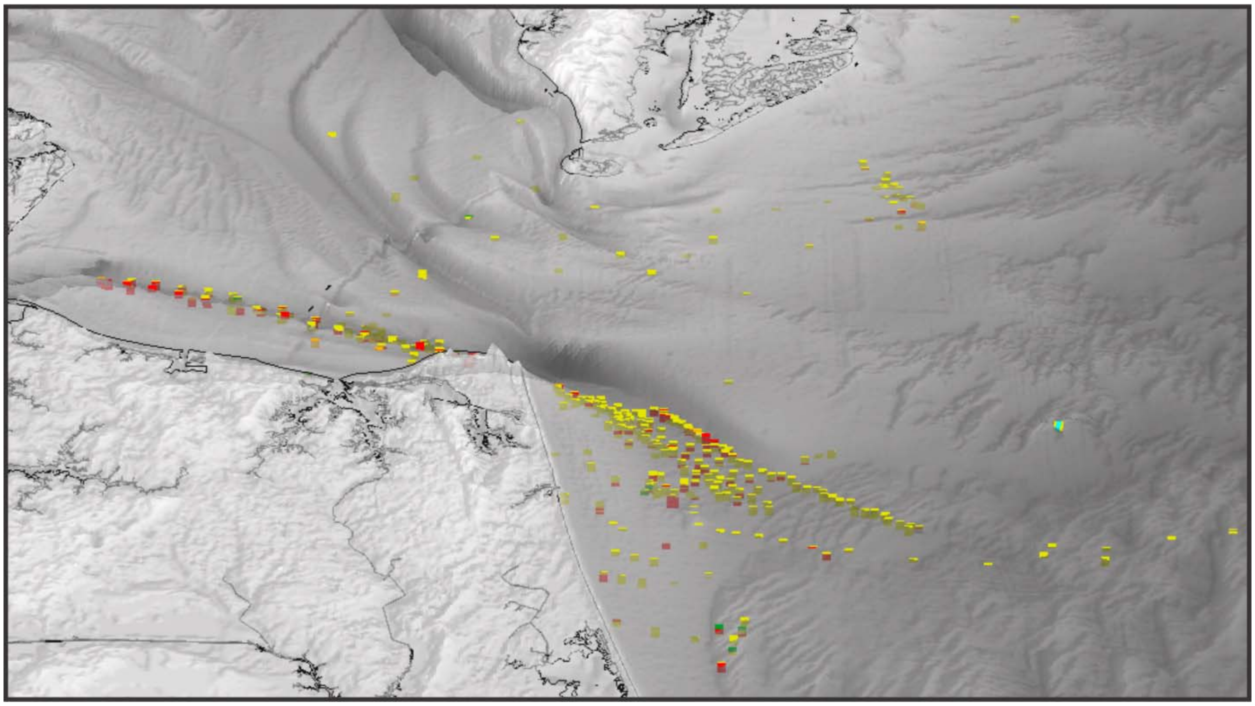
Digital conversion of geologic core data, modeling, and visualization of sand resources on Virginia's continental shelf

Final Draft



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Introduction

For the past 50 years, geologic data has been collected offshore Virginia's ocean coast (Figure 1) from the North Carolina state line to the Maryland state line. Generally, the studies sought to characterize the sediment and geologic structure offshore. Much of the data was taken by personnel at the Virginia Institute of Marine Science (VIMS). Over time, this data and data from other sources became part of the Shoreline Studies Program's (SSP) data archive.

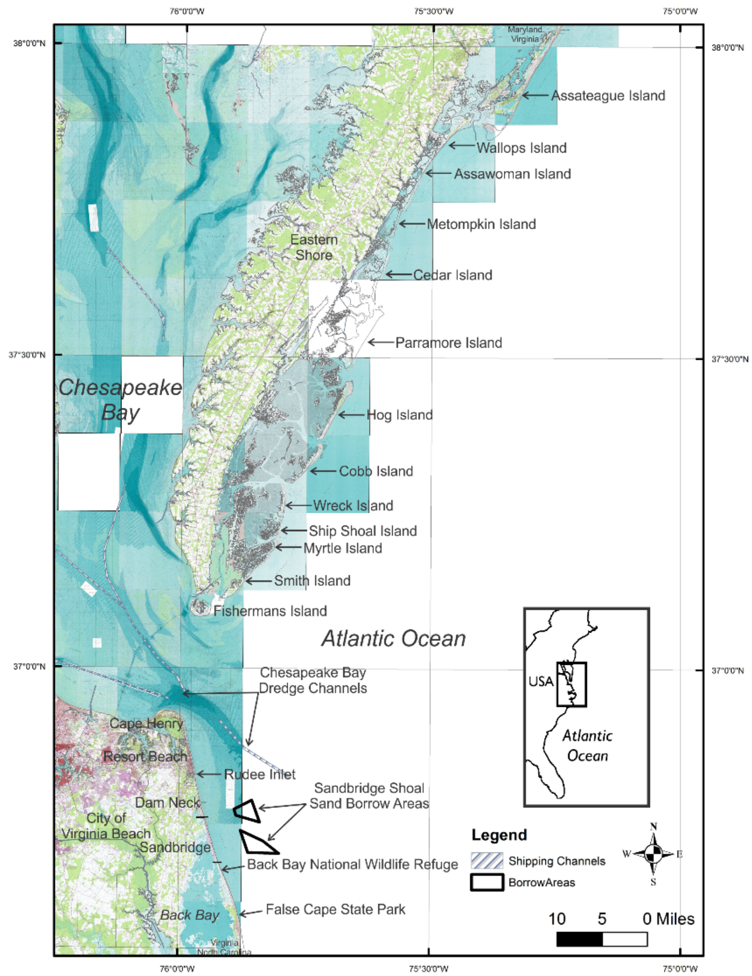


Figure 1. The study area includes inner continental shelf adjacent to Virginia.

In order to better manage sand resources, the Minerals Management Service (now Bureau of Ocean Energy Management) contracted with VIMS in 2006 to create a database of existing offshore geophysical data. This database centralized data that had previously only existed on paper rolls and in various reports. To facilitate the identification of resources, high resolution seismic profiles, cores, and sediment grab samples from the inner continental shelf offshore of Virginia were input to GIS databases. GIS was chosen because of its mapping ability, and because it is a widely-used platform, data could be dispersed to other users. The original trackline and location data, which were logged using a Loran-C and later GPS systems, were converted to ArcGIS point locations. Seismic line rolls and core logs were scanned as images and linked to their point locations in GIS. Grain size data was attributed in GIS at point locations. In all, three separate databases were created in 2006 by SSP and included 147 sub-bottom seismic tracklines, 308 cores, and 834 sediment grab samples.

These databases provided the ability to visually inspect data in the context of its location, but it did not allow for comparison. To manage sand resources appropriately, it is necessary to identify, locate, and describe sources of beach quality material. The goal of this effort was to convert the tiff images of geologic cores into a digital database that could be input to Esri ArcGIS. ArcGIS was chosen because it is a widely-used platform and for its modeling, analytical, and visualization ability. ArcGIS provides the tools needed to model and analyze the digital core log data. Locating and mapping areas where the sand is in the upper section of the core is a priority. This GIS modeling effort provides the means to spatially visualize all available cores in both the horizontal and vertical directions.

Methods

Core Log Acquisition & Input

The SSP's existing geophysical database for the Virginia Ocean Coast was utilized in this analysis as well as data from other sources, including the US Army Corp of Engineers (Meisburger, 1972), USGS (Williams, 1987), Maryland Geological Survey (Toscano *et al*., 1989), Fugro (2013), Tetra Tech (2014), and Alpine (2007 & 2008) (Figure 2). These sources were queried for core log information that could be used to analyze the sand and mineral resources available offshore of Virginia's coast. Hardcopy reports were scanned and converted to Adobe Acrobat format for preservation and organization. Individual core data including source identification, year of collection, top and bottom elevations, water depth, stratigraphy, lithography, color and geographic locations was extracted from each core log sheets and manually input in Microsoft Excel.

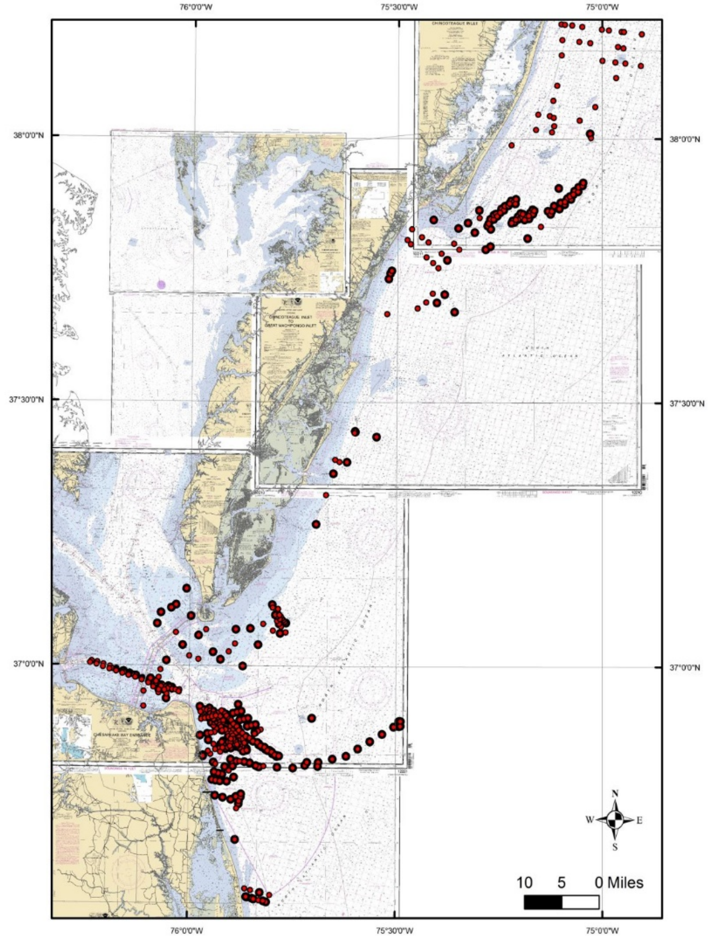


Figure 2. Locations of core logs (red dots) used in analysis.

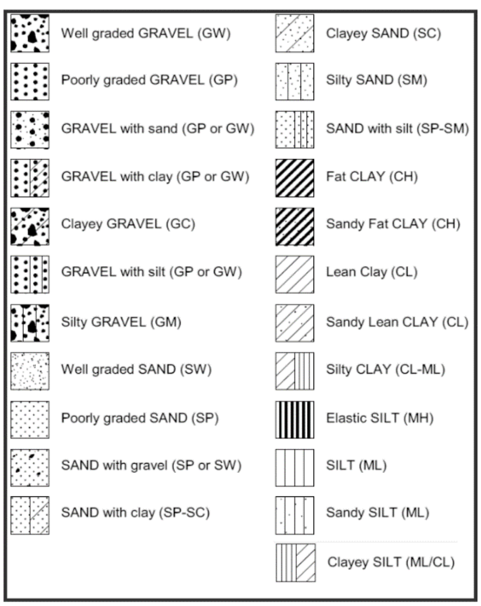


Figure 3. ASTM standard sediment classification designation.

The data used for this analysis ranged from 1963 to 2013 and totaled 494 cores along Virginia's inner continental shelf (Table 1). Quality control was performed by checking selected core logs.

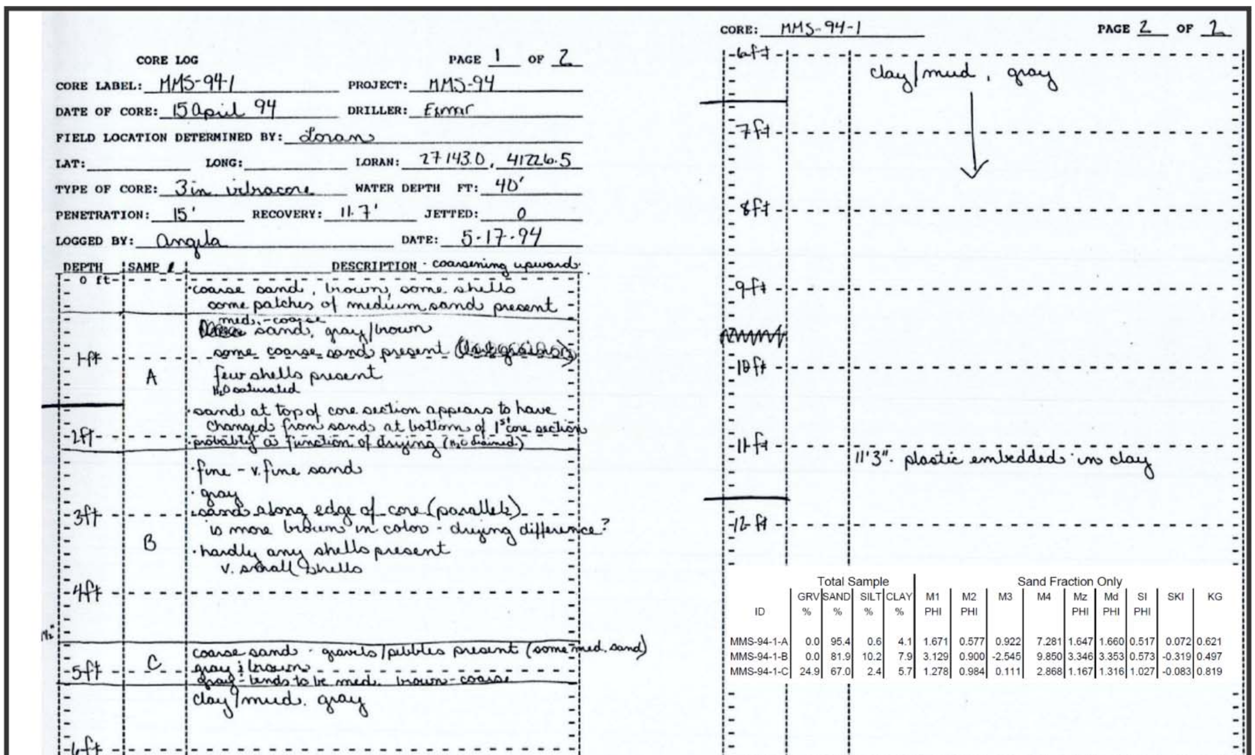
Because the core logs from the different sources and time frames were so varied, each layer within the log was given an ASTM standard classification (Figure 3). Some logs had the standard classification as part of their description, others had grain size analysis, while others simply had a description. The complexity and variability within the core logs required some summarization of information to make analysis feasible (Figure 4). For layers that needed a standard designation, it was assigned by C. Scott Hardaway, Jr., professional geologist, with more than 30 years of experience.

Core Log Modeling & Analysis

Once the individual core log data were input to Excel, the data could be imported to Esri ArcGIS for analysis. This allowed the core information to be viewed spatially, checked, prepared, edited, modeled, and analyzed. Esri ArcMap 10.1 and ArcScene were used in the analysis. ArcScene provides the ability to visualize 3D data by rotating the view and zooming in and out, but figure maps cannot be scaled.

Table 1. Data, number, and source of cores identified for this project.

Date	No. of Cores	Sources
1963	2	FUGRO Consultants
1970	36	USGS/CERC
1981	25	USGS
1983	43	USCOE
1984	28	USCOE
1985	26	VIMS
1985	38	USCOE
1986	60	USCOE
1986	29	Maryland Geological Survey
1987	51	VIMS
1994	21	VIMS
1995	23	USCOE
2007	41	Alpine Ocean
2007	41	Alpine Ocean
2013	31	Tetratech
Total	**495**	



ID	Total Sample GRV %	SAND %	SILT %	CLAY %	Sand Fraction Only M1 PHI	M2 PHI	M3	M4	Mz PHI	Md PHI	SI PHI	SKI	KG
MMS-94-1-A	0.0	95.4	0.6	4.1	1.671	0.577	0.922	7.281	1.647	1.660	0.517	0.072	0.621
MMS-94-1-B	0.0	81.9	10.2	7.9	3.129	0.900	-2.545	9.850	3.346	3.353	0.573	-0.319	0.497
MMS-94-1-C	24.9	67.0	2.4	5.7	1.278	0.984	0.111	2.868	1.167	1.316	1.027	-0.083	0.819

Standard Designation			Stratigraphy_ft			Lithology_ft		
Depth2Top	Depth2Base	Soil Type	Depth2Top	Depth2Base	Formation	Depth2Top	Depth2Base	Keyword
0	1.7	SP	0	5.2	Sand	0	1.7	Medium to coarse Sand; some shells
1.7	5.2	SW	5.2	11.7	Clay	1.7	5.2	Fine to very fine Sand/coarse Sand, few shells/gravel and pebbles
5.2	11.7	CL				5.2	11.7	Clay/mud

Figure 4. Example of the log data sheet conversion to digital data. The top image shows a log data sheet and grain size of samples. The bottom image shows the corresponding Excel data sheet for the log. The complexity of some data sheets required summarizing within the data set. When an ASTM classification was not included in the original data, other available information was used to assign the standard classification. Not shown in the Excel table figure are the described colors and any additional comments on the core log sheets.

Each different material layer in the log became a row in the shapefile attribute table in order to plot the data in three dimensions (Figure 5). The depth to top and bottom of layer were corrected for water depth so that similar stratigraphic layers could be compared (Figure 6). Most logs did not have water elevation datum reference on their data sheets. In that case, water depth was not corrected for tide. All of the core log data were collected in US customary units and were convert to metric for input to GIS.

Label	Depth2Top	Depth2Base	Formation	CollectionDate	Easting	Northing	WtrLevel_mtr	Datum	CoreLngth	CoreRecov	GISLabel	Adj_CoreTop	Adj_Corebase
1994_MMS_1	0.00	5.20	Sand	4/15/1994	419001.87	4078207.26	-12.19		4.57	3.57	MMS-94-1	-12.19	-17.39
1994_MMS_1	5.20	11.70	Clay	4/15/1994	419001.87	4078207.26	-12.19		4.57	3.57	MMS-94-1	-17.39	-23.89
1994_MMS_2	0.00	7.10	Sand	4/15/1994	418007.57	4078660.55	-11.58		7.10	7.10	MMS-94-2	-11.58	-18.68
1994_MMS_3	0.00	4.15	Sand	4/15/1994	416261.14	4078777.39	-9.14		6.64	6.64	MMS-94-3	-9.14	-13.29
1994_MMS_3	4.15	6.64	Clay	4/15/1994	416261.14	4078777.39	-9.14		6.64	6.64	MMS-94-3	-13.29	-15.79
1994_MMS_4	0.00	5.49	Sand	4/15/1994	417857.72	4078839.51	-11.58		5.49	5.49	MMS-94-4	-11.58	-17.07
1994_MMS_5	0.00	4.15	Sand	4/17/1994	419489.19	4078823.92	-10.52		5.79	5.33	MMS-94-5	-10.52	-14.67
1994_MMS_5	4.15	5.36	Clay	4/17/1994	419489.19	4078823.92	-10.52		5.79	5.33	MMS-94-5	-14.66	-15.88
1994_MMS_6	0.00	0.91	Sand	4/17/1994	418594.18	4078466.32	-11.58		6.83	6.83	MMS-94-6	-11.58	-12.50
1994_MMS_6	0.91	1.52	Clay	4/17/1994	418594.18	4078466.32	-11.58		6.83	6.83	MMS-94-6	-12.50	-13.11
1994_MMS_6	1.52	6.83	Sand	4/17/1994	418594.18	4078466.32	-11.58		6.83	6.83	MMS-94-6	-13.11	-18.41

Figure 5. Example of core log attribute table. Notice that each layer of material within the log has its own row so that the data could be plotted in three dimensions. The depth to top and base were corrected for water depth. The Depth2Top and Depth2Base are in feet while the rest of the numbers are in meters.

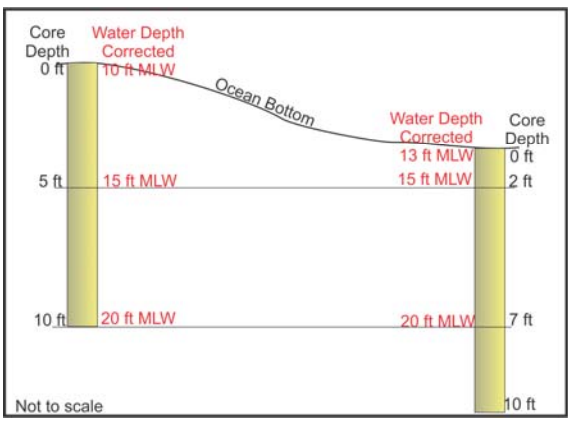


Figure 6. Typical depiction of the water depth correction of core log layers.

ArcMap 3D spatial analysis tools (Geostatistical Analyst and Spatial Analyst) were used to model the core data and produce estimates of sediment type locations and volumes. A series of sub-bottom horizontal depth planes were established at one-meter intervals using the water-depth corrected layer elevations from the sediment surface to the lowest depth reached by the cores. For each of these depth planes, points were extracted from each core that included sediment type at that depth. Indicator kriging was used to interpolate sediment type data from these available points onto the depth plane creating a raster grid. This form of kriging uses spatial statistical information computed from a distribution of points to estimate the probability that a point is in a particular class based on the distance from known points. In this case, separate models were computed for each sediment type (sand, silt, clay, gravel, and peat) within each cell. This was used to estimate the probability that a particular location on the depth plane grid was of a certain sediment type and the error associated with that estimate. These models were then used to assign the most likely sediment type to each grid cell location on the depth plane that also had an acceptable error (0.425). Each sediment type was assigned a number to be used in tallying data: sand (1), silt (2), clay (3), gravel (4), and peat (5). Peat was only found in a few cores and in such a thin layer that it was not represented in the one-meter increment modeling. If all data available for the depth plane was of the same sediment type, the area within 200 meters of the core was assigned to that sediment type, a distance consistent with that computed by the kriging models.

The resulting depth planes were stored in ArcGIS as 20 meter resolution raster grids. These grids were used to represent the data several different ways. Linear transects were created in the study area to visualize the 3D sediment structure. Fence diagrams were constructed in ArcScene for each of these transects and plotted to visualize the possible distribution of sediment formations in the study area.

The modeled grid also provided a means to estimate volume. The entire core database was used to calculate volume, but in the future, smaller areas could be calculated. Using the 424 cores modeled, the number of layers that exist for each sediment category (sand, silt, clay, and gravel) were counted. Because the data is gridded, the cell size is known. Each 20 m grid cell is 1 meter tall. By multiplying the grid dimensions (20 mx 20 m x 1 m) by the count, volume can be estimated.

Some of the cores were excluded from the analysis. Those offshore of Assateague Island in Maryland were not processed. In addition, core log data sheets were not available for the 1981 USGS data set. Data published in the report were used for the suitable sand analysis, but the data did not include enough information to process in GIS. In all, 424 cores were analyzed. Since most cores consist of several layers which differed in sediment type, a total of 820 sediment data layers were processed.

The potential for good beach quality sand was determined by looking at available data such as grain size, percent sand, lithography, when available, for each sediment layer. If a site was labeled as suitable, the data clearly showed that it would be beach quality. If sand was present, but grain size data was lacking, the layer was marked as potential. This indicates that the area has the potential to be beach quality sand, but more investigation is necessary. These data were further refined to show logs that had no overburden, those that had less than two feet of overburden and greater than two feet of overburden.

Results

The 3D core logs were imported to ArcScene to view the generalized layers of material in space. The logs can be viewed in conjunction with bathymetry, but it should be noted that exported maps cannot be scaled. They are for viewing purposes only. Near the mouth of the Bay, a great deal of sand exists interspersed with large areas of clay (Figure 7). Offshore of Assateague, Wallops, and Metompkin Islands, the core data indicate the presence of sand in the sub-bottom. The cores taken off of Wallops and Assateague were located in the shoals and so sand is expected. On the southern end of Virginia, few cores have been taken. Offshore False Cape State Park, the few cores available in this area indicate both sand and clay is present (Figure 8). Farther north, the borrow areas dredged for sand placement along the shoreline at Sandbridge Beach and Naval Air Station Oceana Dam Neck Annex (Dam Neck) are shown. The oblique angle of the 3D representation somewhat distorts the location of the cores relative to the borrow areas.

Yet another way to visualize the data is by plotting the modeled layers of sediment in one-meter increments. Along the southern Virginia coast, the cores taken off of False Cape State Park are shown in Figure 9. The sediment type at each one meter down-core is shown for the 10 cores in that location. By plotting the one-meter increments and gridding the area around the core, the data can be visualized to show areas where sand is most likely available in minable quantities such as offshore the southern end of the Eastern Shore (Figure 10). The data transitions from individual point data to modeled surfaces. If seismic data is located in the vicinity of a core, using the modeled grid may be able to provide a link to seismic reflectors shown.

The volume of the entire analyzed database was calculated (Table 2). The procedure was developed so that, in the future, areas of interest can be modeled and the volume calculated to determine if a sufficient volume of sand is available within a given region. Overall, more than 991,000 cells in the modeled grid are expected to contain sand. This translates to almost 400 million cubic meters of sand in the regions surrounding the 424 cores analyzed.

Table 2. Modeled grid cell count by water-depth corrected elevations and sediment type. Also shown is the calculation of volume for the cells.

Depth	Cell Count			
Layer	**Sand (1)**	**Silt (2)**	**Clay (3)**	**Gravel (4)**
-5	747	0	0	0
-6	1271	0	0	0
-7	2697	0	0	0
-8	12942	385	140	0
-9	20630	124	678	0
-10	34194	1387	533	0
-11	48185	2021	1569	0
-12	64601	424	4384	0
-13	70356	1367	7147	0
-14	71092	408	9016	0
-15	91825	1376	7236	0
-16	118717	1447	8081	0
-17	127202	503	5342	0
-18	120405	755	9679	188
-19	95413	1768	20476	200
-20	59392	3894	19616	0
-21	28401	4199	9933	38
-22	13783	1023	5391	59
-23	2991	0	3812	0
-24	1220	0	0	0
-25	1272	0	0	0
-26	1580	0	175	0
-27	1341	0	326	0
-28	988	0	620	0
-29	197	0	891	0
-30	1	0	275	0
Total # of Cells	991443	21081	115320	485
Total Volume (Cubic meters)	396,577,200	8,432,400	46,128,000	194,000
Total Volume (Cubic Yards)	518,703,149	11,029,158	60,333,118	253,742

The modeled grid also can be used to create linear transects that mimic geologic fence diagrams (Figure 11). Creating the linear transect is another way to determine the location of sand particularly in the region offshore of Virginia Beach where some many cores exist. Thus, there is higher confidence in the accuracy of the fence diagram.

Just because sand is present does not necessarily mean that it is beach quality sand. The final step in the analysis was the determination of whether or not the sediment layer contains sand that is good quality sand. If sand was present, but there was not enough information available to determine if it was beach quality sand, it was marked as potential. Of the 424 cores analyzed, 282 were marked as having some or all of their content considered good for or have the potential to be beach nourishment material (Figure 12). In addition, it was determined if there is an overburden and if so, how much is it. Many of the cores have suitable sand and most have overburdens of less than 2 feet. The cores located around the mouth of Chesapeake Bay and inshore of the borrow areas tend to be the cores with the most overburden. However, the overburden may be the result of the grain size being too fine to be considered beach quality (median grain size equal to or greater than 0.25 mm).

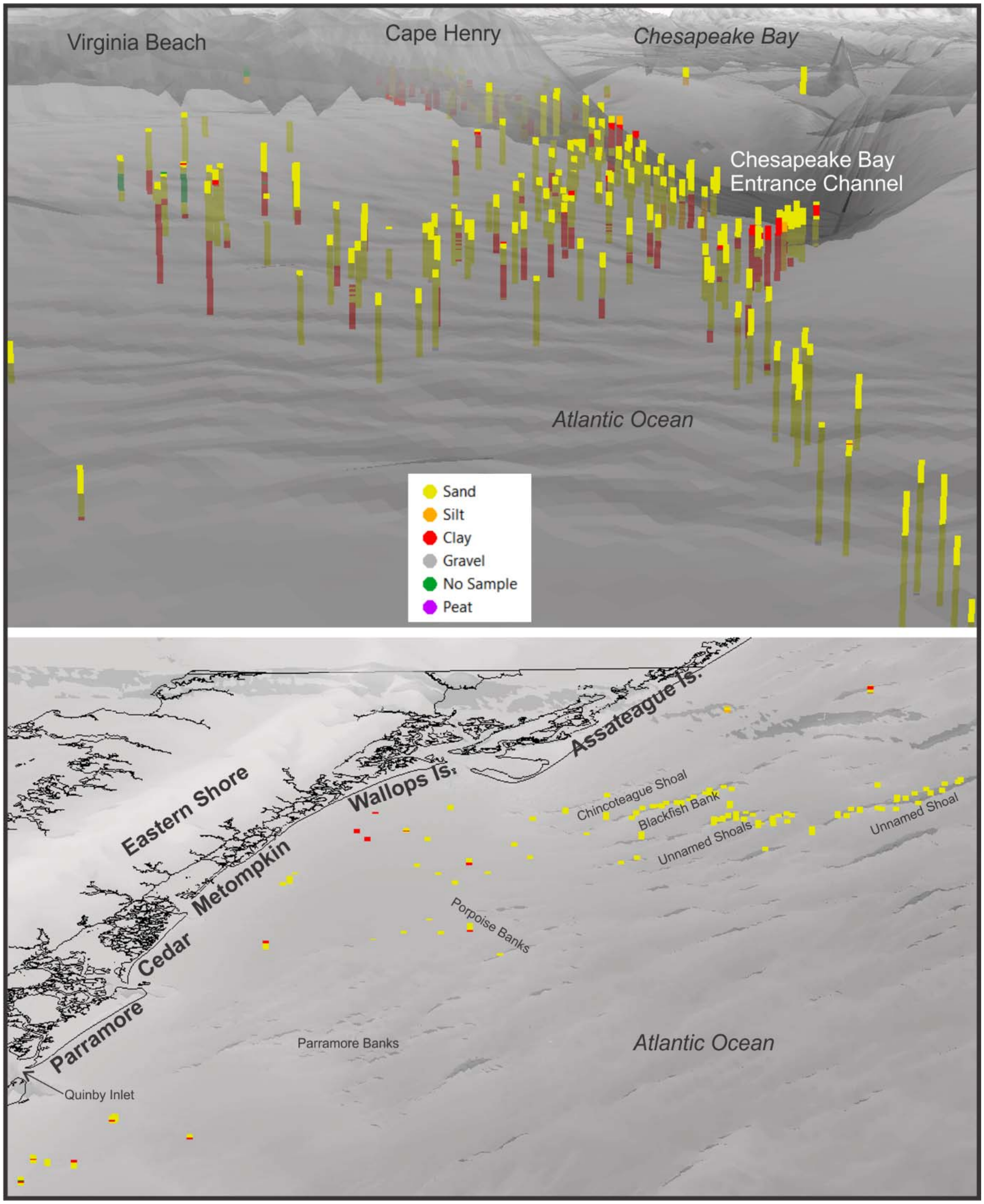


Figure 7. 3D visualization of cores in ArcScene. Top: core logs plotted on an exaggerated scale digital elevation model (DEM) looking into the Chesapeake Bay entrance channel. Bottom: core logs sampled along the sand shoals offshore Wallops and Assateague Island. Note: the gray of the DEM alters the representative colors. Both yellow and brown are sand. Bright red and maroon are both clay.

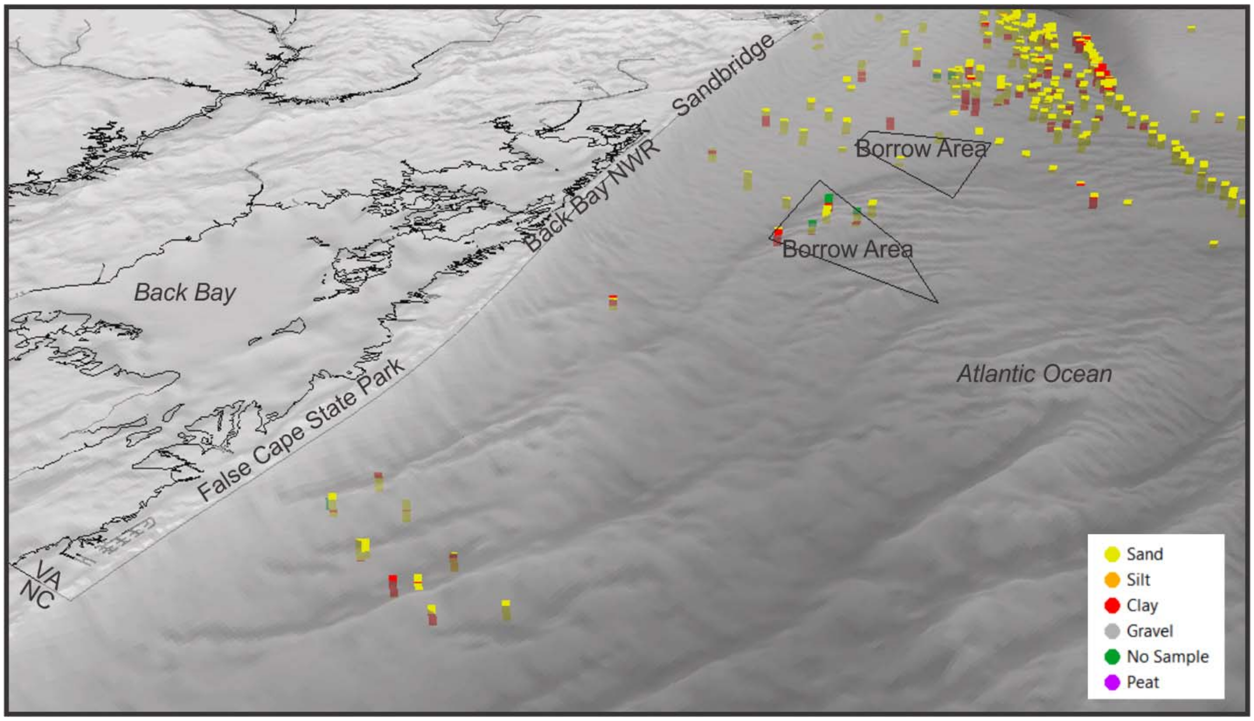
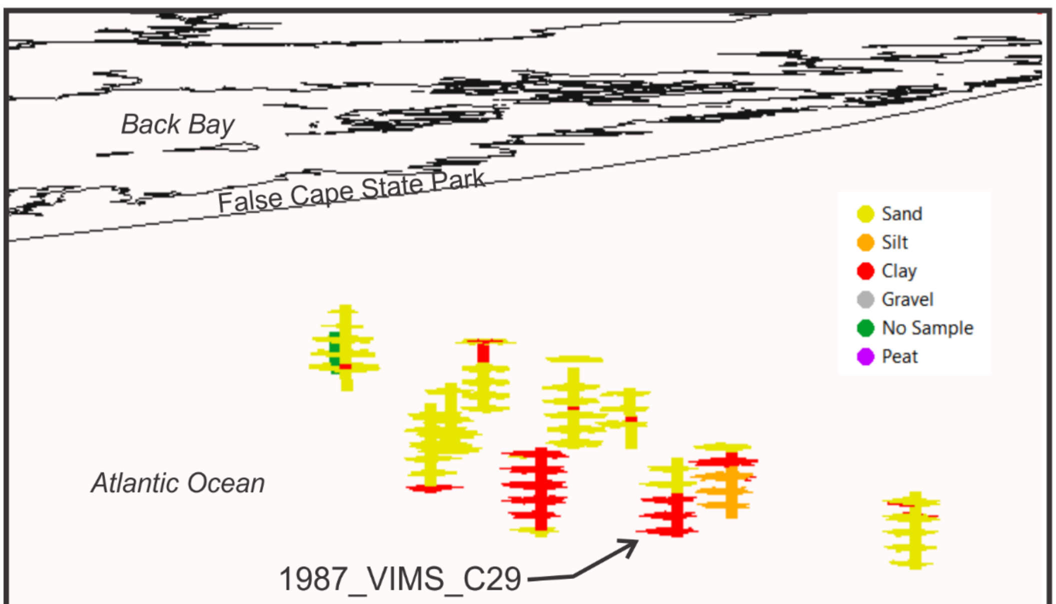


Figure 8. 3D visualization of cores in ArcScene. Core logs plotted on an exaggerated scale digital elevation model (DEM) looking northward from near the North Carolina/Virginia state line.. Also shown are the Sandbridge shoal sand mining borrow areas. The gray of the DEM alters the representative colors. Both yellow and brown are sand. Bright red and maroon are both clay.



Stratigraphy_mtr				Lithology_mtr		
0.00	2.29	Sand		0.00	2.29	Medium to fine sand w/ some silt
2.29	5.12	Clay		2.29	5.12	Well compacted Silty Clay

Figure 9. Modeling of the log data in one meter increments down core. Each increment is computed for sediment type and a probability model is used to create raster grids depicting the projected area around the core where the same sediment type is likely to exist. Also shown is the Excel core log description for VIMS core C29 taken in 1987 in meters. The core is five meters deep and the model contains five, one meter increments.

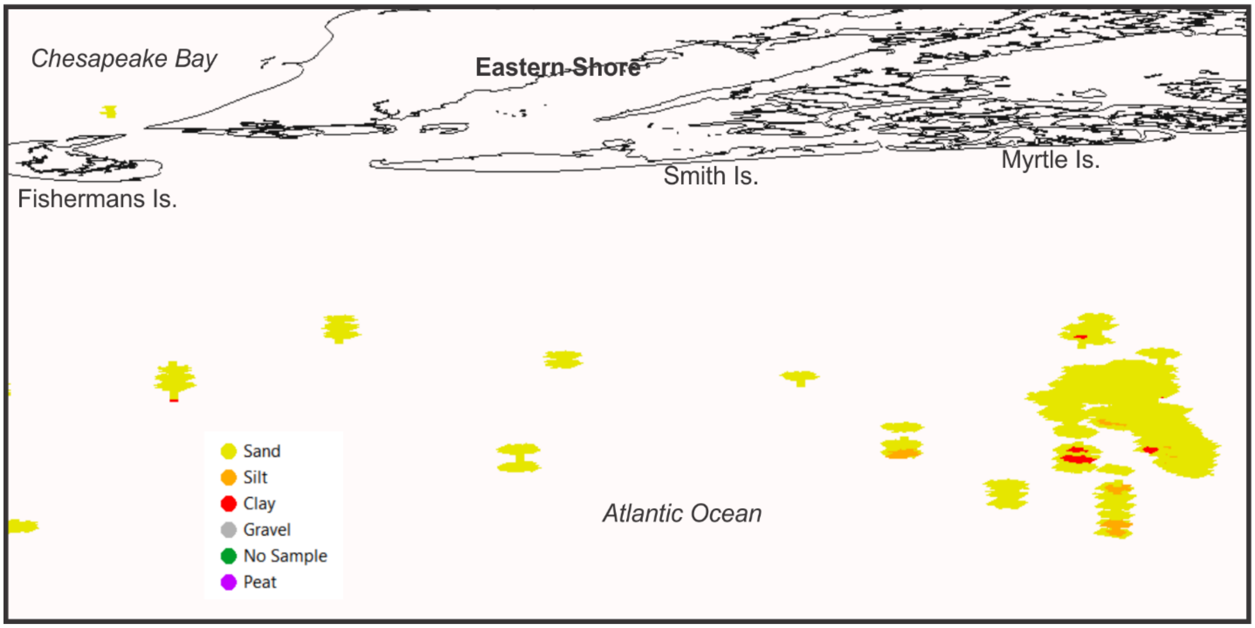


Figure 10. Plot of the modeled one-meter increment plane for each core offshore of the southern end of the Eastern Shore near the mouth of Chesapeake Bay.

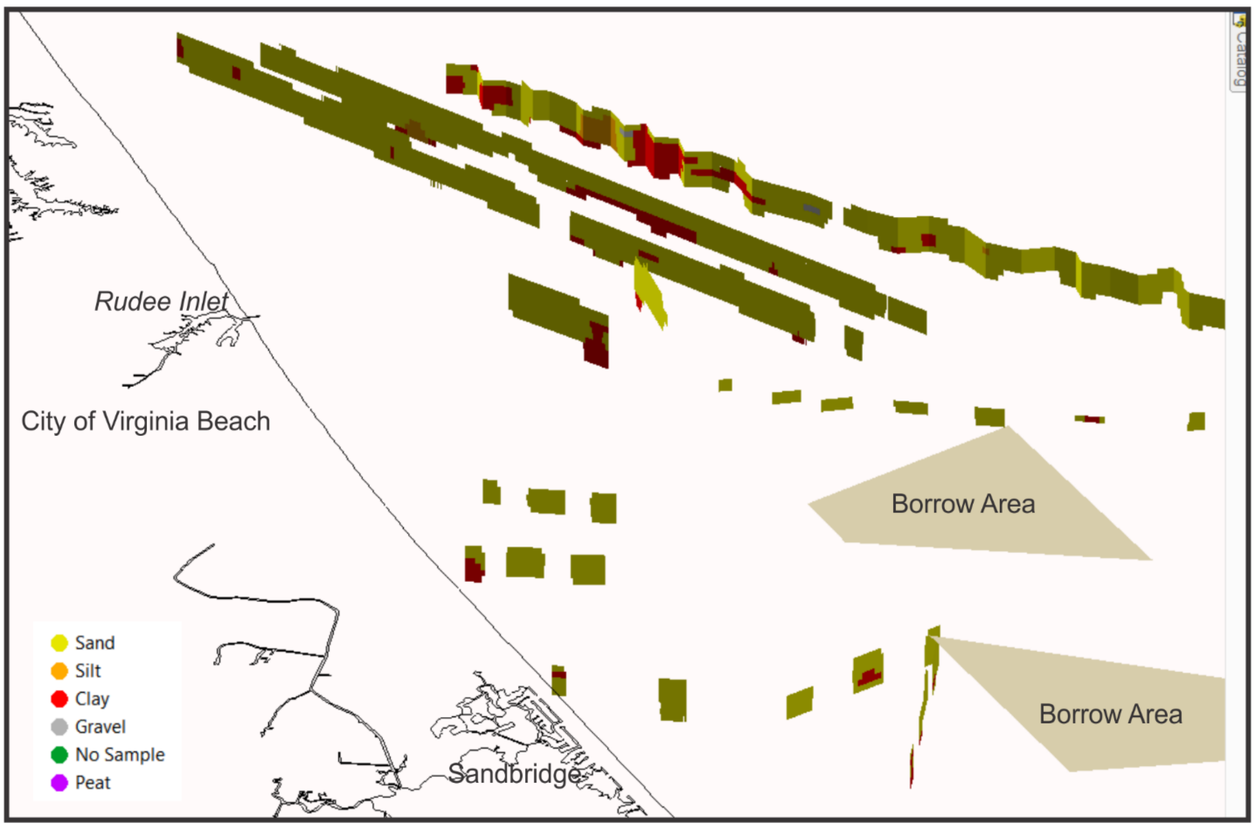


Figure 11. Linear transect fence diagrams of modeled core log data offshore Virginia Beach. The representative colors are slightly different from the legend. Both yellow and brown are sand. Bright red and maroon are both clay.

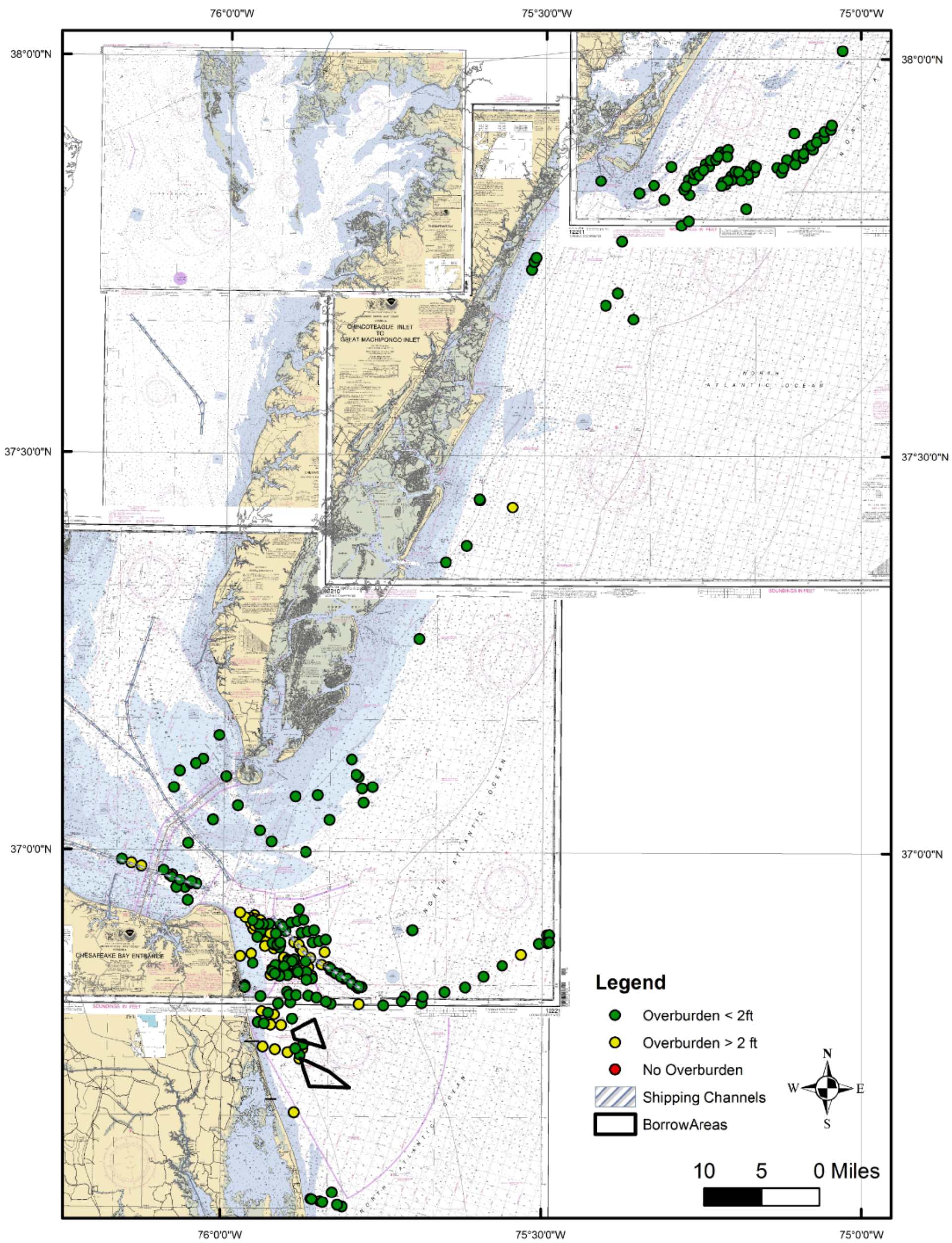


Figure 12. Location of cores with suitable sand shown by overburden amount.

Discussion

The goal of the project was to convert tiff images of core logs to digital data that could be modeled, analyzed, and visualized. The effort to manually input data from the core logs to an Excel archive was time consuming because as much detail as possible was retained for future reference and use. This included sediment descriptions in terms of grain size, color, as well as the location of specific items. However, the complexity of some of the logs did result in some summarization of data.

To facilitate modeling and analysis, the core log data was further categorized into more generic layers of sand, silt, clay, gravel, and peat. In addition, these layers were assigned an ASTM sediment classification. The modeling procedure provided data that is viewable in both ArcMap and ArcScene. This visualization is critical to determine the location and quantity of beach quality sand offshore of Virginia.

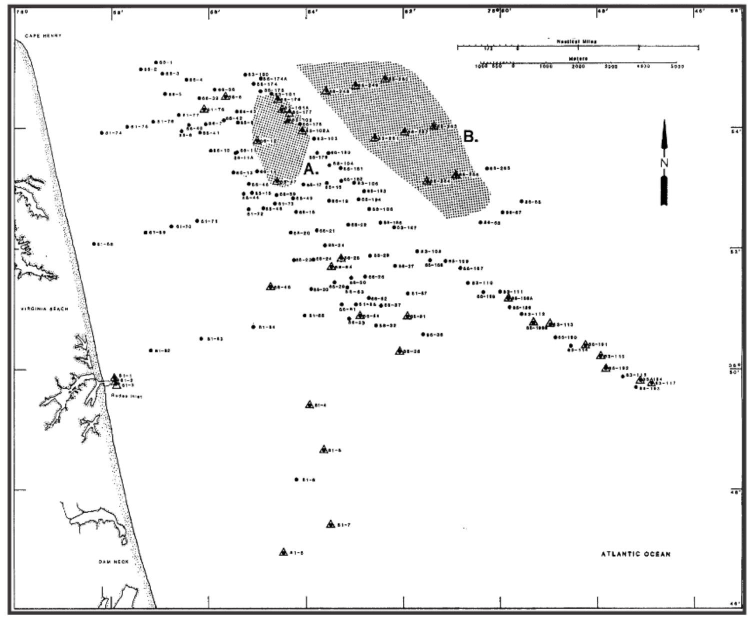


Figure 13. Identified source of beach quality sand offshore Virginia Beach on either side of the Atlantic Ocean Channel to the Chesapeake Bay (from Williams, 1987).

Detailed geologic histories of Virginia's ocean coast are found in Fugro (2013), Hardaway *et al.* (2015), Hobbs (1997), Kimball and Dame (1989), Kimball *et al.* (1991) as well as many other project reports and peer-reviewed journals. As such, it will not be discussed here except as it relates to the present project. Williams (1987) identified two sources of sand offshore Virginia Beach on either side of the Atlantic Ocean Channel into Chesapeake Bay and estimated that Area A contained 22,500,000 cubic yards (cy) of sand and Area B 75,000,000 cy of sand (Figure 13). The logs of the cores used to identify Area B could not be obtained, and therefore were not part of the modeling effort. However, the cores within Area A were included in the modeling effort which confirmed that suitable sand exists in Area A (Figure 7). It is likely that the area of sand available for mining is larger than indicated on Figure 13. Because the shipping channel is dredged, conditions of surrounding areas may be different than when the legacy data was collected in the 1980s. New data collection may be warranted.

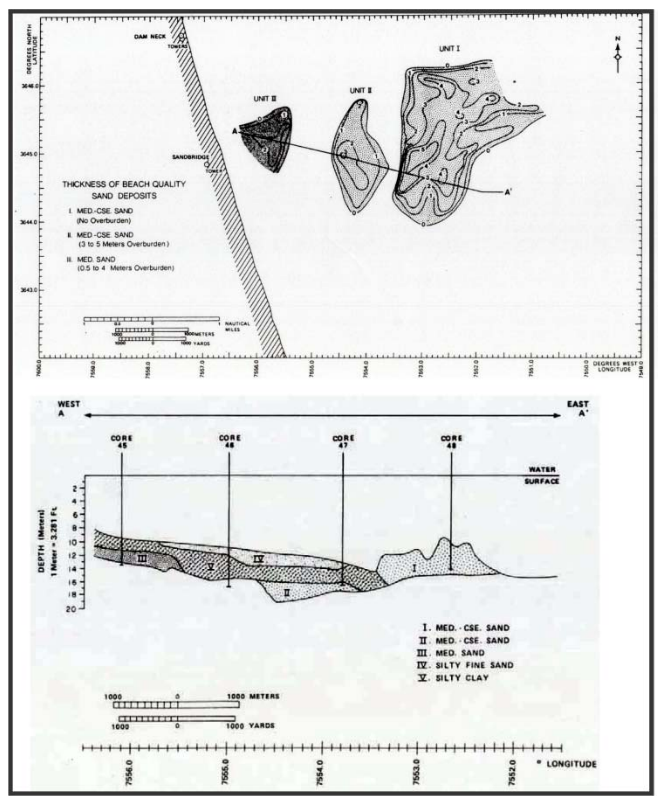


Figure 14. Location of beach quality sand with overburden and sub-bottom profile offshore of Sandbridge Beach correlating seismic data and core data (from Kimball & Dame, 1989).

Kimball and Dame (1989) and Kimball *et al.* (1991) correlated seismic data with cores to identify beach quality sand offshore Virginia Beach (Figure 14). These studies are the original work on the identification of Sandbridge Shoal as a source of beach quality sand. These reports do not provide an estimate of volume; however, Dredging News Online (2003) reports the total volume as 12,000,000 cy. This source of sand was dredged in 1996, 2004, and 2013, and the material placed on Dam Neck. It also was dredged for use on Sandbridge Beach in 1998 (1.1 mill cy), 2003 (2 mill cy), 2005, and 2013 (2 mill cy). More recently, beach quality sand was identified offshore of Assateague and Wallops Islands (Alpine 2007 & 2008) and has been dredged for placement at the flight facility on Wallops.

So, analyses of legacy data exists, but it is generally only accessible in project reports and is location specific. It is very difficult to visualize the interaction of the data throughout the entire inner continental shelf of Virginia. Our analysis incorporates the data into a model that can be used to analyze and visualize the data. From this analysis, a source of sand has been indicated off the southern end of the Eastern Shore. The shoals offshore False Cape State Park may also provide sand, but more information is needed.

To determine the possibility of using the existing legacy seismic data to continue to expand the geophysical modeling analysis beyond the core logs, several steps were taken. The legacy data from the 2006 project were reviewed to determine the viability of converting the scanned sub-bottom seismic image to digital reflector data that could be modeled, analyzed, and visualized in GIS (Table 3). Only 1987 and 1992 were deemed of overall good quality. The other years, 1986, 1996, 1999, and 2003, may possibly be used for analysis. Some of the tracklines for these dates show recognizable sub-bottom features and reflectors that could be mapped, but other areas show no seismic reflectors or have too much noise on the image. Therefore, the viability of including the legacy seismic sub-bottom in the geophysical modeling analysis will be site-specific.

Table 3. Year, number of lines, length in miles of legacy seismic sub-bottom data included in the 2006 GIS database. Also noted is the viability of converting the scanned image data into digital data.

Year	Number of line	Length in miles	Viability
1986	12	60	Possible
1987	80	316	Good
1992	35	154	Good
1996	6	120	Possible
1999	11	72	Possible
2003	3	7	Possible
	Total miles	**727**	

Generally, incorporating the legacy seismic sub-bottom data into the geophysical modeling analysis will require four steps. First is to map the reflectors on the scanned seismic image. If there are no identifiable reflectors, the trackline can be discarded. The second step is to rectify the seismic images and digitize the mapped reflectors. The third step would be to format and attribute the data so that it could be used in the last step, modeling and visualization.

The 1987 seismic sub-bottom reflectors were mapped in two dimensions, and the stratigraphy and sediment type identified where possible (Figure 15) by Kimball and Dame (1989). Because the sub-bottom profiles have already been mapped and the first step is complete, this data is ideal for continuing to develop Virginia's geophysical data modeling. The images for the 2006 GIS database were scanned from original rolls and are clear. They could be rectified used to digitize the seismic reflectors into GIS. However, this would be no easy feat. It would take time and preparation in order to determine the database setup required to make sure the data is usable. In addition, rectifying and digitizing the seismic lines would be time-consuming. Ultimately, though, it could provide an exceptional database for visualizing geophysical data off the coast of Virginia and be more practical than trying to interpret maps from reports.

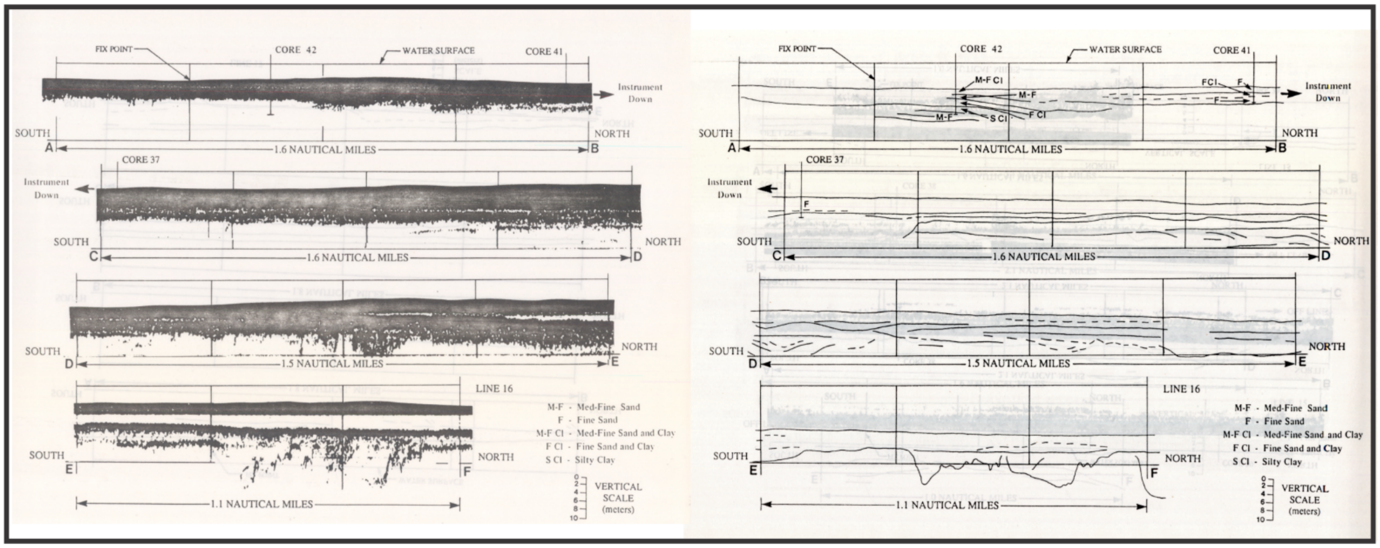


Figure 15. Figures taken from Kimball and Dame (1989) showing scans of 1987 seismic sub-bottom line 16 (left) and the mapped 2D reflectors of sub-bottom features (right).

Conclusions

Data exists to show that sand is available in minable quantities on the inner continental shelf of Virginia. However, the data is generally scattered throughout various agencies, companies, and project reports. Creating a database to locate and evaluate the data in a modern geophysical model was necessary. By making the core log data digital, it could be imported to ArcGIS, modeled, and analyzed. GIS also provides the tools to visualize the core log data in context with its surroundings with the goal of identifying additional sources of sand and determining the volume of those reserves.

Future analyses include the addition of cores if more are located or taken. Volumes can be calculated in subareas to determine the amount of sand available for dredging. It may be possible to incorporate the legacy seismic sub-bottom data into the GIS database. It would require a great deal of work, but it would allow for exceptional modeling and visualization of geophysical data along Virginia's inner continental shelf. Heavy minerals could also be modeled in the database.

Sandbridge Shoal has been dredged at least seven times, and the shoals off of Assateague also have been dredged. Incorporating before and after dredging survey into the GIS model would allow for more accurate tracking of the mineral resource.

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