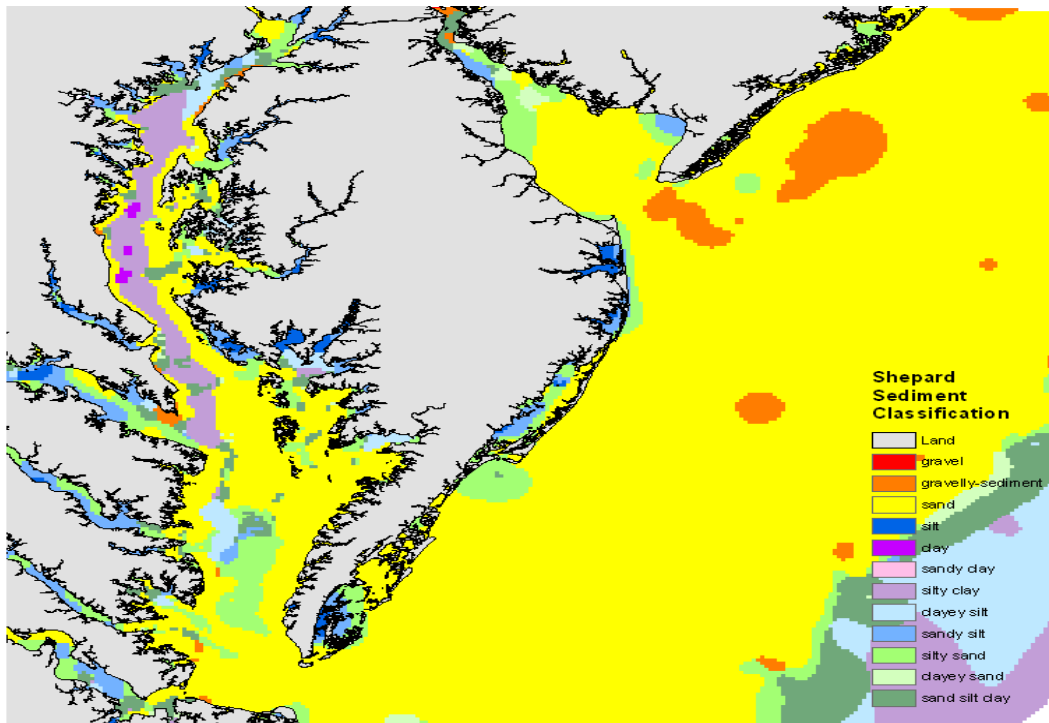


U.S. Geological Survey ArcMap Sediment Classification Tool: Installation and User Guide

By John O'Malley



Open-File Report 2007-1186

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Cover: Results of modified Shepard raster sediment classification for Chesapeake Bay area.

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U.S. Geological Survey ArcMap Sediment Classification Tool: Installation and User Guide

By John O'Malley

Abstract

The U.S. Geological Survey (USGS) ArcMap Sediment Classification Tool is a custom toolbar that extends the Environmental Systems Research Institute (ESRI) ArcGIS 9.2 Desktop application to aid in the analysis of seabed sediment classification. The tool uses as input either a point data layer with field attributes containing percentages of gravel, sand, silt, and clay or four raster data layers representing a percentage of sediment (0-100%) for the various sediment grain size analysis: gravel, sand, silt, and clay. This tool is designed to analyze the percentage of sediment at a given location and classify the sediments according to either the Folk (1954, 1974) or Shepard (1954), as modified by Schlee (1973), classification schemes. The sediment analysis is based upon the USGS SEDCLASS program (Poppe and others 2003).

System Requirements

- ArcGIS 9.2 software installed on a computer with Windows XP Operating System
- Four raster data sets representing percent gravel, sand, silt, and clay for the area to be classified having values between 0 and 100%

OR

- An ArcGIS feature or table data set containing percent gravel, sand, silt, and clay having values between 0 and 100%.

Background

A major component of the research conducted by the U.S. Geological Survey, Coastal and Marine Geology Program, Woods Hole Science Center (WHSC), is sea floor mapping to map and characterize the sea floor. This work provides insight into the geologic makeup of the sea floor and aids in research areas as diverse as habitat mapping, location of geohazards, and identification of areas of erosion and deposition. Geophysical tools including seismic-reflection, sidescan-sonar, and bathymetric systems used to remotely map the sea floor provide information regarding the sea floor and subsurface to define the surficial and subsurface geology and geologic framework of a given region.

Ground-truth techniques, such as sediment grab and core sampling, are an integral part of sea floor mapping activities and provide specific information from directly sampled material that aid in interpreting the geophysics. Sediment samples are analyzed within the WHSC sediment laboratory for mean grain size, percent content of gravel, sand, silt, clay, and mud, and additional analysis as required by a given research project. After completing the various analytic processes, the sample data, with percent content of gravel, sand silt, and clay, are processed using the program **SEDCLASS** (Poppe and others 2003).

SEDCLASS, a program developed at the WHSC, is used to classify sediment grain-size distributions based on relationships between grain-size fractions. The user may choose from either the Shepard (1954), as modified by Schlee (1973), or Folk (1954, 1974) classification schemes. The program analyzes a comma-delimited text file that must contain seven fields: sample-identifier, latitude, longitude, and the percentages of gravel, sand, silt, and clay in that specific order. The output of the program is also a comma-delimited text file similar to the input with the addition of an eighth field containing the calculated sediment classification based on the system selected by the user.

The sample data, with sediment classification information, output from the program **SEDCLASS** are then converted to a Geographic Information System (GIS) point data layer. This allows the sample points to be combined with other project data in a GIS map view, so the samples can be co-located with the geophysical data (such as a sidescan-sonar mosaic). Integrating the grain-size analysis and geophysical data aids the researchers in the interpretation of the sea floor geology.

Installation

The USGS ArcMap Sediment Classification Tool includes a setup program that will guide the user through the installation procedure. The setup program will install a toolbar into the ArcMap software (fig. 1). Once complete, the USGS ArcMap Sediment Classification toolbar will be opened when ArcMap is next launched. To uninstall the USGS ArcMap Sediment Classification toolbar, select 'Add or Remove Programs' from the Windows 'Control Panel.'

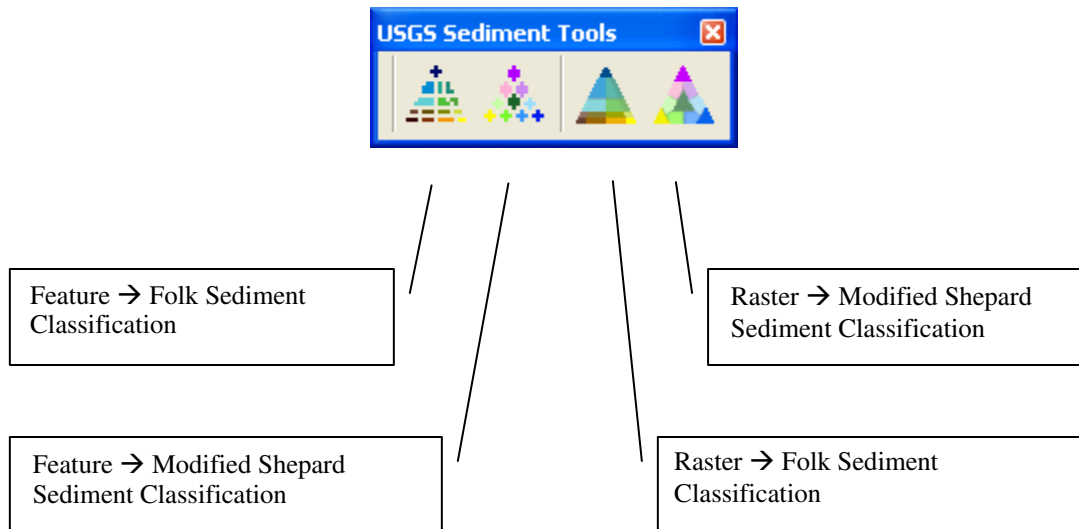


Figure 1. USGS Sediment Tools toolbar.

The USGS ArcMap Sediment Tools toolbar contains four icons. The two triangle symbols in the first group of icons, to the left, provide access to the Folk and Shepard point classification tools respectively. The two symbols in the second group of icons, to the right, provide access to the Folk and Shepard raster classification tools respectively. Placing the cursor over a triangle icon yields tool tips.

Note: After installation, if the toolbar does not start automatically when ArcMap is opened, go to the Tools -> Customize -> Toolbar tab and check the box next to USGS Sediment Tools.

Usage

The USGS ArcMap Sediment Classification Tool presented here is a custom toolbar to extend the ArcGIS Desktop application to provide the SEDCLASS functionality within the ArcMap application. It has two uses: (1) to provide sediment classification for previously unclassified point data that are available in a Feature or standalone table and (2) to produce a raster grid of the surficial sediment distribution from four raster data layers representing percent gravel, sand, silt, and clay. The logic for determining the sediment classification (appendix A) is based upon the SEDCLASS program and allows the user to select either the modified Folk or modified Shepard classification scheme. If the user is missing silt or clay values but does have mud values, then the missing category can be calculated by manipulating the equation “mud = silt + clay”.

Point Data Classification



Figure 2. USGS Sediment Tools toolbar with Feature/Table icons highlighted.

The Point Data Classification option allows the user to add the classification scheme “modified from Folk (1954, 1974) or Shepard (1954) as modified by Schlee (1973)” to previously unclassified sample data. It is intended to provide a way to classify sediment sample data that may have been analyzed outside of the Woods Hole Science Center and do not contain the desired classification information. The input data must contain four numeric fields representing percent gravel, sand, silt, and clay. Those individual values together must total between 99 and 101%, allowing for minor rounding up and rounding down of the total sum. A total percentage of sediment outside of the range between 99 and 101% will not be assigned a sediment classification and will be given a value of zero and no text description. A value of 0 is also assigned if any individual value of gravel, sand, silt, or clay in a record is less than 0. A list of the classification values can be found in appendix A.

Selecting one of the USGS Sediment Tools Feature buttons (fig. 2) opens up the “Feature/Table” dialog. The “Feature/Table” dialog’s input dropdown listbox contains a list of feature layers and standalone tables displayed in the Table of Contents of ArcMap. If the table or feature layer does not have an ObjectID field, it will not be displayed in the input dropdown listbox and you will not be able to perform the sediment classification. Delimited text files or tables from Object Linking and Embedding database (OLE DB) connections are some examples of tables without ObjectID fields. If you want to be able to perform these tasks, you can export the layer to a new feature class or convert a table of coordinates into a point feature class.

For more detailed information regarding this option, please see the section entitled Feature/Table Tutorial.

Raster Classification

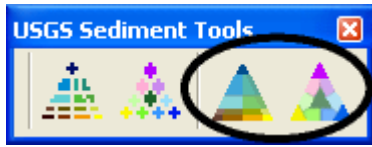


Figure 3. USGS Sediment Tools toolbar with raster icons highlighted.

Having the classified sediment sample point information is helpful when interpreting the surficial geology of an area. Processing those points to produce a surface of the survey area may provide more insight into trends. The Raster Classification option (fig. 3) allows the user to produce a surface raster layer modified from the Folk (1954, 1974) or Shepard (1954) as modified by Schlee (1973), classified sediment distribution. Implementing this option of the sediment classification toolbar is more involved than point classification and requires more preparation by the user.

To begin, the user must locate sediment data that contain, or that can be derived from, the four values of percent gravel, sand, silt, and clay. Each of those individual percentages must be gridded to produce a raster data layer representing the surface distribution (fig. 4). One way to produce a grid is through the use of the ArcMap surface interpolation functions by interpolating point sample data. Interpolation is the estimation of surface values at unsampled points based on known surface values of surrounding points. For further discussion on interpolation and different interpolation techniques, please refer to the ArcGIS Desktop help system online at <http://webhelp.esri.com/arcgisdesktop/9.2>.

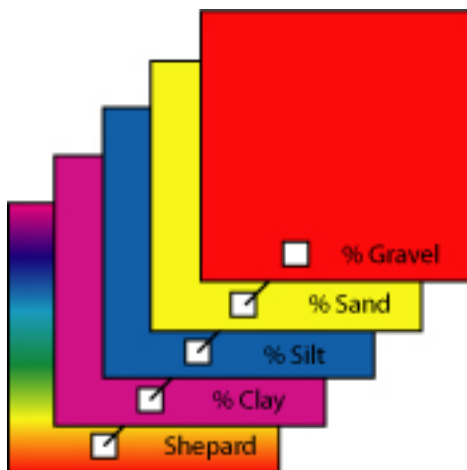


Figure 4. Raster Sediment Layer diagram.

The four raster layers of gravel, sand, silt, and clay must have the same spatial properties, (cell size, extent, and projection) or an error message will be generated and you will not be able to continue. The calculation of the raster sediment type is accomplished using the four raster layers of

gravel, sand, silt, and clay and applying the formula in the appropriate table of appendix A on a cell-by-cell basis. A raster layer having a cell value percentage of sediment of NoData will have its corresponding classification output cell assigned a value of NoData. A raster layer having a cell value percentage of sediment less than 0 or greater than 101 will have its corresponding classification output cell assigned a value of 99. A list of the classification values can be found in appendix A. When the four raster data layers are complete, they may be combined to create the output sediment classification raster. The results of the raster classification for any given area will vary and depend on the accuracy of the sample points, number of sample points, distribution of the data points, gridded cell size, and gridding method employed by the user.

For more detail on preparing data for the raster classification, please see the section entitled Raster Tutorial. The Raster Tutorial section does not address any relationships between the data and the accuracy of the interpolation method chosen.

Tutorial

Prepare Data for Use

For this example, sample data originated from the usSEABED EXTracted data set, ATL_EXT.shp. These data were published as part of the U.S. Geological Survey Data Series 118 (Reid and others, 2005). Some attribute fields within this data set contained a value of -99. This value was assigned by the data set originators to indicate the absence of valid data, whether observed or computed, for any field. As part of the data preparation, the -99 values were replaced with zeroes (0). Percentage of sediment attribute field records where no analysis was conducted is assumed to be zero. Another source for input data is U.S. Geological Survey Open-File Report 2005-1001 (Poppe and others, 2005).

An area around the Chesapeake Bay was clipped from the data set to produce the point shapefile ccb_db.shp. The ccb_db.shp data set contained percent gravel, sand, mud, and clay but not the necessary silt value. To produce the necessary silt value, silt was calculated as $\text{silt} = \text{mud} - \text{clay}$.

Detailed Steps

Location: Chesapeake Bay Area

Software: ESRI ArcGIS 9.2 ArcMap

1. Add the data file ccb_db.shp to the ArcMap active data frame.

2. Reassign all values for gravel, sand, mud, and clay of -99 to zero. Having an amount of sediment less than nothing is not possible. Field values of -99 are indications that the record had not been calculated or there were no data available. For this application a value representing “no data available” will become zero. Also, any values less than zero will become zero. Perform the following steps for each field of gravel, sand, mud, and clay.

Open the attribute table (fig. 5).
Right-click a data field and select ‘Field Calculator’.

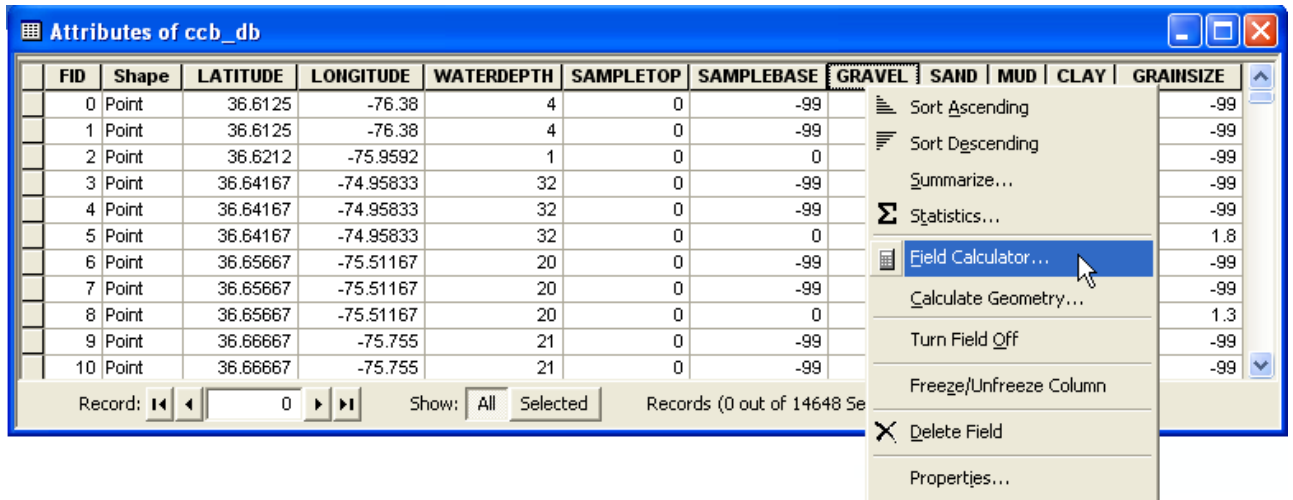


Figure 5. Activate Field Calculator dialog.

Click the Advanced box.

Type the equation below into field calculator's topmost box, the one labeled 'Pre-Logic VBA Script Code' (fig. 6), substituting the selected data field name, gravel, sand, clay, or mud, for the "field_name" variable.

```
if [field_name] >= 0 then
  output = [field_name]
else
  output = 0
end if
```

Type the variable 'output' into the lower text box. Do not enclose it in quotes or brackets. Click OK.

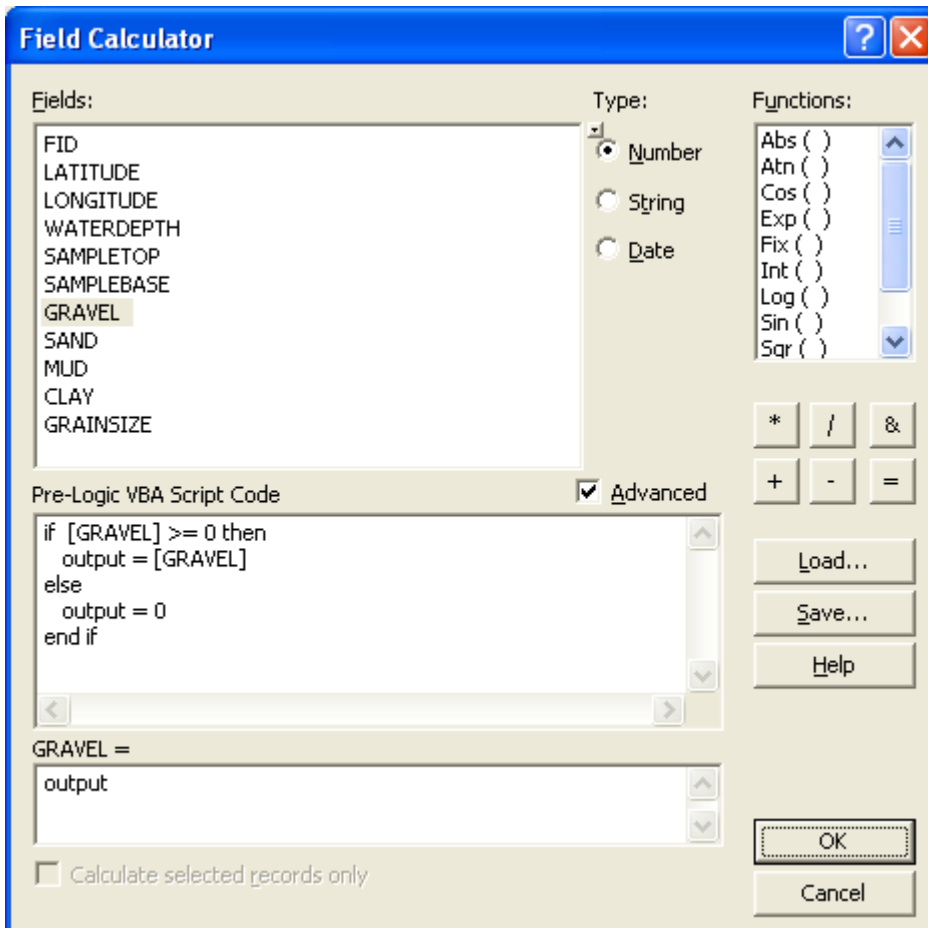


Figure 6. Field Calculator dialog.

3. Add the missing 'silt' field to the attribute table (figs. 7, 8).

Add a new field to the table named "SILT", data type of Short Integer and precision of 3, Options -> Add Field.

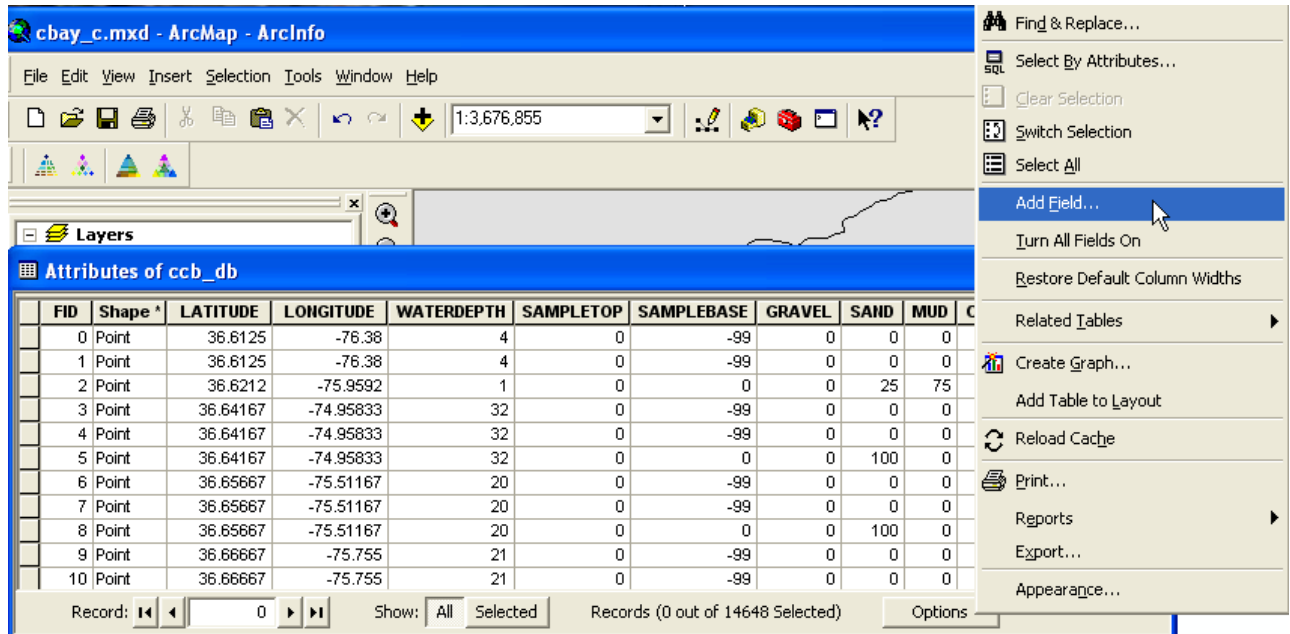


Figure 7. Activate Add Field dialog.

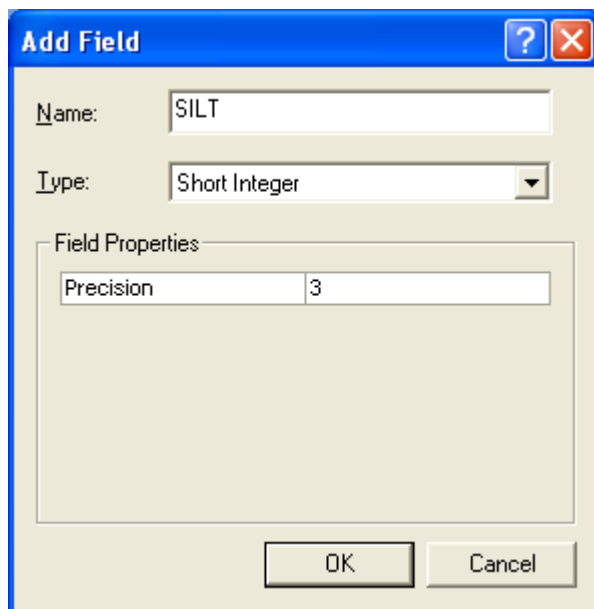


Figure 8. Add Field SILT dialog.

4. Add the missing silt values to the attribute table by using the Field Calculator and the following equation “silt = mud – clay” (fig. 9). When the computation is complete, check the results for erroneous negative silt values and remove all bad records from the attribute table.

Open the attribute table.

Right-click the new SILT attribute field and select Field Calculator.

Type in the equation: [mud] – [clay] into the field calculation expression box.

Click OK.

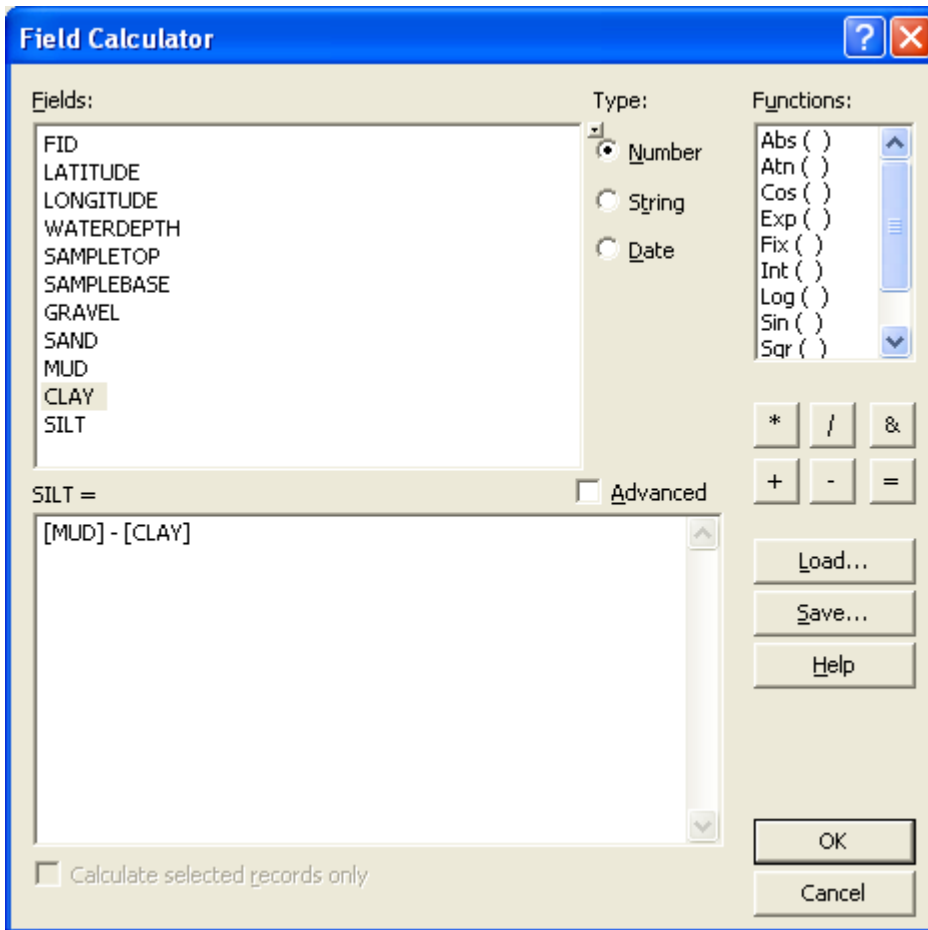


Figure 9. Calculate SILT Field dialog.

5. To check for negative silt values, right-click on the SILT field and select ‘Sort Ascending’. Go to the first record to verify that calculated values are greater than or equal to zero. If there are record values less than zero, then edit the data set to remove the negative value records to avoid problems during raster analysis.

Feature/Table Tutorial

Overview

For this example, sample data originated from the usSEABED EXTracted data set, ATL_EXT.shp. These data were published as part of U.S. Geological Survey Data Series 118 (Reid and others, 2005). Some attribute fields within this data set contained a value of -99. This value was assigned by the data set originators to indicate the absence of valid data, whether observed or computed, for any field. As part of the data preparation, the -99 values were replaced with zeroes (0). Percentage of sediment attribute field records where no analysis was conducted is assumed to be zero.

An area around the Chesapeake Bay was clipped from the data set to produce the point shapefile ccb_db.shp. The ccb_db.shp data set contained percent gravel, sand, mud, and clay but not the necessary silt value. To produce the necessary silt value, silt was calculated as $\text{silt} = \text{mud} - \text{clay}$.

Run the Feature/Table sediment classification tool using the ccb_db.shp layer as input.

Detailed Steps

1. Having prepared the point shapefile data, ccb_db.shp, for use as instructed above, do the following.
2. Click on the Feature -> Modified Shepard Sediment Classification tool. Select the appropriate table fields of gravel, sand, silt, and clay from the ccb_db.shp layer and then click the OK button (fig. 10).

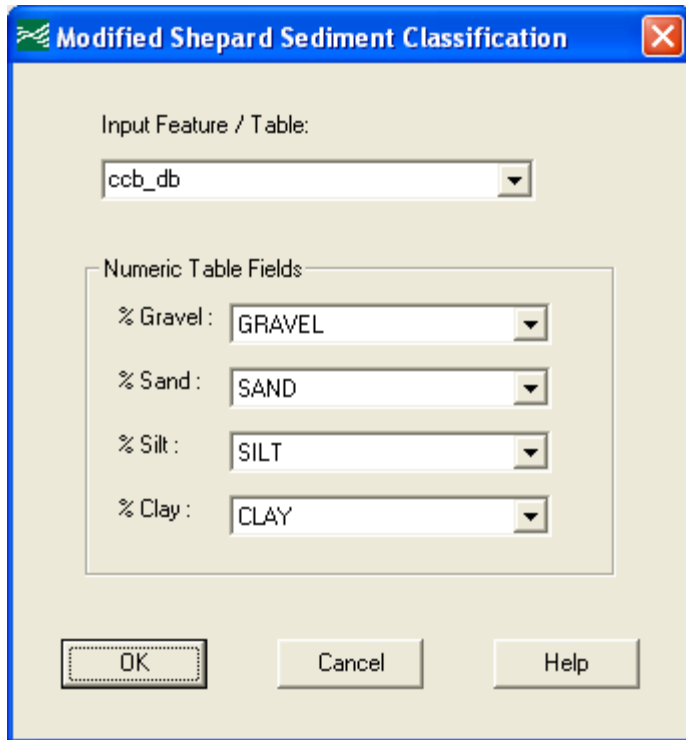


Figure 10. Feature/Table dialog.

The result is that two new field columns, Shep_Val and Shep_Str, Shepard (1954), as modified by Schlee (1973), classification, or Folk_Val and Folk_Str, modified from Folk (1954, 1974) classification, are added to the data layers table (fig. 11). Where Shep_Val and Folk_Val represent the integer classification value assigned, and Shep_Str and Folk_Str represent the textural description of the classification.

	GRAVEL	SAND	CLAY	SILT	Shep_Val	Shep_Str
	0	19	19	62	9	sandy silt
	2	96	1	2	3	sand
	0	75	4	21	3	sand
	0	74	8	18	10	silty sand
	0	39	14	47	9	sandy silt
	0	12	26	62	8	clayey silt
	0	33	20	47	9	sandy silt
	0	18	34	48	8	clayey silt
	0	72	9	19	10	silty sand
	10	88	1	1	2	gravelly sediment

Figure 11. Attribute table results.

Raster Tutorial

Overview

For this example, sample data originated from the usSEABED EXTracted data set, ATL_EXT.shp. These data were published as part of U.S. Geological Survey Data Series 118 (Reid and others, 2005). An area around the Chesapeake Bay was clipped from the data set to produce the point shapefile ccb_db.shp.

To prepare the data set for gridding, some minor preprocessing and data validation was performed. The following steps were completed as the preprocessing:

1. Attribute field records in the ccb_db.shp data set had values set to -99. This value was assigned by the data set originators to indicate the absence of valid data, whether observed or computed, for any field. As part of the preprocessing, the -99 values were replaced with zeroes (0). Percentage of sediment attribute field records where no analysis was conducted, having a value of -99, is being assumed to be zero.
2. The ccb_db.shp data set contained percent gravel, sand, mud, and clay but not the necessary silt value. To produce the necessary silt value, silt was calculated as $\text{silt} = \text{mud} - \text{clay}$.
3. To ensure that only those samples that would reflect surficial sediment were included, the data set was queried to extract the samples with a “Top Sample” depth of 0 meters.
4. Further data preprocessing was completed to validate that the percent gravel, sand, silt, and clay totaled between 99 and 101 percent. Data records that did not fall within this tolerance were eliminated from the data set. The total percent 99 to 101 tolerance was taken from the SEDCLASS program.
5. The data set was then processed to reduce point redundancy in order to eliminate records with multiple sampling at the same location. Data values for the given location were averaged and one data record was created.
6. The final point data set was gridded to produce the four individual raster layers of percent gravel, sand, silt, and clay. The four raster data layers were combined using the USGS ArcMap Sediment Classification tool to produce a classified sediment raster output data set.

Detailed Steps

Location: Chesapeake Bay Area

Software: ESRI ArcGIS 9.2 ArcMap

1. Having prepared the point shapefile data, `ccb_db.shp`, for use as instructed above, do the following.
2. Create new fields ***100pct*** and ***LatLong*** in the attribute table. These fields will be used in the preprocessing to validate and eliminate duplicate records before the final processing.

Add a new field to the table named "100pct", data type of Short Integer and precision of 4, Options -> Add Field.
Add a new field to the table named "LatLong", data type of Text and length of 25, Options -> Add Field.

3. Populate the newly defined fields, *100pct* and *LatLong*, with values using the “Field Calculator”.

Right-click the new *100pct* attribute field and select Field Calculator.

Click the Advanced check box.

Type the equation below into field calculator’s topmost box, the one labeled 'Pre-Logic VBA Script Code', (fig. 12).

```
if [SAMPLETOP] = 0 then
  output = [GRAVEL] + [SAND] + [SILT] + [CLAY]
else
  output = 0
end if
```

Type the variable ‘output’ into the lower text box. Do not enclose it in quotes or brackets.
Click OK.

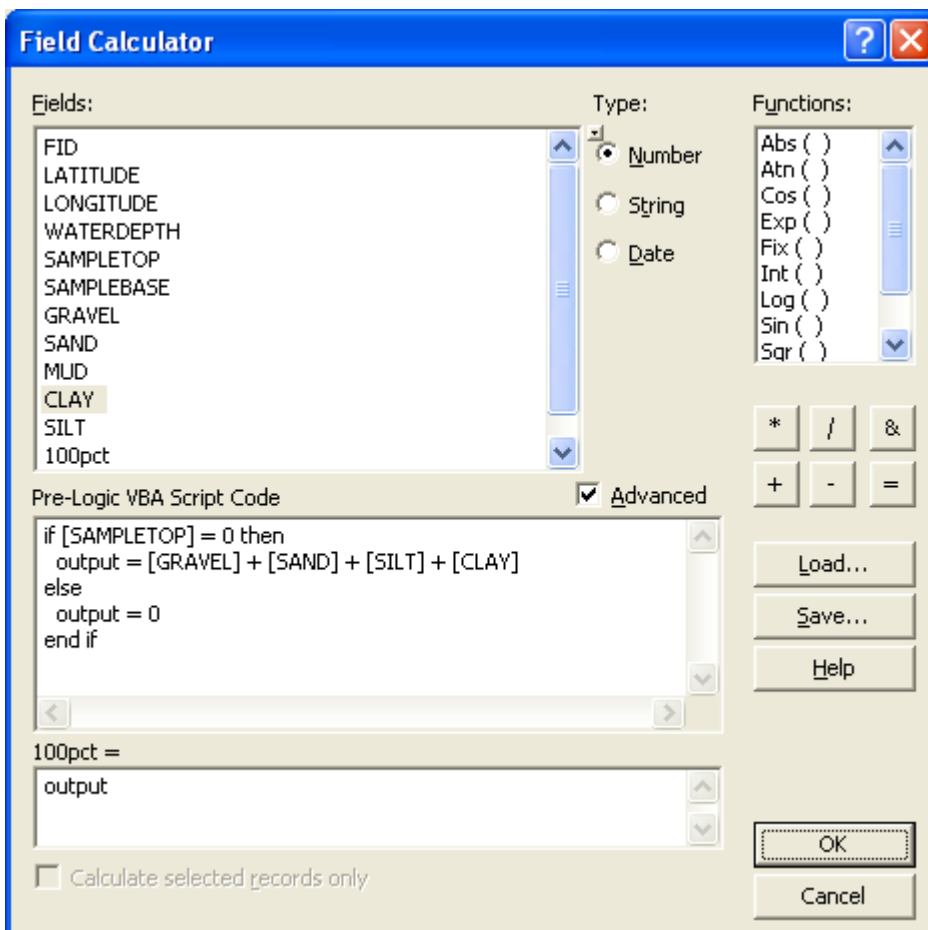


Figure 12. Calculate 100pct Field dialog.

Right-click the new **LatLong** attribute field and select Field Calculator.
Type [LATITUDE] & "," & [LONGITUDE] into the field calculation expression box (fig. 13).
Click OK.

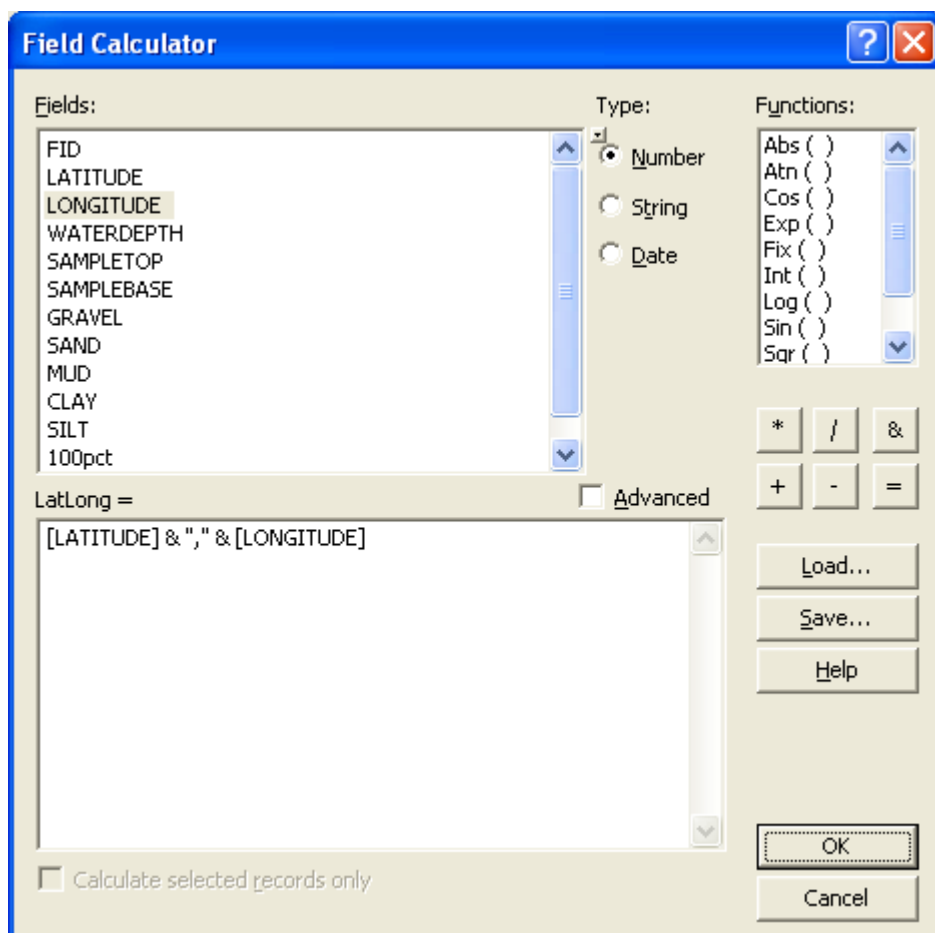


Figure 13. Calculate LatLong Field dialog.

- Extract only those points with a *SAMPLETOP* = 0. This will eliminate samples taken from within the cores and will ensure that only the surficial samples are used within the calculations. The *100pct* field was calculated based on the value of the *SAMPLETOP* field equaling zero. Select the data points using the attribute field *100pct* where *100pct* is ≥ 99 and ≤ 101 . Create a new data layer from the selected features. The total percent 99 to 101 tolerance was taken from the SEDCLASS program.

Open the attribute table of ccb_db.
 Select Options -> Select By Attributes (fig. 14).

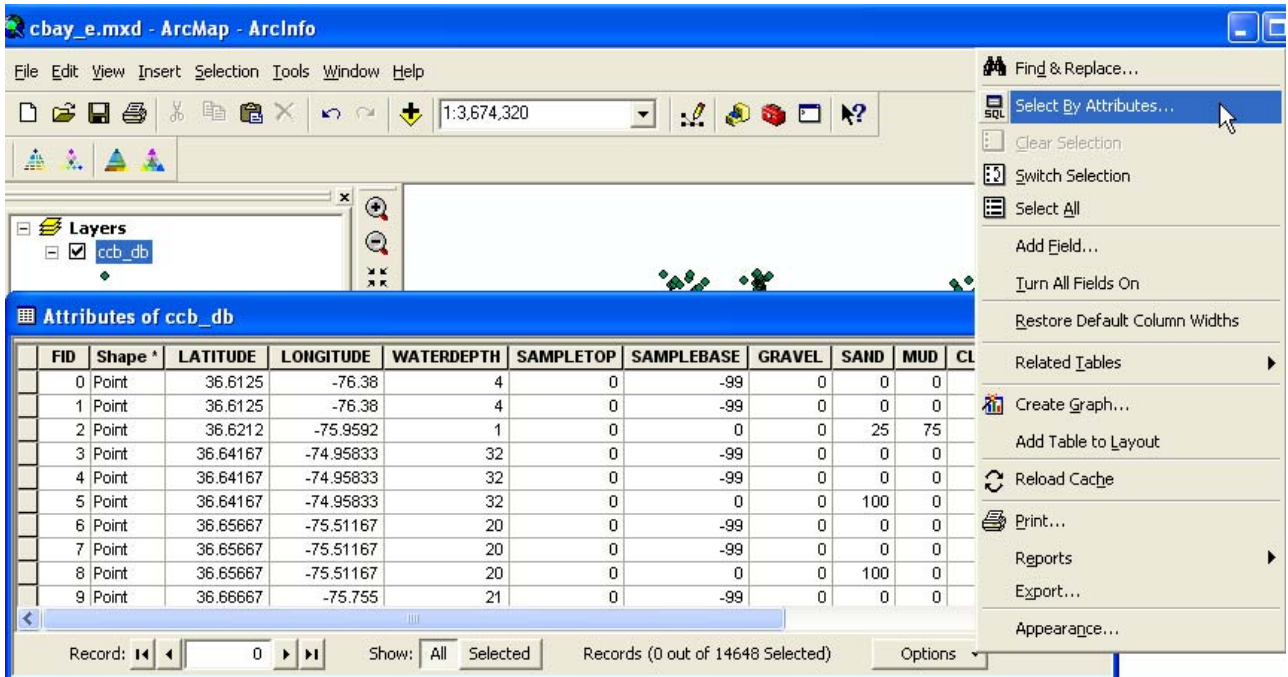


Figure 14. Activate Select by Attributes dialog.

Type **"100pct"** >=99 and **"100pct"** <=101 into the text box (fig. 15).

Click Apply.

Click Close.

Right-click ccb_db feature in Table of Contents and select Selection -> Create Layer From Selected Features.

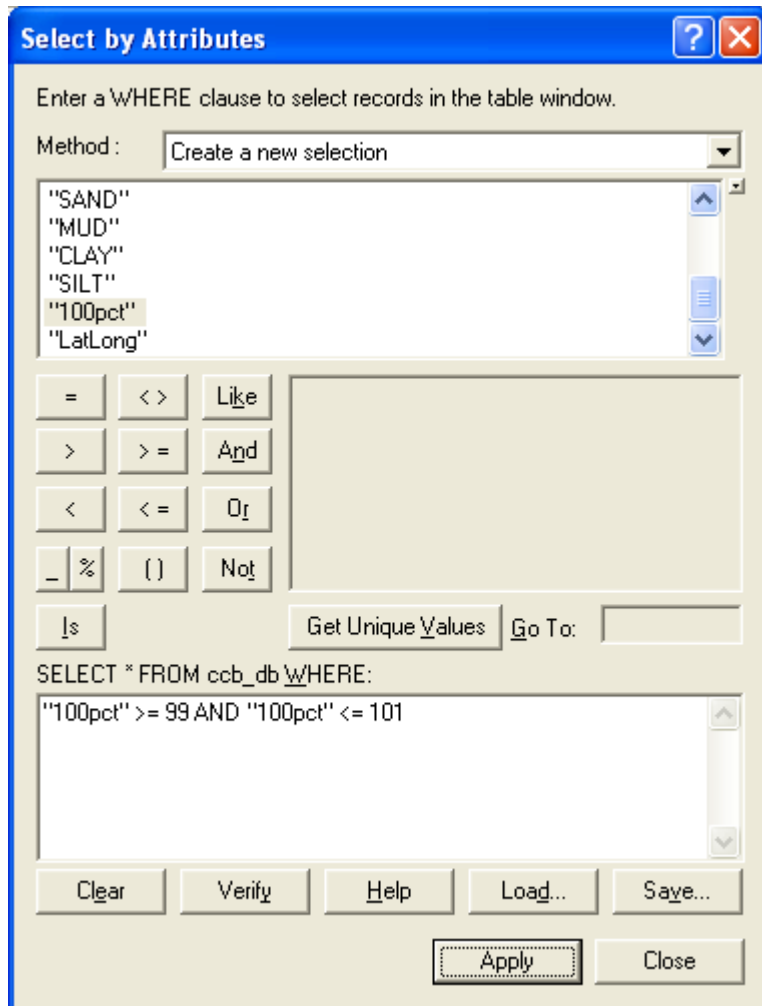


Figure 15. Select By Attributes dialog.

5. Remove duplicate points by summarizing the data on the *LatLong* field. The *LatLong* field represents the latitude and longitude point locations of records on the map. Summarizing the table on the *LatLong* field one can average the sediment values where there are multiple points. In order to preserve the location of the points take the minimum value of the Latitude and Longitude fields to avoid any rounding errors.

Open the attribute table of “ccb_db selection”.

Right-click the *LatLong* attribute field and select Summarize (fig. 16).

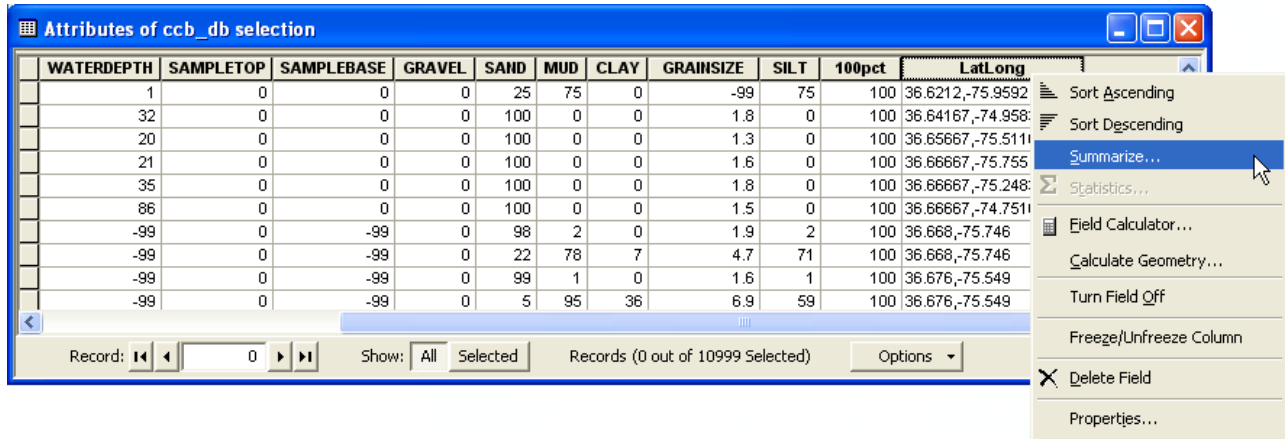


Figure 16. Activate Summarize dialog.

Choose the summary statistics to be included in the output table (fig. 17) as:

- Latitude - check the minimum box.
- Longitude - check the minimum box.
- Gravel - check the average box.
- Sand - check the average box.
- Clay - check the average box.
- Silt - check the average box.

Specify the output table as: ccb_summ.dbf.

Click OK.

Click Yes to add result table to map.

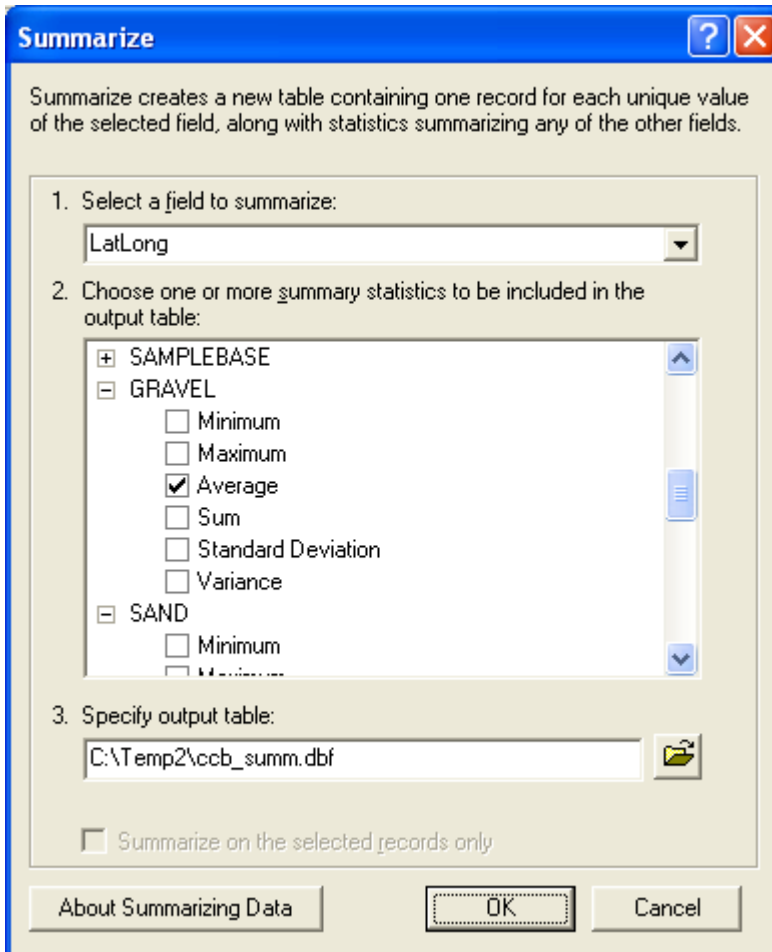


Figure 17. Summarize LatLong Field dialog.

6. Add summary table to map as XY Data (fig. 18, 19).

Right-click the summary table *ccb_summ* in the Table of Contents. Select Display XY Data.

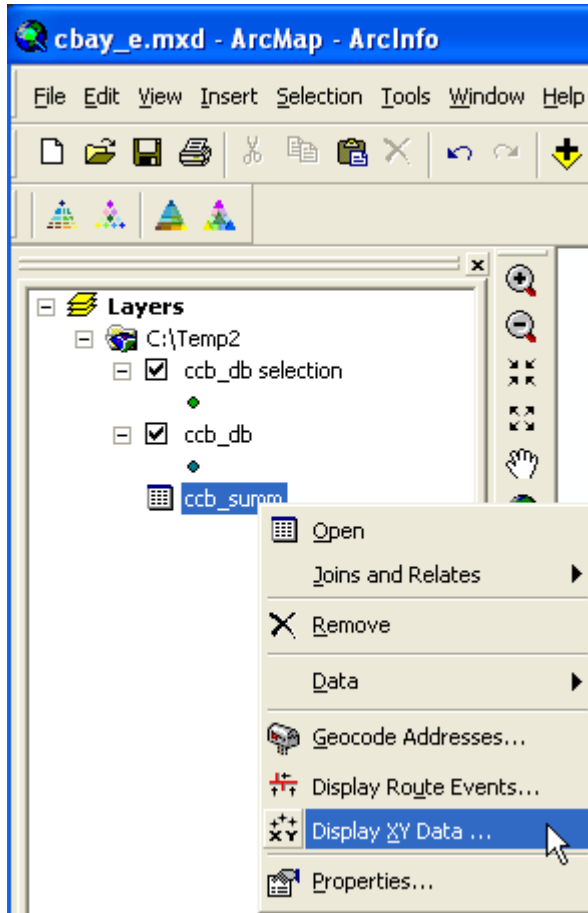


Figure 18. Activate XY Data dialog.

For the X Field dropdown list select Min_LONGIT.
For the Y Field dropdown list select Min_LATITU.
For the coordinate system click the Edit button.
Click Import.
Browse to and select the ccb_db.shp file, the original input data the summary table is based on.
Click Add.
Click OK.
Click OK.

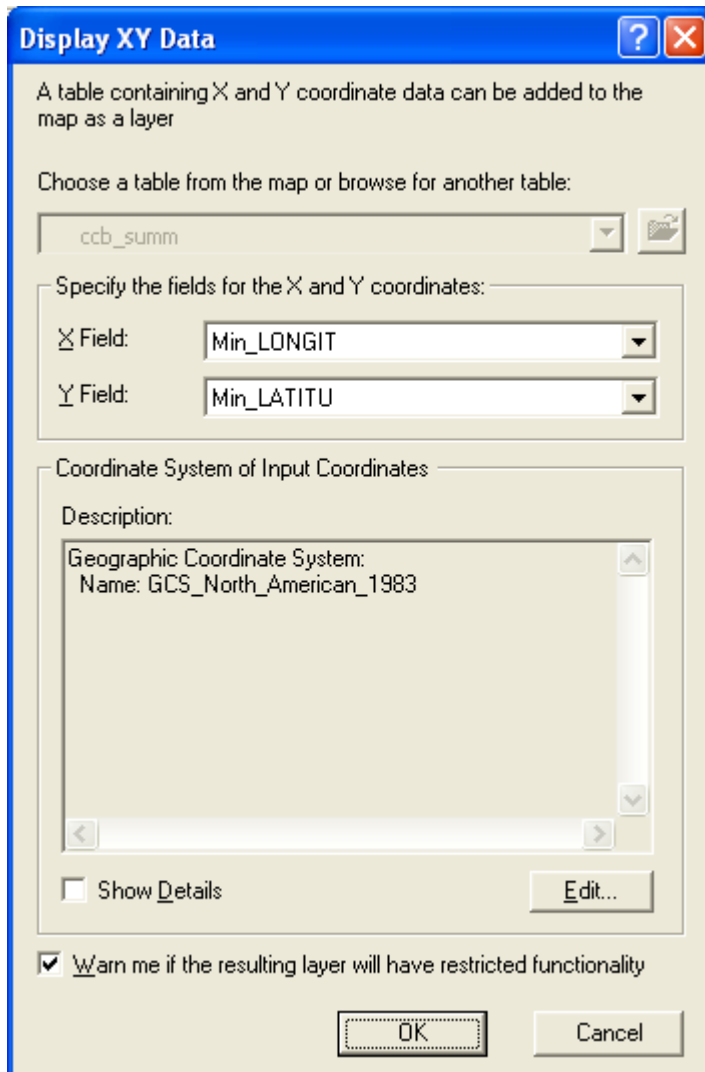


Figure 19. Display XY Data for ccb_summ layer dialog.

- Interpolate the point data to create raster surface data layers of gravel, sand, silt, and clay. For this example, the Natural Neighbor (fig. 20) method in ArcGIS was used and the default cell size accepted. For further discussion on interpolation and different interpolation techniques please refer to the ArcGIS Desktop help system.

Open the ArcToolbox window.

Create the gravel raster layer.

From the ArcToolbox window select 3D Analysis Tools -> Raster Interpolation -> Natural Neighbor.

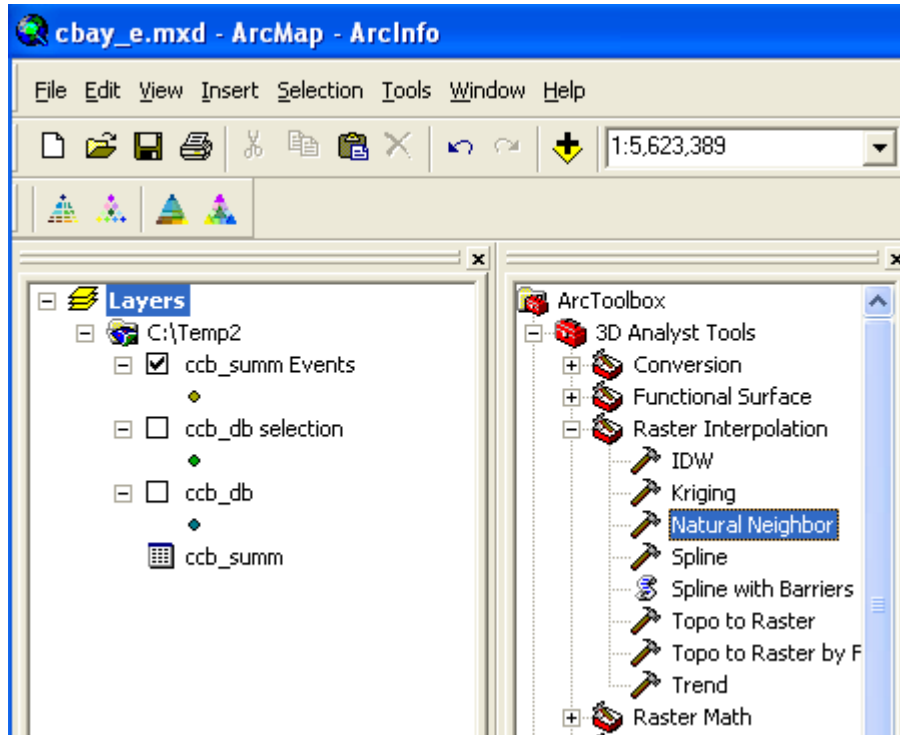


Figure 20. Select Natural Neighbor ArcToolbox tool.

For the Input point features select *ccb_summ Events* (fig. 21).

For the Z value field select Ave_GRAVEL.

For the output raster enter GravelN.

Click OK.

Create the sand, silt, and clay rasters by following the same procedure as was done for gravel, changing the 'Z value field' to 'Ave_SAND', 'Ave_SILT', and 'Ave_CLAY' and naming the output rasters as sandn, siltn, and clayn, respectively.

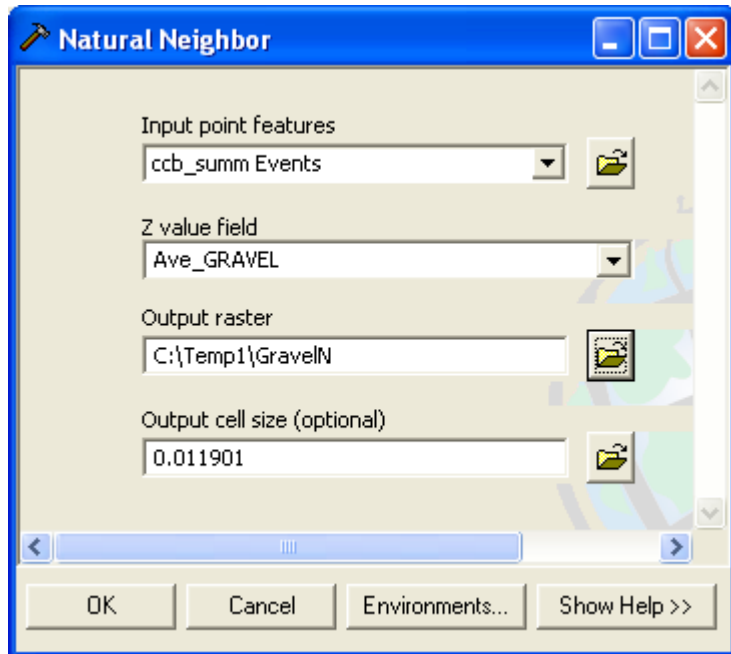


Figure 21. Natural Neighbor Interpolate dialog.

- Click on the Modified Shepard Sediment Classification tool. From the pop-up window (fig. 22), select the appropriate data layers to be analyzed. Enter an output name and destination for the new layer, then click the OK button.

For the Input Gravel Raster select graveln.

For the Input Sand Raster select sandn.

For the Input Silt Raster select siltn.

For the Input Clay Raster select clayn.

For the Output Modified Shepard Raster enter an output name of your choice.

Click OK.

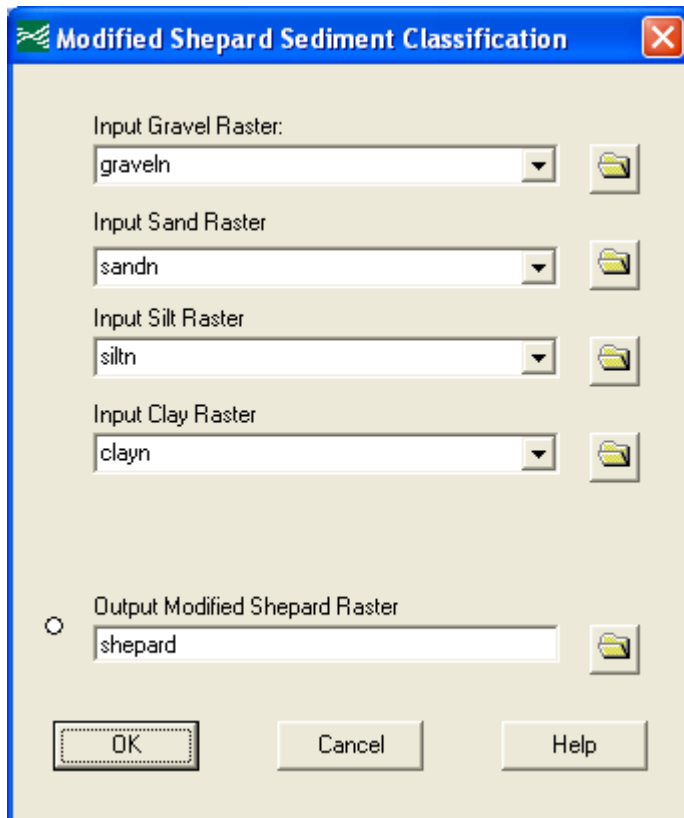


Figure 22. Raster Sediment Classification dialog.

9. When the classification tool tasks have been completed the user can symbolize the data values with the included r_mshepard.lyr or r_mfolk.lyr layer file. Modify the map by adding a title, legend, scale bar and north arrow as shown below (fig. 23), to produce a modified Shepard seabed sediment classification map of the Chesapeake Bay area.

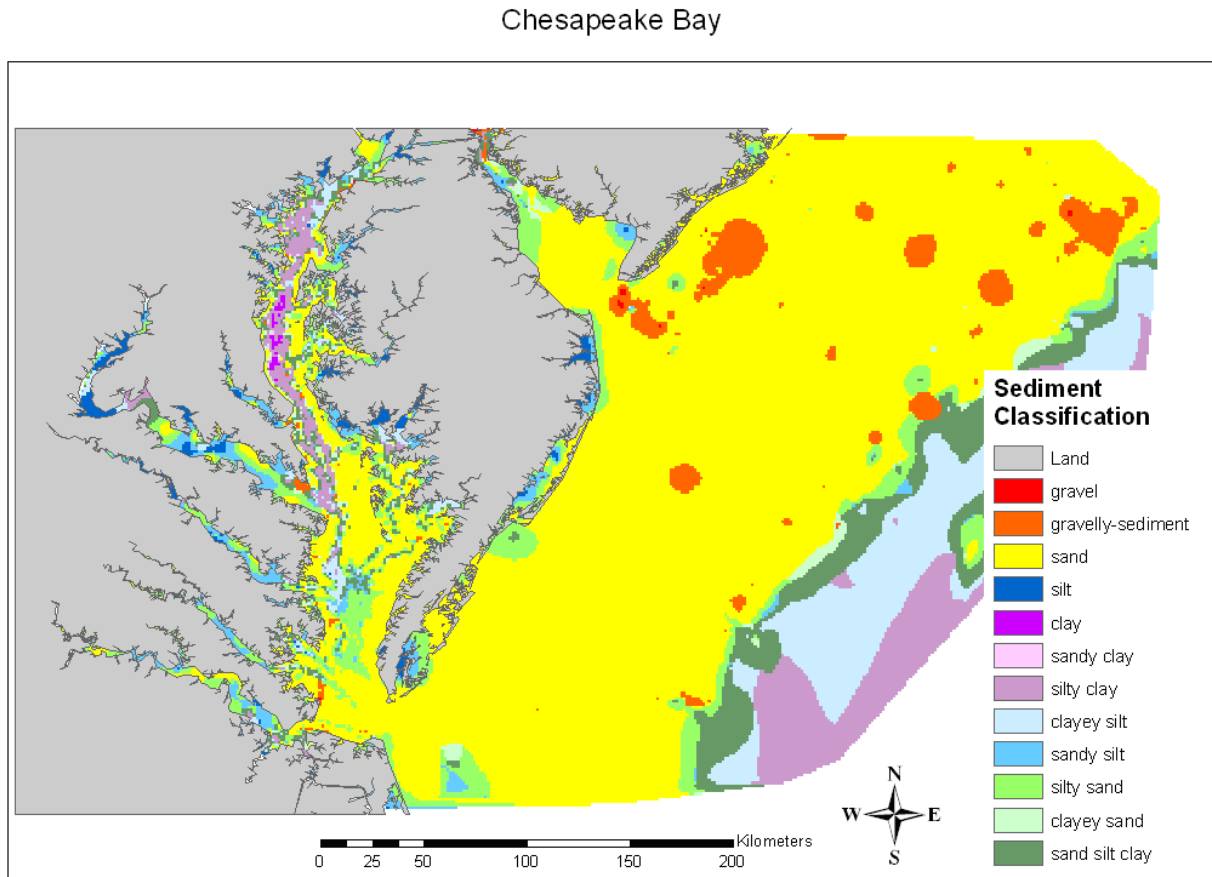


Figure 23. Result of modified Shepard raster sediment classification.

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Schlee, J., 1973, Atlantic continental shelf and slope of the United States -- sediment texture of the northeastern part: U.S. Geological Survey Professional Paper 529-L, 64 p.

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Appendix A. Sediment Classification Systems

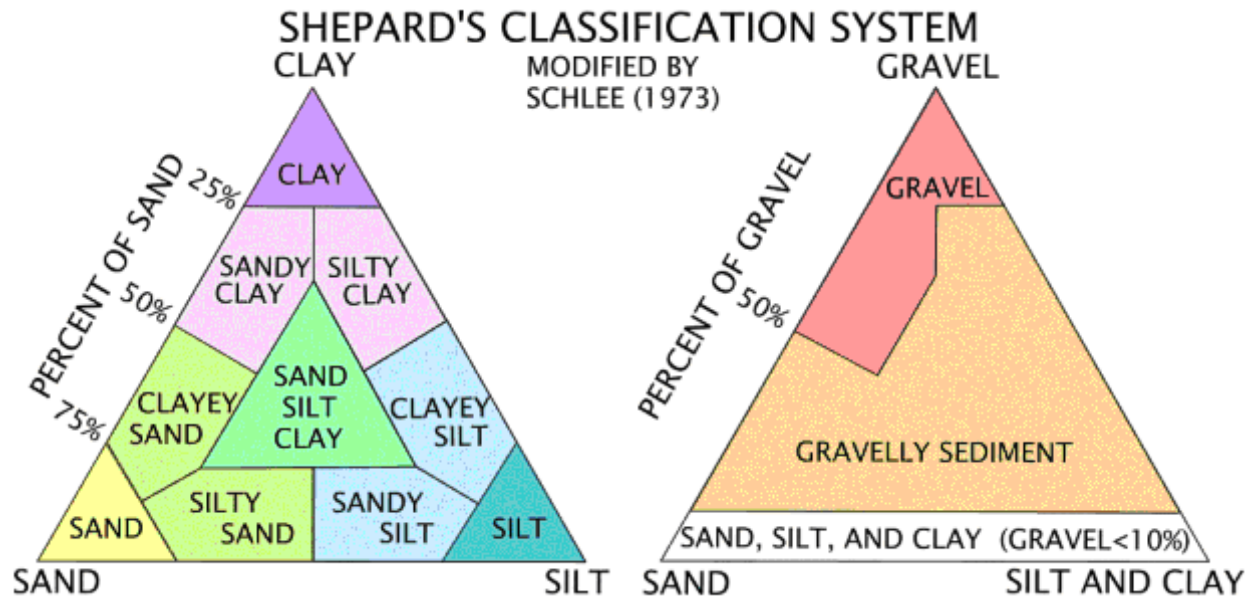


Figure 24. Shepard (1954) as modified by Schlee (1973) Sediment Classification System.

Table A1. Shepard (1954) as modified by Schlee (1973) Sediment Classification output values.

Integer Value	Description	Sediment Classification Determination
01	gravel	gravel \geq 50
02	gravelly sediment	gravel \geq 10
03	sand	gravel < 10 and (sand + gravel) \geq 75
04	silt	gravel < 10 and silt \geq 75
05	clay	gravel < 10 and clay \geq 75
06	sandy clay	gravel < 10 and (sand + gravel) \leq 20 and (sand + gravel) / silt > 1 or gravel < 10 and (sand + gravel) > 20 and clay \leq 20 and (sand + gravel) / silt \geq 1 and silt / clay \leq 1 and clay / (sand + gravel) > 1 or gravel < 10 and (sand + gravel) > 20 and clay > 20 and silt \leq 20 and clay / (sand + gravel) > 1
07	silty clay	gravel < 10 and

Integer Value	Description	Sediment Classification Determination
		(sand + gravel) <= 20 and (sand + gravel) / silt <= 1 and silt / clay < 1
08	clayey silt	gravel < 10 and (sand + gravel) <= 20 and (sand + gravel) / silt <= 1 and silt / clay >= 1 and clay / (sand + gravel) > 1
09	sandy silt	gravel < 10 and (sand + gravel) <= 20 and (sand + gravel) / silt <= 1 and silt / clay >= 1 and clay / (sand + gravel) <= 1 or gravel < 10 and (sand + gravel) > 20 and clay <= 20 and (sand + gravel) / silt < 1
10	silty sand	gravel < 10 and (sand + gravel) > 20 and clay <= 20 and (sand + gravel) / silt >= 1 and silt / clay > 1
11	clayey sand	gravel < 10 and (sand + gravel) > 20 and clay <= 20 and (sand + gravel) / silt >= 1 and silt / clay <= 1 and clay / (sand + gravel) <= 1 or gravel < 10 and (sand + gravel) > 20 and clay > 20 and silt <= 20 and clay / (sand + gravel) <= 1
12	sand silt clay	gravel < 10 and (sand + gravel) > 20 and clay > 20 and silt > 20
0 ^{1,2}	NoData	99 > gravel + sand + silt + clay > 101 OR (gravel OR sand OR silt OR clay < 0) gravel OR sand OR silt OR clay = NoData
99 ²	Out of range	(gravel OR sand OR silt OR clay > 101) OR (gravel OR sand OR silt OR clay < 0)

¹Point Data - A value of 0 is assigned if the cumulative total of percent gravel, sand, silt, and clay is not between 99 and 101. A value of 0 is assigned if any of the percent sediment types being gravel, sand, silt, or clay is less than zero.

²Raster Data - A value of 0, NoData, is assigned to a cell if any layer of gravel, sand, silt, or clay has a corresponding cell value of NoData. A value of 99, data is out of range, is assigned to a cell if any layer of gravel, sand, silt, or clay has a corresponding cell less than 0 or greater than 101.

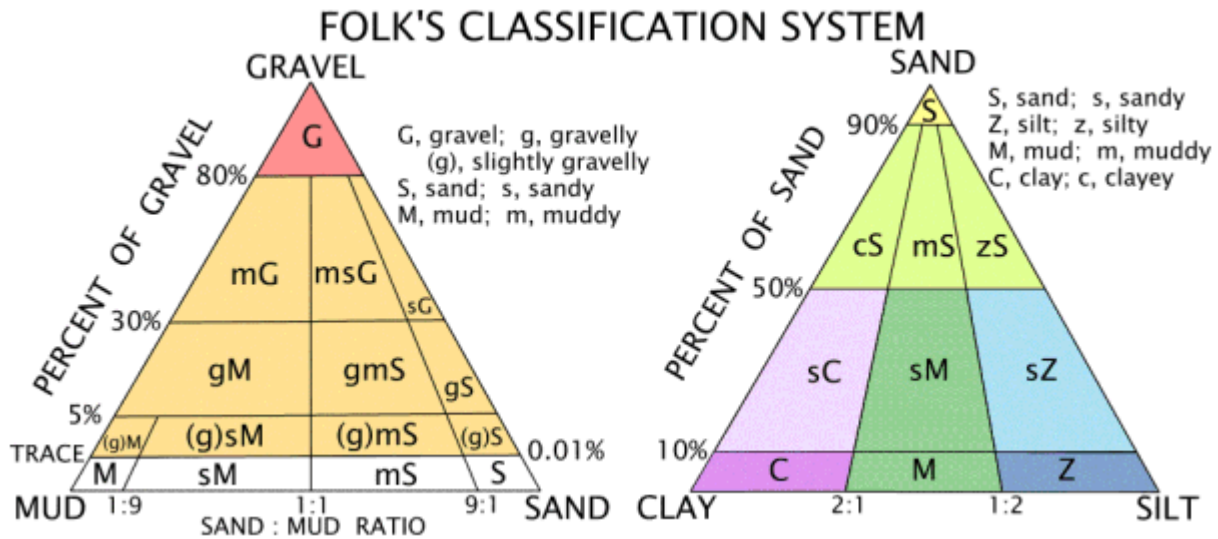


Figure 25. Modified from Folk (1954, 1974) sediment classification.

Table A2. Modified from Folk (1954, 1974) sediment classification output values.

Integer Value	Description	Sediment Classification Determination
01	gravel	gravel >= 80
02	muddy gravel	gravel < 80 and gravel >= 30 and sand / mud < 1
03	muddy sandy gravel	gravel < 80 and gravel >= 30 and sand / mud >= 1 and sand / mud < 9
04	sandy gravel	gravel < 80 and gravel >= 30 and sand / mud >= 9
05	gravelly mud	gravel < 30 and gravel >= 5 and sand / mud < 1
06	gravelly muddy sand	gravel < 30 and gravel >= 5 and

Integer Value	Description	Sediment Classification Determination
		sand / mud ≥ 1 and sand / mud < 9
07	gravelly sand	gravel < 30 and gravel ≥ 5 and sand / mud ≥ 9
08	slightly gravelly mud	gravel < 5 and gravel ≥ 0.01 and sand / mud $< 1/9$
09	slightly gravelly sandy mud	gravel < 5 and gravel ≥ 0.01 and sand / mud $\geq 1/9$ and sand / mud < 1
10	slightly gravelly muddy sand	gravel < 5 and gravel ≥ 0.01 and sand / mud ≥ 1 and sand / mud < 9
11	slightly gravelly sand	gravel < 5 and gravel ≥ 0.01 and sand / mud ≥ 9
12	mud	gravel < 0.001 and sand < 10 and (silt / clay $\geq 1/2$ and silt / clay < 2)
13	sandy mud	gravel < 0.001 and sand < 50 and sand ≥ 10 and silt / clay $\geq 1/2$ and silt / clay < 2
14	muddy sand	gravel < 0.001 and sand < 90 and sand ≥ 50 and silt / clay $\geq 1/2$ and silt / clay < 2
15	sand	gravel < 0.001 and sand ≥ 90
16	clayey sand	gravel < 0.001 and sand < 90 and sand ≥ 50 and silt / clay $< 1/2$
17	silty sand	gravel < 0.001 and sand < 90 and sand ≥ 50 and silt / clay ≥ 2
18	sandy clay	gravel < 0.001 and sand < 50 and sand ≥ 10 and silt / clay $< 1/2$
19	sandy silt	gravel < 0.001 and sand < 50 and sand ≥ 10 and silt / clay ≥ 2
20	clay	gravel < 0.001 and sand < 10 and silt / clay $< 1/2$
21	silt	gravel < 0.001 and

Integer Value	Description	Sediment Classification Determination
		sand < 10 and silt / clay >= 2
22	mud with trace gravel	gravel < 0.01 and gravel >= 0.001 and sand / mud < 1/9
23	sandy mud with trace gravel	gravel < 0.01 and gravel >= 0.001 and sand / mud >= 1/9 and sand / mud < 1
24	muddy sand with trace gravel	gravel < 0.01 and gravel >= 0.001 and sand / mud >= 1 and sand / mud < 9
25	sand with trace gravel	gravel < 0.01 and gravel >= 0.001 and sand / mud >= 9
0 ^{1,2}	NoData	99 > gravel + sand + silt + clay > 101 OR (gravel OR sand OR silt OR clay < 0) gravel OR sand OR silt OR clay = NoData
99 ²	Out of range	(gravel OR sand OR silt OR clay > 101) OR (gravel OR sand OR silt OR clay < 0)

¹Point Data - A value of 0 is assigned if the cumulative total of percent gravel, sand, silt, and clay is not between 99 and 101. A value of 0 is assigned if any of the percent sediment types being gravel, sand, silt, or clay is less than zero.

²Raster Data - A value of 0, NoData, is assigned to a cell if any layer of gravel, sand, silt, or clay has a corresponding cell value of NoData. A value of 99, data is out of range, is assigned to a cell if any layer of gravel, sand, silt, or clay has a corresponding cell less than 0 or greater than 101.

Percentage of mud sediment may be calculated as follows:

$$\text{mud} = \text{silt} + \text{clay}$$

