Mineral resources on Virginia’s outer continental shelf: new insights concerning sand for beach restoration and economic heavy minerals

William Lasseter, (DMME-DGMR), Jessi Blanchette (AECOM), Christopher Holm-Denoma (USGS)

Virginia Geological Research Symposium
Charlottesville VA - 18 April 2019
Inventoried and digitally converted geologic, geophysical data from the OCS offshore of Virginia;

BOEM Atlantic Sand Assessment Project (ASAP);

Estimated volume of beach-quality sand resources in Wallops and Sandbridge resource areas: 5-ft, 10-ft dredge cuts with minimal overburden;

Processed 129 sediment samples, assessed heavy mineral composition and grain size characteristics;

Conducted preliminary evaluation of economic resource potential;

Analyzed controlling depositional factors, Q-mode factor analysis, zircon U-Pb geochronology.
Project location 3–8 nautical miles offshore

Wallop's resource area

Smith Island Shoal

Sandbridge resource area

Legend:
- ASAP tracklines (109 nm)
- 2015 vibrocore (6)
- 2016 vibrocore (6)
- 2017 vibrocore (17)
- 3 nm SLA boundary
- 8 nm project boundary
- BOEM Admin boundary
- Federal sand lease area
Beach quality sand specifications

Sandbridge Beach, VA
- phi size 4 to -1
- 50% greater than 0.2 mm, prefer 0.25 mm
- low shell content
- low rock content
- prefer low opaques

Wallops Island, VA
- ASTM D 2487 SW, SP, and SP-SM, no more than 10% fines passing #200 sieve (0.074 mm)
- no color or shell/rock requirements

Sources: Roehrs, P. (2017) per comm; US Army Corps of Engineers Permit No NAO-1192-1455 issued to NASA. photo credit NASA, http://www.nasa.gov/centers/wallops/home
Generalized stratigraphy offshore of Virginia

Typical seismic profile

[Seismic profile image]

- Red: Seafloor
- Orange: Holocene – Pleistocene unconformity
- Purple: Pleistocene – Pleistocene reflector
- Blue: Pleistocene – Pliocene unconformity

Water Column
- Holocene
- Pleistocene (Tabb Fm)
- Pliocene (Yorktown Fm)

References:
- Williams 1986; Shideler and others, 1972
Calculated thickness

beach-quality sand identified in vibracore mapped with Chirp subbottom data, extent and thickness calculated using SonarWiz

Point location thicknesses imported to ArcMap
Sandbridge resource area - 54 nm² (187 km²)

northern Sandbridge area
- identified two large paleochannels
- extensive sheet sands

southern Sandbridge area
- Pleistocene estuarine fill more common
- paleochannels are rare
- extensive sheet sands and shoals
Sources: Berquist and others, 1990; Kimball and others, 1991
Sandbridge Shoal
5-ft nominal: 26M yd³

49 nm² (167 km²)
Estimated sand resource (seafloor to 5-ft depth): 333 million yd³

Sandbridge resource area
>5 ft thickness

Source: BOEM Marine Minerals Information System
20 nm² (68 km²) 36% of assessed area
Estimated sand resource (seafloor to 10-ft depth): 271 million yd³

Sandbridge resource area
>10 ft thickness

- ASAP trackline
- 2015 vibracore
- 2016 vibracore
- 2017 vibracore
- 3 nm SLA boundary
- 8 nm project boundary
- BOEM Admin boundary

Federal sand lease area

NOAA multibeam hillshade
- high
- low

sand resource thickness (ft)
- >30
- 25 - 30
- 20 - 25
- 15 - 20
- 10 - 15
- 5 - 10
- <5

nautical miles (nm)
Wallop's resource area - 72 nm² (245 km²)

- two large paleochannels in the north
- more sand shoals than in Sandbridge area
- Pleistocene exposed at surface between shoals
62 nm² (211 km²)
Estimated sand resource (seafloor to 5-ft depth): 421 million yd³

Wallops resource area
>5-ft thickness

Wallop's resource area

- grab sample (mean phi)
- core sample (mean phi)
- USGS Delmarva 2014 grab sample

- ASAP tracklines
- 2015 vibracore
- 2016 vibracore
- 2017 vibracore

- 3 nm SLA boundary
- 8 nm project boundary
- BOEM Admin boundary

Federal sand lease area

- NOAA multibeam hillshade
  - high
  - low

sand resource thickness (ft)

- >30
- 25 - 30
- 20 - 25
- 15 - 20
- 10 - 15
- 5 - 10
- <5

nautical miles (nm)
29 nm² (99 km²) 41% of assessed area
Estimated sand resource (seafloor to 10-ft depth): 393 million yd³

Wallops resource area >10-ft thickness

# Economic minerals in heavy mineral sands

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Composition</th>
<th>Critical Commodities*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ilmenite</td>
<td>FeTiO$_3$</td>
<td>Ti</td>
</tr>
<tr>
<td>Leucoxene</td>
<td><em>altered</em> FeTiO$_3$</td>
<td>Ti</td>
</tr>
<tr>
<td>Rutile</td>
<td>TiO$_2$</td>
<td>Ti</td>
</tr>
<tr>
<td>Titanite</td>
<td>CaTiO(SiO$_4$)</td>
<td>Ti</td>
</tr>
<tr>
<td>Zircon</td>
<td>ZrSiO$_4$</td>
<td>Zr, U, Th, Hf, REE</td>
</tr>
<tr>
<td>Xenotime</td>
<td>YPO$_4$</td>
<td>Y, REE</td>
</tr>
<tr>
<td>Monazite</td>
<td>CePO$_4$</td>
<td>La, Ce, Pr, Nd, Th, Y</td>
</tr>
<tr>
<td>Sillimanite group</td>
<td>Al$_2$SiO$_5$</td>
<td>Al</td>
</tr>
<tr>
<td>Chromite</td>
<td>(Fe, Mg)Cr$_2$O$_4$</td>
<td>Cr</td>
</tr>
<tr>
<td>Garnet group</td>
<td>(Ca,Fe,Mg,Al)(SiO$_4$)$_3$</td>
<td>abrasive sand</td>
</tr>
</tbody>
</table>

*Critical commodities include rare earth elements (REE), Uranium (U), Thorium (Th), Hafnium (Hf), Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Thulium (Th), and Yttrium (Y).

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 (n = 516)

- **Ilmenite**: 25.4%
- **Garnet**: 15.5%
- **Rutile**: 7.3%
- **Other**: 37.9%
  - amphibole > pyroxene > epidote
  - quartz, staurolite, pyrite
- **Chromite**: 0.1%
- **Magnetite**: 5.0%
- **Kyanite**: 2.0%
- **Zircon**: 3.4%
- **Leucoxene**: 1.6%
- **Titanite**: 0.6%
- **Xenotime REE**: 1.0%
- **Monazite**: 0.2%

Mean THM: 2.7 wt %
Mean EHM: 41.5 wt % of THM

Sources: Berquist and others, 1990; present study
mid-point value of Virginia’s heavy mineral concentrate ~US $263 per metric ton based on current market price ranges for individual commodities

- **Ilmenite**: 25.4% ($94)
- **Rutile**: 7.3% ($81)
- **Garnet**: 15.5% ($15)
- **Other**: 37.9%
  - Amphibole > Pyroxene > Epidote
  - Quartz, staurolite, pyrite

**Added value if garnet is recovered**

- Zircon 3.4% ($39)
- Leucoxene 1.6% ($12)
- Titanite 0.6% ($2)
- Xenotime REE 1.0% ($30+)
- Monazite 0.2% ($1+)

**Value of 1 yd³ sand containing 2.7 wt % THM is about $9.70**

Sources: *Industrial Minerals, 2019; US Census Bureau (export prices); SME Mining Engineering Industrial Minerals Review, 2018; USGS Mineral Commodity Summaries, 2019; Bloomberg per. comm.*
Highest THM concentrations are in very-fine to fine sand fractions.
Mean grain sizes of heavy minerals are in the range of very fine sand to silt, n=126

Grain size data available only for Ti- and Zr-minerals identified in the concentrates
Critical commodities in heavy mineral concentrates offshore of Virginia

Source: Rudnick and Gao, 2003; Taylor and McLennan, 1985
Major oxides in heavy mineral concentrates

Source: Rudnick and Gao, 2003; Taylor and McLennan, 1985
Rare earth elements in heavy mineral concentrates offshore of Virginia

Source: Rudnick and Gao, 2003; Taylor and McLennan, 1985
REE enrichment in heavy mineral concentrates, HREE enrichment due to fractionating phases zircon and garnet

Sample ppm / Chondrite ppm

Wallops and Sandbridge mean, n=27

upper continental crust

Chondrite normalized, Taylor and McLennan (1985)
Sandbridge relatively enriched in LREEs compared to Wallops, not due to higher wt % monazite, possibly allanite?
629 sediment samples analyzed for THM averaging 2.7 wt % overall

- seafloor grab 5-gallon bucket containers
- vibracore typically 0-5’, 5-10’ composites

- 44% of samples contain THM >2.5 wt %
- 2% of samples contain THM >10 wt %
Sandbridge resource area >10 ft thickness

- ASAP trackline
- 2015 vibracore
- 2016 vibracore
- 2017 vibracore
- 3 nm SLA boundary
- 8 nm project boundary
- BOEM Admin boundary

Federal sand lease area

NOAA multibeam hillshade
- high
- low

sand resource thickness (ft)
- >30
- 25 - 30
- 20 - 25
- 15 - 20
- 10 - 15
- 5 - 10
- <5

Nautical miles (nm)
Sandbridge resource area

Area 1: 133M ft² (3.6 nm²) @thickness: 5 ft
volume: 25M yd³ (34Mt)
THM avg 2.0 wt %
estimated value $177M
~$7.15 per yd³

Area 2: 164M ft² (4.4 nm²) @thickness: 5 ft
volume: 30M yd³ (41Mt)
THM avg 2.1 wt %
estimated value $228M
~$7.51 per yd³
Wallop's resource area

VC-09, 09A
0 - 18.3 ft
THM avg 0.5 wt%

C-1
0 – 10 ft
THM avg 2.7 wt%

VC-08
0 – 16.5 ft
THM avg 0.57 wt%
VC-06,06A
0 – 25 ft
THM avg 0.75 wt%

VC-06
Area 1
DGMR grab #10
THM 7.7 wt%

Area 2

Wallop resource area

THM wt% (grab and core)
- 0 - 1.0
- 1.0 - 2.5
- 2.5 - 5.0
- 5.0 - 10.0
- >10

ASAP tracklines
3 nm SLA boundary
8 nm project boundary
BOEM Admin boundary

Federal sand lease area
NOAA multibeam hillshade
high
low

sand resource thickness (ft)
- >30
- 25 - 30
- 20 - 25
- 15 - 20
- 10 - 15
- 5 - 10
- <5

nautical miles (nm)
Wallop resource area

Area 1: 73M ft² (2.0 nm²)
@thickness: 5 ft
volume: 14M yd³ (18Mt)
THM avg 0.75 wt %
estimated value $36M
~$2.68 per yd³

Area 2: 198M ft² (5.4 nm²)
@thickness: 5 ft
volume: 37M yd³ (50Mt)
THM avg 2.1 wt %
estimated value $275M
~$7.51 per yd³

US Bureau of Mines OFR 4-87 tonnage factor 1.36 tonne/yd³; values rounded.
Smith Island Shoals

Area 1: 232M ft² (6.3 nm²) @thickness: 5 ft volume: 43M yd³ (58Mt) THM avg 6.0 wt % estimated value $920M ~$21.46 per yd³

Core 2017-07 (0-5”) contained THM = 1.1 wt %

US Bureau of Mines OFR 4-87 tonnage factor 1.36 tonne/yd³; values rounded.
detrital zircon U-Pb dates

R-11368
1028, 1152 Ma
376, 1400, 2681 Ma

R-11362
448, 1055, 1120, 1159 Ma
399, 1418 Ma

R-11006
455, 1073 Ma
1181, 1453 Ma

R-11007
1050, 1141 Ma
444, 1443 Ma

R-10970
446, 1043 Ma
1491, 1617 Ma

R-11373
1004, 1074, 1155 Ma

R-11042
1113 Ma
400, 1427 Ma
Detrital zircon U-Pb

Ma

0 500 1000 1500 2000 2500 3000

R-11368  R-11362  R-11006  R-11007  R-10970  R-11373  R-11042

375 ~ 455
1004 ~ 1180
1400 ~ 1617

~ 2680
Mean phi of detrital zircon U-Pb geochron samples
Mining offshore mineral deposits

- Are EHM concentrations in marine sands economic?
- What permits will be required and from whom?
- Public safety and environmental concerns – stockpiles, etc.
- Concentrate the minerals on the beach after emplacement, or offshore as part of the dredging operation?
- Who gets heavy mineral royalties – Feds? State? Locality?

- Sand will be cleaner when opaque minerals are removed.
- Processing will be simpler due to fewer fines, simple gravity separation/concentration, no chemicals.
- Small, mobile beachside concentrator or on a barge.
- Other commodities – high purity silica sand, phosphate, garnet, staurolite.
What we have learned

Analysis of ASAP reconnaissance survey data completed as part of the BOEM-VA State Cooperative indicates substantial beach-quality sand resources in two offshore regions:

<table>
<thead>
<tr>
<th>resource area</th>
<th>minimum 10-ft thickness</th>
<th>minimum 5-ft thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandbridge</td>
<td>271 million yd$^3$</td>
<td>333 million yd$^3$</td>
</tr>
<tr>
<td>Wallops</td>
<td>393 million yd$^3$</td>
<td>421 million yd$^3$</td>
</tr>
</tbody>
</table>

Heavy mineral concentrates from 629 sediment samples indicate a mean THM content of 2.7 wt %, ranging from 0.01% up to 16.6%. Minerals with economic value containing critical commodities such as Ti, Zr, REE, U, Hf, among others, make up about 42% of the Virginia’s THM concentrate.

Estimated value of 1 yd$^3$ sand containing 2.7 wt% THM is about $9.70.

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.
Thank you

Contact information
William Lassetter
william.lassetter@dmme.virginia.gov
434-951-6361
DMME web site:  https://dmme.virginia.gov/

Special thanks to:
Kelvin Ramsey, Robin Mattheus – Delaware Geological Survey
Rick Berquist – DGMR (retired), College of W&M
Mike Enomoto - DGMR
Eleanor Worthington - College of W&M
Patti Burton - VIMS
Laura Brothers - USGS
AMINO ACID RACEMIZATION (AAR)

- AAR dating was completed on 8 out of 9 cores

<table>
<thead>
<tr>
<th>ID</th>
<th>Below MSL</th>
<th>Hole Depth</th>
<th>#AAR Analyses</th>
<th>Likely Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA-BOEM-15-01</td>
<td>-48.5</td>
<td>17.0</td>
<td>10</td>
<td>Holocene/L. Pleistocene</td>
</tr>
<tr>
<td>VA-BOEM-15-04</td>
<td>-55.6</td>
<td>15.9</td>
<td>6</td>
<td>L. Pleistocene</td>
</tr>
<tr>
<td>VA-BOEM-15-04a</td>
<td>-55.7</td>
<td>8.1</td>
<td>15</td>
<td>M. Pleistocene?</td>
</tr>
<tr>
<td>VA-BOEM-15-05</td>
<td>-48.6</td>
<td>13.5</td>
<td>5</td>
<td>L. Pleistocene</td>
</tr>
<tr>
<td>VA-BOEM-15-05a</td>
<td>-48.8</td>
<td>10.0</td>
<td>8</td>
<td>L. Pleistocene</td>
</tr>
<tr>
<td>VA-BOEM-15-06</td>
<td>-61.9</td>
<td>13.3</td>
<td>4</td>
<td>L. Pleistocene</td>
</tr>
<tr>
<td>VA-BOEM-15-08</td>
<td>-67.8</td>
<td>16.5</td>
<td>5</td>
<td>L. Pleistocene</td>
</tr>
<tr>
<td>VA-BOEM-15-09</td>
<td>-55.6</td>
<td>13.3</td>
<td>2</td>
<td>L. Pleistocene</td>
</tr>
<tr>
<td>VA-BOEM-15-09a</td>
<td>-55.5</td>
<td>7.7</td>
<td>2</td>
<td>Holocene</td>
</tr>
</tbody>
</table>

Wehmiller and Belknap, 1982
HEAVY MINERAL DATA

- Data encompasses samples from the 1980s to 2017
- Concentration due to Susquehanna drainage channel migration?

Colman and others 1990