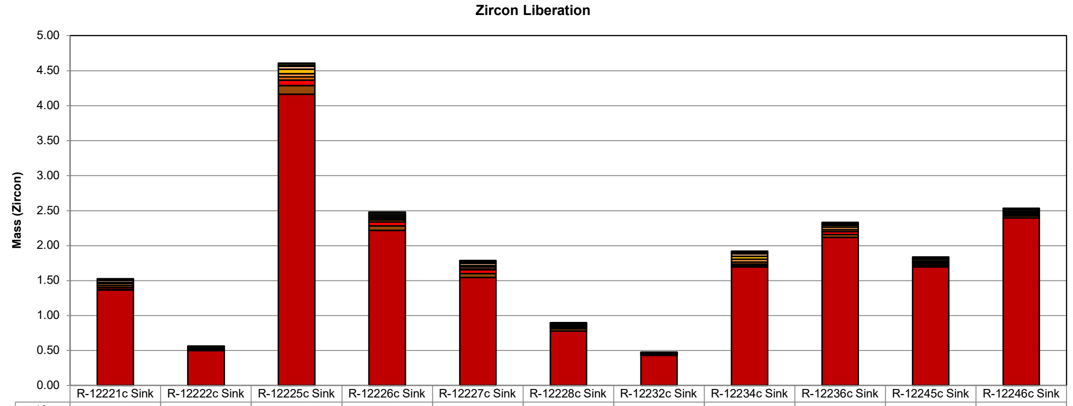
Virginia Department of Energy, Geology and Mineral Resources Program
CALR-17512-02
MI6024-MAY22 & MI6031-NOV22

Image Grid of Rutile Association





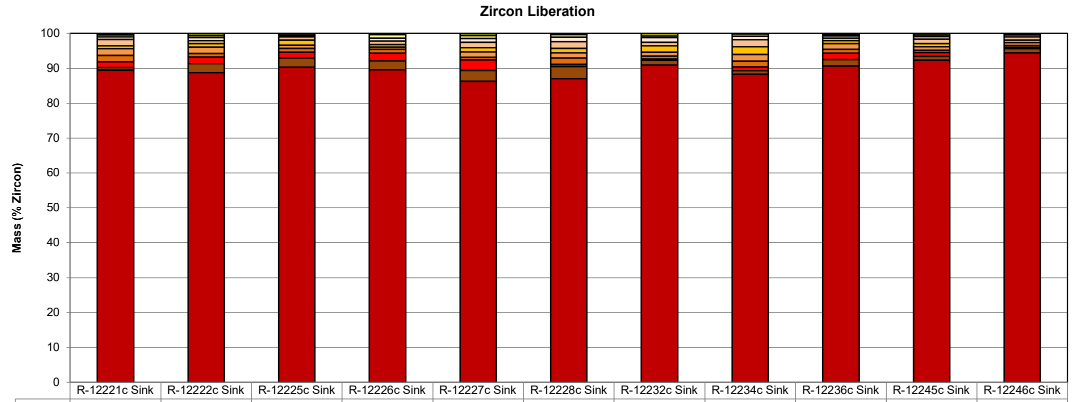
Zircon Liberation



	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
■<10	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00
■≥10<20	0.01	0.00	0.02	0.02	0.02	0.01	0.00	0.01	0.01	0.01	0.01
■≥20<30	0.01	0.00	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.02
■≥30<40	0.03	0.00	0.04	0.02	0.03	0.02	0.00	0.04	0.02	0.02	0.02
■≥40<50	0.01	0.01	0.07	0.02	0.02	0.01	0.01	0.04	0.02	0.02	0.02
■≥50<60	0.03	0.01	0.04	0.02	0.03	0.01	0.01	0.04	0.04	0.02	0.02
■≥60<70	0.03	0.01	0.05	0.03	0.01	0.02	0.00	0.03	0.03	0.01	0.02
■≥70<80	0.03	0.01	0.08	0.05	0.05	0.01	0.00	0.02	0.04	0.02	0.01
■≥80<90	0.01	0.01	0.12	0.06	0.06	0.03	0.01	0.02	0.04	0.02	0.03
■≥90	1.37	0.50	4.17	2.22	1.55	0.78	0.43	1.70	2.12	1.70	2.40

Absolute Mass of Zircon Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	1.37	0.50	4.17	2.22	1.55	0.78	0.43	1.70	2.12	1.70	2.40
≥80<90	0.01	0.01	0.12	0.06	0.06	0.03	0.01	0.02	0.04	0.02	0.03
≥70<80	0.03	0.01	0.08	0.05	0.05	0.01	0.00	0.02	0.04	0.02	0.01
≥60<70	0.03	0.01	0.05	0.03	0.01	0.02	0.00	0.03	0.03	0.01	0.02
≥50<60	0.03	0.01	0.04	0.02	0.03	0.01	0.01	0.04	0.04	0.02	0.02
≥40<50	0.01	0.01	0.07	0.02	0.02	0.01	0.01	0.04	0.02	0.02	0.02
≥30<40	0.03	0.00	0.04	0.02	0.03	0.02	0.00	0.04	0.02	0.02	0.02
≥20<30	0.01	0.00	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.02
≥10<20	0.01	0.00	0.02	0.02	0.02	0.01	0.00	0.01	0.01	0.01	0.01
<10	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00
Total	1.53	0.56	4.61	2.48	1.79	0.90	0.47	1.92	2.33	1.84	2.54

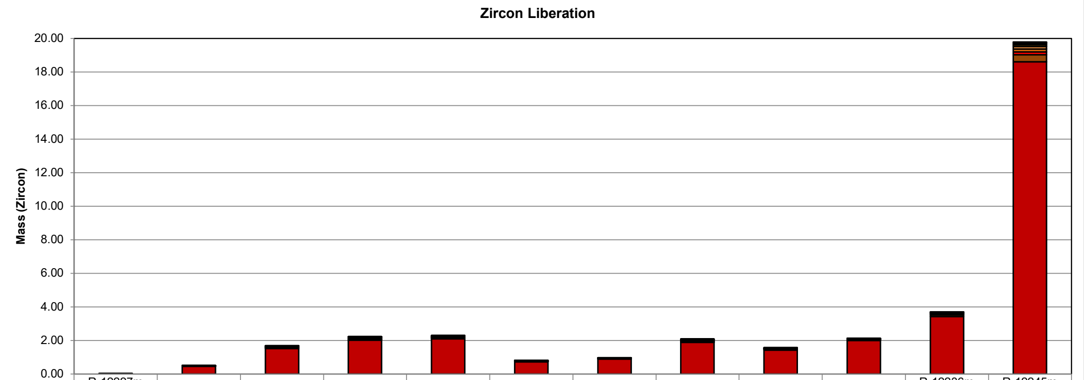


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
■<10	0.37	0.54	0.14	0.31	0.58	0.32	0.64	0.17	0.30	0.42	0.16
■≥10<20	0.55	0.60	0.45	0.97	0.85	0.70	0.49	0.63	0.39	0.41	0.20
■≥20<30	0.80	0.88	0.35	0.89	1.06	1.29	1.39	0.98	0.63	0.74	0.60
■≥30<40	1.76	0.87	0.94	0.99	1.57	1.90	1.02	2.02	0.70	1.28	0.93
■≥40<50	0.86	1.04	1.42	0.71	1.23	1.32	1.83	2.16	0.86	0.98	0.72
■≥50<60	1.94	1.74	0.94	0.61	1.49	1.47	1.09	1.99	1.64	1.01	0.77
■≥60<70	1.81	1.10	1.06	1.18	0.76	1.79	0.78	1.60	1.14	0.57	0.60
■≥70<80	1.65	1.86	1.69	2.20	3.01	0.69	0.44	1.15	1.77	1.18	0.37
■≥80<90	0.74	2.59	2.65	2.57	3.10	3.45	1.33	1.01	1.85	1.05	1.16
■≥90	89.5	88.8	90.4	89.6	86.3	87.1	91.0	88.3	90.7	92.4	94.5

Normalized Mass of Zircon Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	89.5	88.8	90.4	89.6	86.3	87.1	91.0	88.3	90.7	92.4	94.5
≥80<90	0.74	2.59	2.65	2.57	3.10	3.45	1.33	1.01	1.85	1.05	1.16
≥70<80	1.65	1.86	1.69	2.20	3.01	0.69	0.44	1.15	1.77	1.18	0.37
≥60<70	1.81	1.10	1.06	1.18	0.76	1.79	0.78	1.60	1.14	0.57	0.60
≥50<60	1.94	1.74	0.94	0.61	1.49	1.47	1.09	1.99	1.64	1.01	0.77
≥40<50	0.86	1.04	1.42	0.71	1.23	1.32	1.83	2.16	0.86	0.98	0.72
≥30<40	1.76	0.87	0.94	0.99	1.57	1.90	1.02	2.02	0.70	1.28	0.93
≥20<30	0.80	0.88	0.35	0.89	1.06	1.29	1.39	0.98	0.63	0.74	0.60
≥10<20	0.55	0.60	0.45	0.97	0.85	0.70	0.49	0.63	0.39	0.41	0.20
<10	0.37	0.54	0.14	0.31	0.58	0.32	0.64	0.17	0.30	0.42	0.16
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

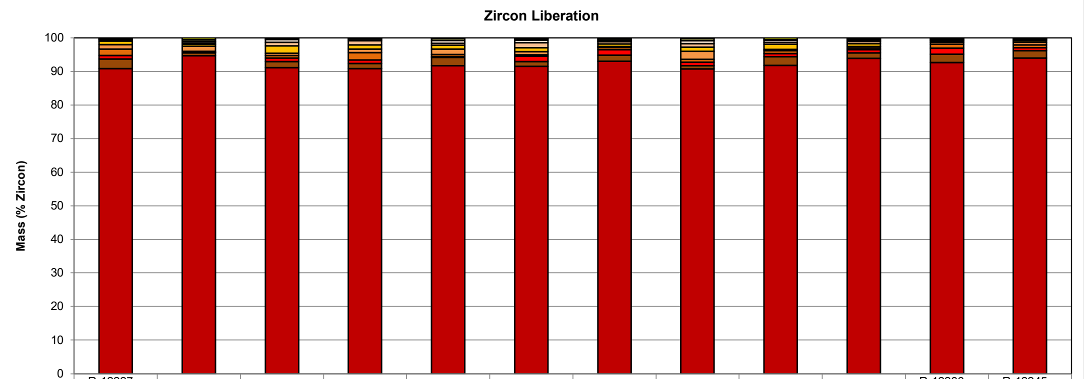
Zircon Liberation



	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
■≥10<20	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.03
■≥20<30	0.00	0.00	0.01	0.01	0.02	0.01	0.00	0.02	0.01	0.01	0.01	0.05
■≥30<40	0.00	0.00	0.02	0.03	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.08
■≥40<50	0.00	0.00	0.04	0.03	0.03	0.01	0.01	0.02	0.02	0.02	0.01	0.09
■≥50<60	0.00	0.01	0.01	0.02	0.04	0.01	0.00	0.05	0.01	0.01	0.02	0.16
■≥60<70	0.00	0.00	0.01	0.05	0.02	0.00	0.01	0.02	0.01	0.01	0.04	0.17
■≥70<80	0.00	0.00	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.07	0.16
■≥80<90	0.00	0.00	0.03	0.03	0.06	0.01	0.02	0.02	0.04	0.03	0.09	0.43
■≥90	0.00	0.46	1.52	2.01	2.09	0.72	0.88	1.88	1.43	1.99	3.4	18.6

Absolute Mass of Zircon Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	0.00	0.46	1.52	2.01	2.09	0.72	0.88	1.88	1.43	1.99	3.4	18.6
≥80<90	0.00	0.00	0.03	0.03	0.06	0.01	0.02	0.02	0.04	0.03	0.09	0.43
≥70<80	0.00	0.00	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.07	0.16
≥60<70	0.00	0.00	0.01	0.05	0.02	0.00	0.01	0.02	0.01	0.01	0.04	0.17
≥50<60	0.00	0.01	0.01	0.02	0.04	0.01	0.00	0.05	0.01	0.01	0.02	0.16
≥40<50	0.00	0.00	0.04	0.03	0.03	0.01	0.01	0.02	0.02	0.02	0.01	0.09
≥30<40	0.00	0.00	0.02	0.03	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.08
≥20<30	0.00	0.00	0.01	0.01	0.02	0.01	0.00	0.02	0.01	0.01	0.01	0.05
≥10<20	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.03
<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Total	0.00	0.48	1.66	2.21	2.28	0.79	0.95	2.07	1.55	2.11	3.7	19.8

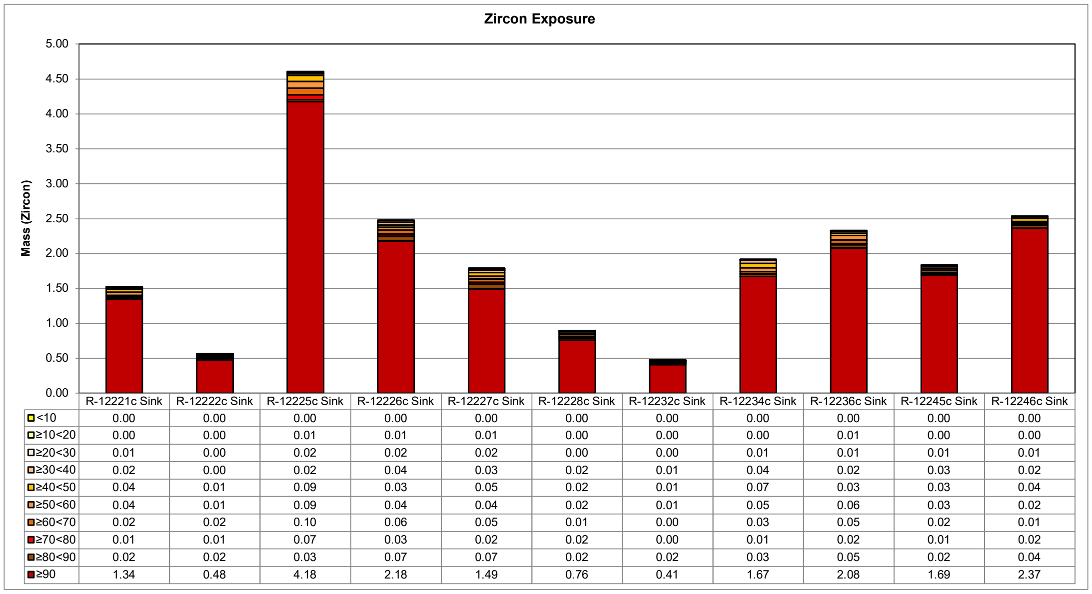


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■<10	0.14	0.55	0.14	0.21	0.21	0.28	0.33	0.32	0.52	0.35	0.29	0.04
■≥10<20	0.19	0.47	0.30	0.18	0.53	0.37	0.56	0.51	0.19	0.46	0.18	0.16
■≥20<30	0.25	0.51	0.86	0.47	0.90	0.82	0.26	0.93	0.62	0.26	0.25	0.27
■≥30<40	0.36	0.40	1.03	1.19	0.59	1.49	0.61	1.04	0.62	0.66	0.24	0.38
■≥40<50	1.09	0.58	2.26	1.23	1.12	1.10	0.81	1.19	1.48	0.86	0.40	0.46
■≥50<60	1.27	1.51	0.60	1.13	1.58	0.95	0.33	2.44	0.39	0.44	0.54	0.81
■≥60<70	1.94	0.35	0.80	2.12	0.66	0.44	0.64	0.84	0.88	0.48	1.10	0.87
■≥70<80	1.01	0.13	1.02	1.09	0.25	1.63	1.64	1.00	0.94	1.00	1.81	0.82
■≥80<90	2.89	0.80	1.81	1.49	2.45	1.43	1.81	0.98	2.58	1.58	2.55	2.17
■≥90	90.9	94.7	91.2	90.9	91.7	91.5	93.0	90.8	91.8	93.9	92.6	94.0

Normalized Mass of Zircon Across Samples

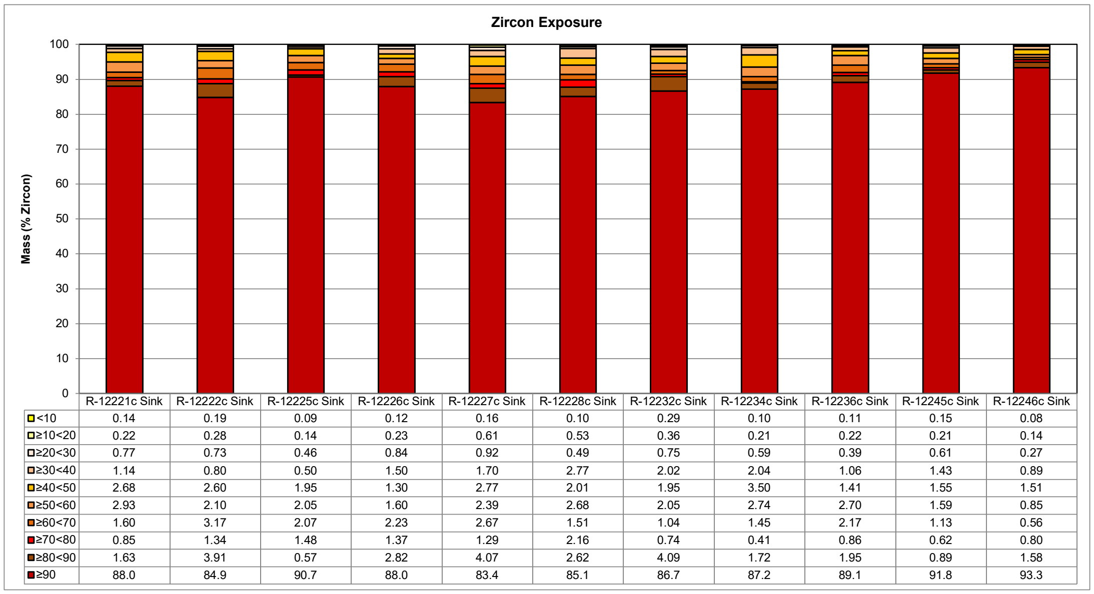
Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	90.9	94.7	91.2	90.9	91.7	91.5	93.0	90.8	91.8	93.9	92.6	94.0
≥80<90	2.89	0.80	1.81	1.49	2.45	1.43	1.81	0.98	2.58	1.58	2.55	2.17
≥70<80	1.01	0.13	1.02	1.09	0.25	1.63	1.64	1.00	0.94	1.00	1.81	0.82
≥60<70	1.94	0.35	0.80	2.12	0.66	0.44	0.64	0.84	0.88	0.48	1.10	0.87
≥50<60	1.27	1.51	0.60	1.13	1.58	0.95	0.33	2.44	0.39	0.44	0.54	0.81
≥40<50	1.09	0.58	2.26	1.23	1.12	1.10	0.81	1.19	1.48	0.86	0.40	0.46
≥30<40	0.36	0.40	1.03	1.19	0.59	1.49	0.61	1.04	0.62	0.66	0.24	0.38
≥20<30	0.25	0.51	0.86	0.47	0.90	0.82	0.26	0.93	0.62	0.26	0.25	0.27
≥10<20	0.19	0.47	0.30	0.18	0.53	0.37	0.56	0.51	0.19	0.46	0.18	0.16
<10	0.14	0.55	0.14	0.21	0.21	0.28	0.33	0.32	0.52	0.35	0.29	0.04
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Zircon Exposure



Absolute Mass of Zircon Across Samples

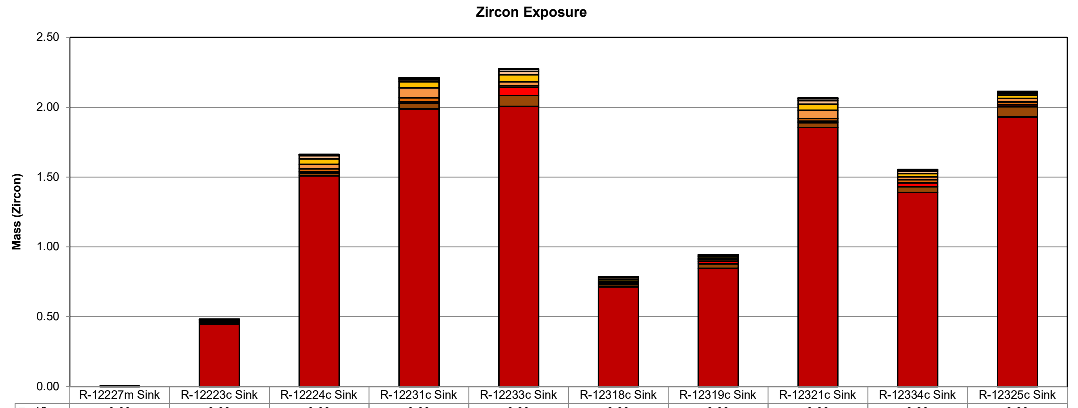
Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	1.34	0.48	4.18	2.18	1.49	0.76	0.41	1.67	2.08	1.69	2.37
≥80<90	0.02	0.02	0.03	0.07	0.07	0.02	0.02	0.03	0.05	0.02	0.04
≥70<80	0.01	0.01	0.07	0.03	0.02	0.02	0.00	0.01	0.02	0.01	0.02
≥60<70	0.02	0.02	0.10	0.06	0.05	0.01	0.00	0.03	0.05	0.02	0.01
≥50<60	0.04	0.01	0.09	0.04	0.04	0.02	0.01	0.05	0.06	0.03	0.02
≥40<50	0.04	0.01	0.09	0.03	0.05	0.02	0.01	0.07	0.03	0.03	0.04
≥30<40	0.02	0.00	0.02	0.04	0.03	0.02	0.01	0.04	0.02	0.03	0.02
≥20<30	0.01	0.00	0.02	0.02	0.02	0.00	0.00	0.01	0.01	0.01	0.01
≥10<20	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00
<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.53	0.56	4.61	2.48	1.79	0.90	0.47	1.92	2.33	1.84	2.54



Normalized Mass of Zircon Across Samples

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
≥90	88.0	84.9	90.7	88.0	83.4	85.1	86.7	87.2	89.1	91.8	93.3
≥80<90	1.63	3.91	0.57	2.82	4.07	2.62	4.09	1.72	1.95	0.89	1.58
≥70<80	0.85	1.34	1.48	1.37	1.29	2.16	0.74	0.41	0.86	0.62	0.80
≥60<70	1.60	3.17	2.07	2.23	2.67	1.51	1.04	1.45	2.17	1.13	0.56
≥50<60	2.93	2.10	2.05	1.60	2.39	2.68	2.05	2.74	2.70	1.59	0.85
≥40<50	2.68	2.60	1.95	1.30	2.77	2.01	1.95	3.50	1.41	1.55	1.51
≥30<40	1.14	0.80	0.50	1.50	1.70	2.77	2.02	2.04	1.06	1.43	0.89
≥20<30	0.77	0.73	0.46	0.84	0.92	0.49	0.75	0.59	0.39	0.61	0.27
≥10<20	0.22	0.28	0.14	0.23	0.61	0.53	0.36	0.21	0.22	0.21	0.14
<10	0.14	0.19	0.09	0.12	0.16	0.10	0.29	0.10	0.11	0.15	0.08
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

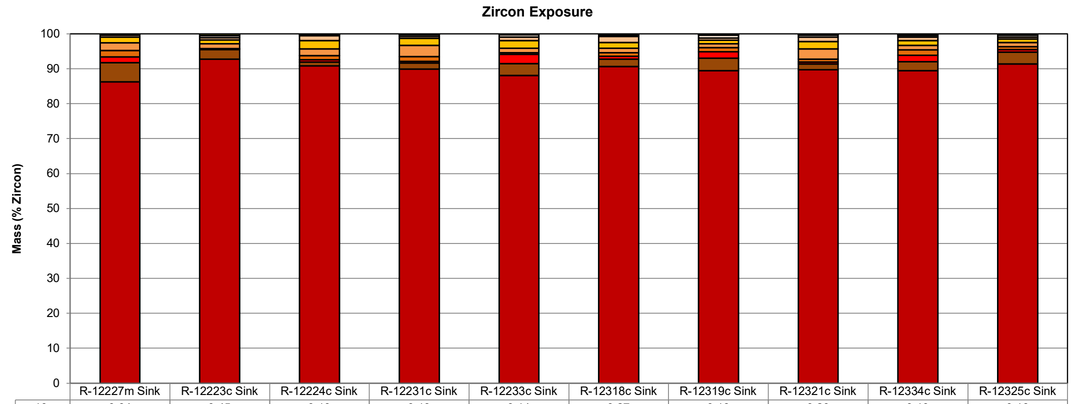
Zircon Exposure



	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink
▨<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
▨≥10<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
▨≥20<30	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01
▨≥30<40	0.00	0.00	0.02	0.01	0.02	0.01	0.01	0.03	0.02	0.01
▨≥40<50	0.00	0.01	0.04	0.04	0.05	0.01	0.01	0.04	0.02	0.02
▨≥50<60	0.00	0.01	0.03	0.07	0.03	0.01	0.01	0.06	0.02	0.02
▨≥60<70	0.00	0.00	0.02	0.03	0.01	0.01	0.01	0.02	0.02	0.02
▨≥70<80	0.00	0.00	0.01	0.01	0.06	0.01	0.02	0.01	0.03	0.01
▨≥80<90	0.00	0.01	0.02	0.04	0.08	0.02	0.03	0.04	0.04	0.07
▨≥90	0.00	0.45	1.51	1.99	2.01	0.71	0.85	1.85	1.39	1.93

Absolute Mass of Zircon Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	0.00	0.45	1.51	1.99	2.01	0.71	0.85	1.85	1.39	1.93	3.2	17.4
≥80<90	0.00	0.01	0.02	0.04	0.08	0.02	0.03	0.04	0.04	0.07	0.26	1.07
≥70<80	0.00	0.00	0.01	0.01	0.06	0.01	0.02	0.01	0.03	0.01	0.07	0.47
≥60<70	0.00	0.00	0.02	0.03	0.01	0.01	0.01	0.02	0.02	0.02	0.09	0.28
≥50<60	0.00	0.01	0.03	0.07	0.03	0.01	0.01	0.06	0.02	0.02	0.03	0.21
≥40<50	0.00	0.01	0.04	0.04	0.05	0.01	0.01	0.04	0.02	0.02	0.04	0.18
≥30<40	0.00	0.00	0.02	0.01	0.02	0.01	0.01	0.03	0.02	0.01	0.01	0.14
≥20<30	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.03
≥10<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
<10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Total	0.00	0.48	1.66	2.21	2.28	0.79	0.95	2.07	1.55	2.11	3.7	19.8



	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink
▨<10	0.04	0.45	0.10	0.13	0.14	0.27	0.16	0.20	0.19	0.16
▨≥10<20	0.08	0.07	0.04	0.13	0.12	0.05	0.24	0.13	0.31	0.18
▨≥20<30	0.24	0.55	0.40	0.43	0.65	0.45	0.76	0.61	0.40	0.58
▨≥30<40	0.56	0.64	1.38	0.61	1.03	1.69	0.64	1.27	1.05	0.55
▨≥40<50	1.66	1.10	2.41	2.01	2.15	1.63	1.02	2.05	1.36	0.98
▨≥50<60	2.15	1.42	1.85	3.21	1.28	1.34	1.10	2.93	1.30	1.17
▨≥60<70	1.88	0.09	1.23	1.34	0.46	0.94	1.20	0.84	1.56	0.91
▨≥70<80	1.63	0.13	0.62	0.50	2.68	0.88	1.89	0.54	1.79	0.70
▨≥80<90	5.49	2.82	1.15	1.75	3.36	2.05	3.51	1.70	2.61	3.42
▨≥90	86.3	92.7	90.8	89.9	88.1	90.7	89.5	89.7	89.4	91.4

Normalized Mass of Zircon Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
≥90	86.3	92.7	90.8	89.9	88.1	90.7	89.5	89.7	89.4	91.4	85.7	87.9
≥80<90	5.49	2.82	1.15	1.75	3.36	2.05	3.51	1.70	2.61	3.42	7.03	5.41
≥70<80	1.63	0.13	0.62	0.50	2.68	0.88	1.89	0.54	1.79	0.70	1.95	2.37
≥60<70	1.88	0.09	1.23	1.34	0.46	0.94	1.20	0.84	1.56	0.91	2.49	1.40
≥50<60	2.15	1.42	1.85	3.21	1.28	1.34	1.10	2.93	1.30	1.17	0.89	1.06
≥40<50	1.66	1.10	2.41	2.01	2.15	1.63	1.02	2.05	1.36	0.98	1.01	0.93
≥30<40	0.56	0.64	1.38	0.61	1.03	1.69	0.64	1.27	1.05	0.55	0.35	0.70
≥20<30	0.24	0.55	0.40	0.43	0.65	0.45	0.76	0.61	0.40	0.58	0.34	0.14
≥10<20	0.08	0.07	0.04	0.13	0.12	0.05	0.24	0.13	0.31	0.18	0.14	0.04
<10	0.04	0.45	0.10	0.13	0.14	0.27	0.16	0.20	0.19	0.16	0.06	0.03
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Virginia Department of Energy, Geology and Mineral Resources Progra
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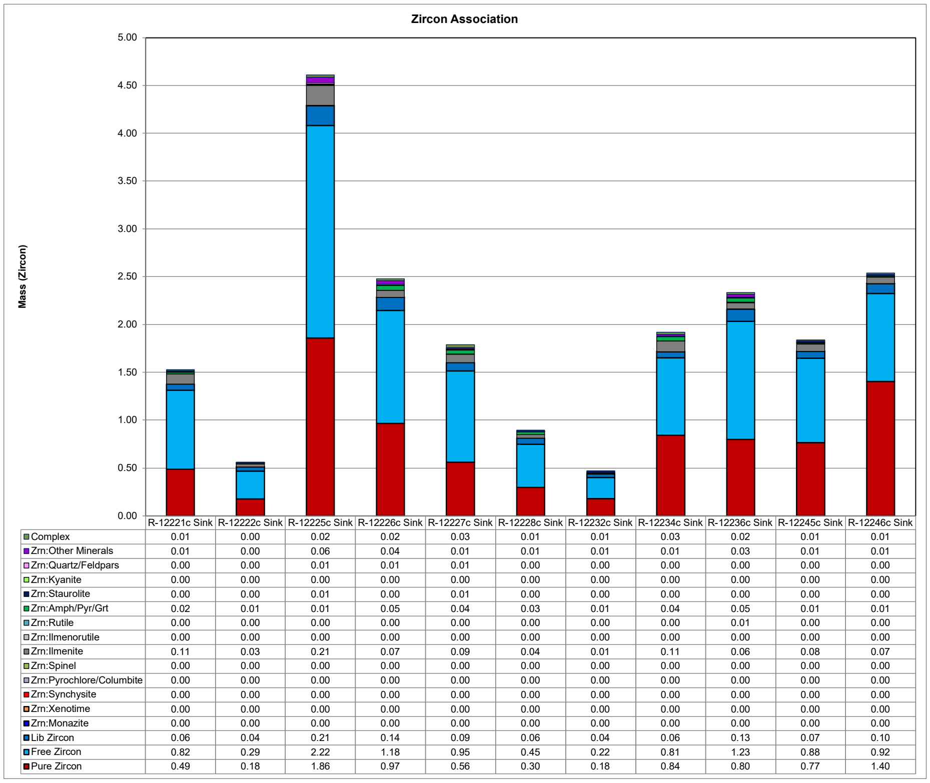
Zircon Associatio

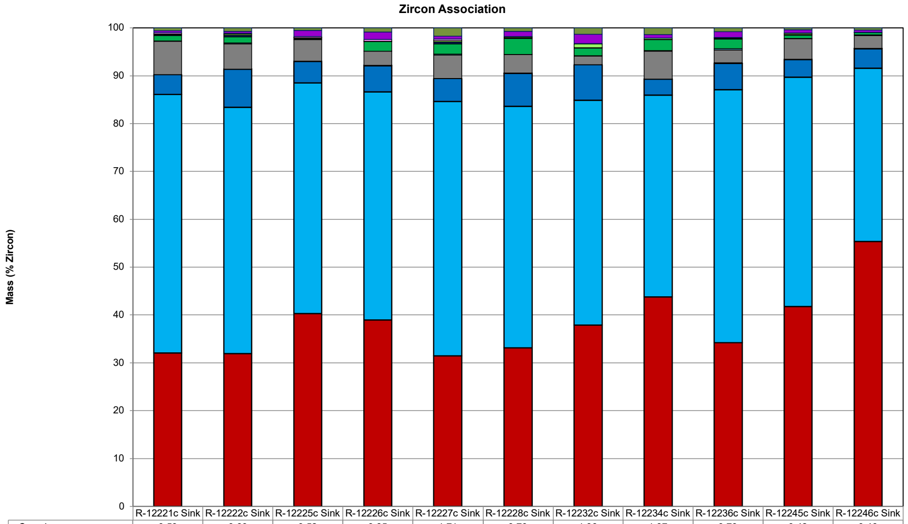


	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
■ Complex	0.01	0.00	0.02	0.02	0.03	0.01	0.01	0.03	0.02	0.01	0.01
■ Zrn:Other Minerals	0.01	0.00	0.06	0.04	0.01	0.01	0.01	0.01	0.03	0.01	0.01
■ Zrn:Quartz/Feldpars	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Staurolite	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Amph/Pyr/Grt	0.02	0.01	0.01	0.05	0.04	0.03	0.01	0.04	0.05	0.01	0.01
■ Zrn:Rutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
■ Zrn:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Ilmenite	0.11	0.03	0.21	0.07	0.09	0.04	0.01	0.11	0.06	0.08	0.07
■ Zrn:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Monazite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Lib Zircon	0.06	0.04	0.21	0.14	0.09	0.06	0.04	0.06	0.13	0.07	0.10
■ Free Zircon	0.82	0.29	2.22	1.18	0.95	0.45	0.22	0.81	1.23	0.88	0.92
■ Pure Zircon	0.49	0.18	1.86	0.97	0.56	0.30	0.18	0.84	0.80	0.77	1.40

Absolute Mass of Zircon Across Sample

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
Pure Zircon	0.49	0.18	1.86	0.97	0.56	0.30	0.18	0.84	0.80	0.77	1.40
Free Zircon	0.82	0.29	2.22	1.18	0.95	0.45	0.22	0.81	1.23	0.88	0.92
Lib Zircon	0.06	0.04	0.21	0.14	0.09	0.06	0.04	0.06	0.13	0.07	0.10
Zrn:Monazite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Pyrochlore/Columbit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Spinel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Ilmenite	0.11	0.03	0.21	0.07	0.09	0.04	0.01	0.11	0.06	0.08	0.07
Zrn:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Rutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Zrn:Amph/Pyr/Grt	0.02	0.01	0.01	0.05	0.04	0.03	0.01	0.04	0.05	0.01	0.01
Zrn:Staurolite	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Kyanite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Quartz/Feldpars	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Other Minerals	0.01	0.00	0.06	0.04	0.01	0.01	0.01	0.01	0.03	0.01	0.01
Complex	0.01	0.00	0.02	0.02	0.03	0.01	0.01	0.03	0.02	0.01	0.01
Total	1.53	0.56	4.61	2.48	1.79	0.90	0.47	1.92	2.33	1.84	2.54

Zircon Associatio



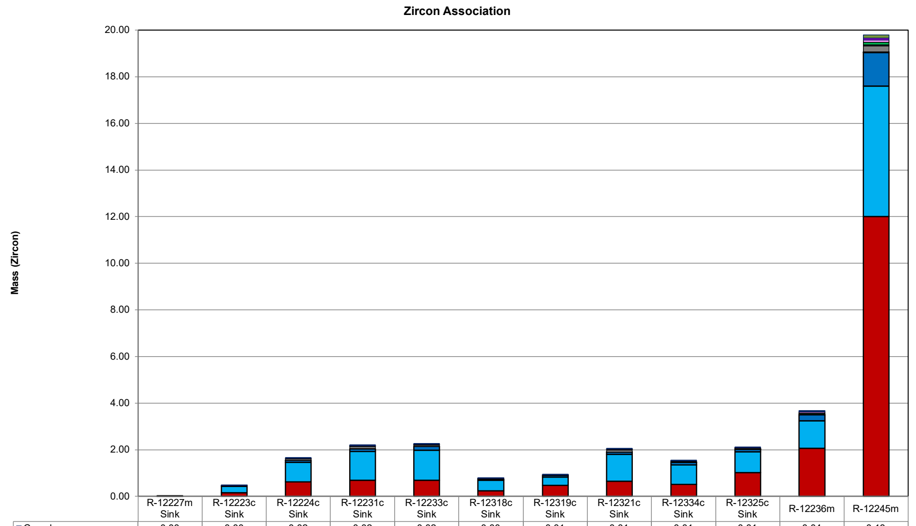
	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
Complex	0.59	0.69	0.52	0.85	1.71	0.70	1.36	1.37	0.79	0.42	0.46
Zrn:Other Minerals	0.41	0.44	1.26	1.56	0.62	1.08	1.90	0.77	1.23	0.61	0.46
Zrn:Quartz/Feldpars	0.23	0.13	0.27	0.39	0.33	0.11	0.10	0.02	0.02	0.13	0.03
Zrn:Kyanite	0.19	0.23	0.01	0.07	0.24	0.20	0.80	0.22	0.12	0.21	0.02
Zrn:Staurolite	0.20	0.39	0.12	0.00	0.43	0.08	0.02	0.06	0.19	0.17	0.05
Zrn:Amph/Pyr/Grt	1.14	1.25	0.22	2.02	2.15	3.33	1.65	2.29	1.98	0.67	0.43
Zrn:Rutile	0.05	0.20	0.04	0.00	0.17	0.01	0.08	0.13	0.26	0.09	0.18
Zrn:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Ilmenite	6.94	5.28	4.49	2.96	4.89	3.92	1.77	5.82	2.70	4.25	2.64
Zrn:Spinel	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.14	0.00	0.05
Zrn:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Xenotime	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Zrn:Monazite	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.03	0.00	0.04	0.02
Lib Zircon	4.16	7.96	4.51	5.49	4.86	6.93	7.43	3.33	5.52	3.74	4.05
Free Zircon	54.0	51.5	48.2	47.7	53.1	50.5	47.0	42.2	52.8	47.9	36.3
Pure Zircon	32.1	31.9	40.3	39.0	31.5	33.1	37.9	43.8	34.2	41.8	55.3

Normalized Mass of Zircon Across Sample

Mineral Name	R-12221c Sink	R-12222c Sink	R-12225c Sink	R-12226c Sink	R-12227c Sink	R-12228c Sink	R-12232c Sink	R-12234c Sink	R-12236c Sink	R-12245c Sink	R-12246c Sink
Pure Zircon	32.1	31.9	40.3	39.0	31.5	33.1	37.9	43.8	34.2	41.8	55.3
Free Zircon	54.0	51.5	48.2	47.7	53.1	50.5	47.0	42.2	52.8	47.9	36.3
Lib Zircon	4.16	7.96	4.51	5.49	4.86	6.93	7.43	3.33	5.52	3.74	4.05
Zrn:Monazite	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.03	0.00	0.04	0.02
Zrn:Xenotime	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Zrn:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Pyrochlore/Columbit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Spinel	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.14	0.00	0.05
Zrn:Ilmenite	6.94	5.28	4.49	2.96	4.89	3.92	1.77	5.82	2.70	4.25	2.64
Zrn:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Rutile	0.05	0.20	0.04	0.00	0.17	0.01	0.08	0.13	0.26	0.09	0.18
Zrn:Amph/Pyr/Grt	1.14	1.25	0.22	2.02	2.15	3.33	1.65	2.29	1.98	0.67	0.43
Zrn:Staurolite	0.20	0.39	0.12	0.00	0.43	0.08	0.02	0.06	0.19	0.17	0.05
Zrn:Kyanite	0.19	0.23	0.01	0.07	0.24	0.20	0.80	0.22	0.12	0.21	0.02
Zrn:Quartz/Feldpars	0.23	0.13	0.27	0.39	0.33	0.11	0.10	0.02	0.02	0.13	0.03
Zrn:Other Minerals	0.41	0.44	1.26	1.56	0.62	1.08	1.90	0.77	1.23	0.61	0.46
Complex	0.59	0.69	0.52	0.85	1.71	0.70	1.36	1.37	0.79	0.42	0.46
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Liberate	90.3	91.4	93.0	92.1	89.5	90.5	92.3	89.3	92.6	93.4	95.7

Virginia Department of Energy, Geology and Mineral Resources Progra
CALR-17512-02
MI5024-MAY22 & MI5031-NOV22

Zircon Associatio

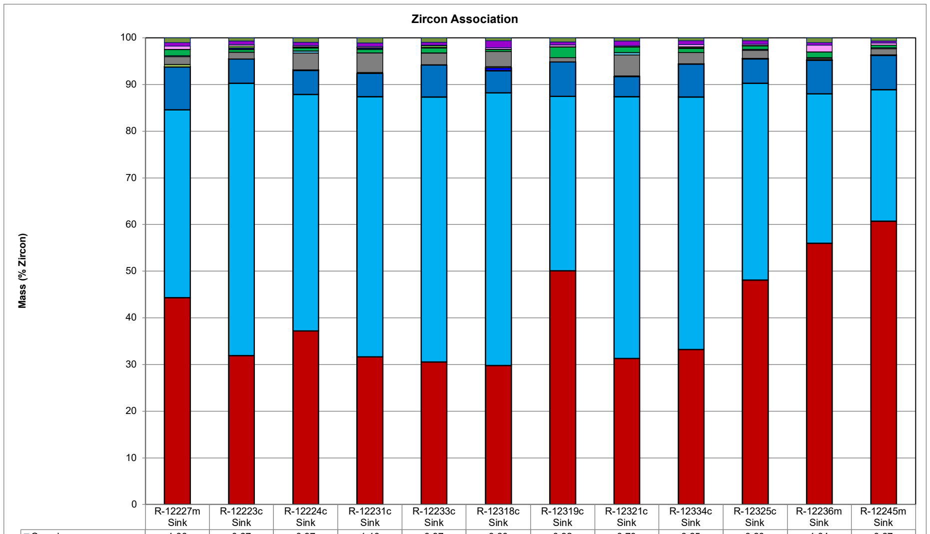


	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m	R-12245m
■ Complex	0.00	0.00	0.02	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.04	0.13
■ Zrn:Other Minerals	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.09
■ Zrn:Quartz/Feldpars	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.05	0.09
■ Zrn:Kyanite	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Staurolite	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Amph/Pyr/Grt	0.00	0.00	0.01	0.02	0.02	0.00	0.02	0.02	0.01	0.02	0.05	0.12
■ Zrn:Rutile	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.03
■ Zrn:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Ilmenite	0.00	0.01	0.06	0.09	0.06	0.03	0.01	0.09	0.04	0.04	0.01	0.26
■ Zrn:Spinel	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
■ Zrn:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
■ Zrn:Monazite	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02
■ Lib Zircon	0.00	0.03	0.09	0.11	0.16	0.04	0.07	0.09	0.11	0.11	0.27	1.44
■ Free Zircon	0.00	0.28	0.84	1.23	1.29	0.46	0.35	1.16	0.84	0.89	1.18	5.58
■ Pure Zircon	0.00	0.15	0.62	0.70	0.70	0.23	0.47	0.65	0.52	1.02	2.07	12.01

Absolute Mass of Zircon Across Sample

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m	R-12245m
Pure Zircon	0.00	0.15	0.62	0.70	0.70	0.23	0.47	0.65	0.52	1.02	2.07	12.01
Free Zircon	0.00	0.28	0.84	1.23	1.29	0.46	0.35	1.16	0.84	0.89	1.18	5.58
Lib Zircon	0.00	0.03	0.09	0.11	0.16	0.04	0.07	0.09	0.11	0.11	0.27	1.44
Zrn:Monazite	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02
Zrn:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Zrn:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Spinel	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Zrn:Ilmenite	0.00	0.01	0.06	0.09	0.06	0.03	0.01	0.09	0.04	0.04	0.01	0.26
Zrn:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Rutile	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.03
Zrn:Amph/Pyr/Grt	0.00	0.00	0.01	0.02	0.02	0.00	0.02	0.02	0.01	0.02	0.05	0.12
Zrn:Staurolite	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Kyanite	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Quartz/Feldpars	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.05	0.09
Zrn:Other Minerals	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.09
Complex	0.00	0.00	0.02	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.04	0.13
Total	0.00	0.48	1.66	2.21	2.28	0.79	0.95	2.07	1.55	2.11	3.69	19.79

Zircon Associatio



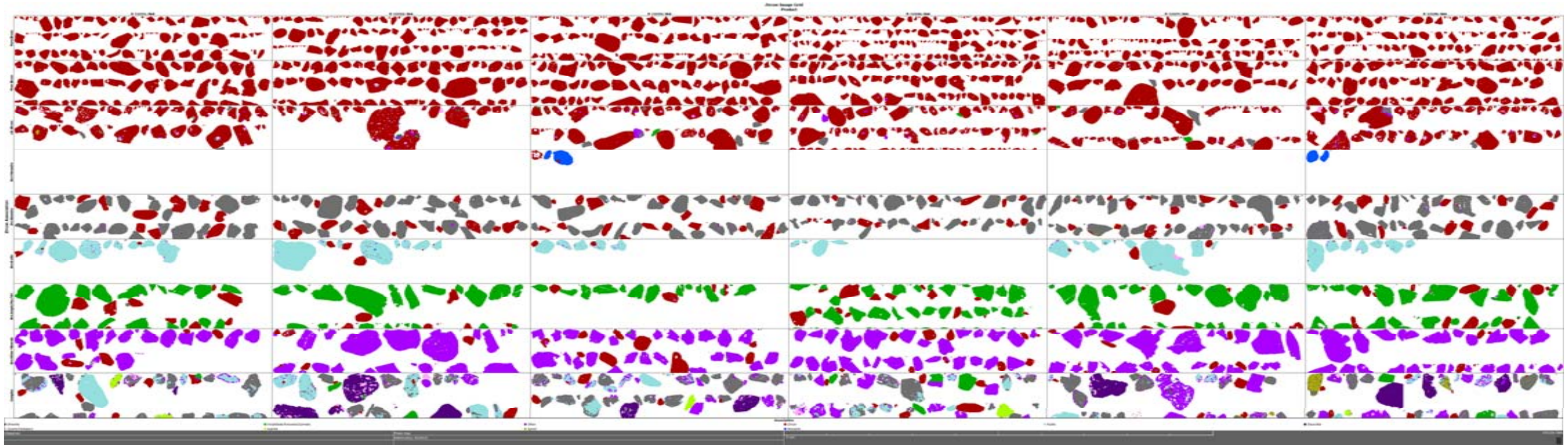
	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
■ Complex	1.06	0.67	0.97	1.10	0.97	0.60	0.92	0.70	0.65	0.60	1.04	0.67
■ Zrn:Other Minerals	0.75	0.77	0.67	0.71	0.59	1.54	0.62	1.02	0.79	0.77	0.56	0.43
■ Zrn:Quartz/Feldpars	0.64	0.33	0.28	0.28	0.13	0.33	0.37	0.21	0.51	0.30	1.42	0.45
■ Zrn:Kyanite	0.08	0.33	0.13	0.01	0.36	0.03	0.06	0.03	0.18	0.02	0.01	0.00
■ Zrn:Staurolite	0.00	0.42	0.17	0.33	0.16	0.02	0.00	0.06	0.12	0.01	0.00	0.00
■ Zrn:Amph/Pyr/Grt	1.28	0.57	0.58	0.78	1.01	0.40	2.27	1.17	0.93	0.74	1.25	0.60
■ Zrn:Rutile	0.23	0.01	0.52	0.00	0.06	0.01	0.04	0.52	0.01	0.21	0.00	0.16
■ Zrn:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
■ Zrn:Ilmenite	1.66	1.40	3.52	4.15	2.49	3.24	0.89	4.46	2.34	1.73	0.32	1.31
■ Zrn:Spinel	0.54	0.00	0.00	0.24	0.08	0.19	0.02	0.08	0.09	0.02	0.21	0.02
■ Zrn:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
■ Zrn:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Zrn:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03
■ Zrn:Monazite	0.01	0.01	0.17	0.00	0.00	0.72	0.00	0.01	0.02	0.07	0.00	0.09
■ Lib Zircon	9.15	5.26	5.11	5.01	6.83	4.68	7.37	4.32	7.03	5.23	7.19	7.30
■ Free Zircon	40.2	58.3	50.7	55.7	56.8	58.5	37.4	56.1	54.2	42.2	32.0	28.2
■ Pure Zircon	44.4	31.9	37.2	31.6	30.6	29.8	50.1	31.3	33.2	48.1	56.0	60.7

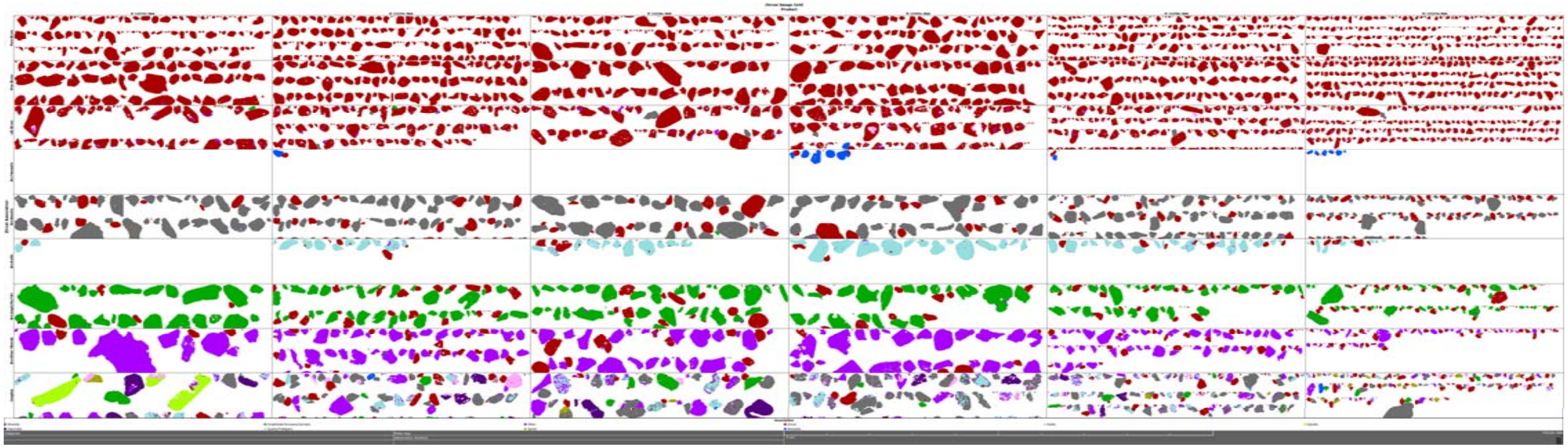
Normalized Mass of Zircon Across Samples

Mineral Name	R-12227m Sink	R-12223c Sink	R-12224c Sink	R-12231c Sink	R-12233c Sink	R-12318c Sink	R-12319c Sink	R-12321c Sink	R-12334c Sink	R-12325c Sink	R-12236m Sink	R-12245m Sink
Pure Zircon	44.4	31.9	37.2	31.6	30.6	29.8	50.1	31.3	33.2	48.1	56.0	60.7
Free Zircon	40.2	58.3	50.7	55.7	56.8	58.5	37.4	56.1	54.2	42.2	32.0	28.2
Lib Zircon	9.15	5.26	5.11	5.01	6.83	4.68	7.37	4.32	7.03	5.23	7.19	7.30
Zrn:Monazite	0.01	0.01	0.17	0.00	0.00	0.72	0.00	0.01	0.02	0.07	0.00	0.09
Zrn:Xenotime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03
Zrn:Synchysite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zrn:Pyrochlore/Columbite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Zrn:Spinel	0.54	0.00	0.00	0.24	0.08	0.19	0.02	0.08	0.09	0.02	0.21	0.02
Zrn:Ilmenite	1.66	1.40	3.52	4.15	2.49	3.24	0.89	4.46	2.34	1.73	0.32	1.31
Zrn:Ilmenorutile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Zrn:Rutile	0.23	0.01	0.52	0.00	0.06	0.01	0.04	0.52	0.01	0.21	0.00	0.16
Zrn:Amph/Pyr/Grt	1.28	0.57	0.58	0.78	1.01	0.40	2.27	1.17	0.93	0.74	1.25	0.60
Zrn:Staurolite	0.00	0.42	0.17	0.33	0.16	0.02	0.00	0.06	0.12	0.01	0.00	0.00
Zrn:Kyanite	0.08	0.33	0.13	0.01	0.36	0.03	0.06	0.03	0.18	0.02	0.01	0.00
Zrn:Quartz/Feldpars	0.64	0.33	0.28	0.28	0.13	0.33	0.37	0.21	0.51	0.30	1.42	0.45
Zrn:Other Minerals	0.75	0.77	0.67	0.71	0.59	1.54	0.62	1.02	0.79	0.77	0.56	0.43
Complex	1.06	0.67	0.97	1.10	0.97	0.60	0.92	0.70	0.65	0.60	1.04	0.67
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Liberated	93.7	95.5	93.0	92.4	94.2	92.9	94.8	91.7	94.4	95.5	95.2	96.2

Virginia Department of Energy, Geology and Mineral Resources Program
CALR-17512-02
MI6024-MAY22 & MI6031-NOV22

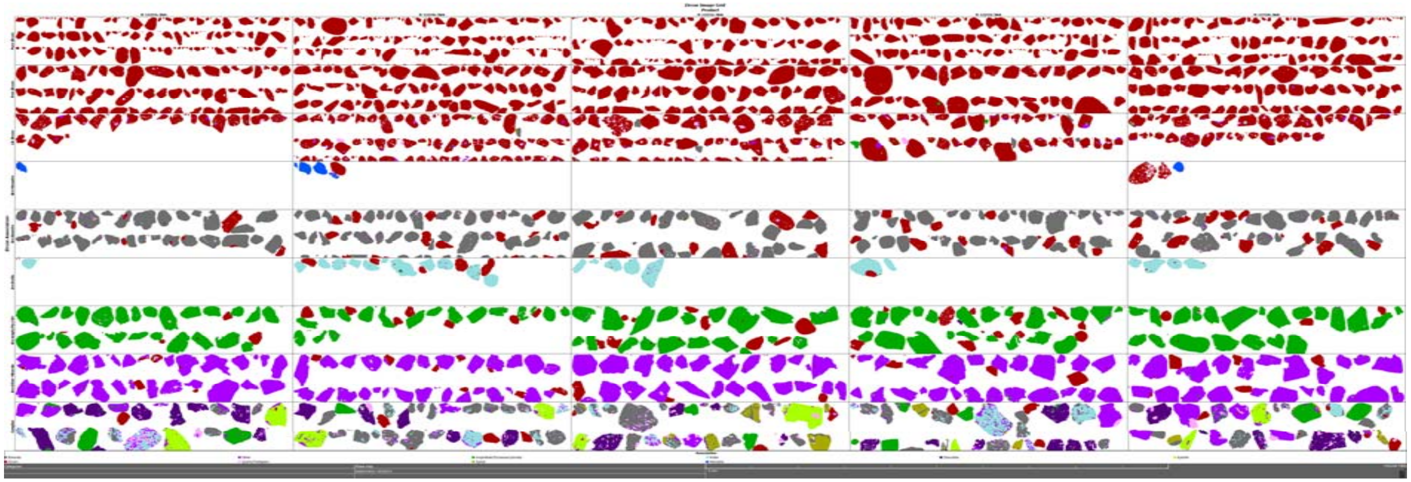
Image Grid of Zircon Association

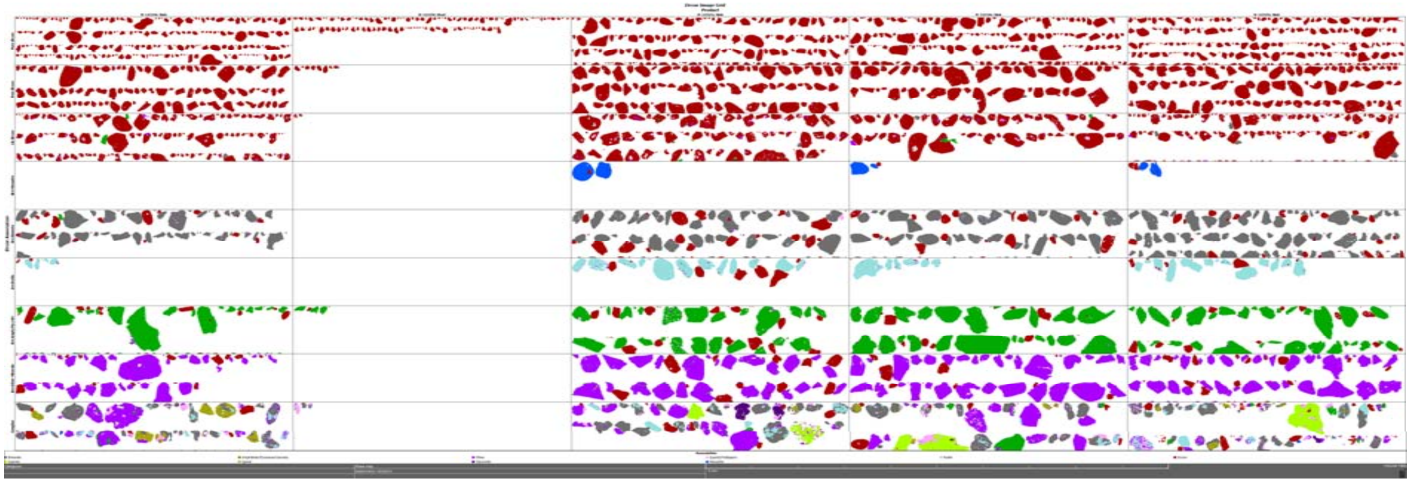




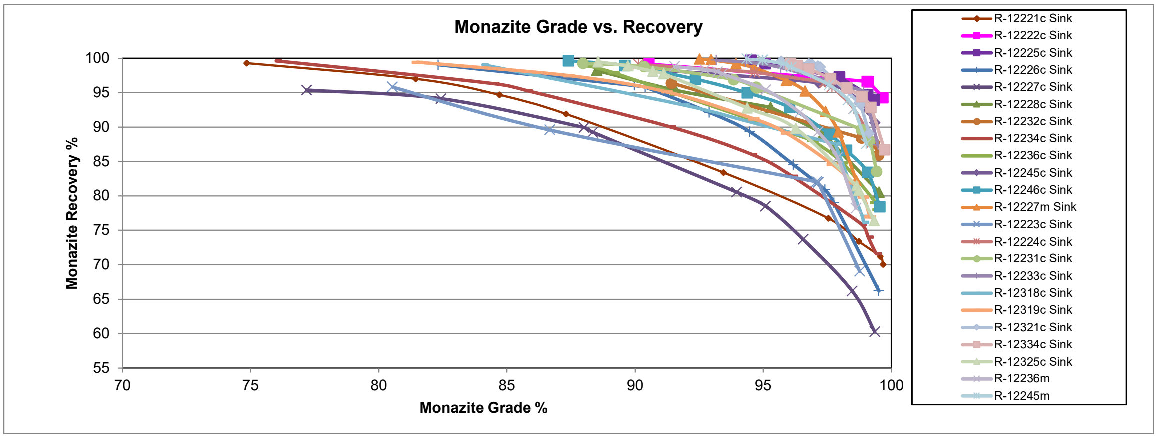
Virginia Department of Energy, Geology and Mineral Resources Program
CALR-17512-02
MI6024-MAY22 & MI6031-NOV22

Image Grid of Zircon Association





Monazite Grade vs. Recovery:



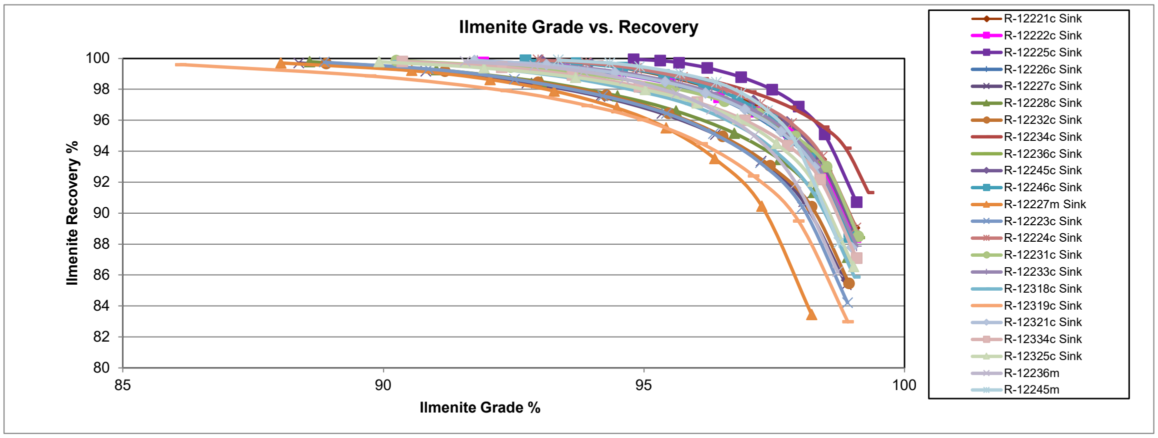
Volume % of Monazite / Samples	R-12221c Sink		R-12222c Sink		R-12225c Sink		R-12226c Sink		R-12227c Sink		R-12228c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	0.20	100.0	0.18	100.0	0.30	100.0	0.16	100.0	0.15	100.0	0.23	100.0
≥10	74.8	99.3	90.5	99.2	94.5	99.7	82.3	99.0	77.2	95.4	88.5	98.2
≥20	81.4	97.0	99.1	96.6	94.5	99.7	90.0	96.0	82.4	94.1	88.5	98.2
≥30	84.7	94.7	99.1	96.6	95.1	99.2	90.4	95.8	88.0	89.9	91.6	95.4
≥40	87.3	91.9	99.1	96.6	98.0	97.3	92.9	92.1	88.3	89.3	95.3	92.9
≥50	93.4	83.4	99.1	96.6	98.0	97.3	94.5	89.3	94.0	80.5	95.3	92.9
≥60	97.5	76.8	99.1	96.6	99.1	94.7	96.2	84.5	95.1	78.5	97.3	89.0
≥70	98.7	73.4	99.1	96.6	99.3	94.0	97.4	80.9	96.6	73.7	97.8	87.2
≥80	99.6	71.2	99.7	94.3	99.3	94.0	97.8	79.0	98.5	66.2	99.5	80.5
≥90	99.7	70.1	99.7	94.2	99.3	94.0	99.5	66.2	99.4	60.3	99.5	80.5

Volume % of Monazite / Samples	R-12232c Sink		R-12234c Sink		R-12236c Sink		R-12245c Sink		R-12246c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	0.09	100.0	0.24	100.0	0.16	100.0	0.20	100.0	0.36	100.0
≥10	91.4	96.4	76.0	99.6	88.1	98.9	91.4	98.2	87.4	99.6
≥20	91.4	96.4	84.5	96.3	88.2	98.9	96.2	96.8	89.6	99.0
≥30	91.4	96.4	85.8	95.3	89.2	97.9	97.2	96.4	92.4	97.0
≥40	98.8	88.4	91.4	90.0	90.6	96.1	98.2	95.6	94.4	95.0
≥50	98.8	88.4	94.5	86.0	96.9	88.1	98.2	95.6	96.0	92.9
≥60	99.3	87.7	96.1	82.9	96.9	88.1	98.2	95.6	97.6	89.0
≥70	99.3	87.7	98.8	75.9	98.1	84.8	98.2	95.6	98.2	86.6
≥80	99.3	87.6	99.1	74.1	99.4	79.0	99.1	92.4	99.1	83.4
≥90	99.5	85.9	99.4	71.6	99.5	78.0	99.4	90.6	99.5	78.4

Volume % of Monazite / Samples	R-12227m Sink		R-12223c Sink		R-12224c Sink		R-12231c Sink		R-12233c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	1.46	100.0	0.05	100.0	0.17	100.0	0.12	100.0	0.16	100.0
≥10	92.5	99.9	80.5	95.8	90.1	99.1	88.0	99.3	93.2	99.7
≥20	93.0	99.8	80.5	95.8	94.7	98.0	90.3	98.8	94.3	99.4
≥30	93.9	99.2	86.7	89.6	94.7	98.0	93.8	96.9	95.7	98.6
≥40	94.6	98.6	97.1	82.1	97.4	96.6	94.7	95.8	98.9	95.2
≥50	95.9	96.8	97.1	82.1	97.4	96.5	94.8	95.7	98.9	95.2
≥60	96.6	95.2	97.1	82.0	97.7	95.8	98.8	89.6	98.9	95.2
≥70	97.4	92.2	97.1	82.0	98.5	92.7	98.8	89.6	98.9	95.2
≥80	97.9	89.3	97.1	82.0	99.3	87.8	99.2	88.0	98.9	95.2
≥90	98.6	82.2	98.8	69.0	99.3	87.8	99.4	83.6	99.5	87.4

Volume % of Monazite / Samples	R-12318c Sink		R-12319c Sink		R-12321c Sink		R-12334c Sink		R-12325c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	0.17	100.0	0.21	100.0	0.26	100.0	0.20	100.0	0.26	100.0
≥10	84.1	99.0	81.5	99.4	95.7	99.6	96.1	99.2	88.6	99.5
≥20	84.1	99.0	87.4	97.5	96.8	99.2	96.1	99.2	89.7	98.9
≥30	91.9	93.2	91.2	95.1	96.9	99.1	96.3	99.0	90.7	98.1
≥40	94.7	90.5	94.6	91.2	97.1	98.8	96.8	98.5	91.1	97.7
≥50	97.8	87.6	95.9	89.1	97.2	98.7	97.6	97.0	94.4	92.8
≥60	97.8	87.6	97.7	84.6	97.2	98.7	98.3	95.7	96.3	89.8
≥70	97.8	87.6	98.5	81.9	98.7	93.5	98.8	94.4	98.6	81.5
≥80	98.9	77.0	98.9	79.8	98.8	93.2	99.2	92.8	98.7	80.8
≥90	98.9	76.2	99.2	77.0	99.1	89.1	99.7	86.7	99.3	76.4

Ilmenite Grade vs. Recovery:



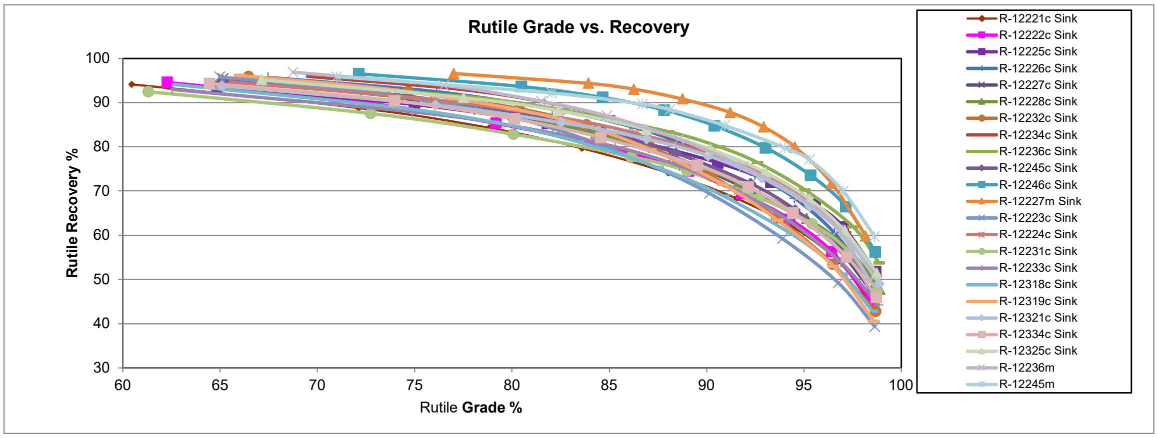
Volume % of Ilmenite/ Samples	R-12221c Sink		R-12222c Sink		R-12225c Sink		R-12226c Sink		R-12227c Sink		R-12228c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	57.8	100.0	46.0	100.0	63.7	100.0	34.5	100.0	35.7	100.0	38.0	100.0
≥10	92.8	99.9	91.9	99.7	94.8	100.0	91.7	99.8	88.4	99.7	88.6	99.8
≥20	93.7	99.7	93.5	99.4	95.3	99.9	93.3	99.5	90.8	99.2	91.0	99.3
≥30	94.5	99.4	94.5	99.0	95.7	99.7	94.7	98.9	92.8	98.4	93.0	98.5
≥40	95.5	98.8	95.5	98.4	96.2	99.4	95.6	98.3	94.2	97.5	94.5	97.6
≥50	96.5	97.8	96.4	97.5	96.9	98.8	96.3	97.6	95.3	96.4	95.6	96.6
≥60	97.2	96.9	97.1	96.5	97.5	98.0	97.0	96.6	96.4	95.1	96.7	95.2
≥70	97.9	95.5	97.8	95.2	98.0	96.9	97.7	95.0	97.3	93.3	97.6	93.5
≥80	98.5	93.5	98.4	92.9	98.5	95.1	98.4	92.7	98.1	90.7	98.3	91.3
≥90	99.1	89.1	99.1	88.4	99.1	90.7	99.0	88.3	98.9	85.4	98.9	87.1

Volume % of Ilmenite/ Samples	R-12232c Sink		R-12234c Sink		R-12236c Sink		R-12245c Sink		R-12246c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	25.0	100.0	47.8	100.0	38.4	100.0	52.1	100.0	51.0	100.0
≥10	88.9	99.7	93.3	99.9	91.9	99.8	93.0	99.9	92.7	99.9
≥20	91.2	99.2	94.1	99.8	93.6	99.4	94.0	99.7	93.7	99.7
≥30	93.0	98.4	95.1	99.4	94.7	99.0	94.9	99.4	94.6	99.4
≥40	94.3	97.6	96.1	98.7	95.4	98.5	95.7	98.8	95.4	98.9
≥50	95.5	96.5	97.0	97.8	96.2	97.7	96.4	98.2	96.2	98.3
≥60	96.5	95.0	97.8	96.8	97.1	96.4	97.1	97.3	96.8	97.4
≥70	97.4	93.1	98.5	95.6	97.9	94.9	97.7	95.9	97.5	96.0
≥80	98.2	90.4	98.9	94.2	98.5	92.7	98.4	93.7	98.2	93.6
≥90	98.9	85.5	99.3	91.3	99.1	88.4	99.0	88.8	98.9	88.5

Volume % of Ilmenite/ Samples	R-12227m Sink		R-12223c Sink		R-12224c Sink		R-12231c Sink		R-12233c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	27.5	100.0	27.7	100.0	51.5	100.0	57.6	100.0	46.1	100.0
≥10	88.0	99.7	88.9	99.8	93.0	99.9	90.2	99.9	91.8	99.9
≥20	90.5	99.2	90.9	99.3	93.9	99.7	92.4	99.4	93.5	99.5
≥30	92.0	98.6	92.5	98.7	94.9	99.3	94.2	98.9	94.6	99.1
≥40	93.3	97.9	94.2	97.6	95.7	98.8	95.5	98.1	95.6	98.4
≥50	94.5	96.8	95.4	96.4	96.5	98.1	96.5	97.2	96.3	97.8
≥60	95.4	95.5	96.3	95.1	97.2	97.0	97.2	96.4	97.1	96.7
≥70	96.4	93.5	97.2	93.2	97.8	95.8	97.9	95.0	97.7	95.3
≥80	97.3	90.4	98.0	90.4	98.4	93.7	98.5	93.0	98.3	93.1
≥90	98.2	83.4	98.9	84.2	99.1	89.0	99.1	88.5	99.1	87.9

Volume % of Ilmenite/ Samples	R-12318c Sink		R-12319c Sink		R-12321c Sink		R-12334c Sink		R-12325c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	35.4	100.0	24.0	100.0	43.4	100.0	36.9	100.0	35.3	100.0
≥10	90.2	99.8	86.1	99.6	91.8	99.9	90.4	99.8	89.9	99.8
≥20	91.8	99.4	89.8	98.9	93.1	99.6	92.3	99.4	91.9	99.4
≥30	93.5	98.8	92.4	97.9	94.4	99.1	93.6	98.9	93.7	98.8
≥40	94.9	97.9	93.9	97.0	95.4	98.5	94.9	98.2	95.0	98.0
≥50	95.8	97.1	95.0	96.0	96.2	97.8	96.0	97.2	96.0	97.1
≥60	96.7	95.9	96.1	94.5	96.9	96.7	96.9	96.0	96.8	96.1
≥70	97.4	94.2	97.1	92.4	97.6	95.2	97.8	94.4	97.5	94.5
≥80	98.3	91.3	98.0	89.5	98.3	93.0	98.4	92.2	98.2	92.0
≥90	99.0	85.9	98.9	83.0	99.0	87.8	99.1	87.1	99.0	86.5

Rutile Grade vs. Recovery:



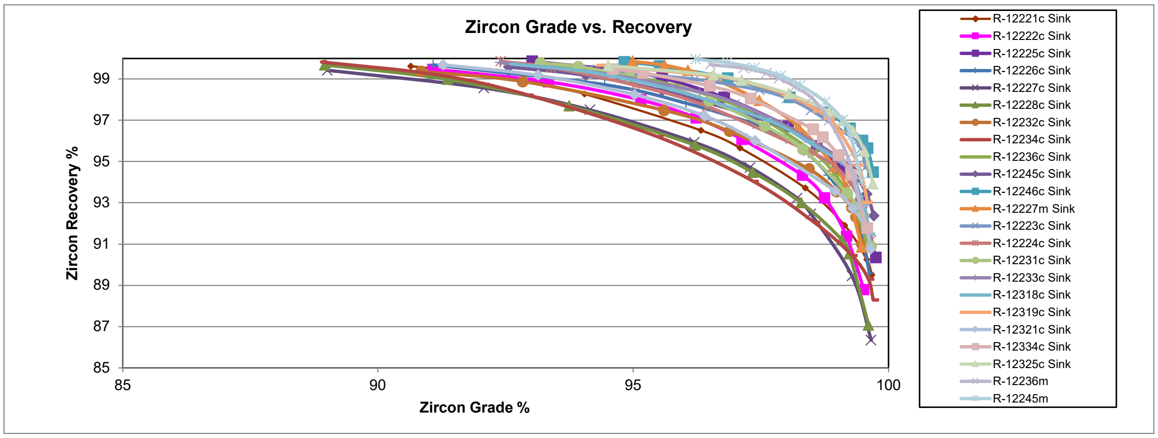
Volume % of Rutile / Samples	R-12221c Sink		R-12222c Sink		R-12225c Sink		R-12226c Sink		R-12227c Sink		R-12228c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	5.07	100.0	4.74	100.0	5.12	100.0	4.33	100.0	4.14	100.0	3.65	100.0
≥10	60.5	94.1	62.3	94.6	64.8	93.6	67.5	95.7	65.2	95.4	65.0	95.1
≥20	72.1	88.8	72.6	89.9	75.0	89.6	76.1	92.4	74.6	91.4	74.2	91.3
≥30	78.8	84.3	79.2	85.3	81.8	85.3	82.1	88.5	79.8	87.7	80.0	87.2
≥40	83.6	79.7	84.4	80.4	86.1	81.6	86.1	84.7	84.3	83.0	84.3	83.1
≥50	88.0	74.1	89.1	74.5	90.6	76.4	88.9	80.5	88.3	77.8	88.5	77.4
≥60	91.5	68.3	91.8	69.3	93.3	72.1	92.5	73.6	91.9	70.8	91.6	71.9
≥70	94.4	61.9	94.3	63.6	95.6	67.0	94.5	68.4	94.4	65.1	95.1	63.8
≥80	96.8	54.1	96.4	56.3	97.0	61.9	96.6	60.5	96.6	57.4	97.3	56.7
≥90	98.3	45.3	98.5	45.2	98.7	51.8	98.5	49.3	98.4	47.8	98.9	47.8

Volume % of Rutile / Samples	R-12232c Sink		R-12234c Sink		R-12236c Sink		R-12245c Sink		R-12246c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	3.96	100.0	4.52	100.0	3.66	100.0	5.85	100.0	7.44	100.0
≥10	66.4	95.9	69.5	95.9	67.6	95.2	65.1	95.1	72.1	96.5
≥20	74.7	92.5	77.1	93.1	78.1	91.1	74.7	91.3	80.5	93.6
≥30	80.4	88.6	81.4	90.3	82.6	88.3	80.5	87.5	84.7	91.2
≥40	83.8	85.0	85.0	86.8	88.1	83.4	84.7	83.5	87.8	88.3
≥50	87.1	79.9	88.8	81.3	90.7	80.0	88.4	78.6	90.4	84.8
≥60	90.3	73.4	92.2	74.7	92.6	76.5	92.3	71.7	93.0	79.8
≥70	93.6	64.0	95.1	67.5	95.1	70.2	94.6	65.7	95.3	73.6
≥80	96.5	53.4	97.1	60.6	97.5	61.9	96.9	57.5	97.2	66.5
≥90	98.7	42.8	98.7	50.9	98.9	53.8	98.5	47.3	98.7	56.2

Volume % of Rutile / Samples	R-12227m Sink		R-12223c Sink		R-12224c Sink		R-12231c Sink		R-12233c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	3.77	100.0	5.55	100.0	6.07	100.0	4.18	100.0	4.42	100.0
≥10	77.0	96.6	65.0	95.8	65.6	94.6	61.3	92.5	62.5	93.0
≥20	83.9	94.4	72.5	92.5	76.0	90.6	72.7	87.6	74.9	87.9
≥30	86.3	93.0	78.3	88.3	82.5	86.6	80.1	82.9	80.1	84.7
≥40	88.8	90.8	82.2	84.0	86.4	83.0	86.1	77.8	85.3	80.0
≥50	91.2	87.8	86.3	77.4	90.1	78.4	89.0	74.6	88.6	75.6
≥60	92.9	84.5	90.2	69.4	92.9	73.8	92.7	68.5	91.5	70.3
≥70	94.5	80.0	93.9	59.2	95.0	68.4	95.4	62.6	94.2	63.5
≥80	96.4	71.7	96.8	49.2	97.1	60.7	97.3	56.3	96.9	53.8
≥90	98.2	59.8	98.6	39.3	98.8	49.7	98.8	47.4	98.8	44.2

Volume % of Rutile / Samples	R-12318c Sink		R-12319c Sink		R-12321c Sink		R-12334c Sink		R-12325c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	4.13	100.0	4.08	100.0	4.90	100.0	3.98	100.0	4.96	100.0
≥10	62.6	94.1	66.0	96.2	65.1	93.8	64.5	94.3	67.1	95.2
≥20	73.6	89.2	73.9	92.9	76.1	89.4	74.0	90.4	77.5	91.1
≥30	79.1	85.6	80.0	88.6	82.5	85.5	80.1	86.3	82.4	88.2
≥40	83.4	81.1	83.9	84.6	86.9	81.8	84.6	82.1	86.9	84.0
≥50	87.5	75.3	87.1	79.3	90.1	78.0	89.5	75.8	90.2	79.5
≥60	90.9	68.8	90.8	71.6	92.8	73.0	92.1	70.9	93.0	74.2
≥70	94.7	59.3	93.6	63.4	95.3	66.6	94.4	65.1	95.3	68.1
≥80	97.0	51.2	96.5	53.0	97.2	59.3	97.2	55.2	97.1	61.1
≥90	98.5	42.9	98.6	40.6	98.9	49.0	98.7	46.0	98.7	51.5

Zircon Grade vs. Recovery:



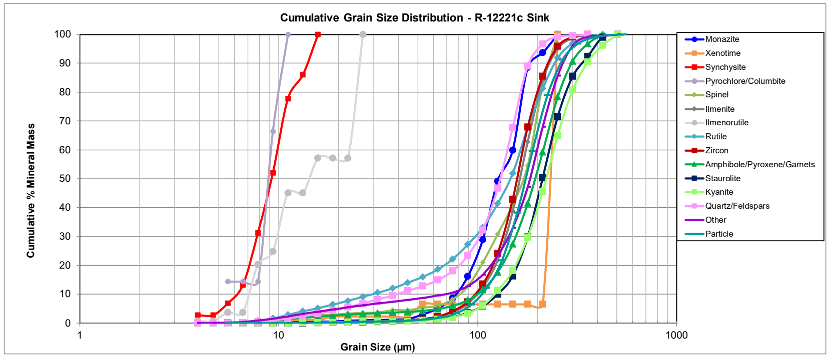
Volume % of Zircon / Samples	R-12221c Sink		R-12222c Sink		R-12225c Sink		R-12226c Sink		R-12227c Sink		R-12228c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	5.61	100.0	5.30	100.0	7.33	100.0	4.57	100.0	4.85	100.0	5.24	100.0
≥10	90.6	99.6	91.1	99.5	93.0	99.9	91.1	99.7	89.0	99.4	89.0	99.7
≥20	92.6	99.1	93.3	98.9	94.8	99.4	94.4	98.7	92.1	98.6	91.4	99.0
≥30	94.0	98.3	95.1	98.0	95.6	99.1	96.0	97.8	94.2	97.5	93.7	97.7
≥40	96.3	96.5	96.2	97.1	96.8	98.1	97.4	96.8	96.2	95.9	96.2	95.8
≥50	97.1	95.7	97.1	96.1	98.0	96.7	98.0	96.1	97.3	94.7	97.3	94.5
≥60	98.4	93.7	98.3	94.3	98.6	95.8	98.3	95.5	98.2	93.2	98.3	93.0
≥70	99.1	91.9	98.8	93.2	99.0	94.7	98.8	94.3	98.5	92.5	99.1	91.2
≥80	99.6	90.3	99.2	91.4	99.5	93.0	99.4	92.1	99.3	89.5	99.2	90.5
≥90	99.7	89.5	99.5	88.8	99.8	90.4	99.6	89.6	99.7	86.3	99.6	87.1

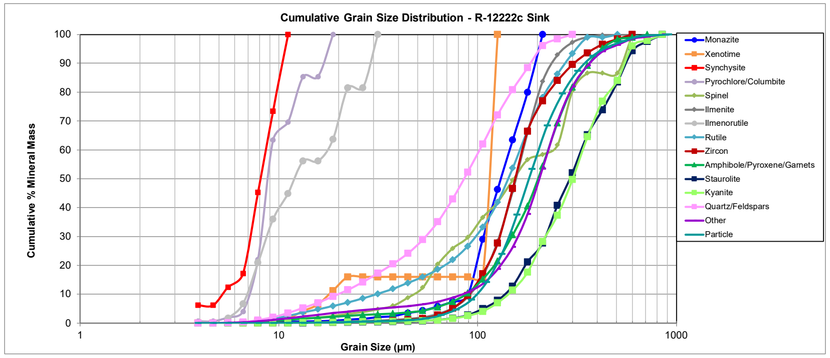
Volume % of Zircon / Samples	R-12232c Sink		R-12234c Sink		R-12236c Sink		R-12245c Sink		R-12246c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	2.45	100.0	5.60	100.0	4.95	100.0	5.52	100.0	8.34	100.0
≥10	90.8	99.4	88.9	99.8	92.9	99.7	92.6	99.6	94.8	99.8
≥20	92.8	98.9	91.2	99.2	94.5	99.3	94.1	99.2	95.5	99.6
≥30	95.6	97.5	92.9	98.2	95.8	98.7	95.6	98.4	96.8	99.0
≥40	96.9	96.5	95.5	96.2	96.7	98.0	97.4	97.2	98.1	98.1
≥50	98.4	94.6	97.3	94.0	97.5	97.1	98.4	96.2	98.8	97.4
≥60	99.0	93.5	98.5	92.1	98.5	95.5	99.0	95.2	99.2	96.6
≥70	99.3	92.8	99.3	90.5	99.0	94.4	99.3	94.6	99.5	96.0
≥80	99.4	92.3	99.6	89.3	99.4	92.6	99.6	93.4	99.6	95.7
≥90	99.5	91.0	99.7	88.3	99.6	90.7	99.7	92.4	99.7	94.5

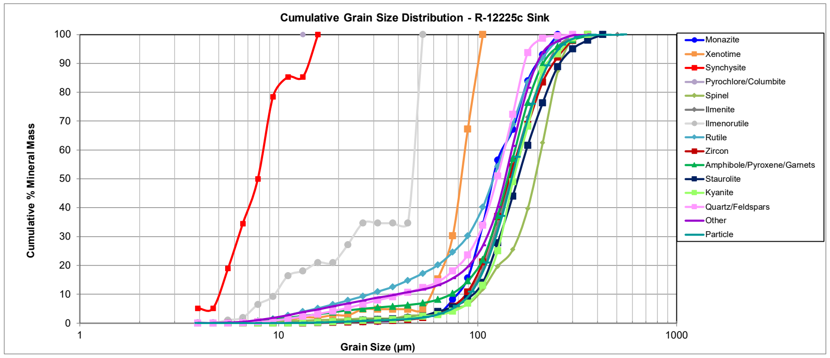
Volume % of Zircon / Samples	R-12227m Sink		R-12223c Sink		R-12224c Sink		R-12231c Sink		R-12233c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	22.1	100.0	2.22	100.0	5.31	100.0	5.84	100.0	5.22	100.0
≥10	95.0	99.9	94.1	99.5	92.4	99.9	93.2	99.8	92.4	99.8
≥20	95.6	99.7	96.2	99.0	93.4	99.6	93.9	99.6	94.4	99.3
≥30	96.1	99.4	97.5	98.5	95.0	98.7	94.9	99.1	96.3	98.4
≥40	96.5	99.1	98.0	98.1	96.4	97.7	96.5	97.9	97.1	97.8
≥50	97.5	98.0	98.5	97.5	98.5	95.4	97.6	96.7	98.0	96.6
≥60	98.2	96.7	99.4	96.0	98.9	94.8	98.3	95.6	99.1	95.1
≥70	98.9	94.7	99.5	95.6	99.2	94.0	99.2	93.5	99.3	94.4
≥80	99.2	93.7	99.5	95.5	99.5	93.0	99.5	92.4	99.4	94.2
≥90	99.5	90.9	99.5	94.7	99.7	91.2	99.7	90.9	99.6	91.7

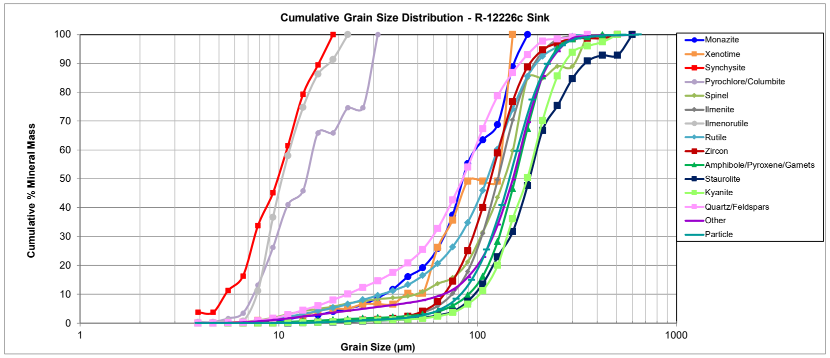
Volume % of Zircon / Samples	R-12318c Sink		R-12319c Sink		R-12321c Sink		R-12334c Sink		R-12325c Sink	
	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery	Grade	Recovery
All particles	3.64	100.0	3.81	100.0	5.27	100.0	4.63	100.0	5.06	100.0
≥10	92.6	99.7	94.4	99.7	91.3	99.7	94.6	99.5	94.5	99.7
≥20	94.1	99.4	96.7	99.1	93.1	99.2	95.2	99.3	96.6	99.2
≥30	95.7	98.5	97.2	98.9	95.0	98.2	96.5	98.7	97.1	98.9
≥40	97.6	97.0	98.0	98.2	96.4	97.2	97.3	98.1	98.0	98.3
≥50	98.4	95.9	98.6	97.4	97.4	96.0	98.5	96.6	98.8	97.4
≥60	99.1	95.0	98.8	97.1	99.0	93.6	98.7	96.2	99.1	97.0
≥70	99.2	94.5	99.0	96.5	99.3	92.7	99.0	95.3	99.3	96.5
≥80	99.5	92.9	99.4	94.8	99.6	91.7	99.3	94.4	99.5	95.5
≥90	99.6	91.5	99.6	93.0	99.6	90.8	99.6	91.8	99.7	93.9

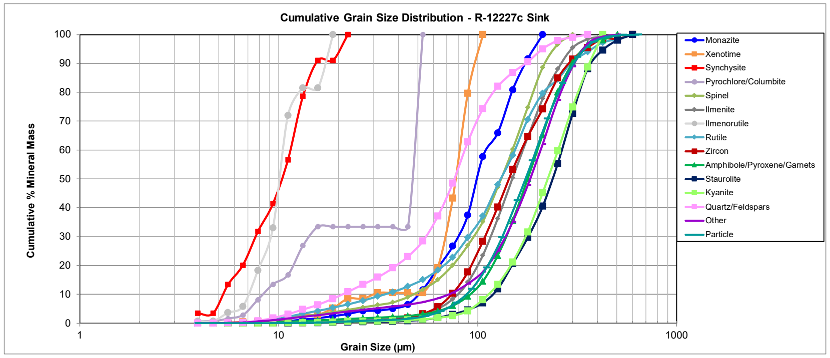
Grain size distribution

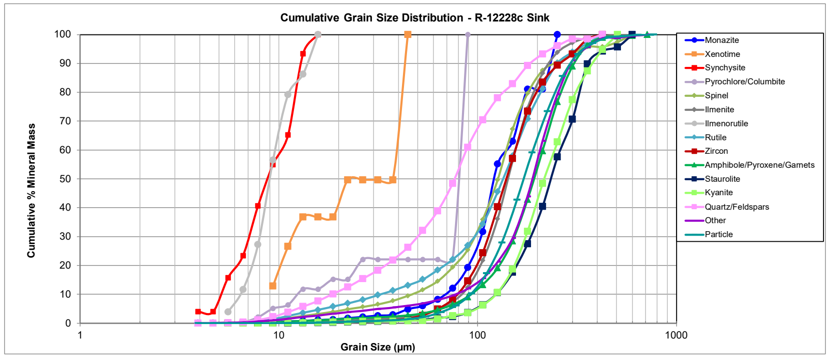












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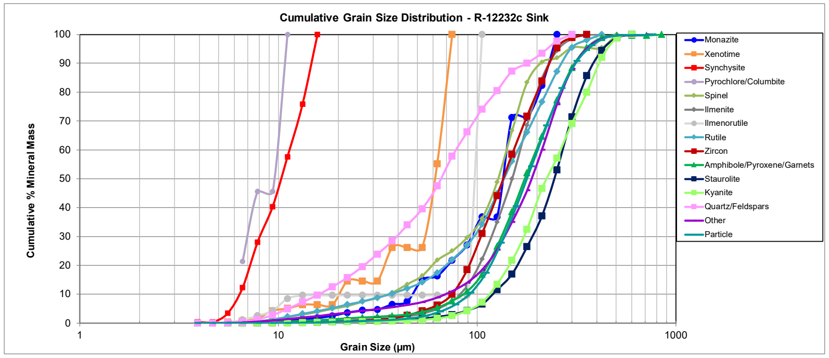

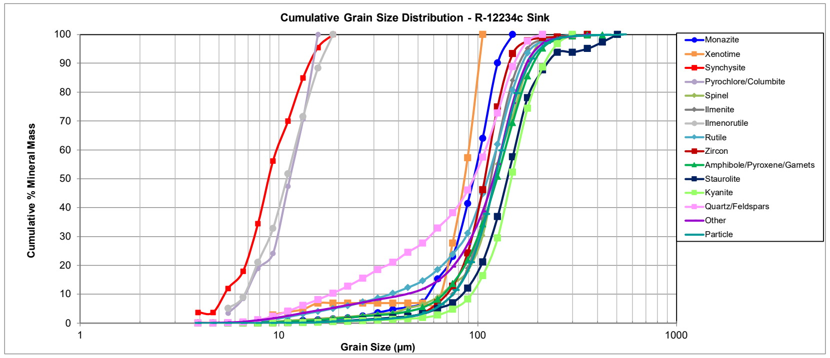

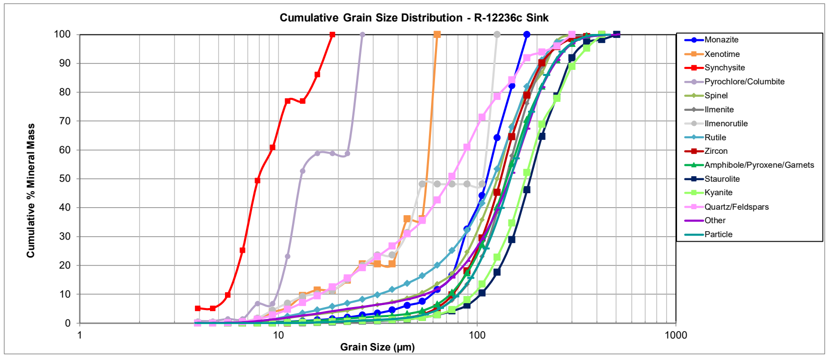

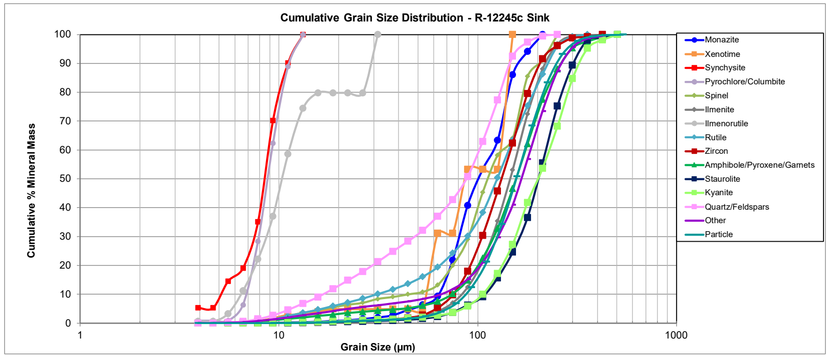

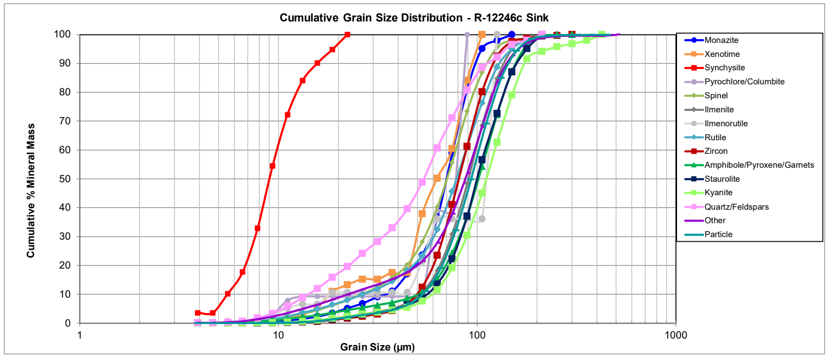

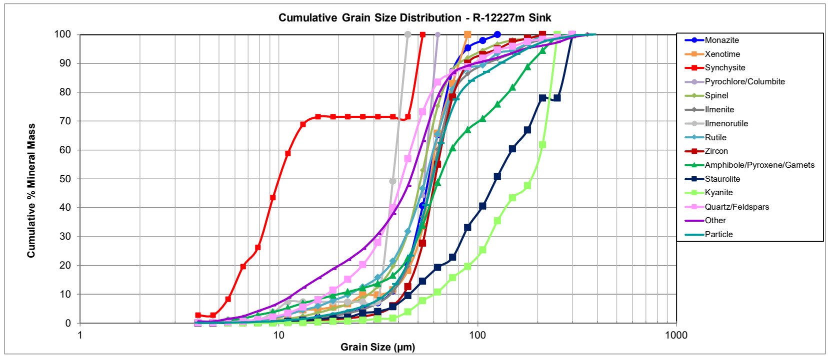

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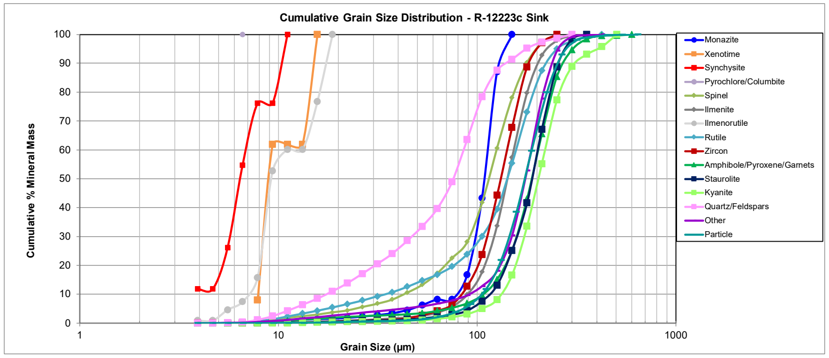
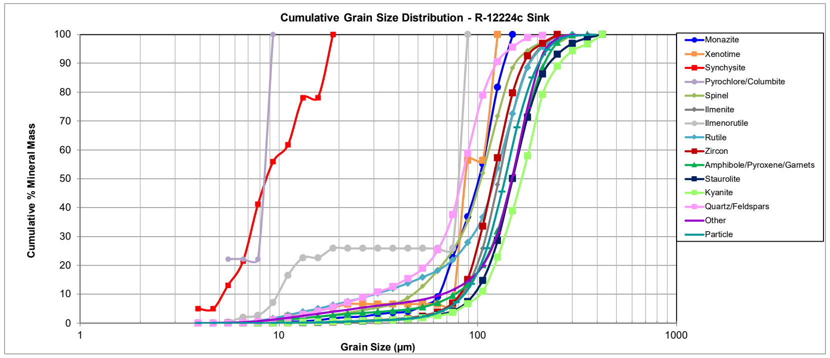
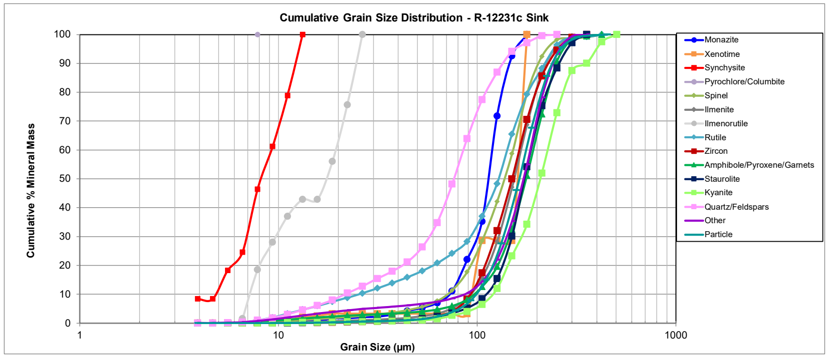
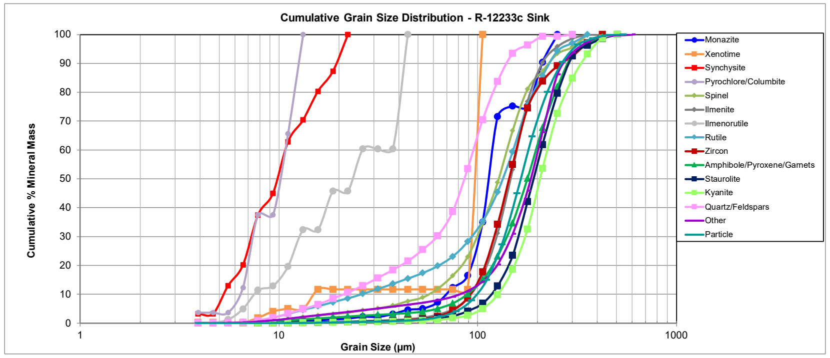
CALR-17512-02
MI5024-MAY22 & MI5031-NOV22

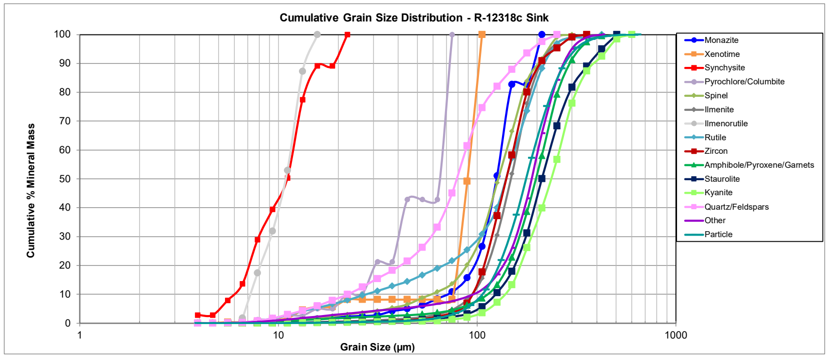
Grain size distribution

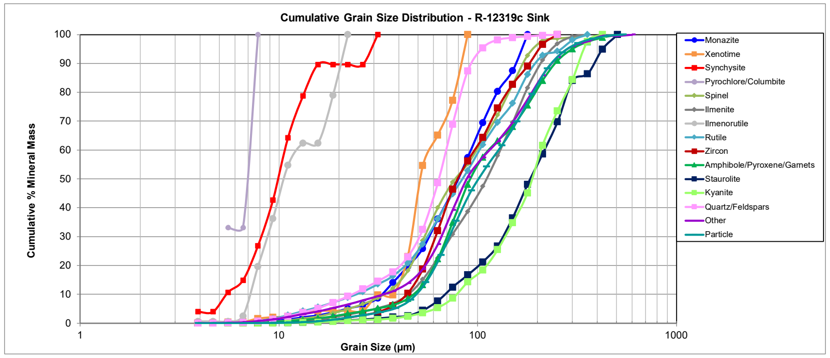




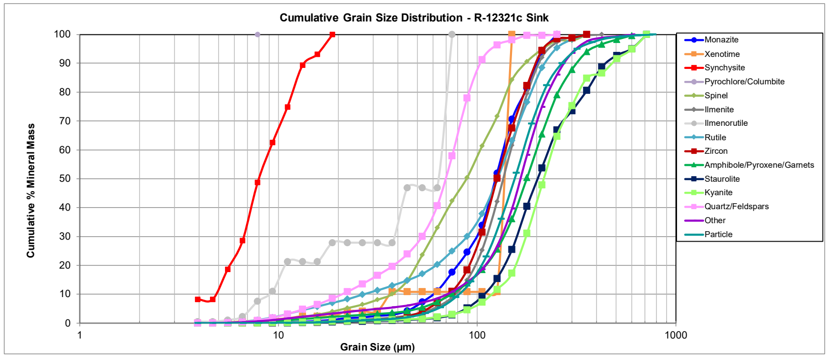


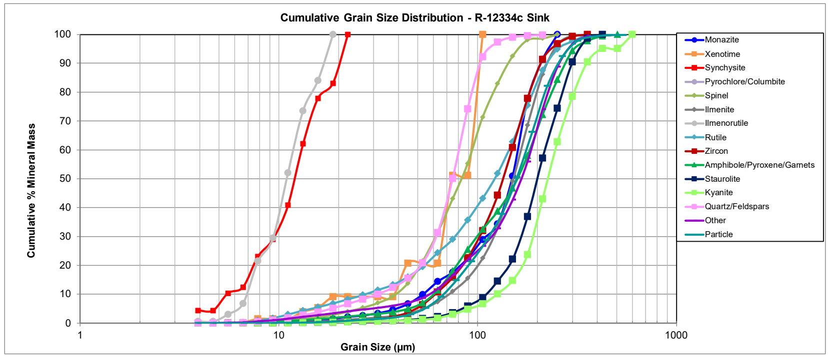


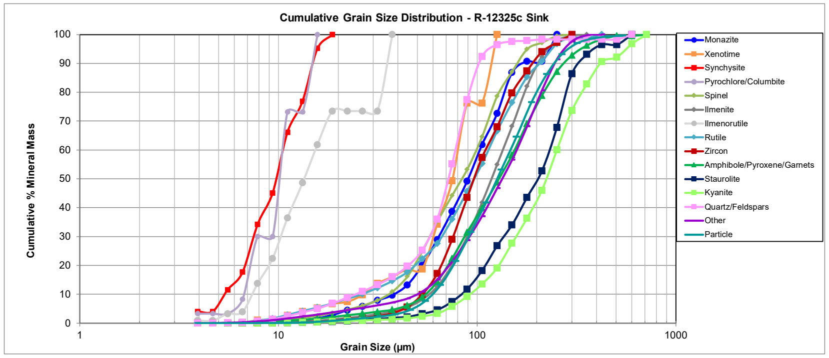


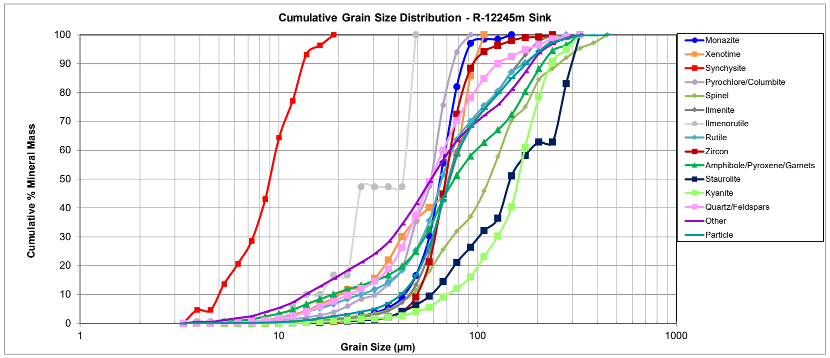


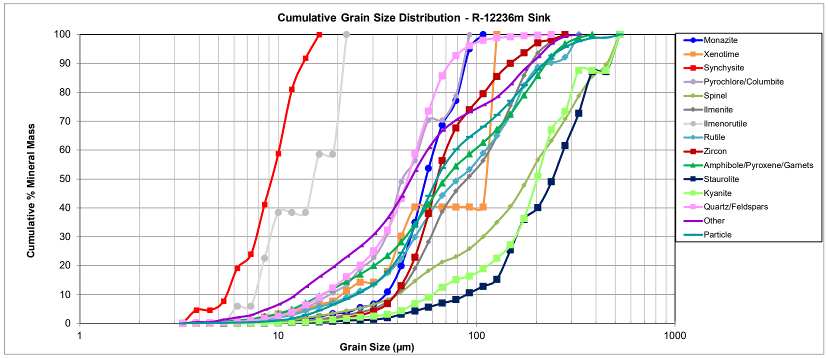
Grain size distribution











Grain size distribution

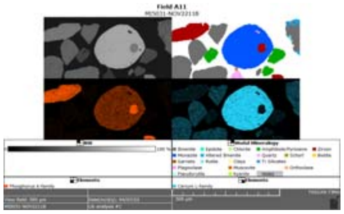
Sample	Grain Size [µm]	Monazite	Xenotime	Synchysite	Pyrochlore/ Columbite	Spinel	Ilmenite	Ilmenorutile	Rutile	Zircon	Amphibole/ Pyroxene/ Garnets	Staurolite	Kyanite	Quartz/ Feldspars	Other	Particle
R-12221c Sink	Median	131	234	8	9	172	163	14	147	158	195	210	220	130	184	174
	P80	164	234	12	10	209	204	26	209	200	255	278	298	165	236	226
R-12222c Sink	Median	128	123	8	9	153	155	12	141	154	201	290	301	85	204	181
	P80	199	123	10	12	293	204	20	220	233	295	461	474	148	292	270
R-12225c Sink	Median	120	79	8	11	187	146	47	121	143	141	159	151	125	138	148
	P80	158	102	10	11	235	196	52	170	202	185	222	199	157	176	197
R-12226c Sink	Median	86	146	10	14	140	126	10	111	115	154	183	178	84	150	144
	P80	144	146	14	26	173	166	14	164	155	199	271	232	129	198	194
R-12227c Sink	Median	99	84	10	45	130	149	10	132	143	178	235	223	76	182	173
	P80	149	89	14	45	190	218	12	215	230	252	320	319	118	260	255
R-12228c Sink	Median	122	39	9	82	126	142	9	134	139	192	240	215	77	188	170
	P80	177	39	12	82	180	190	11	204	199	261	317	303	134	255	246
R-12232c Sink	Median	138	56	10	10	129	150	105	136	135	174	247	220	66	188	178
	P80	184	70	14	10	173	202	105	228	197	262	341	360	125	265	262
R-12234c Sink	Median	93	76	9	12	121	116	11	113	108	125	141	148	95	120	123
	P80	115	91	13	14	168	144	16	149	130	166	182	186	136	157	158
R-12236c Sink	Median	116	57	8	13	126	140	113	121	131	141	185	174	73	146	147
	P80	149	62	14	26	188	186	113	173	184	205	256	259	129	207	205
R-12245c Sink	Median	100	88	9	8	115	146	10	125	132	156	205	198	87	166	157
	P80	146	127	10	11	177	193	26	189	179	221	263	284	128	228	214
R-12246c Sink	Median	69	57	9	86	70	90	115	79	81	102	100	110	54	87	93
	P80	87	79	12	86	96	119	115	110	106	137	136	151	86	121	125
R-12227m Sink	Median	56	61	10	56	52	59	40	55	61	64	119	183	41	46	59
	P80	68	68	49	56	67	75	40	73	76	145	289	237	58	64	82
R-12223c Sink	Median	107	9	6	6	117	142	9	141	130	189	189	202	76	175	174
	P80	122	15	11	6	151	179	17	195	164	240	232	261	109	215	224
R-12224c Sink	Median	97	88	9	9	104	128	79	122	120	149	150	168	83	148	137
	P80	124	111	16	9	139	160	79	161	150	191	192	213	107	186	177
R-12231c Sink	Median	119	165	9	7	138	153	17	128	150	176	175	207	77	171	163
	P80	137	165	13	7	179	197	23	181	202	227	222	281	109	214	211
R-12233c Sink	Median	119	93	10	10	129	147	26	134	145	178	190	208	86	185	165
	P80	186	93	14	11	174	185	43	191	193	246	253	276	120	237	224
R-12318c Sink	Median	124	89	10	68	128	148	10	139	141	198	211	239	79	188	176
	P80	149	89	14	68	167	185	12	189	178	256	289	312	119	239	237
R-12319c Sink	Median	81	53	10	7	77	111	11	84	79	92	179	186	64	88	101
	P80	114	87	15	7	142	173	19	164	144	196	284	281	83	188	190
R-12321c Sink	Median	121	134	8	7	88	135	67	127	126	177	202	218	70	164	154
	P80	178	134	11	7	138	179	67	185	173	257	336	316	91	226	216
R-12334c Sink	Median	148	71	12	-	83	151	11	122	134	159	199	227	75	166	157
	P80	190	90	16	-	118	200	14	189	182	236	262	306	93	226	218
R-12325 Sink	Median	90	85	10	10	83	119	14	97	97	129	204	220	71	134	126
	P80	131	115	14	14	128	174	36	161	151	216	282	339	91	210	198
R-12236m	Median	56	117	10	46	178	88	15	83	64	69	253	202	45	47	63
	P80	81	117	11	79	334	159	21	167	110	178	350	309	62	135	163
R-12245m	Median	66	72	9	59	117	71	46	66	69	76	148	166	58	58	72
	P80	77	83	12	72	187	124	46	124	83	172	267	210	96	145	129

Association/Range	**Min**	**Max**	**Avg.**
Pure Monazite	15.3	52.2	32.2
Free Monazite	26.9	69.1	47.5
Lib Monazite	0.0	14.6	7.7
Mnz:Xenotime	0.0	0.0	0.0
Mnz:Synchysite	0.0	0.1	0.0
Mnz:Pyrochlore/Columbite	0.0	0.0	0.0
Mnz:Spinel	0.0	1.4	0.1
Mnz:Ilmenite	0.0	27.5	3.7
Mnz:Ilmenorutile	0.0	0.0	0.0
Mnz:Rutile	0.0	4.1	0.4
Mnz:Zircon	0.0	1.8	0.4
Mnz:Amph/Pyr/Grt	0.0	9.1	1.3
Mnz:Staurolite	0.0	8.6	0.5
Mnz:Kyanite	0.0	9.3	0.5
Mnz:Quartz/Feldspars	0.0	2.8	0.5
Mnz:Other Minerals	0.0	8.1	1.9
Complex	0.0	9.9	3.2
Liberated	71.3	96.6	87.4

Association/Range	**Min**	**Max**	**Avg.**
Pure Zircon	29.8	60.7	39.4
Free Zircon	28.2	58.5	47.9
Lib Zircon	3.3	9.1	5.8
Zrn:Monazite	0.0	0.7	0.1
Zrn:Xenotime	0.0	0.0	0.0
Zrn:Synchysite	0.0	0.0	0.0
Zrn:Pyrochlore/Columbite	0.0	0.0	0.0
Zrn:Spinel	0.0	0.5	0.1
Zrn:Ilmenite	0.3	6.9	3.2
Zrn:Ilmenorutile	0.0	0.0	0.0
Zrn:Rutile	0.0	0.5	0.1
Zrn:Amph/Pyr/Grt	0.2	3.3	1.2
Zrn:Staurolite	0.0	0.4	0.1
Zrn:Kyanite	0.0	0.8	0.2
Zrn:Quartz/Feldpars	0.0	1.4	0.3
Zrn:Other Minerals	0.4	1.9	0.9
Complex	0.4	1.7	0.8
Liberated	89.3	96.2	93.0

Association/Range	**Min**	**Max**	**Avg.**
Pure Rutile	9.3	23.7	14.7
Free Rutile	18.1	31.8	26.0
Lib Rutile	14.3	24.4	18.0
Rt:Monazite	0.0	0.4	0.0
Rt:Xenotime	0.0	0.0	0.0
Rt:Synchysite	0.0	0.0	0.0
Rt:Pyrochlore/Columbite	0.0	0.0	0.0
Rt:Spinel	0.0	0.3	0.1
Rt:Ilmenite	4.5	27.4	15.4
Rt:Ilmenorutile	0.0	0.0	0.0
Rt:Zircon	0.0	1.0	0.2
Rt:Amph/Pyr/Grt	0.0	1.0	0.4
Rt:Staurolite	0.0	0.1	0.0
Rt:Kyanite	0.0	0.2	0.0
Rt:Quartz/Feldpars	0.1	1.1	0.5
Rt:Other Minerals	3.2	9.3	6.1
Complex	11.9	27.6	18.6
Liberated	49.2	71.7	58.7

Association/Range	**Min**	**Max**	**Avg.**
Pure Ilmenite	30.5	51.0	37.4
Free Ilmenite	36.7	55.0	45.4
Lib Ilmenite	6.1	17.4	10.2
Ilm:Monazite	0.0	0.1	0.0
Ilm:Xenotime	0.0	0.0	0.0
Ilm:Synchysite	0.0	0.0	0.0
Ilm:Pyrochlore/Columbite	0.0	0.0	0.0
Ilm:Spinel	0.0	2.9	0.9
Ilm:Ilmenorutile	0.0	0.0	0.0
Ilm:Rutile	0.5	3.2	1.6
Ilm:Zircon	0.0	1.1	0.4
Ilm:Amph/Pyr/Grt	0.2	1.7	0.7
Ilm:Staurolite	0.0	0.2	0.1
Ilm:Kyanite	0.0	0.2	0.0
Ilm:Quartz/Feldspars	0.0	0.4	0.1
Ilm:Other Minerals	0.4	1.3	0.8
Complex	1.2	3.9	2.4
Liberated	90.0	95.5	93.0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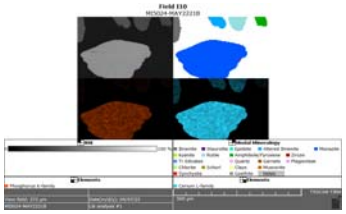
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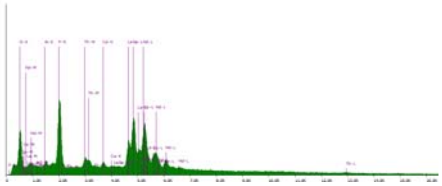

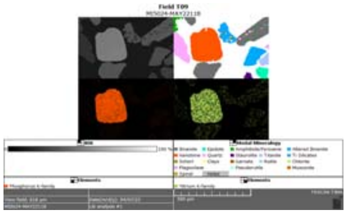
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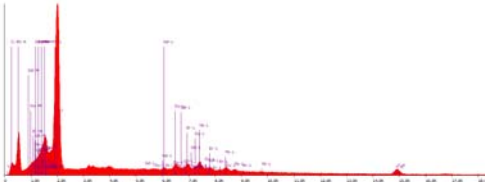
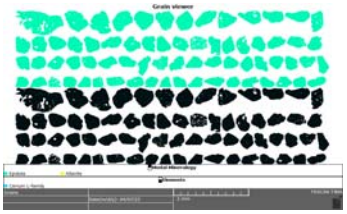
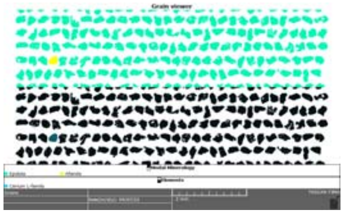
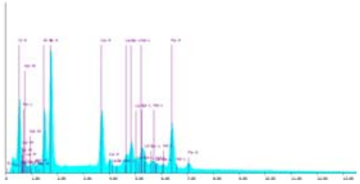
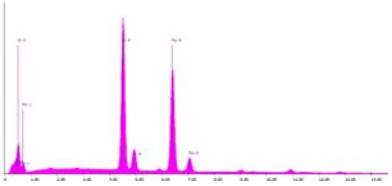


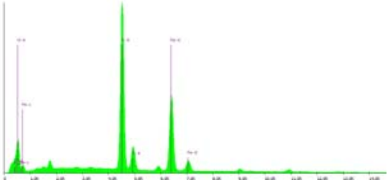








Element	Ilmenite	Altered Ilmenite
	weight %	
Ti	38.2	40.9
Fe	34.6	25.5
O	25.6	30.1
Mn	1.0	1.6
Si	0.4	1.4
Al	0.3	0.7
Total	100	100



Appendix D – Data from EPMA

Appendix E – Data from LA-ICP-MS

APPENDIX D

Portable X-Ray Fluorescence Protocol

PORTABLE X-RAY FLUORESCENCE SCREENING PROTOCOL

Portable x-ray fluorescence (pXRF) is a non-destructive analytical technique that measures low-energy x-rays produced from high-energy x-ray interaction with atoms. A stream of electrons sourced from a heated cathode is accelerated toward an anode by a voltage difference in a vacuum. When these high-energy electrons strike the anode, they decelerate and emit x-rays known as bremsstrahlung radiation (Klockenkämper and von Bohlen 2015). These high-energy x-rays are passed through a set of filters, aimed at the sample, and displace orbiting electrons. A release of energy, in the form of low-energy x-rays, occurs when an electron from an outer orbital shell (e.g., L, M, N) fills the vacancy at an inner shell (e.g., K) (Figure D1). This energy transition produces a unique characteristic spectrum with specific peaks and emission lines for each element (Figure D2). Elements are identified by energy-dispersive analysis (energy sorting) and subtracting a known background radiation. For standard pXRF measurements, detection of elements lighter than Mg are problematic due to absorption of their x-rays by air.

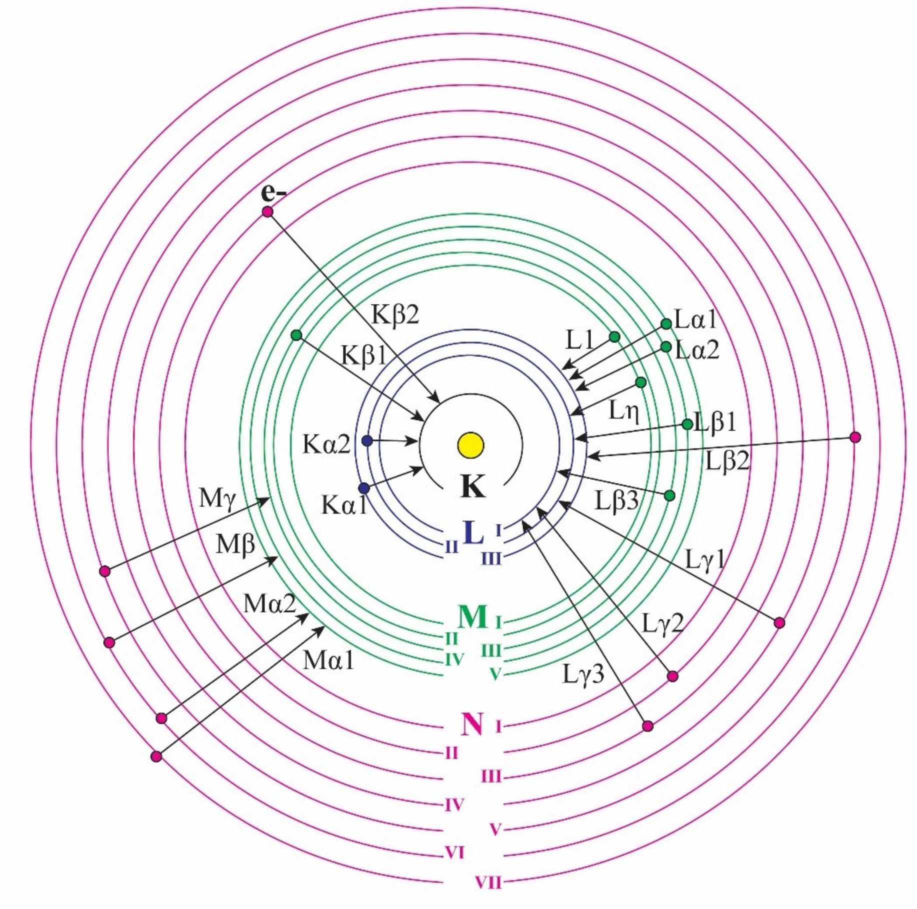


Figure D1: After Klockenkämper and von Bohlen (2015). Electron transitions that may produce principle lines or peaks in a typical x-ray spectrum for a heavy element. Electron orbital shells are represented as colored circular lines, electrons are represented as colored dots, arrows indicate energy transitions with Siegbahn notation.

Appendix D from Nelson, M.S., Hawkins, D.W., and Lassetter, W.L., 2024, A capacity assessment on the recovery of critical and economic minerals from sand used for coastal resilience projects: Virginia Department of Energy, Geology and Mineral Resources Program, Open-file report 2024-16.

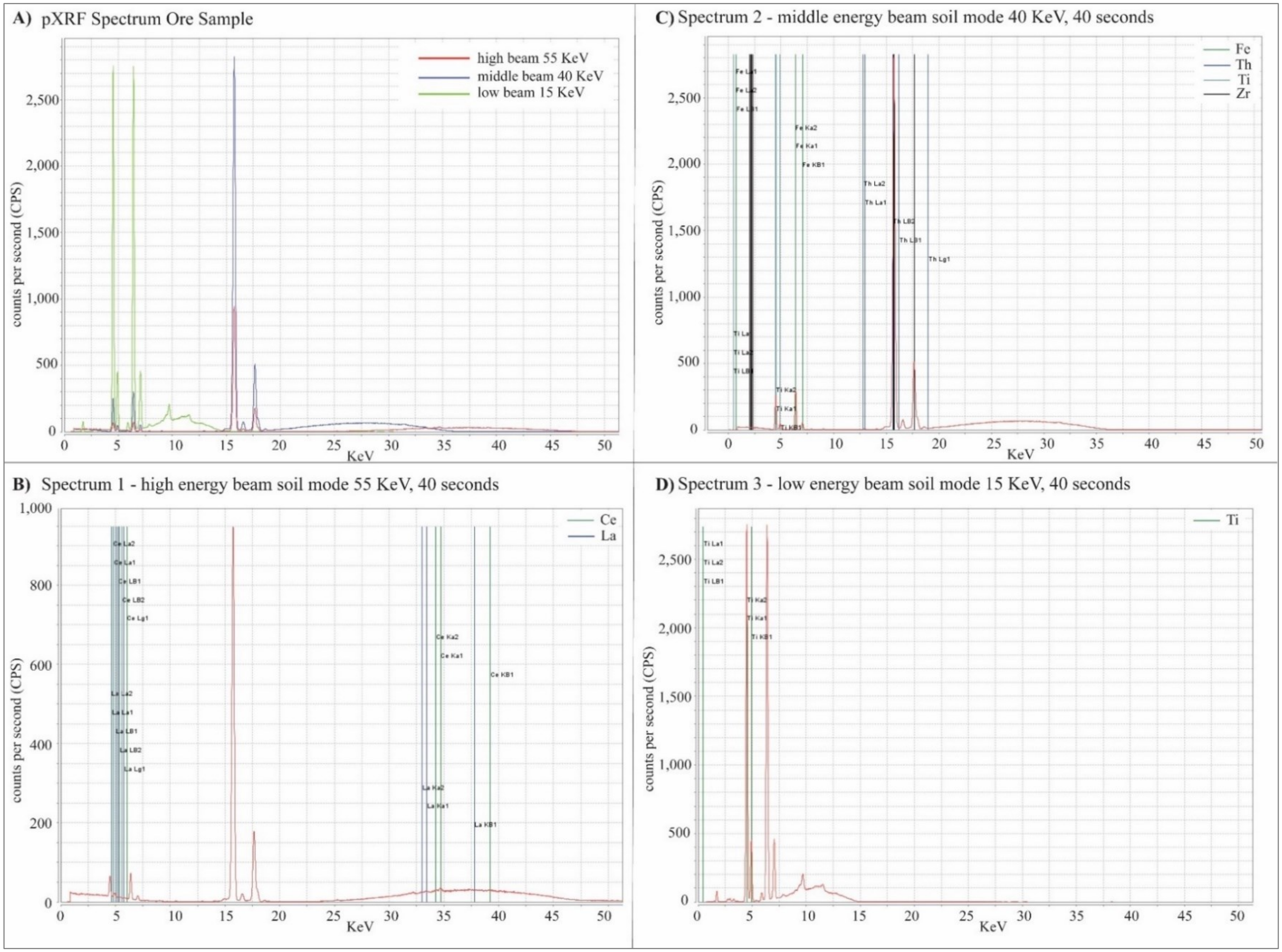


Figure D2: A) Portable XRF spectrum from SciAps X-555 and Profile Builder computer program containing three energy beams (soil mode) for heavy mineral sand ore sample. High beam in red (55 KeV), middle beam in blue (40 KeV), low beam in green (15 KeV). B) Same sample, high beam only spectrum, with elemental emission lines (vertical lines) highlighted for Ce, La. C) Same sample, middle beam only spectrum, with elemental emission lines highlighted for Fe, Th, Ti, Zr. D) Same sample, low beam only spectrum, with elemental emission lines highlighted for Ti.

The SciAps X-555 pXRF spectrometer uses two operating modes, mining and soil mode (Table D1). Mining mode should be selected to detect elements expected to exceed 1% concentration and includes elements that are often referred to as major elements. Mining mode is normalized to 100% and may over or underestimate certain elements depending on what other elements are present in the sample. This mode often utilizes ‘fundamental parameters’, an algorithm that applies x-ray physics to correct for overlapping peaks and matrix differences.

Soil mode is used for elemental concentrations expected to occur within or less than 1% (e.g., trace elements, rare earth elements (REEs)). The Compton peak is present in the spectrum of every sample, changes with different matrices, and is produced from random backscattering of x-ray radiation from the excitation source (USEPA 2007). The Compton normalization method is based on analysis of a single, certified standard and normalization for the Compton peak (USEPA 2007) and is used to correct for variations in sample density and thickness. Compton normalization is better for heavy elements (i.e., REEs) because it produces a smaller peak from backscattered x-rays than lighter mass elements. It ensures that the XRF signal is proportional to the concentration of the elements in the sample rather than being affected by variations in sample properties. It is best for simple matrices (e.g., homogenous well-sorted and well-packed sediment) and when measuring elements that occur below 2–3%.

The pXRF screening protocol outlined in this report is based on available and accessible geochemical data and may be updated as more data is acquired. It highlights current best practices for identifying critical elements in heavy mineral sands from offshore sand resources. We recommend the evaluation of the elements related to ilmenite, rutile, zircon, and REE-bearing phosphates as these are the critical commodities at Sandbridge Borrow Areas and the Atlantic Ocean Federal Navigation Channel. Major elements present in these mineral concentrates are Fe, Ti and Zr, with trace amounts of La, Ce, Y, Sc, Nb and/or V. The scope is to provide efficient screening turnaround time, and to guide sampling for laboratory submittal for analytical geochemistry and mineralogy. This protocol provides a discussion of general sampling and processing procedures, and does not address specific x-ray certification, inspection, or training requirements of equipment manufacturers. The user should be familiar with elemental chemistry of specific minerals and/or rock material and understand the heterogeneity of the material being tested.

Table D1: Beam settings for SciAps X-555 pXRF used to develop this protocol.

Mode	Beam #	Voltage (KeV)	Current (µA)	Elements measured[1]
Soil	1	55.0	90.0	Ag, Cd, Sn, Sb, Te, Ba, **La, Ce**, Pr, Nd, Sm, Eu, Gd
Soil	2	40.0	80.0	**Ti**, V, Cr, Mn, **Fe**, Co, Ni, Cu, Zn, Ga, As, Se, Rb, Sr, **Y**, **Zr**, Nb, Mo, Hg, Tl, Pb, **Th**, U
Soil	3	15.0	80.0	P, S, K, Ca, Sc, **Ti**, V, Cr
Mining	1	40.0	23.0	Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ta, W, As, Sr, Rb, Zr, Nb, Mo, Pb, Ag, Sn, Sb
Mining	2	10.0	200.0	Mg, Al, Si, P, S, K, Ca

[1] Elements and beam settings may vary depending on make, model and year of pXRF unit. See manufacturer details for specific settings. Example of spectral data for ore sample and elements in bold shown in Figure D2.

Instrument Calibration

The SciAps X-555 pXRF spectrometer at Virginia Energy was calibrated by the SciAps manufacturer prior to shipment. It uses the fundamental parameters algorithm which is a calibration method used to measure samples of unknown chemical composition in which concentrations of light and heavy elements can vary from parts per million (ppm) to high percentage. This method simultaneously compensates for a wide variety of geometric effects plus x-ray absorption along with second and third fluorescent effects (low-energy x-ray production). The fundamental parameters process is calibrated without a standard, but rather uses the spectrometer's response to pure elements along with an algorithm to correct for matrix affects. Matrix correction methods make a universal factory calibration on the instrument, meaning it is independent of sample type. Physical assumptions that must be met are sample homogeneity (assumes atoms are infinitely mixed at the atomic level) and completeness (i.e., all beams are used for analyses to not skew mining mode normalization). The X-555 also uses the Compton normalization method for calibration which subtracts a background signal equal to ~99% SiO_2.

A metal calibration disk was provided with the spectrometer and must be run prior to data collection each time it is powered on. When the analyzer is on for an extended period (>20 measurements), it is useful to re-start the unit and re-run the calibration disk. Analyzers will have a manual calibration option using certified standards; however, due to the use of the instrument for multiple sample media, we have not calibrated the unit to a site or media-specific material. We utilized material from an onshore heavy mineral deposit to determine threshold ranges for specific elements of economic interest in this protocol.

Interferences

The maximum energy beam for most pXRF spectrometers is commonly 40-50 KeV, which is not high enough to excite the K lines of elements heavier than Mo. This can result in excitation of the L lines for heavier elements that fall in the spectra range of 0-10 KeV, which is also the same as K lines of transition metals (e.g., Ti, V, Cr, Fe) (Table D2) (Gallhofer and

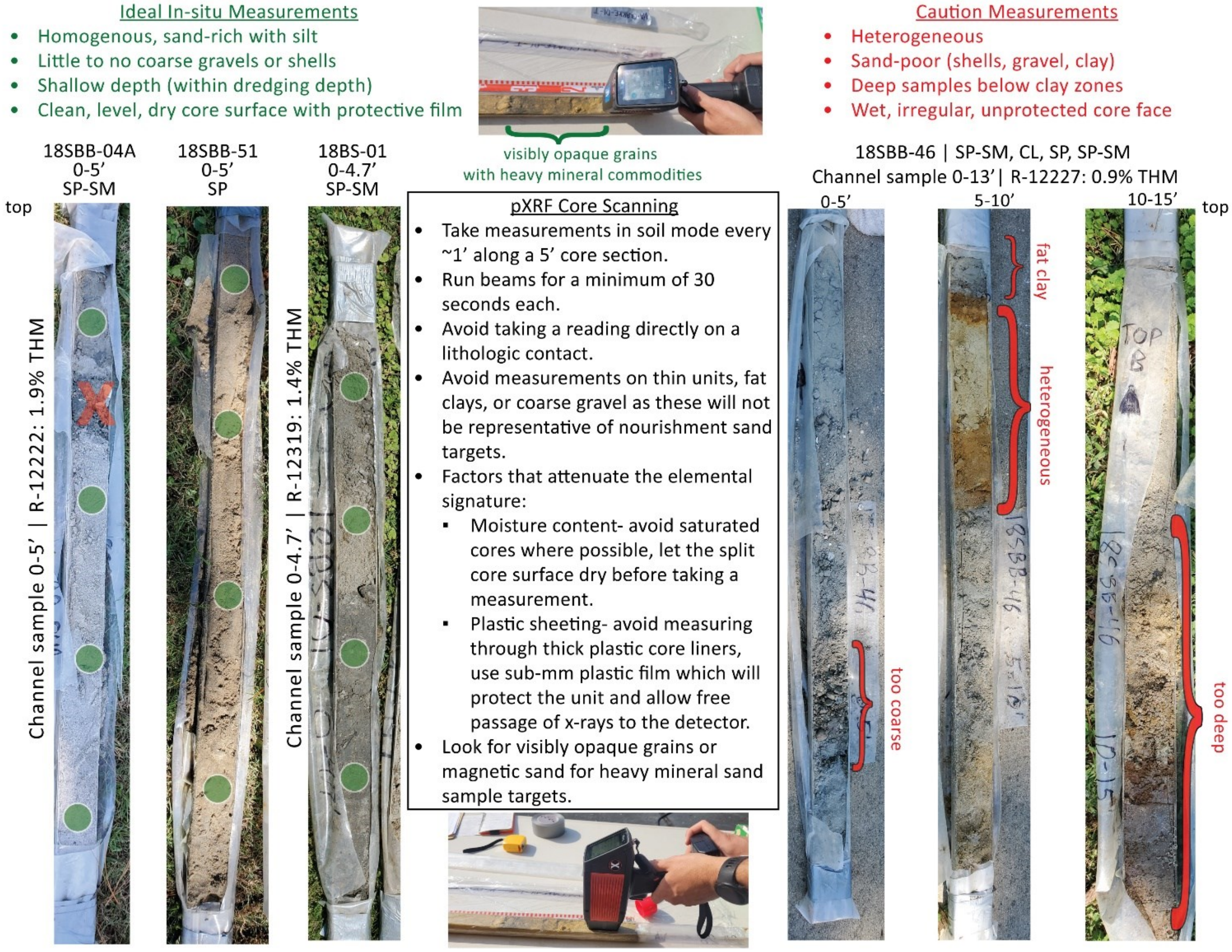
Lottermoser 2018). Thus, interferences occur between electron orbital lines K and L, K and M, and L and M. For example, when Kα of element 1 overlaps with Lα of element 2, this can force the software to use Kβ and Lβ. This is not ideal given that the sensitivity is lower due to the lower intensity of those energy bands (USEPA 2007). Alpha (α) is the most intense peak followed by less intense peaks β, γ, η, and I (Klockenkämper and von Bohlen 2015). Elements that fall in a higher energy beam range (10-20 KeV) are Y, Zr, Nb, and Th and tend to have fewer interferences (Gallhofer and Lottermoser 2018). Additionally, if the ratio between two elements is greater than 10, then the software more than likely cannot correct for low concentration elements in the presence of the high concentration elements, and a beam error will occur, or erroneous data will be recorded (USEPA 2007).

Table D2: Energy signature in KeV for K and L-shell electrons (selected elements). From *Center for X-Ray Optics Advanced Light Source X-Ray Data Booklet* (2001).

Atomic Number	**Element**	**Kα1**	**Kα2**	**Kβ**	**Lα**	**Lβ**
22	Ti	4.51	4.50	4.93	0.45	0.46
23	V	4.95	4.94	5.43	0.51	0.52
24	Cr	5.41	5.41	5.95	0.57	0.58
26	Fe	6.40	6.39	7.06	0.71	0.72
39	Y	14.96	14.88	16.74	1.92	2.00
40	Zr	15.77	15.69	17.67	2.04	2.12
41	Nb	16.61	16.52	18.62	2.17	2.26
57	La	33.44	33.03	37.8	4.65	5.04
58	Ce	34.72	34.28	39.26	4.84	5.26
90	Th	93.33	89.95	105.59	12.97	16.2
92	U	98.43	94.67	111.29	13.61	17.22

Sample Collection and Preparation

Sediment cores may be screened in-situ with the pXRF analyzer (Figure D3), taking care to avoid heterogeneities and saturated sediments. Best practices were developed on ex-situ screening of uniformly prepared samples, which consists of homogenizing the less than 2 mm grain size fraction and preparing in sample cups as described in Table D3. Typically, dried and homogenized samples provide higher elemental concentrations and lower counting errors than wet samples.



Ideal In-situ Measurements

- Homogenous, sand-rich with silt
- Little to no coarse gravels or shells
- Shallow depth (within dredging depth)
- Clean, level, dry core surface with protective film

Caution Measurements

- Heterogeneous
- Sand-poor (shells, gravel, clay)
- Deep samples below clay zones
- Wet, irregular, unprotected core face

pXRF Core Scanning

- Take measurements in soil mode every ~1' along a 5' core section.
- Run beams for a minimum of 30 seconds each.
- Avoid taking a reading directly on a lithologic contact.
- Avoid measurements on thin units, fat clays, or coarse gravel as these will not be representative of nourishment sand targets.
- Factors that attenuate the elemental signature:
    - Moisture content- avoid saturated cores where possible, let the split core surface dry before taking a measurement.
    - Plastic sheeting- avoid measuring through thick plastic core liners, use sub-mm plastic film which will protect the unit and allow free passage of x-rays to the detector.
- Look for visibly opaque grains or magnetic sand for heavy mineral sand sample targets.

Figure D3: In-situ core scanning guidelines. Green circles represent locations for pXRF measurements along 5-foot core. Red areas should be avoided for pXRF measurements and geochemical sampling as they are not representative of the dominant lithology, will not result in heavy mineral commodities, and/or are not sand-rich units targeted for beach nourishment material.

Table D3: Parameters for pXRF protocol for prepared samples of unconsolidated sediment and soil (i.e., ex-situ).

Instrument Calibration	Sample Collection	Sample Preparation	Sample Analysis	Interpretation and Validation of Results
1) Confirm list of elements included in the factory calibration from the manufacturer. 2) Calibrate unit via site specific or media specific material using certified analytical standards (if available and applicable to analytical needs). 3) Follow calibration instructions per unit. 4) Prepare blank standards or checks to routinely measure for possible contamination between runs and background elements. 5) Ensure the instrument aperture window is kept clean.	1) Representative subsample of target material. Minimum: 20 grams. 2) Sample interval should not exceed 5 feet of core length as this can dilute the final THM calculation. 3) Avoid sampling at the sediment-core liner contact as material can slump along the plastic. 4) Best to sample at a split core face that is devoid of organics, coarse gravel and/or shell material. 5) Avoid sampling clay-rich zones.	1) Use a 2-mm mesh sieve to remove all coarse particles. 2) Dry <2 mm fraction in annealing oven. 3) Homogenize <2 mm fraction. 4) Split using a sediment splitter. 5) Prepare sample cups with protective film (i.e., 4 µm thick Prolene)[1]. 6) Scoop material into sample cup to the appropriate volume. Ensure that the sample thickness is > 4 mm or meets the appropriate "infinite thickness"[2] requirements (up to 10 mm in some cases). 7) Add cotton ball and bottom lid to contain sample in puck.	1) Ideally, turn on analyzer to warm up 15-20 minutes prior to collecting data. 2) Conduct stainless steel check calibration. 3) Depending on the data needs, adjust run time per beam to account for reduced error (recommend 30-60 seconds per beam). 4) Check for spectral interferences. 5) Collect at least three readings and average[3].	1) Confirm if potential spectral interferences mask results (i.e., lighter elements masked by heavier elements). 2) Consider reporting requirement needs and error thresholds. 3) If analytical data are available for the site, attempt appropriate validation and potential re-calibration of instrument.

[1] There are different brands of sample preparation cups with different sizes, volume capacities, and specifications.

[2] Infinite thickness refers to the necessary thickness of a given sample ensuring that x-rays do not penetrate deeper than the sample.

[3] Averaging sample readings will provide a more representative result in a heterogeneous sample; however, if time is limited and the goal is simple spot screening of a material that appears relatively homogenous, one sample reading may be appropriate.

Comparison to Laboratory Analyses

Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES) is an analytical laboratory technique that provides accurate quantitative elemental data by vaporizing and exciting samples in a high-temperature plasma and detecting the emitted light at specific wavelengths. It offers superior sensitivity and the ability to analyze a wide range of elements at low detection limits, making it ideal for detailed and precise elemental quantification. We utilized previously acquired ICP-OES geochemical data for sediment samples to compare with our pXRF measurements. The comparison focused on elements of interest for Ti, Zr, U, Th, and REE-bearing economic minerals found in the Sandbridge Shoal and Atlantic Channel areas. The purpose was to better understand the level of certainty with the pXRF measurements made on unknown samples. The variables that can affect the random uncertainties are water content, grain size and packing of the sediment, and low elemental concentrations that approach detection limits. Systematic errors related to instrument uncertainties are mainly caused by calibration methods.

To determine if ICP-OES and pXRF data correlate, we calculated a trendline between the ICP-OES and pXRF data (soil mode) for samples with both analyses and report R^2 for the linear trendline (Table D4, Figure D4). The correlation coefficient was calculated between the elements of interest. Overall, R^2 and the correlation coefficient agree and the ICP-OES and pXRF data are in good agreement. Zr has the strongest linear correlation between the datasets, followed by Ce, Th, La, and Ti with very strong linear correlations. Fe, U, and Y have correlation coefficients < 0.9, which indicates that while there might be a relationship between the variables, it is not strongly linear. It is important to note that a weak correlation does not indicate that the variables are unrelated; rather that they might not have a strong linear relationship which can result from spectral interferences in the pXRF measurements or variations in the processing techniques (acid-dissolution for ICP-OES vs. sediment pucks for pXRF). Based on these correlations, we feel confident in the magnitude of the pXRF results on unknown samples for the elements listed in Table D4.

Table D4: Linear correlation statistics for ICP-OES and pXRF for selected elements.

Element	Equation	R^2	Correlation Coefficient	Number of samples
Zr	y = 0.71x + 2233.21	0.94	0.97	28
Ti	y = 0.84x + 2537.27	0.85	0.92	28
Ce	y = 0.64x + 20.73	0.92	0.96	10
La	y = 0.69x + 57.95	0.88	0.94	10
Th	y = 0.53x + 7.40	0.91	0.96	26
Fe	y = 0.67x + 3916.61	0.76	0.87	27
Y	y = 0.31x + 3.40	0.76	0.87	22
U	y = 1.40x - 4.25	0.76	0.88	19

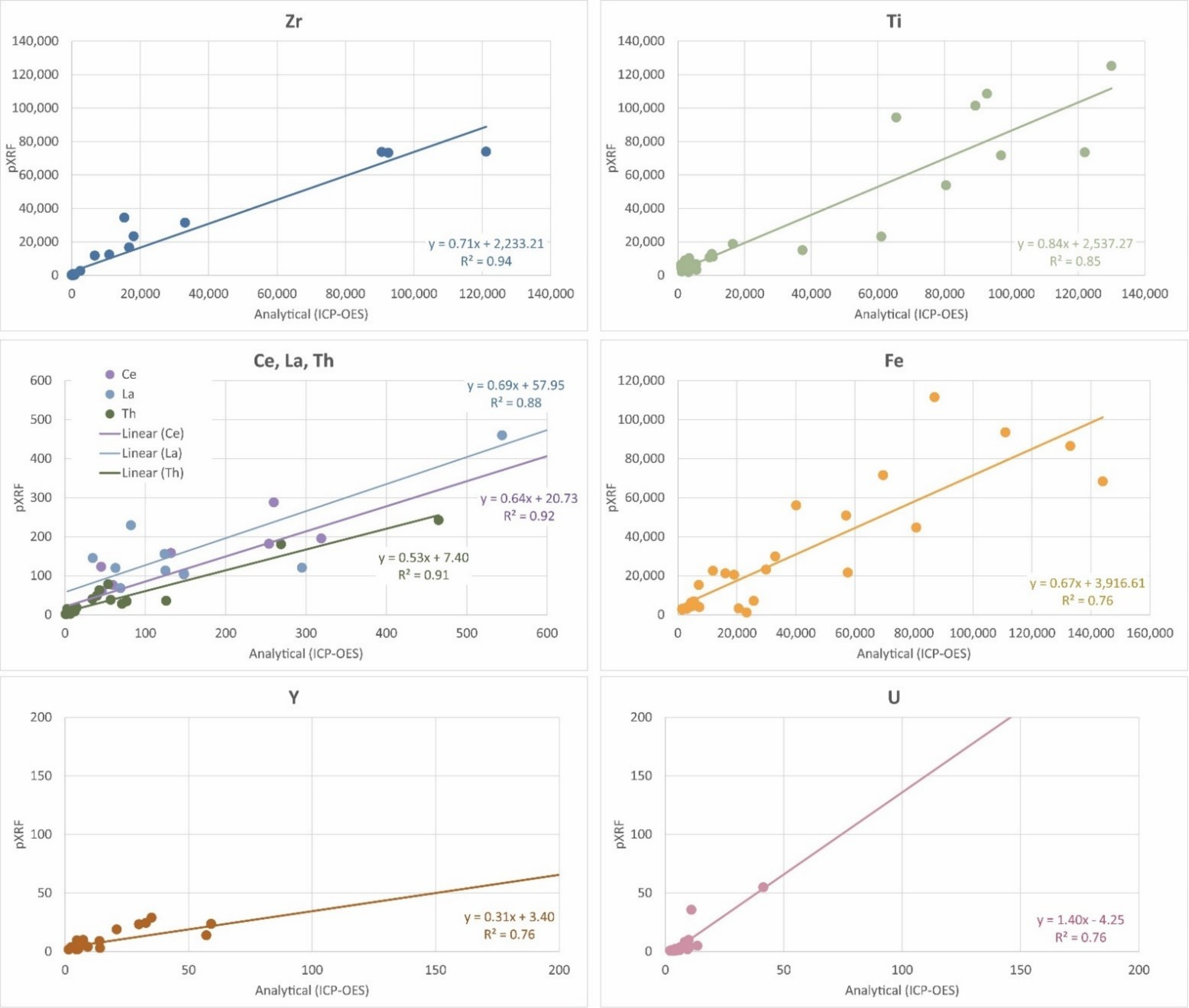


Figure D4: Comparison of ICP-OES analytical data (x-axis) to pXRF (soil mode) (y-axis). All data reported in ppm.

Using pXRF Elemental Data for Screening

Using pXRF screening data to identify the presence of heavy minerals in bulk sediment can reduce the need for additional processing and laboratory-based separation techniques. Table D5 provides the average concentration based on 2-4 measurements per sample for Fe, Th, Ti, U, Y, and Zr in onshore and offshore sediment samples, alongside the wt% THM. Elements with no concentration were not measurable above the lowest detection limit.

Table D5: Average (n=2-4 per sample) pXRF data (soil mode) for offshore and onshore sediment samples used to determine correlation coefficients for indicator elements and relative amount of total heavy minerals.

R-#	wt% THM	Fe (ppm)	Th (ppm)	Ti (ppm)	U (ppm)	Y (ppm)	Zr (ppm)
Onshore Sediment Samples:							
R-11945	1.05%	4319.33	3.20	10222.33	3.30	2.07	886.33
R-11947	0.58%	2578.33	1.75	3848.00	--	1.67	482.67
R-11948	0.23%	20452.50	12.00	11059.50	6.35	29.00	903.00
R-11949	0.13%	3101.00	1.43	6403.00	2.00	3.63	219.67
R-11953	5.54%	3337.67	--	3829.33	--	1.60	514.00
R-11955	1.52%	4273.00	2.00	5836.50	--	1.85	762.00
R-11956	0.48%	6834.33	15.00	7911.00	3.97	9.70	852.67
R-11958	0.92%	47632.00	13.00	8638.00	11.30	17.50	731.50
R-11960	1.22%	28923.00	10.73	10630.33	6.73	14.00	1642.33
R-11961	1.36%	7404.33	5.30	9663.00	4.10	10.03	1718.00
R-11962	3.33%	11168.67	3.47	9145.67	--	--	11340.67
R-11964	0.81%	4759.00	7.00	6767.00	3.10	15.33	1184.00
R-11965	3.22%	20729.67	5.97	23625.00	--	3.73	4133.67
R-11968	9.67%	71055.00	20.00	32414.00	--	4.20	10665.67
R-11969	12.93%	28128.33	12.20	22762.67	--	4.40	7754.67
R-11970	4.93%	7019.33	4.57	24531.67	--	--	11870.67
R-11971	9.47%	625.33	2.00	265.00	2.90	1.50	31.67
R-12147	0.09%	26298.00	8.37	5275.67	5.10	5.67	340.67
R-12149	0.79%	101481.00	5.30	6717.00	10.03	14.00	273.00
Offshore Sediment Samples:							
R-12221	0.60%	2168.33	1.45	2348.33	39.00	1.67	126.33
R-12222	1.90%	9918.33	3.80	8203.67	30.65	6.13	1013.00
R-12223	0.40%	5738.00	6.07	2715.33	41.00	3.60	221.00
R-12224	0.70%	6056.33	4.53	2735.67	20.83	4.90	269.67
R-12225	1.00%	4230.33	3.33	1836.33	24.20	6.43	304.33
R-12226	0.60%	2874.67	2.80	1484.00	34.00	2.57	284.67
R-12227	0.90%	10683.67	3.43	3544.00	32.20	5.50	513.00

R-#	wt% THM	Fe (ppm)	Th (ppm)	Ti (ppm)	U (ppm)	Y (ppm)	Zr (ppm)
R-12228	1.00%	4065.50	1.95	1554.00	18.45	3.13	303.75
R-12231	0.60%	4824.67	3.40	2674.67	46.00	3.10	340.33
R-12232	1.20%	5524.67	2.05	2502.33	24.75	3.67	225.33
R-12233	0.70%	8593.00	2.90	6979.00	38.00	3.40	201.50
R-12234	1.20%	4865.67	2.30	1230.67	32.50	2.93	181.67
R-12236	0.60%	5108.00	2.60	1747.33	27.65	2.97	127.67
R-12245	0.80%	5187.25	2.80	6354.50	15.55	3.18	699.00
R-12246	0.80%	9141.00	5.87	2277.33	53.30	11.40	466.67
R-12318	0.60%	8145.33	2.27	6574.00	23.75	3.23	240.67
R-12319	1.40%	10746.67	4.30	2267.67	32.87	8.93	322.33
R-12321	1.10%	5316.33	2.60	2394.33	22.90	4.20	333.33
R-12325	0.70%	7273.67	2.90	1297.33	39.60	7.77	233.00
R-12334	0.70%	6281.00	4.20	1301.00	26.73	5.73	318.67

Note: “--” indicates element not detected in analysis above detection limit.

We compared the pXRF data with wt% total heavy mineral (THM) by calculating correlation coefficients. The correlation coefficient quantifies the strength and direction of the relationship between two variables (e.g., elemental concentration from pXRF and wt% THM). The most common correlation coefficient is the Pearson correlation coefficient (CORREL in Excel) which ranges from -1 to 1, where:

- 1 indicates a perfect positive correlation: as one variable increases, the other also increases proportionally.
- -1 indicates a perfect negative correlation: as one variable increases, the other decreases proportionally.
- 0 indicates no correlation between the variables.

Performing a correlation analysis aids in decision-making, identifying patterns, and predicting outcomes based on the data. Correlation does not imply causation; a strong correlation between variables does not necessarily mean that changes in one variable cause changes in the other. A strong correlation between certain elements and wt% THM can be used to guide further sampling for mineralogy or analytical geochemistry depending on the needs of the project.

The correlation coefficient for comparing wt% THM from heavy liquid separation to pXRF data (soil mode) is 0.54-0.59 (Table D6), which suggests that the elemental concentration of Zr in bulk samples has a moderately strong linear correlation with wt% THM, for both offshore and onshore sediment samples. Fe has a weak to moderate correlation to wt% THM for offshore samples with a correlation coefficient of 0.40, while Y and Ti have correlation coefficients of 0.31 and 0.26. There appears to be no correlation between Th and U with wt% THM for offshore samples (Table D6). Ti has a moderate correlation coefficient with wt% THM for onshore samples at 0.50, while Th, Fe, Y and U have weak to very weak correlation with wt% THM. We infer that Zr can be a key indicator for higher wt% THM in both offshore and onshore sediment samples, while Fe is the next preferable element for offshore samples and Ti for onshore samples. Increasing concentrations of Zr, Fe (offshore) and Ti (onshore) may represent increased wt% THM and associated economic heavy minerals in bulk sediment samples with unknown chemistry and mineralogy.

Table D6: Correlation coefficient variables for selected elements and percent total heavy minerals for offshore and onshore sediment samples.

Ratio of element to percent total heavy minerals	**Correlation coefficient- offshore samples**	**Correlation coefficient - onshore samples**
Zr / wt% THM	0.59	0.54
Fe / wt% THM	0.40	0.10
Y / wt% THM	0.31	-0.39
Ti / wt% THM	0.26	0.50
Th / wt% THM	-0.08	0.27
U / wt% THM	-0.23	-0.24

A correlation diagram for elements derived from pXRF analyses showcases the relationships and associations between different elemental concentrations within the offshore samples. Table D7 illustrates the strength and direction of correlations between various elements measured using the pXRF. A strong positive correlation (> 0.9) between two elements implies that their concentrations tend to increase or decrease together, while a negative correlation suggests an inverse relationship where one element's concentration increases while the other decreases. Elements strongly correlated to Fe are Mn, Mo, Nb, Nd, Th, Ti, Zn. Elements strongly correlated to Ti are Fe, Mn, Mo, Nb, Nd, Zn. Mo is strongly correlated to Zr, and Nd is strongly inversely correlated to Zr. Zr is moderately correlated to Ti and Fe (0.7). Given that Ti and Fe have a strong elemental association with one another, and a moderate association with Zr, these three elements are considered good indicator elements for identifying the presence of heavy minerals in offshore sediments.

Table D7: Offshore sample correlation matrix for elemental concentrations determined through pXRF measurements (soil mode). Green cells indicate strong positive correlation between elements (increase or decrease together), while yellow cells indicate strong negative correlation (inverse relationship) between elements. All red cells are below the strong correlation thresholds.

	Ag	*As*	*Ba*	*Ca*	*Ce*	*Cr*	*Cu*	*Fe*	*Ga*	*K*	*La*	*Mn*	*Mo*	*Nb*	*Nd*	*Ni*	*P*	*Pb*	*Rb*	*S*	*Sc*	*Sn*	*Sr*	*Th*	*Ti*	*Tl*	*U*	*V*	*Y*	*Zn*	*Zr*
Ag	1.0																														
As	0.8	1.0																													
Ba		-0.4	1.0																												
Ca	-0.3	-0.4	0.3	1.0																											
Ce	0.4	0.2	-0.2	-0.4	1.0																										
Cr	0.0	0.3	-0.1	-0.2	0.4	1.0																									
Cu	0.4	0.3	-0.5	-0.5	0.9	0.6	1.0																								
Fe	0.5	0.7	-0.2	-0.3	0.6	0.5	0.8	1.0																							
Ga	0.6	0.4	-0.4	-0.4	0.8	0.7	1.0	0.8	1.0																						
K	-0.4	-0.2	0.5	0.4	0.3	-0.3	-0.3	-0.1	-0.1	1.0																					
La	0.5	0.7	0.0	-0.3	0.7	-0.2	0.4	0.7	0.4	0.3	1.0																				
Mn	0.8	0.5	-0.3	-0.4	0.6	0.6	0.9	0.9	0.9	-0.1	0.3	1.0																			
Mo			-0.3	-1.0		0.6	1.0	1.0	1.0	-0.4		1.0	1.0																		
Nb	0.8	0.5	-0.3	-0.4	0.4	0.4	0.8	0.9	0.8	-0.1	0.4	1.0	1.0	1.0																	
Nd		1.0		-1.0	1.0	-1.0	-1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0																
Ni	0.5	0.5	-0.4	-0.5	0.8	0.7	1.0	0.8	1.0	-0.3	0.4	0.9	1.0	0.7	-1.0	1.0															
P	0.8	0.5	0.0	-0.2	0.2	-0.1	0.2	0.7	0.4	0.2	0.5	0.7		0.8	1.0	0.3	1.0														
Pb	0.1	0.6	0.2	-0.2	-0.1	0.3	0.3	0.7	0.5	0.0	0.5	0.5	1.0	0.6	1.0	0.5	0.5	1.0													
Rb	-0.5	0.2	0.6	0.4	-0.5	-0.2	-0.5	-0.1	-0.3	0.3	-0.1	-0.4	-0.3	-0.3	1.0	-0.4	0.0	0.4	1.0												
S	0.7	0.0	0.3	0.1	0.6	0.1	-0.1	0.0	0.0	0.3	0.5	0.0	-0.7	-0.1	1.0	0.0	0.2	0.0	0.1	1.0											
Sc	-0.2	-0.4	-0.2	-0.3	0.3	0.7	0.6	0.3	0.6	-0.2	-0.2	0.3		0.1	-1.0	0.6	-0.3	0.0	-0.2	0.4	1.0										
Sn	0.3	0.4		0.1	-0.4	-0.4	-0.2	-0.2	0.1	-0.1	-0.6	0.7		0.7		-0.2	0.2	-0.3	0.7	-0.2	-0.2	1.0									
Sr	-0.8	-0.1	0.3	0.0	-0.2	0.4	0.4	0.4	0.4	-0.1	-0.4	0.4	1.0	0.3	-1.0	0.5	0.0	0.5	0.3	-0.1	0.7	-0.1	1.0								
Th	0.5	0.6	-0.3	-0.4	0.8	0.6	0.9	0.9	0.9	-0.1	0.8	0.9	1.0	0.8	1.0	0.9	0.6	0.6	-0.2	0.0	0.5	-0.6	0.4	1.0							
Ti	0.8	0.4	-0.3	-0.4	0.5	0.5	0.8	0.9	0.8	0.0	0.4	1.0	0.9	0.9	1.0	0.8	0.7	0.5	-0.3	0.0	0.3	-0.6	0.3	0.9	1.0						
Tl	0.7	0.7	0.0	0.0	0.3	0.6	0.4	0.6	0.6	-0.1	0.4	0.5		0.4	1.0	0.6	0.2	0.6	0.3	0.4	0.4	0.2	0.4	0.7	0.4	1.0					
U	0.0	0.5	-0.4	-0.2	-0.2	0.3	0.2	0.1	0.2	-0.6	-0.1	0.0	0.2	-0.1	-1.0	0.3	-0.4	0.2	0.2	-0.2	0.3	-0.4	0.2	0.2	-0.1	0.6	1.0				
V	0.1	0.2	-0.4	-0.4	0.5	0.7	0.9	0.7	0.9	-0.3	-0.1	0.8	1.0	0.6	-1.0	0.9	0.0	0.4	-0.3	0.0	0.8	0.1	0.5	0.8	0.7	0.6	0.4	1.0			
Y	0.6	0.5	-0.1	-0.3	0.7	0.5	0.8	0.9	0.8	-0.1	0.8	0.8	0.8	0.8	1.0	0.8	0.7	0.5	-0.2	0.0	0.3	-0.5	0.3	0.9	0.8	0.4	0.0	0.6	1.0		
Zn	0.8	0.7	-0.2	-0.4	0.5	0.5	0.8	1.0	0.8	-0.1	0.5	1.0	1.0	1.0	1.0	0.8	0.8	0.6	-0.1	0.0	0.2	0.7	0.4	0.8	0.9	0.5	0.1	0.6	0.8	1.0	
Zr	-0.6	-0.1	-0.2	-0.4	0.1	0.6	0.6	0.7	0.6	-0.1	-0.2	0.6	1.0	0.5	-1.0	0.6	0.2	0.4	-0.3	-0.1	0.5	-0.4	0.5	0.6	0.7	0.2	0.0	0.6	0.5	0.5	1.0

Appendix D from Nelson, M.S., Hawkins, D.W., and Lassetter, W.L., 2024, A capacity assessment on the recovery of critical and economic minerals from sand used for coastal resilience projects: Virginia Department of Energy, Geology and Mineral Resources Program, Open-file report 2024-16.

Ratios

We hypothesize that deposits with higher THM should have less silica content when compared to quartz-rich bulk sand. To assess the relationship between ratios of Si to Ti and Zr, we plotted multiple pXRF measurements for individual onshore and offshore samples against wt% THM (Figures D5, D6). The range of measured heavy mineral ore and heavy mineral concentrate samples from known minable deposits were compared to these results. The ratio of Si/Ti in mining mode versus the wt% THM was compared for onshore and offshore samples. The shaded box represents the ratio range of select ore-derived samples that were also measured in mining mode. Based on the observed clustering of results, it appears that ratios lower than 10 indicate wt% THM grades in the 10% range, while a general increase in wt% THM is observed with a lower Si/Ti ratio for onshore samples. Offshore samples display more variability with a ratio range between 20-240.

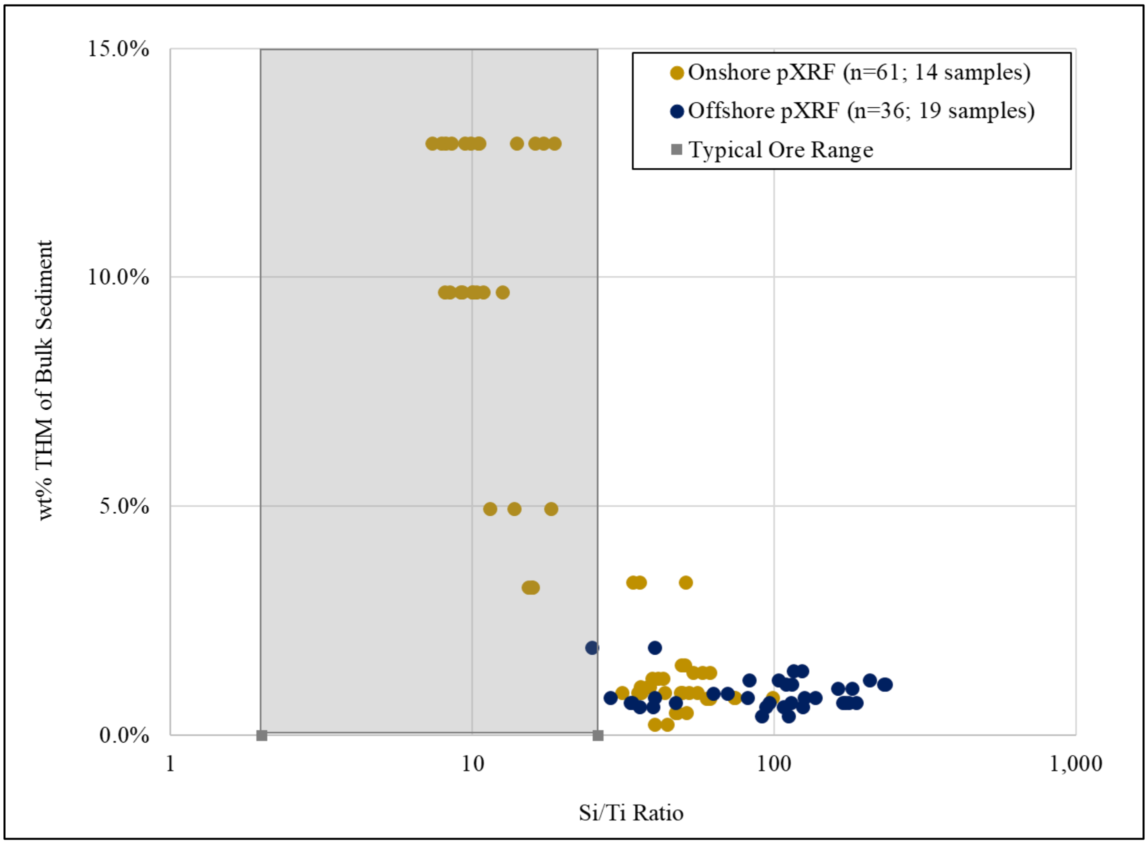


Figure D5: Comparison of Si/Ti ratio (from pXRF mining mode) to wt% THM for bulk sediments. Yellow circles are pXRF data for onshore sediment samples and blue circles are offshore sediment samples. Number of measures (n) is higher than the number of samples for pXRF data due to multiple measurements per sample. The shaded box represents the range in ratios for ore-grade HM material.

Correlation data show that Zr is an important indicator element for heavy mineral sands. Figure D6A displays the ratio of Si/Zr in mining mode versus the wt% THM for onshore and offshore samples, and Figure D6B shows the relationship between Si/Zr and wt% zircon in the bulk material. Figures D6A-B show an increase in %THM and % zircon as ratios of Si/Zr decrease. Notably, it appears that onshore samples are enriched in THM and zircon at ratios less than 10.

The ratio between Ti/Zr in soil mode may be a potential indicator for THM due to the general codependency of these two indicator elements; however, there is more scattering of the data especially in the lower grade threshold (~1% THM) (Figure D7). Generally, the ratios between Si/Zr correlate in a similar manner to %THM and zircon, and Ti/Zr correlate to %THM and ilmenite in similar manner. This implies that these comparisons may be positive initial indicators of those mineral fractions when compared to %THM.

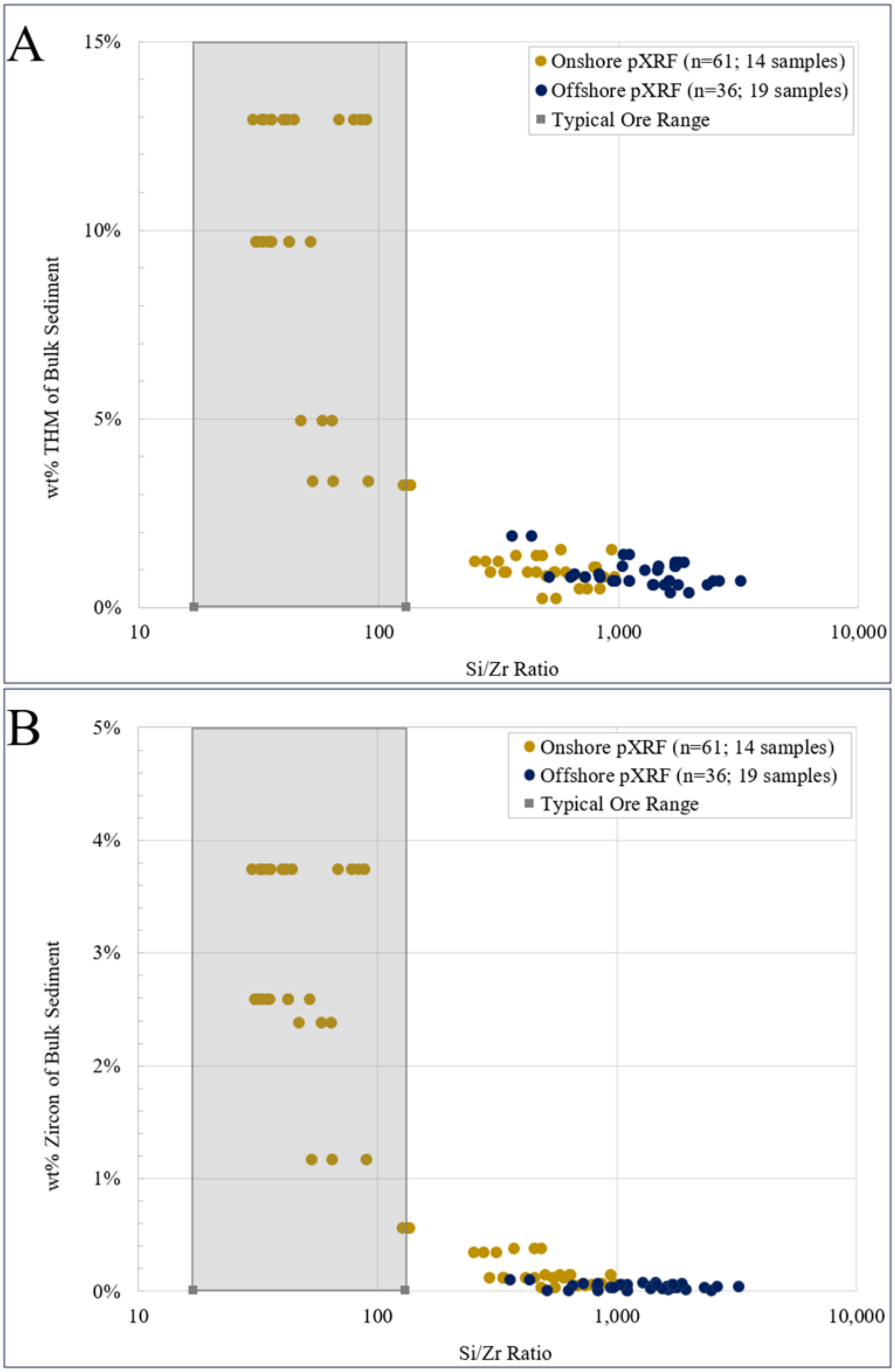


Figure D6: A) Comparison of Si/Zr ratio (from pXRF mining mode) to wt% THM for bulk sediments. B) Comparison of Si/Zr ratio (from pXRF mining mode) to wt% zircon for bulk sediments. Yellow circles are pXRF data for onshore sediment samples, blue circles are offshore sediment samples. Number of measures (n) is higher than the number of samples for pXRF data due to multiple measurements per sample. The shaded box represents the range in ratios for ore-grade HM material.

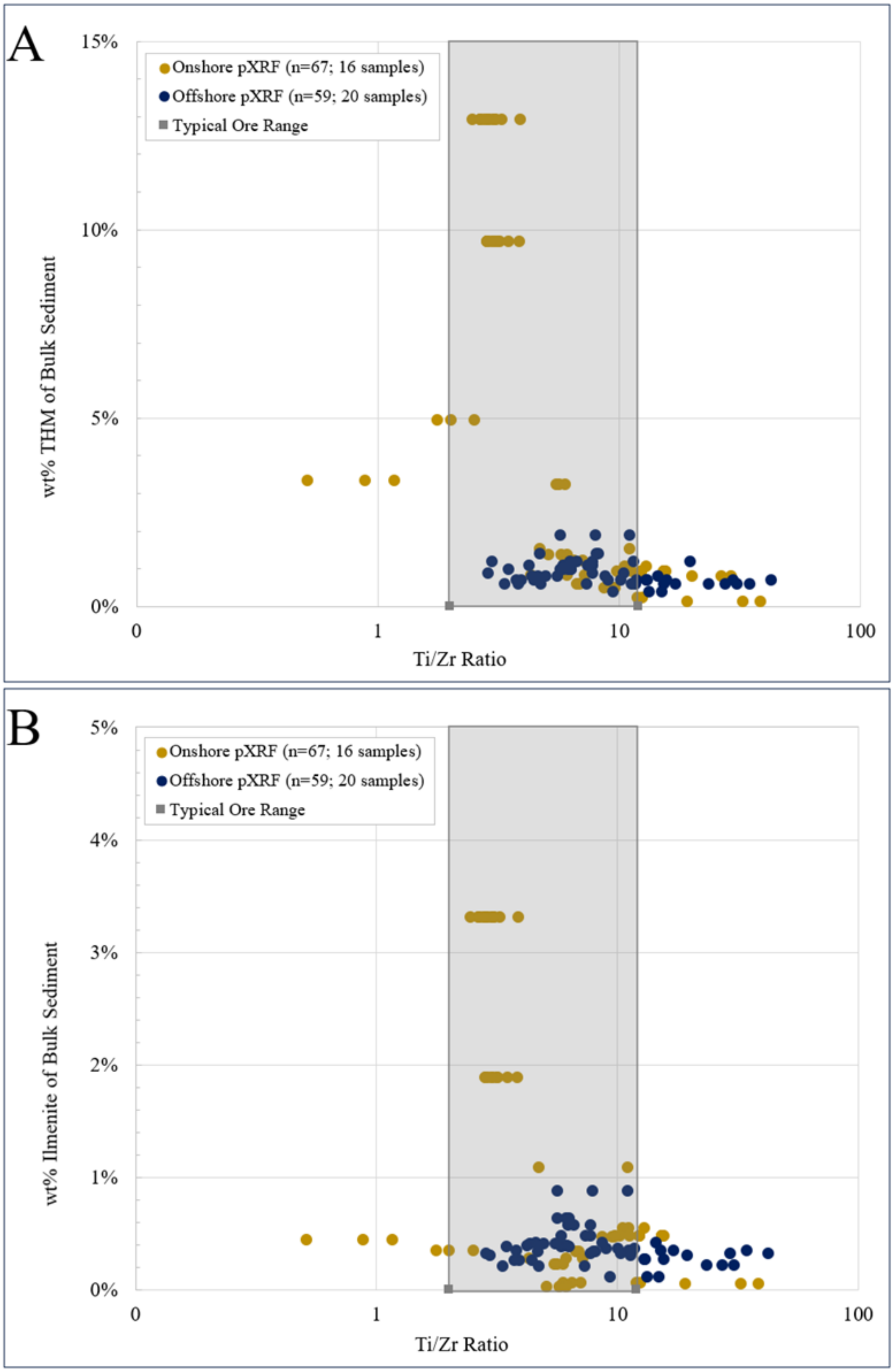


Figure D7: A) Comparison of Ti/Zr ratio in soil mode to wt% THM for bulk sediments. B) Comparison of Ti/Zr ratio in soil mode to wt% ilmenite for bulk sediments. Yellow circles are pXRF data for onshore sediment samples, blue circles are offshore sediment samples. Number of measures (n) is higher than the number of samples for pXRF data due to multiple measurements per sample. The shaded box represents the range in ratios for ore-grade HM material.

Appendix D from Nelson, M.S., Hawkins, D.W., and Lassetter, W.L., 2024, A capacity assessment on the recovery of critical and economic minerals from sand used for coastal resilience projects: Virginia Department of Energy, Geology and Mineral Resources Program, Open-file report 2024-16.

Moisture Content

Moisture content and elemental attenuation is extensively documented in the literature (e.g., Walser et al. 2022; USEPA 2007) with 20% being the recommended upper limit before signal reduction and other interference concerns affect data quality. We evaluated different moisture scenarios (i.e., 0%, 5%, 10%, 20%) on prepared sediment samples and between in-situ and ex-situ samples from core. High moisture content can attenuate trace elements, but also lead to over-exaggeration of lighter major elements (Figure D8). However, when moisture reaches upwards of 20% or more, attenuation of major and minor trace elements is common (Figure D9). Additionally, wetter sample material tends to yield lower concentration values for target elements, and it is recommended that core samples be as dry as possible before pXRF measurements are made. Sediments from in-situ screening of cores will generally have more moisture content than prepared pucks (ex-situ). The measured differences from a core collected from an onshore heavy mineral deposit are seen on Figures D10 and D11, with Ti being overly underestimated in undried material and Zr displaying greater variability.

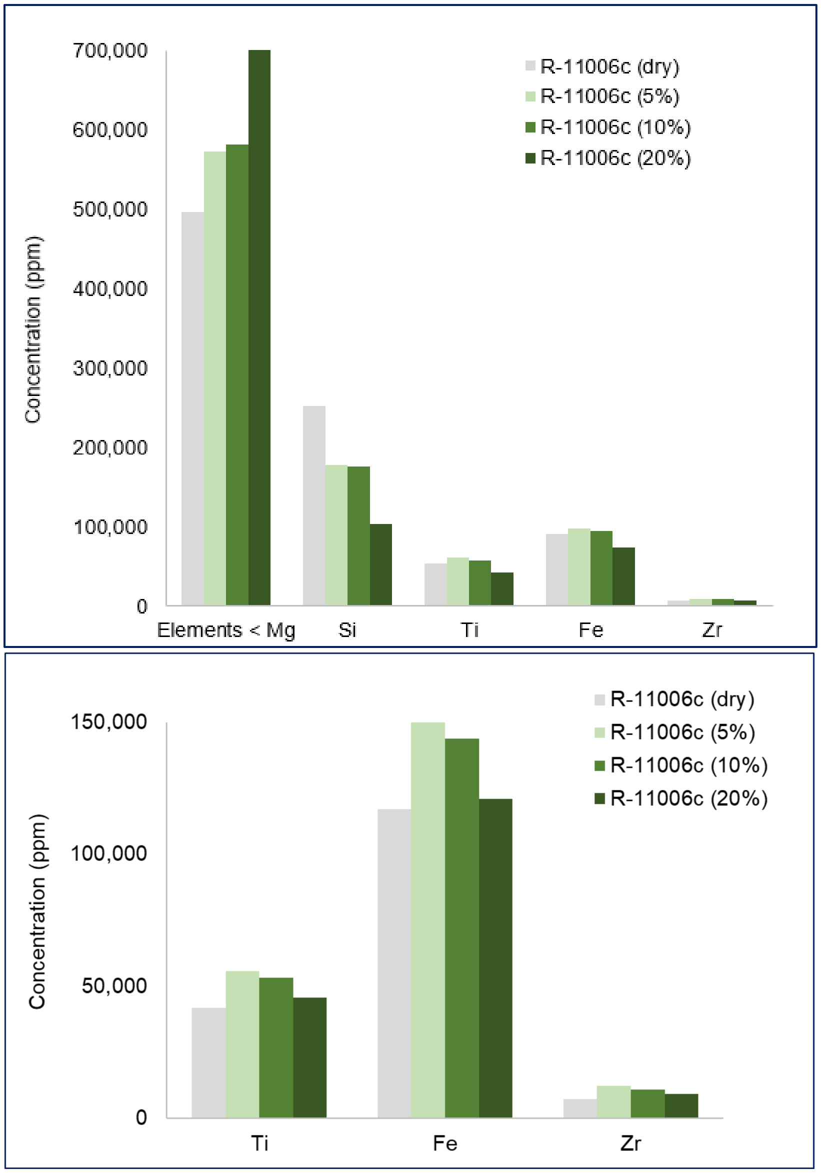


Figure D8: Concentration of major elements showing variability with moisture content (0%, 5%, 10%, 15%, 20%) in mining mode. Data is average of 3 measurements at each moisture content step for select sample.

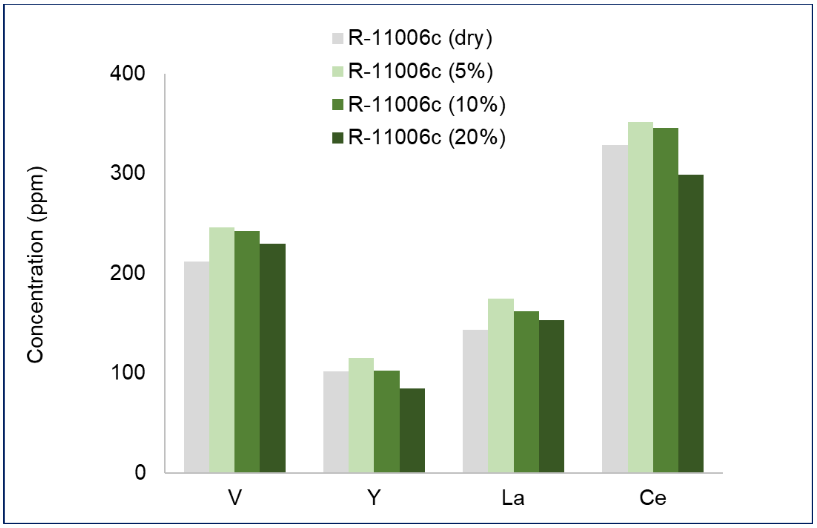


Figure D9: Concentration of trace elements V, Y, La, Ce showing variability with moisture content (0%, 5%, 10%, 15%, 20%) in soil mode. Data is average of 3 measurements at each moisture content step for select sample.

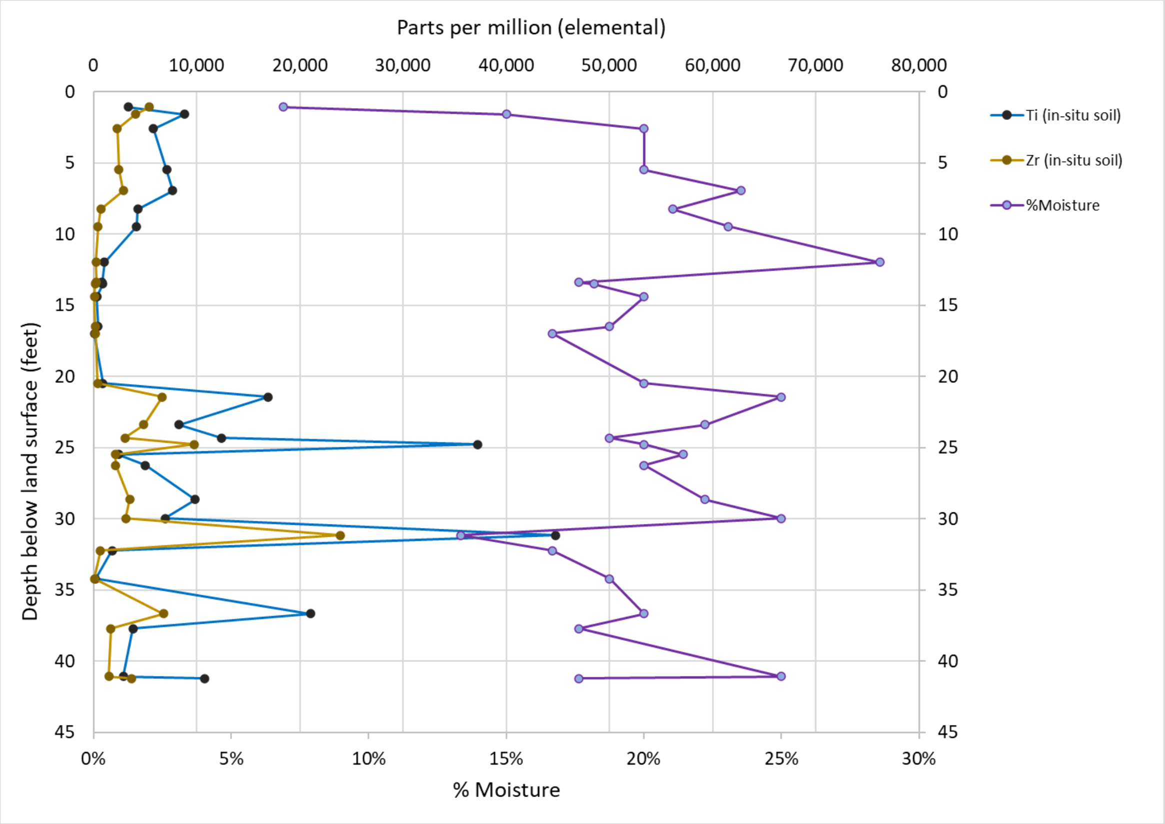


Figure D10: Example of moisture content variation downcore in an onshore ore deposit, with titanium and zirconium concentrations. Core was scanned in-situ with one layer of food-grade plastic wrap to protect the pXRF analyzer window. Heavy mineral sand zone is 20-32 feet below land surface.

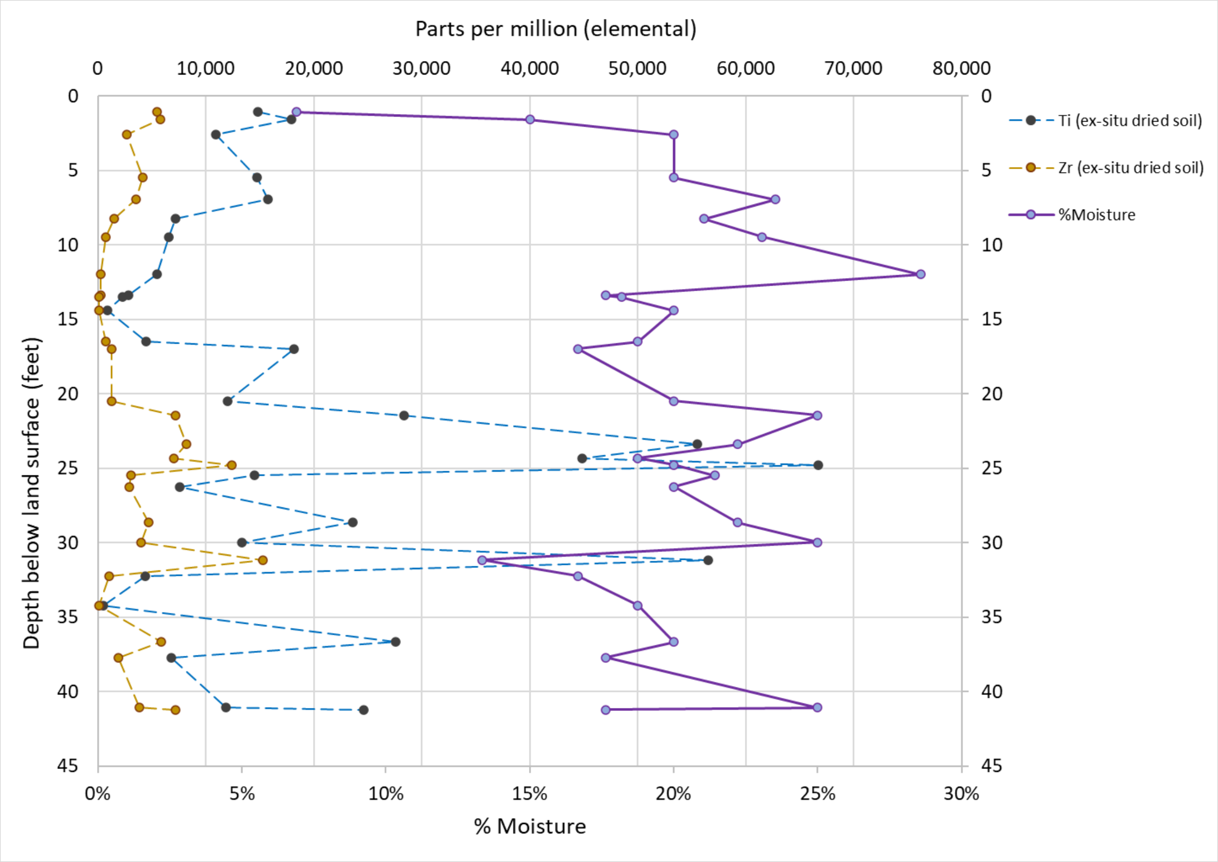


Figure D11: Example of moisture content variation downcore in an onshore ore deposit, with titanium and zirconium concentrations. Samples were homogenized, dried and prepped in sample cups in the laboratory (ex-situ). Heavy mineral sand zone is 20-32 feet below land surface.

Relative Standard Error

Relative standard error on measurements from the pXRF is generally inversely correlated with elemental concentration (ppm). Lower concentrations of elements that may be close to the range of the equipment detection capabilities have higher RSE (Figure D12). The majority of samples in this dataset are over 500 ppm for Ti and over 1,000 ppm for Fe, with RSE less than 3%.

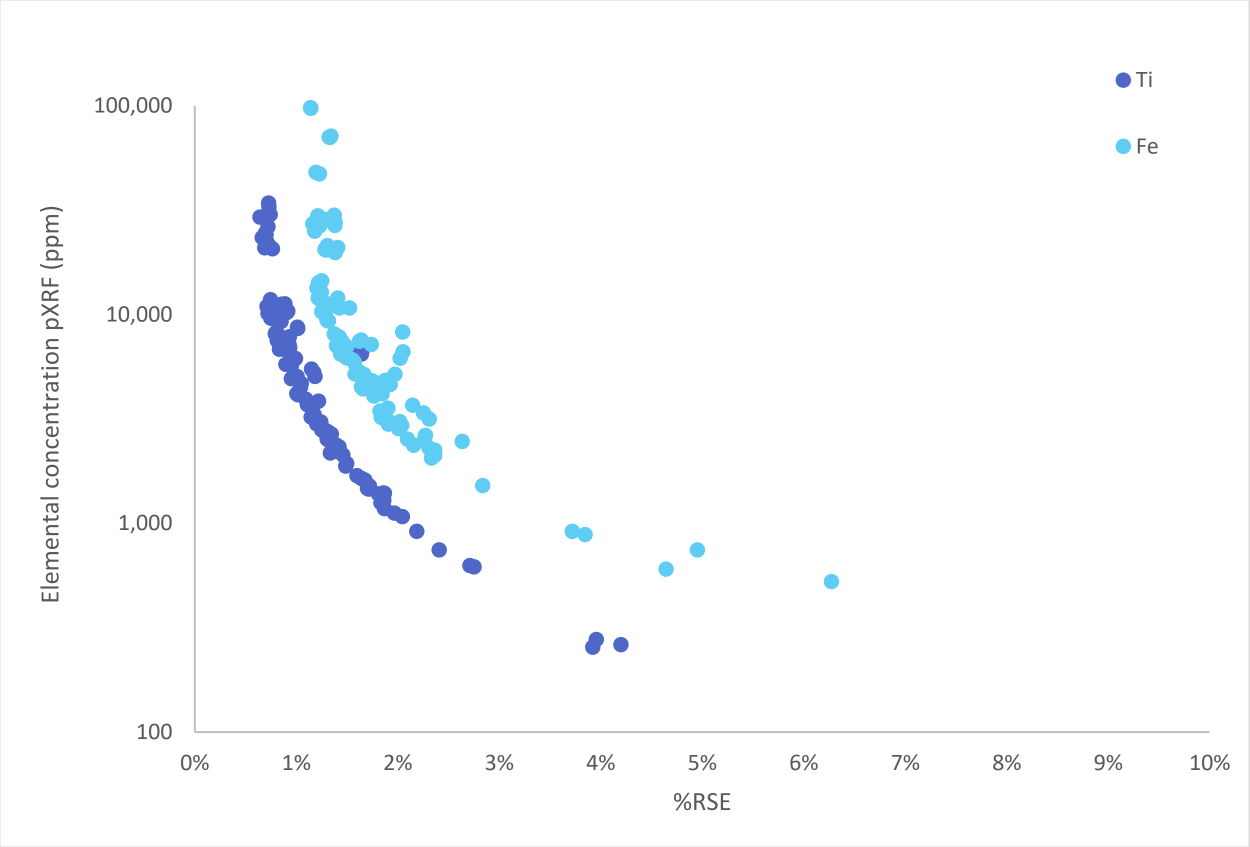


Figure D12: Elemental concentration in ppm from pXRF analyses (soil mode) for Ti (dark blue) and Fe (light blue) from non-concentrate, bulk samples. Total number of measurements is 113 (2-3 per sample), 54 measurements total from onshore paleo-marine, estuarine sediments, and stream sediments, and 59 total from offshore samples in this study.

Geochemical Trends

Ternary diagrams are used to present relative concentrations of specific elements or minerals for a given sample, where the apices are end members. In the case of heavy mineral sand ternary diagrams, Si, Ti, and Fe are indicators of quartz-rich sand (Si), ilmenite, leucoxene, (Fe, Ti), rutile (Ti), and other Fe-oxides associated with heavy mineral sands. We present a ternary diagram (Figure D13) for a variety of sand samples: spiral-concentrated offshore marine sands from cores in the BOEM lease area, bulk material from cores within the lease area, heavy mineral concentrates (HMC) and heavy mineral sand (HMS) from onshore minable deposits, individual heavy mineral concentrates (e.g., ilmenite, leucoxene, rutile), and ore. The non-concentrated marine sediment (BOEM bulk) is dominated by Si when compared to Ti and Fe concentrations, due to the high quartz content. Spiral-concentrated marine sediment (BOEM concentrates) shows a decrease in Si and relative increase in Ti and Fe, given that light-density mineral sands were gravity separated from heavy-density sands, this was expected. HMC and HMS samples show an even greater relative increase in Ti and Fe compared to Si, while the ore material is more variable with respect to Si/Ti/Fe. This is likely due to the limited ore material and inhomogeneity of sample preparation. Individual mineral concentrates separated for ilmenite and leucoxene show a cluster of data points between 50-70% Ti, 25-45% Fe and the remaining <10% is Si. The rutile concentrate samples are distinguished from the other Ti-bearing minerals in that they have little to no Fe (<10%) (Figure D13). The ternary method using pXRF mining mode data is a quick reference tool that can be used to show the potential accumulation of heavy mineral sands (i.e., < 90% Si), and how closely the point is to the Fe apex can help distinguish rutile from ilmenite in the presence of Ti (> 50%).

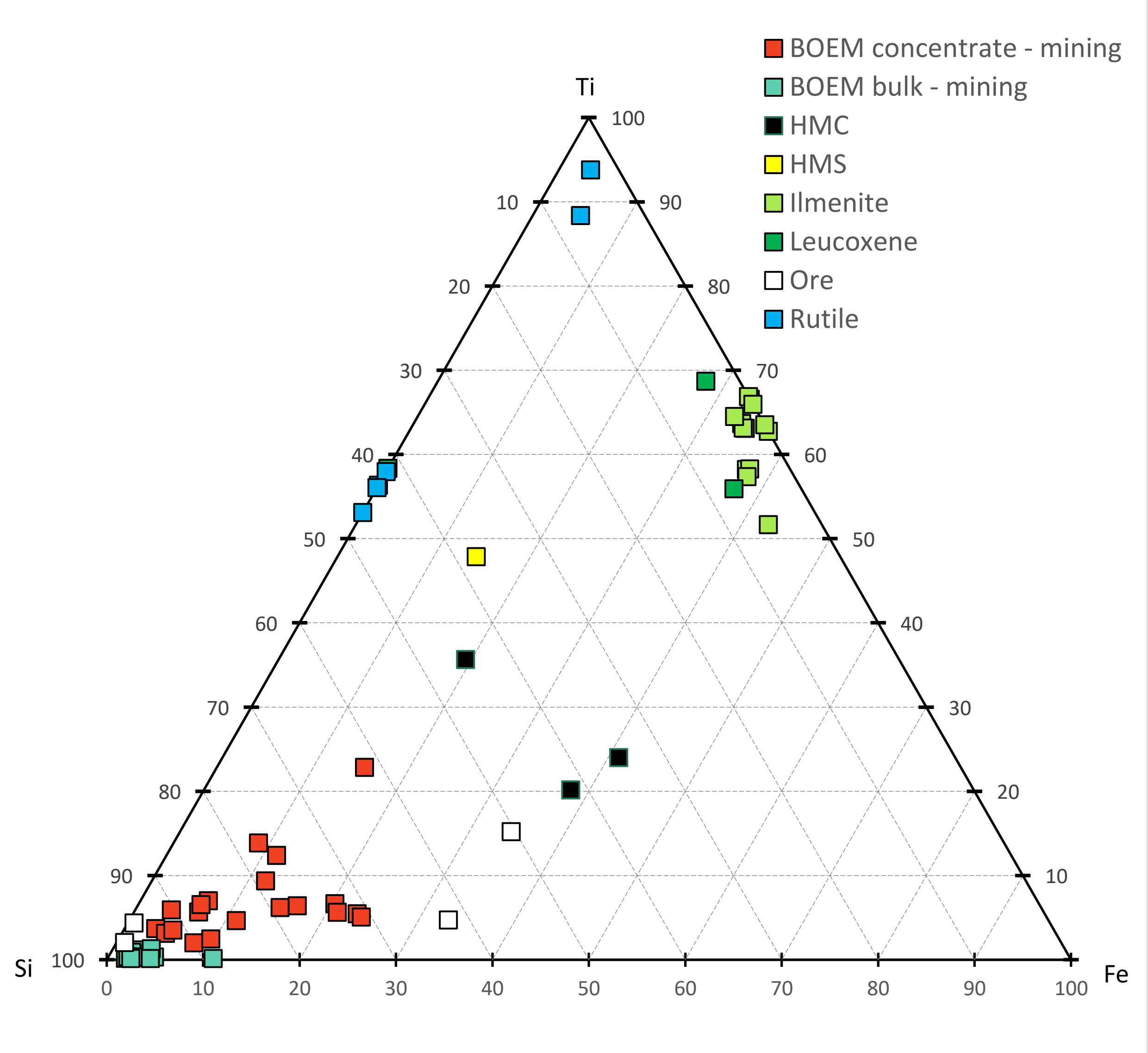


Figure D13. Mining mode from pXRF for Ti, Fe, Si. Ternary diagram is normalized to the sum of the % concentration determined through pXRF analyses for 3 elements. Heavy mineral concentrate (HMC), heavy mineral sand (HMS).

Mineral Chemistry Summary

The data below shows major chemical constituents in economic heavy minerals as determined by SGS Canada Inc. using automated mineralogy Tescan Integrated Mineral Analyzer (TIMA) and Electron Probe Micro-Analyses (EPMA) techniques (Appendix C). This data shows elements of interest and supports our screening protocol by showing major elemental constituents for critical minerals in marine and paleo-marine sediment samples (Figures D14-16).

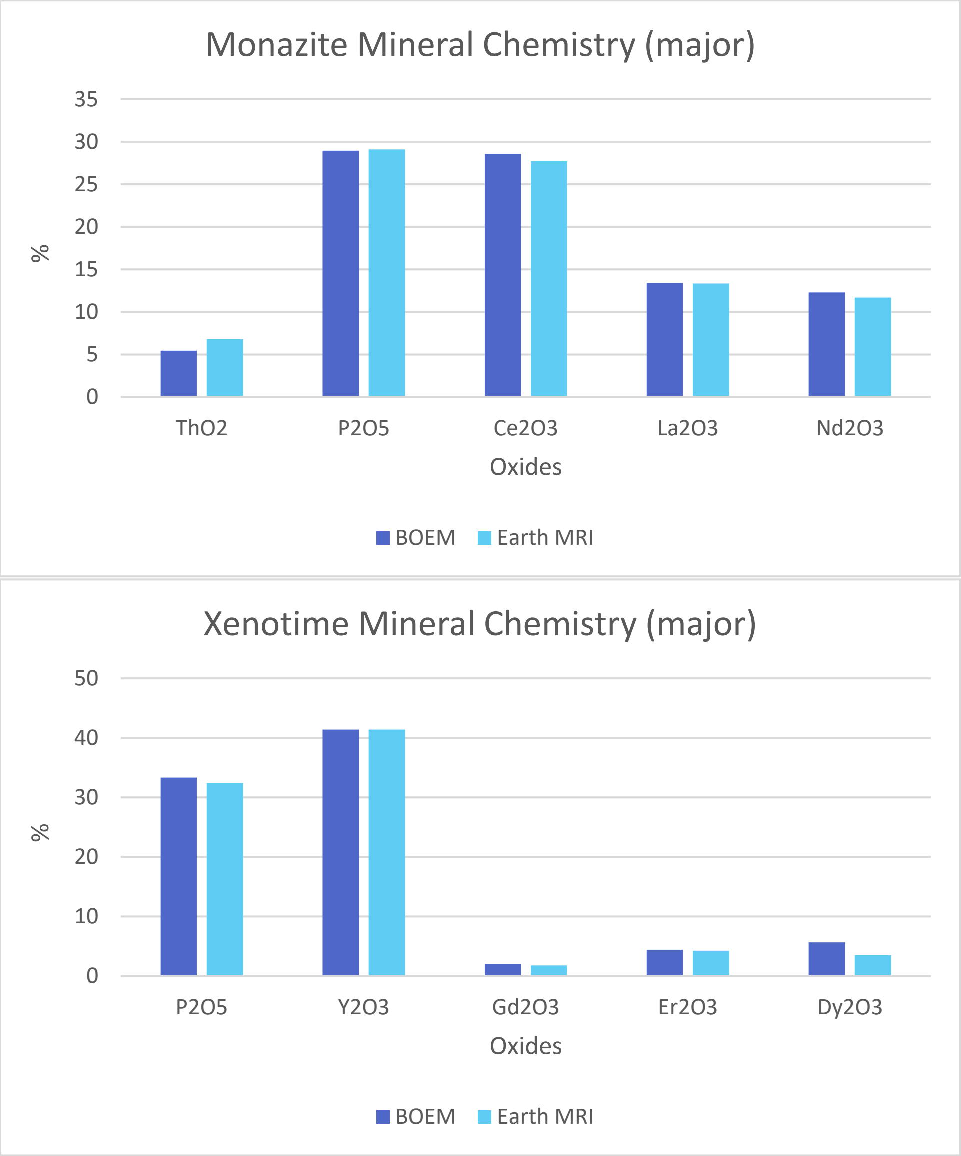


Figure D14: Comparison of REE-bearing heavy mineral samples from offshore (BOEM) and onshore (Earth MRI) heavy mineral samples processed and analyzed by SGS Canada Inc using EPMA. See Appendix SGS Final Report in Appendix C. Top: Major mineral chemistry determined from individual monazite sand grains. Monazite is dominated by P_2O_5, Ce_2O_3, with smaller concentrations of La_2O_3, Nd_2O_3, and ThO_2. Bottom: Major mineral chemistry determined from individual xenotime sand grains. Xenotime is dominated by P_2O_5 and Y_2O_3, with minor amounts of G_2dO_3, Er_2O_3, and Dy_2O_3.

Appendix D from Nelson, M.S., Hawkins, D.W., and Lassetter, W.L., 2024, A capacity assessment on the recovery of critical and economic minerals from sand used for coastal resilience projects: Virginia Department of Energy, Geology and Mineral Resources Program, Open-file report 2024-16.

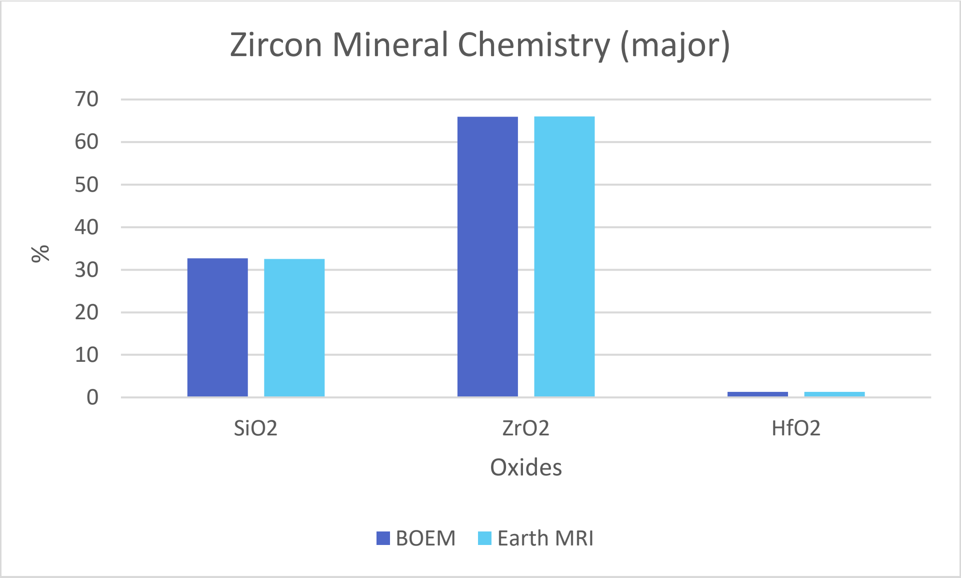


Figure D15: Comparison of zircon mineral chemistry from offshore (BOEM) and onshore (Earth MRI) heavy mineral samples processed and analyzed by SGS Canada Inc using EPMA. See Appendix SGS Final Report in Appendix C. Zircon is dominated by ZrO_2 and SiO_2 with trace HfO_2.

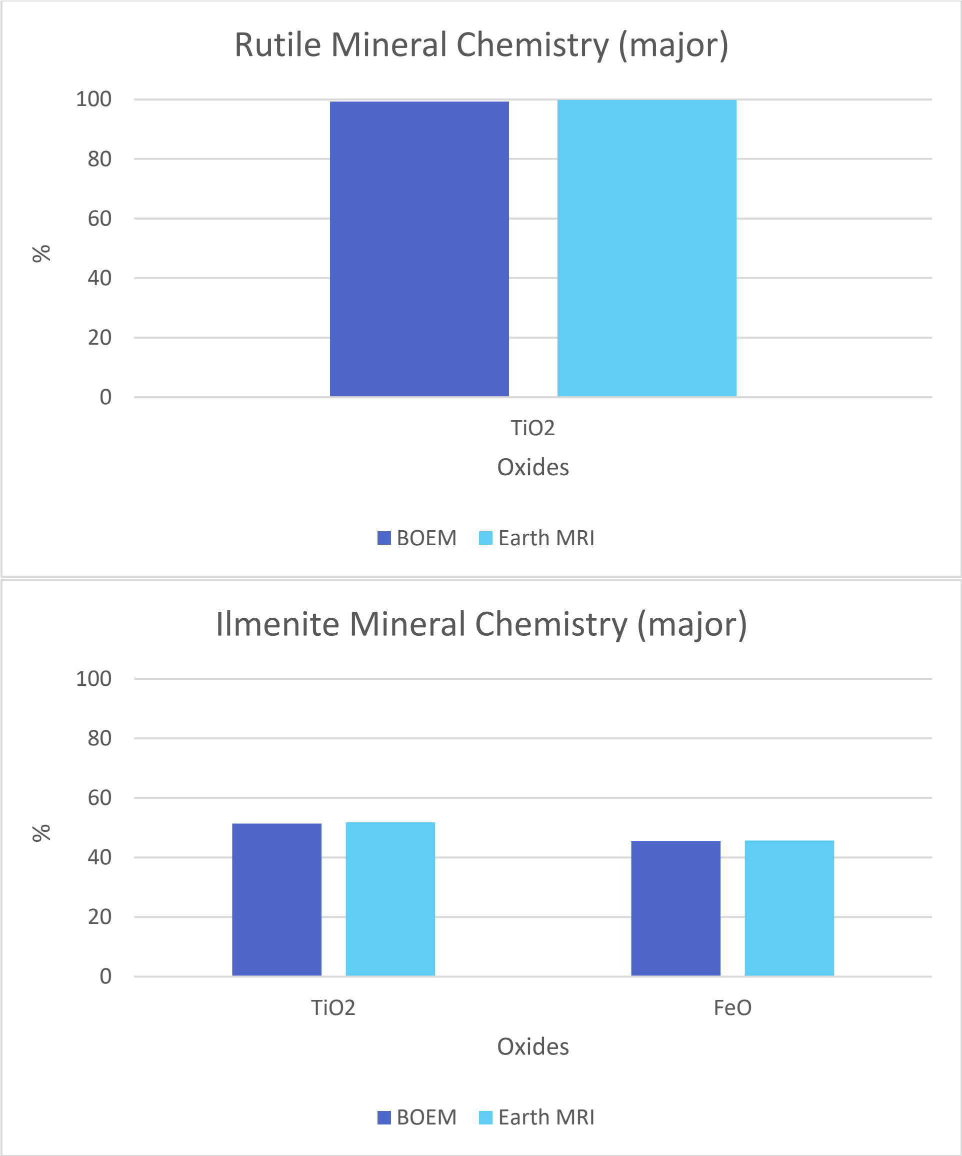


Figure D16: Comparison of Ti-bearing heavy mineral samples from offshore (BOEM) and onshore (Earth MRI) heavy mineral samples processed and analyzed by SGS Canada Inc using EPMA. See Appendix SGS Final Report in Appendix C. Top: Major mineral chemistry determined from individual rutile sand grains. Rutile is nearly 100% TiO_2 with a trace amount of NbO_2 (0.3-0.44%). Bottom: Major mineral chemistry determined from individual ilmenite sand grains, which averages 50% TiO_2 and 50% FeO.

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APPENDIX E

Pilot Study

Pilot Study Conceptual Scenarios

The extraction of heavy mineral sands from offshore sand resources during beach nourishment remains untested in the United States. There is also uncertainty regarding the longevity and transport rate of nourishment sand from the beach post-placement. A pilot study is necessary to address these two issues during a planned beach nourishment event, and this Appendix provides a hypothetical framework to test the viability of such an operation.

Physically separating a subset of heavy mineral sands from beach-quality sands as part of a pilot study requires a separation location (offshore/onshore or off-site), transportation to a processing facility, and processing. As part of the pilot study, the volume and value of recovered economic heavy mineral sands will be calculated, and changes to the visual appearance of processed sand (e.g., color, texture) can be evaluated. Regular monitoring and sampling allow nourishment sediment movement to be traced within the littoral zone. Additionally, innovative tracing mechanisms utilizing the natural luminescence signal within quartz sand grains, may offer a promising new approach to track nourishment material through time.

To conduct an experimental research plan primarily focusing on critical mineral co-extraction during beach re-nourishment, and secondarily on tracing nourishment sands, we propose two potential scenarios for a small-scale pilot study. The success of such a pilot study would serve as a proof of concept that could enable further collaboration between entities needing nourishment sands and heavy mineral sand processors seeking domestic sources of critical minerals.

Scenario 1: Evaluation of dredged material for economic heavy minerals as part of an active beach nourishment

The first scenario would involve separating and transporting a small percentage of dredged material directly to an onshore heavy mineral sand processing facility. The amount of material to be tested would be dependent on the cost (tonnage per mile), volume criteria needed to accurately analyze heavy mineral grade, and volume removal constraints per the lease agreement. This scenario would allow for a baseline assessment prior to nourishment, characterization of the dredged stockpiled material, and quarterly monitoring of the beach post-nourishment to examine the fate of material over a 1-to-2-year period.

Objectives

1. Calculate the grade and economic value of recovered heavy mineral sands from offshore sand resources.
2. Evaluate portable x-ray fluorescence (pXRF) field protocol proficiency to assess the presence and relative abundance (in ppm) of critical heavy minerals containing titanium (Ti), zirconium (Zr), rare earth elements (REEs), and thorium (Th) in the pre-spiraled bulk sediments and in the post-spiral concentrate. Submit a subset of samples for analytical analysis to corroborate the screening data.

Pilot Site Selection

The pilot site should be limited or restricted to the public to minimize disturbance post-placement. Once the site is selected, existing offshore mineral sand data should be reviewed for the site's leased borrow area. If previous offshore heavy mineral data exists (Appendix B), areas with higher total heavy mineral content can be targeted, and an initial valuation of the economic resource may be estimated.

Set-up

In Scenario 1, an onshore location will be designated to stockpile a subset of nourishment sand. The location should not obstruct nourishment operations (e.g., piping, pumpout, grading, surveying) and public beach access should be restricted. A baseline sampling event prior to nourishment, sampling of the stockpiled material, and quarterly monitoring of designated control sites will be conducted to assess the feasibility of stockpiling and understand transport of placed material. Figure E1 displays a conceptual design for the pilot test.

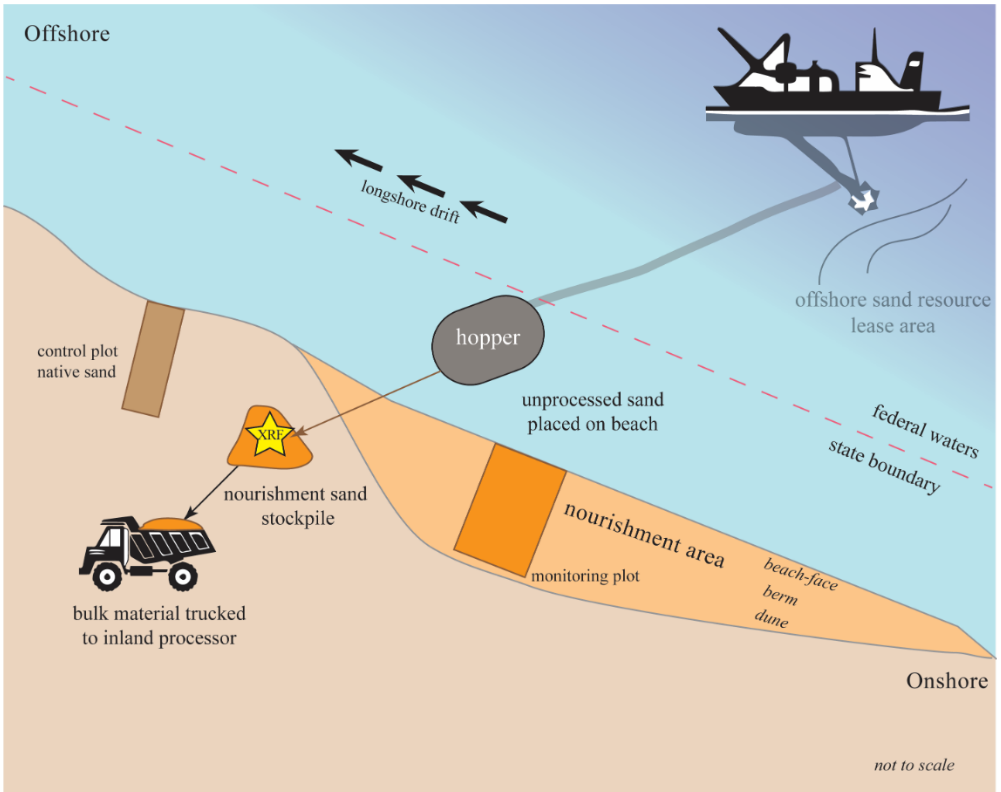

Figure E1: Conceptual site diagram for Scenario 1.

Coordination and Collaboration

An organization should be responsible for coordinating tasks between all involved entities (i.e., government agency). To facilitate to the pilot test, the following initiatives are needed:

- BOEM and a relevant entity (governmental, private) will need to enter into a non-competitive negotiated agreement (NNA) for the pilot study. Leasing of offshore sand resources in federal waters is managed by BOEM and authorized by the Outer Continental Shelf Lands Act (OCSLA) (43 U.S.C. 1331, et. Seq.). The lease process will establish the borrow source material, stakeholders involved, environmental permitting needs, and beach nourishment specifications (e.g., volume, area, grain-size).
- Application of the sand to the shoreline will be completed via a subcontract with a dredging company and may involve the U.S. Army Corps of Engineers (USACE). Other subcontractors will be needed to excavate and load temporarily stockpiled material. This could be accomplished via an agreement with the existing contractors performing the nourishment, if preferred.
- Transport of beach nourishment sand to/from the mining facility should be completed by a trucking subcontractor.
- Heavy mineral sand separation should be completed by a mining company with the capacity to extract minerals of interest at an onshore facility, to be determined, after transport of the bulk material.
- Management of collaborators, subcontractors, and monitoring (including sample collection, data analysis and reporting) would be the responsibility of the managing government agency.

Regulations and Permitting

Permitting and environmental compliance will be completed as part of the BOEM leasing process. Relevant entities will consult with the Virginia Marine Resources Commission (VMRC) for other necessary permitting requirements. As this pilot project is not intended to produce a for-profit commodity and is purely for research purposes, we do not anticipate permitting requirements by the Virginia Energy - Mineral Mining Program. As part of the BOEM leasing process, an Environmental Assessment (EA) and/or Environmental Impact Statement (EIS) per the National Environmental Policy Act (NEPA) will be completed.

Screening, Sampling, and Monitoring

This proposed hypothetical monitoring plan will include field work prior to and following sand separation and placement. Screening will be conducted on dredged material at to-be-determined intervals with a pXRF unit. Repeat sampling and monitoring will be completed on the plots after placement over a one to two-year period. The following table is a general sample and analysis plan for these activities.

Table E1: Preliminary Sample and Analysis Plan.

Sample Event	Monitoring	Sampling
Baseline	GPS survey - elevation, photos, temperature, color; radiometrics survey (i.e., gamma scintillometer)	Grain-size, pXRF screening, select samples for ICP-OES bulk geochemistry, modal mineralogy, luminescence
Post-placement	GPS survey - elevation, photos, temperature, color; radiometrics survey (i.e., gamma scintillometer)	Grain-size, pXRF screening, select samples for ICP-OES bulk geochemistry, modal mineralogy, luminescence
Quarterly events	GPS survey - elevation, photos, temperature, color; radiometrics survey (i.e., gamma scintillometer)	Grain-size, pXRF screening, luminescence
Post processing at onshore facility	Bench-scale monitoring study on concentrates and processing techniques	Modal mineralogy

Note: this is not an all-inclusive sample and analysis plan (SAP) and is a generalized approach. If a pilot test is scoped, a detailed SAP breakdown with monitoring requirements, analytical limits, and costs would be needed. A radiometric survey could be employed to measure naturally occurring levels of Th and U in the sediments which may be associated with the presence of zircon and/or monazite, coproducts and proxies for heavy mineral sands.

Modeling and Resource Estimation

Heavy mineral data will be analyzed and combined with current commodity data to estimate an economic resource specific to the nourishment project pilot study. Field monitoring events will provide information which can be fed into a model to better understand the littoral processes that help to concentrate heavy mineral sands and transport of placed-sediment after a nourishment.

Cost Considerations

In addition to the standard leasing and nourishment costs, the total pilot project budget will need to include costs for 1) personnel planning, field, travel, and reporting time, 2) laboratory analysis, 3) transportation, and 4) heavy mineral sand processing.

Scenario 1a: Use of residual material

An alternative to separating a subset of dredged material in Scenario 1, would be to use residual material remaining in the hull of the dredge. This material could be excavated and preserved from the dredge during refueling events and then transported to a heavy mineral sand processor. Utilizing this leftover material would eliminate the need to provide extra material for processing and could result in less transport distance depending on the nourishment and processor locations. One limitation to this scenario is that there would be no control over the precise source location for the material submitted to the processor. It would be advantageous to target the portion of the borrow area with the highest estimated heavy mineral sand content. Second, there could be a skew in the grain size and/or mineralogy of the sediment preserved in the hull, which may or may not reflect the natural sedimentology of the borrow area.

Scenario 2: On-site gravity separator to obtain heavy mineral concentrates during active beach nourishment.

Objectives

1. Conduct a small-scale pilot test to evaluate the efficacy of a mobile multi-spiral gravity concentrator on-site for the extraction of the heavy mineral fraction from beach nourishment marine sand.
2. Test the potential scalability of the operation and effective recovery rates of heavy minerals.
3. Calculate the grade and economic value of recovered heavy mineral sands.
4. Determine additional costs and environmental permitting requirements for gravitational spiral concentrators added to beach re-nourishment engineering plans.
5. Evaluate the pXRF field protocol proficiency to assess the presence and relative abundance (in ppm) of critical heavy minerals containing Ti, Zr, REEs, and Th in the pre-spiraled bulk sediments and in the post-spiral concentrate. Submit a subset of samples for analytical analysis to corroborate the screening data.

Pilot Site Selection

The pilot site should be limited or restricted to the public to minimize disturbance post-placement. Once the site is selected, existing offshore mineral sand data should be reviewed for the site's leased borrow area. If previous offshore heavy mineral data exists (Appendix B), areas with higher total heavy mineral content can be targeted, and an initial valuation of the economic resource may be estimated.

Set-up

When considering a hypothetical scenario of mineral separation at a beach nourishment site, the time-consuming factor will likely be gravity separation with a nested spiral unit temporarily installed onshore. In a hypothetical scenario of 1 million (M) cubic yards (cy) of offshore sand placed for nourishment, a very small portion of that would need to be diverted from the hopper and stockpiled for heavy mineral separation (i.e., <10,000 cy). If a typical dredge-hopper-beach pumping rate is ~20,000 cy per 24-hours, the stockpile could be available for separation processing within the first day of nourishment operations. Mobile heavy mineral sand separation spirals that are temporarily installed on the beach may have the capacity to separate at a rate of 6 cy per hour; therefore, the stockpile to be processed should be 3,000 cy or less to fit within a typical nourishment operation schedule of 4-12 weeks.

The efficiency of the gravitational separation at the beach will reduce the volume of the concentrate that is produced and sent for further processing. Hypothetically, a separation that removed 10% of the 3,000 cy would result in 300 cy of pre-concentrate. Transporting 300 cy of pre-concentrate to a heavy mineral sand processor would require ~16 dump truck loads at 19 cy per load. For this hypothetical scenario, cost estimates will use 20 dump truck loads of pre-concentrate material sent off for further testing.

To assess the impacts of heavy mineral sand removal on environmental parameters such as sediment color, temperature, texture, shoreline habitat, and erosional stability, monitoring should consist of an experimental plot of processed nourishment material, a plot of unprocessed nourishment material, and a native sand control plot. These plots could be set up perpendicular to the shoreface covering the dune, berm, and beach-face locations (Figure E2). These plots should be established after nourishment to avoid interference with dredging pipes and pump out operations.

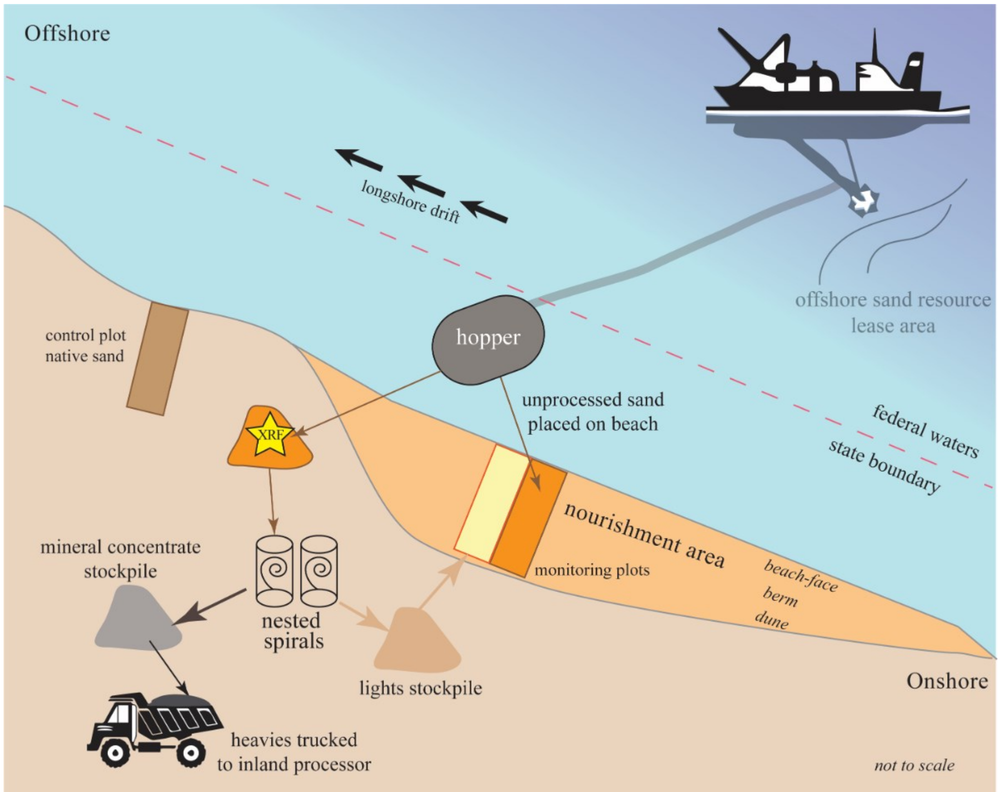

Figure E2: Conceptual site diagram for monitoring and control plots. Plots will be perpendicular to the shoreline and will consist of placed offshore material containing separated and non-separated sand.

Equipment Needs

Existing heavy mineral sand operators will be solicited to gauge collaborative interest and potential rental options for equipment. At a minimum, a mobile concentrator unit should be equipped with enough spiral chutes to allow for the 6 cy per hour flow rate, which could be nested to reduce the project footprint. A feeder piping system will be needed to provide a constant slurry to the separation unit. Discharge water could be recycled in the separation process and could utilize seawater, as salinity does not affect the gravitational spiral separation. The set-up will include a bucket loader to place the material to the respective monitoring plots. The heavy mineral concentrate will be stockpiled and transported to an inland processor.

Coordination and Collaboration

An organization should be responsible for coordinating tasks between all involved entities (i.e., government agency). To facilitate to the pilot test, the following initiatives are needed:

- BOEM and a relevant entity (governmental, private) will need to enter into an NNA for the pilot study. Leasing of offshore sand resources in federal waters is managed by BOEM and authorized by the OCSLA (43 U.S.C. 1331, et. Seq.). The lease process will establish the borrow source material, stakeholders involved, environmental permitting needs, and beach nourishment specifications (i.e., volume, area, grain-size, etc.).
- Application of the sand to the shoreline will be completed via a subcontract with a dredging company and may involve the USACE. Other subcontractors will be needed to excavate and load temporarily stockpiled material. This could be accomplished via an agreement with the existing contractors performing the nourishment, if preferred.
- Operation of the mobile multi-spiral separators should be handled by a mining company partner or by a team of trained operators.
- Transport of beach nourishment sand to/from mining facility should be handled through a trucking subcontractor.
- Operation of heavy mineral sand separation equipment should be handled by a mining company with capacity to extract minerals of interest. This will be handled at an existing (ideally local) onshore facility.
- Management of collaborators, subcontractors, and monitoring (including sample collection, data analysis and reporting) would be the responsibility of the managing government agency.

Regulations and Permitting

Permitting and environmental compliance will be completed as part of the BOEM leasing process. Relevant entities will consult with the VMRC for other necessary permitting requirements. As this pilot project is not intended to produce a for-profit commodity and is purely for research purposes, we do not anticipate permitting requirements by the Virginia Energy - Mineral Mining Program. As part of the BOEM leasing process, an EA and/or EIS per the NEPA will be completed.

Screening, Sampling, and Monitoring

A hypothetical monitoring plan is proposed below and will include field work prior to and following sand separation and placement. Screening will be conducted on dredge material at determined frequencies with a pXRF unit. Repeat sampling and monitoring will be completed on the plots after placement over a one to two-year period. The following table is a general sample and analysis plan for these activities:

Table E2: Preliminary Sample and Analysis Plan.

Sample Event	Monitoring	Sampling
Baseline	Location: native beach GPS survey - elevation, color, photos, temperature; radiometrics survey (i.e., gamma scintillometer)	Grain-size, pXRF screening, select samples for ICP-OES bulk geochemistry, modal mineralogy, luminescence
Post placement	Location: native beach control plot, renourished plot with unprocessed sand and processed sand (light mineral fraction only) GPS survey - elevation, color, photos, temperature; radiometrics survey (i.e., gamma scintillometer)	Grain-size, pXRF screening, select samples for ICP-OES bulk geochemistry, modal mineralogy, luminescence
Quarterly events	Location: native beach control plot, renourished plot with unprocessed sand and processed sand (light mineral fraction only) GPS survey - elevation, color, photos, temperature; radiometrics survey (i.e., gamma scintillometer)	Grain-size, pXRF screening, luminescence
Pre-concentrate (prior to transport)	Color	Grain-size, pXRF screening, ICP-OES bulk geochemistry
Post processing at onshore facility	Bench-scale monitoring study on concentrates and processing techniques	Modal mineralogy

Note: this is not an all-inclusive SAP and is a generalized approach. If a pilot test is scoped, a detailed SAP breakdown with monitoring requirements, analytical limits, and costs would be needed. A radiometric survey could be employed to measure naturally occurring levels of Th and U in the sediments which may be associated with the presence of zircon and/or monazite, coproducts and proxies for heavy mineral sands.

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Cost Considerations

In addition to the standard leasing and nourishment costs, the total pilot project budget will need to include costs for 1) personnel planning, field, travel, and reporting time, 2) laboratory analysis, 3) transportation, and 4) heavy mineral sand processing.