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Differentiating Pleistocene Alloformations in the South Carolina Coastal Plain Through Lithologic, Textural, Mineralogical, and Cluster Analyses

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by

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ABSTRACT

Currently, there is no textural or mineralogic basis for identifying and differentiating Pleistocene strand deposits in the South Carolina (SC) Lower Coastal Plain (LCP). Historically, geologic mapping of the SC coastal plain uses geomorphologic and biostratigraphic techniques for identifying and mapping LCP surficial strand deposits. While useful, both approaches have problems. The aim of this study is to develop a cost-effective approach to differentiate and identify strand deposits of different Pleistocene alloformations occurring in the SC LCP. To accomplish this task, four strand samples were taken from the Ten Mile Hill, the Ladson, and Wicomico alloformations in Horry County, SC. As a control, four samples were taken from an active Holocene strand deposit on Waites Island in Horry County, SC. The samples were analyzed for grain size, grain shape, and mineralogic composition. Analysis of the samples determined that the strand deposits associated with the Ten Mile Hill deposits were significantly coarser, more spherical, and more symmetrical than those of the other deposits, and could be identified using these methods. The deposits associated with the modern strand deposits occurring at Waites Island were significantly less spherical and symmetrical when compared to the Pleistocene strand deposits. K-means cluster analysis, using a combination of the data collected, was successfully able to cluster 15 of 16 samples into their associated units. This study demonstrates that Pleistocene strand deposits occurring in the SC LCP can be differentiated using grain texture and mineralogic characteristics, especially when integrated with statistical analyses such as k-means cluster analysis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The Atlantic Coastal Plain (ACP) of South Carolina (SC) is a classic example of a trailing edge continental margin. Strata of SC's ACP are particularly valuable because they contain records of Earth's past climate, sea-level, and constitute important natural resources. Investigation of past sea-level changes recorded in the ACP should help better predict how coastal areas will be affected by rising sea levels. This is important considering global sea levels have the potential to rise between 0.3 meters and 2.5 meters by 2100 (Sweet et al., 2017), and more than half of the U.S. population resides in coastal counties (Barnhardt et al., 2009). Being composed of sediment from past highstands of sea level, several coastal plain units should contain suitable materials to help with the problem of coastal erosion and sand loss (Natural Resource Council, 1995). Discovering new sand deposits could aid in industrial and infrastructure projects, especially considering that sand is the most used construction material and is scarce in many regions (John, 2021). Heavy mineral placer and rare earth element-bearing mineral deposits can provide important technological raw materials, including ones used for 'green' energy (Shah et al., 2017). In 2019, the U.S. imported 93% of its titanium mineral concentrates (USGS, 2020); less reliance on imports such as titanium mineral concentrates could be achieved through better mapping of the SC ACP. For instance, there are areas with anomalous concentrations of titanium near the South Carolina-North Carolina State Line, but discrepancies in geologic units across the state line make interpretations of these anomalies troublesome (Gosen and Ellefsen, 2018). Thus, it is critical to gain a better understanding and further our knowledge of the SC coastal plain through geologic mapping.

The coastal plain of South Carolina is separated into three regions: The Upper Coastal Plain (UCP), the Middle Coastal Plain (MCP), and the Lower Coastal Plain (LCP) (Fig. 1.1). The UCP extends from the Fall Zone to the Orangeburg Scarp (Nystrom et al., 1989), and at the surface, it is mainly composed of Lower Cretaceous to Miocene deposits. The MCP extends from the Orangeburg Scarp to the Surry Scarp, and at the surface is primarily composed of Pliocene sediments. The LCP extends from the Surry Scarp to the coastline of the Atlantic Ocean. At the surface, the LCP is primarily composed of Pleistocene sediments with a thin cover of Holocene sediments at the modern-day coastline. This project will investigate the Pleistocene and Holocene strand deposits that occur at the surface of the SC LCP.

Historically, geologic mapping of the SC LCP uses geomorphologic and biostratigraphic techniques, as well as the elevation of deposits for identifying and mapping surficial alloformations (Cook, 1936; Dubar, 1971; Doar, 2015 a; Wykel and Doar, 2019). Whereas these approaches have contributed to an understanding of coastal plain architecture, both have shortcomings. In particular, there is currently no textural or mineralogic basis in practice for identifying and mapping LCP units. Thus, in the absence of fossil material, a 1.2 Ma strand deposit and a 450 ka strand deposit are difficult to discriminate using conventional approaches without knowing the deposit's surface elevation. Even when the elevation is known, post-depositional erosion, differential subsidence, or surface uplift can locally alter the unit's elevation. This can lead to issues and uncertainties when trying to accurately map, interpret, and correlate deposits in SC's ACP. The ability to identify Pleistocene alloformations in the SC LCP, using simple tools such as grain texture and mineralogy, would significantly increase the understanding of these deposits, while also leading to the creation of more accurate geologic maps.

This work tested and developed several methods for differentiating strand deposits in the SC LCP. To accomplish this task, twelve strand deposit samples from three different Pleistocene LCP alloformations (four samples from each alloformation) in Horry County, SC, and four modern strand deposit samples from Waites Island, South Carolina were analyzed for grain size, grain shape, and mineralogic composition. K-means cluster analysis, using IBM SPSS Statistics for Windows, version 28.0 was then used to attempt to differentiate the four units using the grain texture and mineralogic data. This study suggests that there are mineralogic and textural differences in the four units sampled that can be identified by means of cluster analysis.

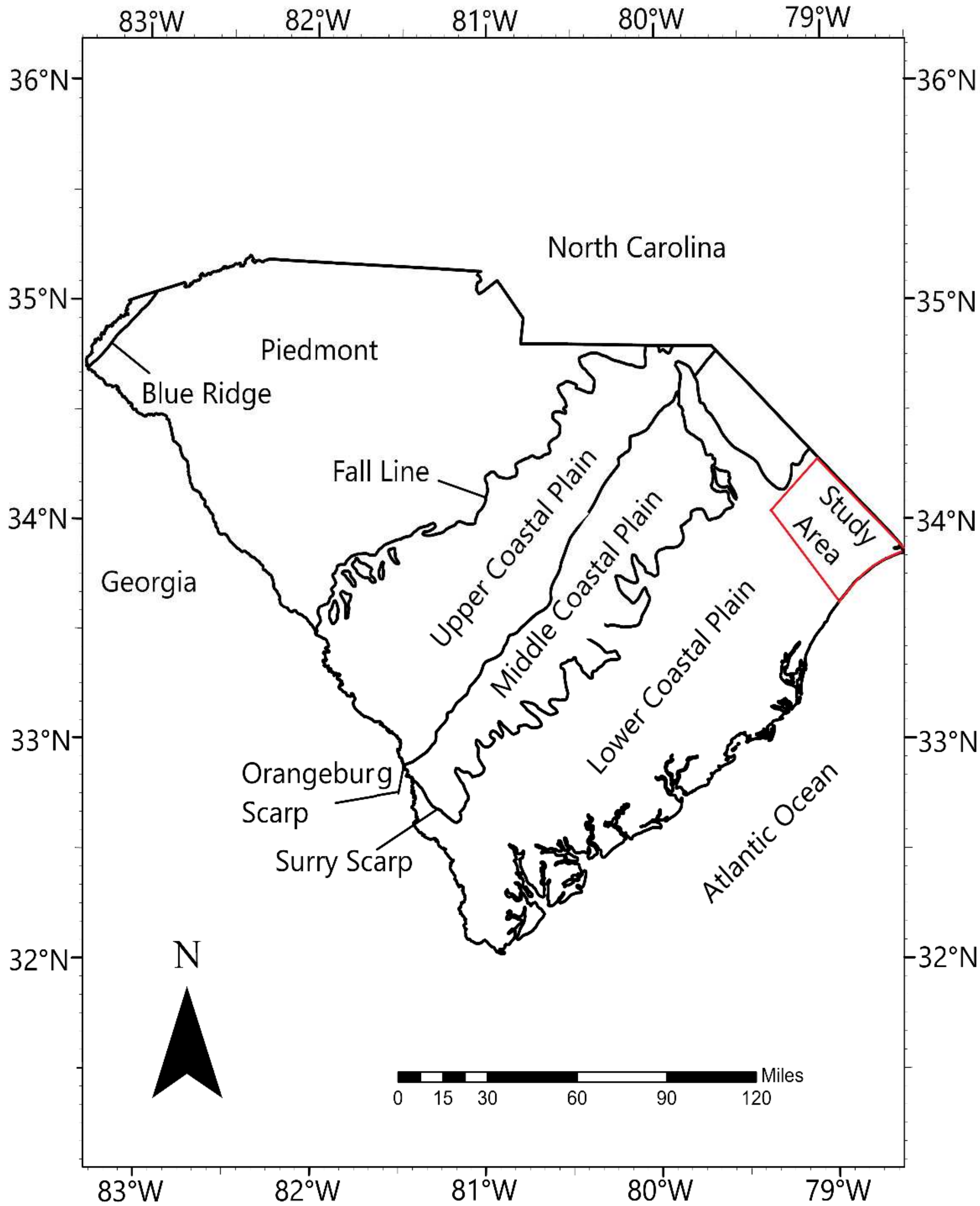


Figure 1.1 The Physiographic Provinces of South Carolina. The major scarp lines are labeled, and the study area is outlined in red. Figure modified from Doar (2014).

CHAPTER 2

BACKGROUND

2.1 REGIONAL GEOLOGIC SETTING

The coastal plain of the southeastern United States developed as a result of late Mesozoic rifting (Olsen et al., 1991) that began to separate Laurentia and Gondwanaland, which previously collided during the late Paleozoic Alleghanian phase of the Appalachian orogeny to create the supercontinent of Pangea (Horton and Zullo, 1991). This rifting created accommodation for sediments shedding from the Appalachian Mountains and the modern-day Atlantic Ocean. The modern-day ACP extends from the coast to the Fall Zone, where Meso-Cenozoic coastal plain sediments abut older crystalline rocks of the Appalachian Piedmont (Cooke, 1936). The sediments of SC's ACP form a generally SE-dipping wedge of post-Jurassic terrestrial and marine deposits, both siliciclastic and carbonate; these overlie Triassic and Jurassic basin deposits and pre-Mesozoic crystalline rocks (Horton and Zullo, 1991).

2.1 GEOLOGY OF THE SC LCP

The surficial Pleistocene deposits of SC's LCP consist mainly of marine sediments deposited by eustatic changes in sea level and minor tectonic adjustments (Colquhoun, 1974; Ward et al., 1991). Many past studies assume tectonic stability in the ACP. However, Cronin (1984) suggests that uplift and subsidence must be a factor in these deposits considering marine transgressions preserved in the ACP are not always time equivalent on a regional scale. At the surface, these eustatic sea-level fluctuations are preserved in the form of wave-cut notches and estuarine flats; in some parlance, the wave-cut notches are called escarpments (scarps), and their associated estuarine flats are called terraces (Doar and Kendall, 2008). The scarps, in most places, mark an individual transgression's maximum landward extent. In SC, these geomorphic features begin at the Orangeburg Scarp and stair-step down, in both age and elevation, to the modern-day coastline (Soller and Mills, 1991).

There are seven mapped pairs of scarp and terrace features present at the surface in the SC LCP (Table 2.1; Figure 2.1). The modern coastline is currently in the process of creating a new scarp, which will migrate inland with future sea-level rise. Each scarp and terrace pair have an associated stratigraphic formation, or an alloformation (Doar, 2014). An alloformation is defined as "a mappable body of rock that is defined and identified on the basis of its bounding discontinuities" (North American Commission on Stratigraphic Nomenclature (NASCN), 2005). The bounding discontinuities are the unconformities created where a younger alloformation at a lower elevation abuts an older alloformation at a higher elevation. Since each alloformation consists of many genetically related facies created by changes in sea-level, it is difficult to separate these deposits using conventional lithostratigraphic means. Therefore, the deposits of the SC LCP are separated and mapped from one another using allostratigraphy, where each scarp and terrace pair represent the deposits associated with an individual past highstand of sea-level.

Using scarps as proxies for sea-level highstands, it can be determined that there were seven sea-level transgressions during the Pleistocene. However, this is problematic when compared to Marine Isotope Stage (MIS) highstands (Doar, 2014). The MIS highstand data of Lisieki and Raymo (2005) suggest there were more transgressions during the Pleistocene than what is preserved in the stratigraphy of the South Carolina coast. An explanation could be that transgressions along the South Carolina coast tend to be more destructive rather than constructive. This is likely because the coast of South Carolina is a sediment-starved coast (Gayes et al., 2002). In sediment-starved systems, transgressions tend to destroy and recycle previously existing deposits and sediment (Doar, 2014). The MIS highstand data of Lisieki and Raymo (2005) also suggest that sea levels responsible for the alloformations occurring in the SC LCP were much lower in elevation than what is currently mapped in the SC LCP. For instance, the Wicomico alloformation in the SC LCP occurs at elevations of 75 ft above mean sea level. The MIS data suggests that sea levels never occurred above modern mean sea level at the time the Wicomico alloformation was deposited. The alloformations preserved in the geomorphic record of the SC LCP may have been uplifted by tectonic processes associated with glacial isostatic adjustment, protecting them from being destroyed and removed from the geomorphic record by subsequent transgressions (Potter and Lambeck, 2003; Scott et al., 2010; Doar, 2014; Doar and Kendall, 2014). Another explanation could be that the preserved alloformations are remnants of transgressions that were not preserved in the MIS highstand data (Doar, 2014).

In its earliest stages, mapping of the post-Miocene ACP relied heavily on geomorphic divisions of terraces and scarps based on the “terrace-formation” hypothesis of Shattuck (1901). This was made possible by the creation of 1:62,500 scale topographic maps of the ACP made by the USGS, which illustrated that the surficial morphology of the ACP consists of a series of broad terraces and coastward-facing scarps (Oaks and

Dubar, 1974). Cooke (1936) adopted the “terrace-formation” hypothesis and recognized that seven relict shorelines could be identified across the width of the ACP. While dividing coastal plain units using geomorphology is useful on a regional scale, geologic mapping of the ACP in later years relied more heavily on stratigraphic and biostratigraphic context to differentiate units, as the geology of deposits locally was more complex than the regional scarp and terrace mapping conveyed.

Mapping using sedimentary structures, stratigraphic patterns, and paleoecology by methods of subsurface boring, descriptions of subaerial exposures, and to a lesser extent, geomorphic features, became the more common way to map ACP deposits in post-1950 work (Oaks and Dubar, 1974). Using these methods, many units and formations were further subdivided into genetically related lithofacies and biofacies (Dubar, 1971). These different methods of unit identification and division of units led to different nomenclatures for ACP units, which complicated understandings, especially across state lines, of ACP geology (Doar, 2014).

Recent mapping uses scarp toe elevations to aid in geologic mapping of the surficial units of the SC ACP. The toe of a scarp is the point where sediments at the surface abut or overlie older sediments at a higher elevation, marking an unconformity between deposits of differing ages (Doar, 2014; Fig. 2.2). Scarp toes represent an individual transgression’s maximum sea level (Doar and Kendall, 2014). At the scarp toe, estuarine deposits (of the younger deposit) mark the mean high tide elevation (Doar, 2014). Strand deposits could be interpreted as a higher mean high tide elevation because eolian features such as dunes can build well above the high tide mark, therefore estuarine deposits portray the most accurate representation of the mean high tide level. Table 2.1 displays the current scarp to elevations for each individual alloformation.

Table 2.1 Pleistocene Alloformations of the SC LCP. The Data in the table was taken from Doar (2014).

Formation	Scarp	Scarp Toe Elevation (m)	Scarp Toe Elevation (ft)	Assigned Age	Reference
Wicomico	Surry	27.4-28.9	89.89- 94.18	2.12-1.80 Ma, 1.6-1.4 Ma Pleistocene	Weems et al., 1997; McGregor, 2011
Penholoway	Dorchester	21.3-22.8	69.88- 74.8	970-730 ka Pleistocene	Weems and Lemon, 1989
Ladson	Macbeth	17.4	57.08	450-400 ka Pleistocene	McCartan et al., 1984; Weems and Lemon, 1989
Ten Mile Hill	Bethera	10.7	35.1	240-200 ka Pleistocene	Szabo, 1985; Weems et al., 1997; Sanders et al, 2009; Willis, 2006
Pamlico	Suffolk	6.7	21.98	120-90 ka Pleistocene	Wehmiller and Belknap, 1982
Princess Anne	Awendaw	5.2	17.06	100-80 ka Pleistocene	York et al., 2001; Wehmiller et al., 2004; Willis, 2006
Silver Bluff	Mt. Pleasant	3	9.84	100-ka, 35 ka, 34 ka Pleistocene	Hoyt and Hails, 1974; Weems and Lemon, 1993; Zayac, 2003

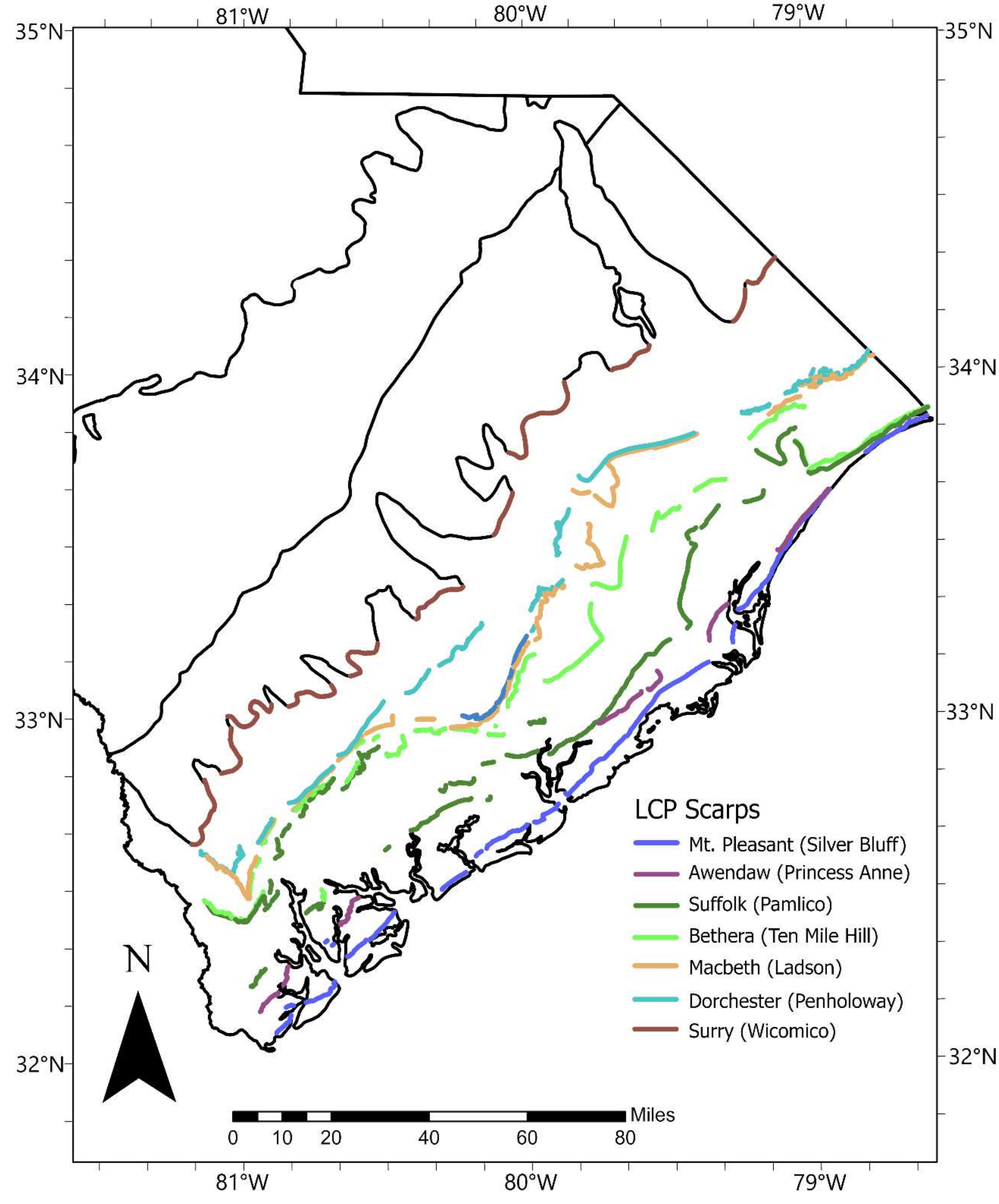


Figure 2.1 Geologic Provinces of South Carolina with Lower Coastal Plain (LCP) Scarp Lines. The scarp lines were interpreted by Will Doar at the SCGS.

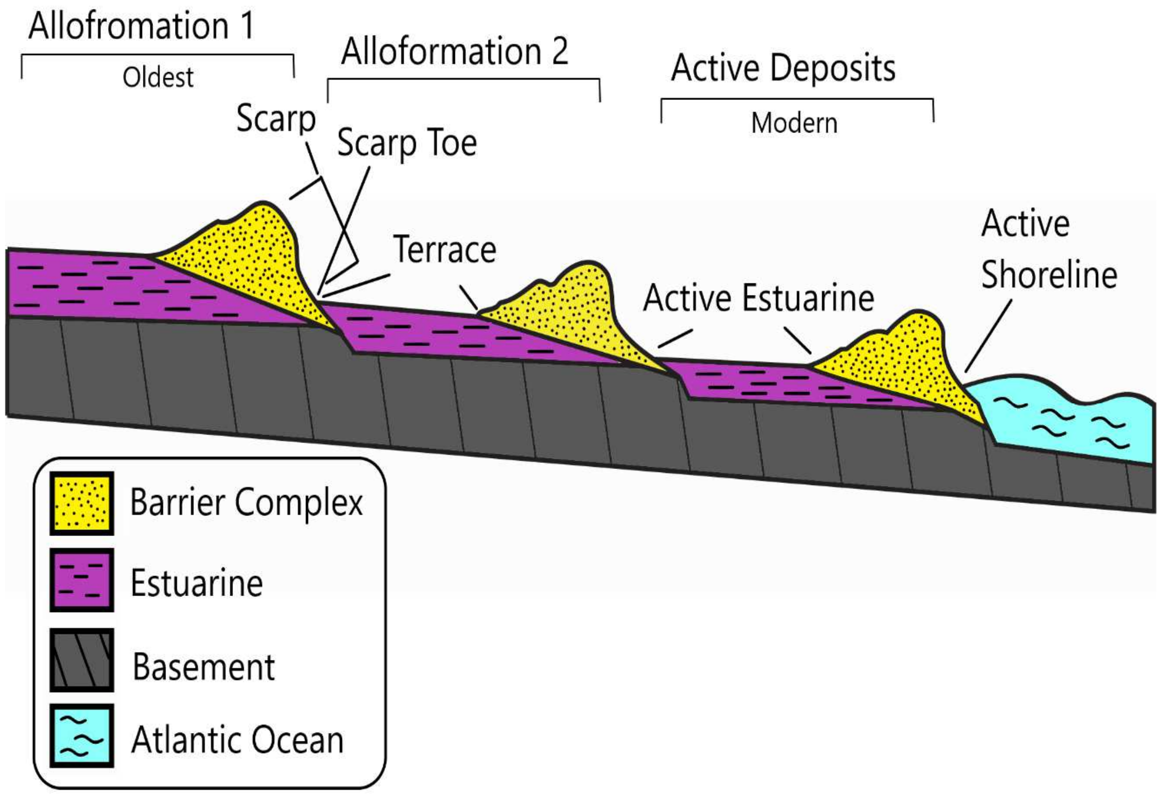


Figure 2.2 Stair Step Scarp and Terrace Model. Alloformations of the SC LCP stair step down in both age and elevation to the active shoreline. This figure depicts two relict deposits and an active deposit, with each deposit representing a different transgressive-regressive sequence

CHAPTER 3

METHODS AND PREPARATORY PROCEDURES

3.1 FIELD WORK AND SAMPLING

Twelve locations (Figure 3.1, Figure 3.2) containing Pleistocene strand deposits and four locations containing active Holocene strand deposits in Horry County were hand augured, described in detail, sampled, and taken to the South Carolina Geological Survey (SCGS) and the University of South Carolina (U of SC) for analysis. The Pleistocene alloformations sampled consist of strand deposits from the Wicomico, Ladson, and Ten Mile Hill alloformations. The modern samples were taken from Waites Island in Horry County, SC. For the modern strand deposit at Waites Island, samples were taken from the berm, the dune, one meter below high tide extent, and one meter above low tide extent. The high tide extent was recognized by the wrack line present the day the sample was taken, and the low tide extent was determined by recognizing the slack tide on the day the sample was taken. The selected locations on Waites Island were sampled to determine whether microfacies (dune, berm, foreshore, etc.) could impact the differentiation of relict Pleistocene strand deposits, as microfacies were not identified or subdivided for the mapped Pleistocene strand deposits (Doar, 2015 a). The sample locations were chosen using 1:24,000 scale geologic maps made by the SCGS (Doar, 2015 a; Doar, 2015 b; Doar, 2015 c, Doar, 2017 a; Doar, 2017 b; Doar, 2018; Doar and Wykel, 2018 a; Doar and Wykel 2018 b; Wykel and Doar, 2019; Gawinski and Doar, 2021). At each site, sampling using a three-inch diameter hand auger started beneath the organic-rich soil zone horizon and continued until ~ one kg of sample was retrieved. The hand auger holes were logged at the inch scale and color, grain size, sorting, rounding, and basic mineralogy were recorded with depth (Figures 3.3-3.18).

3.2 GRAIN SIZE AND SHAPE ANAYLSIS

Grain size and shape analysis for the 16 samples occurred at the University of South Carolina School of the Earth, Ocean, and Environment using a Horiba CAMSIZER P4 Particle Analysis System. Grain size analysis used the 1/4 φ scale and statistical parameters of the grain size distributions were computed by methods proposed by Folk and Ward (1957) using GRADISTAT for Windows, version 9.1 (Blott and Pye, 2001). The grain shape parameters analyzed were sphericity and symmetry. Descriptions and equations for determining shape and sphericity values occur in Figure 3.19.

To prepare the samples for CAMSIZER analysis, all samples were split into 50–60-gram aliquots using a Humboldt Dry Sediment Splitter, and organics, carbonate material, and the silt and clay fractions were removed. The organic and carbonate material were removed to focus on the terrigenous component of the deposits. The clay and silt fractions were removed because the CAMSIZER cannot reliably measure mud-sized particles. The samples from Waites Island contained a small proportion of carbonate material. This material was removed by immersing each aliquot in a cool, 10 percent hydrochloric acid (HCl) bath (Poppe et al., 2000). Small amounts of ten percent HCl were added to each sample's bath until no effervescence was observed, signaling that all $CaCO_3$ material was removed. The HCl was decanted using a Buchner Funnel system with a two-micron size filter so no fine material would be lost. The sample was then rinsed five times with water to remove all remaining HCl from each aliquot. Each aliquot was then dried and weighed to determine the percentage of $CaCO_3$ lost (Table 3.1).

To remove organic material, the aliquots for all 16 samples were incinerated at 550 degrees Celsius for four hours in a muffle oven. After incineration, each aliquot was weighed to determine the percent of organic material lost (Table 3.2). Next, all aliquots were wet sieved to remove all material finer than 63 microns. After wet sieving, samples were oven-dried and weighed to determine the percentage of silt and clay lost (Table 3.3).

3.3 SAND POINT COUNTNG

Aliquots for all 16 samples were shipped to Wagner Petrographic for the creation of thin section grain mounts. Each thin section was ground to 30 microns thick and half-stained for both plagioclase and potassium feldspar. Three hundred sand-sized grains (n=300) were examined at random in each sample from which the abundance of quartz, feldspar, and lithic fragments were determined using the Folk method (Folk, 1968, 1980). The grains were chosen at random by moving the mechanical stage on a petrographic microscope one unit to the left in the x-axis direction by utilizing the graduated locator markings on the mechanical stage itself. The grain that was present in the crosshair of the microscope was noted at each interval. When the end of the slide in the x-axis direction was reached, the mechanical stage was moved five units in the y-axis direction. After moving five units in the y-axis direction, the stage was then moved in one-unit increments to the right in the x-axis direction. This process was repeated until 300 grains were counted and identified. This method was utilized to mimic the shape of a grid because no point counting grid was available. For simplicity, every grain that was neither solely quartz nor feldspar was identified as a lithic fragment. Silt and clay-sized particles were not recorded.

3.4 K-MEANS CLUSTER ANALYSIS

Grain size, grain shape, and mineralogy by point counting are common analyses used to distinguish geologic units and formations (Folk,1980). However, when units are similar, such as the ones investigated in this study, and multiple variables need to be compared, more powerful methods are required for differentiation to be successful. K-means cluster analysis is a statistical method used to partition multivariate observations into homogenous groups (Templ et al., 2008). Cluster analysis is specifically useful in this study because up to seven variables for each sample were analyzed; drawing conclusions from this many variables is difficult using traditional means such as graphing. K-means cluster analysis, using IBM SPSS Statistics for Windows, version 28.0 (SPSS), was used to attempt to distinguish the four sampled units. Data from the grain size, grain shape, and point counting analyses were implemented into the k-means clustering tool in an attempt to group each sample into its appropriate cluster, with each cluster representing the four different units sampled. To standardize all variables, z-scores were calculated and used in the analysis, except in the case of a one-dimensional, elevation-only analysis. Standardization of the one-dimensional elevation-only analysis was not necessary because the elevation values for each sample were all measured in feet above mean sea-level, meaning that the data was already standardized.

K-means cluster analysis requires the user to determine how many clusters to group the data into. Four clusters were chosen to represent each of the four units sampled. Since k-means cluster analysis requires the user to decide the number of clusters, this could be problematic when the number of units being sampled is unknown. For instance, if three units were being sampled and the user only chose two clusters, only two clusters would be returned. In this case, the three units could easily be misidentified as being only two units.

3.5 K-MEANS CLUSTER ANALYSIS WITH SYNTHETIC DATA

An inherent problem with differentiating SC LCP strand deposits, which is currently based heavily on elevation, is that elevations of different alloformations can overlap. This is overlap is created by the fact that strand deposits can build well above the mean high tide line due to eolian processes. Because high confidence in which unit was being sampled was desired, and limited access to locations, no elevations were overlapping in the 16 localities sampled. To demonstrate both that identifying units solely based on elevation can be problematic, and that cluster analysis can address this issue, a synthetic data set was created where elevations were deliberately overlapping.

To create the dataset, bounded normal distributions were created using the data collected from the actual 16 samples. For instance, using the four sorting values associated with the Ten Mile Hill samples, a mean, standard deviation, minimum, and maximum value were calculated. Then, these values were used to create a bounded normal distribution to generate 30 more sorting values that had Ten Mile Hill qualities. This same method was used for the rest of the variables investigated in the study and repeated for each unit. To create the bounded normal distributions, the rnorm_bounded function in the dyngen (Cannoodt, 2021) package was implemented using R (R Core Team, 2021). This increased the sample size for each unit to 34 samples, consisting of four actual samples and 30 synthetic samples that were representative of their associated unit.

An elevation value with respect to mean sea level was assigned to each synthetic sample ranging from -5 ft to 12 ft (1.5 m to 3.7 m) for the modern deposits at Waites Island, 22 ft to 52 ft (6.7 m to 15.8 m) for Ten Mile Hill, 37 ft to 65 ft (11.3 m to 19.8 m) for Ladson, and 79 ft to 108 ft (24.1 m to 33 m) for Wicomico. Elevations values were chosen using known elevations each unit could occur based on recent mapping by the SCGS (Doar, 2015 a; Doar, 2015 b; Doar, 2015 c) Doar, 2017 a; Doar, 2017 b; Doar, 2018; Doar and Wykel, 2018 a; Doar and Wykel 2018 b; Wykel and Doar, 2019; Gawinski and Doar, 2021). The creation of this dataset led to multiple samples where elevations overlapped between the Ten Mile Hill and Ladson alloformation samples. To standardize all variables, z-scores were used in the cluster analysis. Once again, z-scores were not used for the elevation-only analysis because the data was already standardized in feet above mean sea-level.

Table 3.1 Percent $CaCO_3$ Material Removed from Waites Samples

Sample ID	**Weight Before Acid Bath (g)**	**Weight After Acid Bath (g)**	**Percentage of CaCO3 Removed (g)**
Waites-1	55.661	55.447	0.0038
Waites-2	55.204	53.96	0.0225
Waites-3	56.117	55.26	0.0153
Waites-4	56.244	55.974	0.0048

Table 3.2 Percent of Organic Material Lost on Ignition.

Sample ID	Pre-Incineration Weight (g)	Post-Incineration Weight (g)	Percent of Organics Removed (g)
Waites-1	55.447	55.324	0.0022
Waites-2	53.96	53.9	0.0011
Waites-3	55.26	53.513	0.0316
Waites-4	55.974	55.915	0.0011
TMH-1	56.25	55.979	0.0048
TMH-2	54.159	53.612	0.0101
TMH-3	52.475	51.824	0.0124
TMH-4	49.953	49.109	0.0169
LAD-1	54.59	54.002	0.0108
LAD-2	53.056	52.823	0.0044
LAD-3	55.591	54.516	0.0193
LAD-4	53.215	52.735	0.0090
WIC-1	53.93	53.572	0.0066
WIC-2	55.167	54.159	0.0183
WIC-3	54.483	52.883	0.0294
WIC-4	50.22	50.206	0.0003

Table 3.3 Percent of Silt and Clay Removed by Wet Sieving.

Sample ID	**Pre-Wet Sieve Weight (g)**	**Post-Wet Sieve Weight (g)**	**Percent of Silt and Clay Removed (g)**
Waites-1	55.324	55.17	0.2784
Waites-2	53.9	53.744	0.2894
Waites-3	53.513	53.282	0.4317
Waites-4	55.915	55.777	0.2468
TMH-1	55.979	54.276	3.0422
TMH-2	53.612	51.475	3.9860
TMH-3	51.824	49.964	3.5891
TMH-4	49.109	45.97	6.3919
LAD-1	54.002	52.204	3.3295
LAD-2	52.823	49.728	5.8592
LAD-3	54.516	52.19	4.2666
LAD-4	52.735	48.906	7.2608
WIC-1	53.572	51.065	4.6797
WIC-2	54.159	49.336	8.9053
WIC-3	52.883	50.54	4.4305
WIC-4	50.206	44.797	10.7736

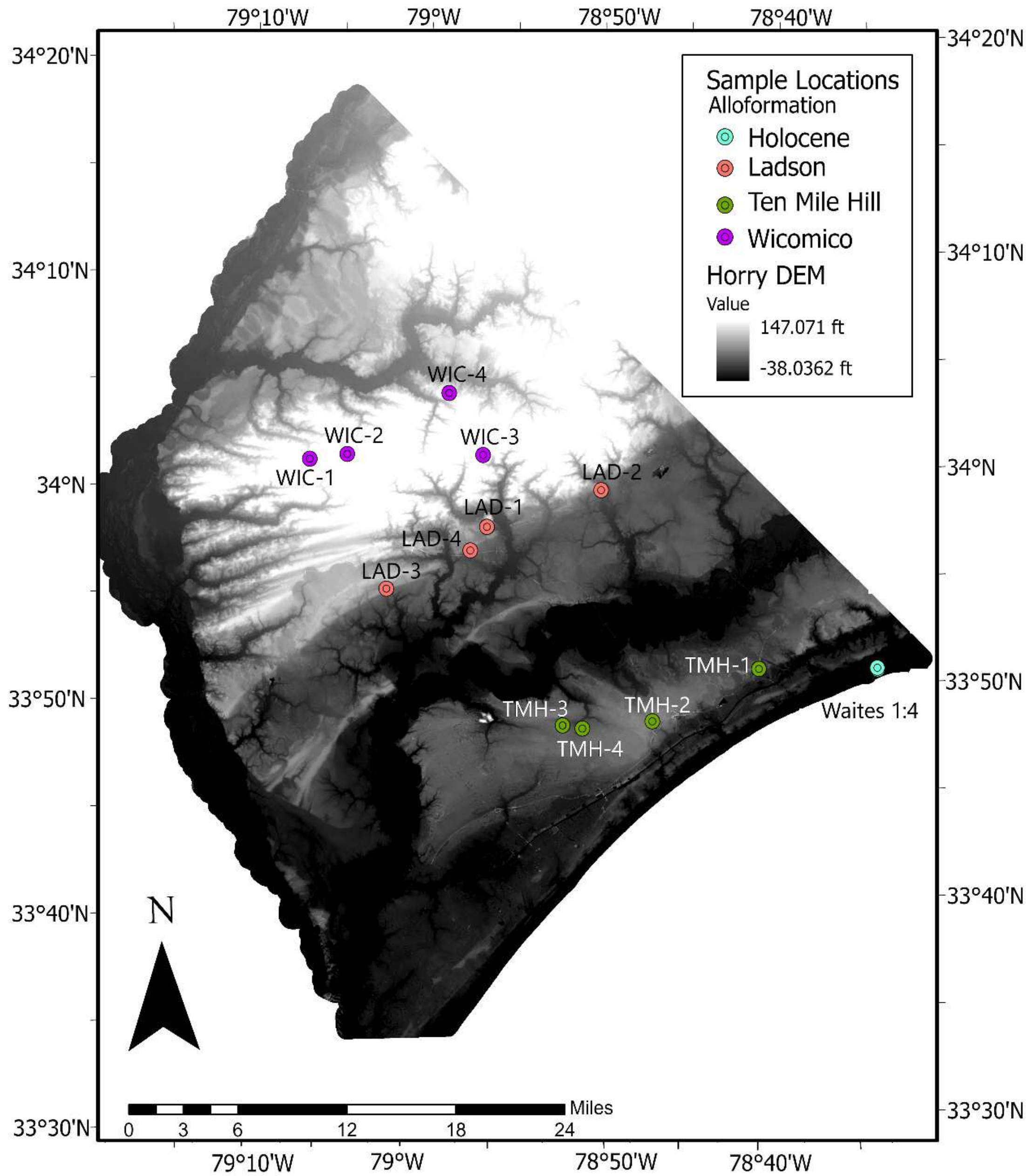


Figure 3.1 Sample Locations with Horry County DEM Base Map.

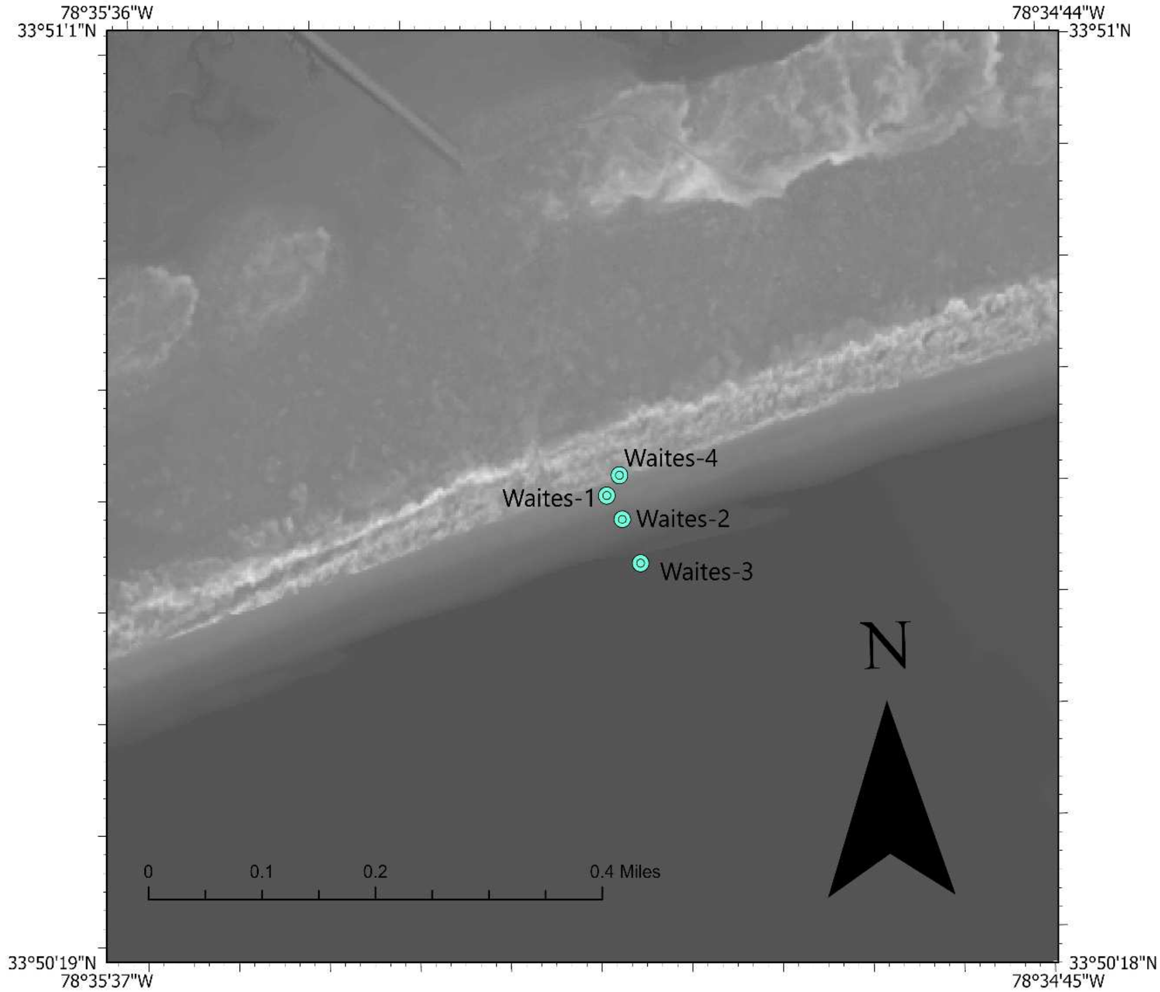


Figure 3.2 Sample Locations on Waites Island in Horry County, SC.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 02/28/2021	County: Horry	Total Depth: 24 inches
Field ID: Waites-1	Logged by: Andy Wykel	Quadrangle: Waites	Sample #:
Collar Elevation: 3 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 723370 E	3747522 N	Helpers: N/A	

Location Description: The Berm

Notes	Color	Depth (in)	Description
	2.5Y 8/1	0- 24	fluffy, fine, subangular to subrounded, v. well sorted, white quartz sand with scattered vf to f opaques, few fien phosphate, rare vf rutile, rare epidote, rare fine olivine *SAMPLING BEIGNS BY & INCHES* -by 7 inches, there is the addition of rare vf to fine iron stained quartz -sample become slightly wet at 14 inches -rare broken shell fragments found at 23 inches *BOH 24 inches, refusal - water table inhibited retrieval*
		10	
		20	
		30	
		40	

Figure 3.3 Sample Log for Waites-1.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 02/28/2021	County: Horry	Total Depth: 25 in
Field ID: Waites-2	Logged by: Andy Wykel	Quadrangle: Waites	Sample #:
Collar Elevation: 0 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 723392 E	3747489 N	Helpers: N/A	

Location Description: Upper Foreshore - 3 ft shoreward of the high tide wrack line.

Notes	Color	Depth (in)	Description
	2.5Y 6/1	0-25	slightly wet, fine to medium, subangular to subrounded, well sorted, gray quartz sand with scattered very fine to fine opaques, rare fine to medium phosphate, rare fine rose quartz, epidote, very fine to fine rutile, and few broken <1mm shell fragments *Sampling begins at 6 inches* -by 8 inches, sand becomes very wet, broken shell frags increase to scattered, and there is the addition of scattered broken echinoid spines
		10	
		20	
		25	*BOH 25 inches, refusal due to water table
		30	
		40	

Figure 3.4 Sample Log for Waites-2.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 02/28/2021	County: Horry	Total Depth: 6 nches
Field ID: Waites-3	Logged by: Andy Wykel	Quadrangle: Waites	Sample #:
Collar Elevation: - 5 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 723418 E	3747428 N	Helpers: N/A	

Location Description: Lower Forshore - 16 feet above water at low tide 2/28/21 at 3:15 PM

Notes	Color	Depth (in)	Description
	5Y 7/1	0- 6	fine to medium, subangular to subrounded, well sorted, fossiliferous yellow quartz sand with with minor 1-2mm shell frags, scattered very fine to fine opaques, rare fine to medium phosphate, rare vf to fine epidote, and vf garnet
			BOH, 6 inches, REFUSAL DUE TO WATER TABlE - SAMPLE HERE WAS TAKEN BETWEEN 0-6 I NCHES

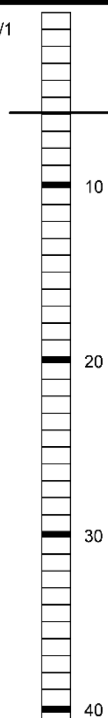


Figure 3.5 Sample Log for Waites-3.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 02/28/2021	County: Horry	Total Depth: 24 inches
Field ID: Waites-4	Logged by: Andy Wykel	Quadrangle: Waites	Sample #:
Collar Elevation: 8 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 723388 E	3747550 N	Helpers: N/A	

Location Description: "Relict Dune Field* Active dune field was removed by storms.

Notes	Color	Depth (in)	Description
	2.5Y 8/1	0-24	Dry, fluffy, very fine to fine, subangular to subrounded, well sorted, white quartz sand with scattered very fine opaques, rare vf rutile, and vf to fine iron stained quartz

SAMPLE STARTS AT 6 INCHES

-by 6 inches, there is the addition of rare very fine garnet and epidote

10

-by 12 inches, there is the addition of rare <1mm shell frags

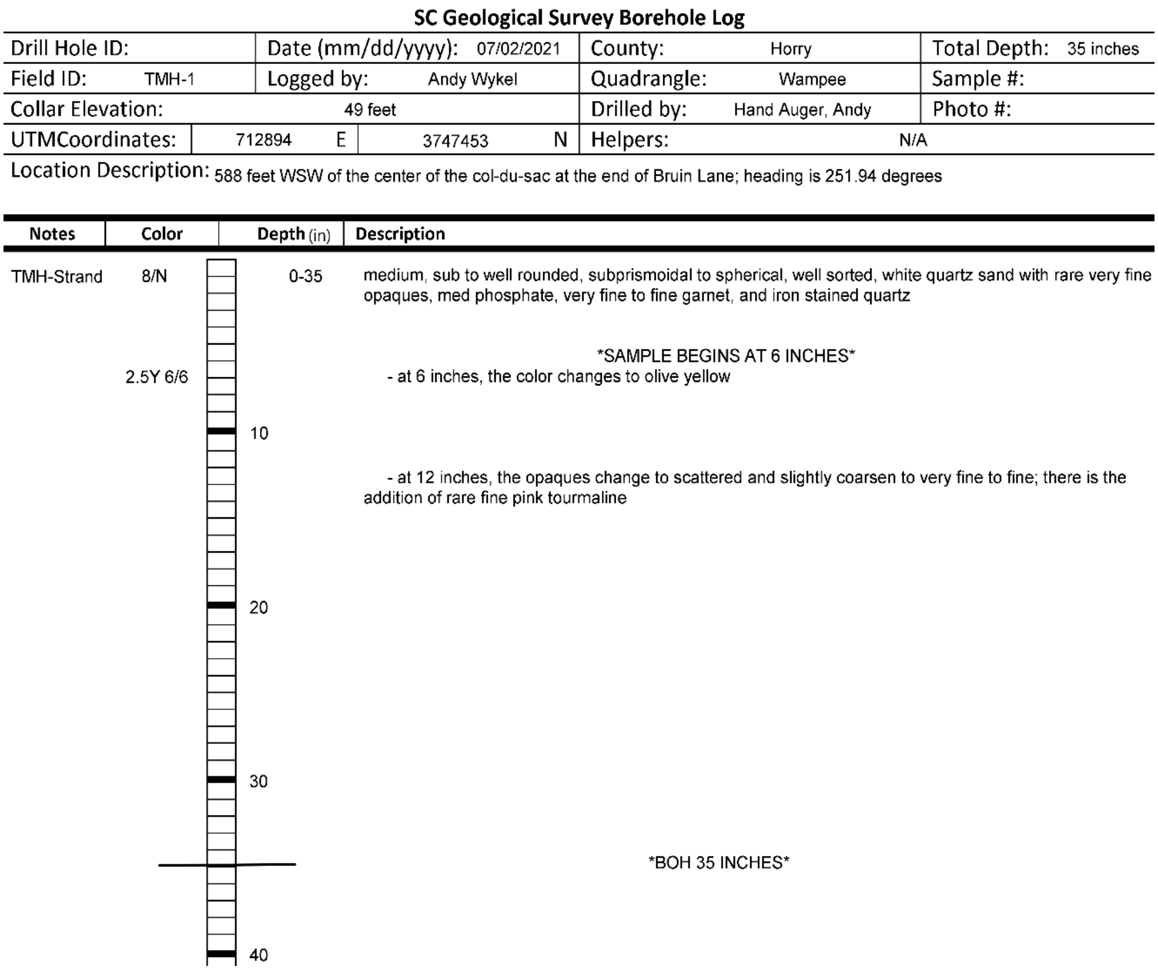
20

BOH 24 inches

30

40

Figure 3.6 Sample Log for Waites-4.



SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 07/02/2021	County: Horry	Total Depth: 35 inches
Field ID: TMH-1	Logged by: Andy Wykel	Quadrangle: Wampee	Sample #:
Collar Elevation: 49 feet		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 712894 E 3747453 N		Helpers: N/A	

Location Description: 588 feet WSW of the center of the col-du-sac at the end of Bruin Lane; heading is 251.94 degrees

Notes	Color	Depth (in)	Description
TMH-Strand	8/N	0-35	medium, sub to well rounded, subprismoidal to spherical, well sorted, white quartz sand with rare very fine opaques, med phosphate, very fine to fine garnet, and iron stained quartz
			SAMPLE BEGINS AT 6 INCHES
	2.5Y 6/6		- at 6 inches, the color changes to olive yellow
		10	
			- at 12 inches, the opaques change to scattered and slightly coarsen to very fine to fine; there is the addition of rare fine pink tourmaline
		20	
		30	
			BOH 35 INCHES
		40	

Figure 3.7 Sample log for TMH-1.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 07/02/2021	County: Horry	Total Depth: 36 inches
Field ID: TMH-2	Logged by: Andy Wykel	Quadrangle: Hand	Sample #:
Collar Elevation: 52 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 703458 E	3742931 N	Helpers: N/A	

Location Description: 560 feet NW of Water Tower Road on the NE side of Telephone Road

Notes	Color	Depth (in)	Description
TMH-Strand Humate	10YR 2/1	0-35	med, sub to well rounded, subprismoidal to spherical, well sorted, black quartz sand
		10	
	2.5Y 4/4		*SAMPLE BEGINS AT 14 INCHES* - at 14 inches, the color changes to olive brown
		20	
		30	-at 30 inches, the color changes to brownish yellow and there is the addition of rare very fine to fine opaques, very fine to fine garnet, and medium milky quartz
			BOH 36 INCHES
		40	

Figure 3.8 Sample Logs for TMH-2.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 07/02/2021	County: Horry	Total Depth: 32 inches
Field ID: TMH-3	Logged by: Andy Wykel	Quadrangle: Hand	Sample #:
Collar Elevation: 42 feet		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 695511 E	3742577 N	Helpers: N/A	

Location Description: 1400 feet east of International Drive on the south side of Water Tower Road; Lewis Ocean Bay Property

Notes	Color	Depth (in)	Description
TMH-Strand	2.5Y 4/4	0-32	medium, sub to well rounded, subprismoidal to spherical, very well sorted olive brown quartz sand with rare very fine opaques and medium iron stained quartz *SAMPLE BEGINS AT 2 INCHES* - at 2 inches, the color changes to light olive brown - at 12 inches, there is the addition of rare med smoky quartz and blue quartz, and rare fine to medium phosphate *BOH 32 INCHES*

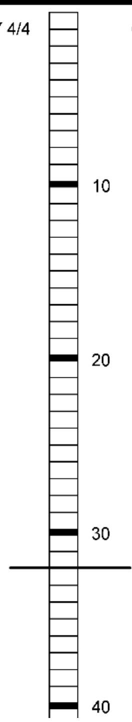


Figure 3.9 Sample Log for TMH-3.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 07/02/2022	County: Horry	Total Depth: 18 inches
Field ID: TMH-4	Logged by: Andy Wykel	Quadrangle:	Sample #:
Collar Elevation: 39 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 697261 E	3742312 N	Helpers: Jordan Suttles	

Location Description: Lewis Ocean Bay Heritage Preserve - 7,200 feet east of International Drive on the south side of Water Tower Road.

Notes	Color	Depth(in)	Description
TMH Strand	10YR 2/2	0-5	med with scattered coarse, subangular to rounded, well sorted, (highly organic) quartz sand
			SAMPLE BEGINS AT 5 INCHES
	10YR 3/2	5-9	fine to med, subangular to rounded, mod sorted, very dark grayish brown quartz sand with a silt matrix
	2.5Y 4/3	9-27	slightly wet, med, subrounded to rounded, well sorted, olive brown quartz sand with interstitial silt content
		10	
		20	
	10YR 5/3		-at 22 inches, the sand fraction coarsens to med to coarse
			- at 25 inches, the silt content increases to becomes a quartz sand with a silt matrix
		30	
			BOH 27 INCHES
		40	

Figure 3.10 Sample Log for TMH-4.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 07/02/2021	County: Horry	Total Depth: 31 inches
Field ID: Ladson-1	Logged by: Andy Wykel	Quadrangle: Shell	Sample #:
Collar Elevation: 65 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 688808 E	3759735 N	Helpers: N/A	

Location Description: 1300 feet west of HWY 19 on the North side of Westmoreland Rd

Notes	Color	Depth (in)	Description
Ladson Strand	10YR 3/2	0-31	fine to medium, subangular to subrounded, subprismoidal to spherical, well sorted, very dark grayish brown quartz sand with scattered organics and rare medium blue quartz
	2.5Y 6/4	10	
			SAMPLE BEGINS AT 12 INCHES
			-at 12 inches, the color changes to light olive brown with the addition of rare very fine opaques and medium smoky quartz
		20	
			-at 23 inches, the color changes to light yellowish brown. the opaques increase to scattered, and there is the addition of rare very fine garnet, rutile, and fine to medium rose quartz
		30	*BOH 31 inches*
		40	

Figure 3.11 Sample Log for LAD-1.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 07/18/2022	County: Horry	Total Depth: 18 inches
Field ID: Ladson-2	Logged by: Andy Wykel	Quadrangle:	Sample #:
Collar Elevation: 56 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 698921 E	3762896 N	Helpers: Jordan Suttles	

Location Description: 640 ft east of Carter Road on the North side of "No Name Road". *The no name road is the side opposite the hypotenuse formed by Daisy, Carter, and "No Name Road"

Notes	Color	Depth (in)	Description
Ladson Strand	10YR 3/2	0-18	fine to med, subangular to subrounded, sub-prismoidal to spherical, well sorted, dark grayish brown (highly organic) quartz sand
		10	
	10YR 2/1		-at 12 inches, the the sample becomes black and gains an organic matrix support
	10YR 5/4	18-32	fine to med, subangular to subrounded, well sorted, yellowish brown quartz sand with a slight silt content and scattered organics
		20	
		30	
			SAMPLING BEGINS AT 32 INCHES
	10YR 5/3	32-42	fine to med, subangular to subrounded, well sorted, brown quartz sand with scattered coarse quartz -at 34 inches, addition of rare vf to fine opaques
			*BOH 40 INCHES *
		40	

Figure 3.12 Sample Log for LAD-2.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 07/18/2021	County: Horry	Total Depth: 24 inches
Field ID: Ladson-3	Logged by: Andy Wykel	Quadrangle: Adrian	Sample #:
Collar Elevation: 64 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 679896 E	3754368 N	Helpers: N/A	

Location Description: 3700 feet west of HWY 701 on the north side of W. Homewood Drive; just across the ditch

Notes	Color	Depth (in)	Description
Ladson Strand	2.5Y 5/3	0-24	sand (100-00-00), light olive brown fine-medium, well sorted, sub angular-sub rounded, sub prismoidal-spherical quartz sand with rare, vf to fine opaques and very fine garnet
			SAMPLE BEGINS AT 8 INCHES
	10YR 6/6		-At 8 inches, the color changes to brownish yellow and the opaques increase to scattered
		10	
		20	
			BOH 24 INCHES
		30	

Figure 3.13 Sample Log for LAD-3.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 07/22/2021	County: Horry	Total Depth: 34 inches
Field ID: Ladson-4	Logged by: Andy Wykel	Quadrangle: Shell	Sample #:
Collar Elevation: 53 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 687336 E	3757704 N	Helpers: N/A	

Location Description: 1500 feet South of Adrian HWY on the west side of Johnson Shelly Road; in field entrance

Notes	Color	Depth (in)	Description
Moved Earth, Tilled	2.5Y 5/3	0-2	medium, subangular to subrounded, moderately sorted, light olive brown quartz sand with scattered coarse quartz and rare very coarse quartz
		2-34	fine to medium, subrounded to well rounded, well sorted, olive brown quartz sand with scattered coarse quartz, rare smoky quartz, and rare very fine opaques *SAMPLE BEGINS AT 7 INCHES* -at 7 inches, the coarse quartz becomes rare
		10	
			-by 12 inches, the sample becomes slightly wet and gains a scattered silt content
		20	*NEW SAMPLE BAG BEGINNING AT 22 INCHES* -at 22 inches, the color changes to light olive brown
		30	
			BOH 34 INCHES
		40	

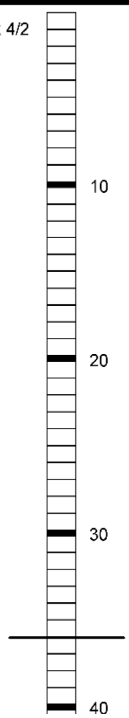
Figure 3.14 Sample Log for LAD-4.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 06/27/2021	County: Horry	Total Depth: 36 inches
Field ID: Wic-1	Logged by: Andy Wykel	Quadrangle: Galivants Ferry	Sample #:
Collar Elevation: 99 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 673114 E	3765609 N	Helpers: N/A	

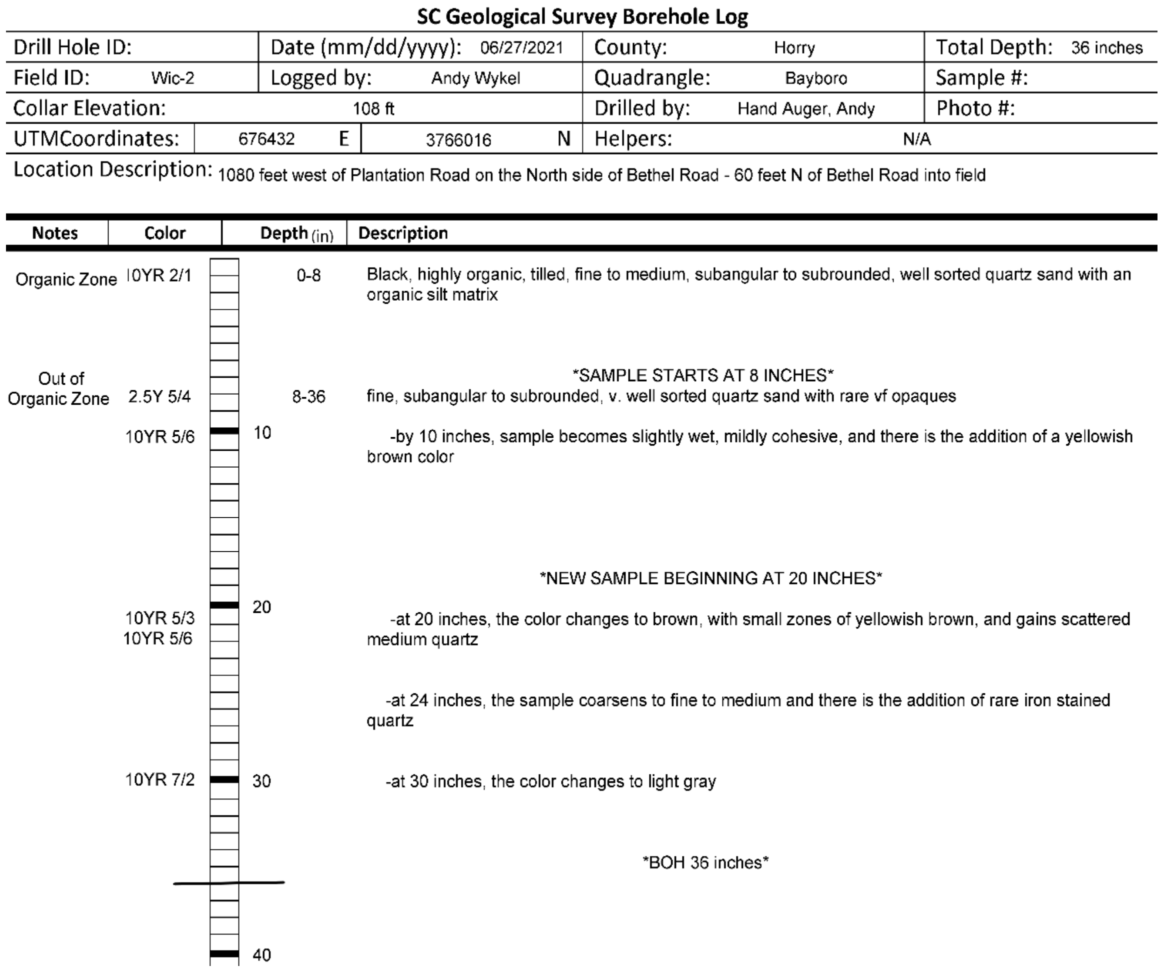
Location Description: 420 feet N of Burroughs Road on the East side of Huckleberry Road

Notes	Color	Depth (in)	Description
Organic Zone	10YR 4/2	0-36	dark grayish brown, organic, fine, subangular to subrounded, v. well sorted quartz sand with rare vf opaques and rare fine garnet -at 4 inches, the color changes to light olive brown and the organics becomes rare -at 8 inches, the opaques increase to scattered and the organic zone ends *BEGIN SAMPLING AT 8 INCHES, OUT OF ORGANIC ZONE*



BOH, 36 INCHES

Figure 3.15 Sample Log for WIC-1.



SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 06/27/2021	County: Horry	Total Depth: 36 inches
Field ID: Wic-2	Logged by: Andy Wykel	Quadrangle: Bayboro	Sample #:
Collar Elevation: 108 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 676432 E	3766016 N	Helpers: N/A	

Location Description: 1080 feet west of Plantation Road on the North side of Bethel Road - 60 feet N of Bethel Road into field

Notes	Color	Depth (in)	Description
Organic Zone	l0YR 2/1	0-8	Black, highly organic, tilled, fine to medium, subangular to subrounded, well sorted quartz sand with an organic silt matrix
			SAMPLE STARTS AT 8 INCHES
Out of Organic Zone	2.5Y 5/4	8-36	fine, subangular to subrounded, v. well sorted quartz sand with rare vf opaques
	10YR 5/6	10	-by 10 inches, sample becomes slightly wet, mildly cohesive, and there is the addition of a yellowish brown color
			NEW SAMPLE BEGINNING AT 20 INCHES
	10YR 5/3 10YR 5/6	20	-at 20 inches, the color changes to brown, with small zones of yellowish brown, and gains scattered medium quartz
			-at 24 inches, the sample coarsens to fine to medium and there is the addition of rare iron stained quartz
	10YR 7/2	30	-at 30 inches, the color changes to light gray
			BOH 36 inches
		40	

Figure 3.16 Sample Log for WIC-2.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 06/27/2021	County: Horry	Total Depth: 36 inches
Field ID: Wic-3	Logged by: Andy Wykel	Quadrangle: Loris	Sample #:
Collar Elevation: 108 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 676432 E	3766016 N	Helpers: N/A	

Location Description: 1080 feet west of Plantation Road on the North side of Bethel Road - 60 feet N of Bethel Road into field

Notes	Color	Depth (in)	Description
Organic Zone	10YR 2/1	0-8	Black, highly organic, tilled, fine to medium, subangular to subrounded, well sorted quartz sand with an organic silt matrix
			SAMPLE STARTS AT 8 INCHES
Out of Organic Zone	2.5Y 5/4	8-36	fine, subangular to subrounded, v. well sorted quartz sand with rare vf opaques
	10YR 5/6	10	-by 10 inches, sample becomes slightly wet, mildly cohesive, and there is the addition of a yellowish brown color
			NEW SAMPLE BEGINNING AT 20 INCHES
	10YR 5/3 10YR 5/6	20	-at 20 inches, the color changes to brown, with small zones of yellowish brown, and gains scattered medium quartz
			-at 24 inches, the sample coarsens to fine to medium and there is the addition of rare iron stained quartz
	10YR 7/2	30	-at 30 inches, the color changes to light gray
			BOH 36 inches
		40	

Figure 3.17 Sample Log for WIC-3.

SC Geological Survey Borehole Log

Drill Hole ID:	Date (mm/dd/yyyy): 07/18/2021	County: Horry	Total Depth: 24 inches
Field ID: WIC-4	Logged by: Andy Wykel	Quadrangle: Loris	Sample #:
Collar Elevation: 107 ft		Drilled by: Hand Auger, Andy	Photo #:
UTMCoordinates: 685467 E	3771272 N	Helpers: N/A	

Location Description: 1300 Feet east of Green Sea Road S. on the south side of Oneal Road.

Notes	Color	Depth (in)	Description
Wicomico Strand	2.5Y 5/3	0-24	sand (100-00-00), light olive brown fluffy fine, very well sorted, sub angular-sub rounded, spherical quartz with scattered, organics (soil layer) with rare, vf opaques
			-by 6 inches, the opaques increase to scattered
			SAMPLING BEGINS AT 9 INCHES
	2.5Y 6/4	10	-at 9 inches, the color changes to light yellowish brown
			-at 18 inches, the color changes to yellowish brown and there is the addition of a silt coating
		20	
			BOH 24 INCHES
		30	
		40	

Figure 3.18 Sample Log for WIC-4.

SPHT	**Sphericity** $SPHT = \frac{4\pi A}{P^2}$ P – measured perimeter/circumference of a particle projection A – measured area covered by a particle projection For an ideal sphere SPHT is expected to be as 1. Otherwise it is smaller than 1.
$Symm_{0,2,3}$	**Symmetry** $Symm_{0,3} = \frac{1}{2}\left(1 + \min\left(\frac{r_1}{r_2}\right)\right)$ r_1 und r_2 are distances from the centre of area to the borders in the measuring direction. For asymmetric particles Symm is < 1. If the centre of area is outside the particle i.e. $\frac{r_1}{r_2} < 0$ Symm is < 0.5 $x_{Ma} = r_1 + r_2$ "Symm" is minimum value of measured set of symmetry values

Figure 3.19 Equations for Sphericity and Symmetry. The figure is taken from the CAMSIZER P4 operations manual.

CHAPTER 4

RESULTS

4.1 GRAIN SIZE AND SHAPE ANALYSIS

Grain-size distribution plots are in Figures 4.1 (‘percent retained’) and 4.2 (cumulative percent). Of the 16 samples analyzed, all grain size distributions were unimodal, moderately to well-sorted, coarse skewed to symmetrical, and mesokurtic to leptokurtic. Mean φ values for grain size range from a maximum of 2.61 φ to a minimum of 1.52 φ. The samples from Waites Island and the Wicomico and Ladson alloformations are fine sand, whereas the Ten Mile Hill samples are medium sand. Multivariate plots of kurtosis vs mean φ; kurtosis vs skewness, kurtosis vs sorting, skewness vs mean φ, and sorting vs mean φ are in figures 4.3-4.7 respectively. The Ten Mile Hill samples are significantly coarser than those associated with the other units. The bivariate plots contain a significant amount of overlap among samples of different units, except in the case of the kurtosis vs mean φ plot. Even though there is no overlap between units in this plot, it would be difficult to discriminate the units from one another accurately if the units were not already known.

Plots of sphericity vs φ and symmetry vs φ are in figures 4.8 and 4.9. Plots of mean sphericity vs mean φ value and mean symmetry vs mean φ value can be seen in figures 4.10 and 4.11. The samples associated with the Ten Mile Hill alloformation are more spherical and symmetrical than the other units. The Waites samples are significantly less spherical and symmetrical than the others. There is a high degree of overlap in both sphericity and symmetry values for the Ladson and Wicomico alloformation samples.

4.2 SAND POINT COUNTING

The results of the point counting analysis can be seen in Table 4.1. Using the sandstone classification method of Folk (1980), all the samples for Ten Mile Hill, Ladson, and Wicomico alloformations are classified as “quartzarenite”. These samples ranged from 97 to 99 percent quartz, with the rest of the material occurring as lithic fragments. There was no feldspar present in these samples. The Waites samples were all classified as “subarkose,” with feldspar percentages ranging from 8 to 12 percent. Quartz percentages in the Waites samples ranged from 82 to 91 percent. The lithic fragments range from 0 to 6 percent in the Waites samples.

4.3 K-MEACLUSTER ANALYSIS

The results of the k-means cluster analysis performed using SPSS can be seen in Figure 4.12. Multiple combinations of variables were used from the grain size, grain shape, and point counting analyses until the combination of variables that achieved the best results was determined. The best results were determined by finding the combination of variables that achieved the most accurate clustering results. The analysis that generated the most fitting results was a six-dimensional analysis that used sorting, percentage of coarse sand, percentage of medium sand, percentage of fine sand, percentage of very fine sand, and percentage of feldspar. This analysis correctly placed 15 of 16 samples into the correct cluster, strictly using grain texture and mineralogical characteristics. Similarly, when combined with elevation in a seven-dimensional analysis (Figure 4.13), 15 of 16 samples were correctly grouped into their appropriate clusters. When a one-dimensional cluster analysis was run using only the variable of elevation, 16 of 16 samples were clustered correctly (Figure 4.14). This is strictly a product of project design, as no units contained overlapping elevations because a high confidence in which unit was being sampled was desired.

4.4 K-MEANS CLUSTER ANALYSIS WITH SYNTHETIC DATA

The results of the cluster analysis using the synthetic dataset can be seen in figures 4.15-4.4.17 respectively. The synthetic data set was created to increase the sample size of each unit while maintaining the unique grain texture and mineralogic characteristics of each unit, so that overlapping elevations could be added to samples within the Ten Mile Hill and Ladson alloformations. Figure 4.15 depicts a one-dimensional cluster analysis, with elevation being the sole variable. As can be seen, Multiple Ten Mile Hill and Ladson samples are incorrectly clustered amongst each other. Figure 4.16 depicts a six-dimensional analysis using the variables identified as yielding the best clustering in the natural data (See section 4.3): sorting, percentage of coarse sand, percentage of medium sand, percentage of fine sand, percentage of very fine sand, and percentage of feldspar. In this analysis, 120 of 120 synthetic samples and 16 of 16 actual samples were correctly grouped in their appropriate clusters. Figure 4.17 depicts a seven-dimensional analysis using the following variables: sorting, percentage of coarse sand, percentage of medium sand, percentage of fine sand, percentage of very fine sand, percentage of feldspar, and elevation. As with the six-dimensional analysis, 120 of 120 synthetic samples and 16 of 16 actual samples were correctly clustered.

Table 4.1 Results of the Sand Point Counting Analysis.

Sample_ID	**%Quartz**	**%Feldspar**	**%Lithics**
Waites-1	91.00	8.00	1.00
Waites-2	89.00	10.00	1.00
Waites-3	82.00	12.00	6.00
Waites-4	90.00	10.00	0.00
TMH-1	98.00	0.00	2.00
TMH-2	98.00	0.00	2.00
TMH-3	98.00	0.00	2.00
TMH-4	98.00	0.00	2.00
LAD-1	97.00	0.00	3.00
LAD-2	98.00	0.00	2.00
LAD-3	97.00	0.00	3.00
LAD-4	98.00	0.00	2.00
WIC-1	97.00	0.00	3.00
WIC-2	99.00	0.00	1.00
WIC-3	99.00	0.00	1.00
WIC-4	98.00	0.00	2.00

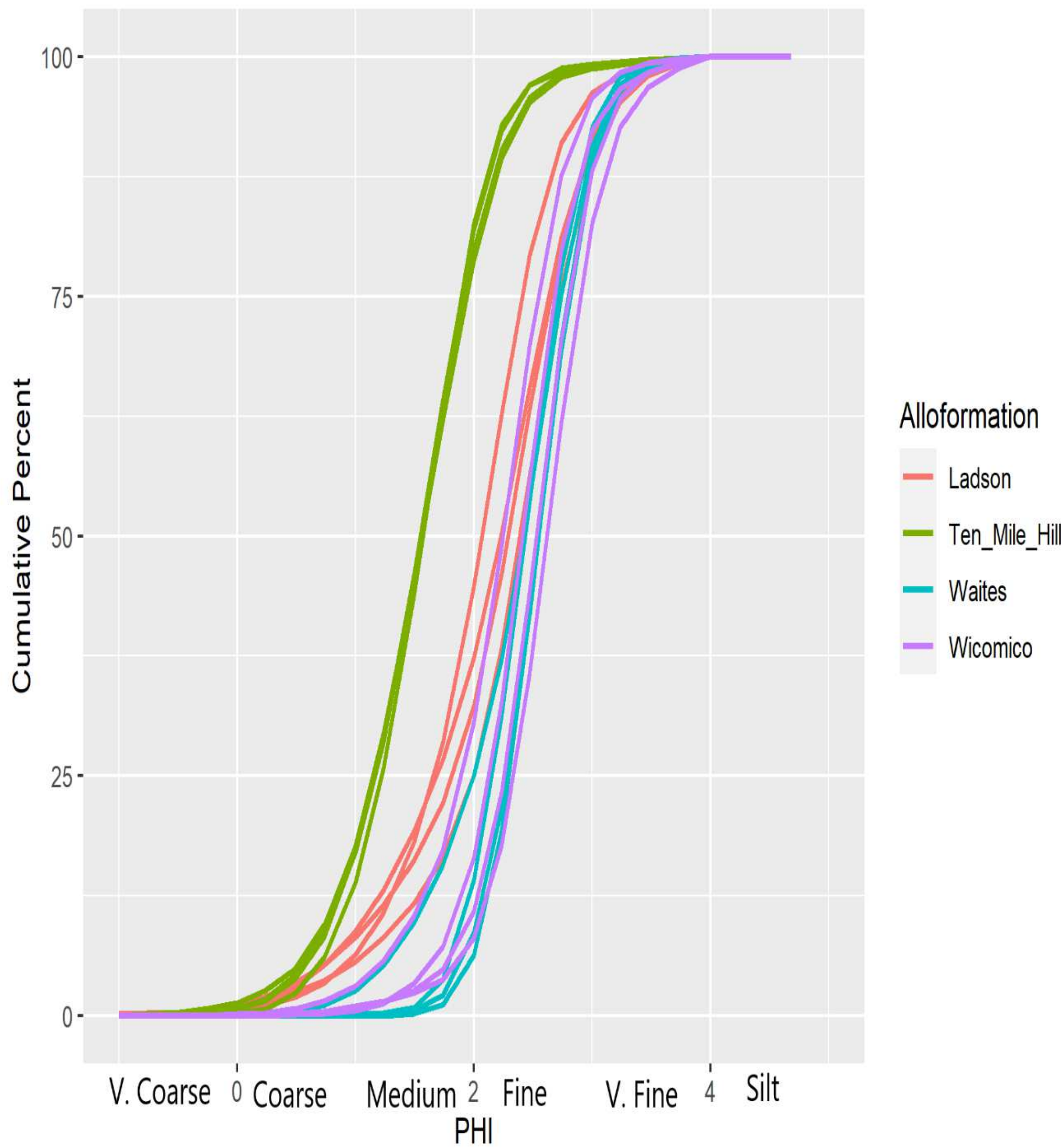


Figure 4.1 Cumulative Percent Retained vs Phi.

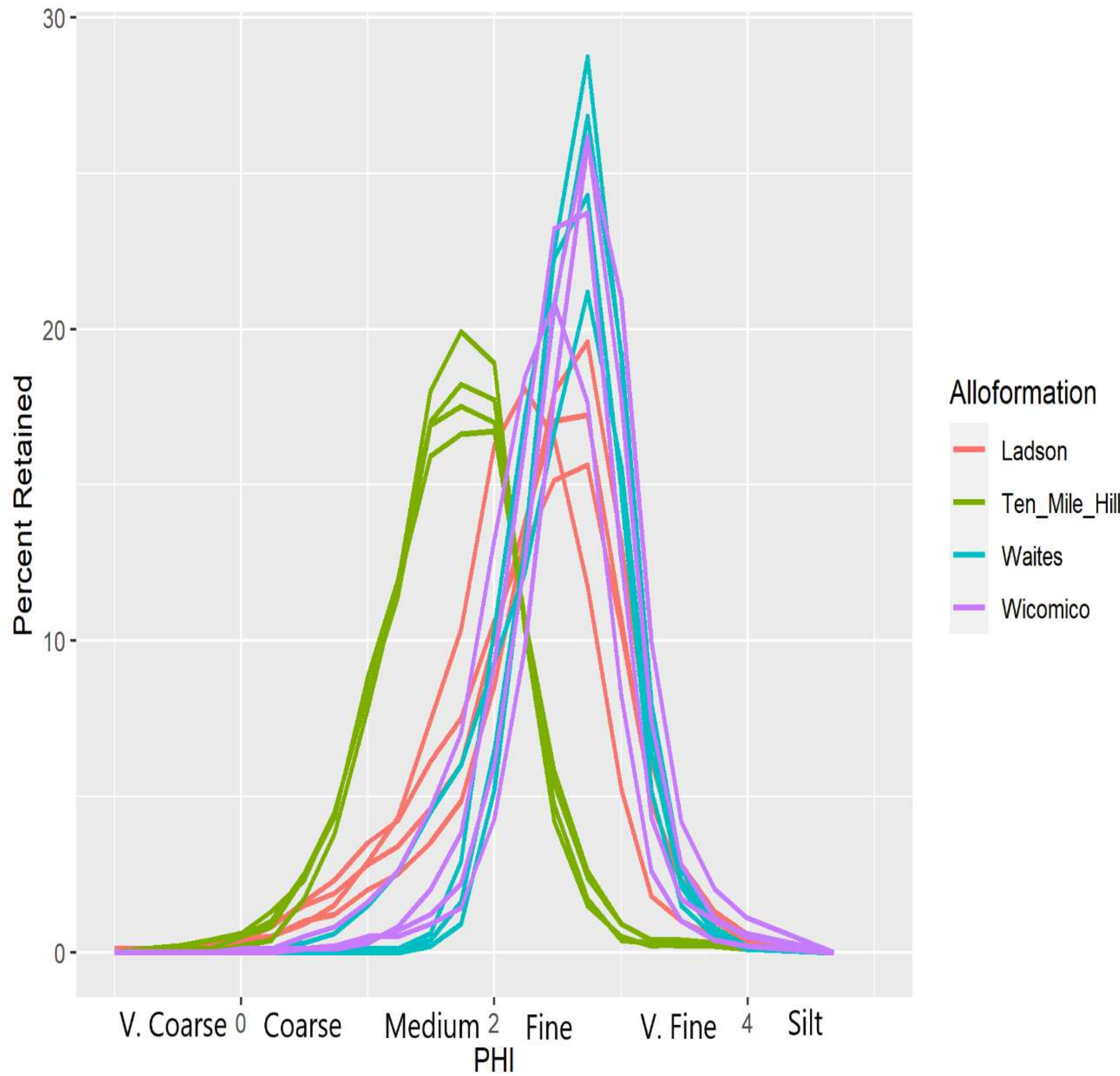


Figure 4.2 Percent Retained vs Phi.

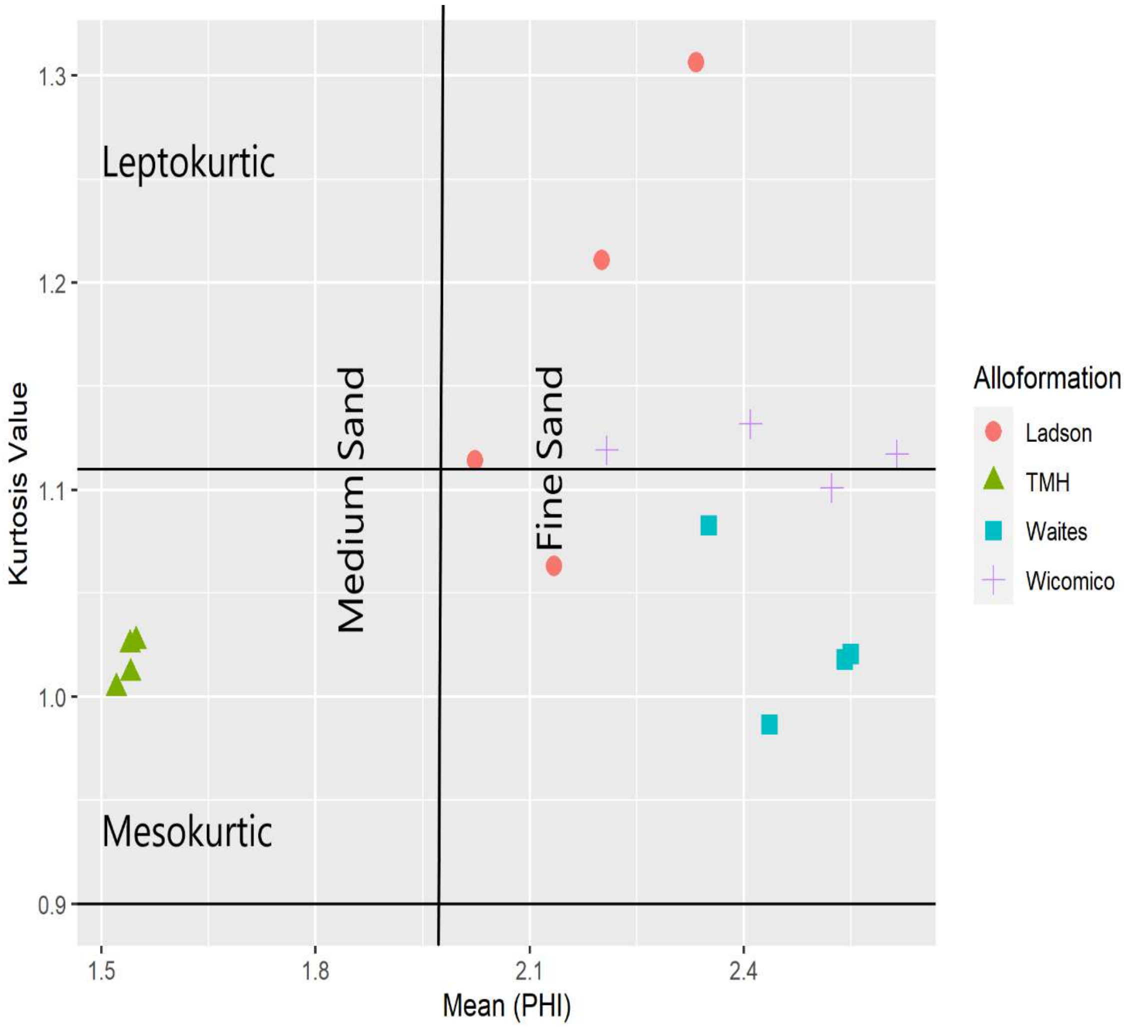


Figure 4.3 Bivariate Plot of Kurtosis vs Mean Phi.

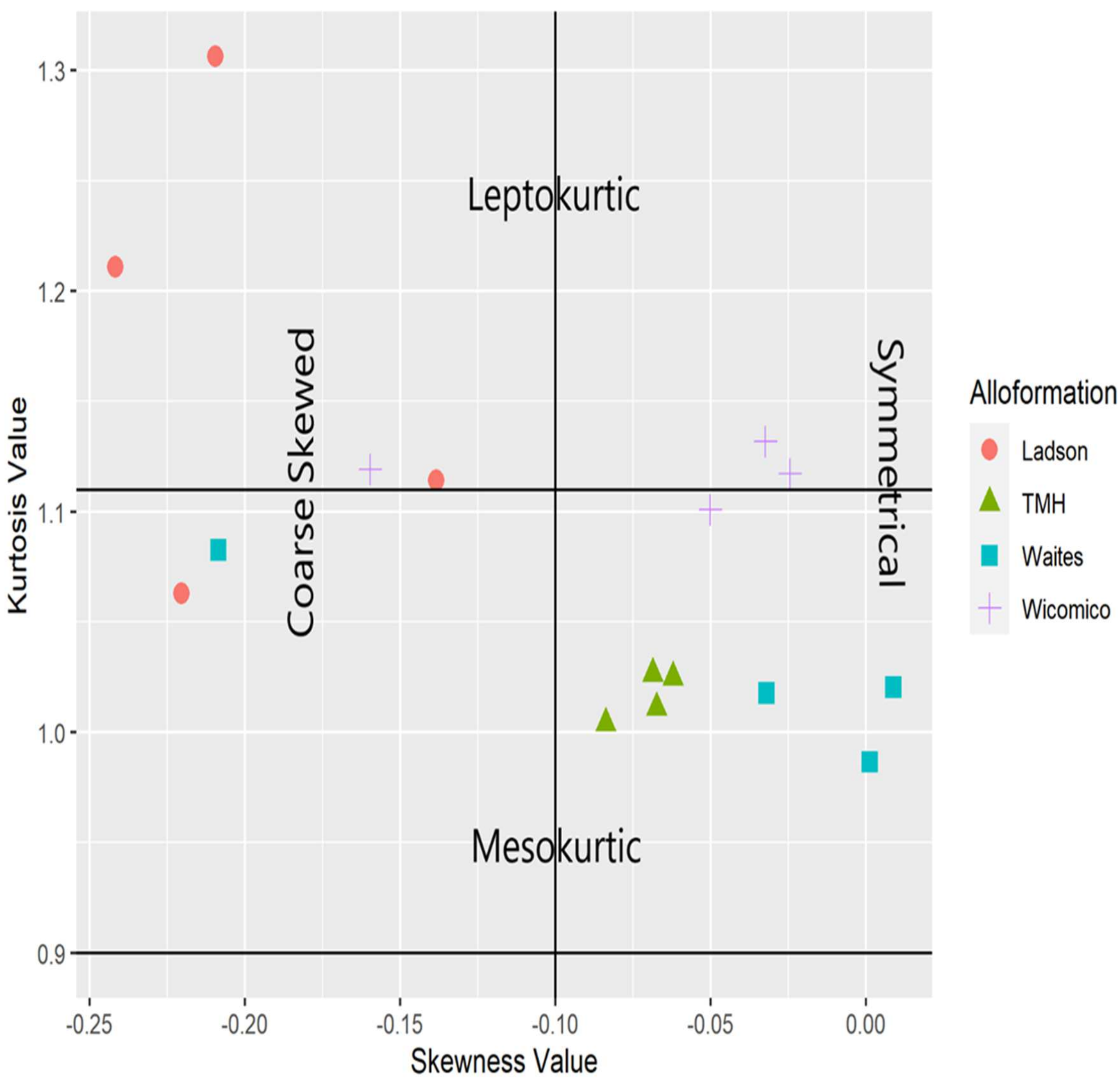


Figure 4.4 Bivariate Plot of Kurtosis vs Skewness.

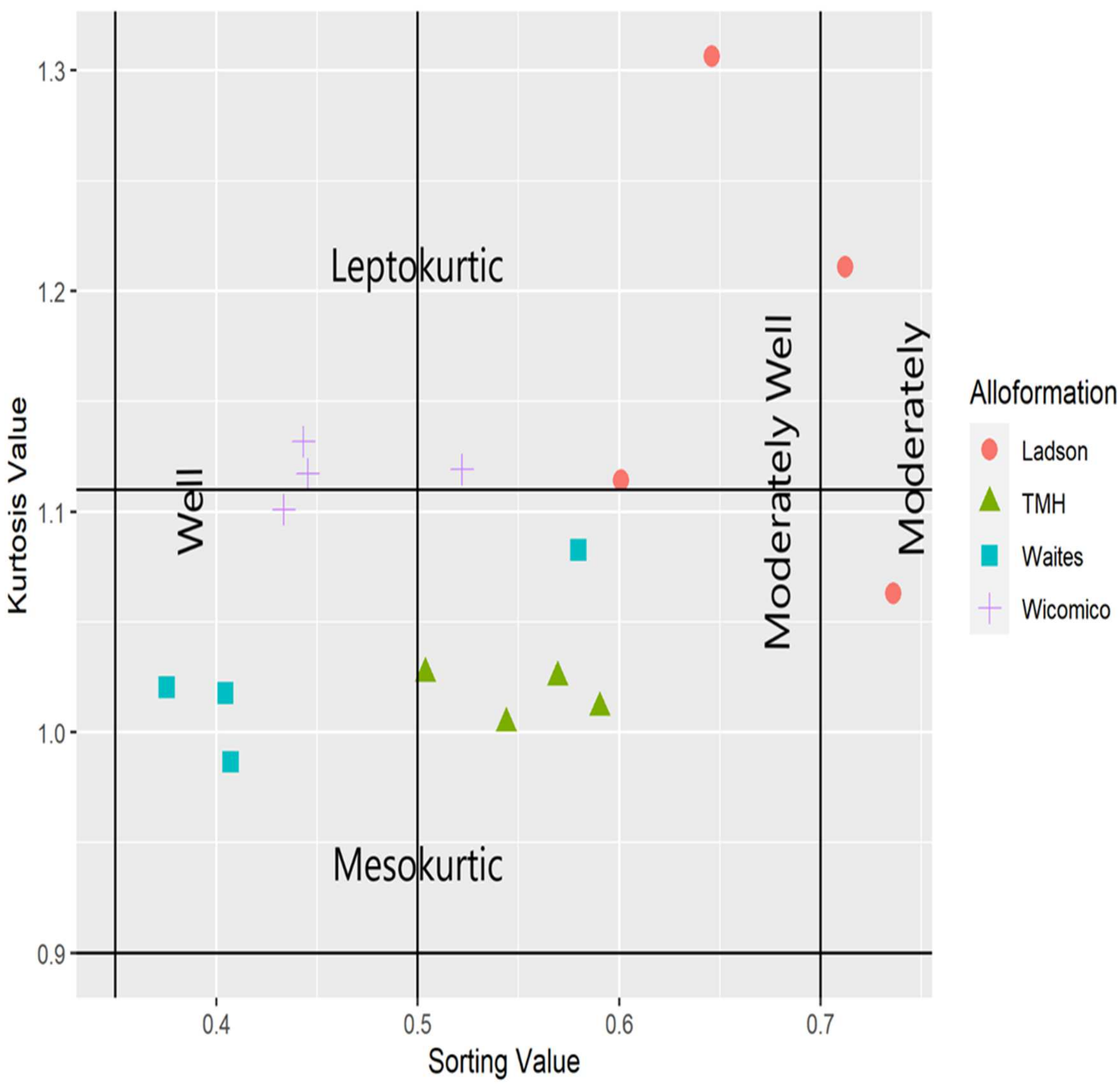


Figure 4.5 Bivariate Plot of Kurtosis vs Sorting.

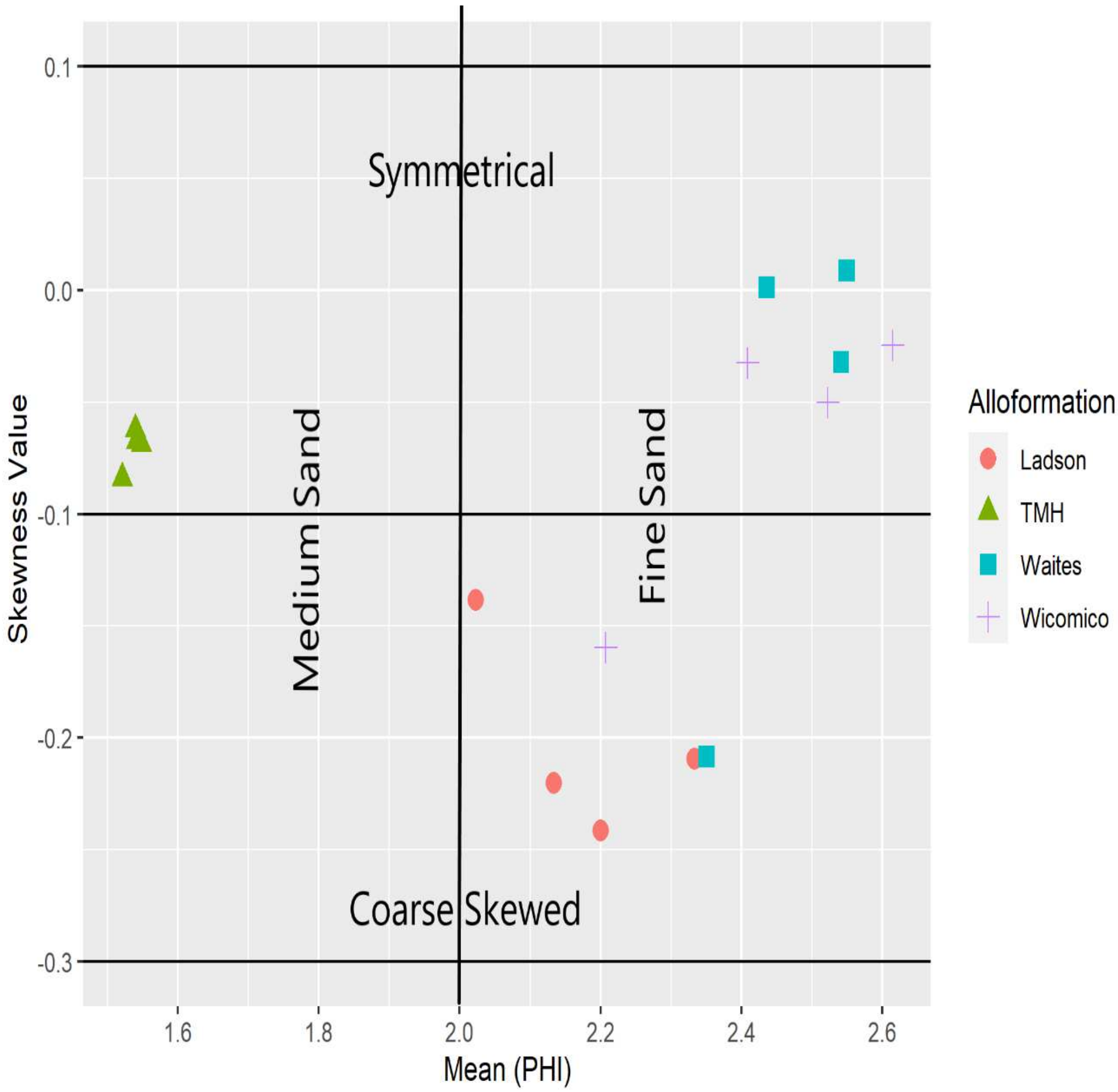


Figure 4.6 Bivariate Plot of Skewness vs Mean Phi.

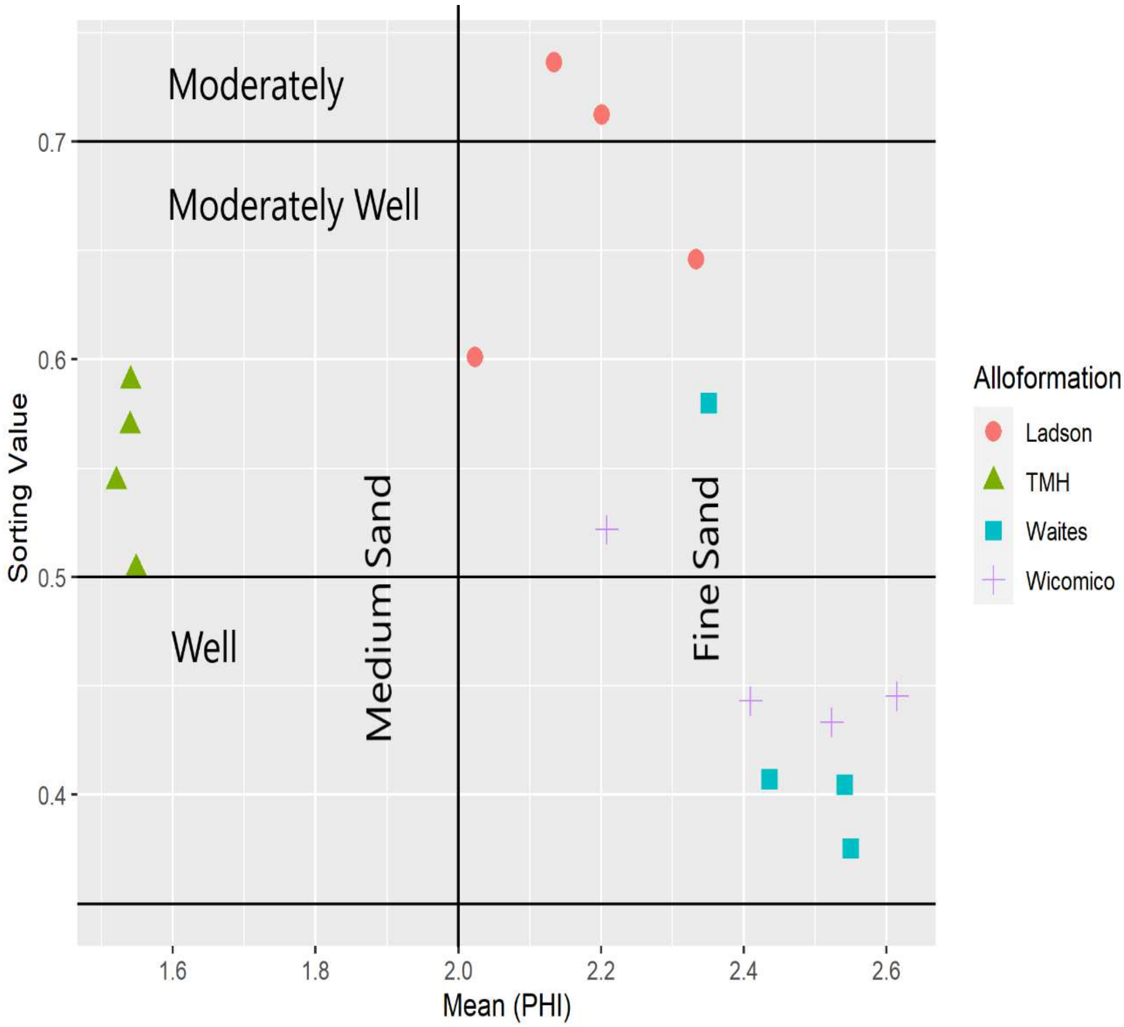


Figure 4.7 Bivariate Plot of Sorting vs Mean Phi.

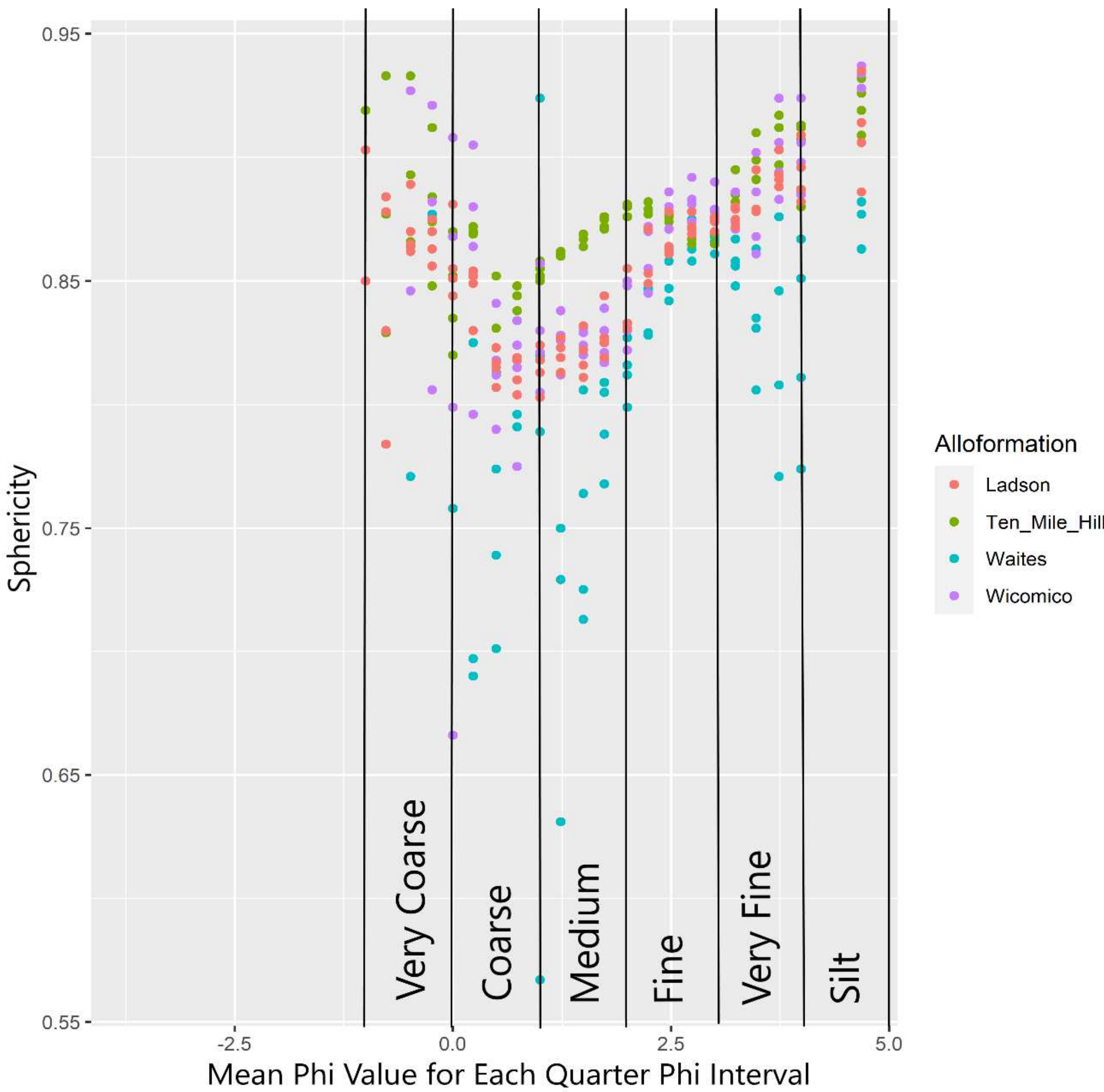


Figure 4.8 Sphericity vs Phi.

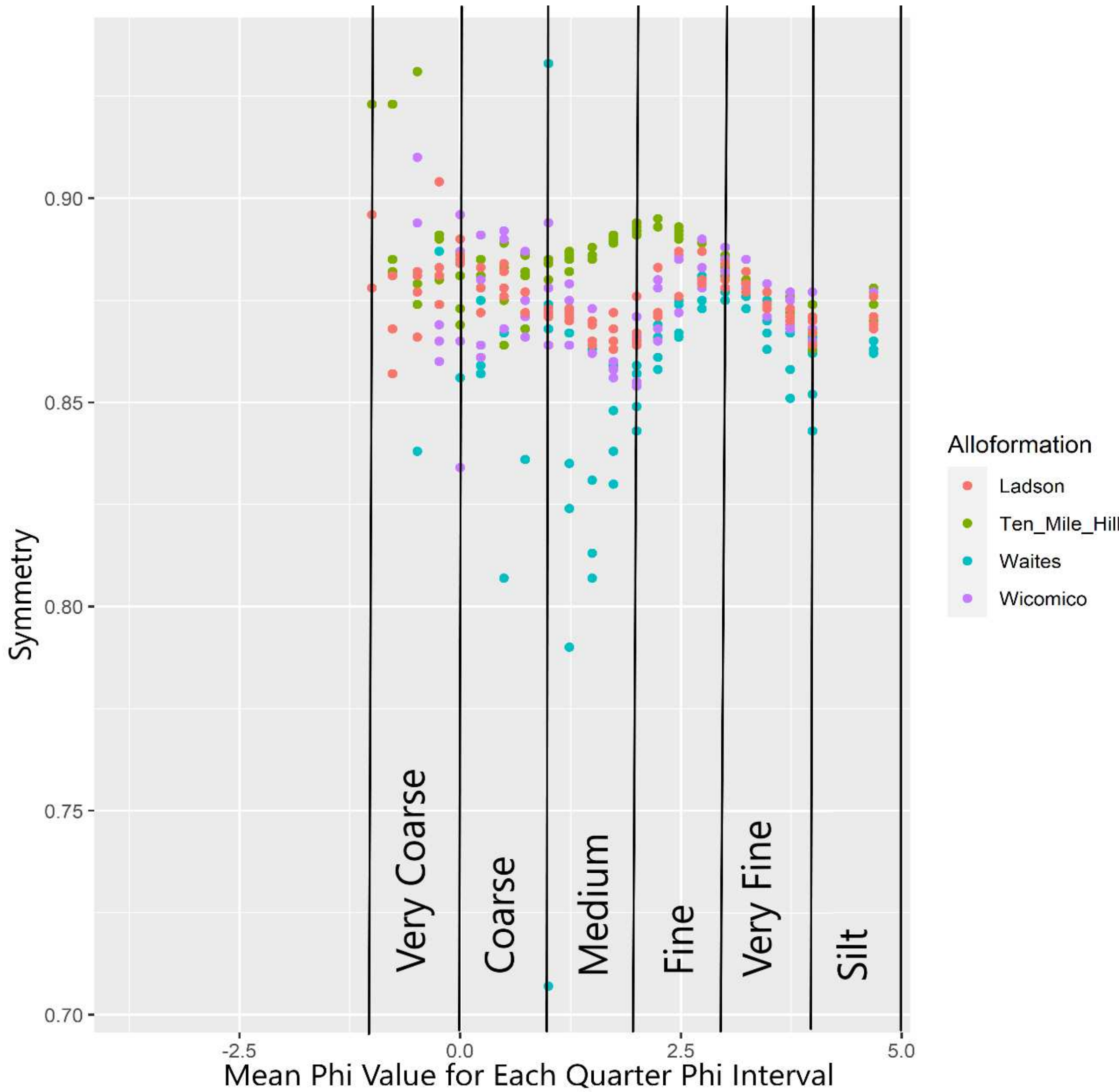


Figure 4.9 Symmetry vs Phi.

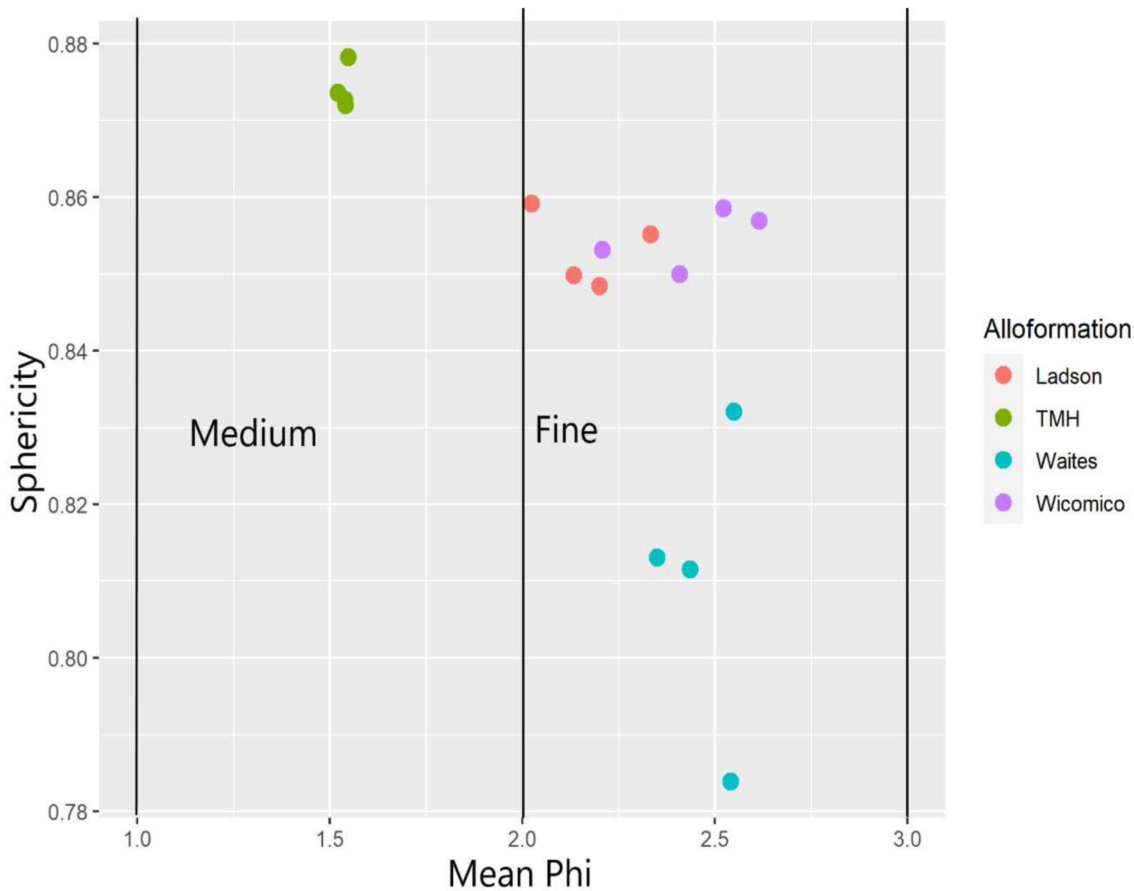


Figure 4.10 Sphericity vs Mean Phi.

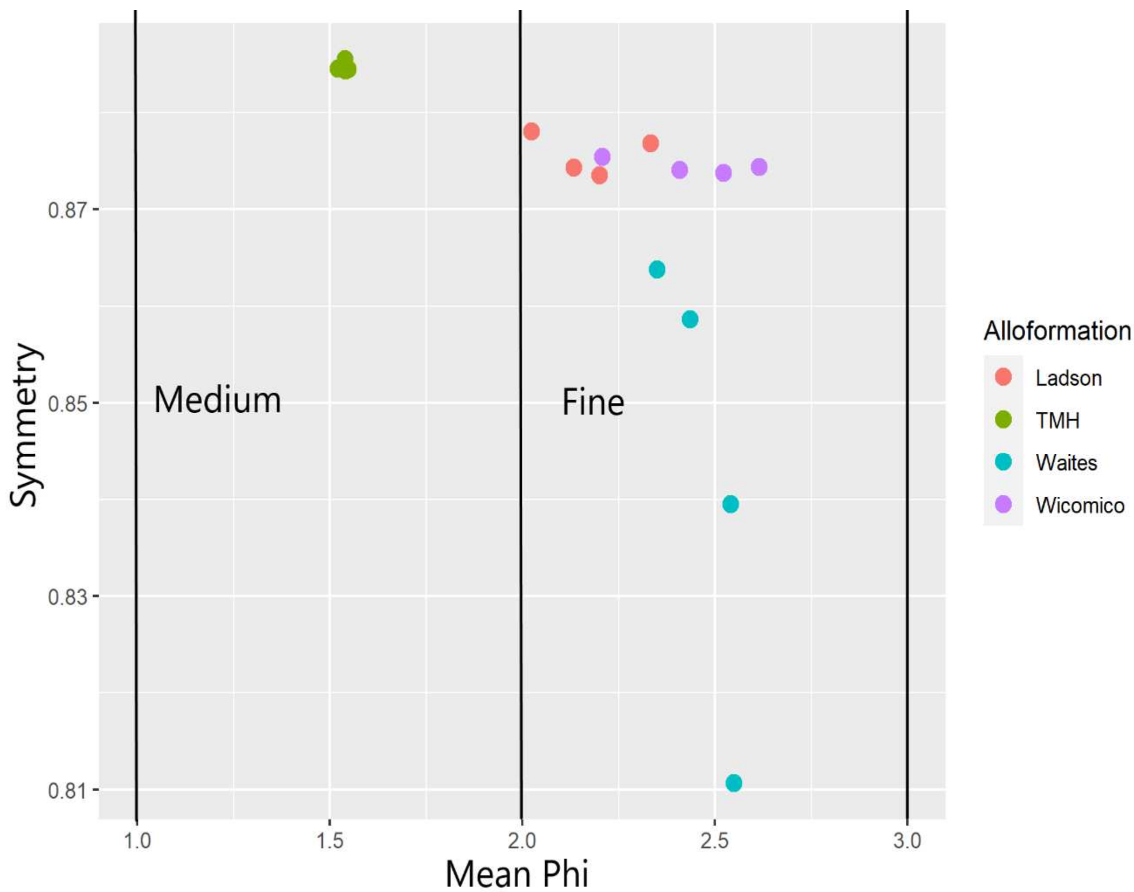


Figure 4.11 Symmetry vs Mean Phi.

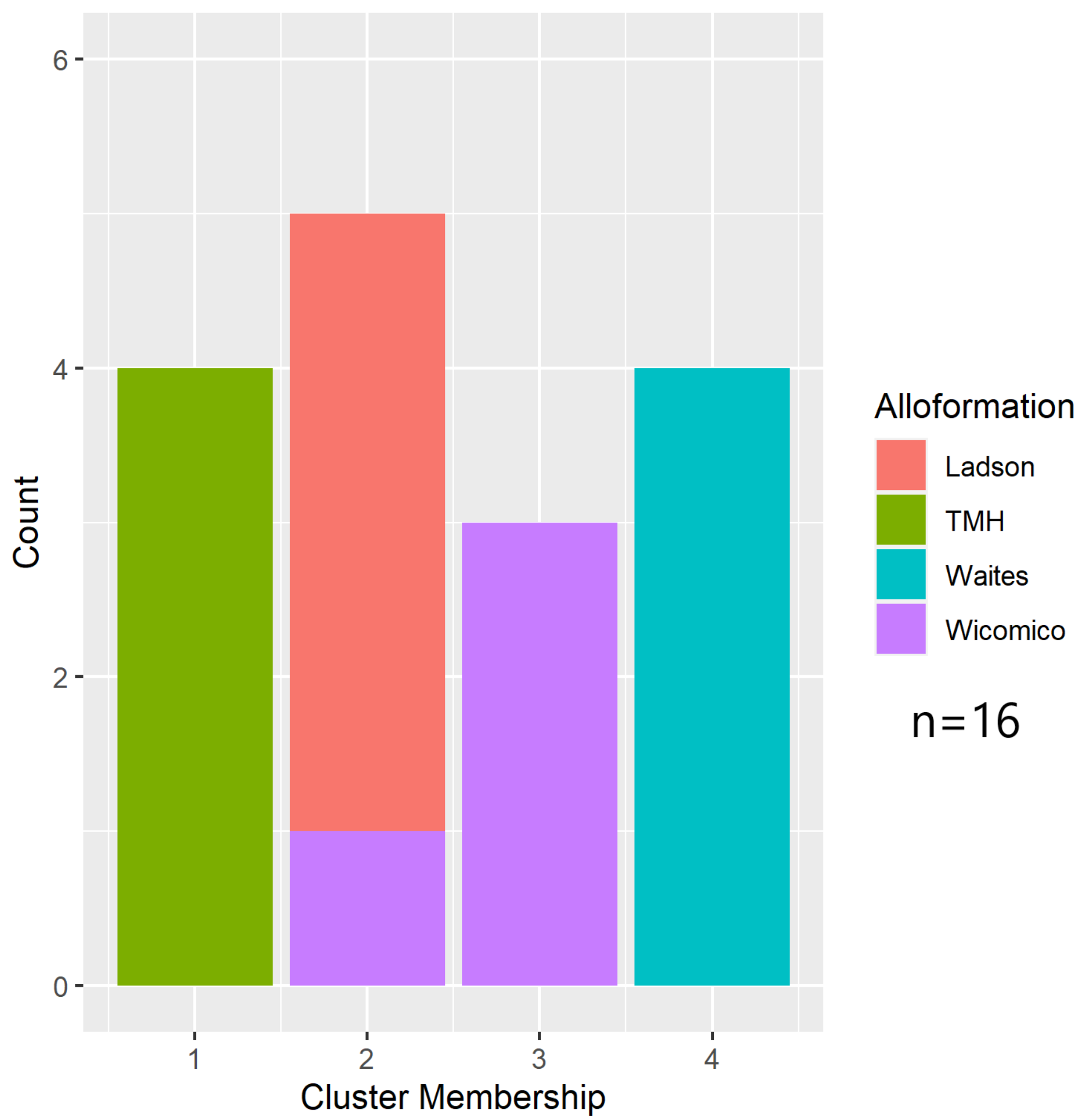


Figure 4.12 Results of the Six-Dimensional Cluster Analysis. This analysis used the following variables: sorting, percentage of coarse sand, percentage of medium sand, percentage of fine sand, percentage of very fine sand, and percentage of feldspar. Variables were converted to z-scores before cluster analysis was run.

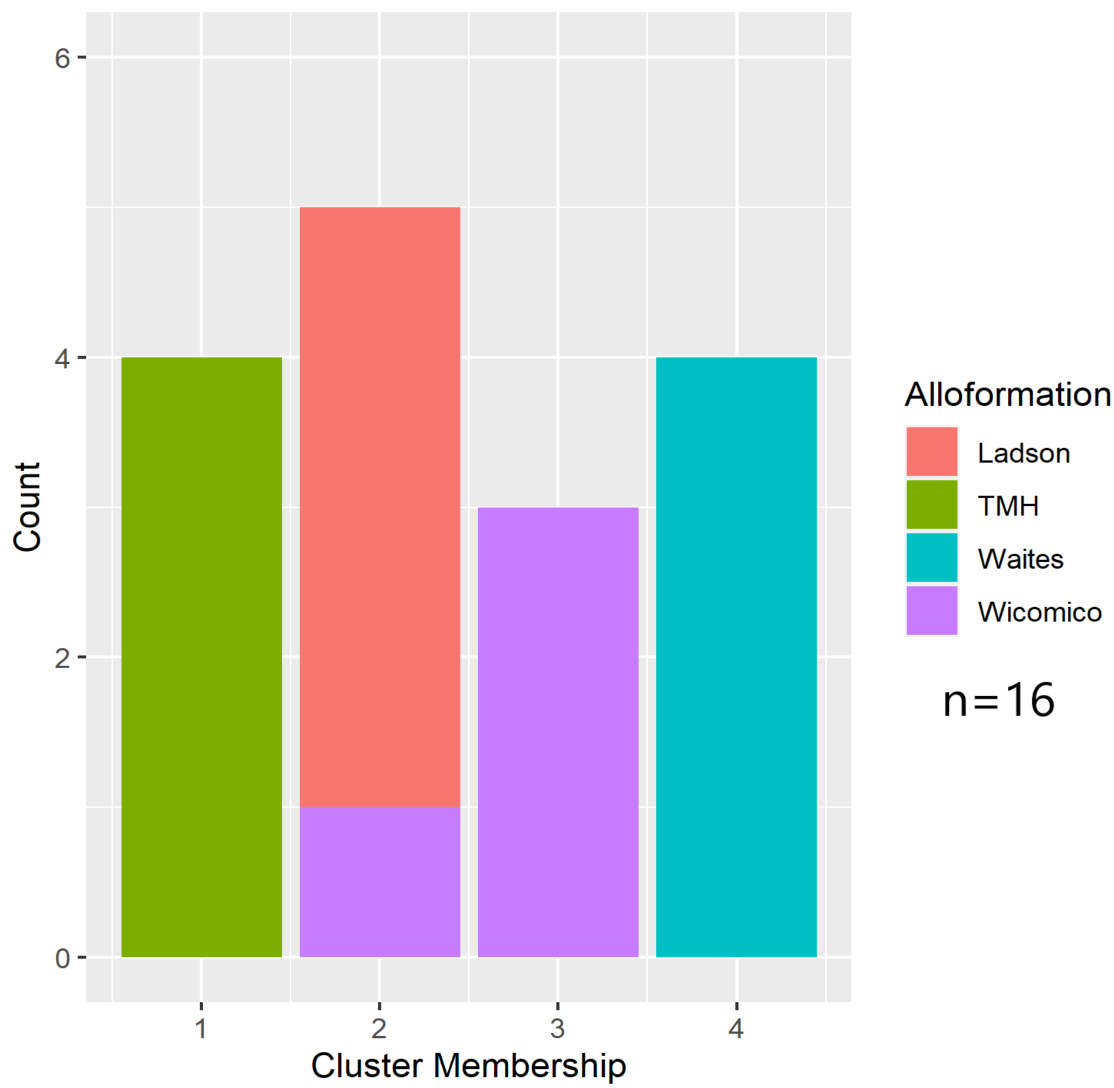


Figure 4.13 Results of the Seven-Dimensional Cluster Analysis. This analysis uses the following variables: sorting, percentage of coarse sand, percentage of medium sand, percentage of fine sand, percentage of very fine sand, percentage of feldspar, and elevation. Variables were converted to z-scores before cluster analysis was run.

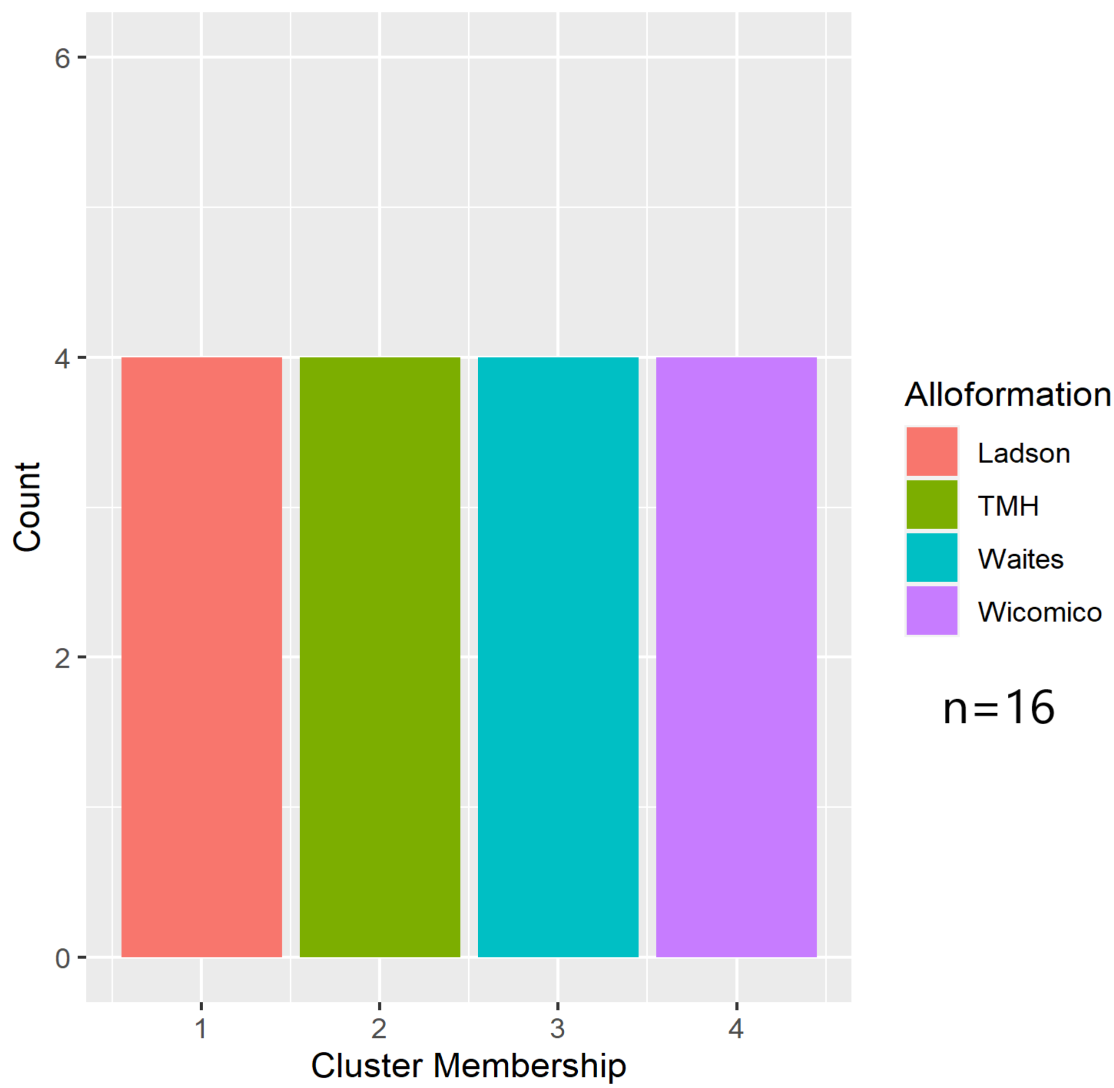


Figure 4.14 Results of the Elevation Only Cluster Analysis.

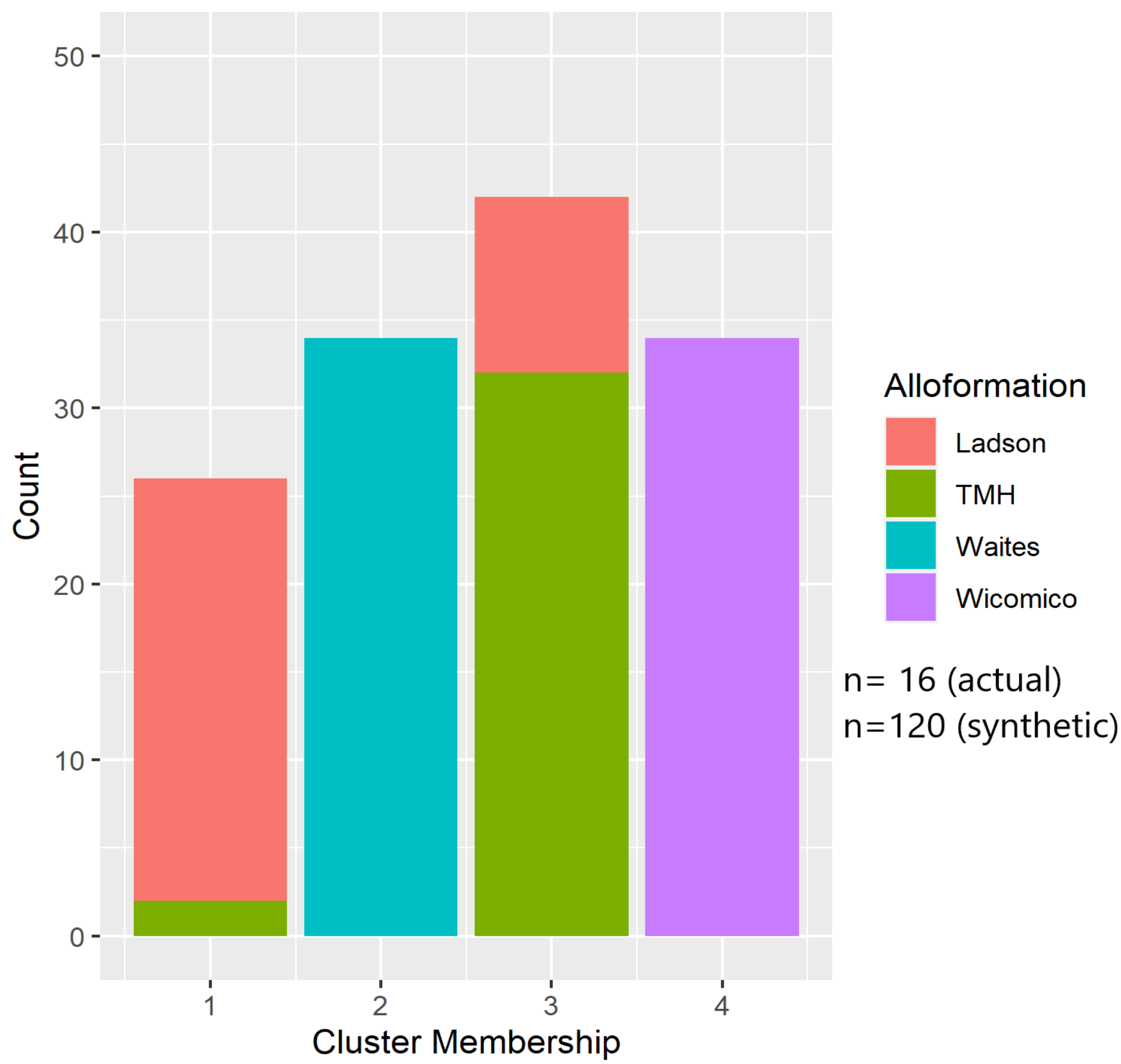


Figure 4.15 Results of the Elevation Only Cluster Analysis Using Synthetic Data.

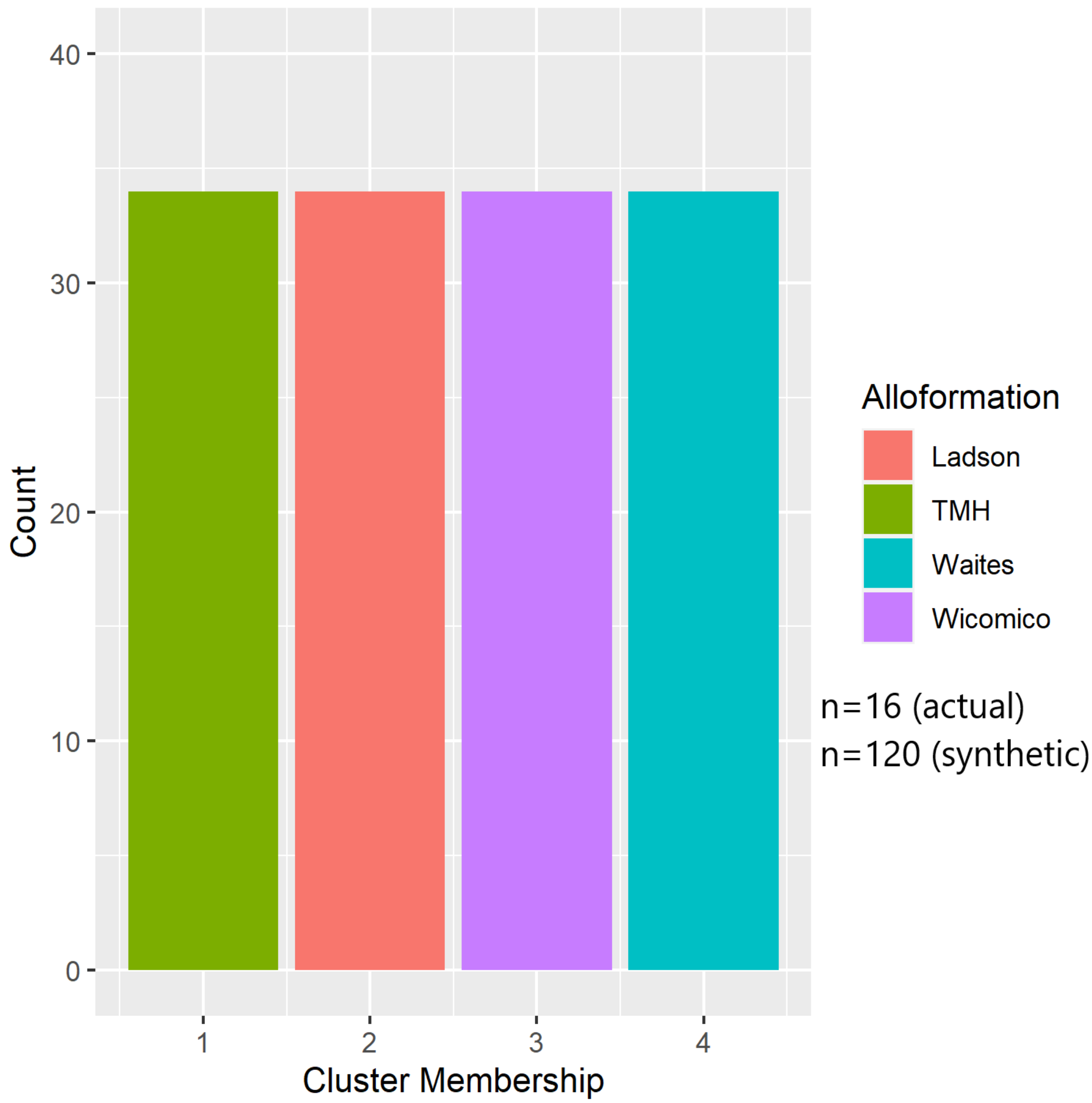


Figure 4.16 Results of the Six-Dimensional Cluster Analysis Using Synthetic Data. This analysis uses the following variables: sorting, percentage of coarse sand, percentage of medium sand, percentage of fine sand, percentage of very fine sand, and percentage of feldspar. Variables were converted to z-scores before cluster analysis was run.

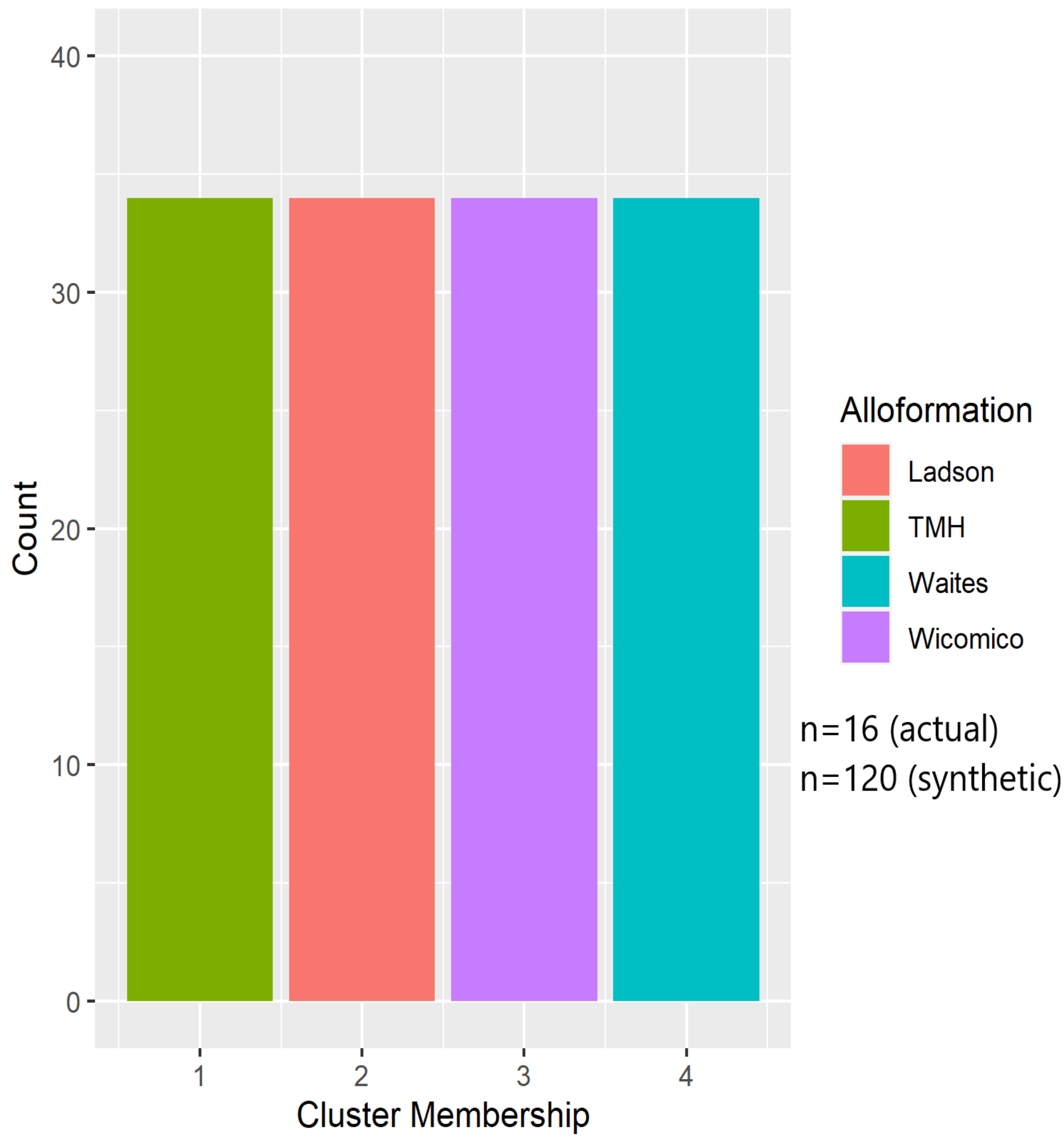


Figure 4.17 Results of the Seven-Dimensional Cluster Analysis Using Synthetic Data. This analysis uses the following variables: percentage of coarse sand, percentage of medium sand, percentage of fine sand, percentage of very fine sand, percentage of feldspar, and elevation. Variables were converted to z-scores before cluster analysis was run.

CHAPTER 5

DISCUSSION

5.1 GRAIN SIZE AND SHAPE ANALYSIS

Discrimination of units based on grain size alone for the Wicomico, Ladson, and Waites samples is hardly diagnostic, however, the Ten Mile Hill samples are clearly distinguishable from the other units by grain size. As can be seen in Figures 4.1 and 4.2, all Ten Mile Hill samples are significantly coarser than the other units and are classified as medium sand. All samples from the other alloformations are classified as fine sand.

Bivariate plots (Figure 4.3-4.7) using a combination of mean grain size (in φ units) and the grain distribution statistical parameters of sorting, skewness, and kurtosis were created in an attempt to cluster units without the need for a complex clustering algorithm. This worked with only moderate success, as most of the alloformations had some degree of overlap. The most useful plot for discriminating alloformations appears to be kurtosis vs mean grain size (Figure 4.3), where no samples from individual alloformations overlap. However, many more samples and analyses would be required to determine if this trend persists. Regardless, the bivariate plots do solidify the observation that the Ten Mile Hill strand deposits in Horry County are unique and easily identifiable using simple grain size measurements, as these samples never overlap with any samples from other units.

Regarding grain shape (Figures 4.8-4.11), the Ten Mile Hill samples are distinctly more symmetrical and spherical than the other units, and the Waites samples are significantly less symmetrical and spherical than the others. The Ladson and the Wicomico samples appear to be indistinguishable from each other based on grain shape alone. Using a combination grain size and shape analysis appears to be a promising way to differentiate the Ten Mile Hill and Waites Strand deposits from the other alloformations investigated in this study however, this is not the case for the strand deposits associated with the Wicomico and Ladson alloformations. More complex means are required to definitively differentiate these units from the other units.

5.2 POINT COUNTING ANALYSIS

The sampled Pleistocene alloformations are indistinguishable from one another using mineralogy by point counting alone (Table 4.1). These samples range from 97 to 99 percent quartz, with the remaining fractions consisting of lithic fragments. No feldspar was present in these samples. The Waites samples, however, were easily distinguishable from the other units because they contained moderate proportions of feldspar. The feldspar percentages in these samples ranged from 8 to 12 percent, yielding a subarkose classification. The percentages of feldspar, while slightly elevated, are consistent with the previous findings of Martens (1935). Martens (1935) analyzed modern beach sands from southern South Carolina to Florida and determined that ratios of feldspar to quartz decreased southward from .062 in southern South Carolina to less than .006 in southern Florida (Hendricks, 2015). This minor elevation in feldspar concentration could be a result of weathering of the jetty on the NE end of Waites Island, or it could suggest that feldspar ratios continue to increase from southern to northern South Carolina. Feldspar in similar concentrations was likely deposited in the Pleistocene units investigated but was weathered and leached away with time since deposition.

5.3 CLUSTER ANALYSIS AND SYNTHETIC DATA CLUSTER ANALYSIS

Cluster analysis is a powerful tool that was used to attempt to distinguish units using grain size, shape, and mineralogic data. It took many attempts to find which variables to use to achieve the best results, which was determined by the outcome which clustered the samples into their appropriate alloformations most correctly. The best results (Figure 4.12), without using elevation as a variable, were from a six-dimensional cluster analysis which used the variables of sorting, percentage of coarse sand, percentage of medium sand, percentage of fine sand, percentage of very fine sand, and percentage of feldspar. This analysis correctly clustered 15 of the 16 samples into their associated alloformations. The only incorrectly clustered sample was a Wicomico sample that was incorrectly grouped into the Ladson cluster.

When a one-dimensional cluster analysis was run using only the variable of elevation (Figure 4.14), 16 of 16 samples were correctly clustered into their associated alloformations. This is slightly concerning, as it suggests elevation is a better way to distinguish alloformations. However, as previously stated, in the larger region where these units occur, elevations can and do overlap. Once again, this is because strand deposits can build well above the mean high tide line through eolian processes. By project design, no samples of different alloformations had overlapping elevations in this study. This is partially due to limited access to undisturbed locations, and because high confidence in which unit was being sampled was desired. If samples from different alloformations with overlapping elevations were taken and analyzed, the clustering algorithm would not have clustered them in a one-dimensional analysis using only elevation with 100 percent accuracy. When a seven-dimensional cluster analysis was run using sorting, percentage of coarse sand, percentage of medium sand, percentage of fine sand, percentage of very fine sand, percentage of feldspar, and the addition of elevation (Figure 4.13), 15 of 16 samples were clustered correctly. Once again, the only incorrectly clustered sample was a Wicomico sample that was incorrectly grouped into the Ladson cluster.

To simulate what would transpire should units be overlapping in elevation, a synthetic dataset was created which increased the sample size of each unit sampled to 34 samples, each having four actual samples and 30 synthetic samples. Each synthetic variable created for each sample had a value that fell within a bounded normal distribution of the authentic variable for each alloformation (see section 3.4). When a one-dimensional, elevation-only, cluster analysis (Figure 4.15) was run using this new dataset, 124 out of 136 samples were clustered correctly. The twelve samples that were clustered incorrectly were all associated with the Ten Mile Hill and Ladson alloformations. These two units abut each other and therefore have overlapping elevations. When a 6-dimensional cluster analysis (Figure 4.16) was run – without elevation – using the variables of sorting, percentage of coarse sand, percentage of medium sand, percentage of fine sand, percentage of very fine sand, and percentage of feldspar, 136 of 136 samples were clustered correctly. When a seven-dimensional cluster analysis (Figure 4.17) was run with the addition of the variable of elevation, 136 of 136 samples were also clustered properly. This demonstrates that the grain texture and mineralogic data collected in this investigation can overcome the challenges of overlapping elevations – the prior approach to unit identification – when implemented into the clustering algorithm.

CHAPTER 6

CONCLUSION

Previously, there was no standard for differentiating strand deposits of differing ages in the SC LCP by grain texture or mineralogic means. As discussed in section 2.2 of this paper, past and present mapping rely heavily on biostratigraphic and geomorphologic techniques. While useful, problems do exist with the two approaches. Establishing a technique to differentiate these units by means of grain texture and mineralogic composition should alleviate these inherent problems with SC LCP mapping while creating a better understanding of these deposits and lead to more accurate geologic mapping.

To address this issue, grain size, shape, and mineralogic analysis of three Pleistocene strand deposits and one modern active strand deposit in Horry County, SC was conducted in an attempt to better differentiate SC LCP units. Samples were taken from Waites Island, SC, and the Ten Mile Hill, the Ladson, and the Wicomico alloformations. Important takeaways are discussed below.

The Ten Mile Hill samples are significantly coarser than all other samples (Figures 4.1, 4.2). All samples from the other alloformations are characterized as fine sand, whereas the Ten Mile Hill samples are all characterized as medium sand. This appears to be a distinguishing factor of the Ten Mile Hill strand deposits in Horry County, SC, at least when compared to the other three units sampled in this study.

Distinguishing the other units using grain size distributions and their associated statistical parameters independently appears to be hardly diagnostic, and more complicated means are required to achieve this goal. The source of the coarser sand in the Ten Mile Hill deposit was not investigated in this paper and should be investigated in future work. Some ideas for the cause of the coarser sand in the Ten Mile Hill are a higher energy regime at the time of deposition or a close proximity to a fluvial source.

Sand grains of the Ten Mile Hill samples are significantly more spherical (Figures 4.8, 4.10) and symmetrical (Figures 4.9, 4.11) than the other units in this study. Similarly, the Waites samples are significantly less spherical (Figures 4.8, 4.10) and symmetrical (Figures 4.9, 4.11) than the other units. Using the grain shape parameters of sphericity and symmetry is a promising way to differentiate these two units, both from each other and the other units. The Wicomico and Ladson samples are not distinguishable (Figures 4.8-4.11) from each other using the shape parameters measured in this study. Once again, the cause of the disparities in grain shape were not considered in this investigation and are an opportunity for future work. However, the Waites samples may be less spherical and symmetrical than the Pleistocene samples because they contain a less mature mineralogical composition, as they are subarkosic in their composition. The Ten Mile Hill samples may be more spherical and symmetrical because of a higher energy regime or a proximal source area at the time of deposition, which as previously mentioned, likely contributed to its coarser grain size as well.

Investigations into the conventional sedimentary petrology of the Pleistocene deposits in this study appears to be an unproductive way to distinguish them, as they all consist of greater than 97 percent quartz with a small fraction of lithic fragments (Table

4.1). However, the modern Waites samples were easily identifiable from their Pleistocene counterparts by their subarkosic composition. Whereas more detailed sedimentary petrography, and/or sediment geochemistry or geochronology are likely to delineate differences between units, these approaches are temporally and financially expensive, making them less available for large-scale mapping purposes. Different aspects of the aforementioned grain-size, grain-shape, and sand petrology data offer clear but unit-dependent opportunities for differentiating strand deposits of the SC LCP.

K-means cluster analysis was used in an attempt to distinguish the four units in this study by using a combination of multiple variables. Without the use of elevation and only using grain texture and mineralogic variables, the cluster analysis successfully clustered 15 of the 16 samples collected (Figure 4.12). This appears to be a propitious way to differentiate strand deposits occurring in the SC LCP.

Previous understandings of the makeup of SC LCP deposits highlight how similar they are to one another in terms of lithology, regardless of age. This investigation demonstrates that there are inherent and appreciable differences in the composition and architecture of these deposits and their associated alloformations. Understanding these differences will lead to a better differentiation of units and ultimately, better geologic mapping. This study used basic sedimentologic and mineralogic measurements that are easily and inexpensively obtained to differentiate previously indistinguishable units. This highlights the power of cluster analysis and how it can be used to advance and improve geologic and scientific knowledge and progress. Based on the results of this study, the combination of grain size and shape analysis with simple sedimentary petrology should be a useful approach to differentiate geologically similar units in other environments and tectonic settings.

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