Sand Microtextures as Indicators of Depositional Environment – a Comparison of Fluvial, Marine and Aeolian Sediments

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SAND MICROTEXTURES AS INDICATORS OF DEPOSITIONAL ENVIRONMENT – A COMPARISON OF FLUVIAL, MARINE AND AEOLIAN SEDIMENTS

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ABSTRACT

The Scanning Electron Microscope (SEM) has been used to examine sediment surfaces since the late 1960's. More recently, results of SEM analyses of grains have been used to link depositional environments and modes of transport for sediments and sandstones (Krinsely and Trusty, 1986; Mahaney and Kalm 2000; Mahaney et al., 2001). This technique has been considered to be a viable, though time consuming, option for researchers interpreting depositional environments. V-pits are a microfeature which is claimed to indicate a littoral deposition environment (Krinsley and Trusty, 1986; Middleton and Kassera, 1987), while others claim it is a result of fluvial processes and deposition (Mahaney and Kalm, 2000; Mahaney et al., 2001; Mahaney, 2002; Strand et al., 2003; Itamiya et al., 2019). The focus of this study was to determine if there was statistical support for the claims that V-pits are indicative of specific depositional environments. To evaluate this claim, sediment samples from differing contemporary environments (littoral, fluvial and aeolian) were taken and subjected to analyses. The results indicated that neither littoral nor fluvial environments effectively produced V-pits. Aeolian deposits, however, showed more V-pits than any other sample.

KEY WORDS: Scanning Electron Microscope, Sedimentary deposits, Sediment transport, V-pits

INTRODUCTION

Sedimentary texture has been a primary area of focus in Sedimentology, as it is commonly believed that texture is influenced preferentially by the environment in which sediments were deposited. Sedimentary texture of a grain includes the size of the grain as well as its shape. Grain fabric is a sedimentary texture used to describe an entire deposit. Grain size analyses of sediments are based on weight percent of the sample which in turn are used to determine the sortedness of the sample and many other useful statistical trends. Fossil fauna and bedding structure are also common methods in determining depositional environments, but fossils are not always present in a rock and many bedding structures can form in multiple depositional environments.

Grain shape analysis has become a more useful tool in Sedimentology with the advent of new technology and methods. Mathematical models (Fourier Analysis) have been created to characterize the grain surface. This method, which "cuts" the grain on a two-dimensional plane, models the surface of the grain by "unrolling" sections whose boundaries are regular degree intervals from the center of the grain. These sections placed in order resemble a periodic wave and, in fact, can be expressed mathematically as a combination of infinite harmonic cosine and sine equations. This method of characterizing grain roundness is currently being applied to determine depositional environment as well as provenance. This method, introduced in the late 1960's, does not have the resolution to measure small surface features, or anything that subtends 7.5 degree angles when measured from the grain center. With this poor resolution, any small features, which may be useful in determining depositional environment, are not seen.

The most recent method for analyzing grain texture is using Scanning Electron Microscope (SEM) analysis' which was first used to map the surface of a solid object in 1942 (Zworykin et al., 1942). Early use was limited by its poor resolution, and as technology improved, more applications for the microscope were found in sciences outside of geology.

The SEM allowed geologists a high magnification view of grains. Sedimentologists aimed to determine the physical differences between grains from different depositional environments, ranging from glacial to fluvial to lacustrine, aeolian, and littoral. In doing so, workers have identified over 34 different microfeatures on grains (Mahaney, 2001). They have also come up with a method of identifying depositional environment and mode of transportation. Micro-features that are observed on a grain are counted and a bar chart of said microfeatures is produced (Mahaney, 2001). This is done because, typically, no microfeatures are indicative of a single depositional environment and an assessment of all features is needed. However, there are some microtextures that are thought to exist preferentially in grains from specific environments (Mahaney, 2001).

V-pits are loosely defined as v-shaped percussion marks in the surface of a grain. It is generally considered to be caused by the high energy impact from grain to grain collisions in a sub-aqueous environment (Krinsley and Trusty, 1986; Mahaney, 2001). This conclusion implies that an aoelian or glacial environment will not produce these features. There has been debate, however, as to what depositional environment these V-pits characterize. Some believe that V-pits are the result of high energy littoral or nearshore beach processes (Krinsley and Trusty, 1986; Middleton and Kassera, 1987). More recently, however, it has been suggested that V-pits are formed from fluvial transport (Mahaney, 2002; Mahaney and Kalm, 2000; Mahaney et al., 2001; Strand et al., 2003). Regardless of depositional environment interpretation, the numerous examples of quartz microtextures have been cataloged by leading researchers in the field. David Krinsley and John Doornkamp produced the original "Atlas of Quartz Grain Microfeatures" in 1973. William Mahaney brought their work up to date as well as adding additional interpretations in 2001 with additional micro textures and imagery in his book, "Atlas of Sand Grain Surface Textures and Applications."
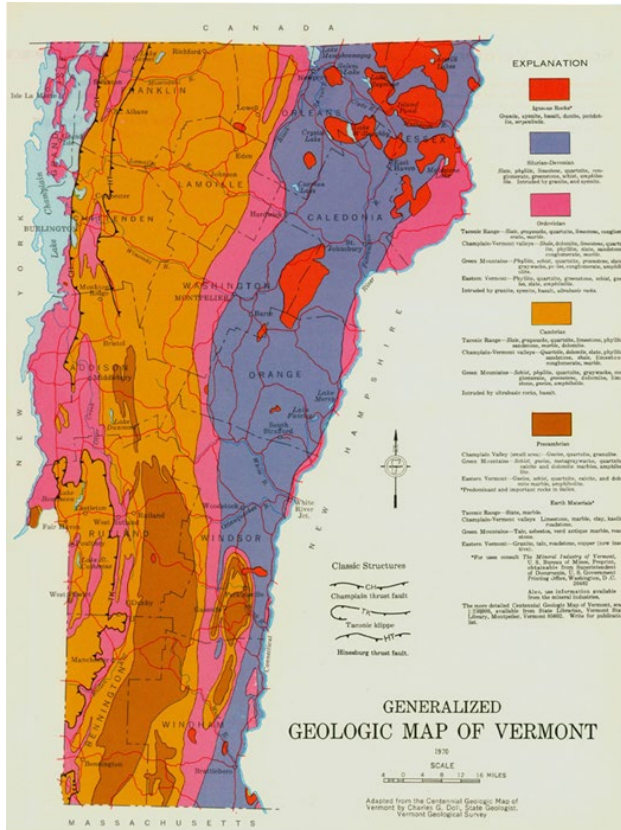
Figure 1. Geologic map of Vermont showing drainage area of the White River over the bedrock lithology of the region. Adapted from Doll, 1961.

BACKROUND GEOLOGY
Fluvial

The White River watershed located in east-central Vermont, covers an area of 1766 square kilometers (Figure 1). The majority of the basement rocks of eastern in central Vermont are composed of a suite of meta-sedimentary rocks from Cambrian to Devonian in age (Doll et al., 1961). Granitic intrusions are also common within the watershed. The majority of the drainage basin overlies silicate bearing rocks while roughly 20% is underlain by carbonate-bearing rocks (Douglas, 2006). On the extreme western edge of the basin, bedrock consists of small pockets of granite, gneiss, and amphibolite facies metasediment of Proterozic age (Douglas, 2006). East of these lay Cambrian schist, mafic gneiss, slate, phyllite and amphibolite units. Farther east lay granofels, mafic gneiss with minor sulfide-bearing sections, phyllite, schist, slate and amphibolites (Douglas, 2006). The eastern portion of the basin is underlain by the carbonate-rich Silurian and Devonian Waits River and Gile Mountain formations. They consist of metasedimentary, carbonate rich, clastic sediments and granofels (Douglas, 2006). Sediments that are derived from metamorphic and igneous rocks in the watershed will be fluvially-influenced as microtextures from grains derived from the bedrock will not have preserved features previously imprinted on them. The entire region was affected by glaciation during the Cenozoic area. Glacial deposits

average 1 – 3 meters thick throughout the watershed (Douglas, 2006).

Figure 2. Surficial geologic map showing sediments in lower White River watershed (middle to upper right) near the confluence with the Connecticut River. Green unit labeled STC is adjacent to Route 14 where samples were collected for analysis. Adapted from Doll, 1970.

The lower White River watershed was covered by Lake Hitchcock which formed by the end moraine blocking flow of the paleo-Connecticut River. A stable lake formed in the Connecticut Valley and adjacent tributary valleys, in which rapid deposition occurred as fast moving sediment laden waters flowed from the highland and interacted with the calm lacustrine environment. Thus, deposits in the sample area (Figure 2) are interpreted as glacio-fluvial in origin and are observed to be silt, silty clay, and clay with some varved layers representing lake bottom deposition (Doll et al., 1970). These sediments would have undergone minimal transportation before deposition and have been actively reworked by the White River since the lake's drainage. The sediment in the watershed is derived from metamorphosed early Proterozoic sediments as well recent glacial deposits.

Aeolian
Little Sahara State Park. The Cimarron Valley in Oklahoma is composed of several distinct terraces all of which are composed of sand, silt, clay and gravel (Lepper and Scott, 2005). These sediments were rapidly deposited by rivers flowing from Rocky Mountain glaciers during the Pleistocene. During the Holocene, glaciers retreated and the prevailing climate became dry enough for aeolian conditions to dominate the landscape (Lepper and Scott, 2005). Subsequent Aeolian

activities since have reworked the fluvial terraces into dunes ranging in size from 10's to 100's of meters in height. The dry conditions, conducive to Aeolian activity, are short lived and tend to be cyclic in nature as changes in annual rainfall vary greatly across the region. An example of the cyclic nature of Aeolian activity can be seen in the Dust Bowl event of the early 20th century, where prolonged drought weakened the soil in the Midwest. This allowed wind to pick up much of the Great Plains soil and presumably sands in the Little Sahara as well. This is opposed to the current climate of Little Sahara region which is generally covered in vegetation due to plentiful rainfall. The Cimarron River has been migrating down slope to the southwest leaving old terraces to the north since the Pleistocene (Lepper and Scott, 2005). These terraces are the main source for sediment which is reworked by Aeolian activities.

Great Sand Dunes National Park. The Great Sand Dunes National Park is located on the eastern edge of the San Luis Valley (an intermontane basin and Colorado's largest). The Rio Grande River flows through this valley and actively deposits sediments in the southwest of the basin (Madole et al., 2008). The largest aeolian dunes cover a 72 km2 area and rise as high as 210m above the surrounding terrain. The Great Dunes occupy less than 10 percent of the sand-covered area (Figure 3) but contain more than half of the sand in the system. Generally, aeolian sand is less than 7 meters thick in other Aeolian sand areas (Figure 3) (Madole et al., 2008). The Alamosa Formation forms the valley floor and is a typical basin fill deposit of sand, silt and gravel (Madole et al., 2008). Sediments resemble the present fluvial deposits of the Rio Grande, as well as the alluvial fans overlying it near the basins edges, to the point that it is indistinguishable from the two. With several possible sources of sand in the region, many theories have arisen as to the origin of the sands. Current research has implied that cyclic wet and dry cycles similar to that of the Little Sahara Desert were catalysts for wind-blown deposition (Madole et al., 2008). During wet cycles, lakes would form on the valley floor and sediments would fill these areas. An ensuing dry cycle would see lakes dry up leaving sediments exposed to the prevailing southwestwardly winds (Madole et al.,

2008). These sediments were blown up over the alluvial fans draping the Sangre de Christo Mountains, forming the dunes actively being reworked today (Madole et al., 2008).
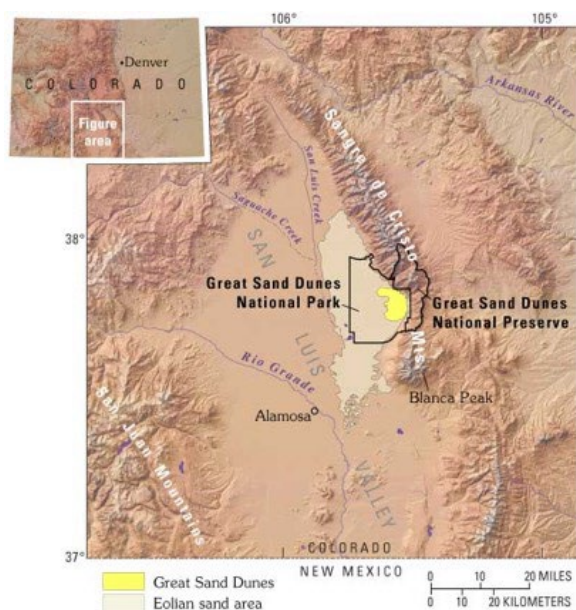

Figure 3. Map of Great Sand Dunes National Park, near Alamosa, Colorado, showing areas of aeolian activity as well as the great sand dunes. Note the areas of aeolian sands and location of great sand dunes within an enclave of the Sange de Christo Mountains. Adapted from Madole, 2005.

Littoral

Masonboro Island is a barrier island on the coast of North Carolina. It is free from human development and can only be reached by boat. Dredging occurs occasionally in the sound adjacent to the island to remove sediments that infill from longshore drift which carries sediments to the north in this area. The Cape Fear River drains a 9,324 square milesection of North Carolina (Mallin et al.,1999). The watershed drains the piedmont region as well as coastal plains of the region. Sediment is the major pollutant in the river and the sediment discharge in mainly clay to silt in size (Mallin et al., 1999). The river enters the Atlantic 40 miles south with sediment drifting northward with longshore drift direction.

MATERIALS AND METHODS

In order to test whether V-pits were indicative of a specific depositional environment, samples from areas of active contemporary environments were gathered. Samples were taking from littoral, aeolian, and fluvial environments across the United States (Figure 4). Glacial deposits were not included because they are not cited by any researcher as exhibiting V-pits. Grains were treated in preparation for SEM analysis and were analyzed for the presence of V-pits.

Figure 4. Map of the United States with sample gathering locations in Vermont, North Carolina, Oklahoma, and Colorado marked by red circles. Adapted from http://www.lib.utexas.edu.

Sample Gathering

Fluvial. Two types of fluvial deposits were gathered for this study. Samples were gathered from the White River in the town of Hartford, Vermont (Figure 5). A bedload deposit was gathered across from Watson Park (Figure 6), 0.5 miles south of the village of Hartford, VT. Sediments were dredged from the channel floor and placed in plastic, closeable sample bags.

An exposed deposit adjacent to the channel was taken from a location next to Vermont Route 14 at the intersection with Runnals Road, roughly 4 miles west of Hartford village, Vt (Figure 5). Another flanking deposit was gathered in West Hartford village (Figure 7). Both samples were placed in separate labeled plastic, closeable bags.

Aeolian. Two different aeolian samples were gathered from locations in Oklahoma and Colorado. Dune

deposits were gathered from Little Sahara State Park in Waynoka, Oklahoma (Figure 8, 9). The second sample was gathered from the Great Sand Dunes National Monument in south-central Colorado (Figures 10, 11, 12). Samples were kept in standard white geologic sampling bags.

Littoral.

Samples were gathered from the southern end of Masonboro Island located in New Hanover County in southern North Carolina (Figures 13, 14, 15). One sample was gathered below the low tide mark, and one sample was gathered from 40 meters behind the shoreline. These were allowed to dry and then were placed in sample bags.

Sample Preparation

After being collected, samples were dried at 120 -150 degrees Centigrade to remove water as well as organics. After 8 hours, samples were removed and allowed to cool. They were then placed in labeled white sample bags. Following this, each sample was dry sieved in order to obtain samples between 100 and 400 microns in width. This was done because grains of smaller size will not produce significant microfeatures. Their small mass results in a minute force of collision which is responsible for V-pit formation. Once the samples were separated into the desirable size range, a small portion of these were placed on a single piece of filter paper and washed with an ethyl alcohol solution to remove any oxides on the surface as well as any particulates from the drying and sieving processes. Samples dried in open air for 15 minutes and were separated using a stainless-steel spatula. An adhering film was placed on an SEM stub to which treated sand grains were attached. The stub was gently pressed onto the filter paper in an attempt to collect a large quantity of grains (100-150). If too many were placed on a stub, views under the SEM were complicated by grains that were too close together. Samples were then placed in a sputter coater to receive a thin veneer of gold. This is commonly done to reduce charging produced by grains (particularly quartz) during SEM analysis. Samples were then placed in airtight containers to keep dust and other particulate matter out.
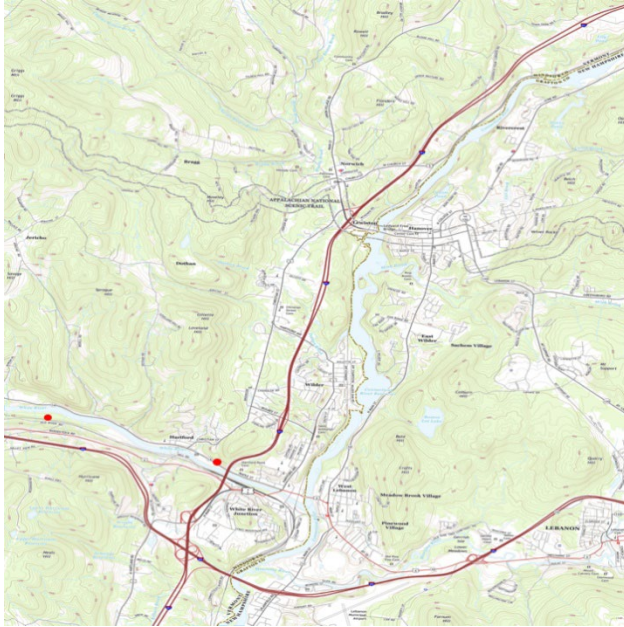
Figure 5. Topographic map of White River Junction depicting Runnals Road gathering location (left red circle) and the bedload sample location across from Watson Park (right red circle). The West Hartford sample location is approximately 2 miles to the west of the area in this map. Adapted from https://geodata.vermont.gov.

Figure 6. View of White River next to Watson Park. Bedload sample was taken from far side of the river where main channel is located tight to the bank (www.hartford-vt.org/rec6parks.htm)

Figure 7. View of White River on opposite bank where sample was taken from, roughly 20 meters to the west. Bedrock (foreground) of schist is draped with glacial debris above riverbank (background).
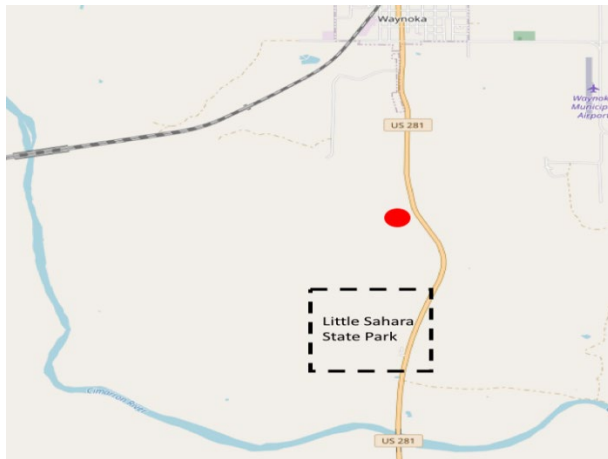
Figure 8. Location map of Waynoka, Oklahoma and Little Sahara State Park depicting sampling site (red circle). Cimarron River flows from Northwest to Southeast in lower left-hand corner. Adapted from http://www.nps.gov/grsa/siteindex.htm.
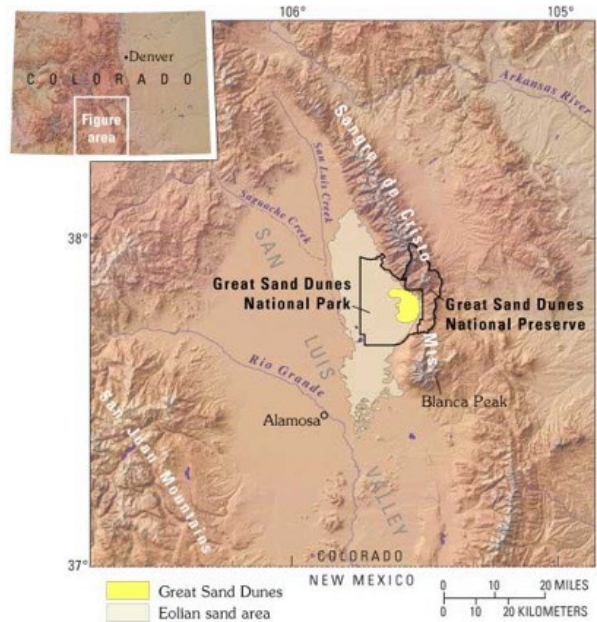

Figure 10. Map of Great Sand Dunes National Park, near Alamosa, Colorado, showing areas of aeolian activity as well as the sand dunes. Sample gathering location depicted in red. Adapted from Madole, 2005.

Figure 9. Foreground: active dune formation in Little Sahara State Park. Background: Dunes stabilized by vegetation close to active dune with large terrace deposit to the far end of the photo. Source: http://www.duneguide.com.

Figure 11. Roadside view of active dune field in Great Sand Dunes National Park. Sangre De Christo Mountains are located in the background.

Figure 12. Close up view of sample location in Great Sand Dunes National Park. Aeolian processes are shaping the dunes though vegetation has stabilized some parts of them is seen in the foreground.

Figure 14. Air photo of Masonboro Island looking towards Wrightsville Beach, North Carolina. The Intercoastal Waterway separates the island from the mainland in the upper left corner of the picture. Source: www.carolinaoceanstudies.com/programs.htm.

Figure 13. Map of Brunswick and New Hanover Counties depicting Masonboro Island, NC sample location (red circle). Adapted from www.pics.city-data.com.

Figure 15. View of southern end of Masonboro Island, NC roughly 300 yards south of sample location, Source: www.carolinaoceanstudies.com/programs.htm.

Sample Analysis

Using the SEM, a picture of a field of view was printed out at the lowest resolution and grains were labeled numerically. The sample was then systematically checked by number and an identification of quartz grains was done using Electron-Dispersive X-ray Spectroscopy (EDS). EDAX software provided elemental signatures for each grain and, once quartz was verified, further investigations for V-pits were made. When V-pits were found, an estimation of coverage of the grain was made. Poor coverage constituted 2 – 3 V-pits in on a small portion of the grain, medium coverage consisted of roughly one quarter of the observable grain surface, and good coverage consisted of roughly 50% or more of the observable grain surface. This was done in an attempt to determine whether or not coverage of V-pits had any relation to depositional environments, but this inquiry was not a primary focus of this study.

RESULTS
Fluvial

Samples gathered from the White River contained a low percentage of quartz and feldspar compared to other sands used in the study. Mica, biotite, and amphibole were common in the samples making up ~10%, ~20%, and ~20% of the observed grains, respectively. The grains from Runnals Road, West Hartford and Watson Park all exhibited similar textural features, including arc-shaped steps, fresh fracture surfaces, linear fractures, and angular features (Figures 17-27). The linear fractures, arc shaped steps, and fresh surfaces are indicative of glacially crushed sediments than fluvial deposits. Overall, these samples contained a notable lack of V-pits though some did occur.

Watson Park. The Watson Park bedload sample contained the lowest percentage of quartz grains of any sample. Grains were angular to subrounded (Figure 16), with a higher degree of rounding than the deposits from Runnals Road and West Hartford. The sample also contained a higher percentage of more mafic minerals than either lateral deposit. Over 350 grains were analyzed with EDAX to accurately identify 81 quartz grains. These grains were examined at higher magnification for V-pits. Of the 81 grains 29% showed a significant coverage of V-pits (Figures 16-20).
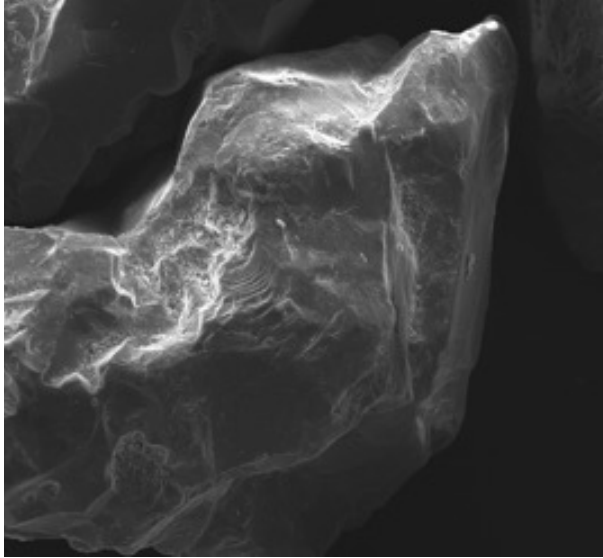
Figure 16. A 221x view of grain with fractures on right, arc-shaped steps in middle, and fresh surfaces on sides typical of the bedload and fluvial sediments. V-pits are located on much of this sample in the upper right, and a large V is present in the middle left area of the picture. Sample from Watson Park, WRJ, VT.
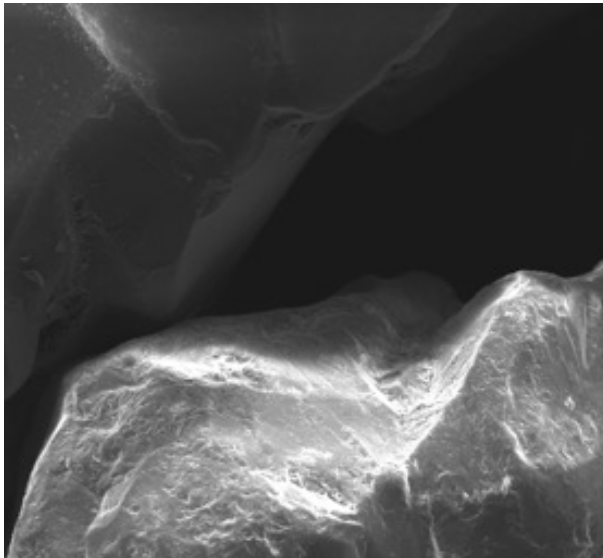

Figure 17. 442x view of upper section of fluvial grain showing smaller V-pits on left edge of grain. Sample from Watson Park, WRJ, VT.
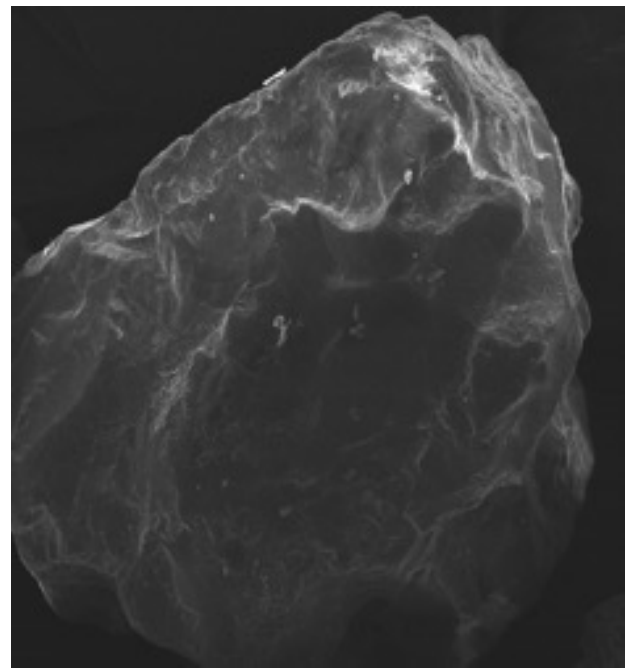

Figure 18. A typical fluvial grain from the bedload deposit; more rounded edges but lacking V-pits(112x). Sample from Watson Park, WRJ, VT.
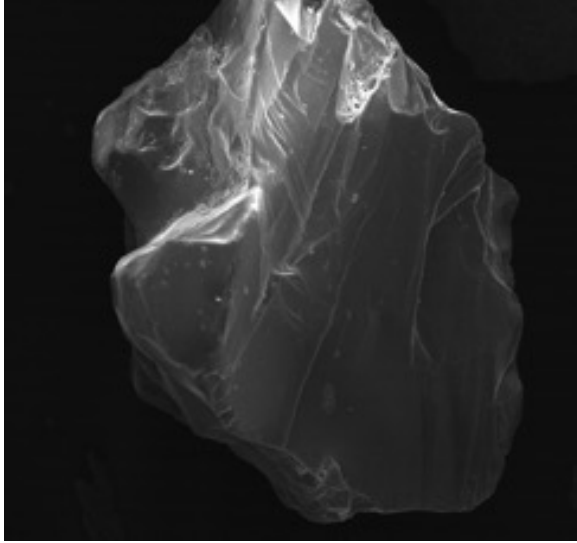
Figure 19. 112x view fluvial grain typical of two localities adjacent to the river with fractures and fresh surfaces but lacking V-pits. Sample from West Hartford, Hartford, VT.
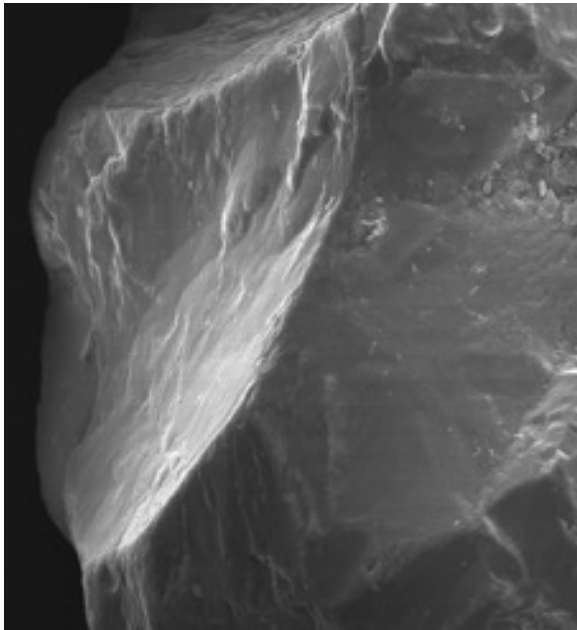
Figure 20. A 221x view of abraded quartz grain from fluvial environment with wide coverage of pits in lower left area of grain. Sample from West Hartford, Hartford, VT.

Runnals Road. Samples from Runnals Road were composed of quartz (~20%), potassium feldspar (~10%), and plagioclase (~20%), biotite (~30%), and amphibole (~20%). Most grains were angular to subangular, and rarely subrounded (Figure 21). A total of 50 quartz grains were identified from 250 clasts and subjected to closer scrutiny. Of these 12 % exhibited V-pits (Figures 21-23) of noticeable coverage (Figures 21-23).

West Hartford. The West Hartford deposit was very similar to the Runnals Road samples. Grains were angular to subangular with rare subrounded grains (Figure 24). The deposit contained the same percentages of minerals as the Runnals Road deposit. EDAX analysis identified 42 grains from a total population of 210 which were viewed under higher magnification for V-pits. V-pits were present on 12.2% of quartz grains (Figures 24-26).
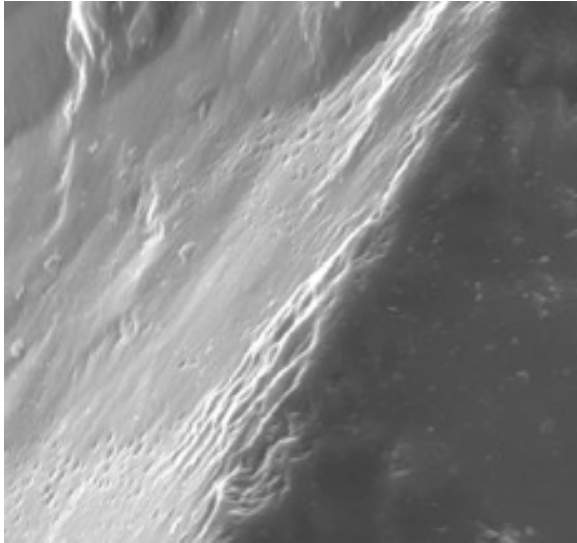
Figure 21. 442x view of same grain from Figure 21 showing multiple V-pits in lower left and upper middle section of the grain. Sample from West Hartford, Hartford, VT.
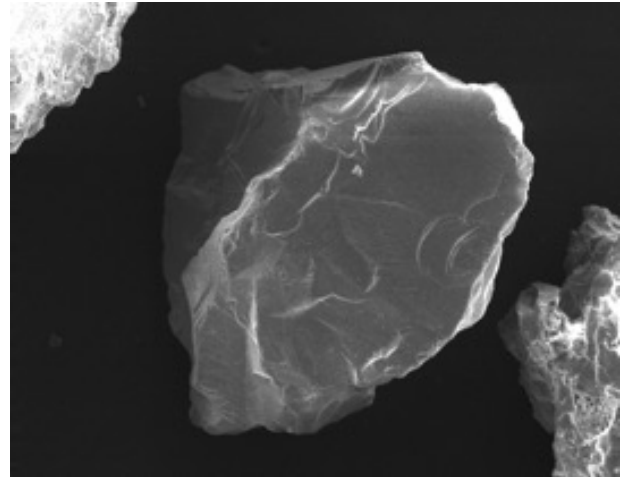

Figure 22. A 115x view of grain with fractures, steps, and fresh surfaces typical of the fluvial sample. Sample from West Hartford, Hartford, VT.
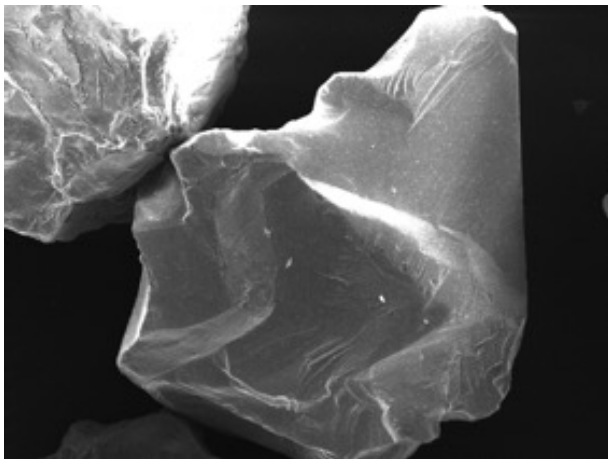

Figure 23. A 115x view of fluvial grain with poor coverage of V-pits in the lower right. Sample from West Hartford, Hartford, VT.
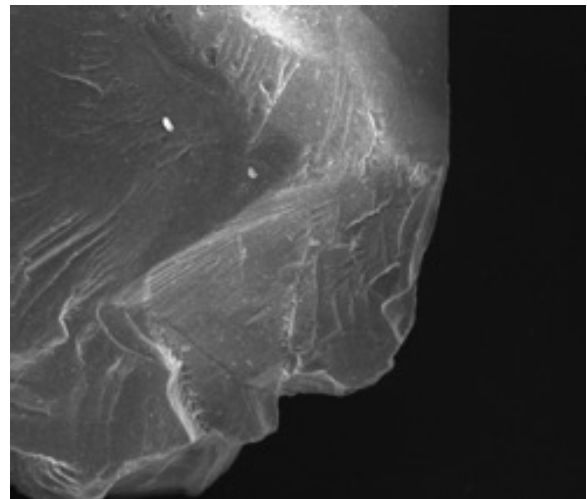

Figure 24. A 221x view of fluvial grain from Figure 24 showing V-pits near the right edge of the grain. Sample from West Hartford, Hartford, VT.
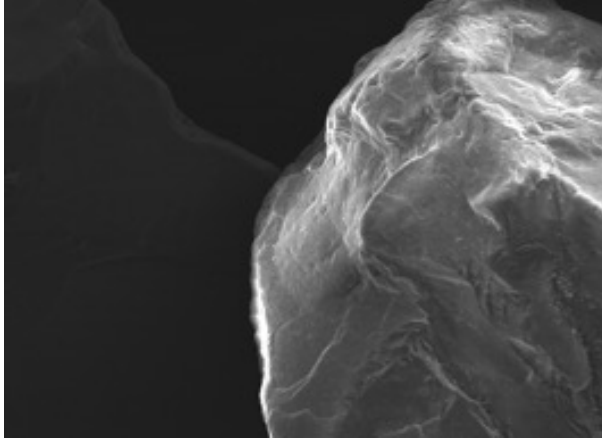
Figure 25. A 221x view of fluvial grain with medium coverage of V-pits in the left center of the grain. Sample from West Hartford, Hartford, VT.
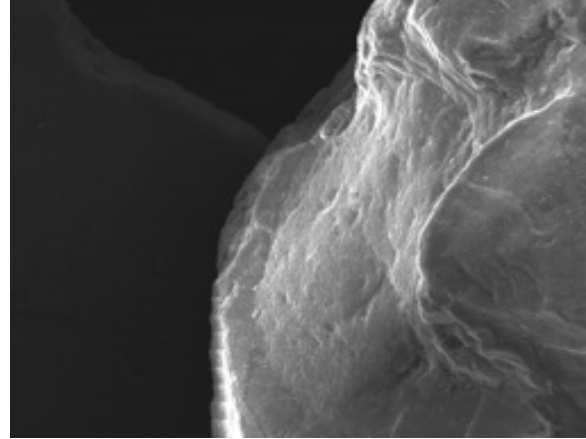

Figure 26. A 442x view of fluvial grain from Figure 26 showing weathering of the V-pits. The grain is more rounded than most from the sample. Sample from West Hartford, Hartford, VT.

Aeolian

Aeolian samples were characterized by a rough cratered surface (Figures 27-33). Adhering particles were common as well as altered V-pits (Figure 28) which were present more frequently the Aeolian samples. These samples were highly felsic with potassium feldspar and quartz being the dominant grain type in the samples making up over 80% of the sediment. Most grains were rounded to well-rounded and occasionally subrounded.

Little Sahara State Park. The Little Sahara Desert sample contained a high percentage of potassium feldspar (~50%) giving the sediment a pinkish coloring. Roughly 50% of the grains were quartz. Grains were subrounded to rounded. Of the entire population of 125 grains, 52 were isolated for further inspection based on EDAX readouts. Of the 52 quartz grains, 42% showed significant coverage of V-pits (Figures 27-29). This was a markedly higher percentage compared to other depositional environments.

Great Sand Dunes National Park. Samples from Great Sand Dunes National Park showed similar features to those samples from the Little Sahara State Park. Grains were rounded to well-rounded. There was a higher percentage of quartz (70%) and was less abundant in potassium feldspar

than the Little Sahara samples (10%). A rough cratered surface was common as well as adhering particles. From a population of 100 grains 40 quartz grains were identified and viewed under higher magnification. Of these grains, 35% contained V-pits (Figures 30-33).
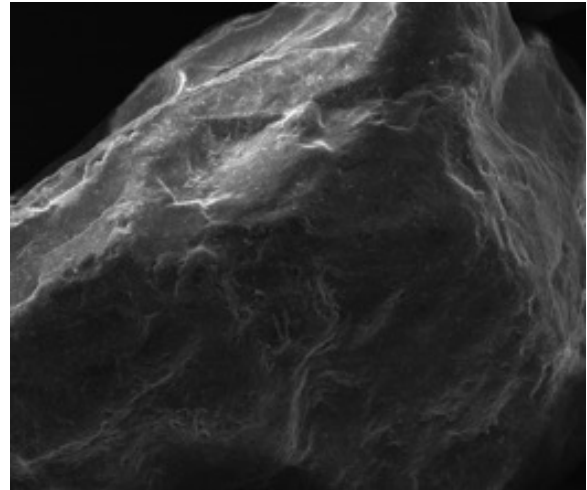

Figure 27. Well-covered aeolian grain with many V-pits on right and top of grain at 221x magnification. Sample from Little Sahara Desert, OK.
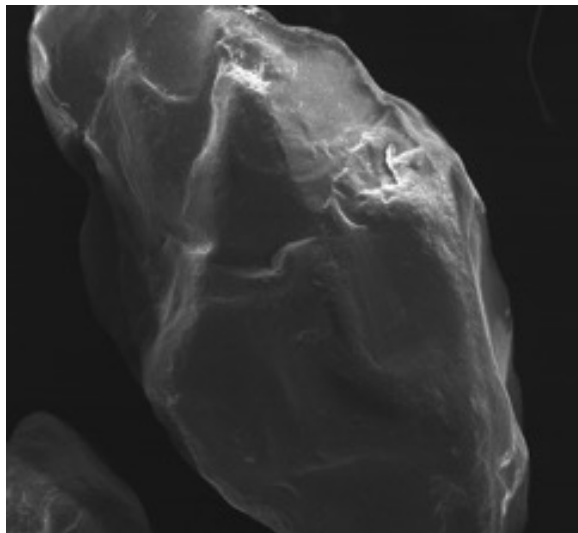

Figure 28. Aeolian grain with medium coverage of small V-pits on middle to lower half of the grain at 221x magnification. Fresh surfaces at top of grain were uncharacteristic for aeolian grains. Sample from Little Sahara Desert, OK.
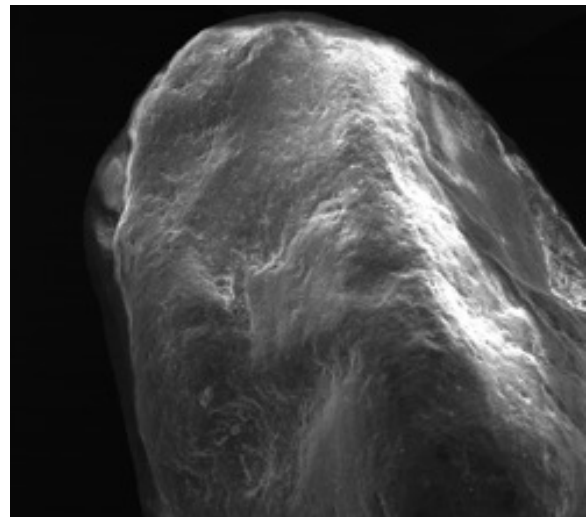

Figure 29. More typical aeolian grain exhibiting large and small V-pits on left side of grain, but the V-pits are weathered. The grain is seen at 221x magnification. Sample from Little Sahara Desert, OK.
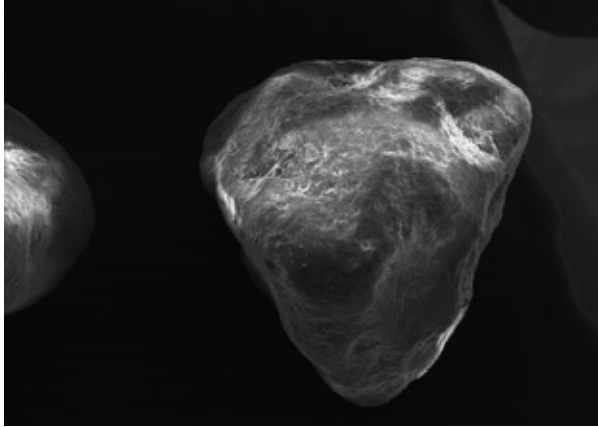
Figure 30. A 112X view of bulbous quartz grain with large, weathered V-pits from an aeolian environment. Sample from Great Sand Dunes NP, CO.
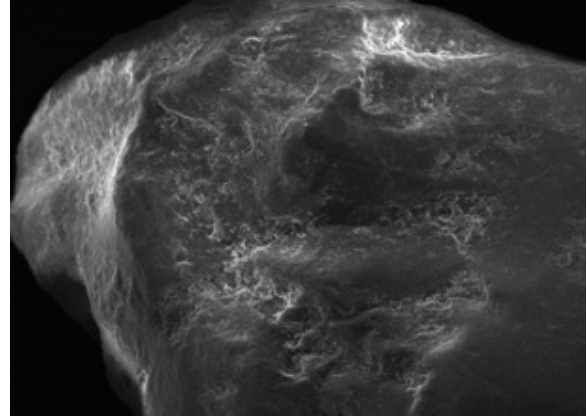

Figure 31. A 221x view of an aeolian grain showing smaller V-pits and adhering particles typical of the sample. Sample from Great Sand Dunes NP, CO.
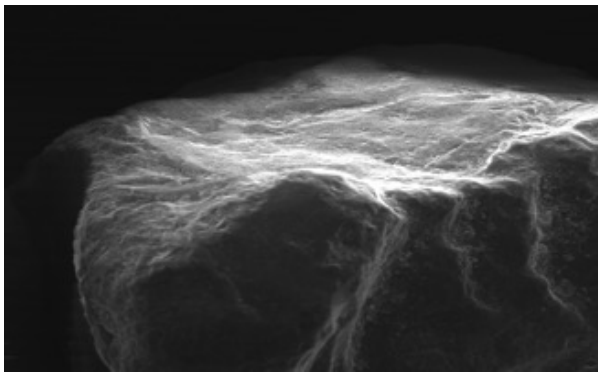

Figure 32. 221x view of an aeolian grain with multiple V-pits on top surface and medium coverage overall. Sample from Great Sand Dunes NP, CO.
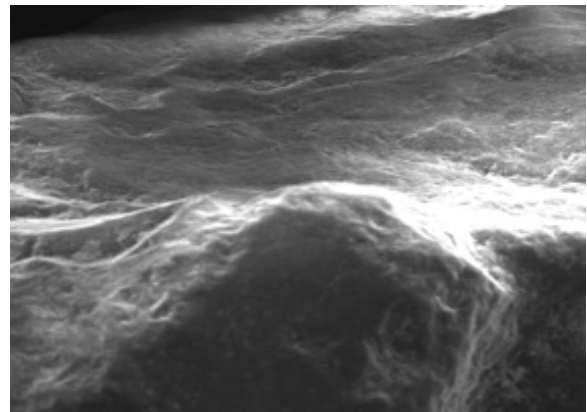

Figure 33. 442x view of an aeolian grain showing weathering of V-pits. Sample from Great Sand Dunes NP, CO.

Littoral

Grains collected from Masonboro Island were mainly quartz (~80%) with some feldspar as well (10%). The other major constituent of the sediment were shell fragments from mollusks in the region that were broken up by wave action. Most grains were well-rounded, and grains lacked V-pits. Common features were grain frosting and dissolution etching (Figures 34-39).

Supratidal. This sample gathered far above the tide line is only affected by littoral processes during large storms and hurricanes. The grains showed characteristic dissolution features as well as grain frosting and well roundedness (Figures 34-36). Of the 170 grains in the samples, 48 quartz grains were analyzed for V-pits; only 15.7% exhibited V-pits.

Littoral. Samples gathered from within the active tidal zone were of similar composition to those located in the supratidal zone. Dissolution etching was the most common feature as well as smooth frosted surfaces. Of the 52 quartz grains analyzed under SEM, only 19% contained V-pits (Figures 36-39).
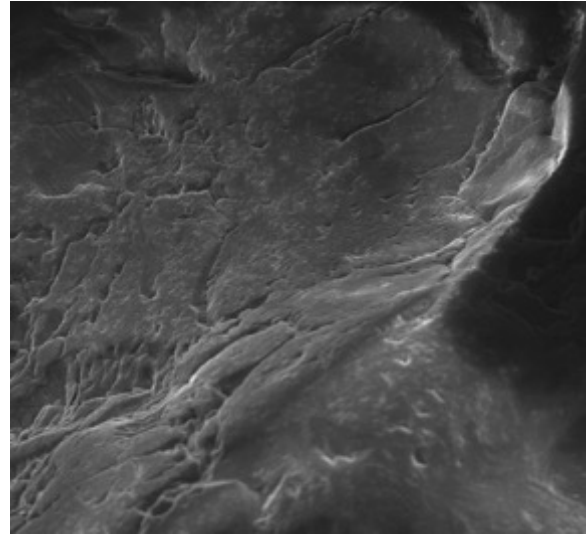

Figure 34. A 442x view of a supratidal grain exhibiting numerous V-pits of varying size in upper middle and lower middle area of the picture. Sample from Wilmington, NC.
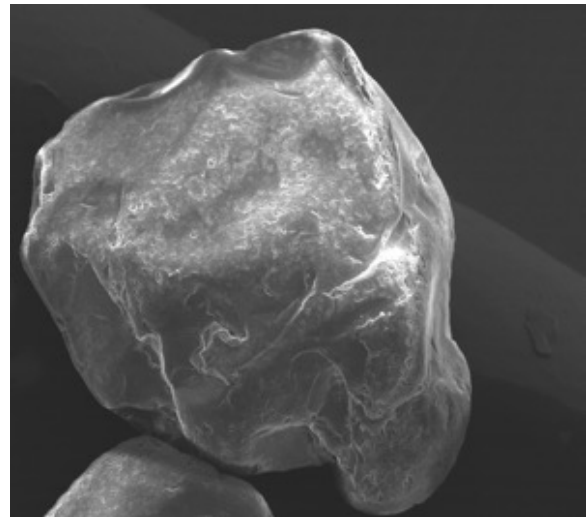

Figure 35. Poor coverage of V-pits at lower right and more typical dissolution surface and frosting of supratidal grain at 112x magnification. Sample from Wilmington, NC.
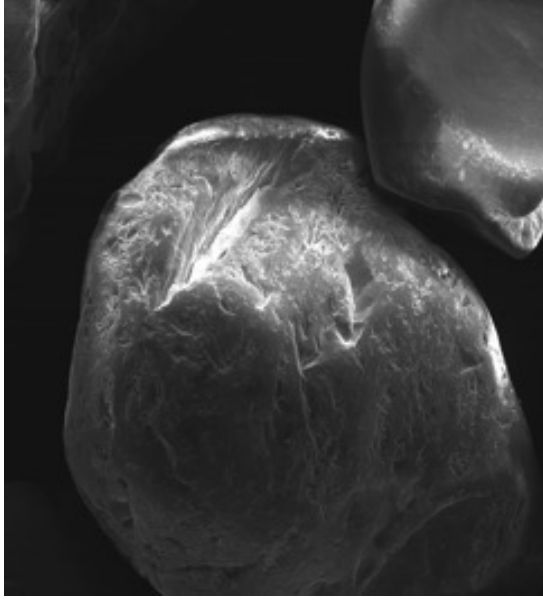
Figure 36. Good coverage of supratidal grain exhibiting V-pits and dissolution as well at 112x magnification. Sample from Wilmington, NC.
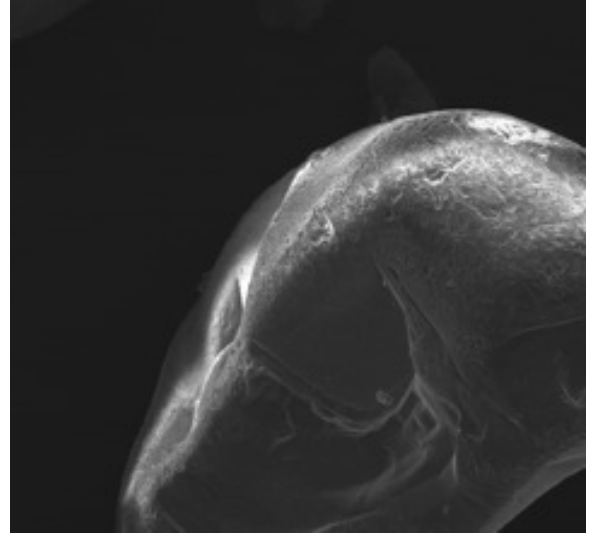
Figure 37. Poor coverage of V-pits (left central) on a littoral grain with characteristic dissolution features on rounded surface at 221x magnification. Sample from Wilmington, NC.

Figure 38. Medium coverage on a smooth rounded littoral grain with large V-pits and smaller V-pits located in the lower right-hand section of the grain seen at 221x magnification. Sample from Wilmington, NC.

Figure 39. Characteristic dissolution features of littoral grains seen at 884x magnification. Sample from Wilmington, NC.
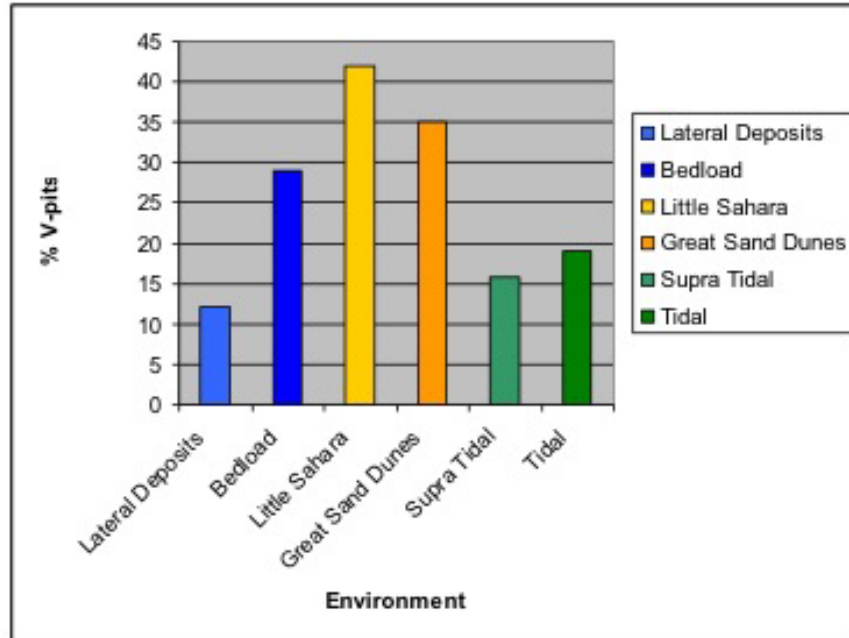
Figure 40. Bar chart of percentages of grain with V-pits from each of the sample locations.

Summary

V-pits were far more abundant both of the aeolian deposits than in other samples. The bedload samples showed abundant V-pit covered gr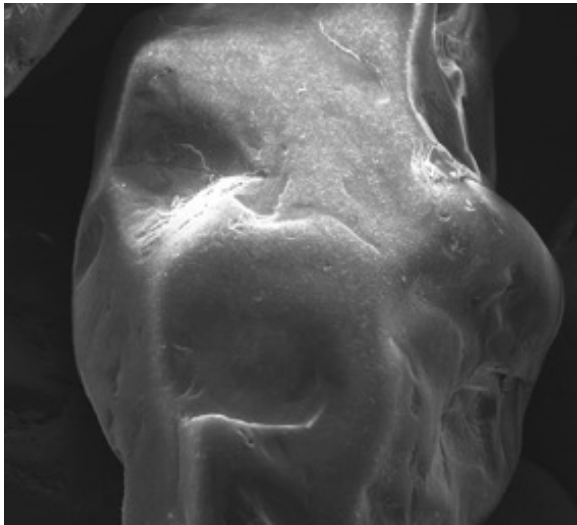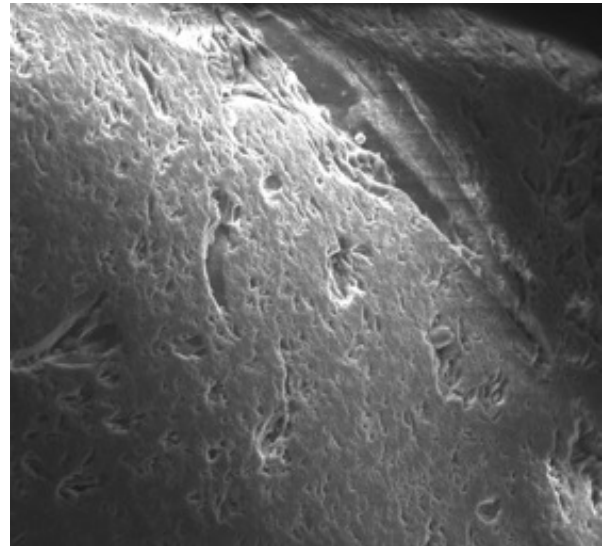ains as well though less so than aeolian deposits. The littoral grains as well as lateral deposits exhibited few V-pits (Figure 40). Grains with V-pits displayed a wide variety of coverage (Table 1). A plot of percentages (Figure 41) shows little variability in coverage of V-pits based on environment.

	% poor	% med	% well
Fluvial	55.9	33.3	11.8
Littoral	47.2	30.6	22.2
Aeolian	64.7	24.5	11.8

Table 1. Percentages of V-pit coverage of grains exhibiting V-pits separated by environment type

DISCUSSION

Quartz grains from the tidal and supra-tidal environments did not commonly exhibit V-pits. Littoral grains showed the less V-pits by percentage than either fluvial or aeolian environments. This implies that previous conclusions claiming that littoral environments are conducive to

the formation of V-pits are incorrect. The sediments compromising the littoral samples were likely carried northward from southern areas by long shore drift. The Cape Fear River is the nearest source of fluvial sediments to the Masonboro locality, but this river contributes mostly clay to fine silt sized sediments to the region (Mallin et al., 1999). Only sand sized grains were observed in this study, which assures that quartz grains were not recently removed from a fluvial environment. Near shores littoral processes were the primary force acting upon the quartz grains and did not produce V-pits.
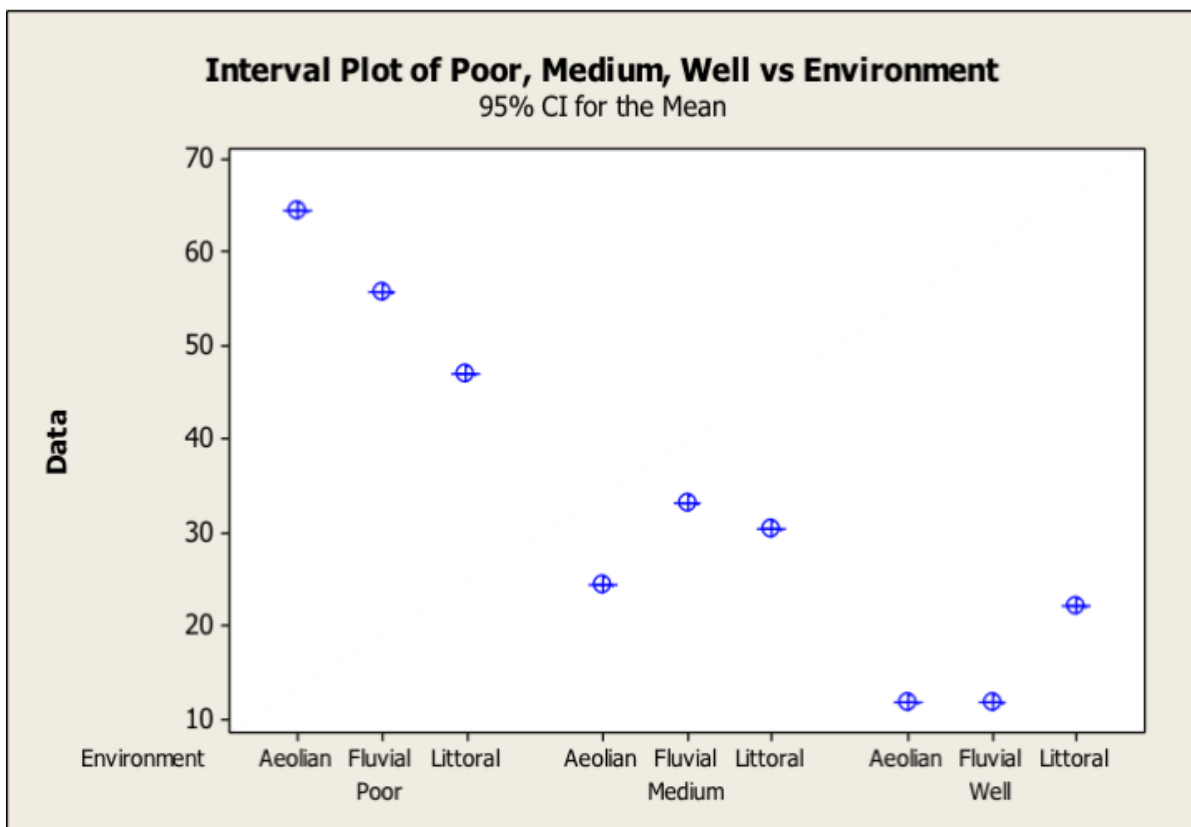

Figure 41. Plot of V-pit coverage type by percentage separating different environments showing little statistical difference in percentage of populations within coverage types.

The claim that fluvial environments form V-pits was not directly supported by samples used in this study. Both Runnals Road and West Hartford deposits along the White River showed the least percentage of

V-pits in the study. The linear fractures, arc-shaped steps, and fresh surfaces resembled what Mahanney (2002) and Krinsely and Trusty (1986) interpret to be glacial grains. This is easily possible as glaciation affected the region in the Wisconsinin. Glacial Lake Hitchcock, which occupied the current Connecticut River Valley, left many glacio-fluvial deposits in the region, most of which have been removed by erosion by existing rivers. The sides of the White River are flanked by the remaining deposits where bedrock is not exposed. The deposits are located up to 20 miles up the Valley from the junction with the Connecticut River. These sediments have likely undergone little or no transportation since their deposition and thus preserve their glacial features. Evidence supporting a fluvial origin for V-pits is seen in the bedload samples that were observed which exhibited twice as many V-pits than the lateral deposits from Runnals Road and West Hartford. The similarity in mineral composition of the three samples suggests that the bedload sediments were derived from these flanking deposits. V-pits were far more abundant in the bedload deposit even

with the minimal transportation distance for the grains. The quartz grains in this study do not discount nor prove that fluvial environments produce V-pits. A sample of purely fluvial origin may be more useful in determining this.

This findings in this study did not support a littoral origin for V-pits and could not support a fluvial origin for V-pits either. The recent work of Mahaney (2000) had used SEM analysis and observed micro textures to determine the depositional environment of Devonian sands. This work is also being extended into sandstones. V-pits are just one micro texture being used to evaluate a sediment or sandstone. The environment in which V-pits form is not conclusive so it is reasonable to conclude that a similar problem may exist for other micro textures.

In summation, the results of this study indicate that aeolian environments produced V-pits. This bears further investigation, but the Little Sahara deposit as well as the Great Sand Dunes National Park sample exhibited the highest percentage of V-pits. These may be relict features from previous

depositional events. The Little Sahara sands are a result of fluvial terraces deposited by the Cimarron River being reworked by aeolian processes. The altered V-pits, common to the samples, are possibly the remnants of fluvial markings which have been overprinted with the pockmarked surface common to aeolian environments, according to Mahaney (2002). The Great Sand Dunes deposits are derived from areas southwest of their location. The winds that have prevailed from southwest for some time have driven sediments from the basin to abut the Sangre De Cristo Mountains to the northwest. This includes fluvial deposits from the Rio Grande as well as underlying basin fill deposits. The altered V-pits were common to Great Sand Dunes samples as well. These grains could be in the process of removing relict features in an aeolian environment. This highlights some problems that could arise from using this method to identify depositional environments. Quartz grains may undergo many modes of transport before finally being deposited in a specific environment. Quartz is weathering resistant mineral. Features that are preserved on a quartz grain as it enters a different environment may

be preserved. Because the timescale during which new textures are imprinted over old ones are unknown, difficulty concluding which micro textures are indicative of specific environments arises.

In order to address some variables that affect grain micro textures, samples should be chosen carefully. Ideally a fluvial deposit near the mouth a river in an area not affected by glaciation would be used for SEM analysis. This might not fully account for the fact that grains may be deposited in a wide range of environments for some time before their final deposition, but it eliminates many sources of error. Another problem with SEM study is lack of a clear definition and type example for many microtextures. V-pits for example have two types. The study was focused on percussion V-pits but a possible chemical origin for some V-pits was noted by Mahaney (2002). Further work clearly defining V-pits in terms of size, depth, coverage, or degree of weathering would be useful to those interpreting a grain's surface.

SEM analysis is an intriguing way to analyze sediments. If the links drawn by researchers between

textures and environment can be strengthened and clarified then a possible shift into a determination of sandstones may be possible. While post depositional factors such as cementation, grain shape distortion, and fluid removal must be studied, SEM could prove to be a useful tool for paleoenvionment reconstruction as well as provenance studies.

CONCLUSIONS

This study suggests that neither a littoral nor a beach environment is conducive to the formation of V-pits. There is, however, statistical evidence to support a claim that V-pits form in an aeolian environment. Additional research and investigations are needed to accurately determine the link between depositional environment and textural features, especially with complications like grain overprinting clouding results.

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