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

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Christopher Holm-Denoma (USGS)

Virginia Geological Research Symposium
Charlottesville VA - 18 April 2019

BOEM
Bureau of Ocean Energy Management

DMME
Virginia Department of Mines Minerals and Energy

BOEM-Virginia State Coop Agreement 2014-19

Inventoried and digitally converted geologic, geophysical data from the OCS offshore of Virginia;

BOEM Atlantic Sand Assessment Project (ASAP);

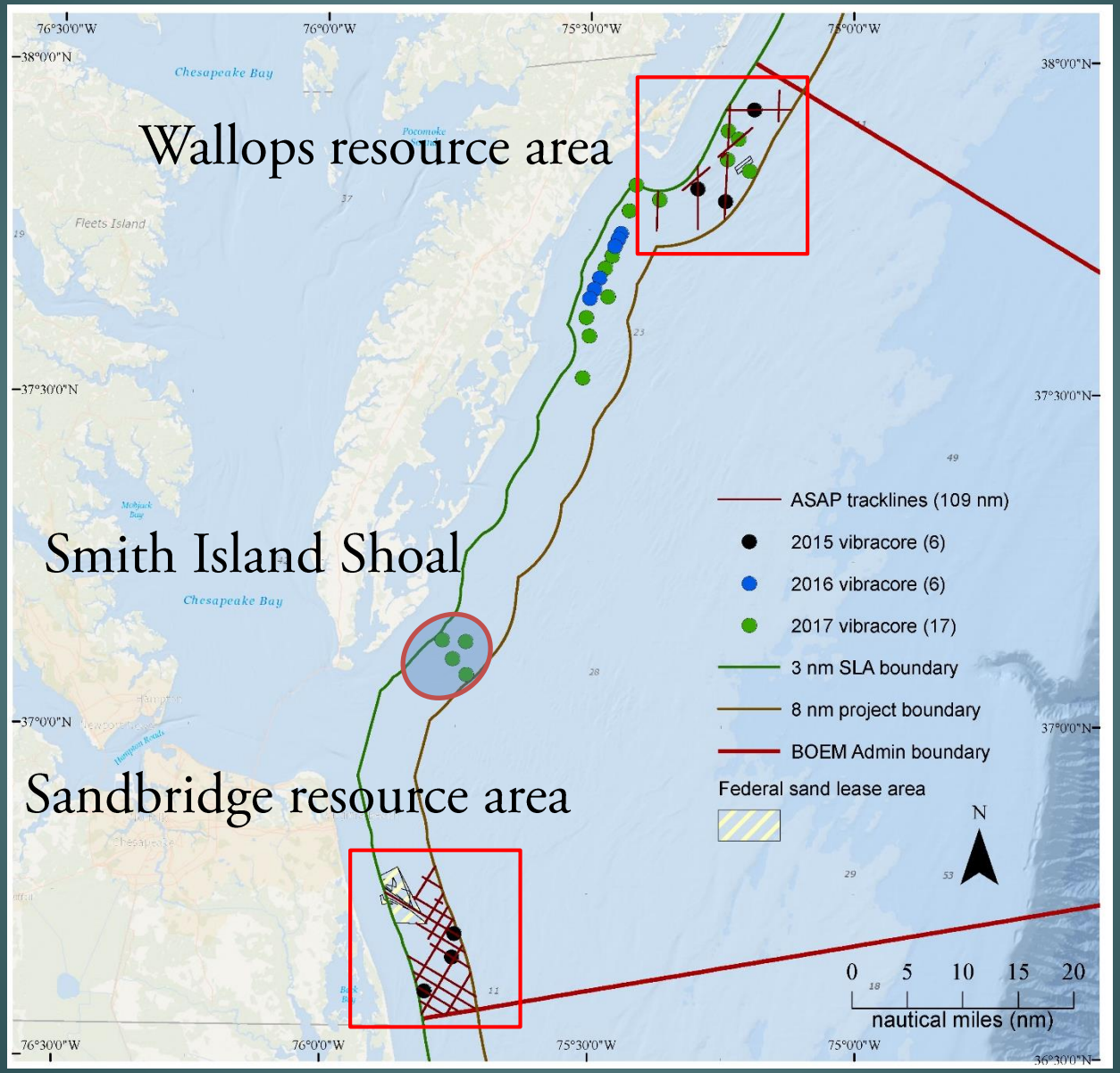
Estimated volume of beach-quality sand resources in Wallops and Sandbridge resource areas: 5-ft, 10-ft dredge cuts with minimal overburden;

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



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

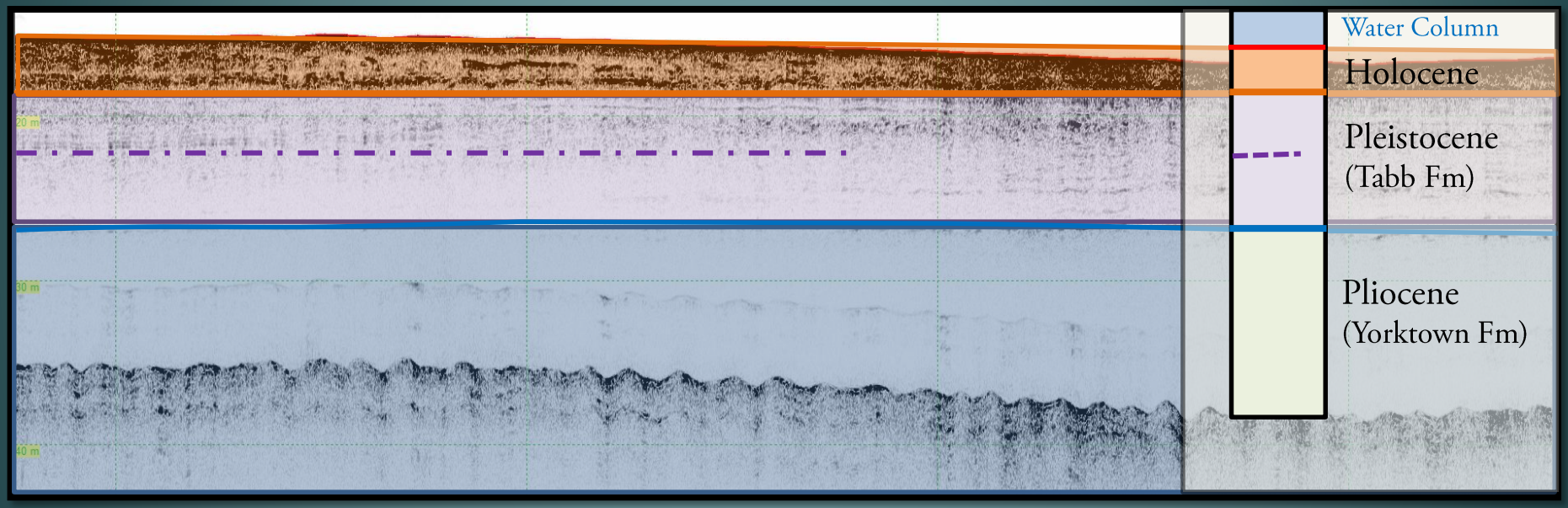
Wallops Island, VA

- 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



Seafloor

Holocene – Pleistocene unconformity

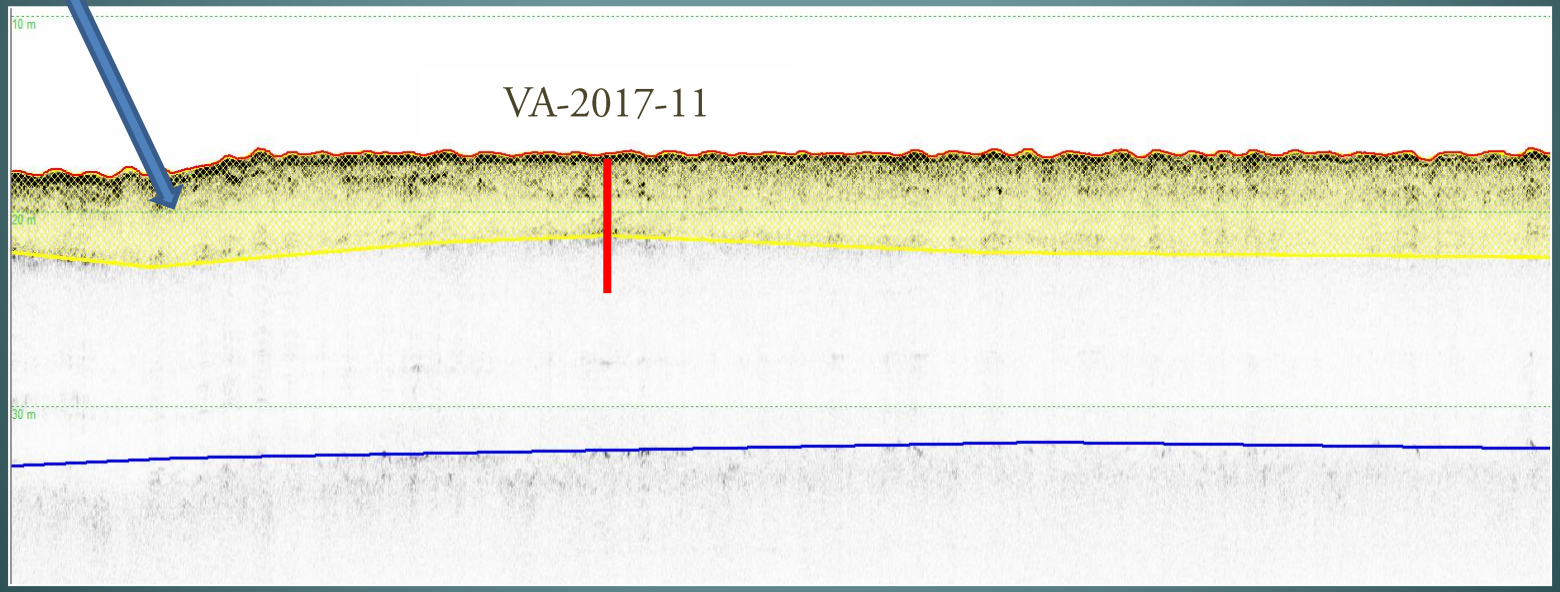
Pleistocene – Pleistocene reflector

Pleistocene – Pliocene unconformity

Williams 1986; Shideler and others, 1972

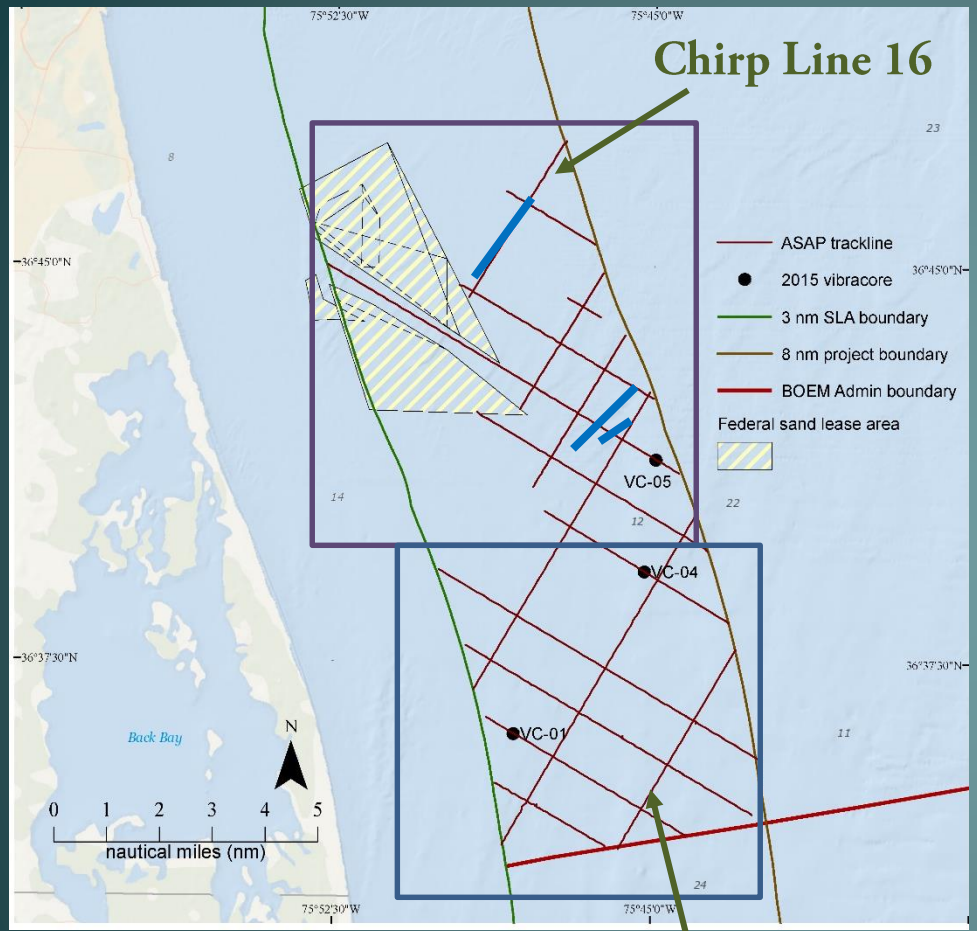
Calculated thickness

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)

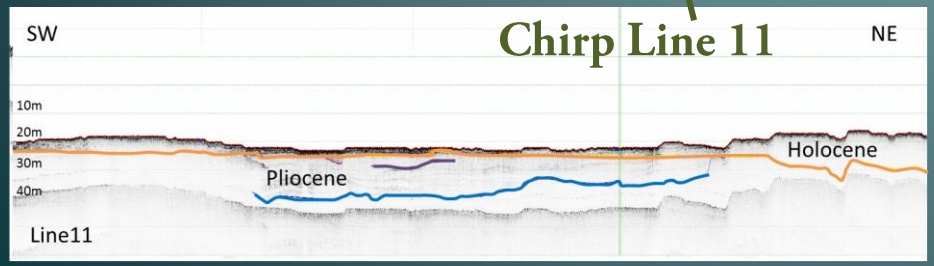


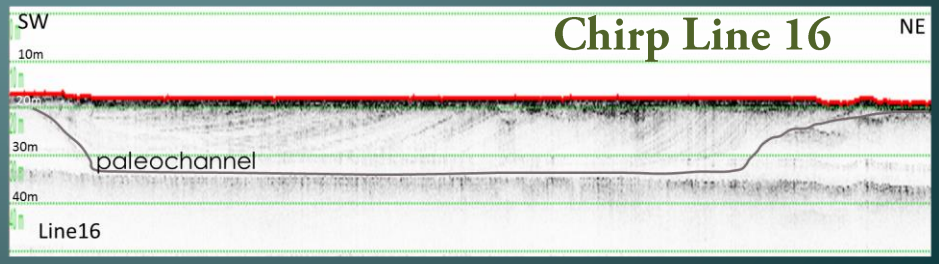
northern Sandbridge area

- identified two large paleochannels
- extensive sheet sands

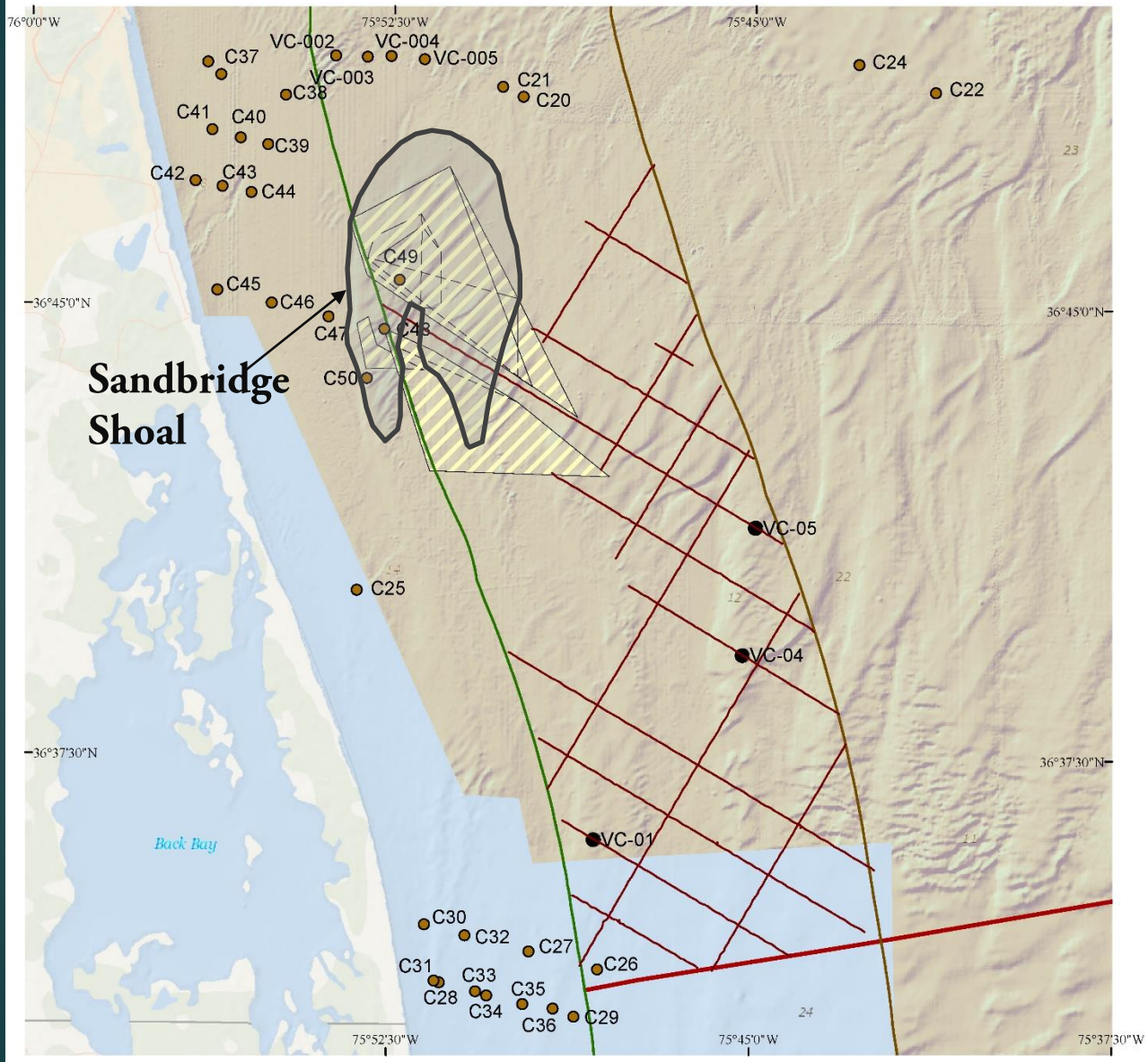
southern Sandbridge area

- Pleistocene estuarine fill more common
- paleochannels are rare
- extensive sheet sands and shoals





Sandbridge resource area



DGMR / Tetra Tech core

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

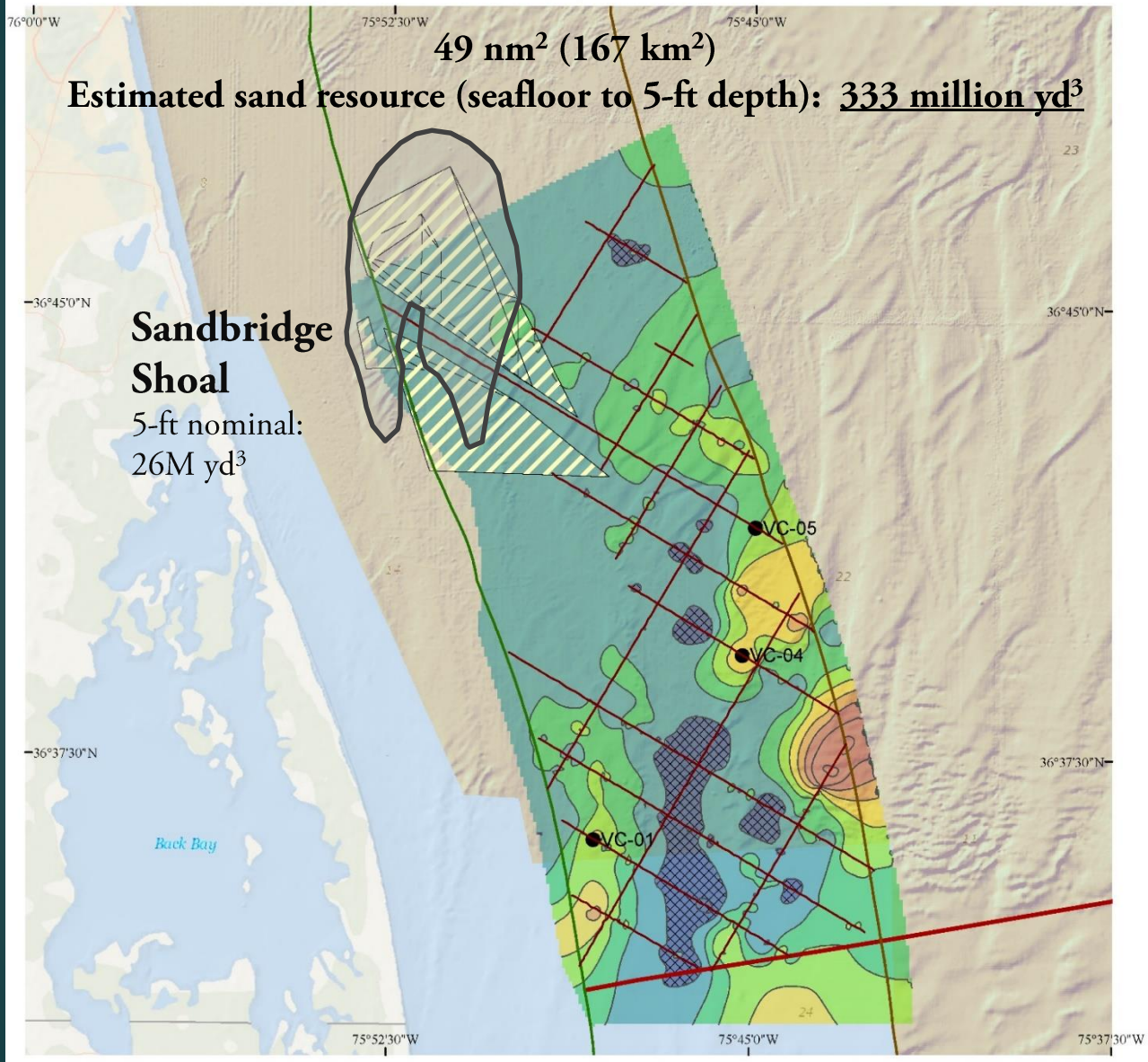
N

0 1 2 3 4 5

nautical miles (nm)

Sources: Berquist and others, 1990; Kimball and others, 1991

Sandbridge resource area >5 ft thickness



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high
low

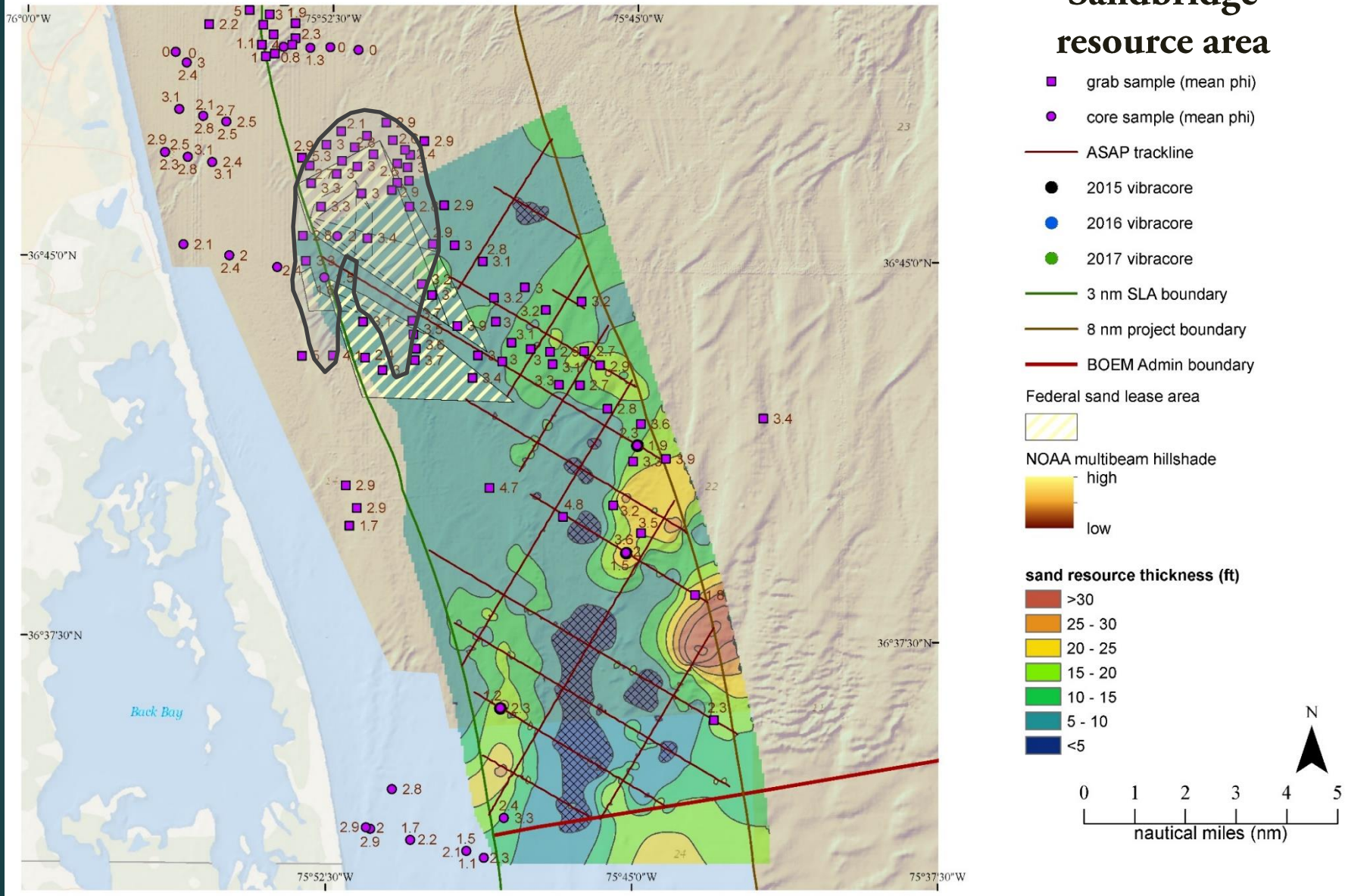
sand resource thickness (ft)
>30
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
<5

N

0 1 2 3 4 5
nautical miles (nm)

Source: BOEM Marine Minerals Information System

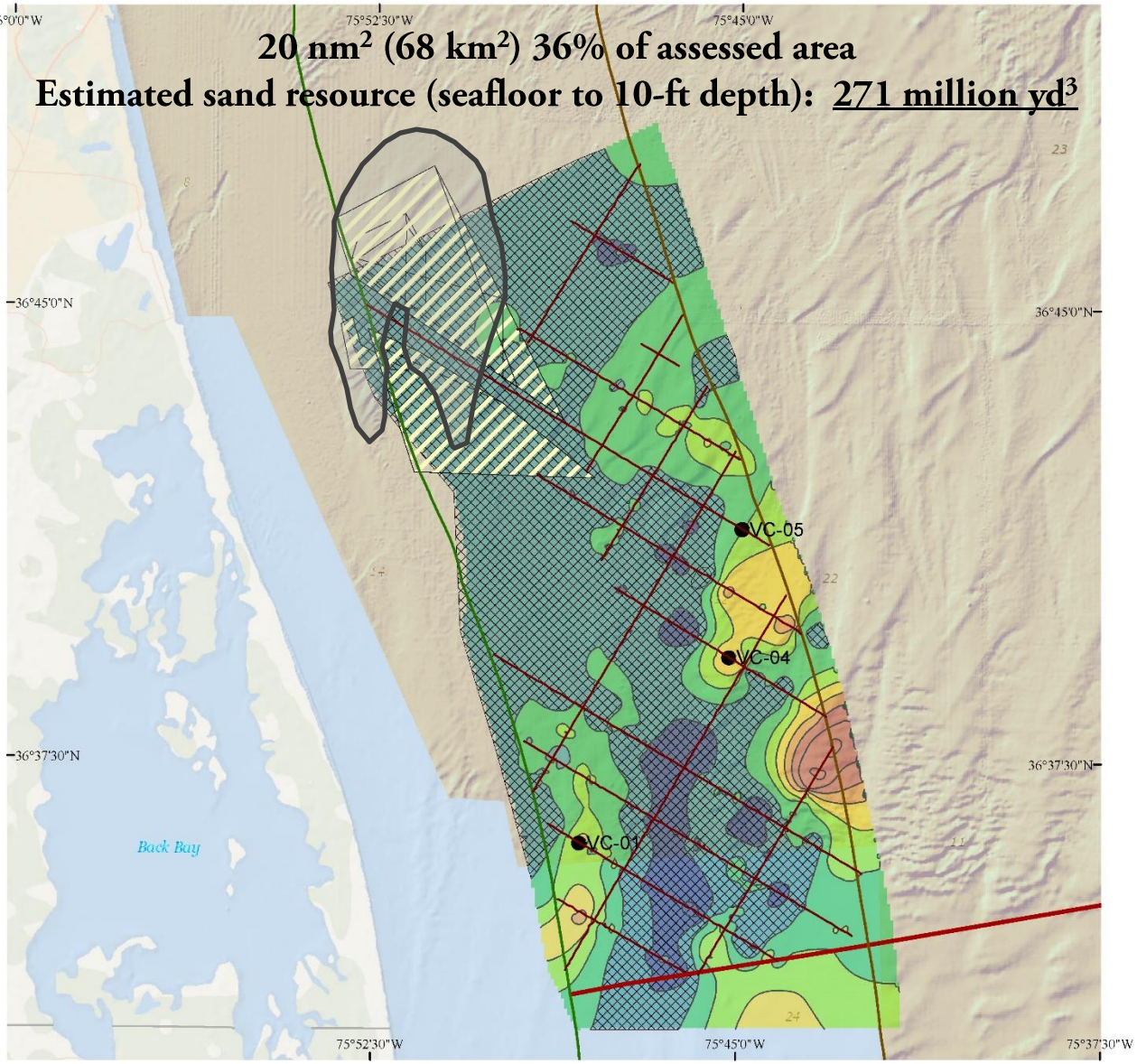
Sandbridge resource area



Sandbridge resource area >10 ft thickness

20 nm^2 (68 km^2) 36% of assessed area

Estimated sand resource (seafloor to 10-ft depth): <u>271 million yd^3</u>



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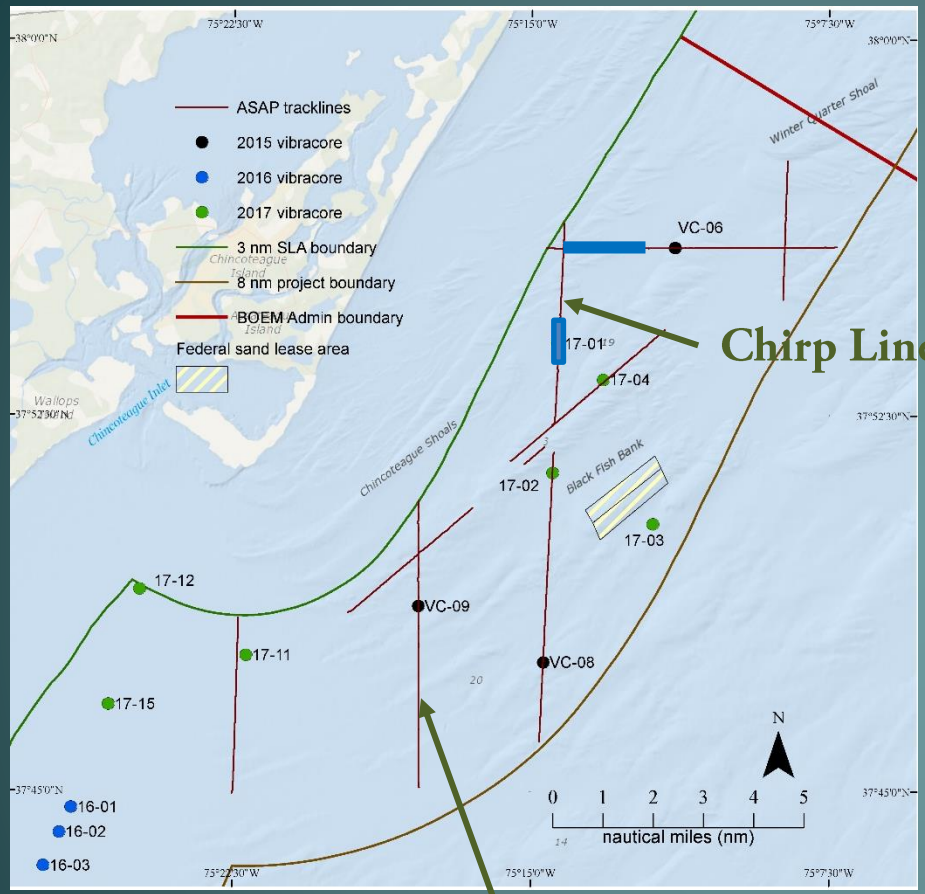
0 1 2 3 4 5
nautical miles (nm)

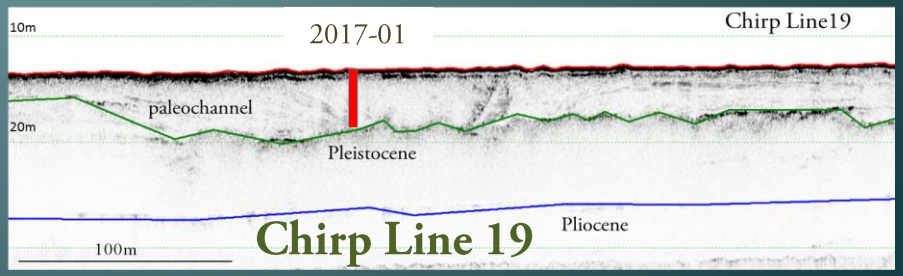
Wallops resource area - 72 nm² (245 km²)



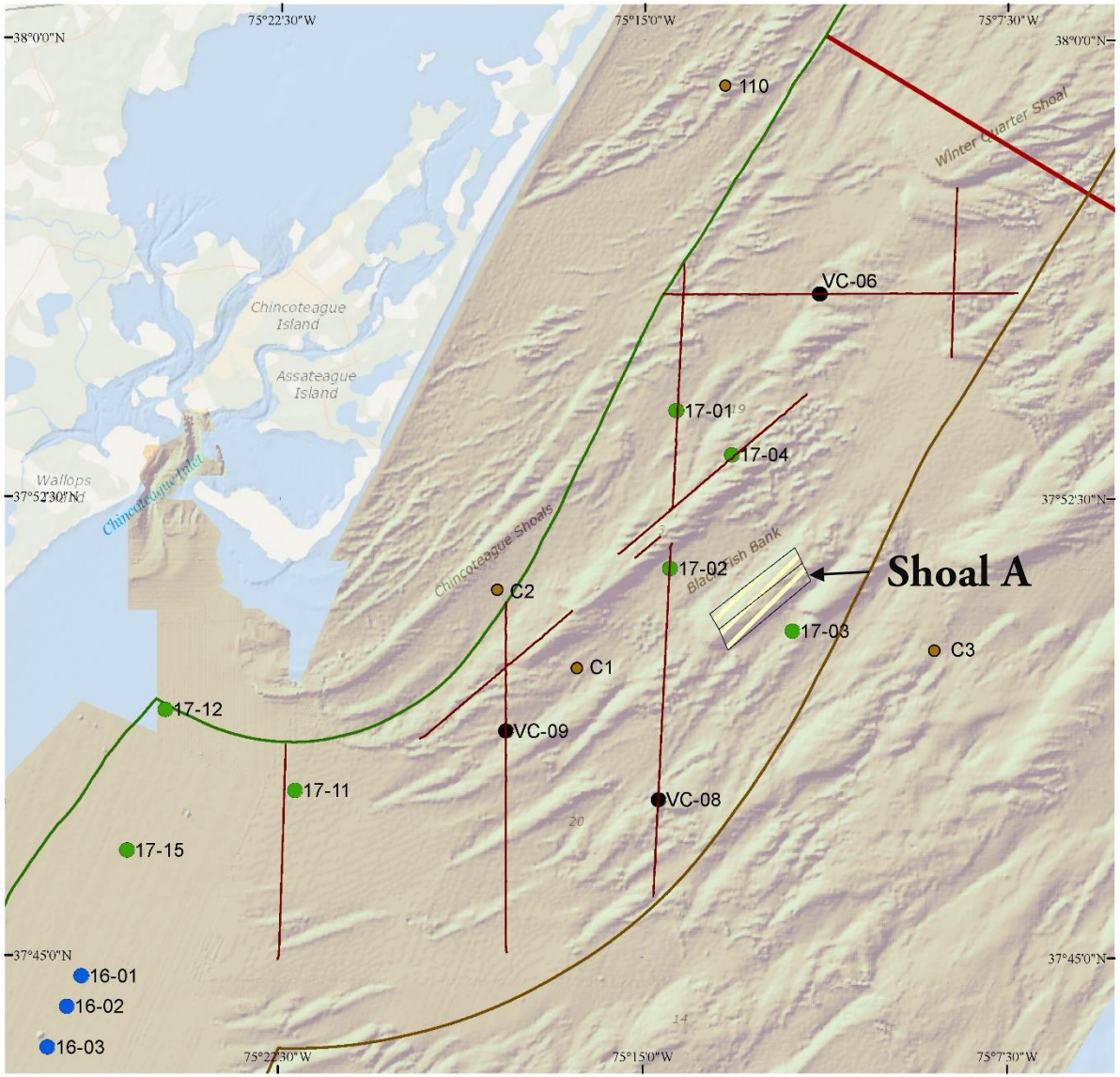
- two large paleochannels in the north
- more sand shoals than in Sandbridge area
- Pleistocene exposed at surface between shoals

N S

N S



Wallops resource area



DGMR core

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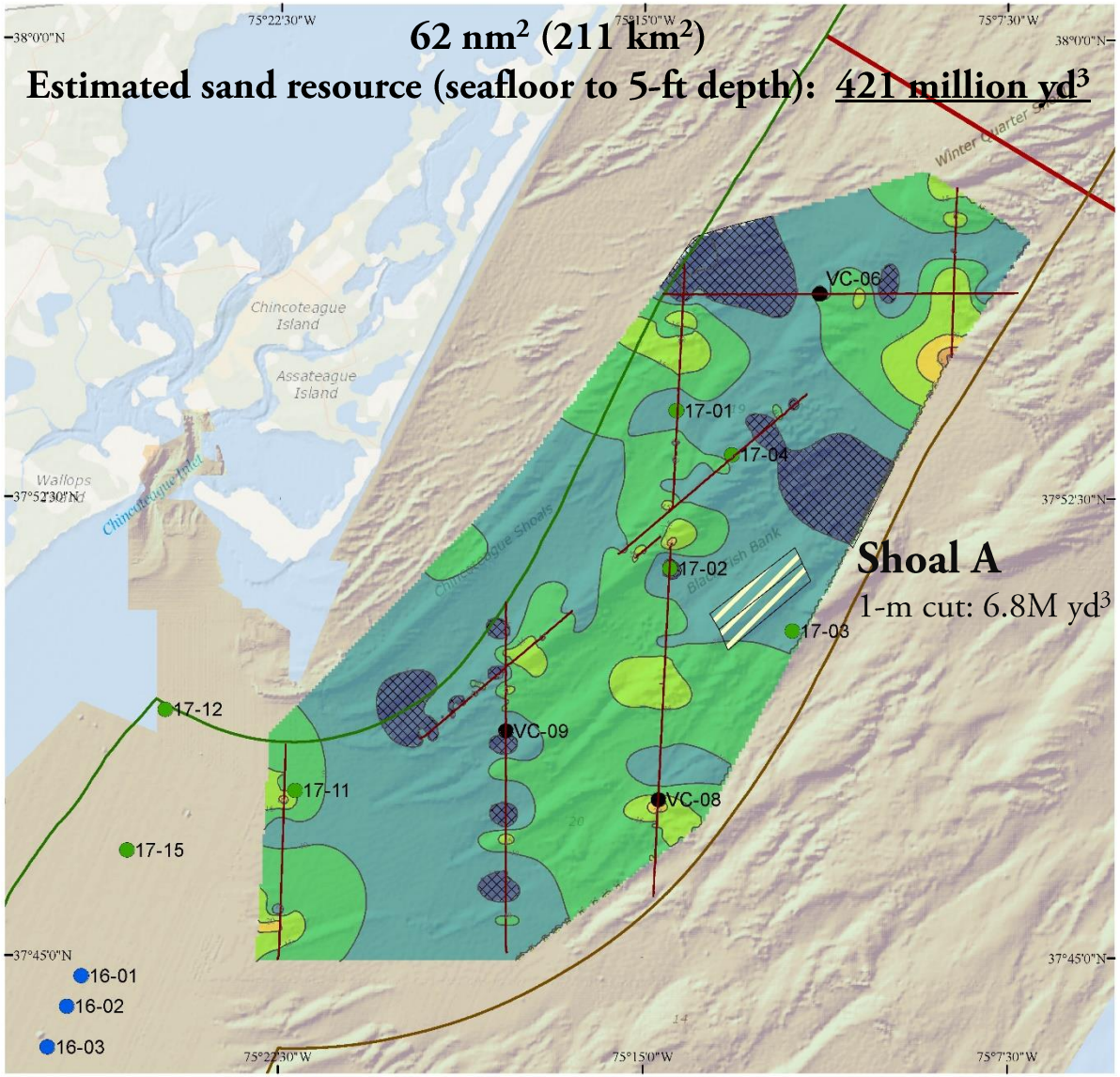
N

0 1 2 3 4 5

nautical miles (nm)

Wallops resource area >5-ft thickness



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sand resource thickness (ft)
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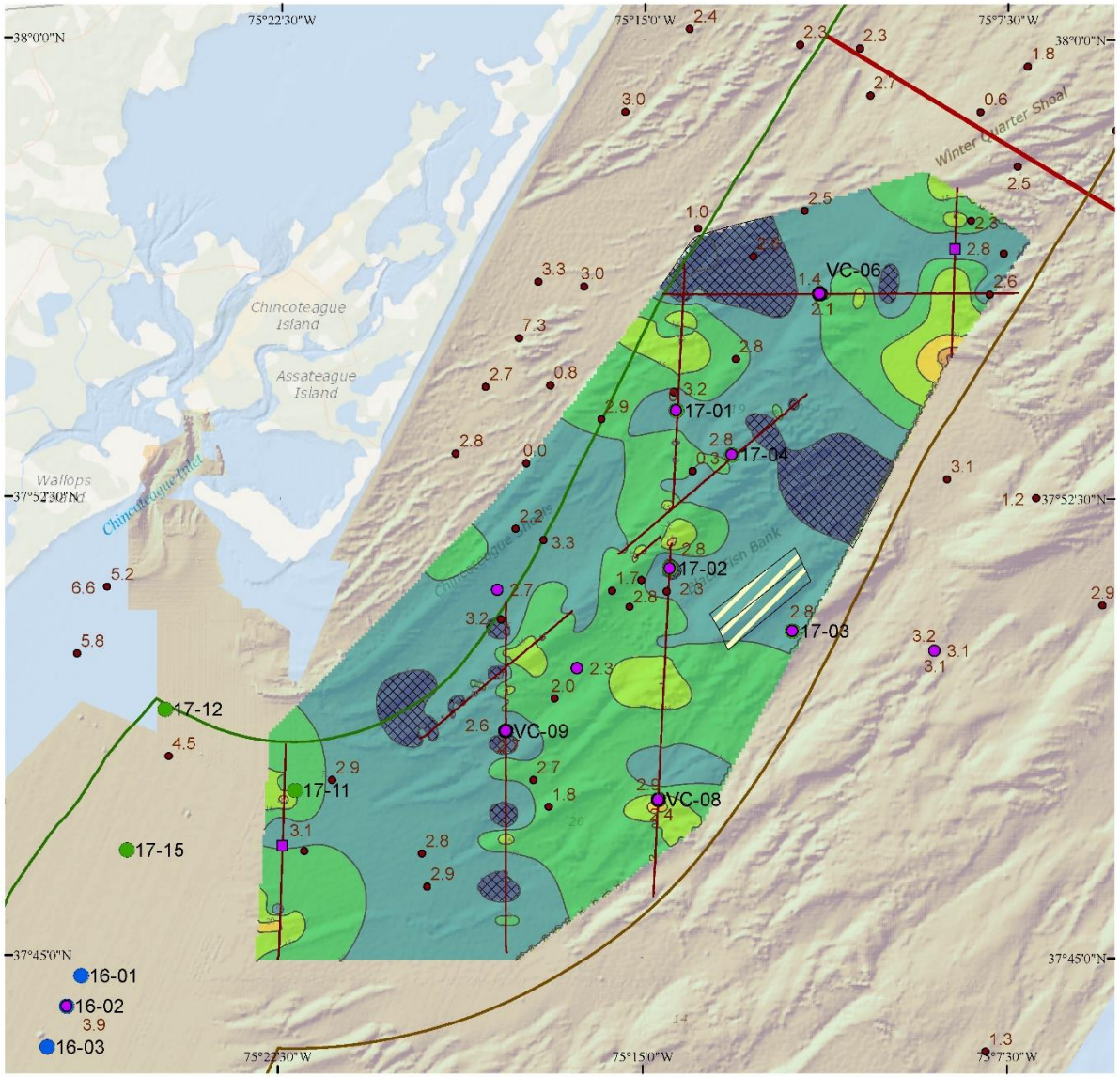
N

0 1 2 3 4 5
nautical miles (nm)

Source: Alpine Ocean Seismic Survey, Inc., 2008, prepared for Norfolk USACE

Wallops resource area



grab sample (mean phi)

core sample (mean phi)

USGS Delmarva 2014 grab sample

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- <5

N

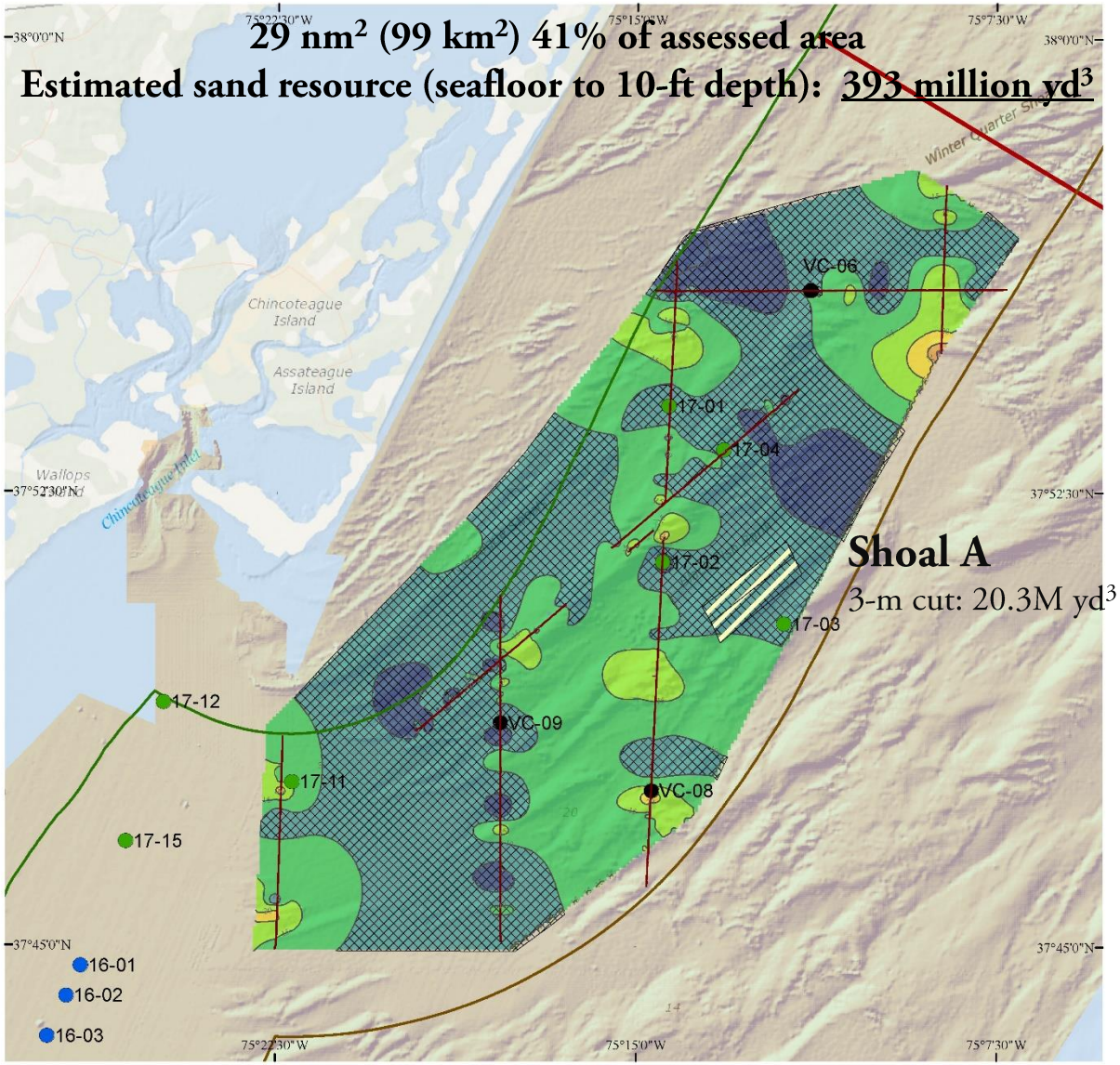
0 1 2 3 4 5

nautical miles (nm)

Wallops resource area >10-ft thickness

29 nm² (99 km²) 41% of assessed area

Estimated sand resource (seafloor to 10-ft depth): 393 million yd³



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low

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nautical miles (nm)

Source: Alpine Ocean Seismic Survey, Inc., 2008, prepared for Norfolk USACE

Economic minerals in heavy mineral sands

Mineral	composition	critical commodities*
Ilmenite	$FeTiO_3$	Ti
Leucoxene	*altered* $FeTiO_3$	Ti
Rutile	TiO_2	Ti
Titanite	$CaTiO(SiO_4)$	Ti
Zircon	$ZrSiO_4$	Zr, U, Th, Hf, REE
Xenotime	YPO_4	Y, REE
Monazite	$CePO_4$	La, Ce, Pr, Nd, Th, Y
Sillimanite group	Al_2SiO_5	Al
Chromite	$(Fe, Mg)Cr_2O_4$	Cr
Garnet group	$(Ca,Fe,Mg,Al)(SiO_4)_3$	abrasive sand

Ilmenite

Leucoxene

Rutile

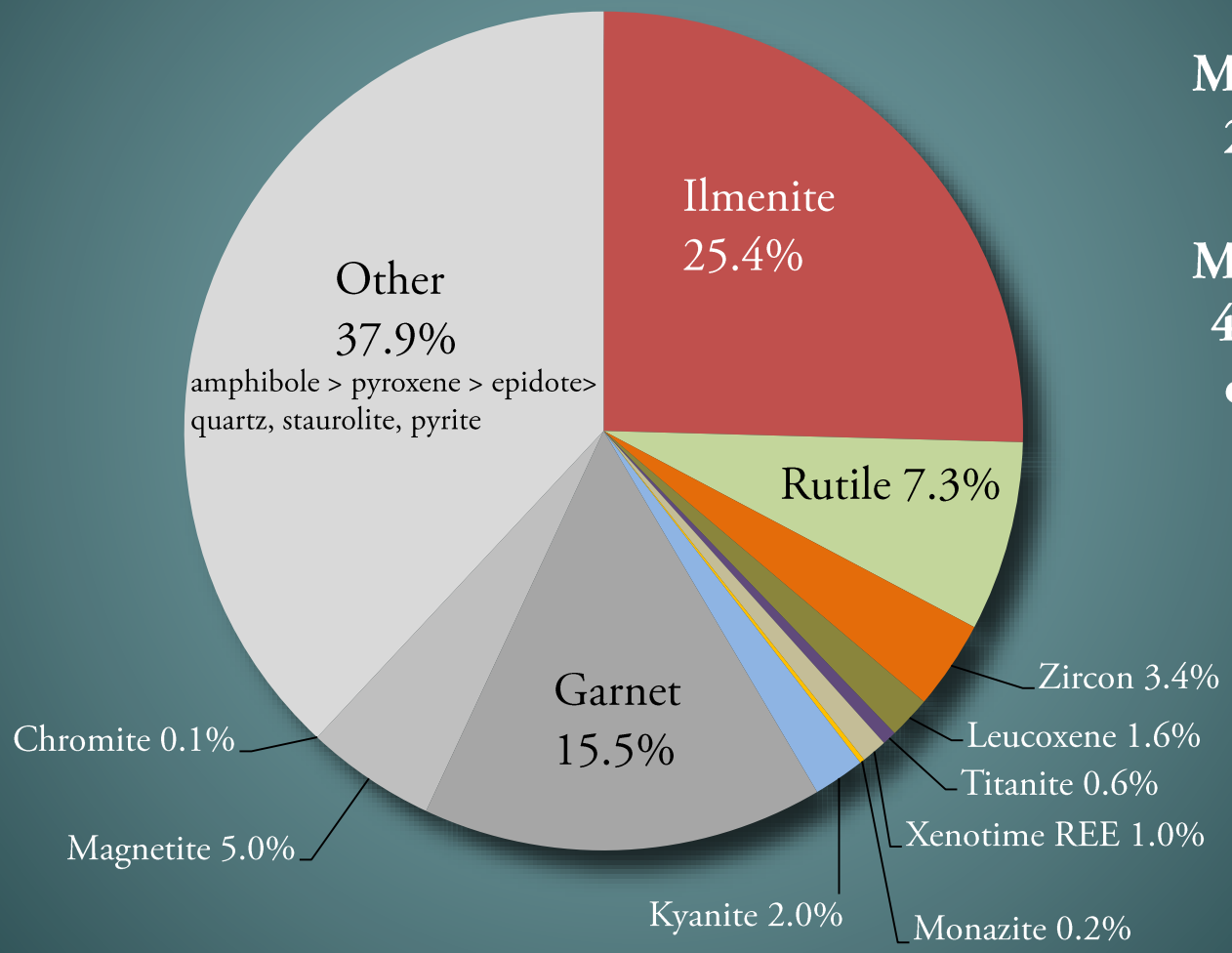
Zircon

Monazite

Kyanite

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)

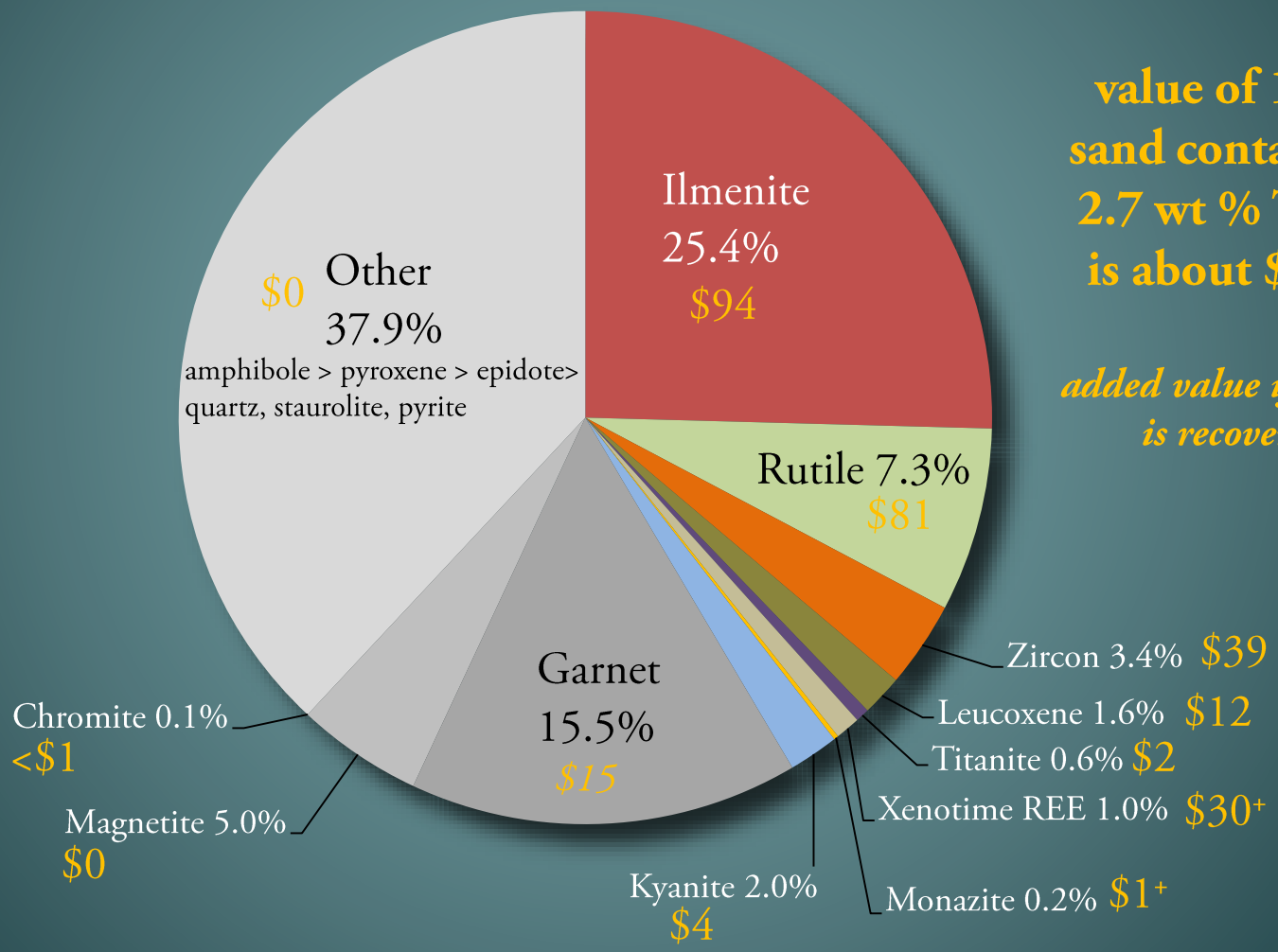


Mean THM
2.7 wt %

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

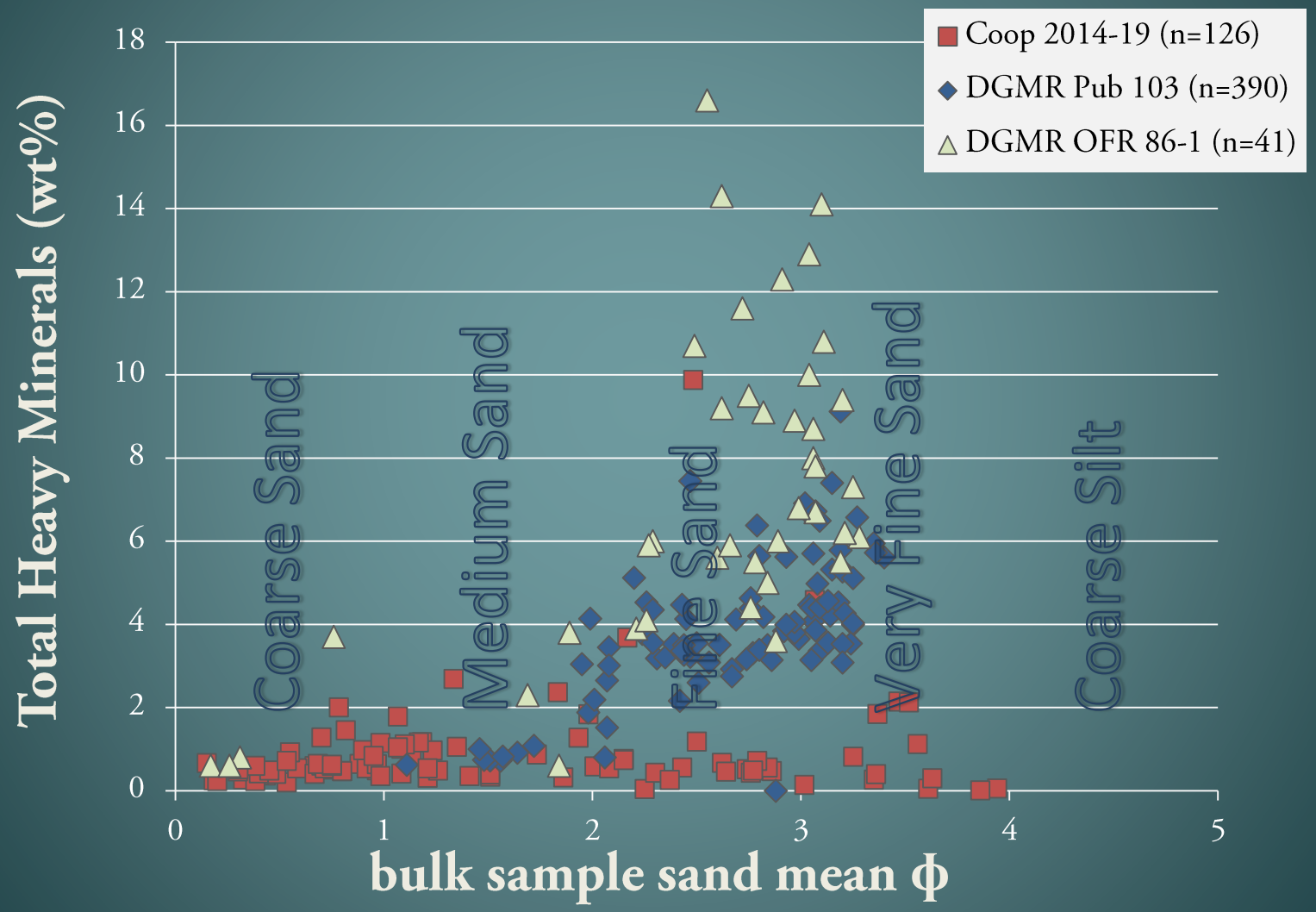


value of 1 yd³ sand containing 2.7 wt % THM is about $9.70

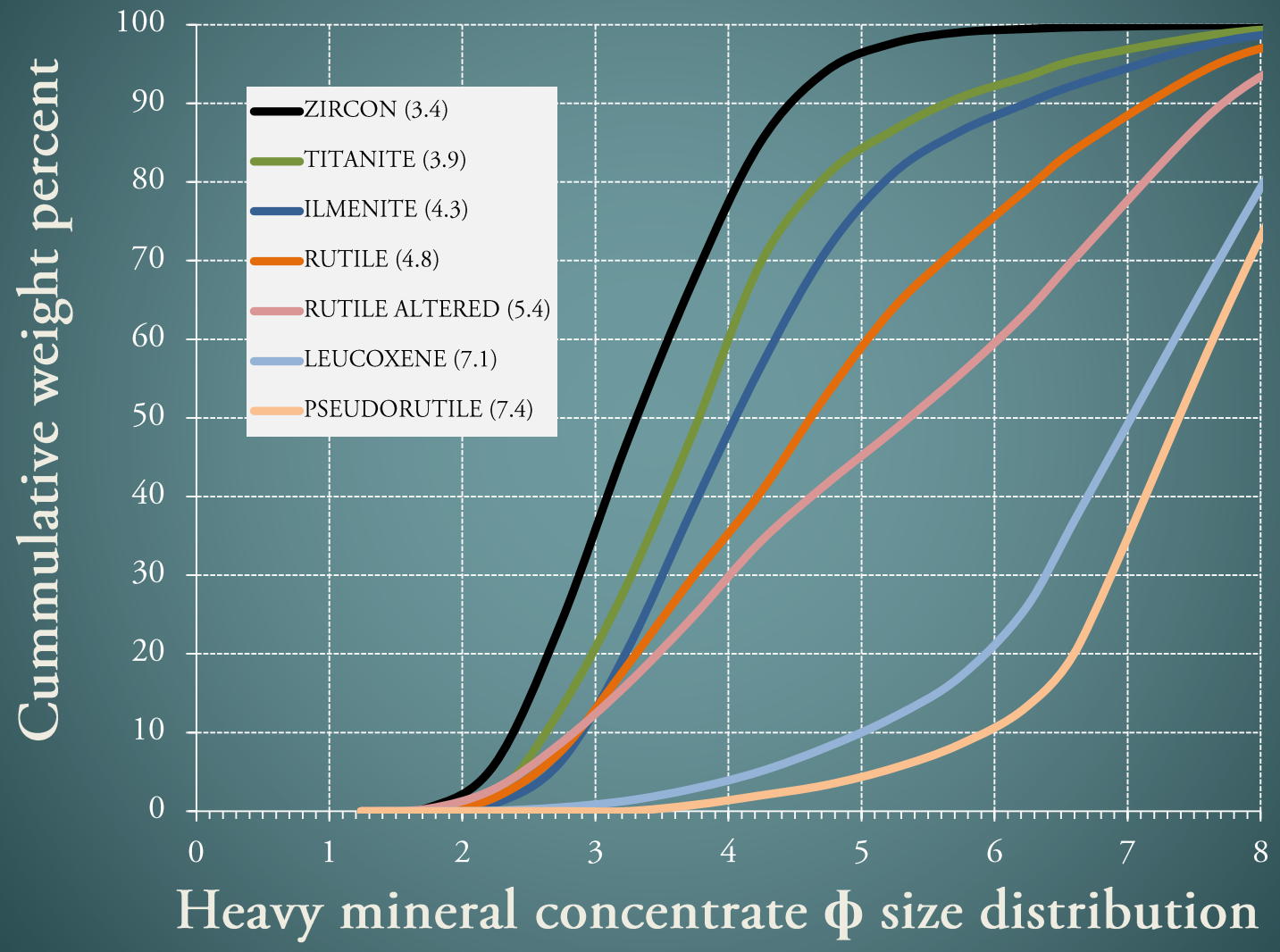
added value if garnet is recovered

Sources: *Industrial Minerals*, 2019; US Census Bureau (export prices); SME *Mining Engineering* Industrial Minerals Review, 2018; USGS Mineral Commodity Summaries, 2019; Bloomburg; per. comm.

Highest THM concentrations are in very-fine to fine sand fractions

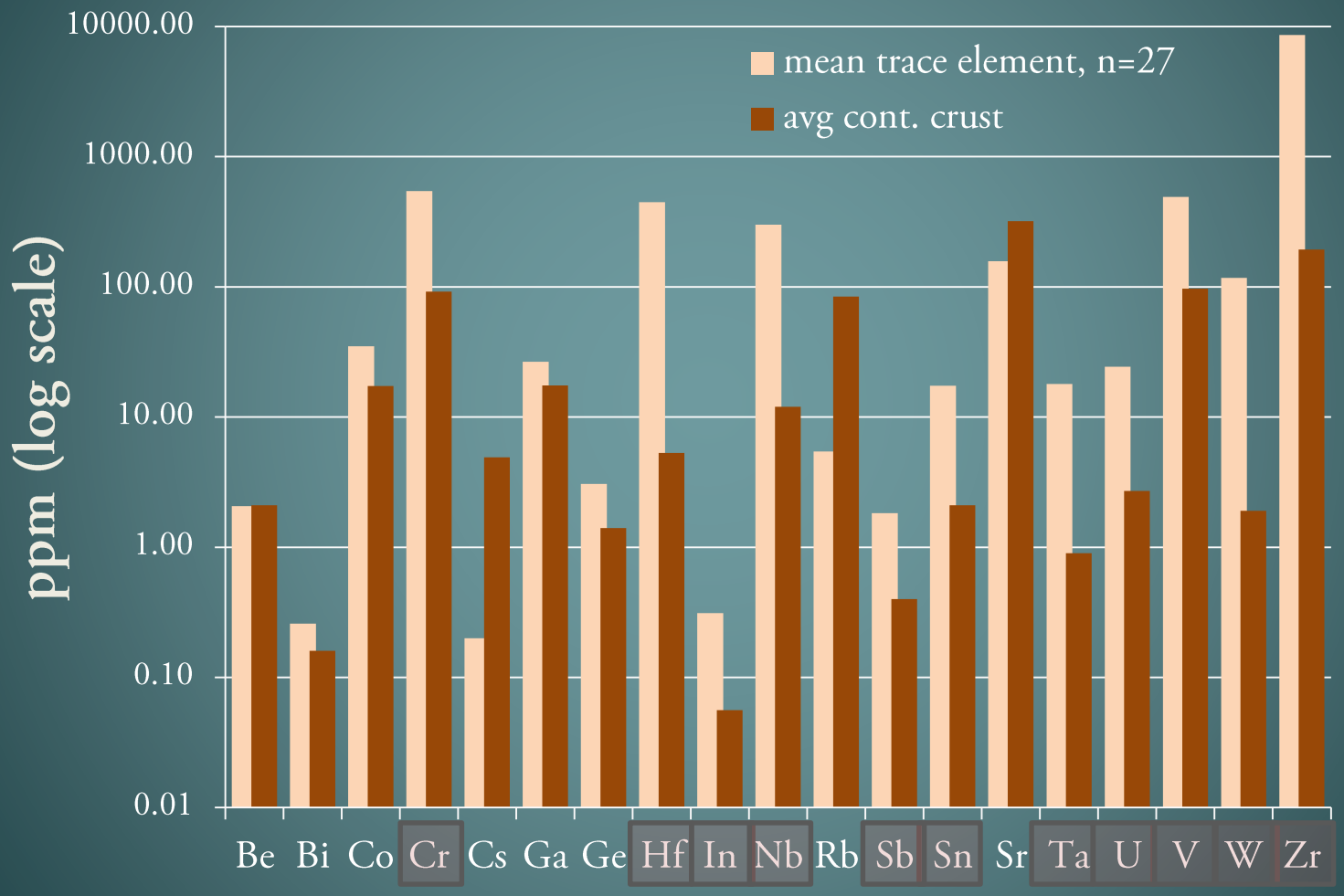


Mean grain sizes of heavy minerals are in the range of very fine sand to silt, n=126



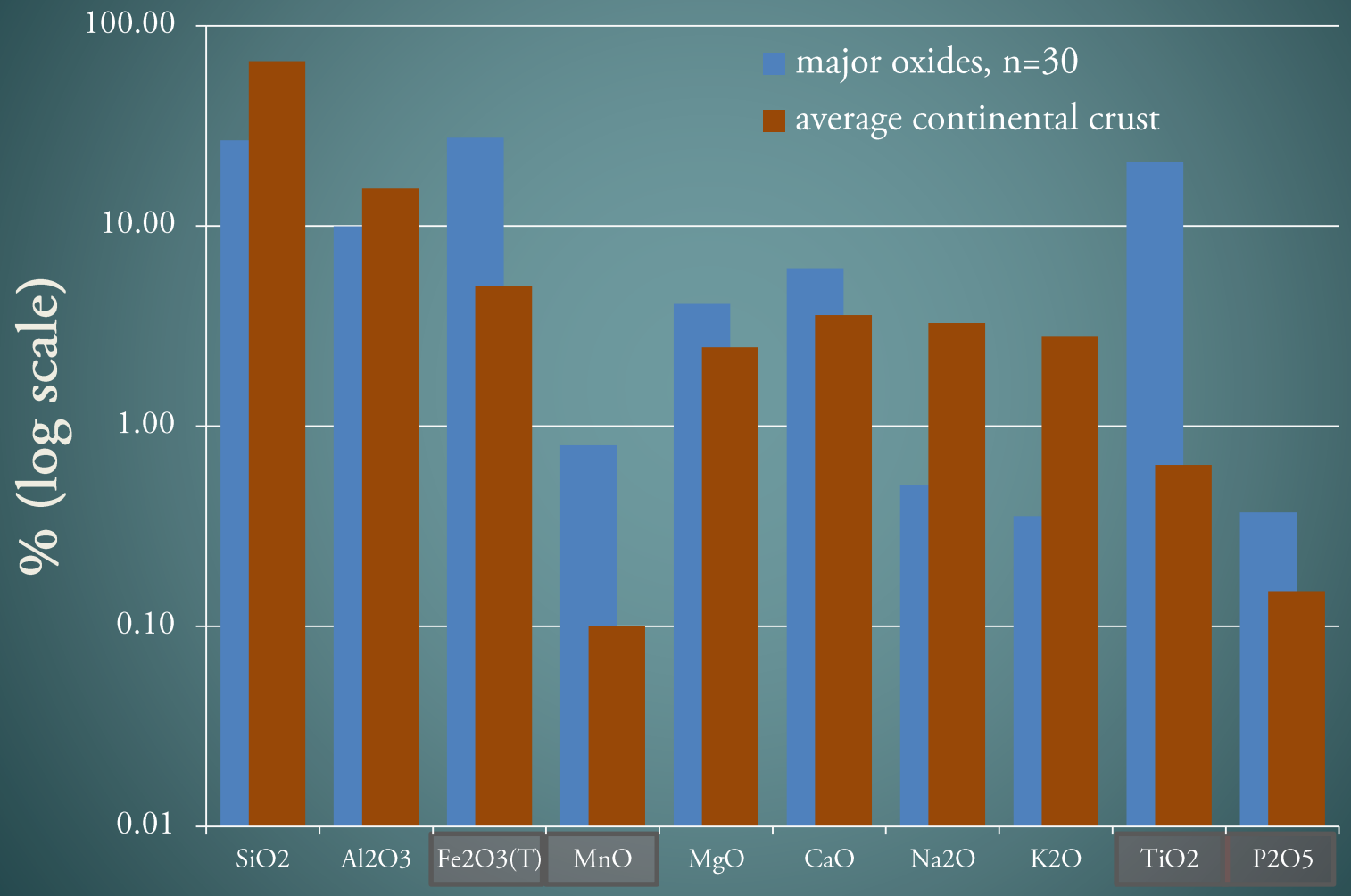
Grain size data available only for Ti- and Zr-minerals identified in the concentrates

Critical commodities in heavy mineral concentrates offshore of Virginia



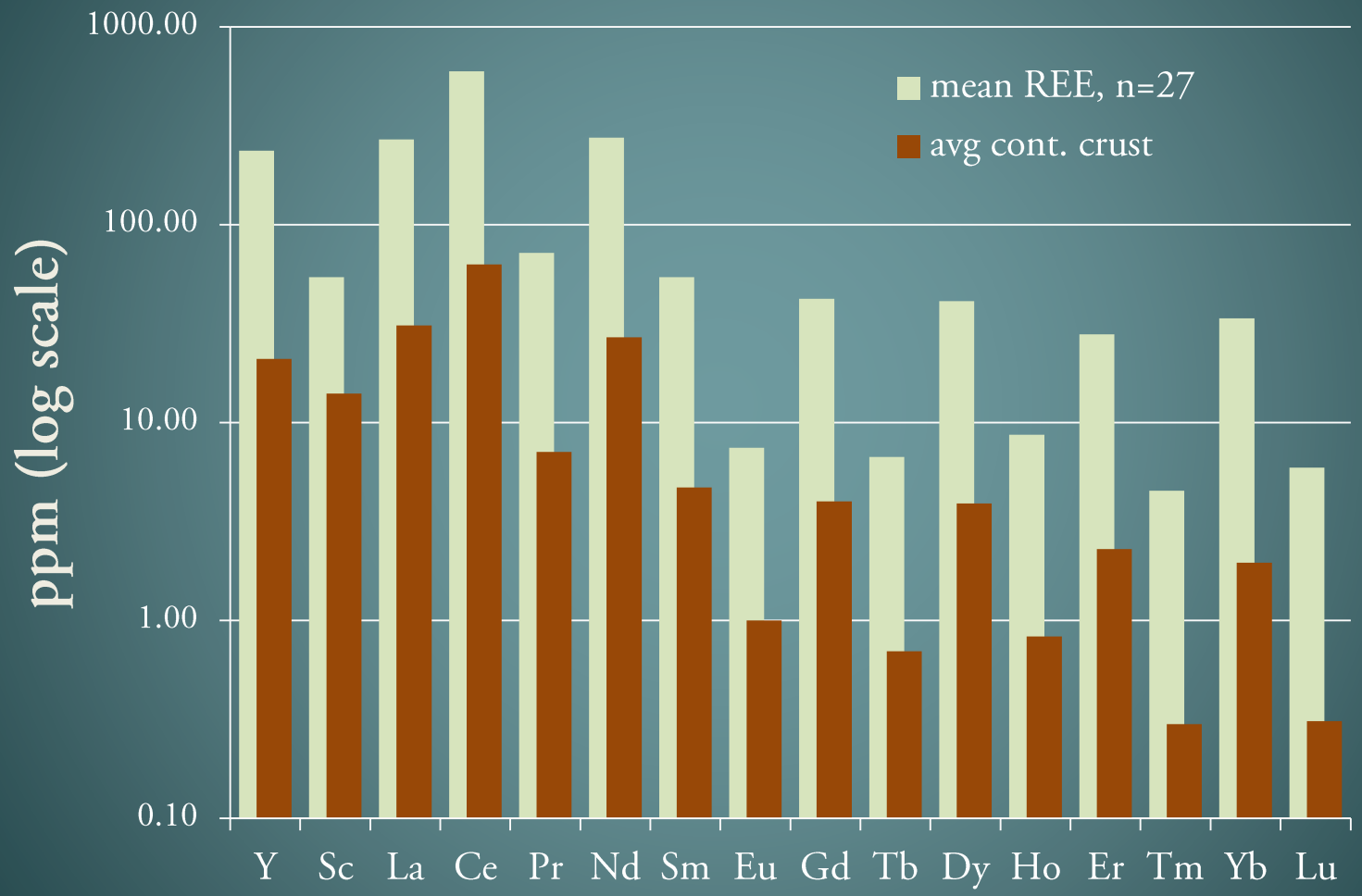
Source: Rudnick and Gao, 2003; Taylor and McLennan, 1985

Major oxides in heavy mineral concentrates



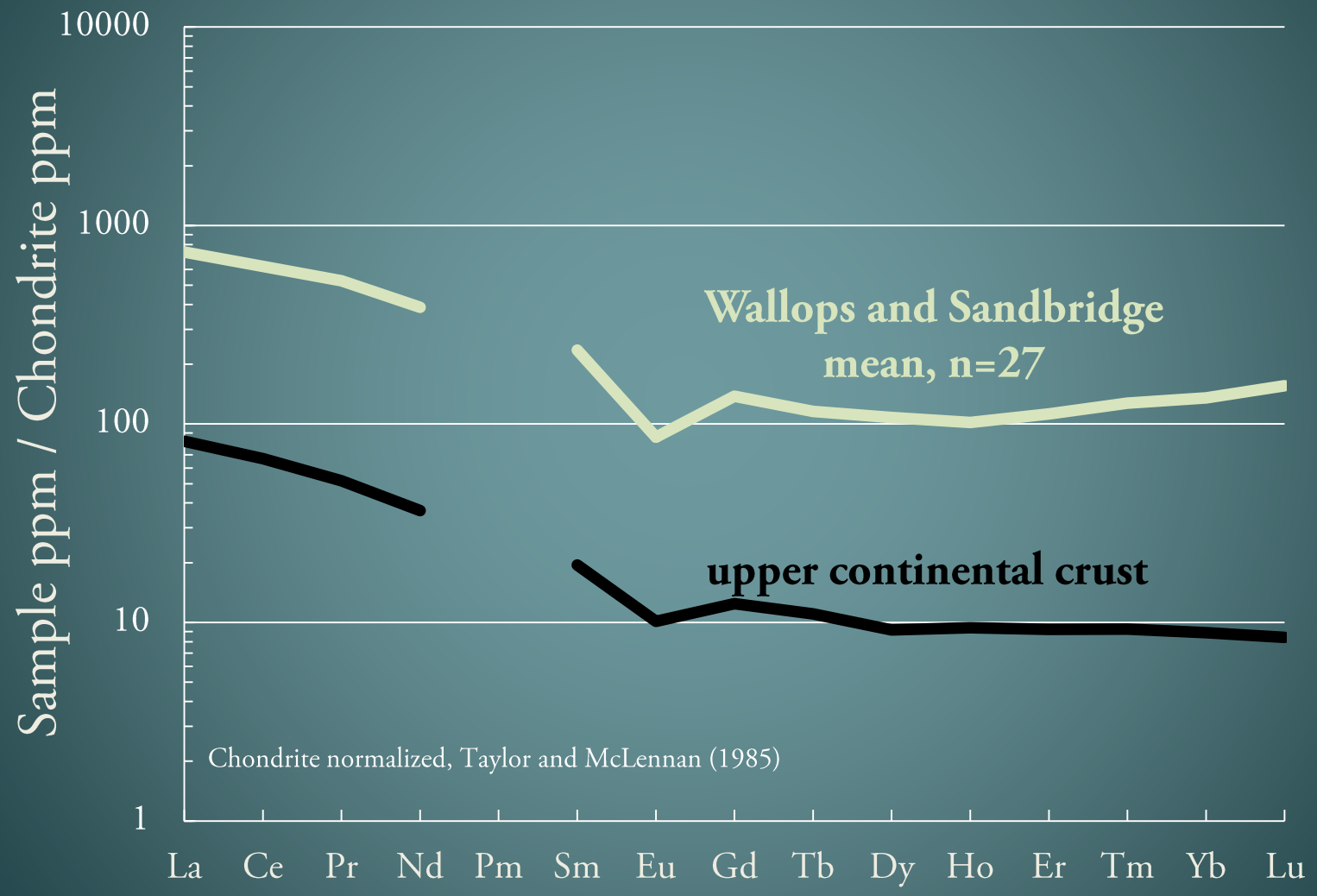
Source: Rudnick and Gao, 2003; Taylor and McLennan, 1985

Rare earth elements in heavy mineral concentrates offshore of Virginia

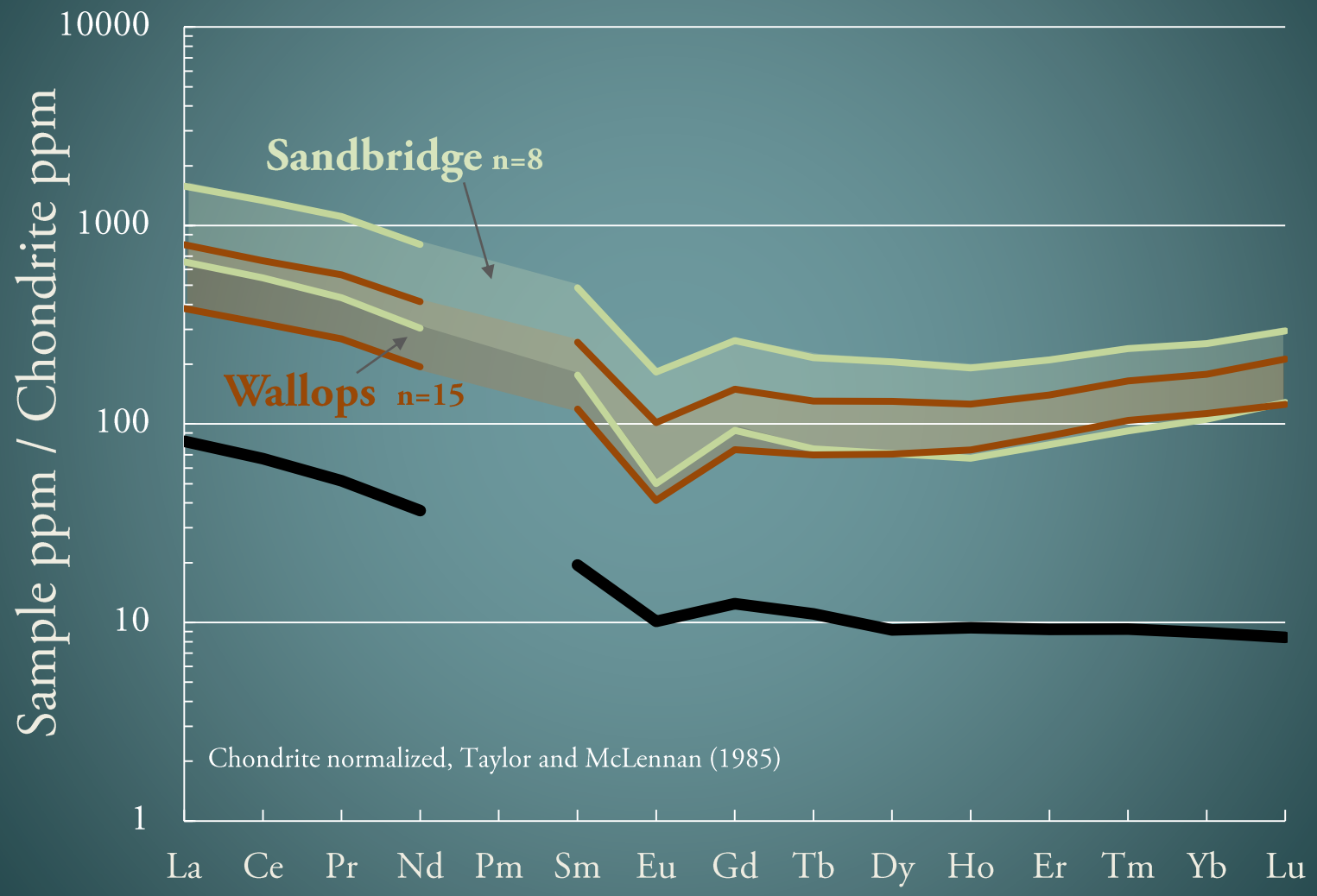


Source: Rudnick and Gao, 2003; Taylor and McLennan, 1985

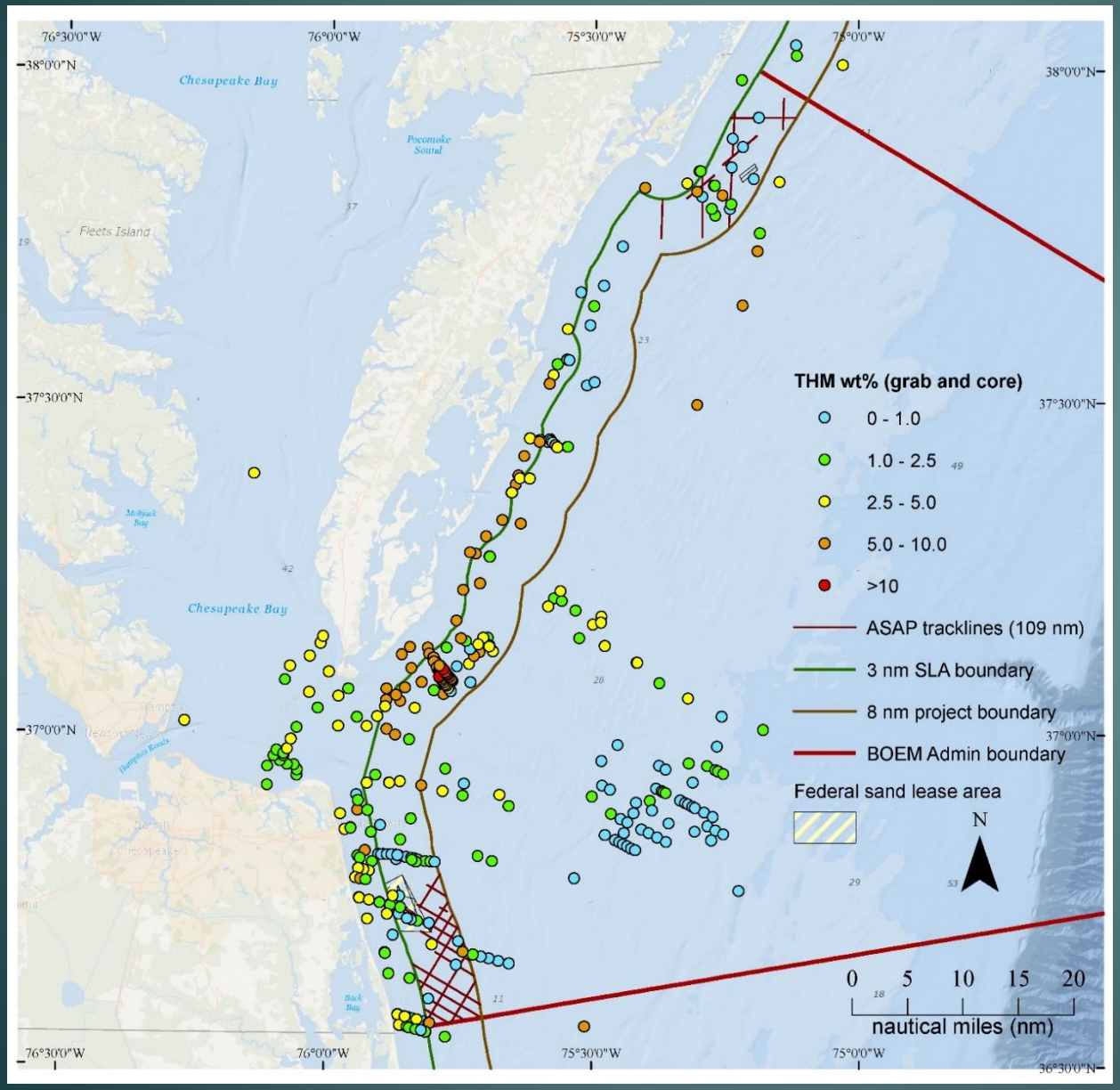
REE enrichment in heavy mineral concentrates, HREE enrichment due to fractionating phases zircon and garnet



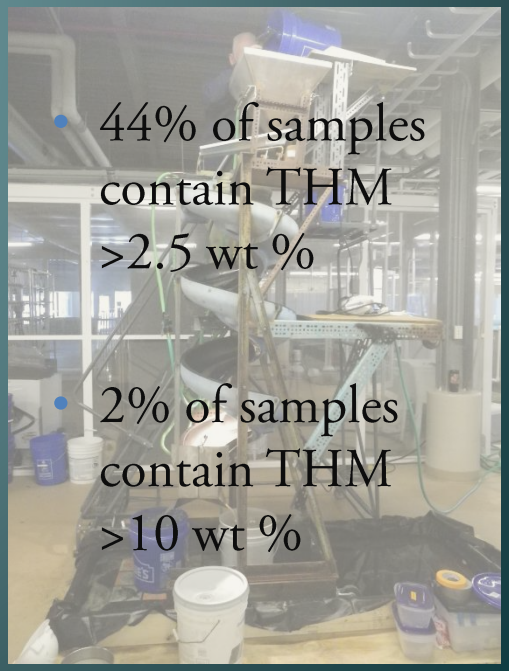
Sandbridge relatively enriched in LREEs compared to Wallops, not due to higher wt % monazite, possibly allanite?



629 sediment samples analyzed for THM averaging 2.7 wt % overall

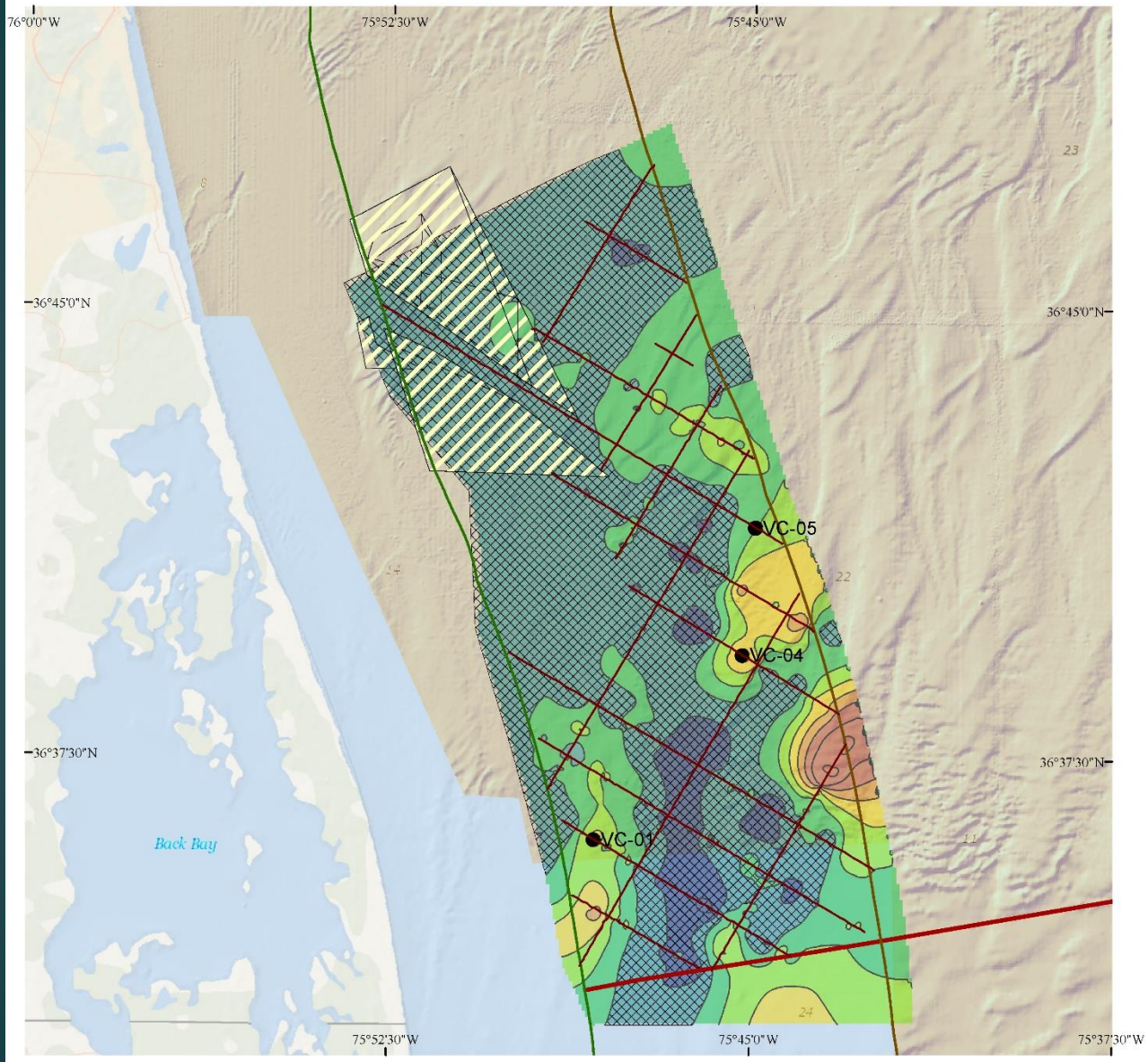


- seafloor grab
  5-gallon bucket containers
- vibracore
  typically 0-5', 5-10' composites



- 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)

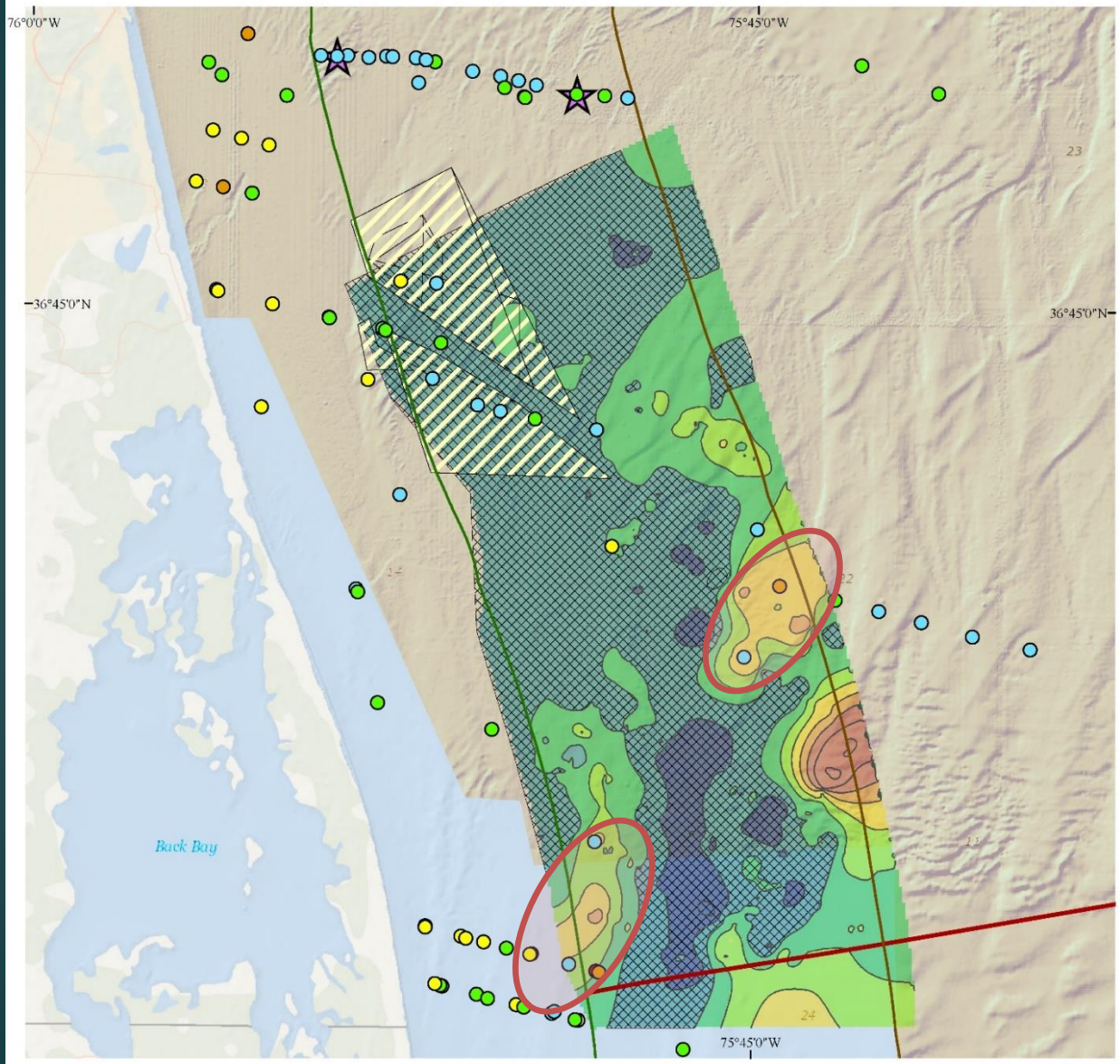
- >30
- 25 - 30
- 20 - 25
- 15 - 20
- 10 - 15
- 5 - 10
- <5

N

0 1 2 3 4 5

nautical miles (nm)

Sandbridge resource area



THM wt% (grab and core)

- 0 - 1.0
- 1.0 - 2.5
- 2.5 - 5.0
- 5.0 - 10.0
- >10
- detrital zircon age date
- 3 nm SLA boundary
- 8 nm project boundary
- BOEM Admin boundary
- Federal sand lease area
- NOAA multibeam hillshade (high – low)

sand resource thickness (ft)

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nautical miles (nm)

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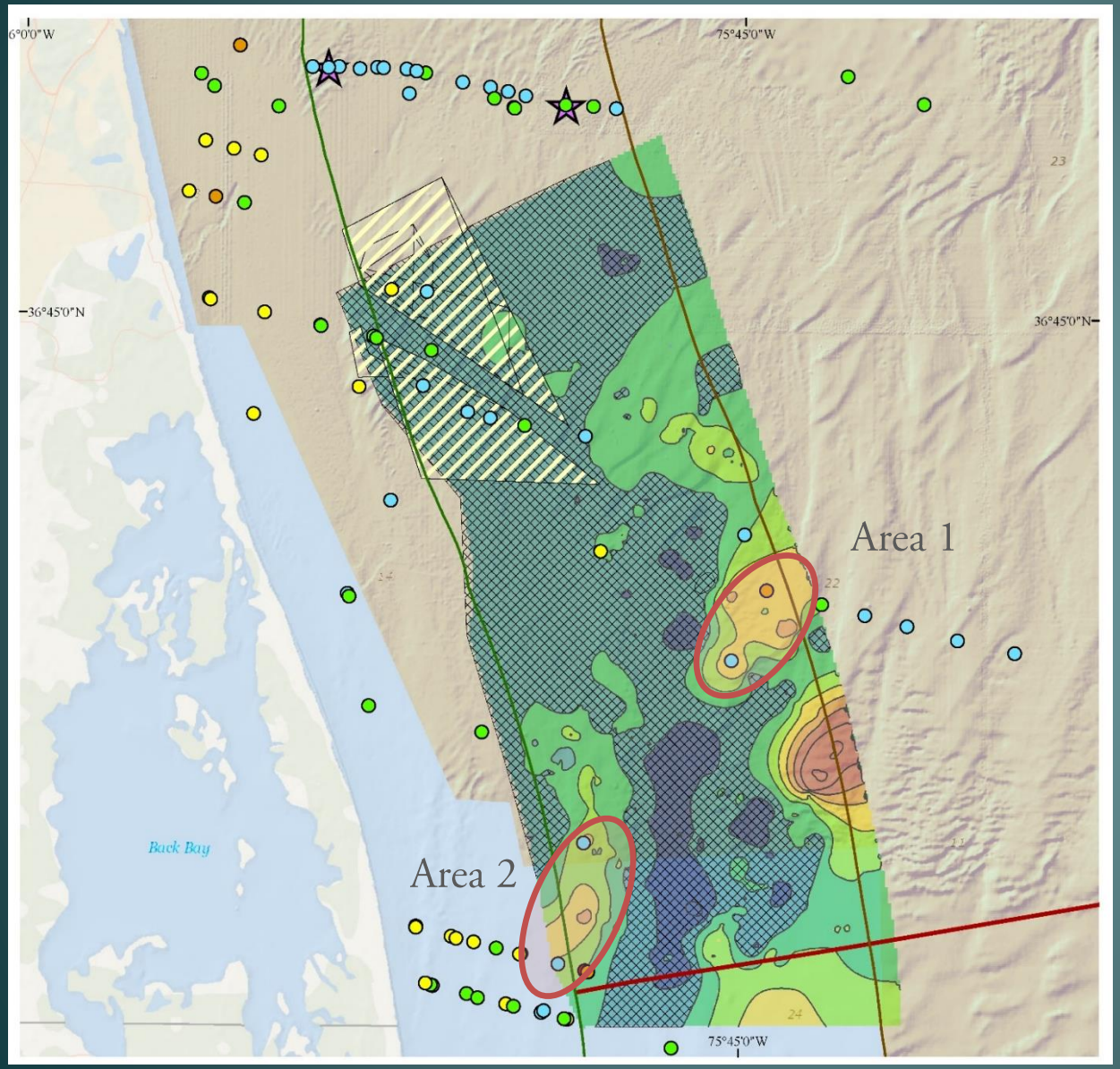
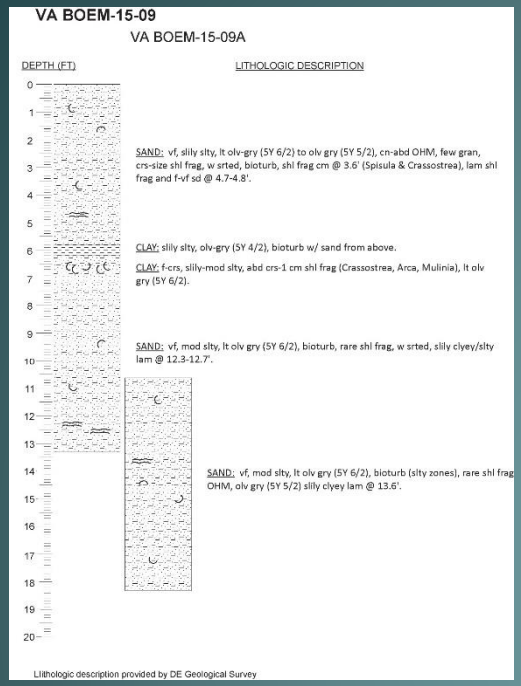


Area 1: 133M ft^2 (3.6 nm^2)
@thickness: 5 ft
volume: 25M yd^3 (34Mt)
THM avg 2.0 wt %
estimated value $177M
~$7.15 per yd^3

Area 2: 164M ft^2 (4.4 nm^2)
@thickness: 5 ft
volume: 30M yd^3 (41Mt)
THM avg 2.1 wt %
estimated value $228M
~$7.51 per yd^3

US Bureau of Mines OFR 4-87 tonnage factor 1.36 tonne/yd^3; values rounded.

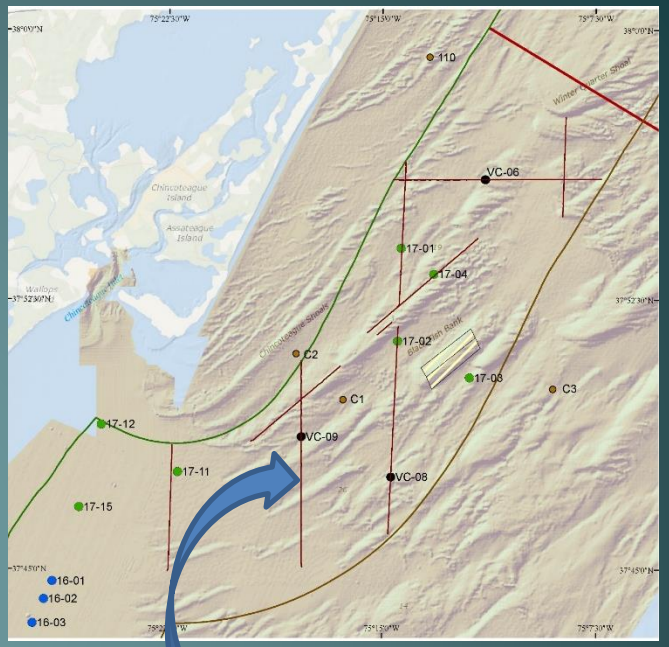
Wallops resource area



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

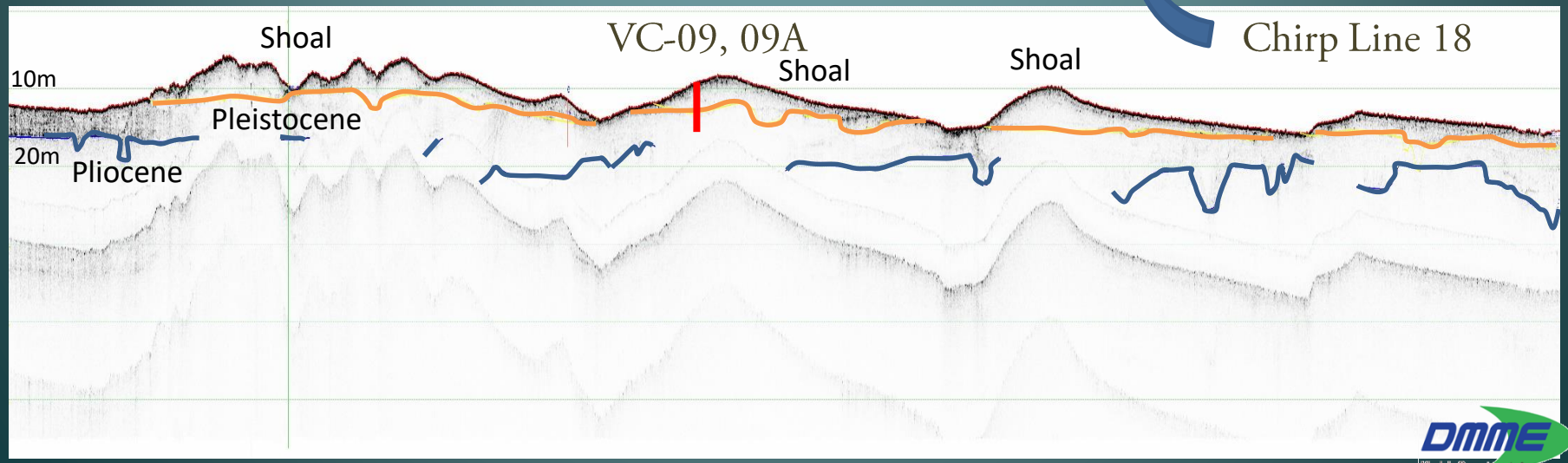
C-1
0 – 10 ft
THM avg 2.7 wt%

VC-08
0 – 16.5 ft
THM avg 0.57 wt%

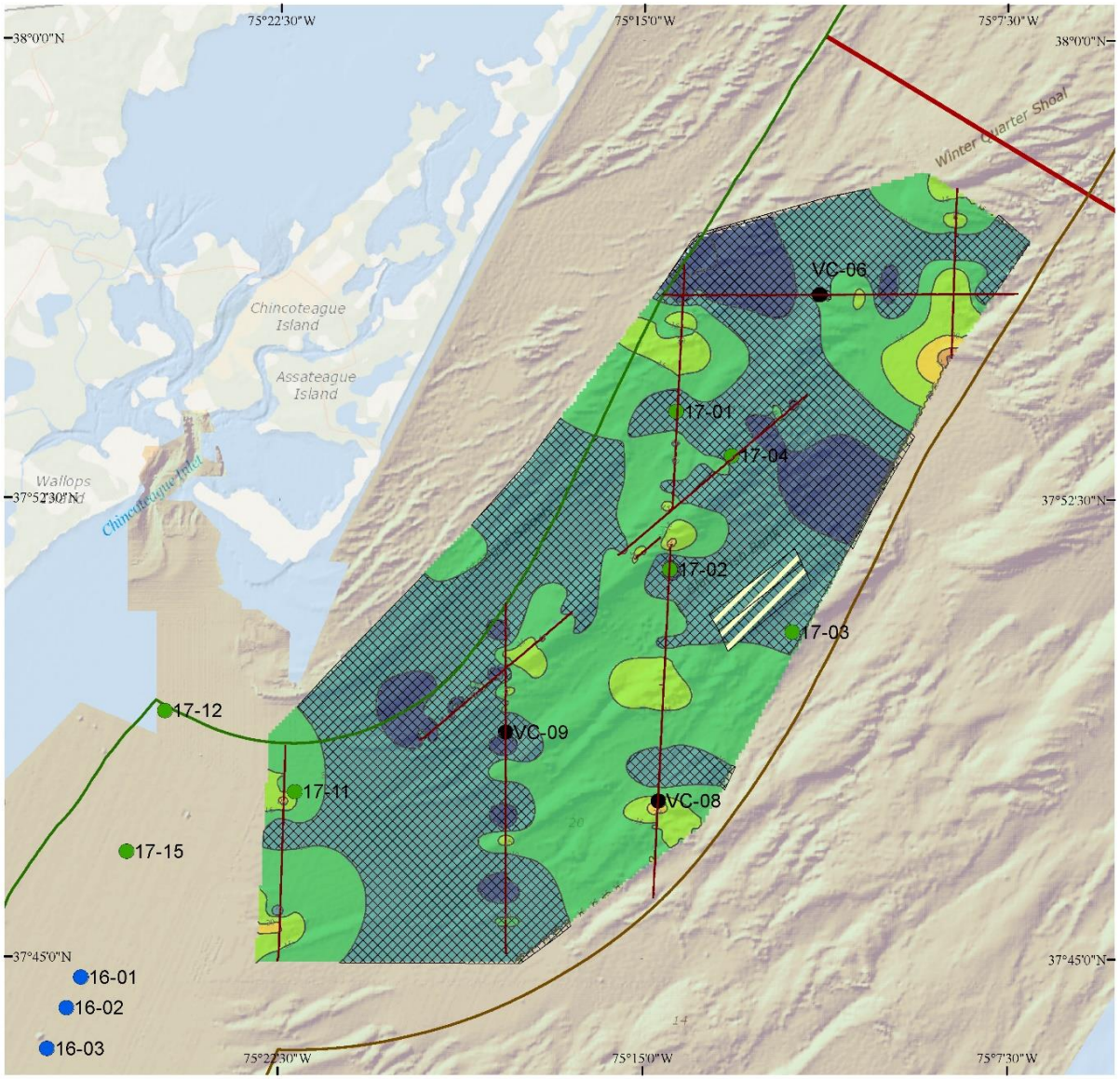


N

S



Wallops resource area >10 ft thickness



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BOEM Admin boundary

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NOAA multibeam hillshade

high

low

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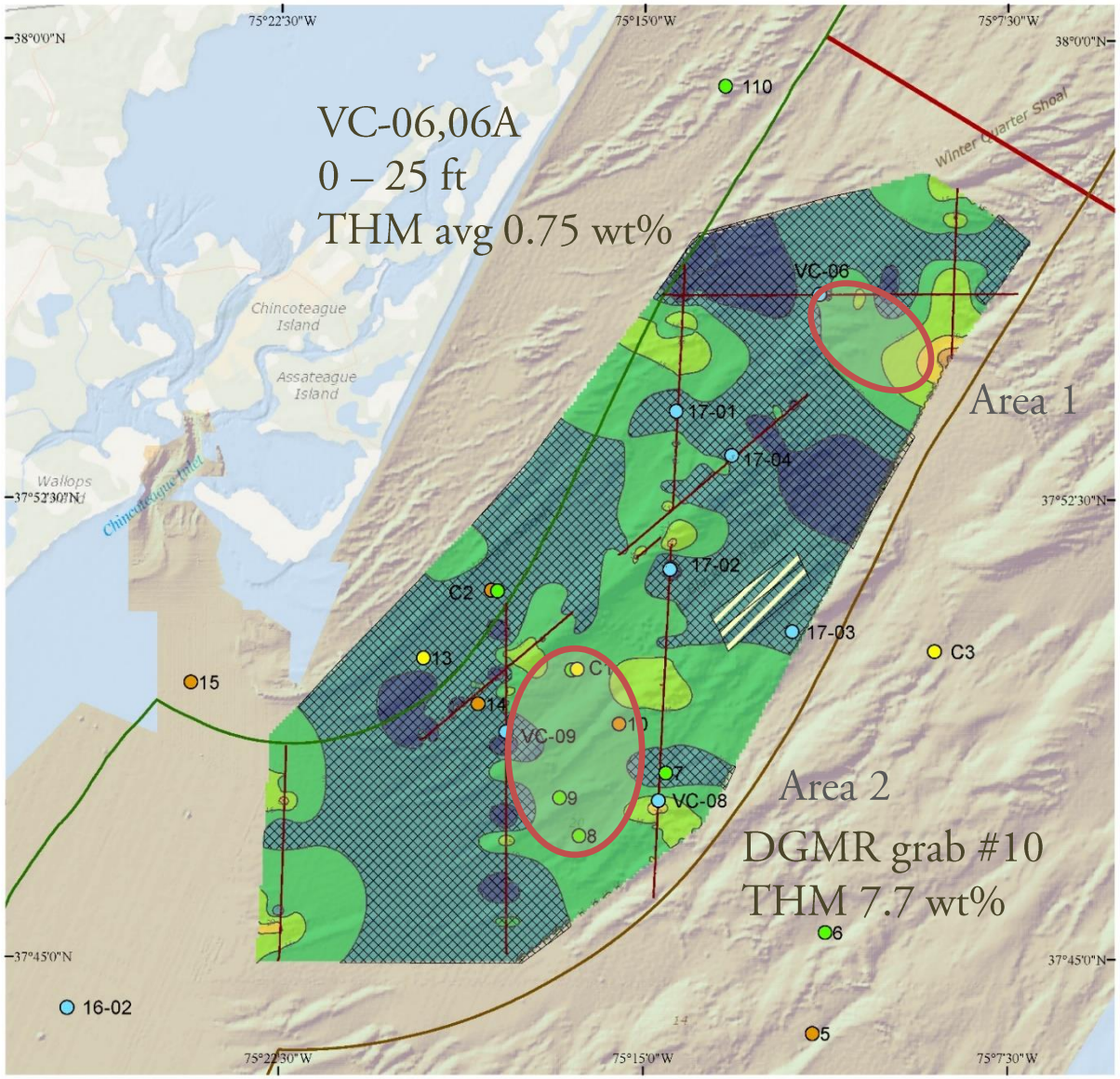
N

0 1 2 3 4 5

nautical miles (nm)

Wallops resource area



THM wt% (grab and core)

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- 1.0 - 2.5
- 2.5 - 5.0
- 5.0 - 10.0
- >10

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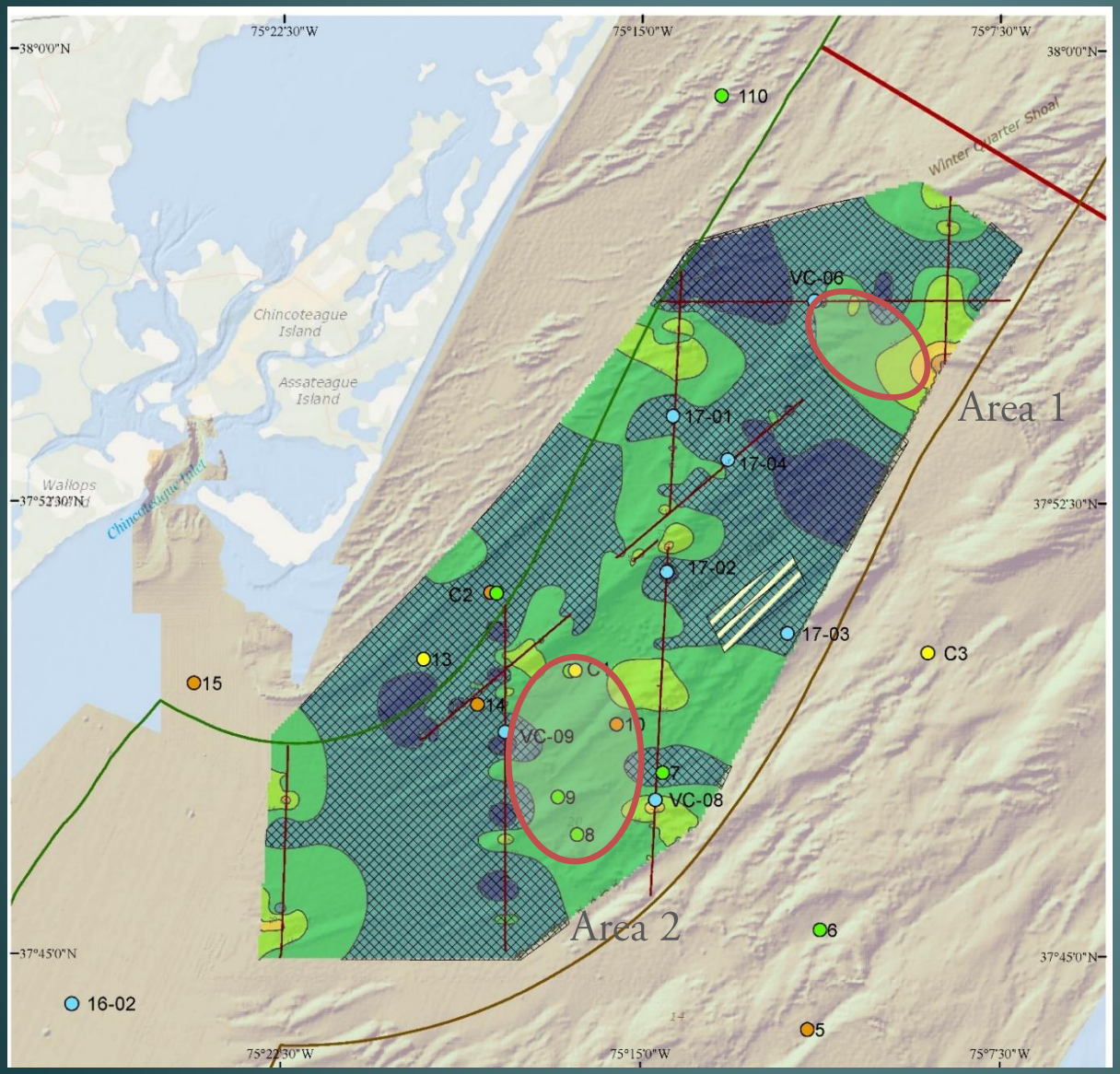
Wallops resource area

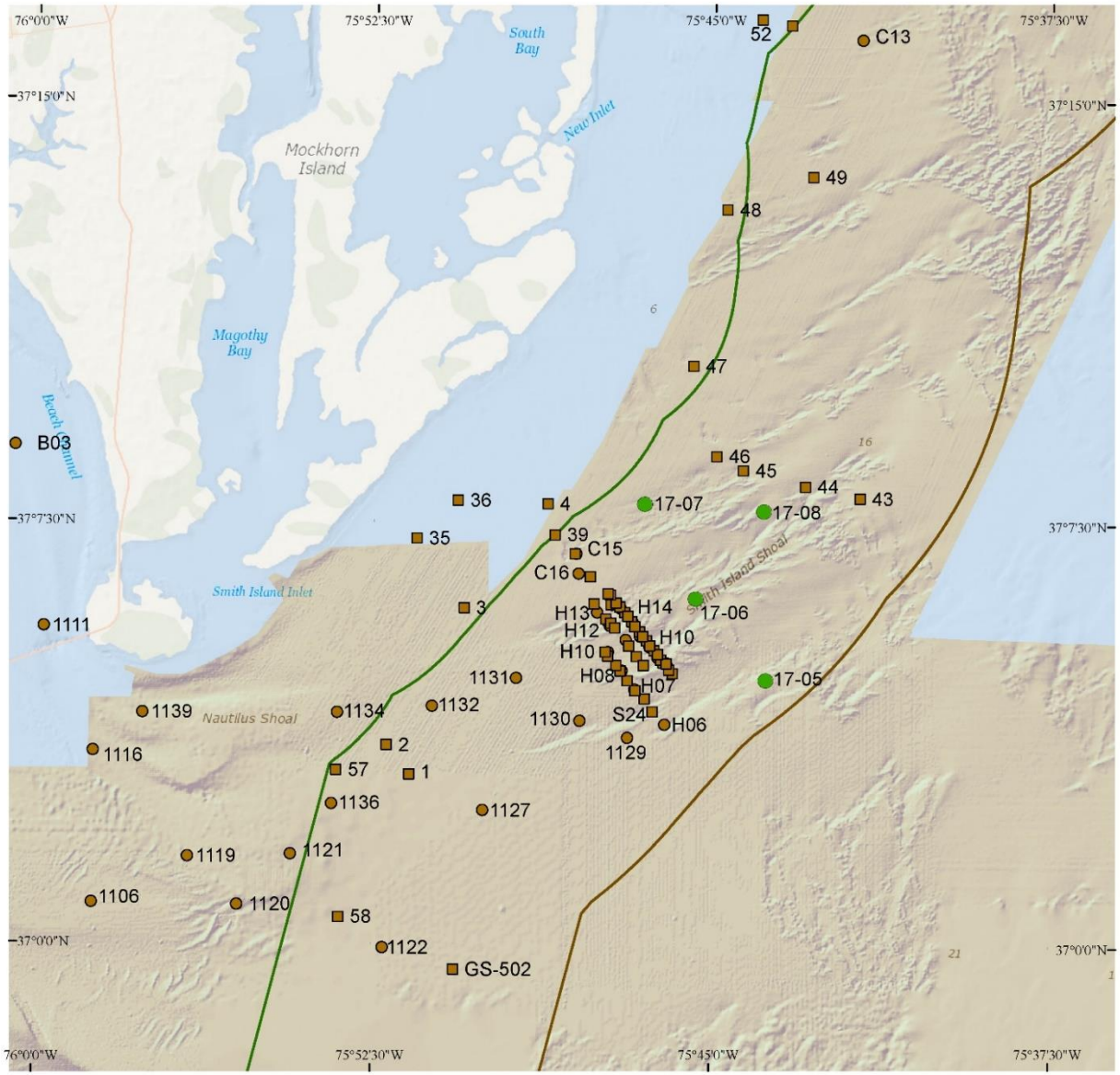


Area 1: 73M ft^2 (2.0 nm^2)
@thickness: 5 ft
volume: 14M yd^3 (18Mt)
THM avg 0.75 wt %
estimated value $36M
~$2.68 per yd^3

Area 2: 198M ft^2 (5.4 nm^2)
@thickness: 5 ft
volume: 37M yd^3 (50Mt)
THM avg 2.1 wt %
estimated value $275M
~$7.51 per yd^3

US Bureau of Mines OFR 4-87 tonnage factor 1.36 tonne/yd^3; values rounded.

Smith Island Shoals



DGMR grab

DGMR core

2017 vibracore

3 nm SLA boundary

8 nm project boundary

BOEM Admin boundary

NOAA multibeam hillshade

high

low

N

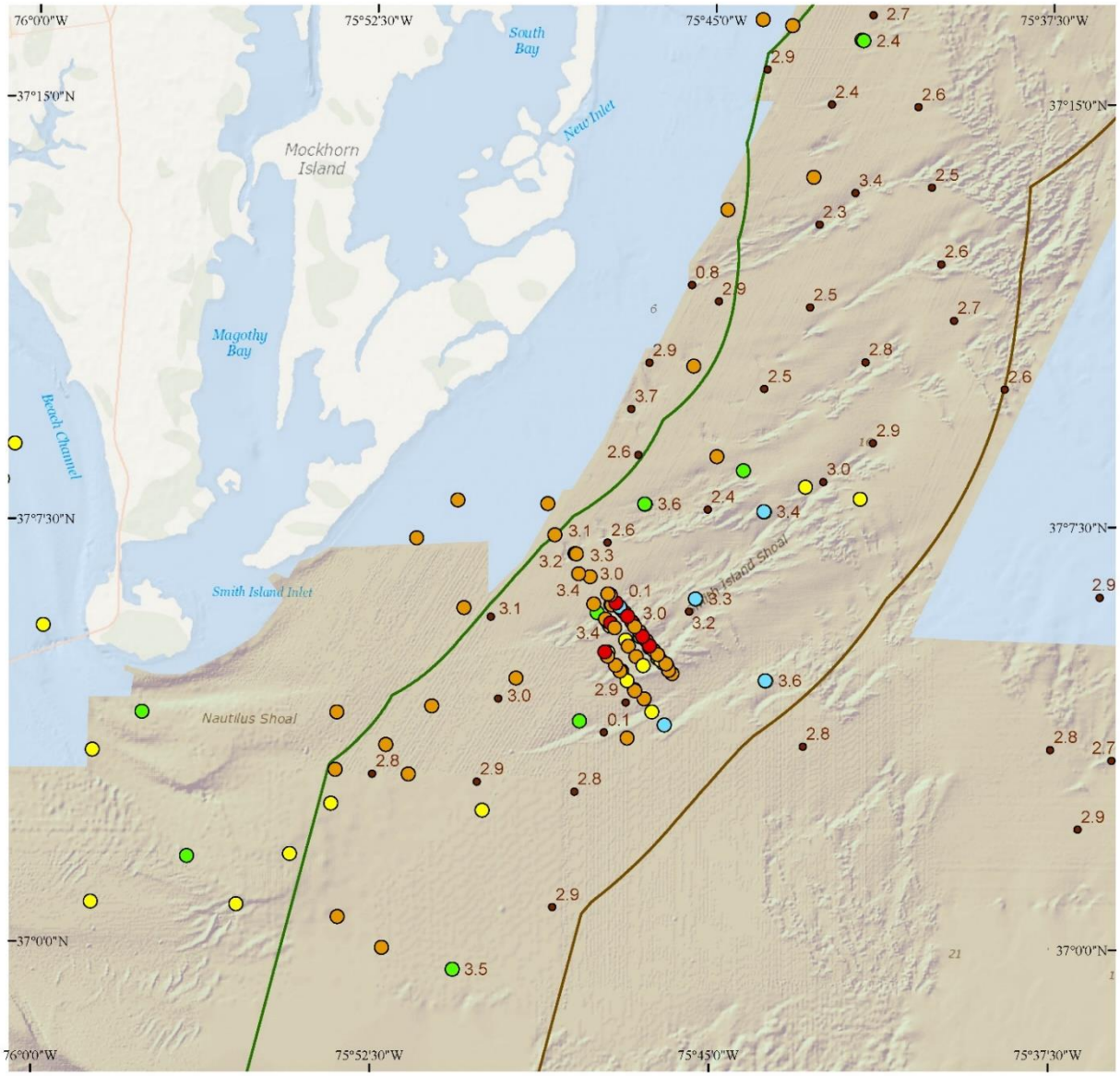
0 1 2 3 4 5

nautical miles (nm)

DMME

Virginia Department of Mines Minerals and Energy

Smith Island Shoals



THM wt% (grab and core)

- 0 - 1.0
- 1.0 - 2.5
- 2.5 - 5.0
- 5.0 - 10.0
- >10
- grab sample (mean phi)
- core sample (mean phi)
- USGS Delmarva 2015 grab sample
- 2017 vibracore
- 3 nm SLA boundary
- 8 nm project boundary
- BOEM Admin boundary

NOAA multibeam hillshade

high

low

N

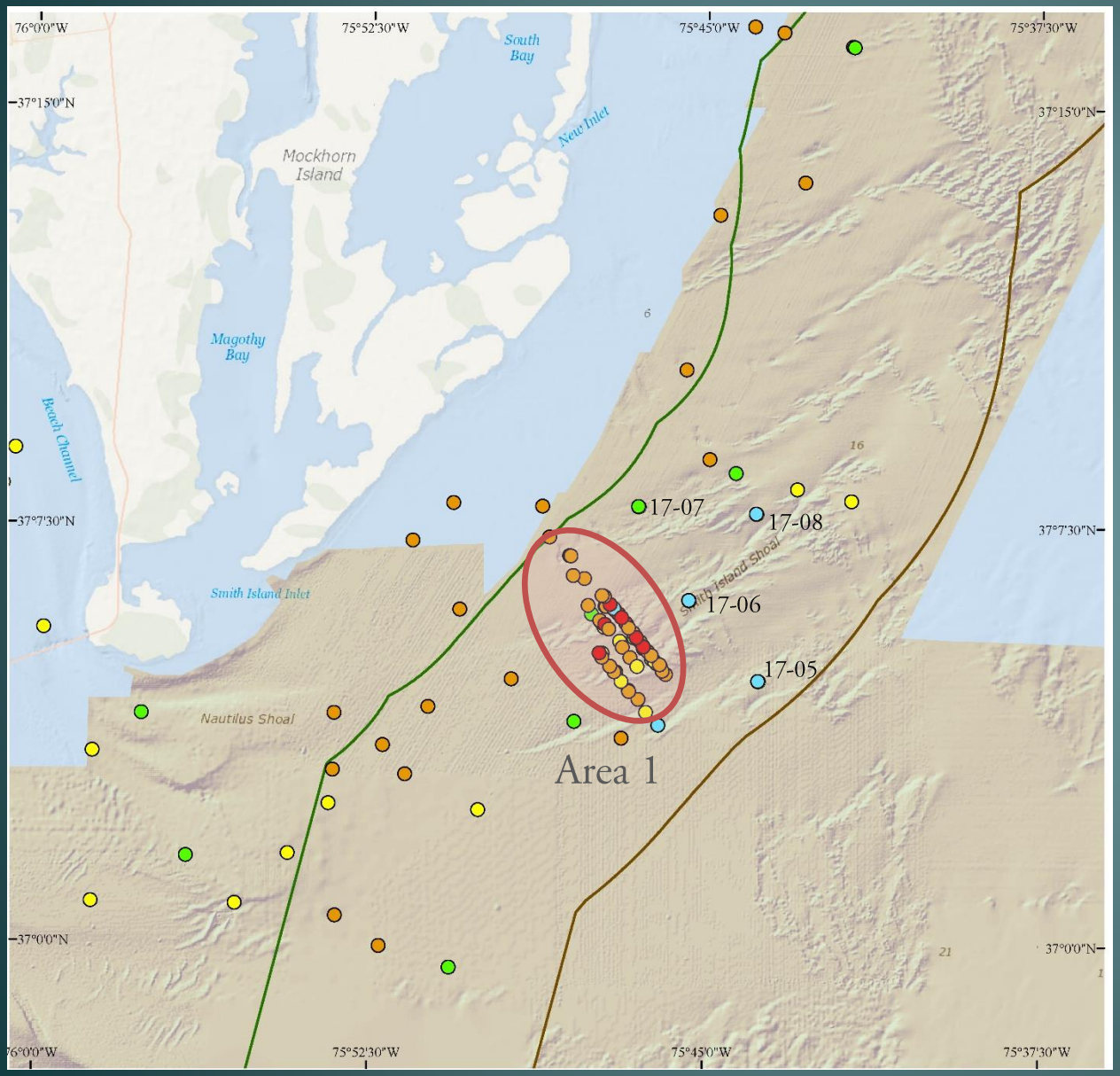
0 1 2 3 4 5

nautical miles (nm)

DMME

Virginia Department of Mines Minerals and Energy

Smith Island Shoals

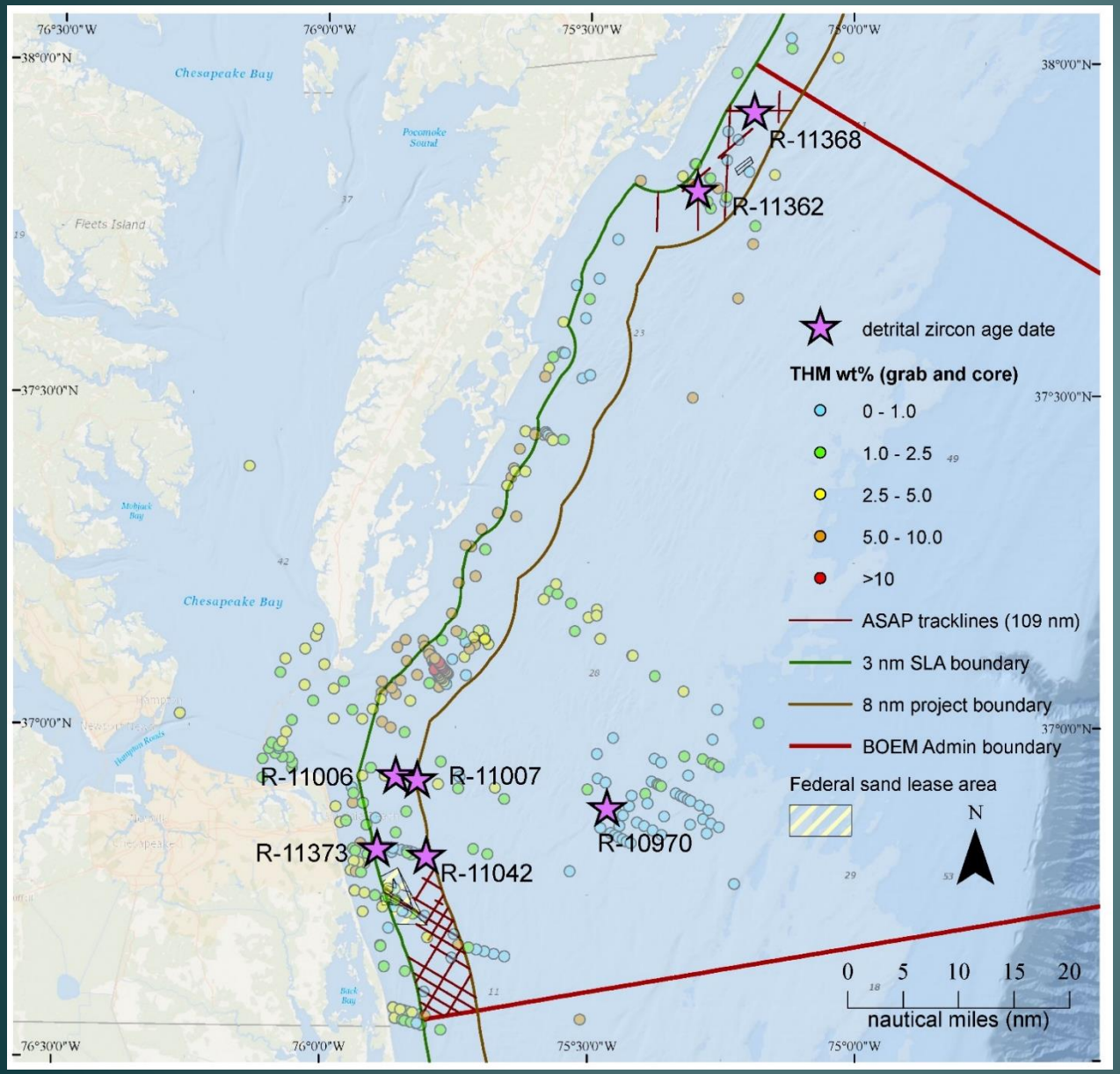


Area 1: 232M ft^2 (6.3 nm^2)
@thickness: 5 ft
volume: 43M yd^3 (58Mt)
THM avg 6.0 wt %
estimated value $920M
~$21.46 per yd^3

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

US Bureau of Mines OFR 4-87 tonnage factor 1.36 tonne/yd^3; 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

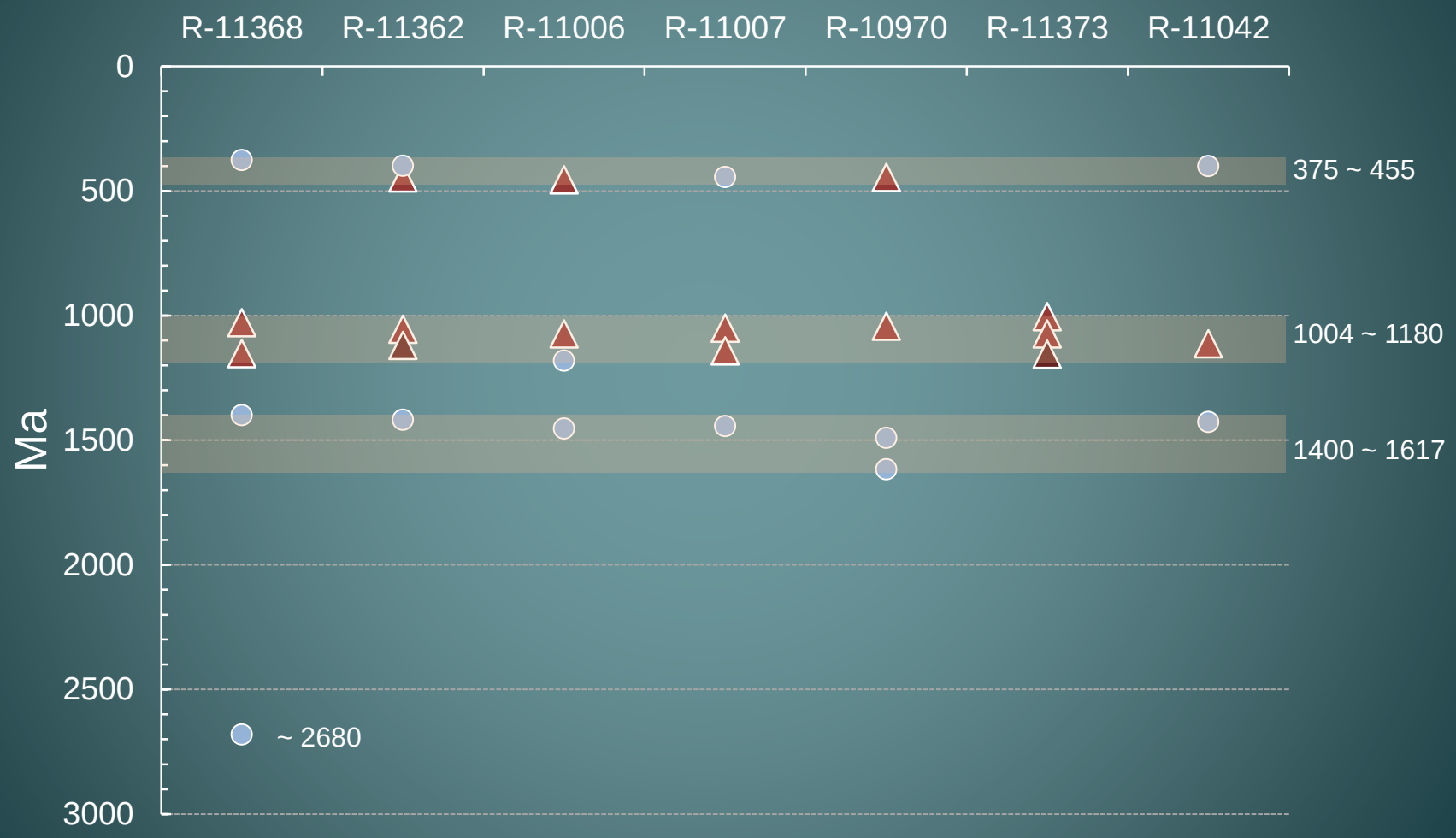
R-11007
1050, 1141 Ma
444, 1443 Ma

R-10970
446, 1043 Ma
1491, 1617 Ma

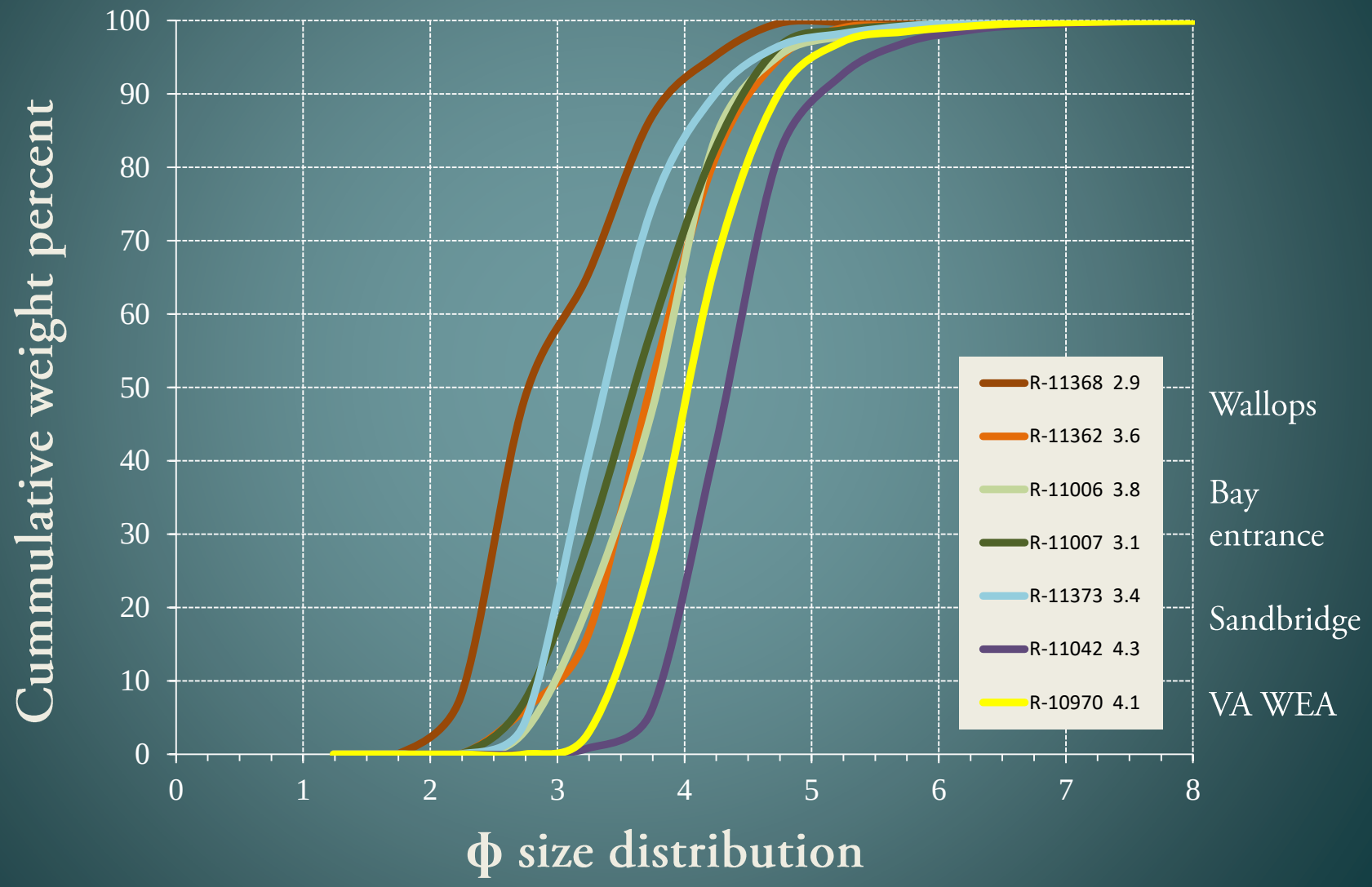
R-11373
1004, 1074, 1155 Ma

R-11042
1113 Ma
400, 1427 Ma

Detrital zircon U-Pb



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, stauroilite.

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:

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

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

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Mike Enomoto - DGMR

Eleanor Worthington - College of W&M

Patti Burton - VIMS

Laura Brothers - USGS

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AMINO ACID RACEMIZATION (AAR)

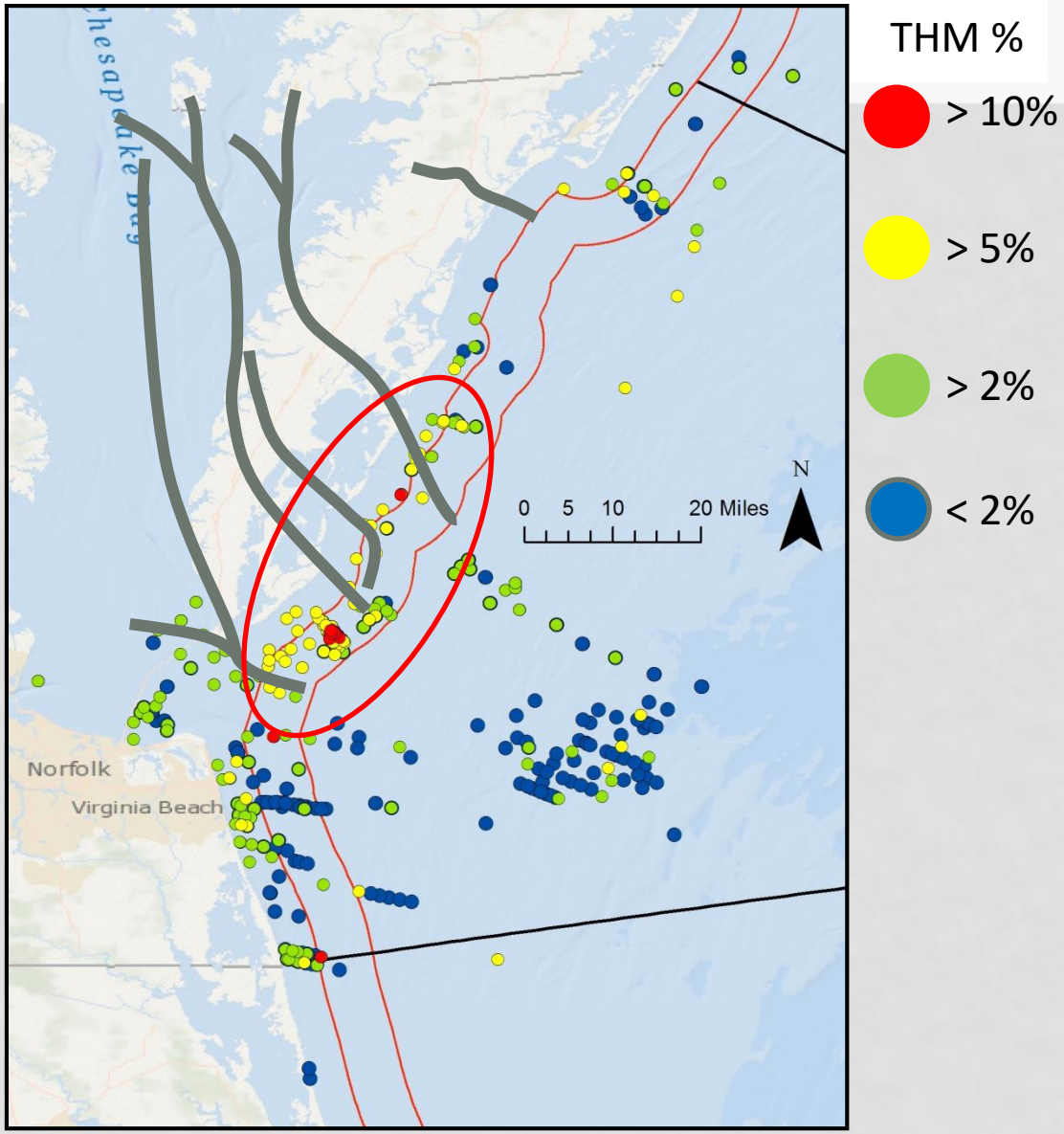
- AAR dating was completed on 8 out of 9 cores

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

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