SOURCE CHARACTERIZATION OF AFRICAN SOILS USING COMPUTER CONTROLLED SEM ANALYSIS

by

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Abstract

SOURCE CHARACTERIZATION OF AFRICAN SOILS,

USING COMPUTER CONTROLLED

SEM ANALYSIS

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An investigation is underway to determine whether African dust can be chemically distinguished by regions and whether it is developed through Pedogenic or Aeolian processes. A total of 29 dust samples were taken from the Sahel and Saharan region of Africa and are to be analyzed using computer controlled scanning electron microscopy (CCSEM). CCSEM collects data on size shape and chemical composition on individual microscopic dust particles present in a media sample analyzed in a scanning electron microscope (SEM). Back-scattered electron imaging (BEI) in the SEM is accomplished using a four-quadrants backscatter electron detector. This method of imaging the particles in the SEM provides particle morphology data. Compositional information on individual particles will be collected with a 10 mm^2 OmegaMax Silicon Drift Detector (SDD) with ultra thin window (UTW) (capable of registering light element X-rays) Peltier-cooled energy dispersive x-ray spectrometer. A variable pressure SEM will be used for the analysis of insulating materials, which eliminated the need for special specimen coating to dissipate charge and remove artifacts. Data from these samples are being used to address the primary question: (1) Can CCSEM technology accurately describe elemental compounds derived from soil samples collected from Africa. The

principal goal of the research is to attempt to identify (by cluster analysis) homogenous groups of particles in each soil sample. By homogenous we mean a group of particles that separates from other groups based on the information gained on the individual particles. The homogenous group will occupy a unique position in information space where the information that defines the group is primarily the composition data from the particles (data on up to 25 elements in each particle), but can also include particle size, shape (e.g., aspect ratio), and backscatter signal strength (a measure of the particle's average atomic number composition). Obviously, the greater the amount of individual particle data in the information space, the greater the likelihood of separating homogenous groups of particles. The term particle "class" is used here to represent homogenous elemental particle groups. Pilot data analysis made use of a 19-class element classification scheme to separate particles in a typical analysis of some 4000 particles in a single dust sample. Initial findings of six samples showed large amounts of Fe, Si, and Al-rich minerals. The Al-Si-rich minerals show a close correlation in relative elemental amounts. This is to be expected from clay minerals of the pyroxene group. The Fe, Si-rich minerals trend towards an inverse relationship, which is also consistent with iron oxides of the spinel group that generally consist of magnetite. Other elemental constituents within the samples include varying amounts of Ti, Ca, and K. An initial run of samples, 2 Burkina Soils and 2 Burkina Laterites, show a similarity in chemical composition, leading to the hypothesis that the Burkina Soils may have originated from the Burkina Laterites. As the experiment progresses we expect to see similar Aeolian processes contributing to the mineral content of other surface dusts. Further research on the effects of these wind driven dusts is needed to assess the potential health and nutrient impacts on the Americas as it is blown across the Atlantic Ocean and deposited in the ocean, Caribbean islands, Florida, the Amazon and Texas.

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Chapter 1

Introduction

African dust is blown across the Atlantic Ocean and deposited throughout North, Central, South America and North America. North African dust incursions across Europe are also relatively common. These dust particles, generally deriving from the Sahel and Saharan region of Africa, are suspended for an unknown amount of time in the upper atmosphere during transport. Specific amounts and percentages of African dust that is collected during transport as well as deposition are unknown. Chemical and physical transformations during the transport process can be affected by the amount of time the dust spends in the atmosphere and have the ability to absorb pollutants such as organics, sulphates, and chlorine (Sullivan et al., 2007; Falkovich et al., 2004; Mamane et al., 1980). Once deposited, these dusts can cause allergy issues for susceptible adults and children (Goudie and Midddleton, 2001; Prospero, 1999; Prospero et al., 1981; Mahowald et al., 2005; Mather et al., 2008). The number of asthma hospitalizations related to, or caused by African dust is currently unclear.

A secondary effect of this atmospheric dust is that it provides an unknown amount of nutrients for Central and South American forests, specifically the Amazon rain forest (Bartholet, 2012). The soil in the Amazon basin is heavily weathered by rain, which can deplete the ground of nutrients that are replenished by the addition of African Dusts. The dust that is collected from South American is generally considered to have a relatively high iron content, which is crucial for the vegetation in the region, but can also cause damage to ocean ecosystems due to the addition of anthropogenic pollutants (Bartholet, 2012). One study showed that iron transported in the atmosphere can mix with acids from the atmosphere, such as biomass burning, and cause the iron to be more soluble and therefore increase the amount of available iron in the ocean (Bartholet, 2012).

A tertiary effect of African dust is the impact on climate by changing the energy balance of solar and thermal radiation. (IPCC, 2007). It is unknown how much of an effect aerosolized dust has and the chemical reactions that take place in the atmosphere (Formenti, et al., 2011). Since these dusts cause harm, provide nutrients, and effect global climate, it is pertinent to characterize and source the parent materials from which the dust originates in order to better understand the process of creation and the chemical and physical effects that take place during transport. In order to fully understand the process that takes place during transport and after deposition, a baseline elemental and chemical analysis of the dust is necessary.

Chapter 2

Previous Research

Previous research has shown that North and Central African Dust has been transported to the Iberian Peninsula and predominantly consists of calcite-dolomite, silica, with minor amounts of micas, feldspars, gypsum and other trace minerals (Avila et al., 1997; Coz et al., 2009). A Scanning Electron Microscope coupled with Energy Dispersive X-ray Spectroscopy (SEM/EDS) was used to characterize 18 basic elements and the mineral content of sampled dust was derived from the elemental analysis. Clustering of the different elements was carried out in order to differentiate between the sample classes. Results showed samples taken in Madrid after transport consisted of 65-85% silica. The North African topsoil hypothetically causes the relative high abundance of silicates in the dust collected in the Iberian Peninsula. Along with chemical analysis, Aspect Ratios (AR) were used to compare particle morphology in order to characterize the ability of the particles to transport in the atmosphere as well as try to determine the source of the dust collected in Spain. It was determined from this research that particle deposition occurred by three mechanisms, impaction, sedimentation and Brownian diffusion (Mormon and Plumlee, 2013). For particles larger than 0.5 μm in diameter, gravitational sedimentation is important, as the particle will not travel far distances. For particles less than 0.5 μm in diameter a particle may be governed by diffusional transport where small displacements are caused by the collision between gas molecules and particles (Shultz et al, 2000).

Additional research was started on the transport of African dusts to the Americas (north, central, south, and Caribbean). These studies are in their infancies and were started by Frank Oldfield and Richard Lyons from the University of Liverpool. Initial results showed that African dusts are being transported across the Atlantic at an unknown rate for an unknown amount of time. The main goals of Oldfield's research was to document spatial variation in magnetic properties, explore the possible links to climate gradients and differentiate potential sources for

Sahara and Sahel-derived dusts. This research concluded that there is a general north-south increase in concentrations of fine-grained ferromagnetic minerals across Niger and Mali, which corresponds with increases in rainfall and therefore enhanced weathering (Lyons et al, 2010). Enhancement of secondary ferromagnetic minerals of surface materials from the Sahel region led to a conclusion that the concentration of fine-grained clay fractions (<2 μm) has a tenfold difference between the arid north and humid south in Niger. There is also a less statistically significant correlation for the hematite concentrations and rainfall across the same transect (Lyons et al, 2010). Some surface soils from the Benin and southern Togo region exhibit magnetic properties consistent with those of the parent rocks below. The conclusion of this research shows that climate variations play an important role in source locations of African dust. In order to fully characterize the source of African dusts, this approach will require more careful sample selection and further work on the separation of particle size (Lyons et al, 2010) and chemical analysis.

Joseph Prospero started preliminary research at the University of Miami with samples of dust collected from areas such as the Florida Keys, Bahamas, and the Amazon Rain Forest. It was determined that the Earth emits 2 billion metric tons of dust every year, with over half of that originating from Africa. 40 million metric tons of dust consisting of iron, and phosphates travel 6400 km across the Atlantic Ocean to the Amazon with approximately half of this amount originating from the Bodele depression in Africa (Bartholet, 2012). The speed of the wind necessary to transport this dust across the Atlantic must be approximately 4-12 meters per second. It has been determined that the dust plays an important role in climate change for the environment. Dust traveling across the Atlantic has dual effects of the climate of the Earth. The darker areas, such as the Atlantic Ocean, cool the planet by reflecting light, while lighter areas, such as ice and sand, tend to warm the planet due to absorption of light. How much this dusts plays on climate variation is, at this point, unknown. Another effect of dust on the atmosphere is the role it plays in cloud formation. In order for a cloud to form, water droplets must form around a condensation nucleus, such as dust, which can increase or decrease the climate and amount of rainfall (Bartholet, 2012).

Recent studies on Aeolian research show that there is a link between inorganic mineral dusts and the health of the population (Morman and Plumlee, 2013). In the past, limited research on source characterizations has caused difficulties in quantifying the health effects of long-range transport dust (Morman and Plumlee, 2013). It is estimated that 1.3 million deaths are caused by outdoor air pollution (WHO, 2012a). The USEPA (2012a) defines inhalable coarse particles as those between 2.5-10 μm in diameter with the toxicological effects of dust particles less than 5 μm being determined by the chemical stability of the particles. Currently, there are few studies that show the link between inorganic mineral dust and health (Mormon and Plumlee, 2013). One of the primary factors in determining whether inorganic mineral dust will affect health in the population is the physical and chemical characteristic of the dust (Plumlee et al, 2006). One of the concerns of African dusts is the high silica content. Pneumoconiosis (Desert Lung) is a concern for both livestock and humans in dusty regions due to an increase in desertification from climate change (Kuehn, 2006). Studies of regional dust from sources, such as the Sahel/Saharan region of Africa, suggest an increase in hospitalization and mortality in areas such as Europe (Morman and Plumlee, 2013; Perez et al, 2007). Contradictory to the studies by Kuehn (2006), others studies found no evidence of increased mortality due to far traveled dusts landing in Barbados with corresponding increases in African Dusts (Bennet et al, 2006, Prospero et al, 2008). It has been theorized that approximately half of African dusts are less than 2.5 μm in diameter (Mormon and Plumlee, 2013), which indicates that most African dust is easily aerosolized and transported across the Atlantic Ocean.

While numerous studies have been conducted on the effects of both long-range and short-range transport dust, inconsistencies and lack of data have led to a conclusion that more research is needed on sample and source characterization (composition and particle size), model parameters, and susceptibility (Morman and Plumlee, 2013). Mormon and Plumlee (2013) state, “Much more information regarding source location, sample characterization (biological, mineralogy, and chemistry), emission rates and models, and particle size are needed to understand the implication of exposure and etiological agent(s) responsible.”

Chapter 3

Research Design

The microscopic constituents of 29 dust and soil samples were characterized at the individual particle level using a combination of scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) (Figure 3-1). Imaging of particles by collecting sample secondary electrons (SE) provided morphological information, while primary beam backscattered electron (BE) collection provided relative particle composition data. The measurement of sample characteristic X-rays provided element composition information for each particle. The SEM/EDX analysis employed an ASPEX™ Personal Scanning Electron Microscope (PSEM). Particle imaging was conducted primarily in the BE imaging mode. Backscattered electrons were collected by a four-quadrant detector located at the base of the SEM column. Variations in BE yield strongly correlate with particle average atomic number composition (essentially the BE gray-scale image reports on variation in particle density). Particle element composition was determined by collecting characteristic X-rays using an OmegaMax EDX system with a silicon drift detector with a $10mm^2$ active area and ultra-thin window for detection of elements from Carbon to Uranium. Individual particle analysis (IPA) involving the collection of size, shape, and element composition data involved BE collection operating in tandem with X-ray data collection under computer control. Obtaining statistically significant IPA data sets, in a time efficient manner involved automated particle (in the SEM referred to as a feature) analysis with the primary SEM electron beam and the sample stage moved under computer control (computer controlled SEM – CCSEM) guided by the resident automated feature analysis (AFA) software. The AFA software operated sequentially in a feature search mode and then in feature measurement mode. The feature search required initially setting an imaging threshold (in BE imaging mode), whereby the sample particles were isolated/separated from the polycarbonate membrane filter on which the particles were collected for CCSEM analysis (optimally separated from each other by at least one particle diameter). As the substrate (the polycarbonate filter) had a low average atomic number (being composed of carbon) all particles with an average atomic number greater than carbon were separated in the BE image from the substrate by a greater BE yield thus allowing a recognition threshold to be set permitting the AFA software to distinguish the particles from the substrate. This is basically a binary image separation. Once the threshold had been set a search magnification was set (500x), each SEM stage field defined for searching was divided into a 5x5 grid of electronic-fields (increasing the efficiency of the AFA analysis by reducing stage travel time). A search grid size, this is the grid of points where the primary electron beam interacted with the substrate at each point. If the beam interacted with a particle on the substrate at a designated point position that point would be recognized as being on-point (the BE yield would be above the threshold indicating a particle had been found) as opposed to an off-point location where the beam is interacting with the substrate with a BE yield below the set threshold. The field search grid size was set at 1024x1024 pixels, which meant that only a particle less than 0.3 μm in diameter that might fall exactly between the search grid points would be missed during the search. When an on-point pixel was encountered the beam point separation was reduced as the particle was scanned. The AFA software then went into the analysis mode. During the feature scan process, the size was measured using a rotating chord algorithm, shape determined (e.g., the aspect ratio) and X-ray data was collected as the beam rastered along chords across the particle (this provided an average particle composition), a minimum dwell time for X-ray collection on the particle was set at 10 seconds, or a minimum of 5,000 X-ray counts acquired. For each particle X-rays counts were measured for an element list that included: Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Mn, and Fe. Relative X-ray concentrations (recorded as normalized k-ratios) for these elements and size information were recorded in a particle-by-particle database. While a fixed element list was used at this stage, the software actually stored complete X-ray spectrum data allowing subsequent reprocessing of data if needed (e.g., removing and/or adding element(s) from the element list). The standard operating conditions for each analysis were: a primary beam current of 1 nA, an accelerating voltage of 25 kV, and a working distance of approximately 16 mm. The duration of AFA was set at either the collection of data on 4,000 particles, or a total analysis time (for search and measure) of 600 minutes.

The goal of CCSEM is to generate statistically significant individual particle data sets that can be used to define the compositionally different particle types that comprise the media sample of interest. Here, defining the different constituent particle types involved a manual divisive hierarchical clustering method that employed the software program STATISTICA for data review. The objective of the cluster analysis is to differentiate homogenous groups of particles in information space described primarily by the element composition information (although, other attributes such as particle size, or aspect ratio, can be used as classifying variables). The element concentration range recorded for the particles in that group manually characterizes each homogenous group, and the list of these elements and their concentration ranges define a particle class. Typically once the class parameters have been designated the classes are ordered in a linear scheme that can be used to classify particles of unknown origin (Table 3-1).

Table 3-1: Linear Sorting Scheme

Class 1: High Silica
Si>99%

Class 2: High Iron
Fe>99%

Class 3: High Calcium
Ca>99%

Class 4: Hi Titanium, Low Lead
Ti>55%
Pb<5%

Class 5: High Iron and Sulfer
(Fe+S)>95%
S>5%

Class 6: High Iron, Low Aluminum
Fe>65%
Al<1%

Class 7: Low Iron, Moderate Silica, Moderate Aluminum
Fe<1%
30%<Si<50%
35%<Al<60%

Class 8: Low Iron, Moderate Silica, Moderate Aluminum
Fe<1%
40%<Si<60%
20%<Al<35%

Class 9: Low Iron, Low Silica, Low Aluminum, Low Lead, Low Nickel, Low Manganese
Fe<1
4%<Si<20%
4%<Al<20%
Pb<5%
Ni<4%
Mn<4%

Class 10: High Calcium, Low Lead
Ca>80%
Pb<5%

Class 11: High Calcium and Magnesium
(Ca+Mg)>90%

Class 12: High Calcium and Phosphorus
(Ca+Pb)>90%

Class 13: High Silica with Iron, Low Aluminum
Al<1%
Fe>4%
Si>80%

Class 14: High Magnesium, Moderate Silica, Low Aluminum
Mg>40%
Si>25%
Al<1%

Class 15: High Iron, Low Aluminum, Low Lead
Al<1%
Fe>64%
Pb<5%

Class 16: High Iron with Calcium
Fe>40%
(Fe+Ca)>75%

Class 17: Low Potassium, High Silica, Low Aluminum, No Calcium
55%<Si<90%
4%<K<30%
10%<Al<30%
Ca<1%

Class 18: Mod Potassium, Moderate Silica, Moderate Aluminum
4%<K<30%
40%>Si>55%
20%>Al>30%
Ca<1%

Class 19: Mod Potassium, Low Aluminum, Low Silica
4%<K<30%
4%>Si>30%
4%>Al>20%

Class 20: Mod Potassium, Moderate Silica, Moderate Aluminum
4%<K<30%
20%>Si>50%
20%>Al>50%

Class 21: High Calcium, Low Aluminum, Low-Mod Silica and Iron, No Potassium
4%<Si<50%
4%<Al<35%
4%<Ca<80%
K<1%

Class 22: High Silica, Low Aluminum, No Potassium or Calcium
Si>60%
4%<Al<20%
Ca<1%
K<1%

Class 23: Mod-High Silica, Low Aluminum, No Potassium or Calcium
15%<Si<66%
4%<Al<20%
Ca<1%
K<1%

Class 24: Low Silica and Aluminum, No Potassium or Calcium
4%<Si<18%
4%<Al<20%
Ca<1%
K<1%

Class 25: Low-Mod Silica, Low Aluminum, No Potassium or Calcium
20%<Si<35%
20%<Al<35%
Ca<1%
K<1%

Class 26: Moderate Silica, Mod-Low Aluminum, No Potassium or Calcium
40%<Si<60%
18%<Al<40%
Ca<1%
K<1%

Class 27: Moderate Aluminum, Mod-Low Silica, No Potassium or Calcium
20%<Si<60%
40%<Al<60%
Ca<1%
K<1%

Class 28: Low Aluminum
Al<1%

Class 29: Not Class 1-28

The linear sorting algorithm sequentially matches the particle variable information to the specifications of each class until a match is arrived at. If there is no match the particles are put into an “unclassified” category (Class 29), and a different particle type is identified that forms a separate homogenous group, a new class can be formulated and added to the scheme.

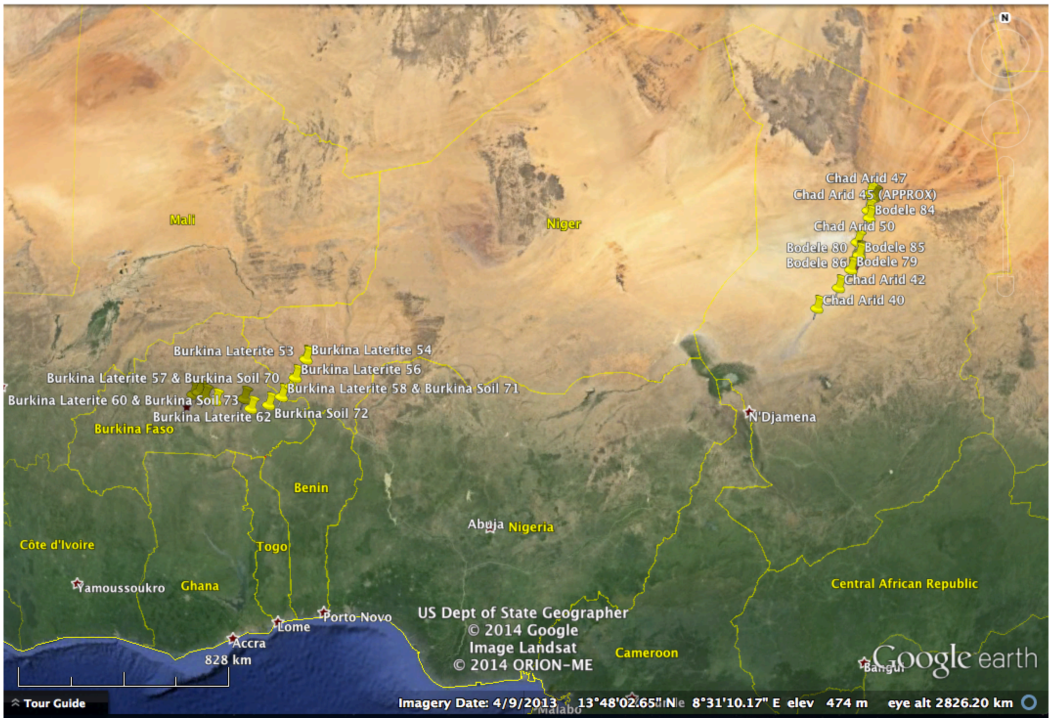

Figure 3-1 Location of African Soil Samples

Once the linear classification scheme is complete, the Euclidean distance was calculated for each particle in order to view the particle distribution from the center of the cluster. The centroid particle of each cluster is calculated, using the Euclidean distance, and subtracted from each of the 4000 CCSEM calculated particles. The chemical distance of each particle is used to view the distribution pattern around the centroid cluster, with the intent of identifying unique patterns of distribution for each sample. Euclidean distance for each category was calculated using the standard Euclidean distance formula (Equation 1).

Equation 1: Euclidean Distance Equation, where q represents each individual element in each particle and p represents the average elemental amount for each of the classes and clusters.

$$\sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + \cdots + (q_n - p_n)^2} = \sqrt{\sum_{i=1}^{n} (q_i - p_i)^2}.$$

Following the chemical/elemental analysis of each sample, each particle within each respective class is analyzed for size (Equation 2).

Equation 2: Equations for radius and diameter where A is equivalent to the area and R is equal to radius.

$$radius = \sqrt{\frac{A}{\pi}}$$

$$\mathrm{diameter} = 2R$$

This equation was used to calculate the diameter for each sample in order to determine the particles ability to transport. Not all of the particles analyzed for size were round in shape. By using the area supplied by the SEM, the assumption that all the samples were relatively round was used in the calculations. This assumption should be accurate as the area is the same regardless of shape. Four categories were then created to classify each of the particles:

1. <2.5 μm diameter
2. 2.5-5 μm diameter
3. 5-10 μm diameter
4. >10 μm diameter

Each of these categories represents different outcomes for each particle. A diameter less than 2.5 μm suggests that it is easily aerosolized and transported long distances, 2.5-5 μm can be transported through the atmosphere long distances, the particles between 5 and 10 μm are those that do not participate in long-range transport, but are able to travel short distances.

Once the chemical/elemental analysis has been completed and analyzed for size, each of the samples are then compared to one another to determine if there are distinguishing characteristics for each location in both the Saharan and Sahel region of North Africa. These distinguishing characteristics will then be used as a baseline for future research on the long-range transport of aerosolized dust, the chemical reactions that take place in the atmosphere, and the specific amount of dust that is traveling across the Atlantic Ocean. Initial readings of current research shows that African dusts are found as far north as North Carolina, USA and as far south as the Amazon River Basin in South America.

Chapter 4

Objectives and Expected Outcomes

The objective of this research is to characterize and quantify the chemical composition and size of African soils that originate in the Sahel and Saharan regions of North Africa. Data has been collected and analyzed on 29 samples from the Sahel and Saharan region of North Africa. These samples were logged as:

1. Bodele 79
2. Bodele 80
3. Bodele 82
4. Bodele 83
5. Bodele 84
6. Bodele 85
7. Bodele 86
8. Burkina Laterite 53
9. Burkina Laterite 54
10. Burkina Laterite 56
11. Burkina Laterite 57
12. Burkina Laterite 58
13. Burkina Laterite 60
14. Burkina Laterite 61
15. Burkina Laterite 62
16. Burkina Laterite 63
17. Burkina Soil 70
18. Burkina Soil 71
19. Burkina Soil 72
20. Burkina Soil 73

21. Burkina Soil 76
22. Burkina Soil 77
23. Burkina Soil 78
24. Chad Arid 40
25. Chad Arid 42
26. Chad Arid 45
27. Chad Arid 47
28. Chad Arid 48
29. Chad Arid 50

The Bodele samples derive from the Bodele Depression in North Africa, which in the past was an inland fresh body of water and seems to be composed primarily of Siliceous Diatoms. The Burkina Soils and Laterites originate from the Burkina Faso region of Africa, are primarily composed of Si, Al and Fe with varying amounts of Ca, Ti and K. While similarities exist among both the Laterites and the Soils, the smaller elemental compositions differ enough to hypothesize that some mixing is occurring though Aeolian processes but each sample derives from a different origin. The Chad Arid Samples derive from the Chad region of Africa and primarily consist of Silica, Aluminum, Iron and Potassium.

Chapter 5

Methods of Analysis

The objective of this research is to characterize and quantify the chemical composition and size of African soils that originate in the Sahel and Saharan Desert in order to identify unique characteristics of each particular area. In order to facilitate identification of the soil samples, the provided samples are organized by regions, Bodele, Burkina Faso, and Chad. Each regional sample is then subdivided into individual samples that identify the chemical analysis, particle volume, Euclidean distance, and size of particles. A summary is then stated about the specific region that combines the information from the individual samples. To conclude the research, a conclusion was added that identifies the unique characteristics of each of the regions.

Bodele Depression

The Bodele Depression in Africa (Figure 5-1) is a vast basin that, in the past, was a massive freshwater lake (Lovett, 2010). Over the last few thousand years the freshwater lake, Mega-Lake Chad, receded to its current location in the southwest corner of Chad. Increased desertification of the Sahel, coupled with increasing need for water, caused the freshwater lake to dry, leaving behind lakebed silts and sediments. These small sediments primarily consist of small siliceous diatoms that are easily lifted into the atmosphere and can stay aloft for years and travel thousands of miles before deposition (NASA, 2004). Bodele is thought to be one of the dustiest places on earth and, therefore, one of the largest contributing areas to dust that is spread across the Atlantic Ocean (Lovett, 2010).

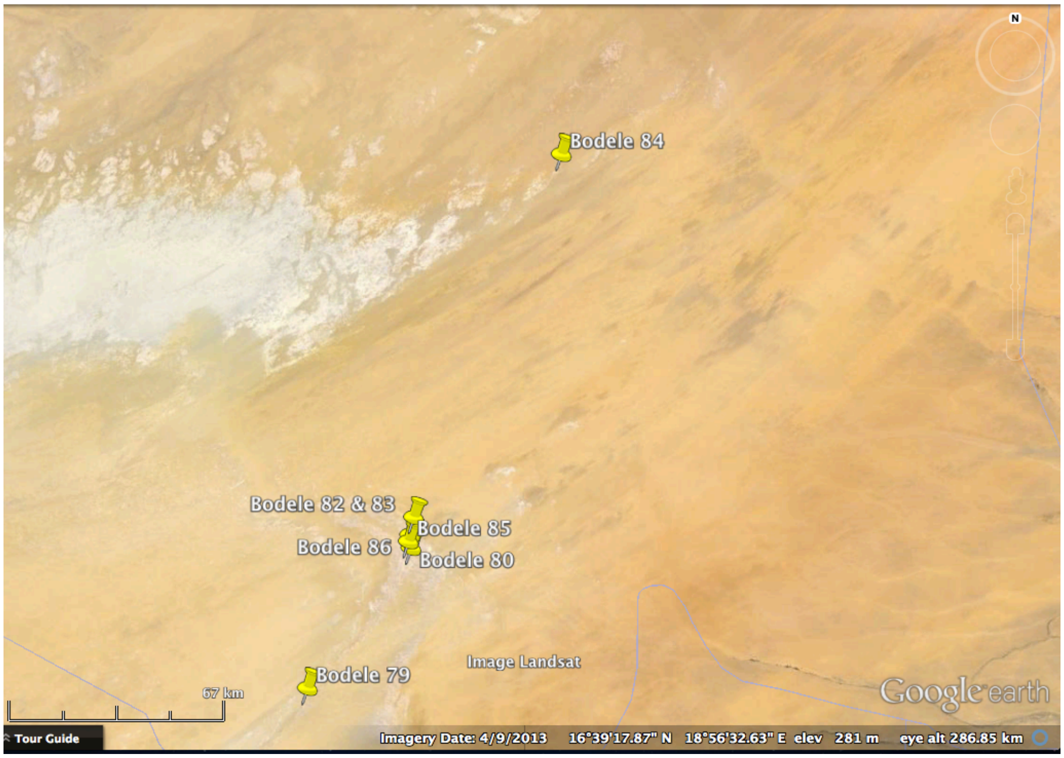

Figure 5-1: Bodele Depression

In 2005, the Bodele Dust Experiment (BoDEx 2005), measured surface and near-surface winds, dust concentrations, and albedo of the area. The wind patterns and turbulence were mapped for the first time to show that winds peaked during certain times of the day and intense heating from the sun induces turbulent winds in the lowest layers (Washington, et al., 2005). This experiment conclude that wind stress, maximum dust output, and the Bodele Depression are all collocated, the Tibesti and Ennedi Mountains play a key role in the increase in low-level wind jets, and enhanced deflation from low-level jets may have created the depression necessary to generate erodible diatoms (Prospero, 2002).

Bodele 79

Numerical and Volumetric Analysis

Bodele 79, located at 15 44.617' N,18 17.881' E, in the Bodele Depression was elementally separated into 29 separate classes (Figure 5-2).

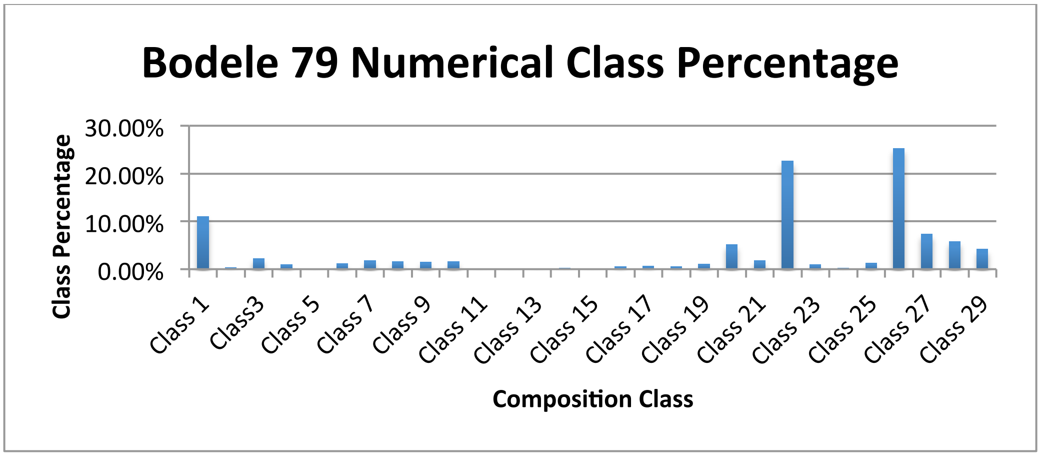

Figure 5-2: Bodele 79 Numerical Classes

The numerical percentage shows the number of Particles in each class, and the percentage those classes represent to the entire sample (Table 5-1).

Table 5-1: Numerical Percentage

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
394	13	81	33	5	41	64	57
11.01%	0.36%	2.26%	0.92%	0.14%	1.15%	1.79%	1.59%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
52	56	0.00	0.00	5.00	7.00	0.00	18.00
1.45%	1.57%	0.00%	0.00%	0.14%	0.20%	0.00%	0.50%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
22.00	19.00	40	184	64	808	34	10
0.62%	0.53%	1.12%	5.14%	1.79%	22.59%	0.95%	0.28%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
46	905	262	208	149	3577		
1.29%	25.30%	7.32%	5.81%	4.17%	100.00%		

Table 5-1 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 1, 22, and 26. Class 1 is composed of greater than 99% silica. Class 22 is composed of less than 1% Potassium and Calcium, between 4% and 20% Aluminum, and greater than 60% Silica. Class 26 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. This represents

58.9% of the entire sample and contains a total of 2107 particles. Class 29 represents the "unclassified" particles and contains only 4.17% of the entire sample.

Similar to the numerical percentage, the volume of every class was calculated to analyze the percentage of volume for each class (Figure 5-3). The volumetric percentage of Bodele 79 represents the volume of particles that are represented in each respective elemental class (Table 5-2).

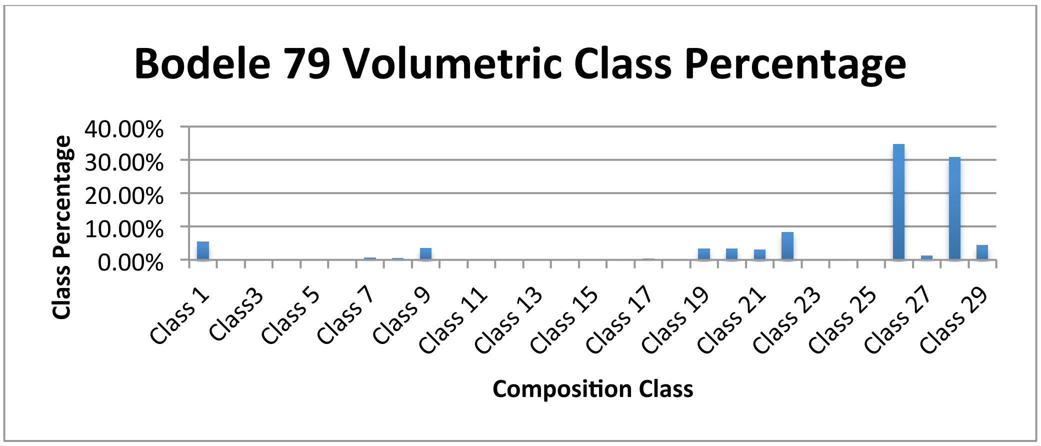

Figure 5-3: Bodele 79 Volumetric Percentage

Table 5-2: Bodele 79

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
12744.25	1.93	181.39	5.04	0.12	154.13	1487.85	991.75
5.37%	0.00%	0.08%	0.00%	0.00%	0.06%	0.63%	0.42%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
8337.38	269.54	0.00	0.00	34.81	251.18	0.00	51.05
3.51%	0.11%	0.00%	0.00%	0.01%	0.11%	0.00%	0.02%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
768.01	88.75	8029.10	7954.73	7238.72	19693.74	105.71	73.30
0.32%	0.04%	3.38%	3.35%	3.05%	8.30%	0.04%	0.03%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
192.16	82338.90	3006.24	73052.18	10281.09	237333.05		
0.08%	34.69%	1.27%	30.78%	4.33%	100.00%		

Figure 5-5 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 22, 23, and 26. Class 22 is composed of less than 1% Potassium and Calcium, between 4% and 20% Aluminum, and greater than 60% Silica. Class 23 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and between 15% and 66% Silica. Class 26 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. This represents 73.77% of the entire sample and contains a total volume of 175084.81μm^3. Class 29 represents the "unclassified" volume of particles and contains 4.33% of the entire sample.

Class 29 represents those particles that do not fall into any of the other 28 elemental classes. A separate analysis was conducted on Bodele sample 79 in order to verify that the particles contained within class 29 should not be attached to another class of particles. Analysis showed the number and volume of particles contained within class 29, 4.17% and 4.33% respectively, are particles that have an even distribution of elements. The highest percentage of element in any of the particles in class 29 is Si, Al and Fe, with small amounts of Ca (Figure 5-4 and Figure 5-5). These particles are relatively evenly represented within the respective category and no additional classes were necessary for Bodele sample 79.

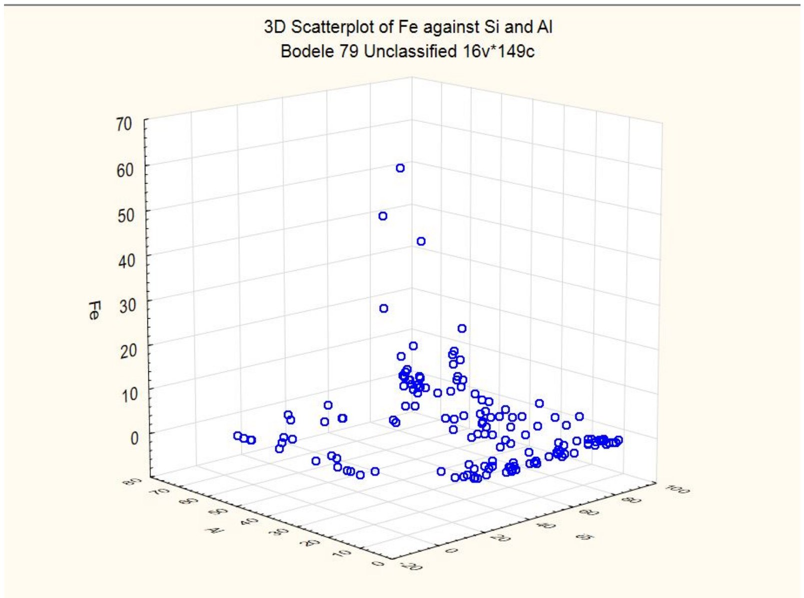

Figure 5-4: Scatterplot of Bodele 79 Unclassified

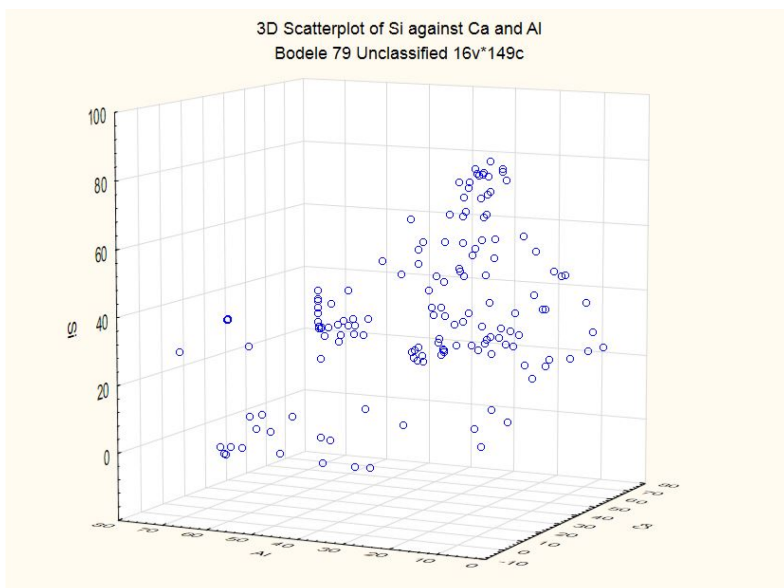

Figure 5-5: Scatterplot of Bodele 79 Unclassified

Euclidean Distance

The Euclidean Distance for Class 1 of Bodele 79 is composed of greater than 99% Silica. There are a total of 394 particles in this class (Image 5-6).

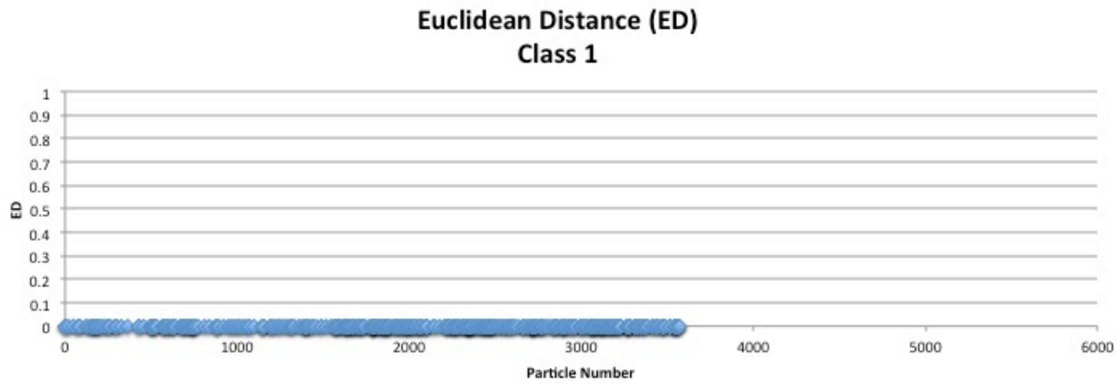

Figure 5-6: Euclidean Distance Class 1

Class 2 of Bodele 79 is composed of greater than 99% Iron. There are a total of 13 particles in this class (Image 5-7).

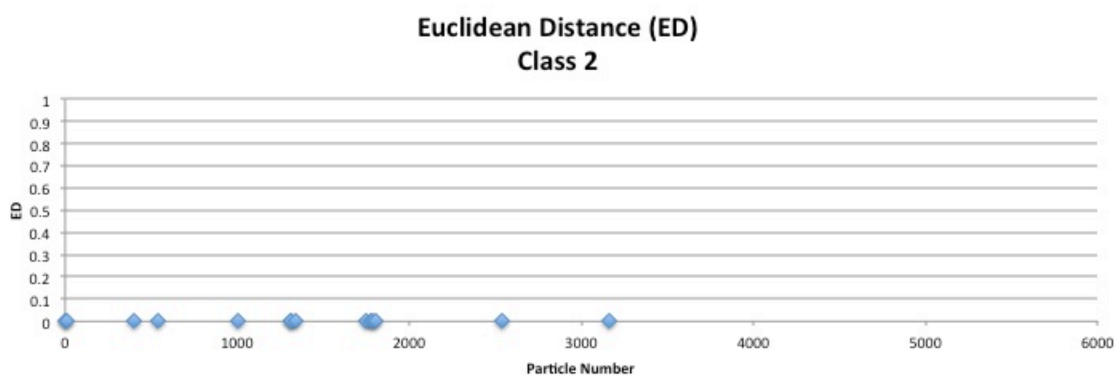

Figure 5-7: Euclidean Distance Class 2

Class 3 of Bodele 79 is composed of greater than 99% Calcium. There are a total of 81 particles in this class (Image 5-8).

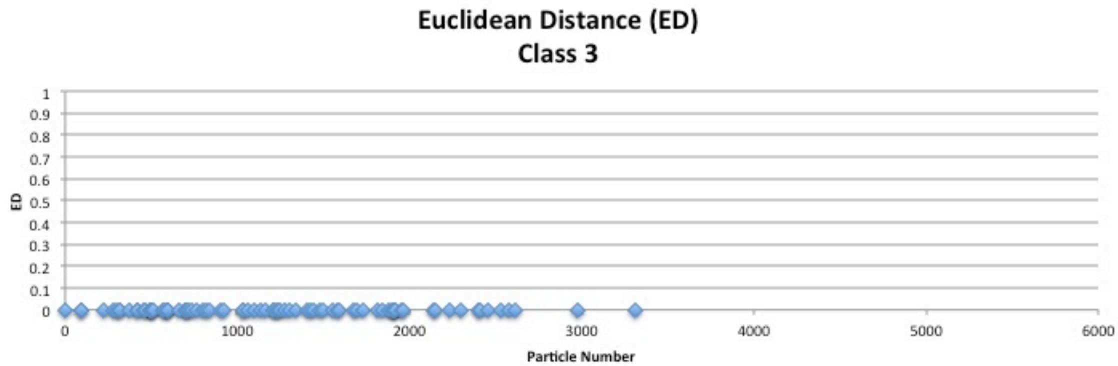

Figure 5-8: Euclidean Distance Class 3

Class 4 of Bodele 79 is composed of Titanium greater than 55% and Lead less than 5%. There are a total of 33 particles in this class (Image 5-9).

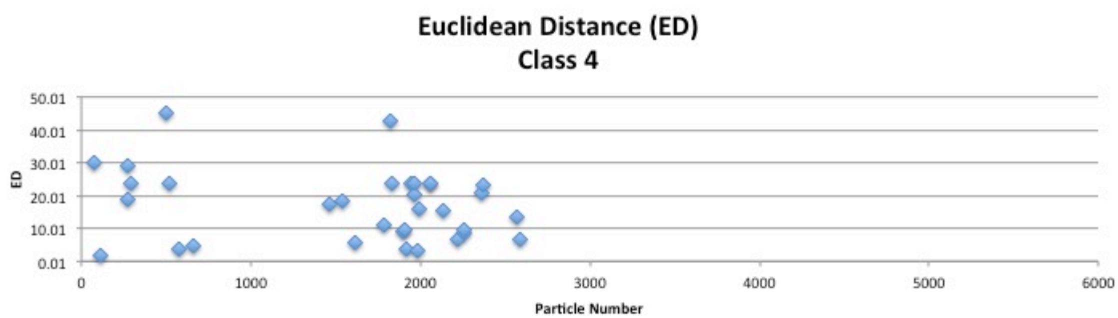

Figure 5-9: Euclidean Distance Class 4

Class 5 of Bodele 79 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are a total of 5 particles in this class (Figure 5-10).

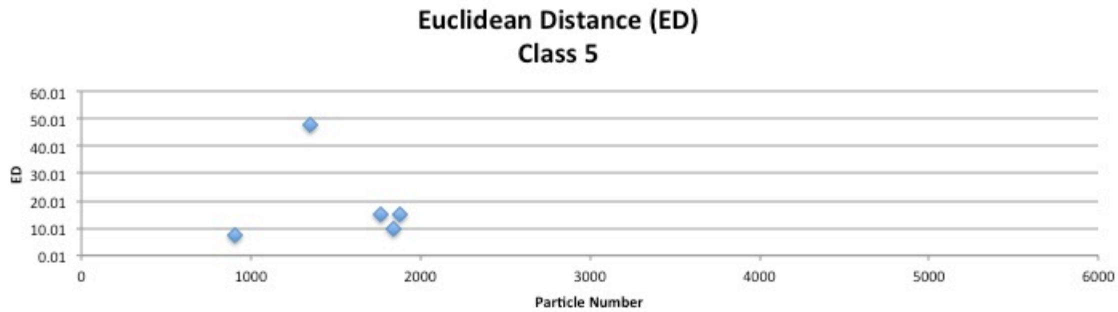

Figure 5-10: Euclidean Distance Class 5

Class 6 of Bodele 79 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 41 particles in this class (Image 5-11).

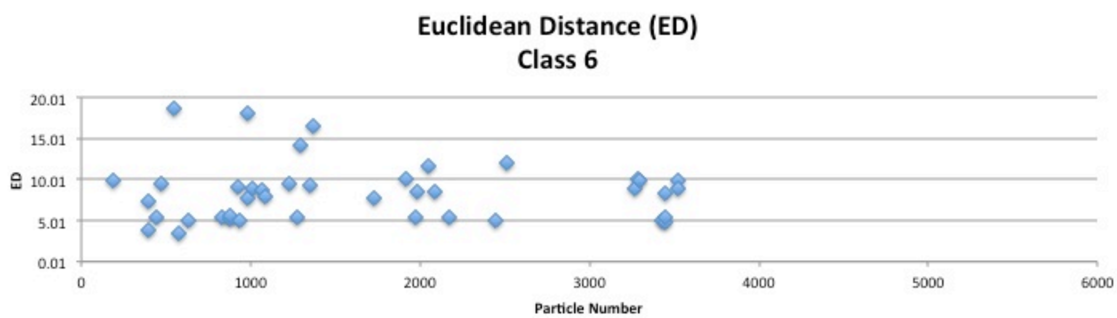

Figure 5-11: Euclidean Distance Class 6

Class 7 of Bodele 79 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 64 particles in this class (Figure 5-12).

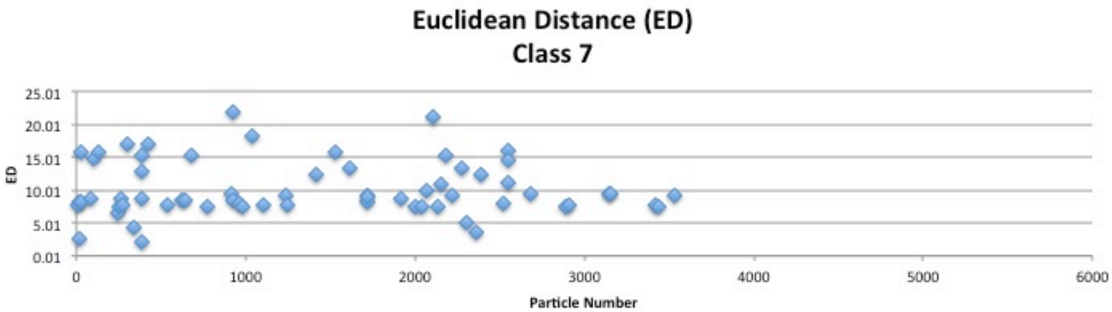

Figure 5-12: Euclidean Distance Class 7

Class 8 of Bodele 79 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 57 particles in this class (Image 5-13).

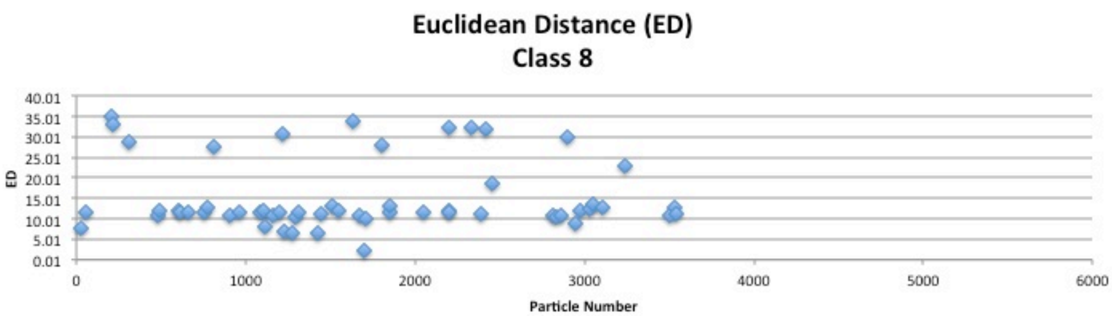

Figure 5-13: Euclidean Distance Class 8

Class 9 of Bodele 79 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are a total of 52 particles in this class (Image 5-14).

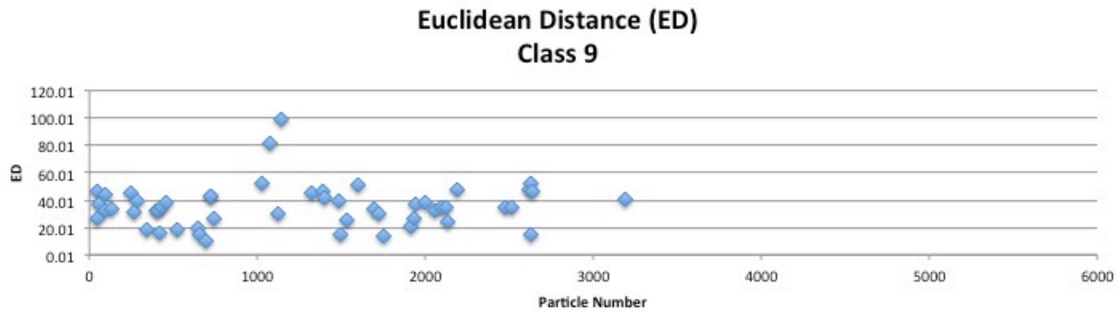

Figure 5-14: Euclidean Distance Class 9

Class 10 of Bodele 79 is composed of Calcium greater than 80% and Lead less than 5%. There are a total of 56 particles in this class (Image 5-15).

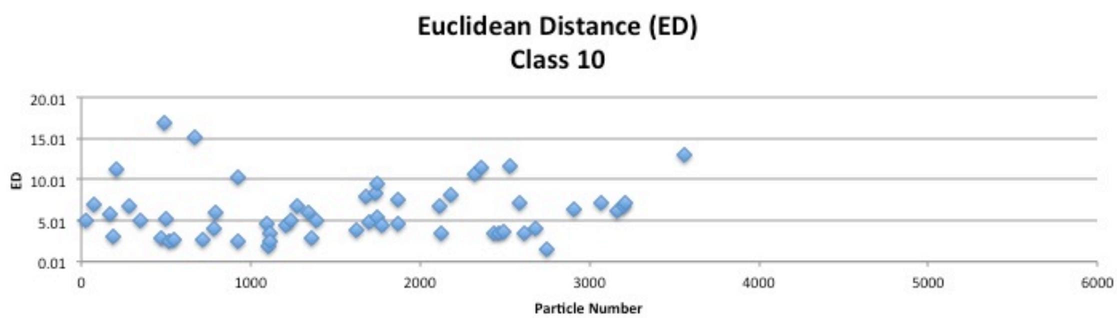

Figure 5-15: Euclidean Distance Class 10

Class 11 of Bodele 79 is composed of the total Calcium and Manganese greater than 90%. There are no particles in this class.

Class 12 of Bodele 79 is composed of the total Calcium and Phosphorus greater than 90%. There are no particles in this class.

Class 13 of Bodele 79 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are a total of 5 particles in this class (Figure 5-16).

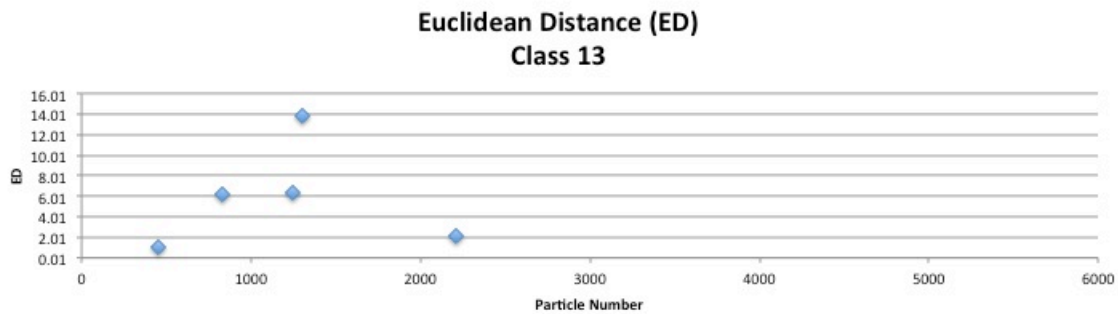

Figure 5-16: Euclidean Distance Class 13

Class 14 of Bodele 79 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are a total of 7 particles in this class (Image 5-17).

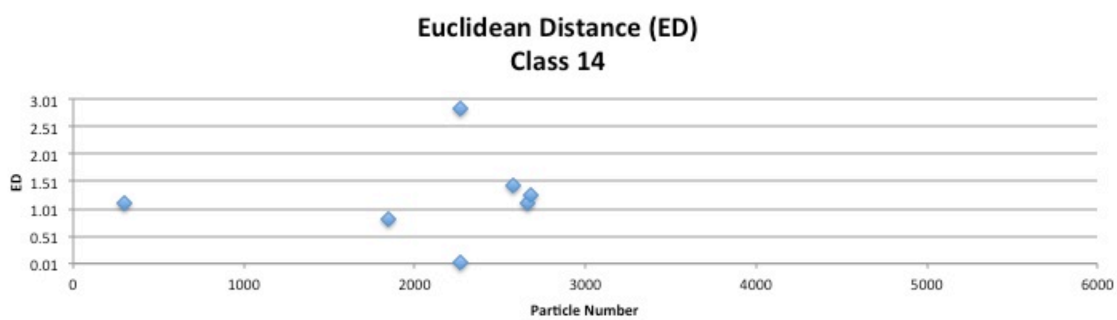

Figure 5-17: Euclidean Distance Class 14

Class 15 of Bodele 79 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Bodele 79 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are a total of 18 particles in this class (Figure 5-18).

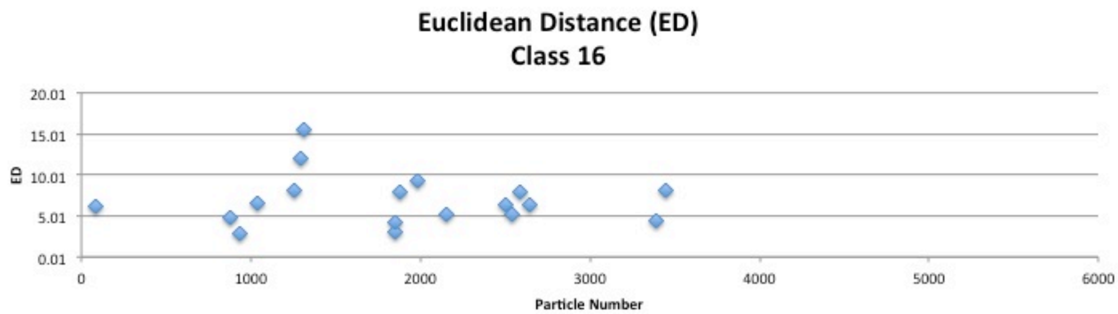

Figure 5-18: Euclidean Distance Class 16

Class 17 of Bodele 79 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 22 particles in this class (Figure 5-19).

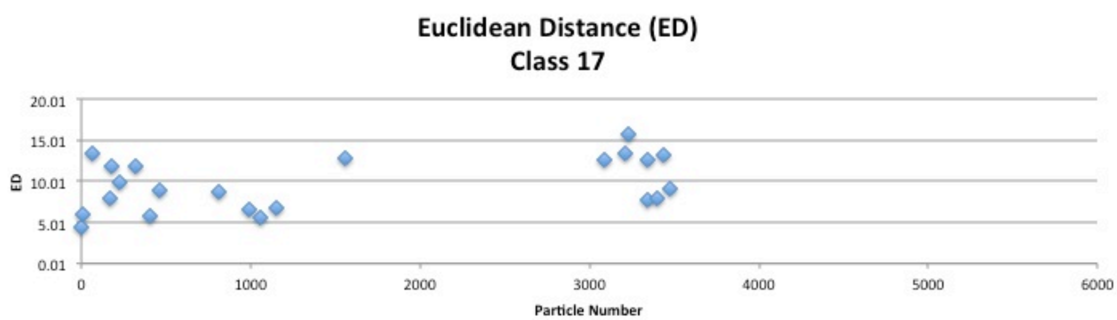

Figure 5-19: Euclidean Distance Class 17

Class 18 of Bodele 79 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 19 particles in this class (Figure 5-20).

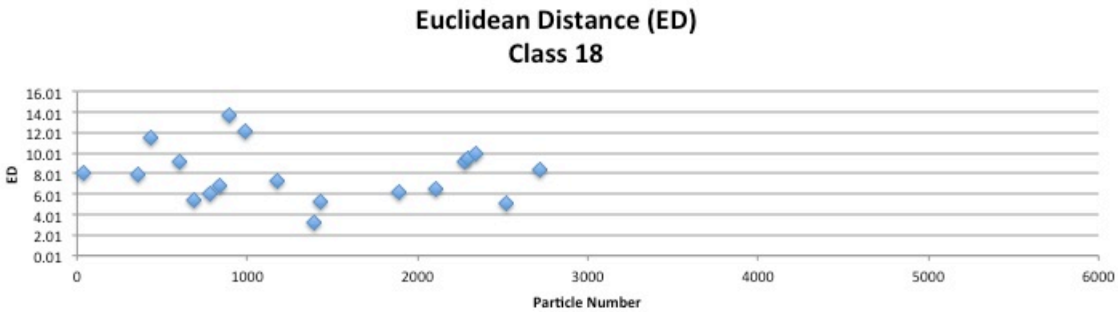

Figure 5-20: Euclidean Distance Class 18

Class 19 of Bodele 79 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 40 particles in this class (Figure 5-21).

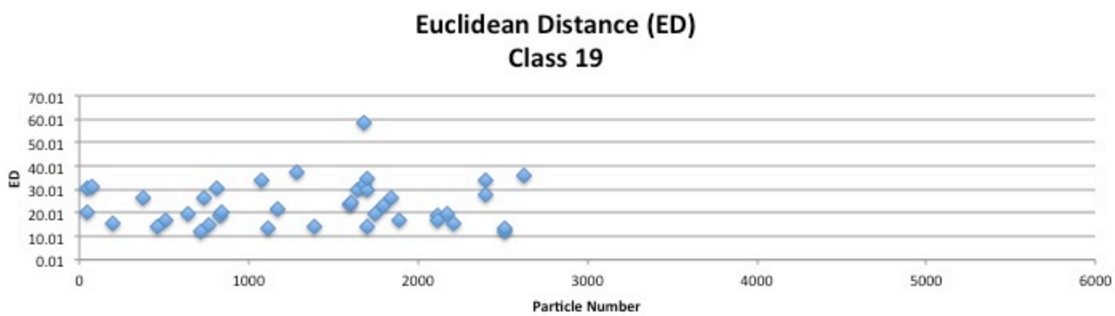

Figure 5-21: Euclidean Distance Class 19

Class 20 of Bodele 79 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 123 particles in this class (Figure 5-22).

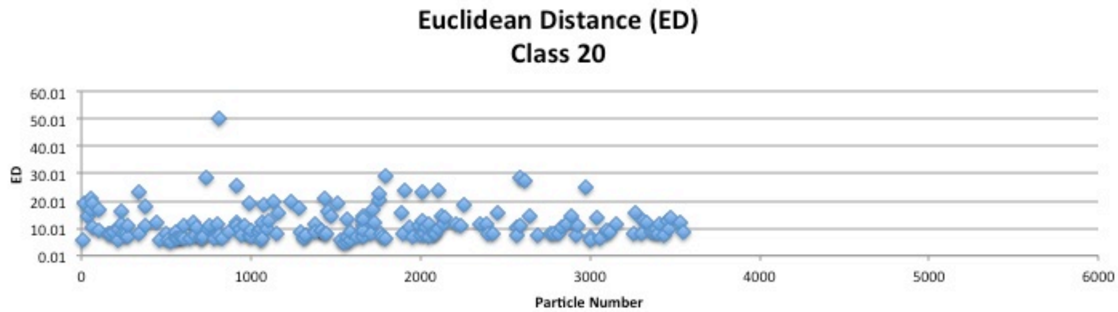

Figure 5-22: Euclidean Distance Class 20

Class 21 of Bodele 79 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 64 particles in this class (Figure 5-23).

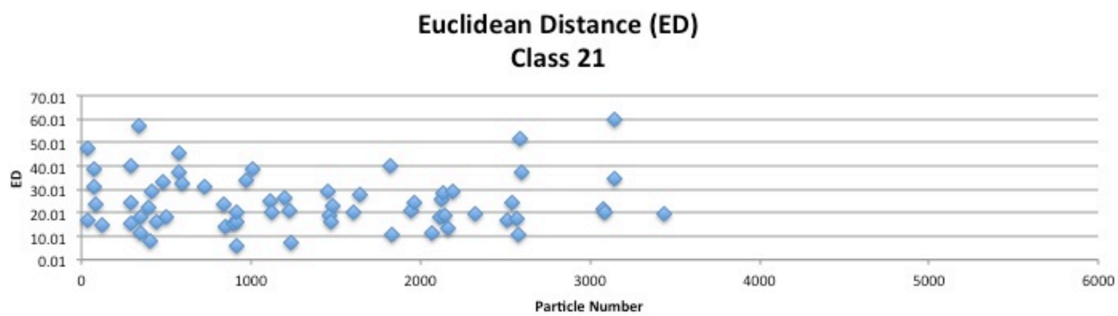

Figure 5-23: Euclidean Distance Class 21

Class 22 of Bodele 79 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 808 particles in this class (Figure 5-24).

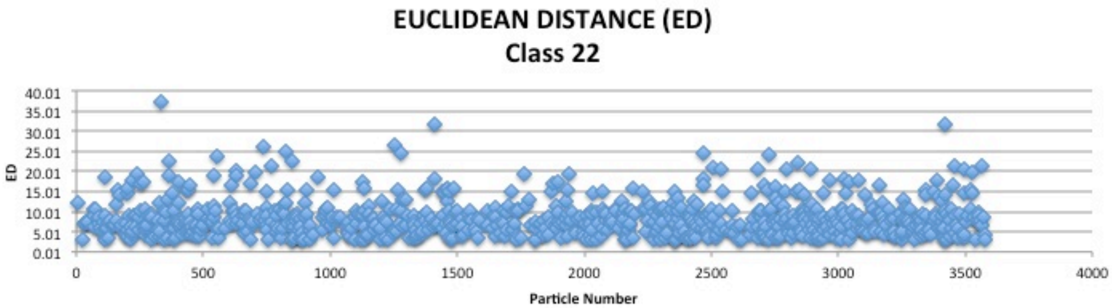

Figure 5-24: Euclidean Distance Class 22

Class 23 of Bodele 79 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 34 particles in this class (Figure 5-25).

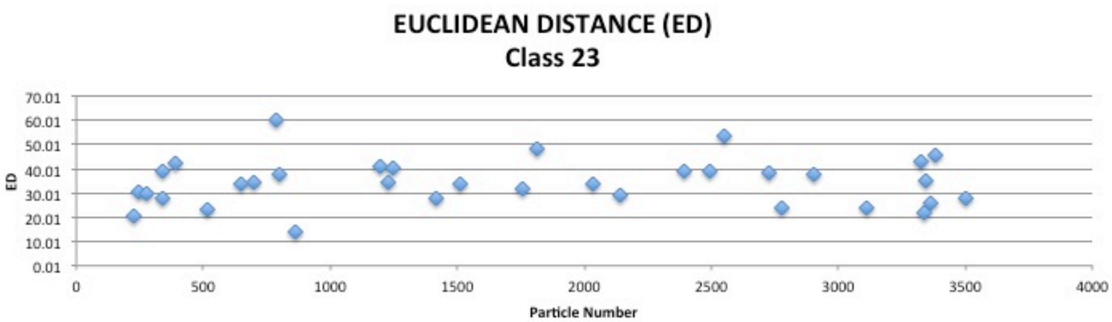

Figure 5-25: Euclidean Distance Class 23

Class 24 of Bodele 79 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 10 particles in this class (Figure 5-26).

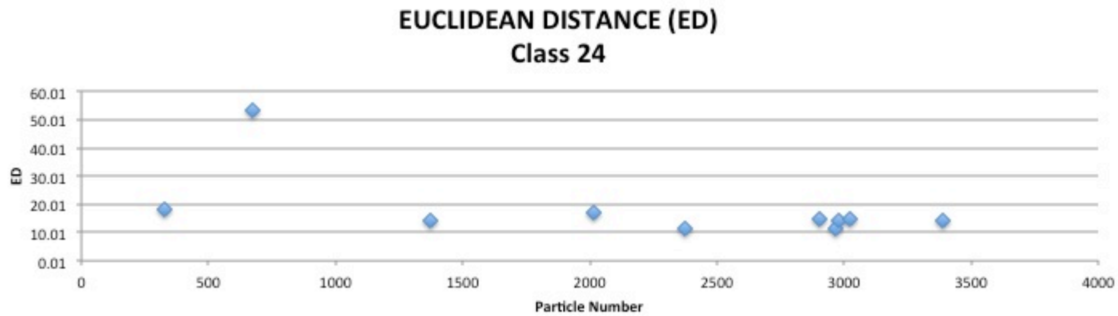

Figure 5-26: Euclidean Distance Class 24

Class 25 of Bodele 79 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 46 particles in this class (Figure 5-27).

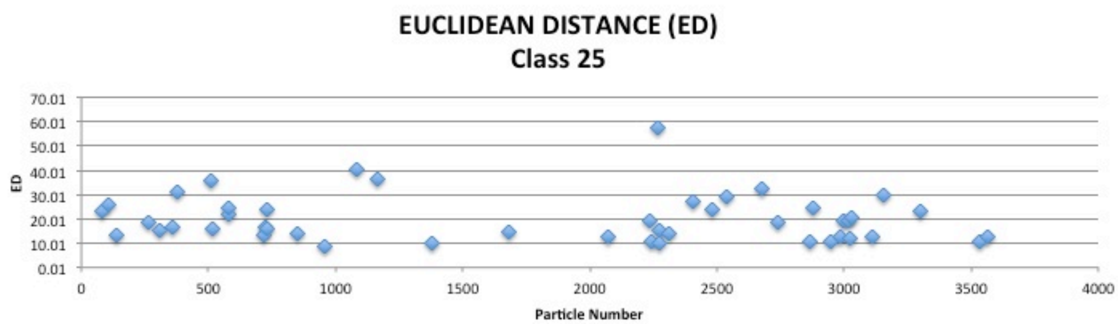

Figure 5-27: Euclidean Distance Class 25

Class 26 of Bodele 79 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 905 particles in this class (Figure 5-28).

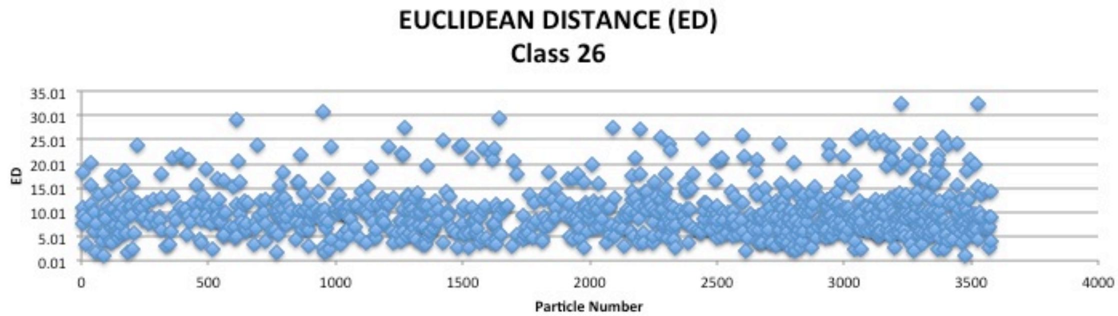

Figure 5-28: Euclidean Distance Class 26

Class 27 of Bodele 79 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 262 particles in this class (Figure 5-29).

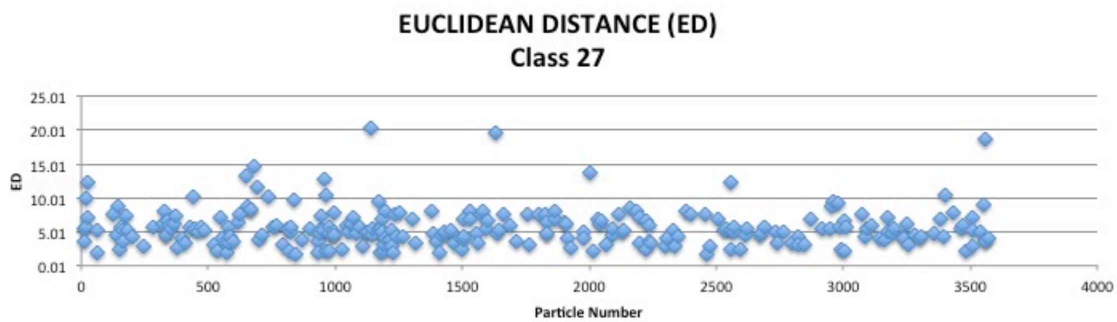

Figure 5-29: Euclidean Distance Class 27

Class 28 of Bodele 79 is composed of Aluminum less than 1%. There are a total of 208 particles in this class (Figure 5-30).

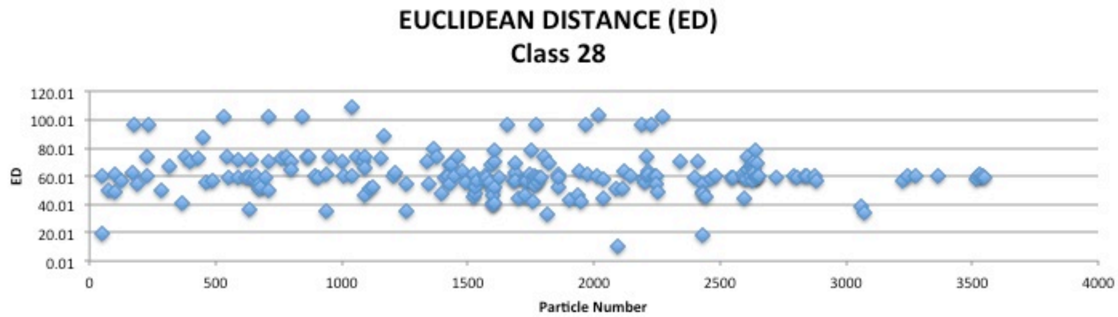

Figure 5-30: Euclidean Distance Class 28

Bodele 80

Numerical and Volumetric Analysis

Bodele 80, located at 16 08.139' N, 18 35.930' E, in the Bodele Depression was elementally separated into 29 separate classes (Figure 5-31).

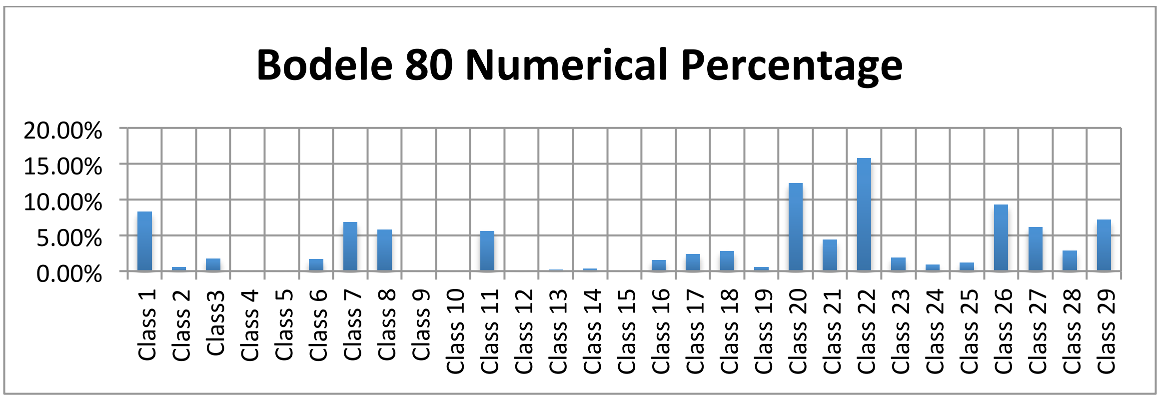

Figure 5-31: Bodele 80 Numerical Classes

The numerical percentage shows the number of Particles in each class, and the percentage those particles represent to the entire class (Table 5-3).

Table 5-3: Numerical Percentage

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
286	18	61	0	0	57	236	200
8.28%	0.52%	1.77%	0.00%	0.00%	1.65%	6.83%	5.79%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	193	3	7	11	0	53
0.00%	0.00%	5.59%	0.09%	0.20%	0.32%	0.00%	1.53%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
81	96	20	423	151	545	65	30
2.34%	2.78%	0.58%	12.24%	4.37%	15.77%	1.88%	0.87%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
41	321	211	99	247	3455		
1.19%	9.29%	6.11%	2.87%	7.15%	100.00%		

Table 5-3 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 20, 22, and 26. Class 20 is composed of between 4% and 30% Potassium, between 20% and 50% Aluminum, and between 20% and 50% Silica. Class 22 is composed of less than 1% Potassium and Calcium, between 4% and 20% Aluminum, and greater than 60% Silica. Class 26 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. This represents 37.3% of the entire sample and contains a total of 1289 particles. Class 29 represents the “unclassified” particles and contains only 7.15% of the entire sample. Most of these samples have either even distribution of elements or contain unreliable data due to low particle counts.

Similar to the numerical percentage, the volume of every class was calculated to analyze the percentage of volume for each class (Figure 5-32). The volumetric percentage of Bodele 80 represents the volume of particles that are represented in each respective elemental class (Table 5-4).

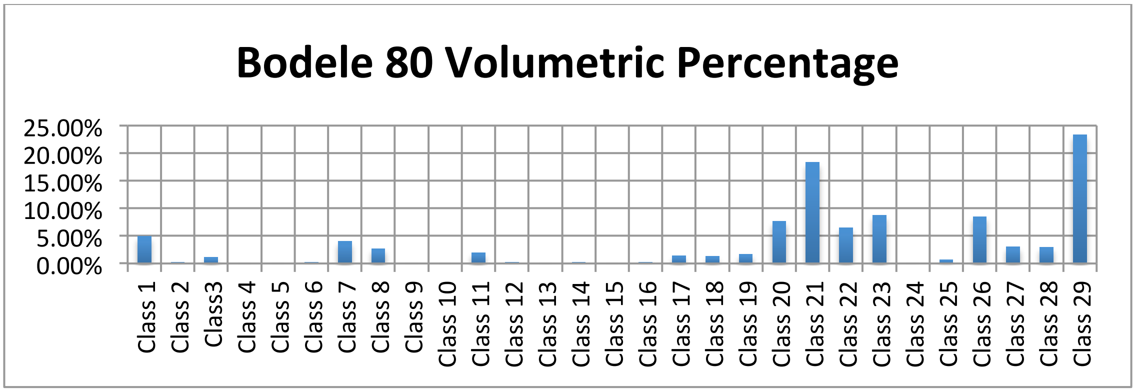

Figure 5-32: Volumetric Classes

Table 5-4: Graph of Bodele 80 Volumetric Percentages

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
12306.66	568.42	2782.34	0.00	0.00	471.35	10144.01	6744.02
4.89%	0.23%	1.11%	0.00%	0.00%	0.19%	4.03%	2.68%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	4948.76	465.84	20.90	526.26	0.00	645.55
0.00%	0.00%	1.97%	0.19%	0.01%	0.21%	0.00%	0.26%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
3565.32	3206.60	4298.72	19164.33	46138.77	16382.81	22060.54	164.36
1.42%	1.28%	1.71%	7.62%	18.35%	6.51%	8.77%	0.07%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
1647.26	21365.51	7610.30	7469.02	58787.96	251485.61		
0.66%	8.50%	3.03%	2.97%	23.38%	100.00%		

Table 5-4 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 21, 23, and 26. Class 21 is composed of between 4% and 80% Calcium, Potassium less than 1%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. Class 23 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. Class 26 is composed of less than 1% Calcium and Potassium, between 18% and 40% Aluminum, and between 40% and 60% Silica. This represents 35.62% of the entire sample and contains a total volume of 251485.61µm. Class 29 represents the “unclassified” volume of particles and contains 23.38% of the entire sample.

Analysis of class 29 showed no significant clusters of elements. The highest elements contained within Bodele 80 are Fe, Si, Al and Ca. These elements are relatively evenly distributed across the elements (Figure 5-33 and Figure 5-34). There are no significant clusters of particles to add additional classes to this sample.

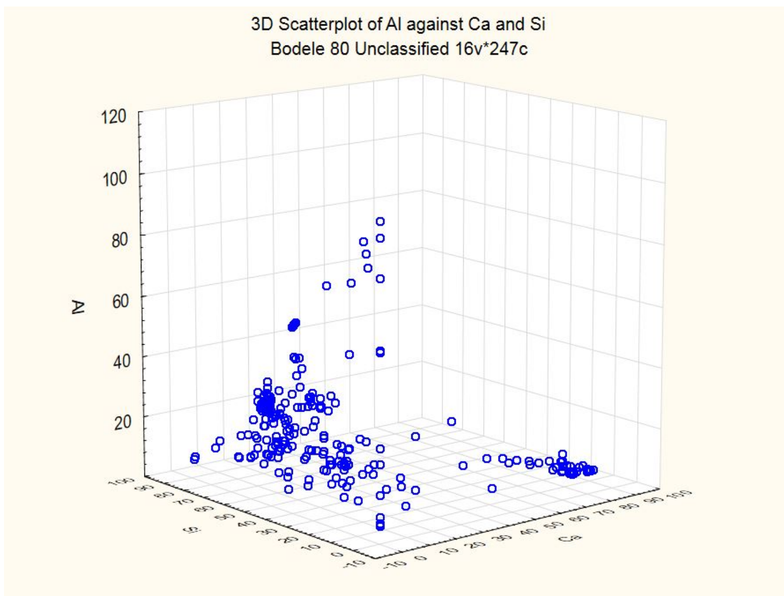

Figure 5-33: Scatterplot of Bodele 80 Unclassified

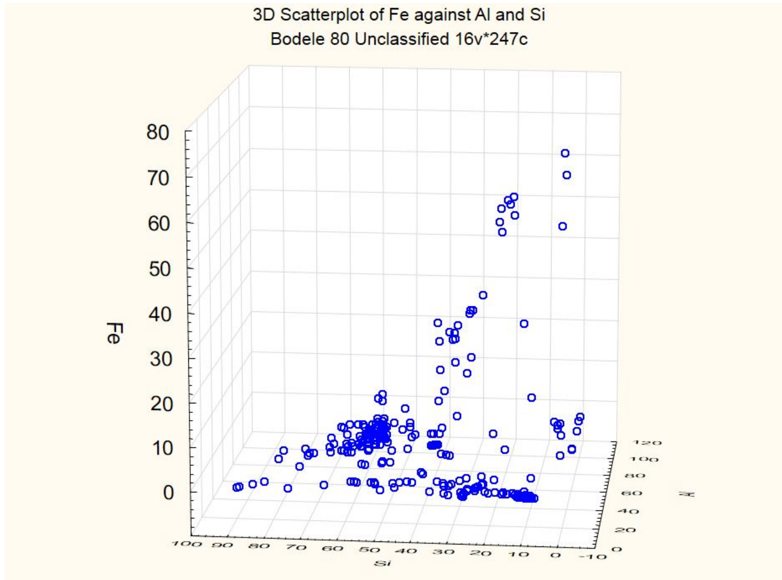

Figure 5-34: Scatterplot of Bodele 80 Unclassified

Euclidean Distance

The Euclidean Distance for Class 1 of Bodele 80 is composed of greater than 99% Silica. There are a total of 286 particles in this class (Image 5-35).

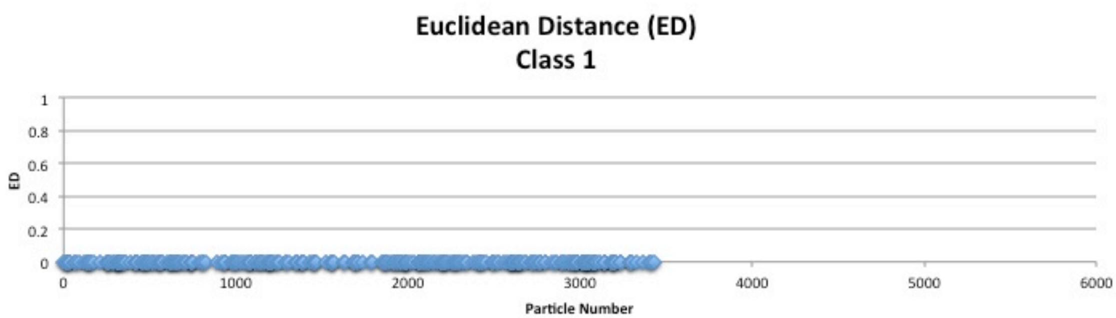

Figure 5-35: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 18 particles in this class (Figure 5-36).

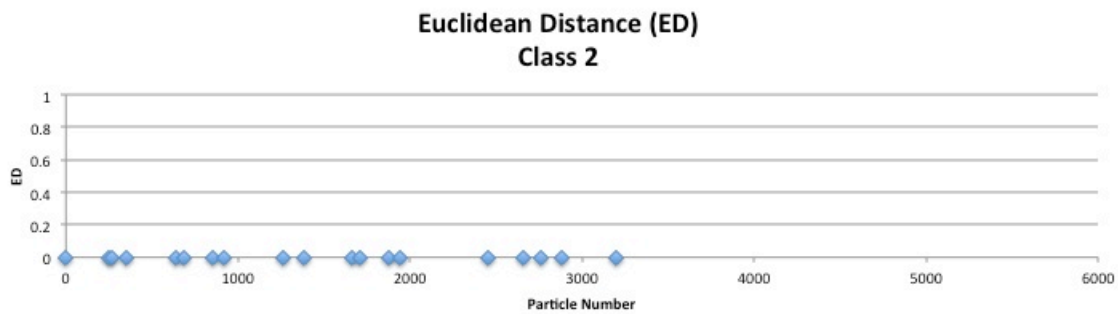

Figure 5-36: Euclidean Distance Class 2

Class 3 of Bodele 80 is composed of greater than 99% Calcium. There are a total of 61 particles in this class (Figure 5-37).

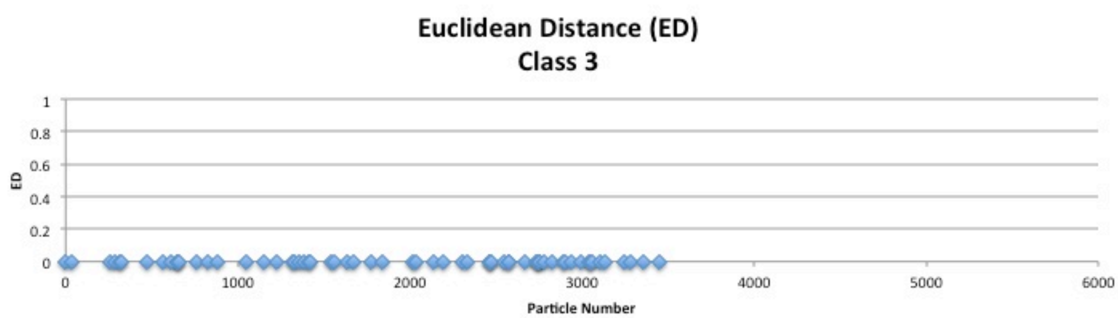

Figure 5-37: Euclidean Distance Class 3

Class 4 of Bodele 80 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Bodele 80 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Bodele 80 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 57 particles in this class (Figure 5-38).

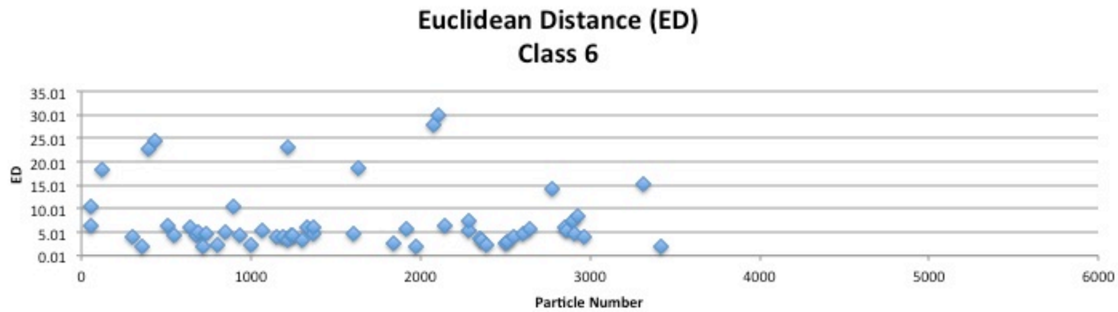

Figure 5-38: Euclidean Distance Class 6

Class 7 of Bodele 80 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 236 particles in this class (Figure 5-39).

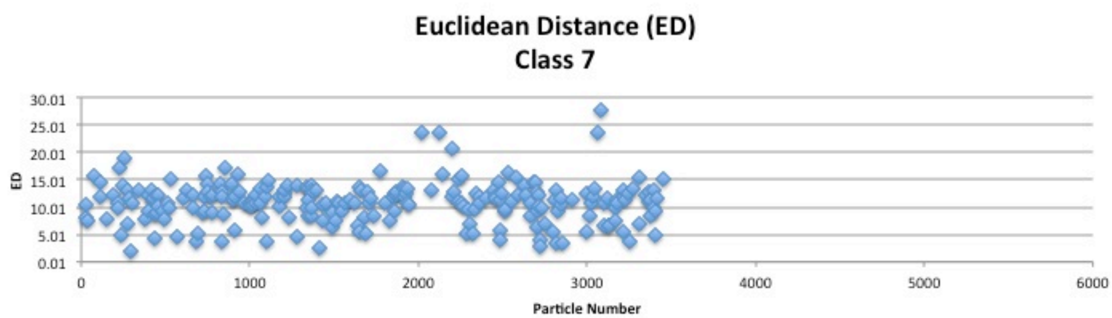

Figure 5-39: Euclidean Distance Class 7

Class 8 of Bodele 80 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 200 particles in this class (Figure 5-40).

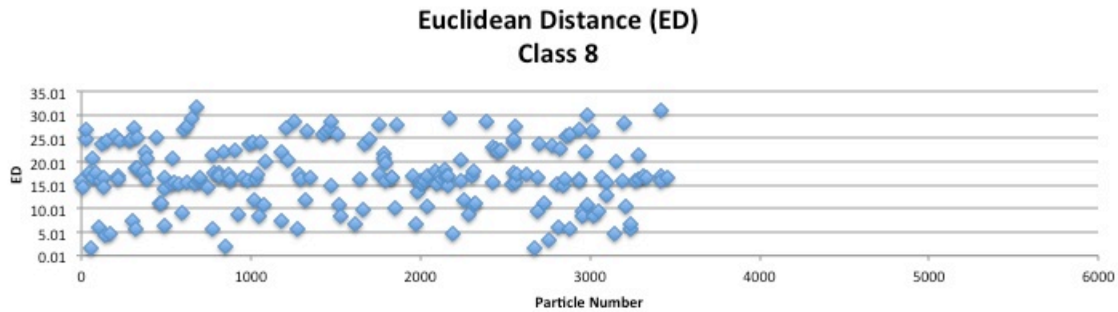

Figure 5-40: Euclidean Distance Class 8

Class 9 of Bodele 80 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Bodele 80 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Bodele 80 is composed of the total Calcium and Manganese greater than 90%. There are 193 particles in this class (Figure 5-41).

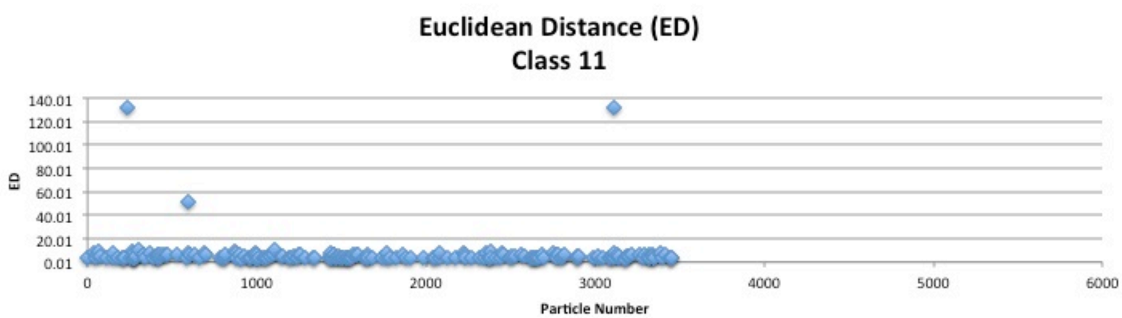

Figure 5-41: Euclidean Distance Class 11

Class 12 of Bodele 80 is composed of the total Calcium and Phosphorus greater than 90%. There are 3 particles in this class (Figure 5-42).

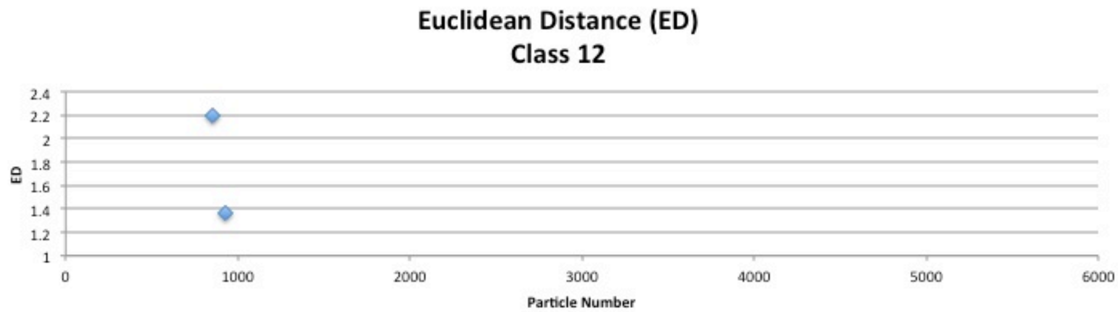

Figure 5-42: Euclidean Distance Class 12

Class 13 of Bodele 80 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are a total of 7 particles in this class (Figure 5-43).

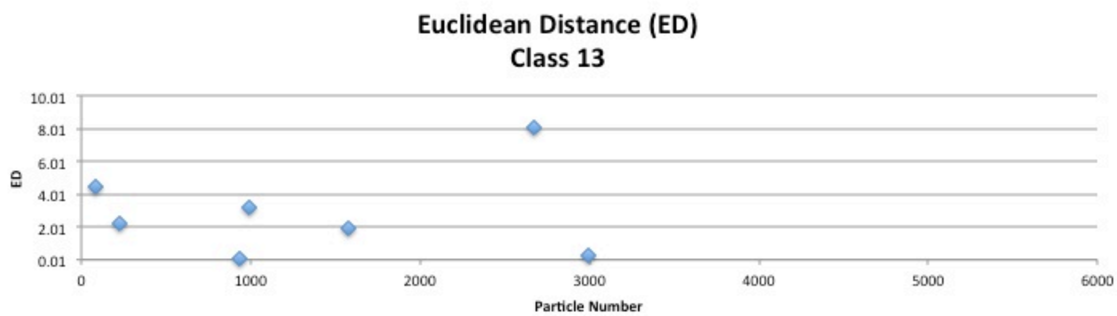

Figure 5-43: Euclidean Distance Class 13

Class 14 of Bodele 80 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are a total of 11 particles in this class (Figure 5-44).

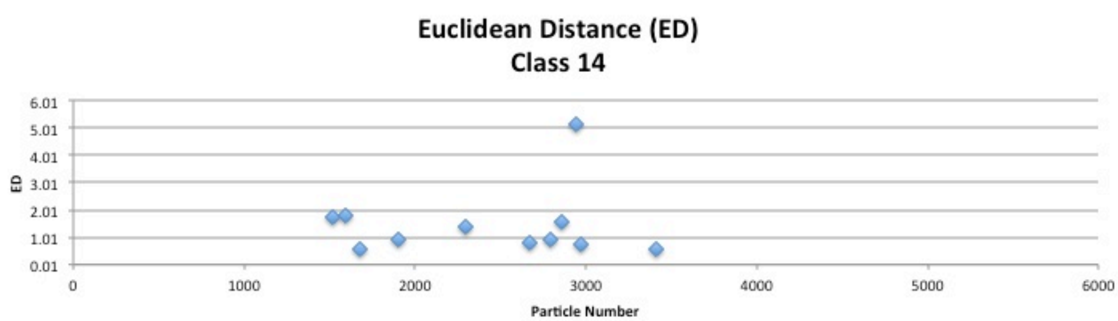

Figure 5-44: Euclidean Distance Class 14

Class 15 of Bodele 80 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Bodele 80 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are a total of 53 particles in this class (Figure 5-45).

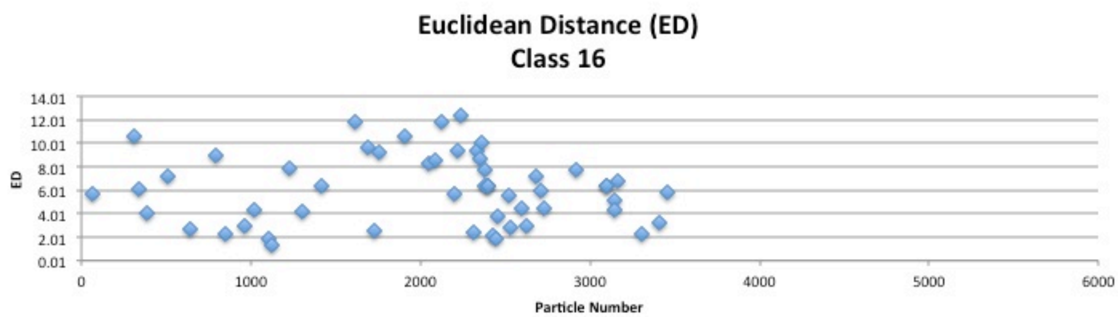

Figure 5-45: Euclidean Distance Class 16

Class 17 of Bodele 80 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 22 particles in this class (Figure 5-46).

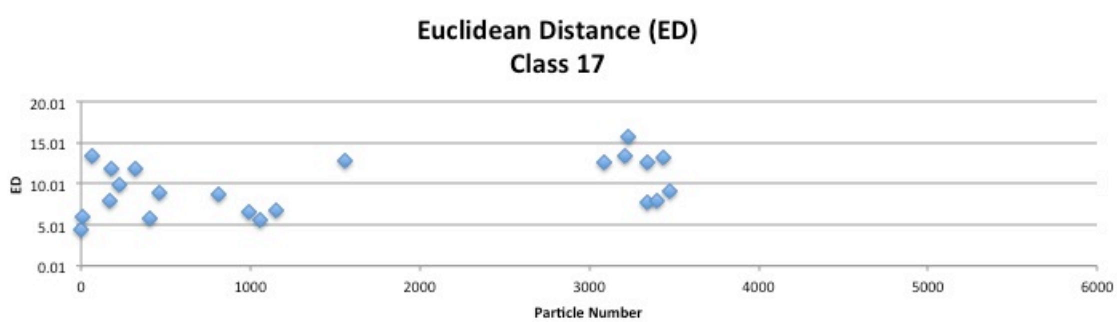

Figure 5-46: Euclidean Distance Class 17

Class 18 of Bodele 80 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 96 particles in this class (Figure 5-47).

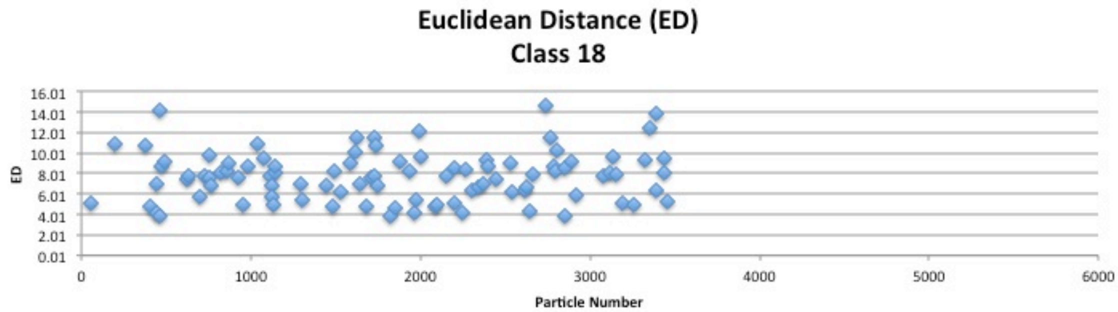

Figure 5-47: Euclidean Distance Class 18

Class 19 of Bodele 80 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 20 particles in this class (Figure 5-48).

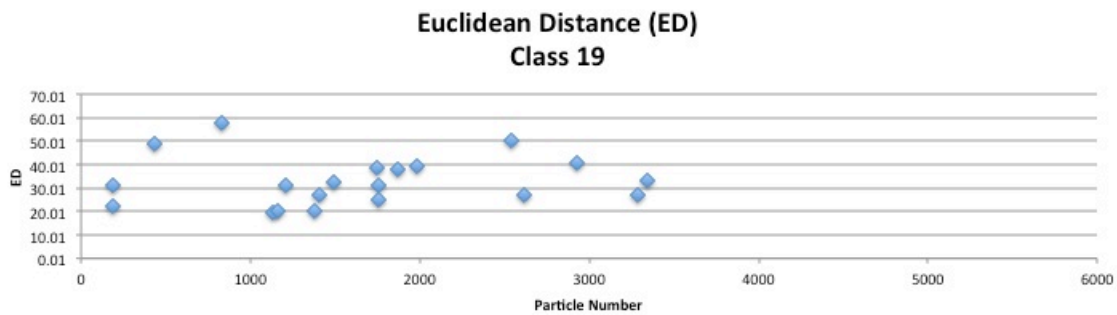

Figure 5-48: Euclidean Distance Class 19

Class 20 of Bodele 80 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 423 particles in this class (Figure 5-49).

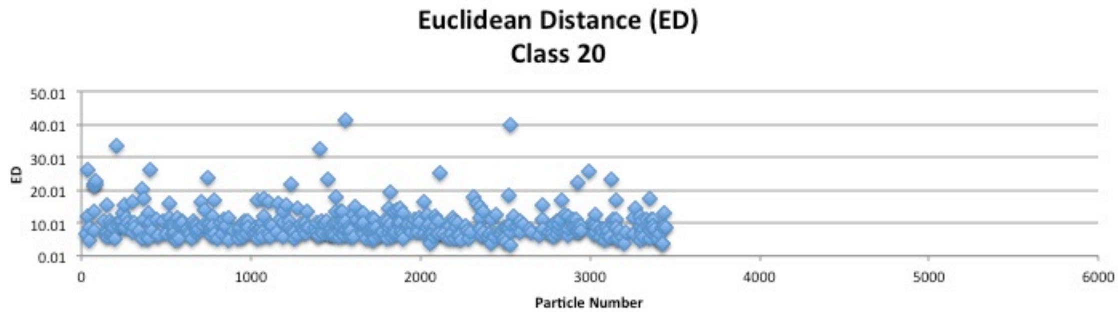

Figure 5-49: Euclidean Distance Class 20

Class 21 of Bodele 80 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 64 particles in this class (Figure 5-50).

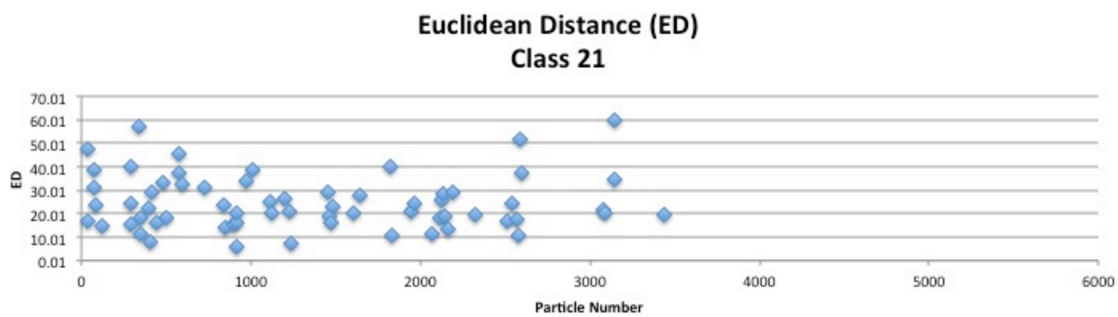

Figure 5-50: Euclidean Distance Class 21

Class 22 of Bodele 80 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 808 particles in this class (Figure 5-51).

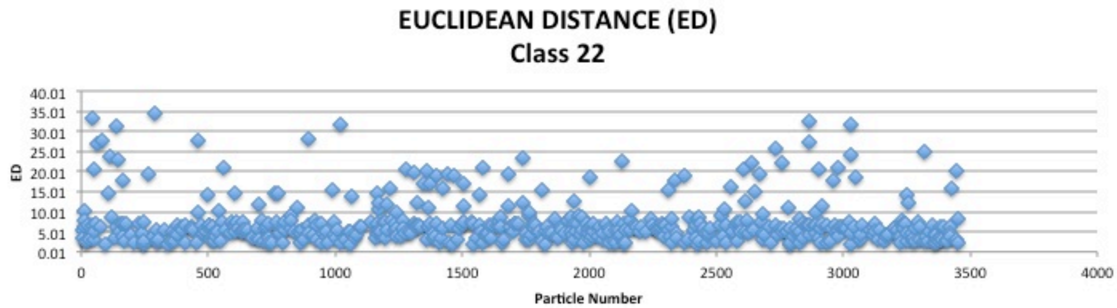

Figure 5-51: Euclidean Distance Class 22

Class 23 of Bodele 80 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 34 particles in this class (Figure 5-52).

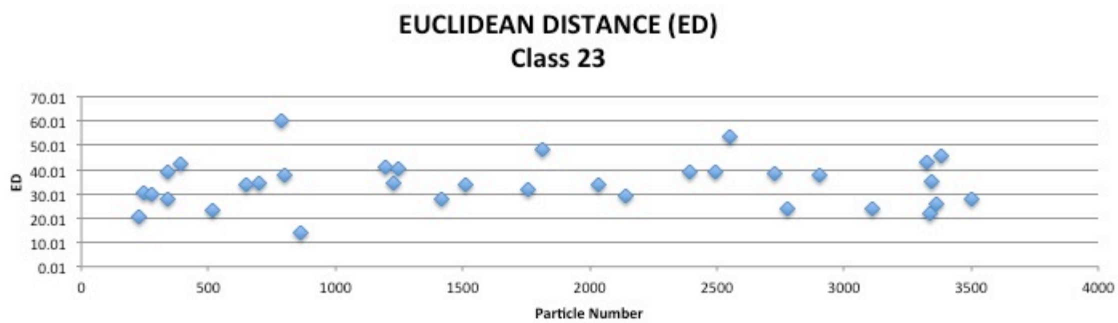

Figure 5-52: Euclidean Distance Class 23

Class 24 of Bodele 80 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 30 particles in this class (Figure 5-53).

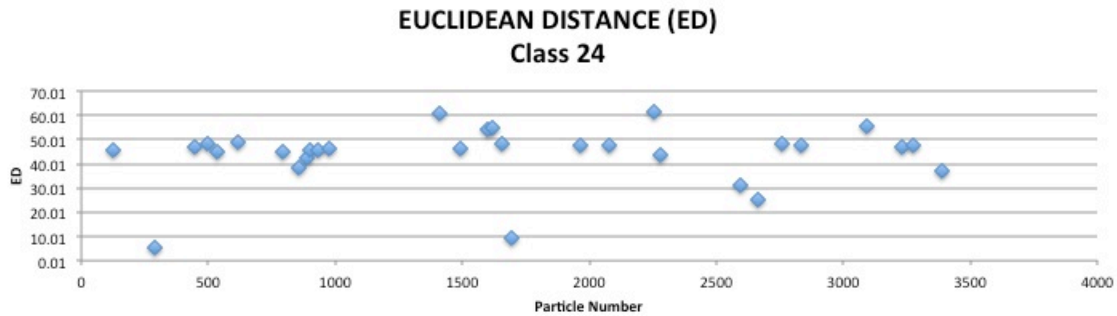

Figure 5-53: Euclidean Distance Class 24

Class 25 of Bodele 80 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 46 particles in this class (Figure 5-54).

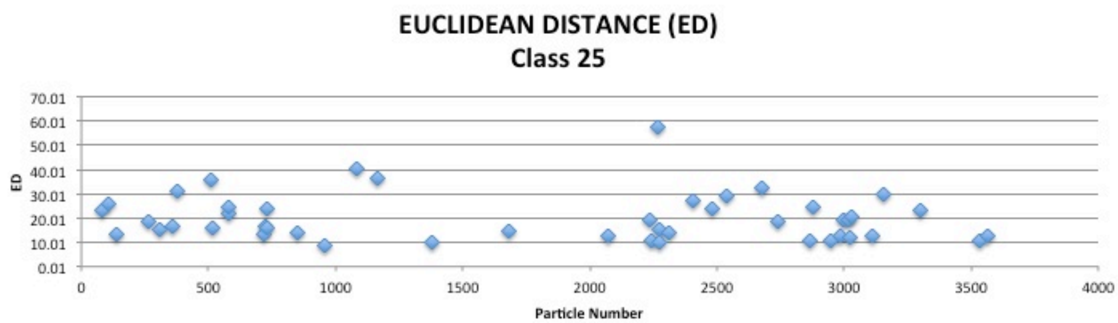

Figure 5-54: Euclidean Distance Class 25

Class 26 of Bodele 80 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 321 particles in this class (Figure 5-55).

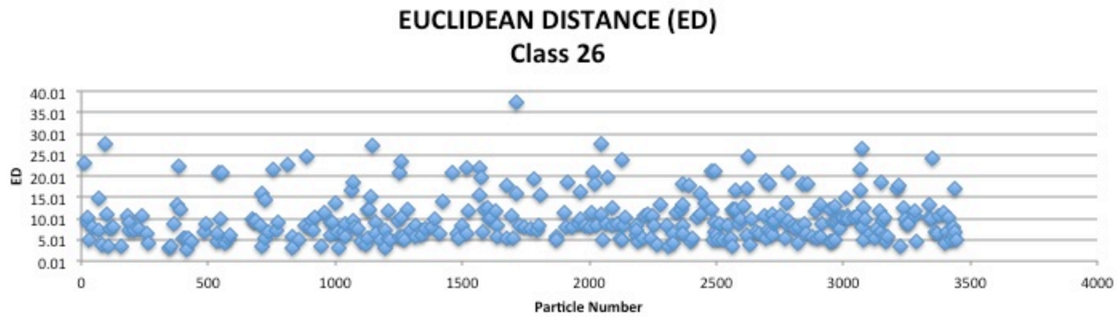

Figure 5-55: Euclidean Distance Class 26

Class 27 of Bodele 80 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 211 particles in this class (Figure 5-56).

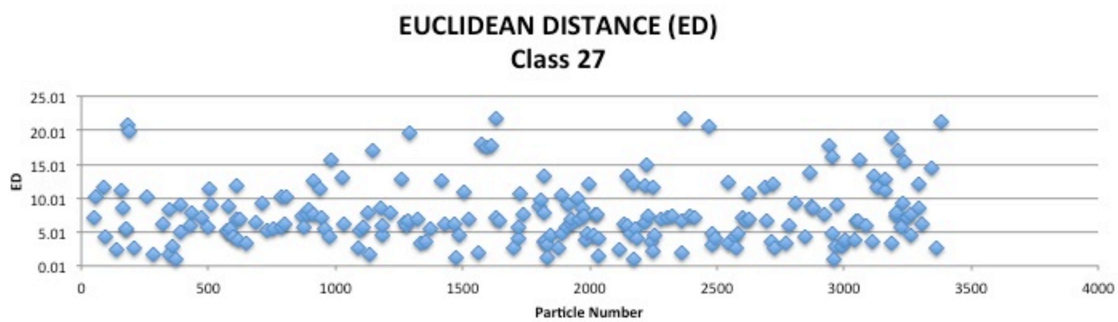

Figure 5-56: Euclidean Distance Class 27

Class 28 of Bodele 80 is composed of Aluminum less than 1%. There are a total of 99 particles in this class (Figure 5-57).

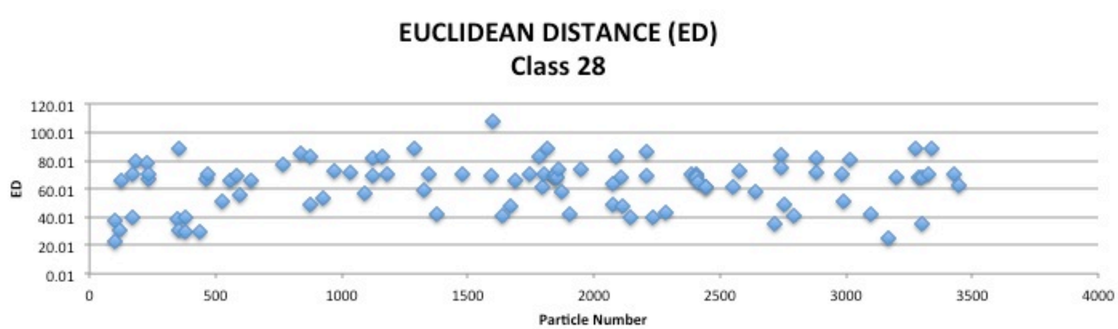

Figure 5-57: Euclidean Distance Class 28

Bodele 82

Numerical and Volumetric Analysis

Bodele 82, located at 16 13.273' N, 18 36.397' E, in the Bodele Depression was elementally separated into 29 separate classes (Figure 5-58). The numerical percentage shows the number of Particles in each class, and what percentage those particles represent to the entire class (Table 5-5).

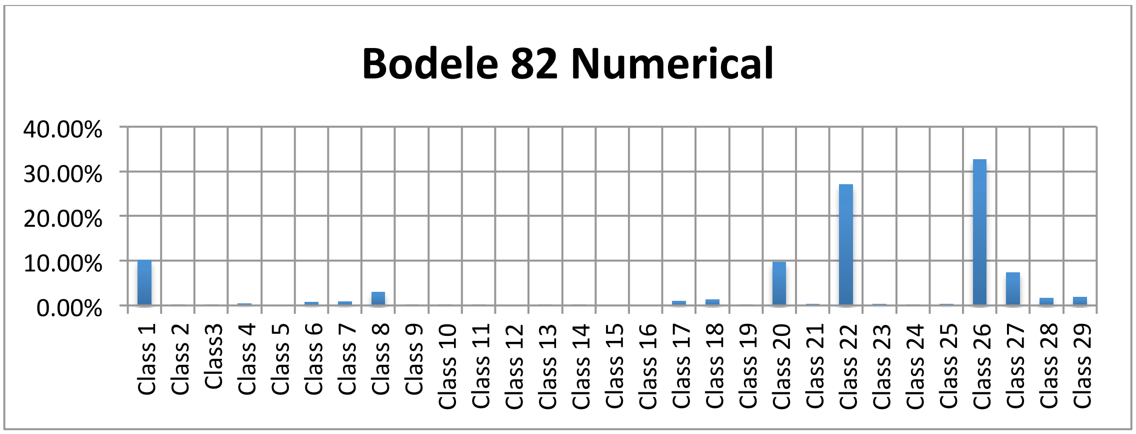

Figure 5-58: Bodele 82 Classes

Table 5-5: Numerical Percentage

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
408	9	4	18	0	31	35	119
10.20%	0.23%	0.10%	0.45%	0.00%	0.78%	0.88%	2.98%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
8	9	1	0	1	3	0	0
0.20%	0.23%	0.03%	0.00%	0.03%	0.08%	0.00%	0.00%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
37	54	6	389	10	1081	12	3
0.93%	1.35%	0.15%	9.73%	0.25%	27.03%	0.30%	0.08%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
13	1308	296	68	77	4000		
0.33%	32.70%	7.40%	1.70%	1.93%	1		

Table 5-5 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 1, 22, and 26. Class 1 is composed of greater than 99% silica. Class 22 is composed of less than 1% Potassium and Calcium, between 4% and 20% Aluminum, and greater than 60% Silica. Class 26 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. This represents 69.93% of the entire sample and contains a total of 2797 particles. Class 29 represents the "unclassified" particles and contains only 1.93% of the entire sample.

Similar to the numerical percentage, the volume of every class was calculated to analyze the percentage of volume for each class (Figure 5-59). The volumetric percentage of Bodele 82 represents the volume of particles that are represented in each respective elemental class (Table 5-6).

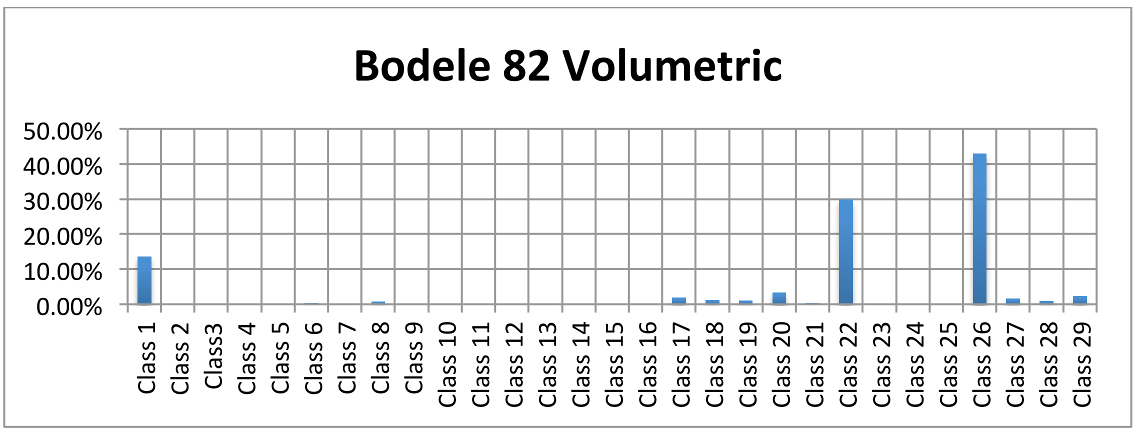

Figure 5-59: Volumetric Classes.

Table 5-6: Graph of Bodele 82 Volumetric Percentages

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7
75435.09	49.39	14.66	109.07	0.00	1908.68	952.68
13.52%	0.01%	0.00%	0.02%	0.00%	0.34%	0.17%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15
233.13	31.89	65.19	0.00	3.76	412.62	0.00
0.04%	0.01%	0.01%	0.00%	0.00%	0.07%	0.00%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23
10007.47	6149.84	5815.38	18323.56	1380.89	166564.35	68.83
1.79%	1.10%	1.04%	3.28%	0.25%	29.85%	0.01%
Class 25	Class 26	Class 27	Class 28	Class 29	Total	
82.28	239523.49	8782.19	5160.24	12638.82	558059.50	
0.01%	42.92%	1.57%	0.92%	2.26%	100.00%	

Table 5-4 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 1, 22, and 26, which is consistent with the numerical percentages. Class 1 is composed of greater than 99% silica. Class 22 is composed of less than 1% Potassium and Calcium, between 4% and 20% Aluminum, and greater than 60% Silica. Class 26 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. This represents 86.92% of the entire sample and contains a total volume of 481522.93 μm^3. Class 29 represents the “unclassified” volume of particles and contains 2.26% of the entire sample.

Analysis of class 29 showed no significant clusters of elements. The highest elements contained within Bodele 82 are Fe, Si, Al and Ca. These elements are relatively evenly distributed across the elements (Figure 5-60 and Figure 5-61). There are no significant clusters of particles to add additional classes to this sample.

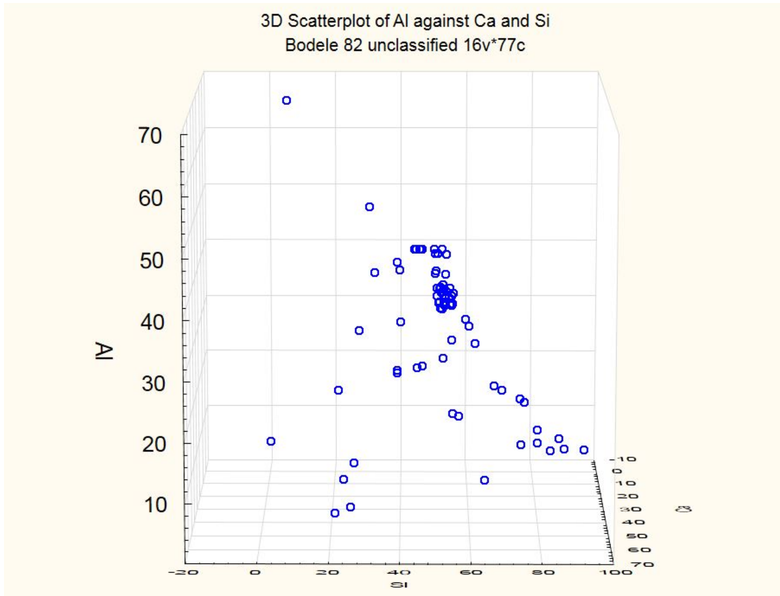

Figure 5-60: Scatterplot of Bodele 82 Unclassified

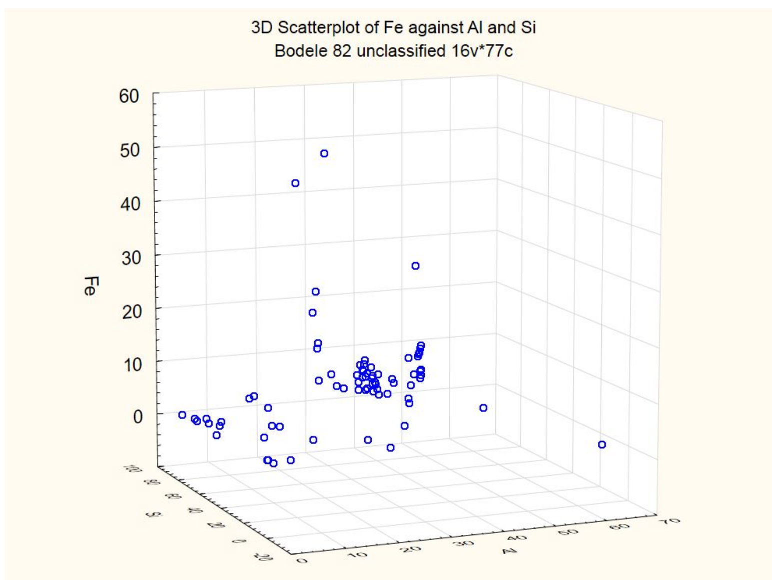

Figure 5-61: Scatterplot of Bodele 82 Unclassified

Euclidean Distance

The Euclidean Distance for Class 1 of Bodele 82 is composed of greater than 99% Silica. There are a total of 408 particles in this class (Figure 5-62).

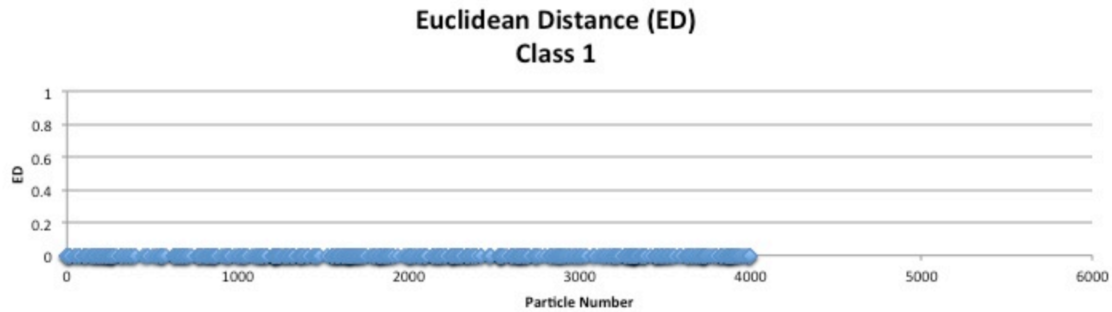

Figure 5-62: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 9 particles in this class (Figure 5-63).

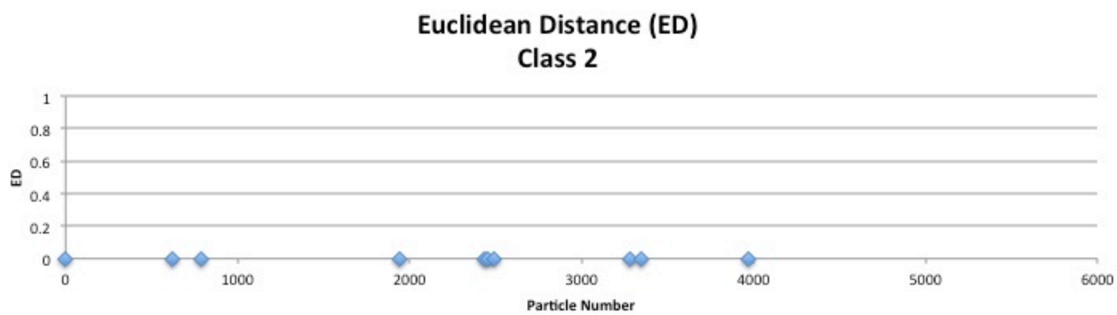

Figure 5-63: Euclidean Distance Class 2

Class 3 of Bodele 82 is composed of greater than 99% Calcium. There are a total of 4 particles in this class (Figure 5-64).

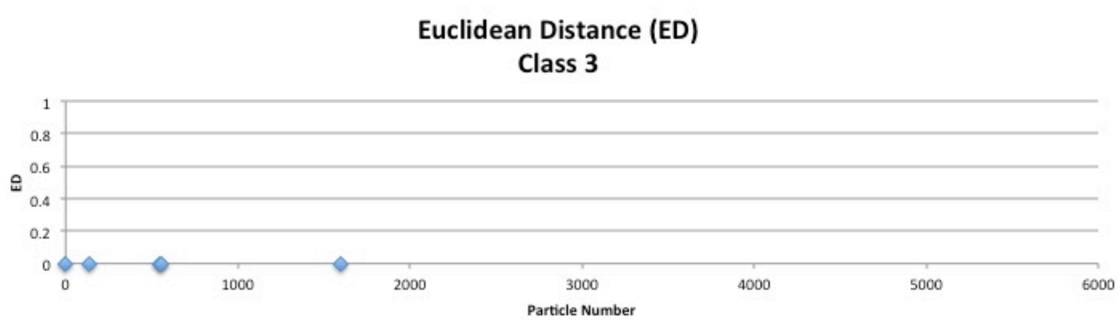

Figure 5-64: Euclidean Distance Class 3

Class 4 of Bodele 82 is composed of Titanium greater than 55% and Lead less than 5%. There are 18 particles in this class (Figure 5-65).

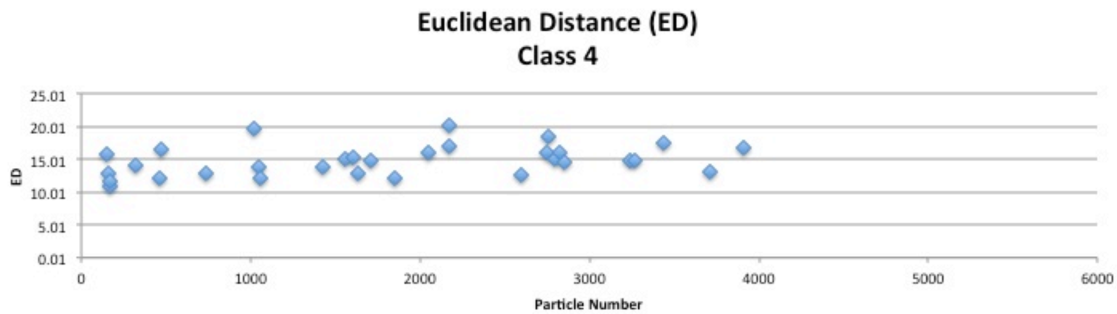

Figure 5-65: Euclidean Distance Class 4

Class 5 of Bodele 82 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Bodele 82 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 31 particles in this class (Figure 5-66).

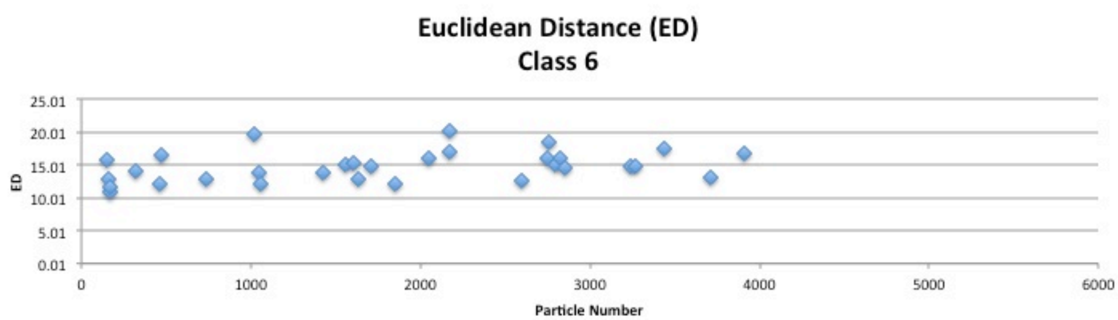

Figure 5-66: Euclidean Distance Class 6

Class 7 of Bodele 82 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 35 particles in this class (Figure 5-67).

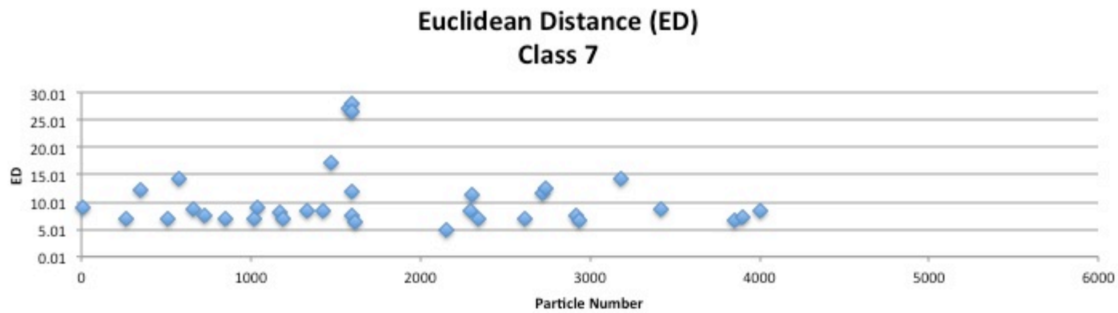

Figure 5-67: Euclidean Distance Class 7

Class 8 of Bodele 82 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 119 particles in this class (Figure 5-68).

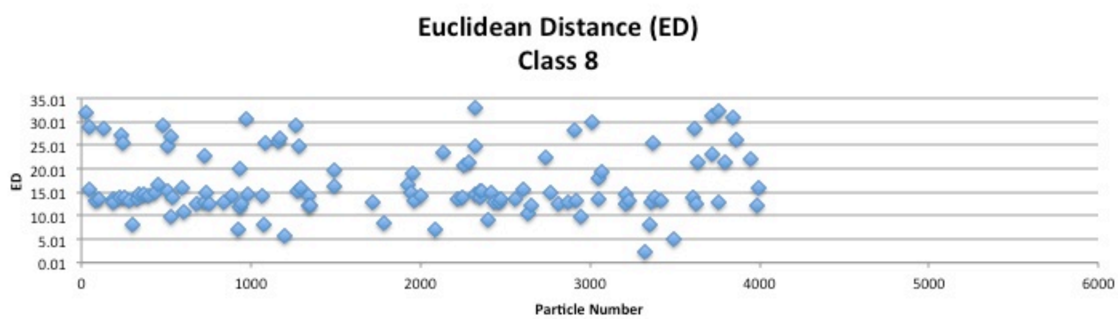

Figure 5-68: Euclidean Distance Class 8

Class 9 of Bodele 82 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 8 particles in this class (Figure 5-69).

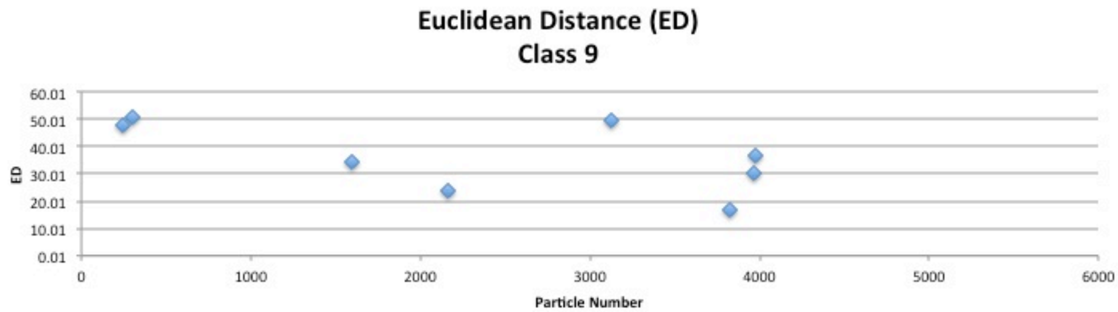

Figure 5-69: Euclidean Distance Class 9

Class 10 of Bodele 82 is composed of Calcium greater than 80% and Lead less than 5%. There are 10 particles in this class (Figure 5-70).

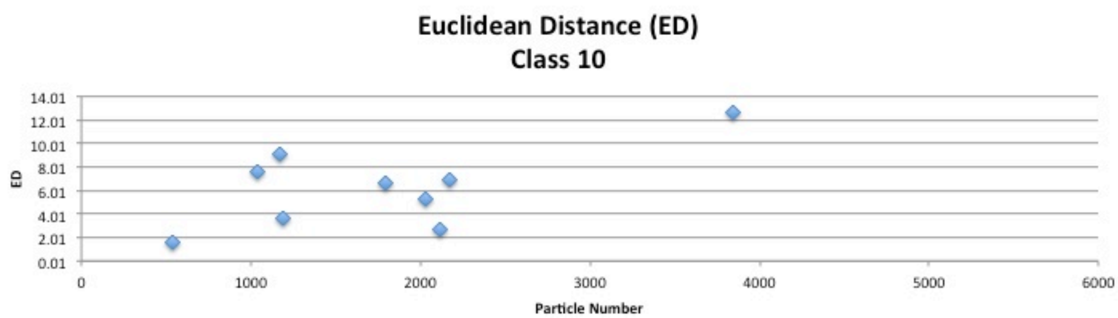

Figure 5-70: Euclidean Distance Class 10

Class 11 of Bodele 82 is composed of the total Calcium and Manganese greater than 90%. There is 1 particle in this class (Figure 5-71).

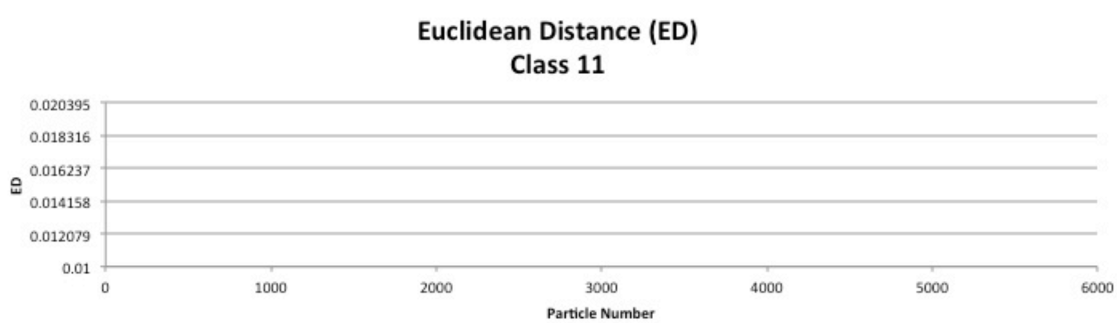

Figure 5-71: Euclidean Distance Class 11

Class 12 of Bodele 82 is composed of the total Calcium and Phosphorus greater than 90%. There are no particles in this class.

Class 13 of Bodele 82 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There is 1 particle in this class (Figure 5-72).

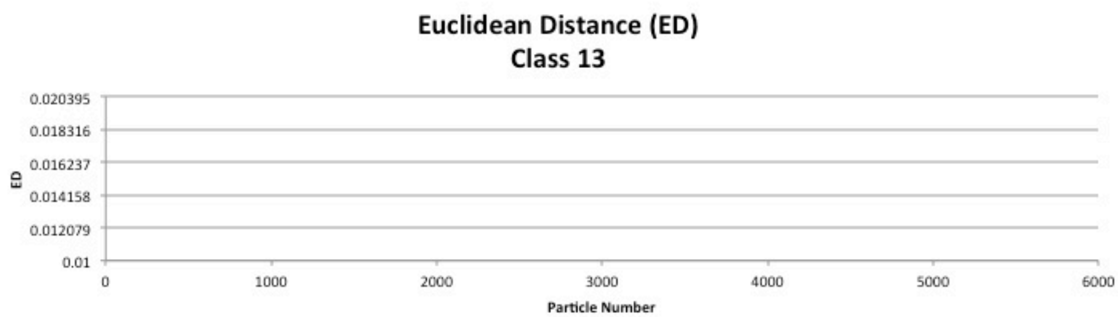

Figure 5-72: Euclidean Distance Class 13

Class 14 of Bodele 82 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are a total of 3 particles in this class (Figure 5-73).

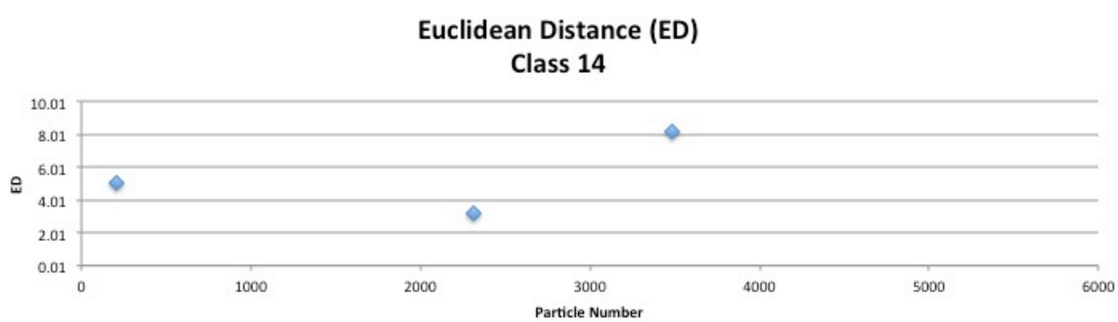

Figure 5-73: Euclidean Distance Class 14

Class 15 of Bodele 82 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Bodele 82 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are no particles in this class.

Class 17 of Bodele 82 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 37 particles in this class (Figure 5-74).

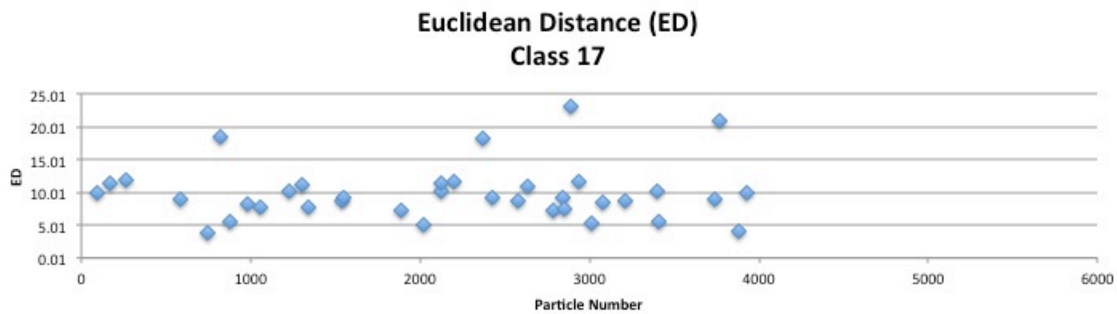

Figure 5-74: Euclidean Distance Class 17

Class 18 of Bodele 82 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 96 particles in this class (Figure 5-75).

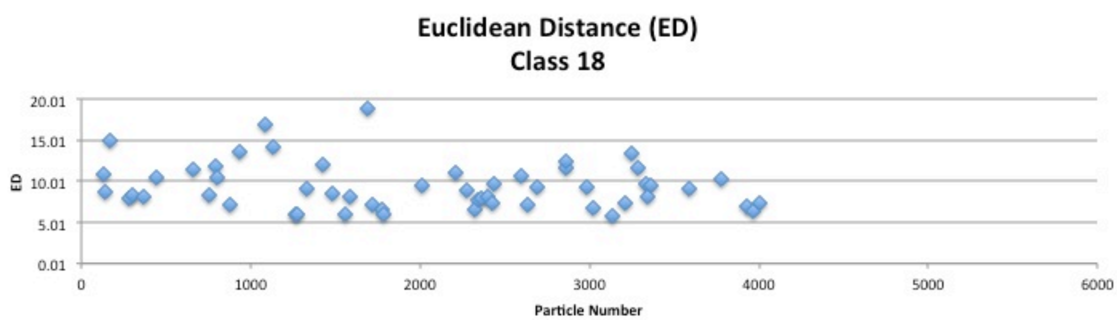

Figure 5-75: Euclidean Distance Class 18

Class 19 of Bodele 82 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 6 particles in this class (Figure 5-76).

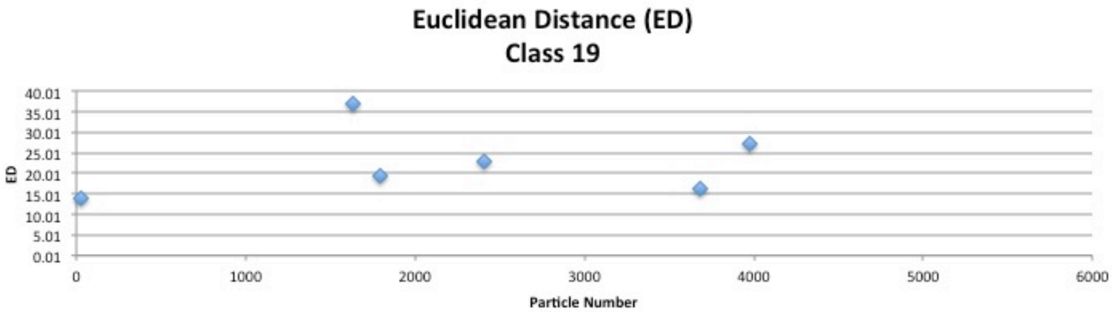

Figure 5-76: Euclidean Distance Class 19

Class 20 of Bodele 82 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 389 particles in this class (Figure 5-77).

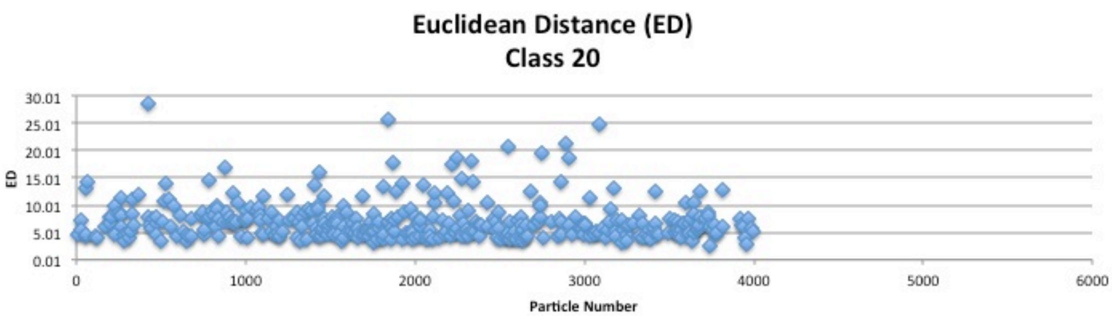

Figure 5-77: Euclidean Distance Class 20

Class 21 of Bodele 82 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 10 particles in this class (Figure 5-78).

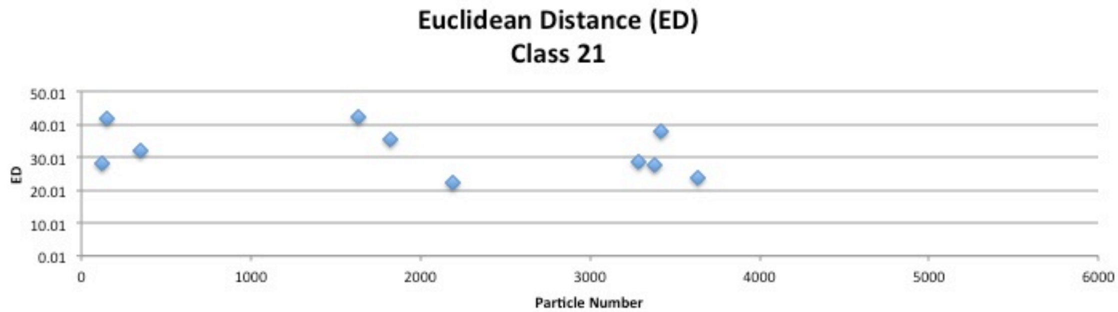

Figure 5-78: Euclidean Distance Class 21

Class 22 of Bodele 82 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 1081 particles in this class (Figure 5-79).

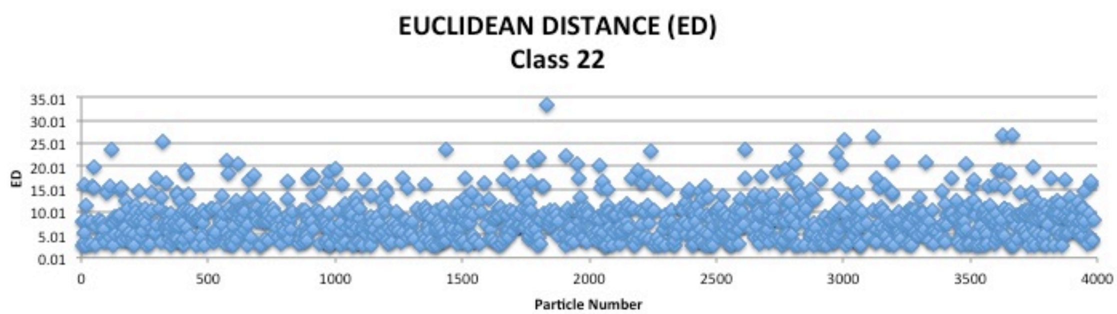

Figure 5-79: Euclidean Distance Class 22

Class 23 of Bodele 82 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 12 particles in this class (Figure 5-80).

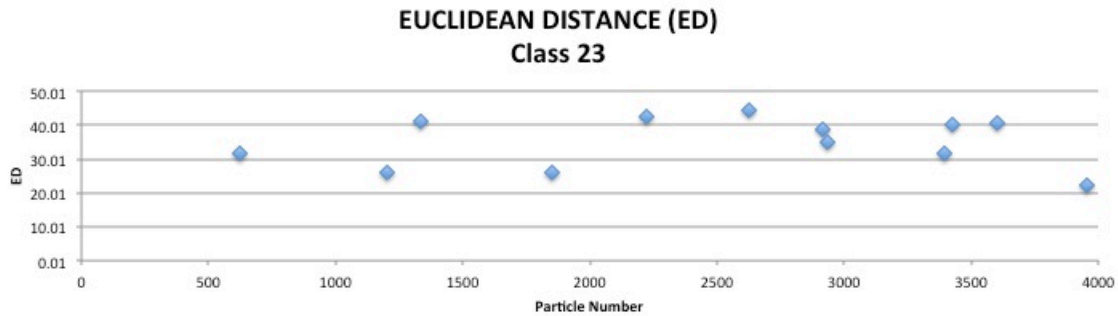

Figure 5-80: Euclidean Distance Class 23

Class 24 of Bodele 82 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 3 particles in this class (Figure 5-81).

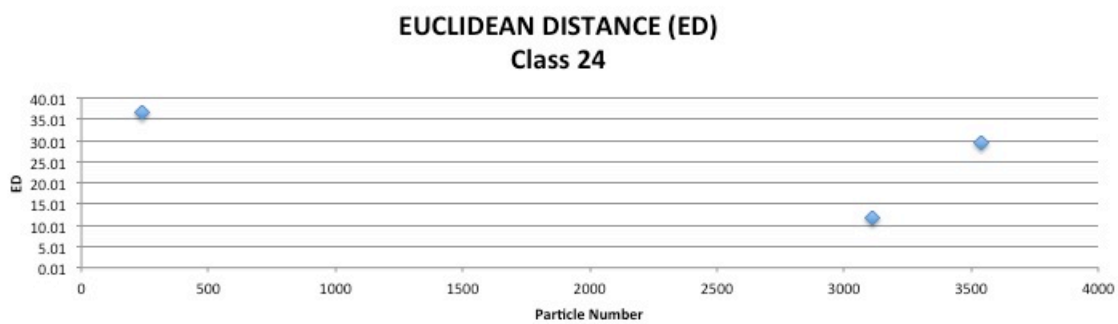

Figure 5-81: Euclidean Distance Class 24

Class 25 of Bodele 82 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 13 particles in this class (Figure 5-82).

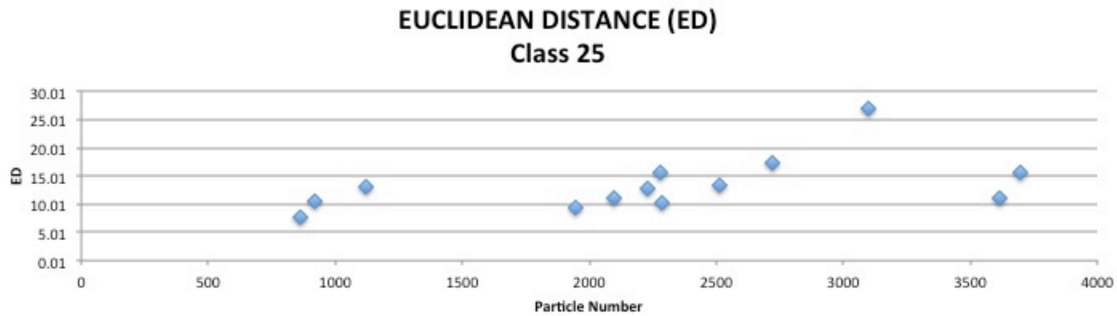

Figure 5-82: Euclidean Distance Class 25

Class 26 of Bodele 82 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 1308 particles in this class (Figure 5-83).

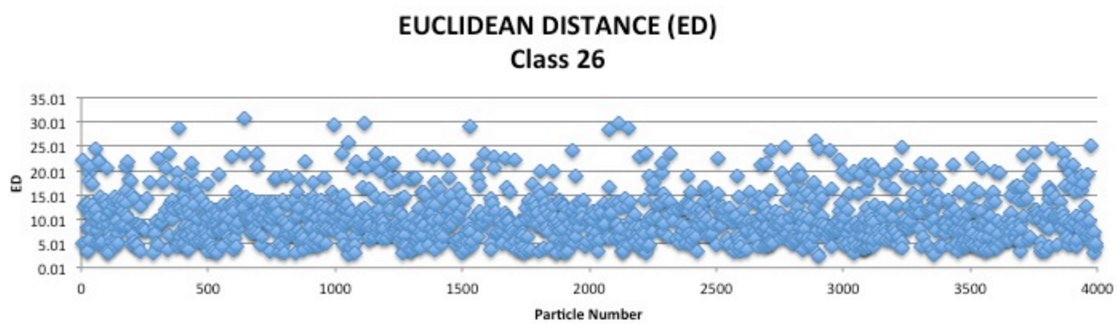

Figure 5-83: Euclidean Distance Class 26

Class 27 of Bodele 82 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 296 particles in this class (Figure 5-84).

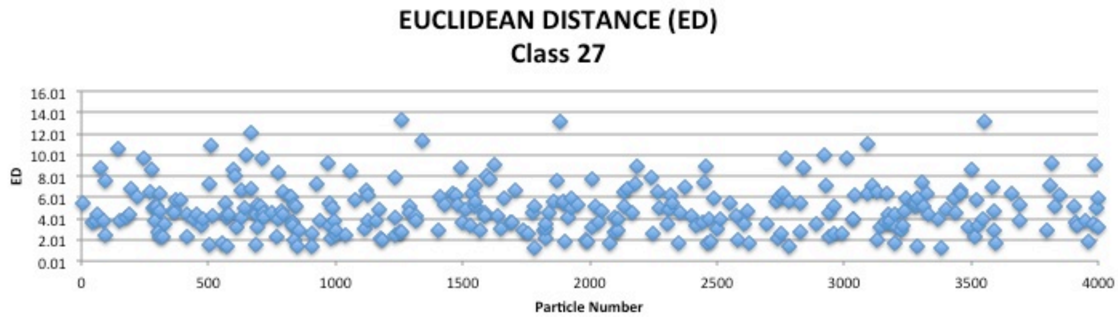

Figure 5-84: Euclidean Distance Class 27

Class 28 of Bodele 82 is composed of Aluminum less than 1%. There are a total of 77 particles in this class (Figure 5-85).

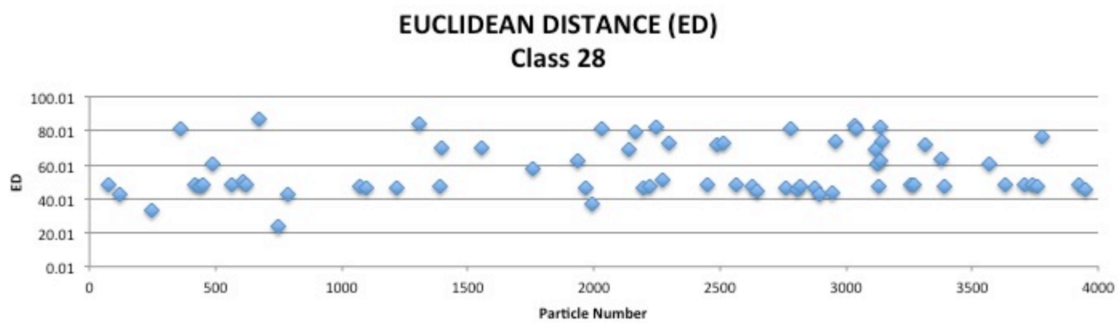

Figure 5-85: Euclidean Distance Class 28

Bodele 83

Numerical and Volumetric Analysis

Bodele 83, located at 16 13.273' N, 18 36.397' E, in the same location as Bodele 82 in the Bodele Depression was elementally separated into 29 separate classes (Figure 5-86). The numerical percentage shows the number of Particles in each class, and what percentage those particles represent to the entire class (Table 5-7).

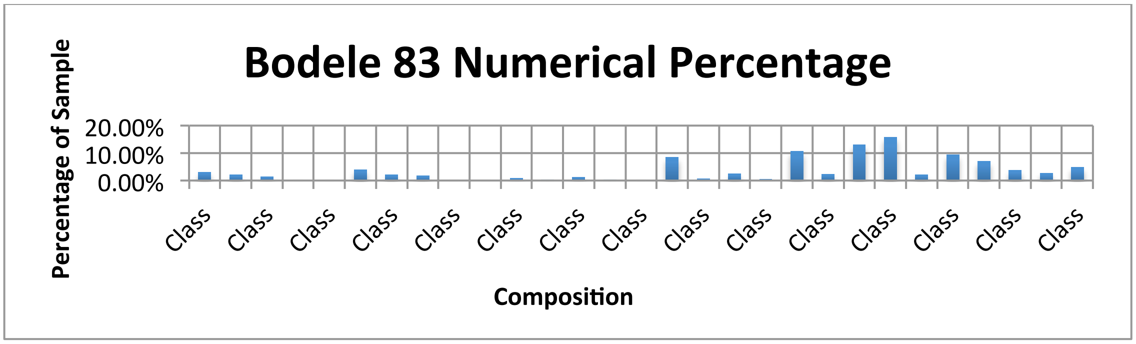

Figure 5-86: Bodele 83 Classes

Table 5-7: Numerical Percentage

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
97	64	43	0	0	126	67	55
3.06%	2.02%	1.36%	0.00%	0.00%	3.98%	2.12%	1.74%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	26	1	38	5	0	266
0.00%	0.00%	0.82%	0.03%	1.20%	0.16%	0.00%	8.40%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
20	76	16	338	74	412	500	67
0.63%	2.40%	0.51%	10.68%	2.34%	13.01%	15.79%	2.12%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
298	223	117	86	151	3166		
9.41%	7.04%	3.70%	2.72%	4.77%	100.00%		

Table 5-7 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 20, 22, and 23. Class 20 consists of Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica Greater than 60%. Class 23 has less than 1% of Potassium and Calcium, between 4% and 20% Aluminum and Silica between 15% and 66%. This represents 39.48% of the entire sample and contains a total of 1250 particles. Class 29 represents the “unclassified” particles and contains only 4.77% of the entire sample.

The volumetric percentage of Bodele 83 represents the volume of particles that are represented in each respective elemental class (Figure 5-87).

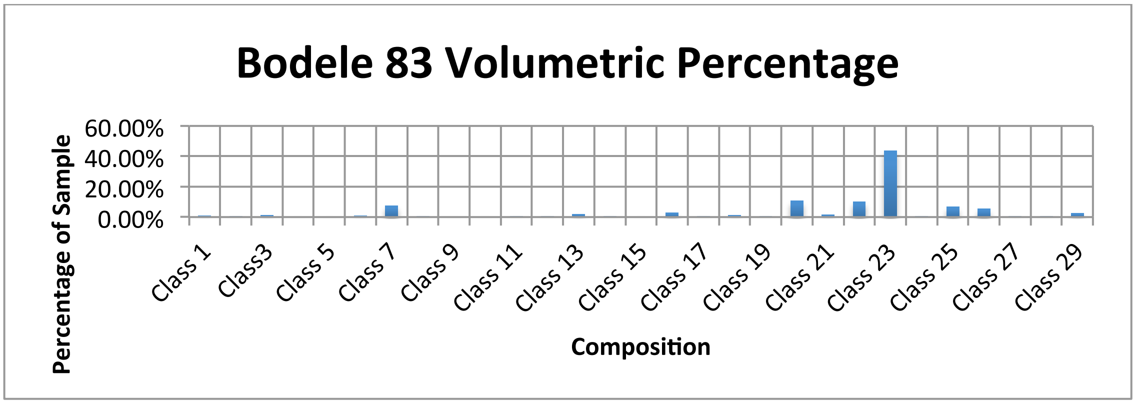

Figure 5-87: Volumetric Classes

Table 5-8 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 20, 22, and 23, which is consistent with the numerical percentages. Class 20 consists of Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica Greater than 60%. Class 23 has less than 1% of Potassium and Calcium, between 4% and 20% Aluminum and Silica between 15% and 66%. This represents 64.65% of the entire sample and contains a total volume of 67460.41 µm^3. Class 29 represents the “unclassified” volume of particles and contains 2.54% of the entire sample.

Table 5-8: Graph of Bodele 83 Volumetric Percentages

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7
785.31	363.63	1230.34	0.00	0.00	965.93	7946.78
0.75%	0.35%	1.18%	0.00%	0.00%	0.93%	7.62%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15
0.00	0.00	157.79	1.00	2026.42	89.78	0.00
0.00%	0.00%	0.15%	0.00%	1.94%	0.09%	0.00%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23
190.98	1333.19	12.26	11115.51	1670.08	10657.62	45687.28
0.18%	1.28%	0.01%	10.65%	1.60%	10.21%	43.79%
Class 25	Class 26	Class 27	Class 28	Class 29	Total	
7200.75	5804.13	542.27	482.73	2645.87	104342.29	
6.90%	5.56%	0.52%	0.46%	2.54%	100.00%	

Analysis of class 29 showed no significant clusters of elements. The highest elements contained within Bodele 83 are Fe, Si, Al and Ca. These elements are relatively evenly distributed across the elements (Figure 5-88 and Figure 5-89). There are no significant clusters of particles to add additional classes to this sample.

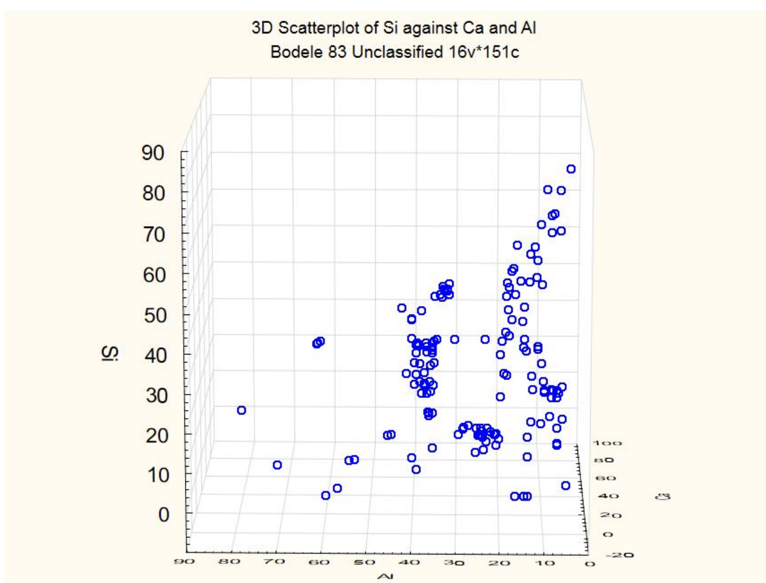

Figure 5-88: Scatterplot of Bodele 83 Unclassified

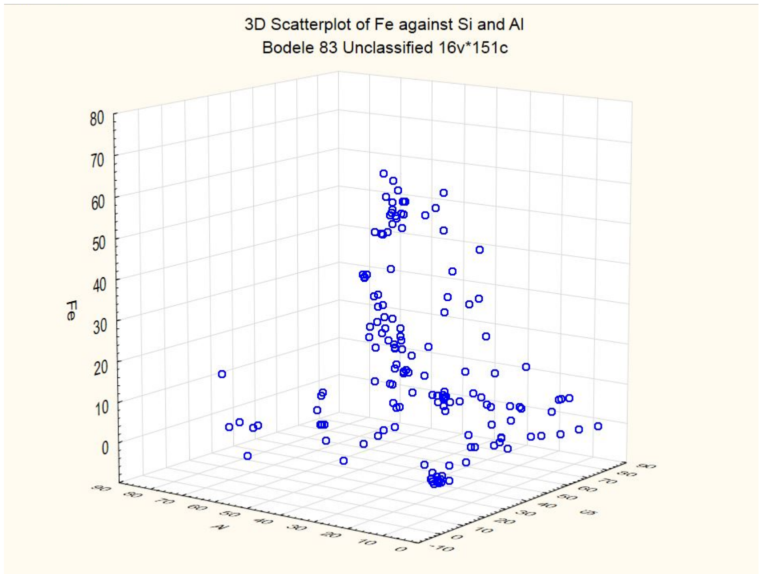

Figure 5-89: Scatterplot of Bodele 83 elements Al, Si and Si, showing no clusters of particles within the sample.

Euclidean Distance

The Euclidean Distance for Class 1 of Bodele 83 is composed of greater than 99% Silica. There are a total of 97 particles in this class (Figure 5-90).

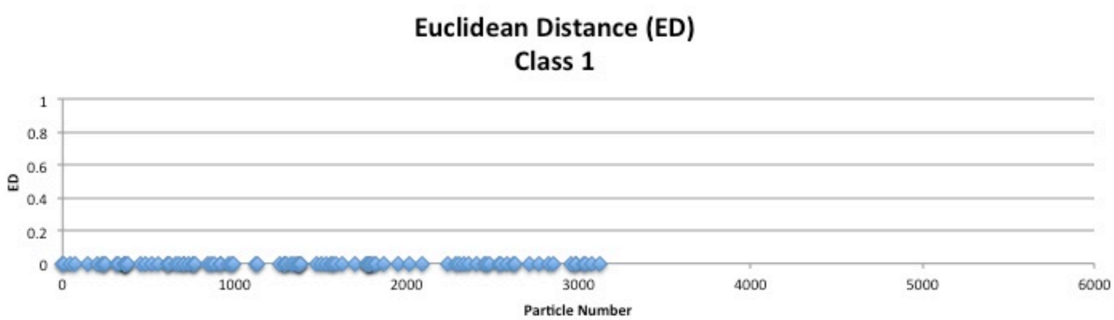

Figure 5-90: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 64 particles in this class (Figure 5-91).

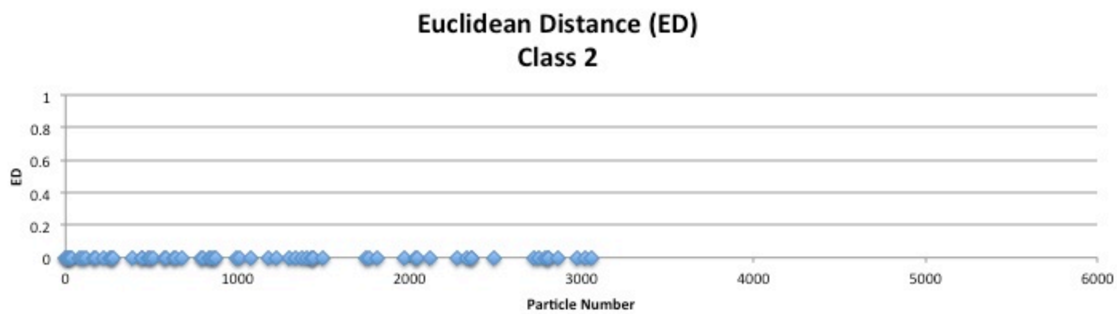

Figure 5-91: Euclidean Distance Class 2

Class 3 of Bodele 83 is composed of greater than 99% Calcium. There are a total of 43 particles in this class (Figure 5-92).

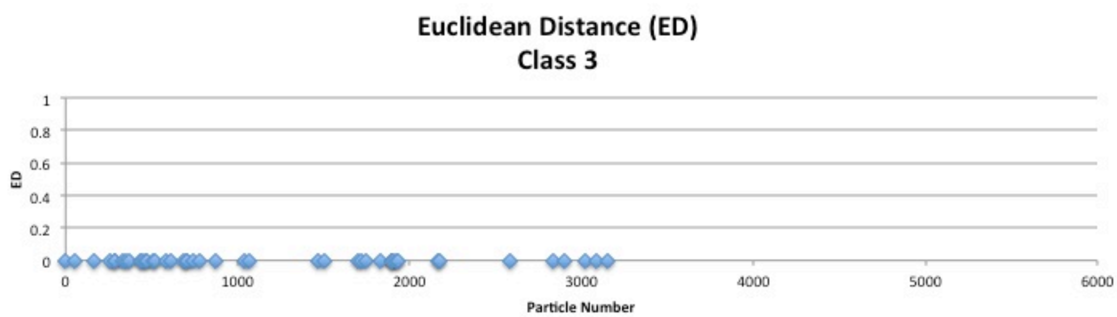

Figure 5-92: Euclidean Distance Class 3

Class 4 of Bodele 83 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Bodele 83 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Bodele 83 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 126 particles in this class (Figure 5-93).

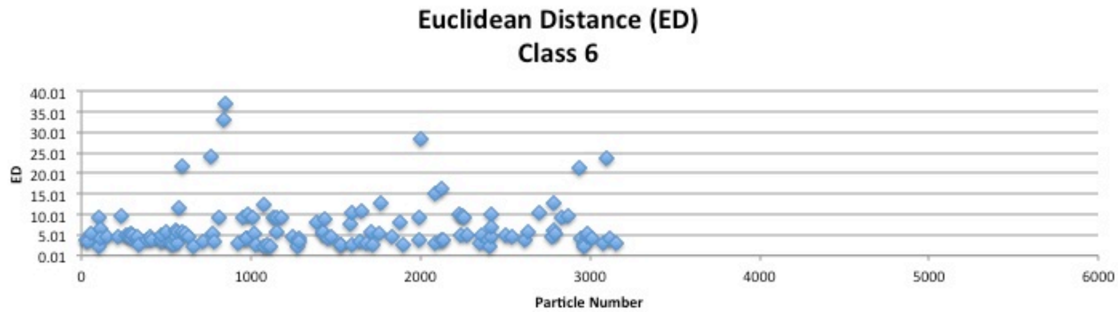

Figure 5-93: Euclidean Distance Class 6

Class 7 of Bodele 83 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 67 particles in this class (Figure 5-94).

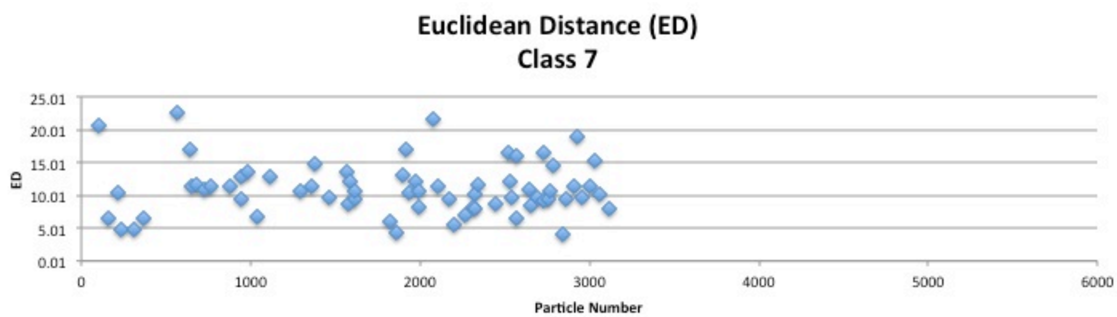

Figure 5-94: Euclidean Distance Class 7

Class 8 of Bodele 83 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 55 particles in this class (Figure 5-95).

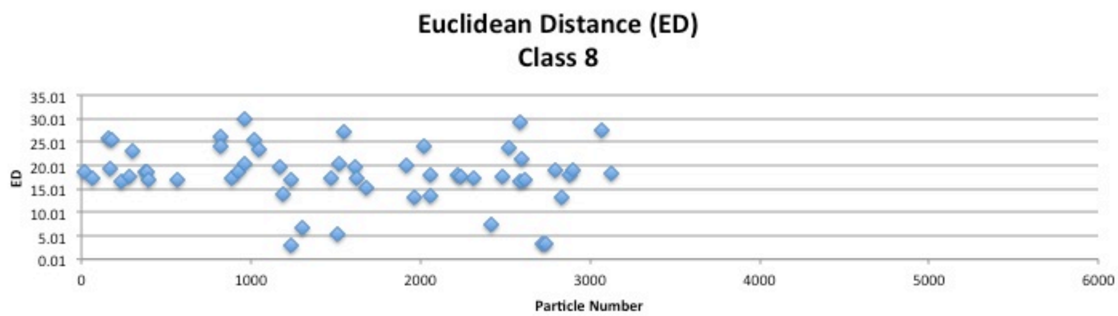

Figure 5-95: Euclidean Distance Class 8

Class 9 of Bodele 83 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Bodele 83 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Bodele 83 is composed of the total Calcium and Manganese greater than 90%. There are 2 particles in this class (Figure 5-96).

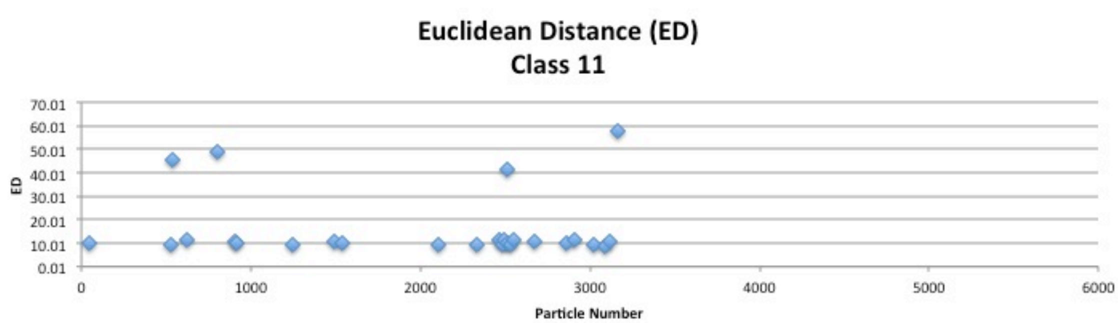

Figure 5-96: Euclidean Distance Class 11

Class 12 of Bodele 83 is composed of the total Calcium and Phosphorus greater than 90%. There is 1 particle in this class (Figure 5-97).

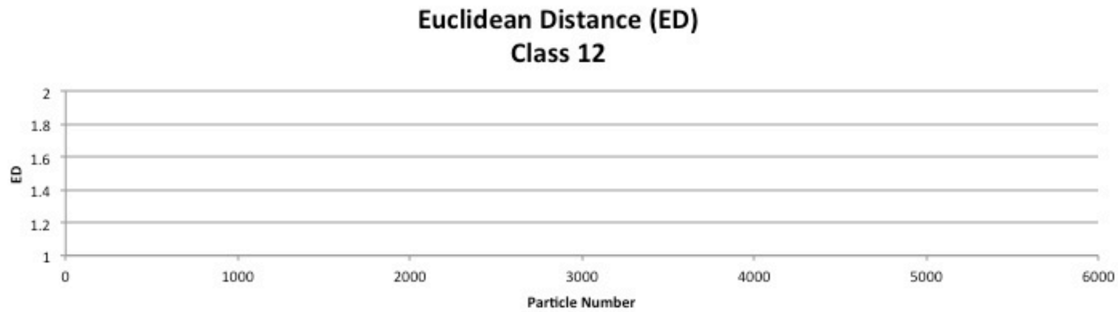

Figure 5-97: Euclidean Distance Class 12

Class 13 of Bodele 83 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 38 particles in this class (Figure 5-98).

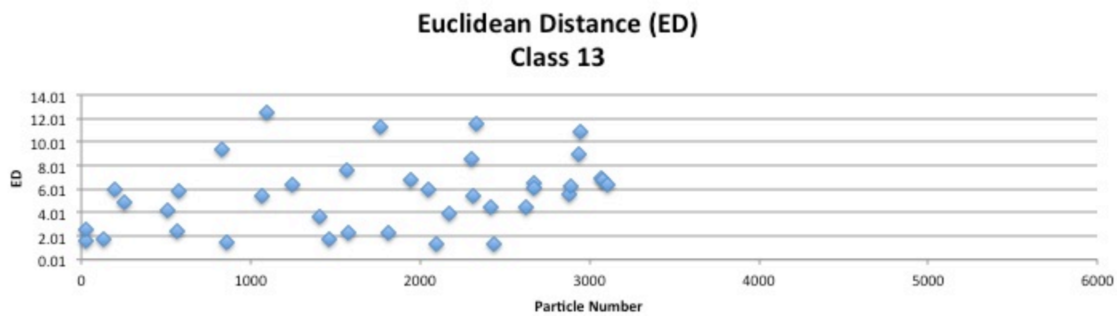

Figure 5-98: Euclidean Distance Class 13

Class 14 of Bodele 83 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are a total of 5 particles in this class (Figure 5-99).

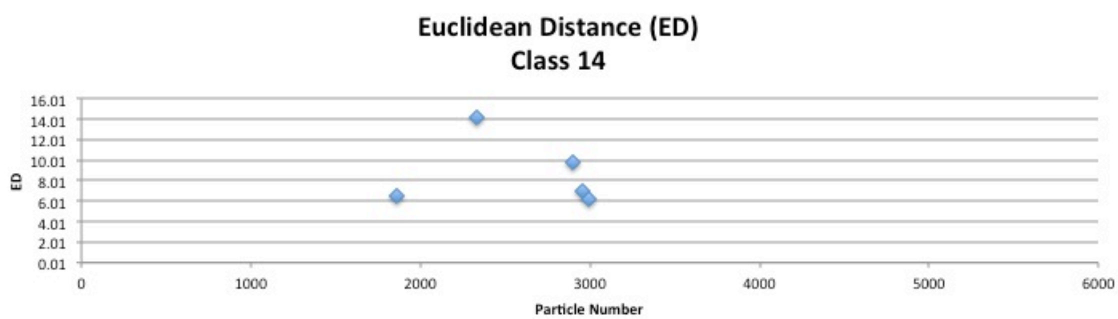

Figure 5-99: Euclidean Distance Class 14

Class 15 of Bodele 83 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Bodele 83 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 266 particles in this class (Figure 5-100).

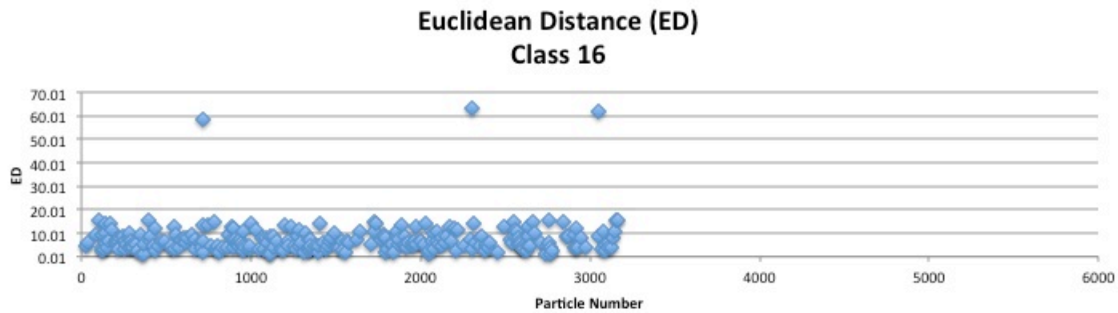

Figure 5-100: Euclidean Distance Class 16

Class 17 of Bodele 83 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 20 particles in this class (Figure 5-101).

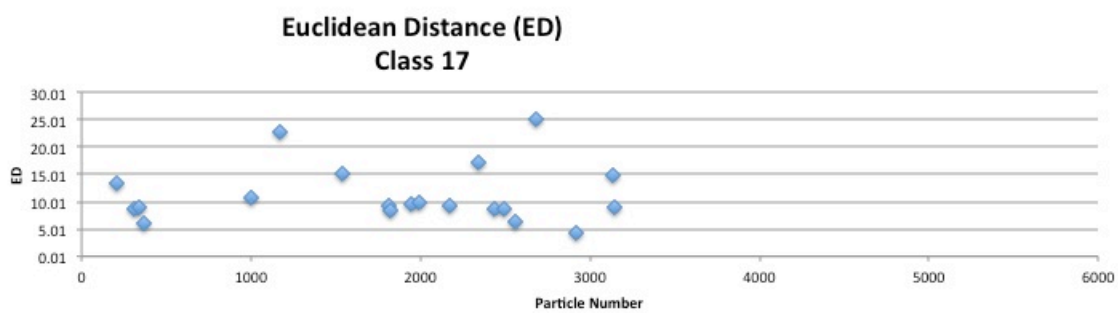

Figure 5-101: Euclidean Distance Class 17

Class 18 of Bodele 83 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 76 particles in this class (Figure 5-102).

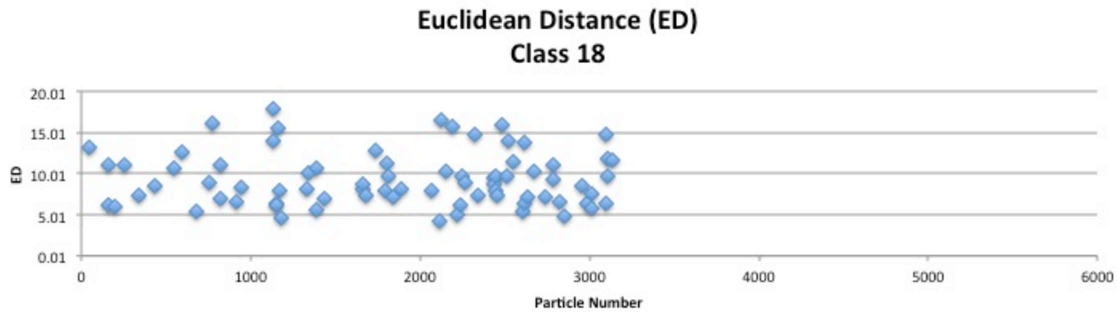

Figure 5-102: Euclidean Distance Class 18

Class 19 of Bodele 83 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 16 particles in this class (Figure 5-103).

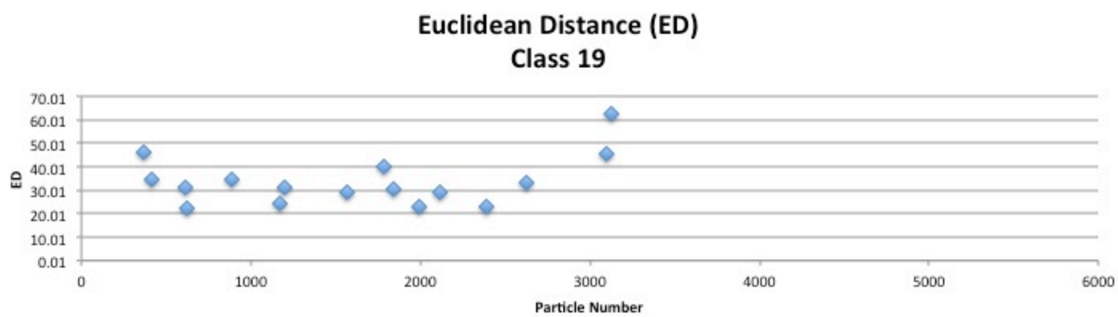

Figure 5-103: Euclidean Distance Class 19

Class 20 of Bodele 83 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 338 particles in this class (Figure 5-104).

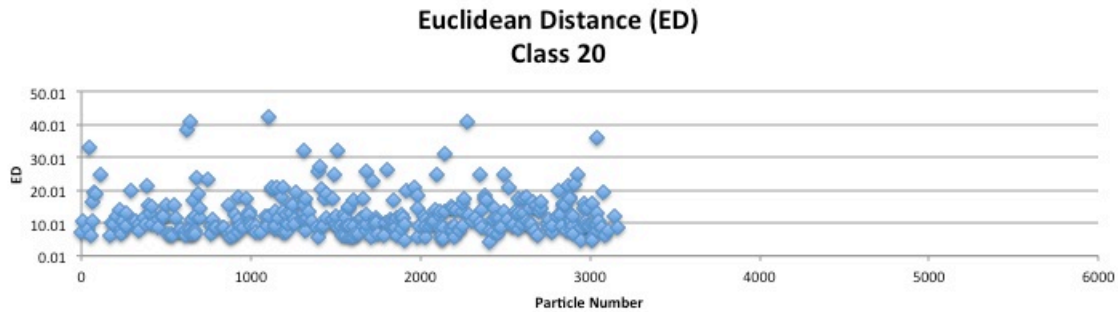

Figure 5-104: Euclidean Distance Class 20

Class 21 of Bodele 83 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 74 particles in this class (Figure 5-105).

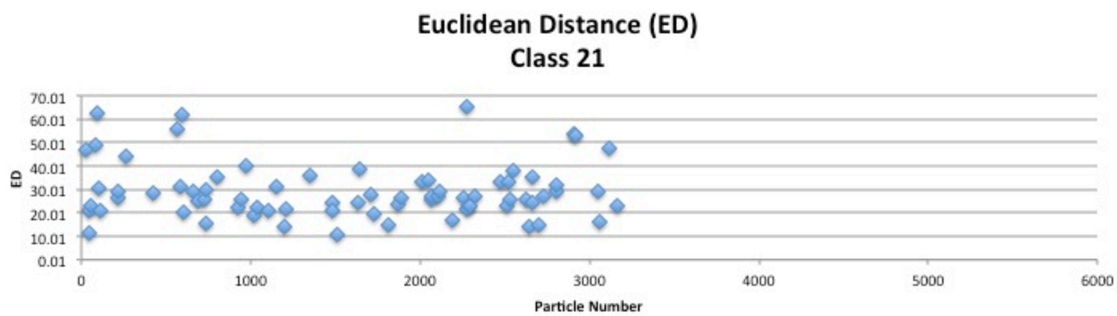

Figure 5-105: Euclidean Distance Class 21

Class 22 of Bodele 83 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 412 particles in this class (Figure 5-106).

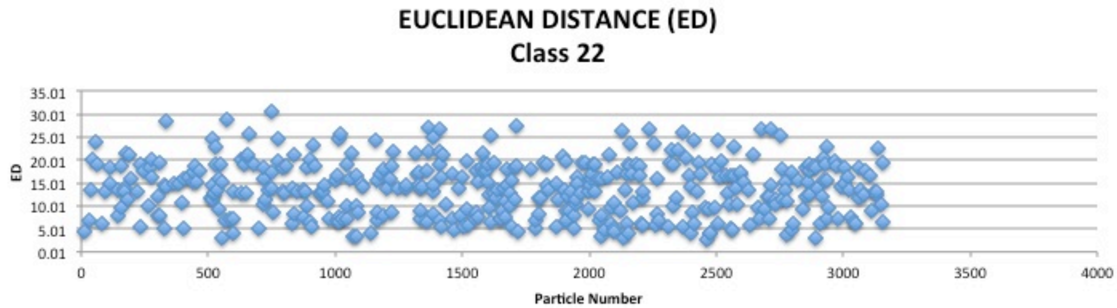

Figure 5-106: Euclidean Distance Class 22

Class 23 of Bodele 83 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 500 particles in this class (Figure 5-107).

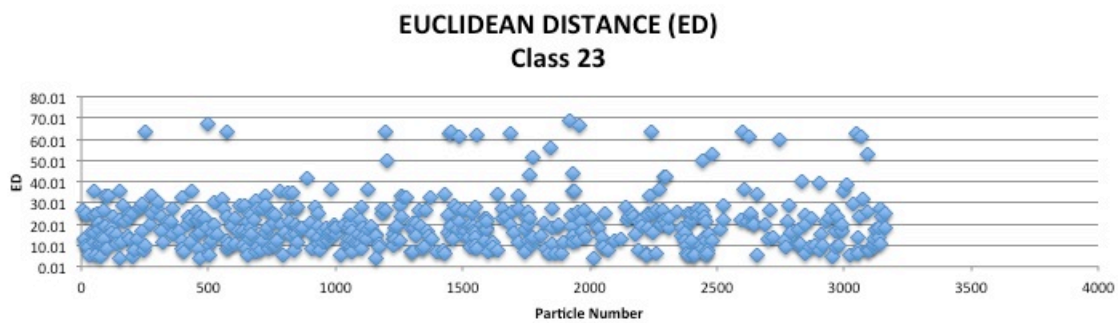

Figure 5-107: Euclidean Distance Class 23

Class 24 of Bodele 83 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 67 particles in this class (Figure 5-108).

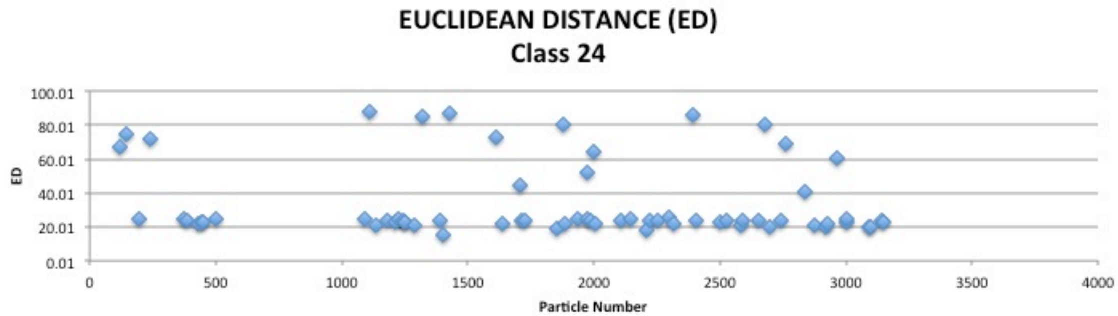

Figure 5-108: Euclidean Distance Class 24

Class 25 of Bodele 83 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 298 particles in this class (Figure 5-109).

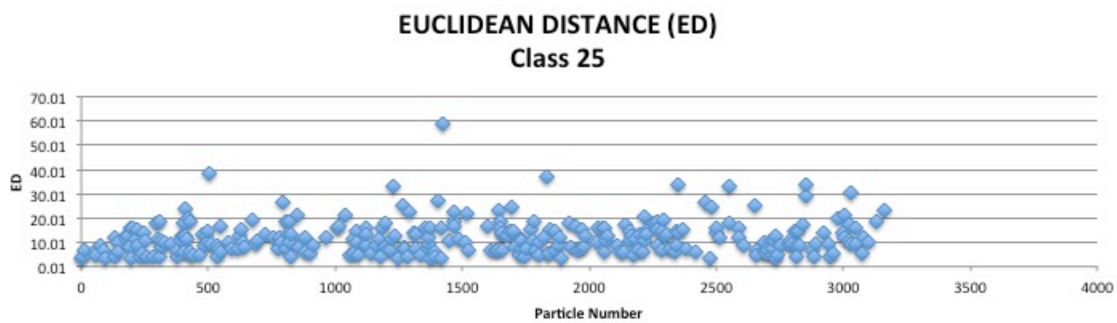

Figure 5-109: Euclidean Distance Class 25

Class 26 of Bodele 83 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 223 particles in this class (Figure 5-110).

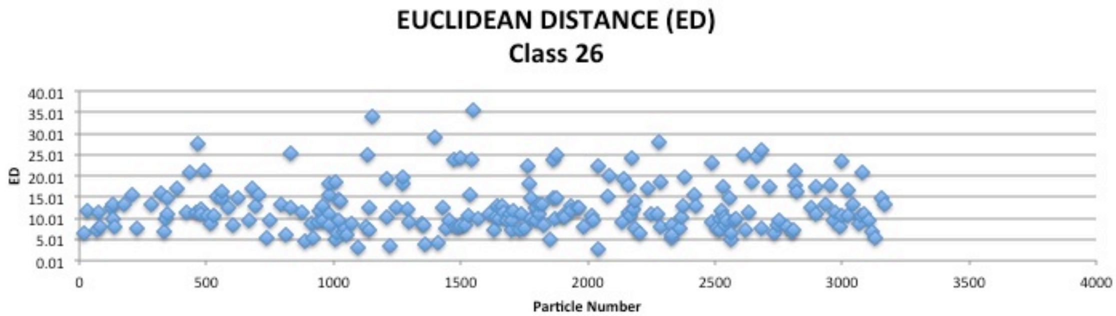

Figure 5-110: Euclidean Distance Class 26

Class 27 of Bodele 83 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 117 particles in this class (Figure 5-111).

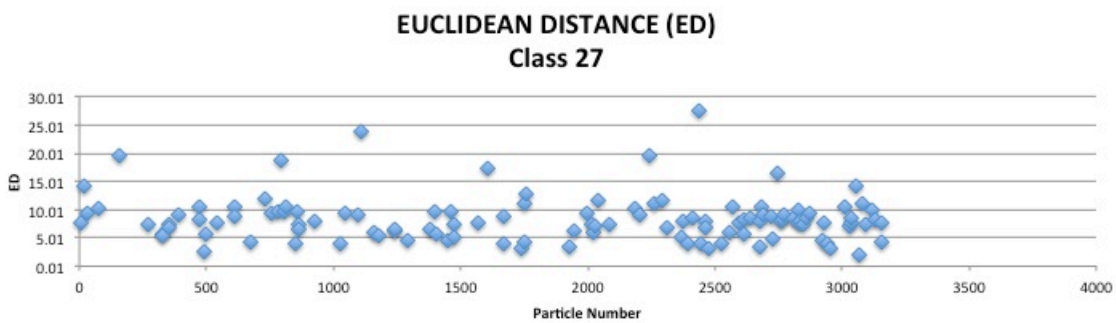

Figure 5-111: Euclidean Distance Class 27

Class 28 of Bodele 83 is composed of Aluminum less than 1%. There are a total of 86 particles in this class (Figure 5-112).

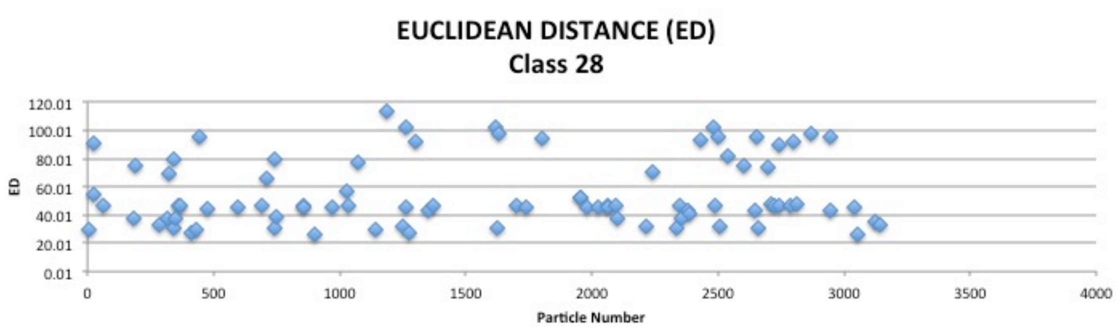

Figure 5-112: Euclidean Distance Class 28

Bodele 84

Numerical and Volumetric Analysis

Bodele 84, located at 17 13.777' N, 19 02.149' E, was elementally separated into 29 separate classes (Figure 5-113). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-9).

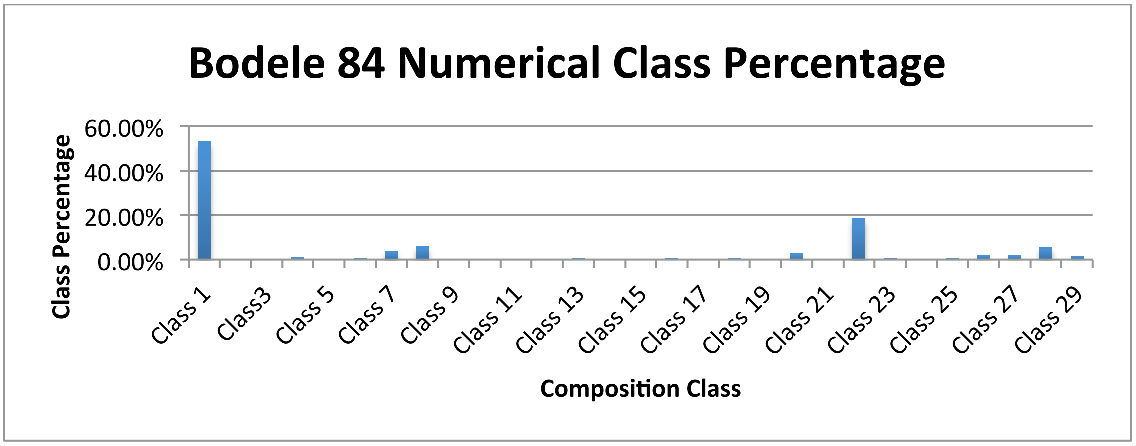

Figure 5-113: Bodele 84 showing the number of particles in percentages of elemental classes.

Table 5-9: Numerical Percentage showing the three highest class percentages and the total number of particles and percentages.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
1683	6	1	30	1	17	123	185
53.01%	0.19%	0.03%	0.94%	0.03%	0.54%	3.87%	5.83%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
1	1	0	0	20	1	0	14
0.03%	0.03%	0.00%	0.00%	0.63%	0.03%	0.00%	0.44%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
8	18	2	83	9	583	13	0
0.25%	0.57%	0.06%	2.61%	0.28%	18.36%	0.41%	0.00%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
20	64	62	177	53	3175		
0.63%	2.02%	1.95%	5.57%	1.67%	100.00%		

Table 5-9 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 1, 8, and 21. Class 1 has Silica greater than 99%. Class 8 has Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica Greater than 60%. This represents 77.20% of the entire sample and contains a total of 2451 particles. Class 29 represents the “unclassified” particles and contains only 1.67% of the entire sample.

The volumetric percentage of Bodele 84 represents the volume of particles that are represented in each respective elemental class (Figure 5-114).

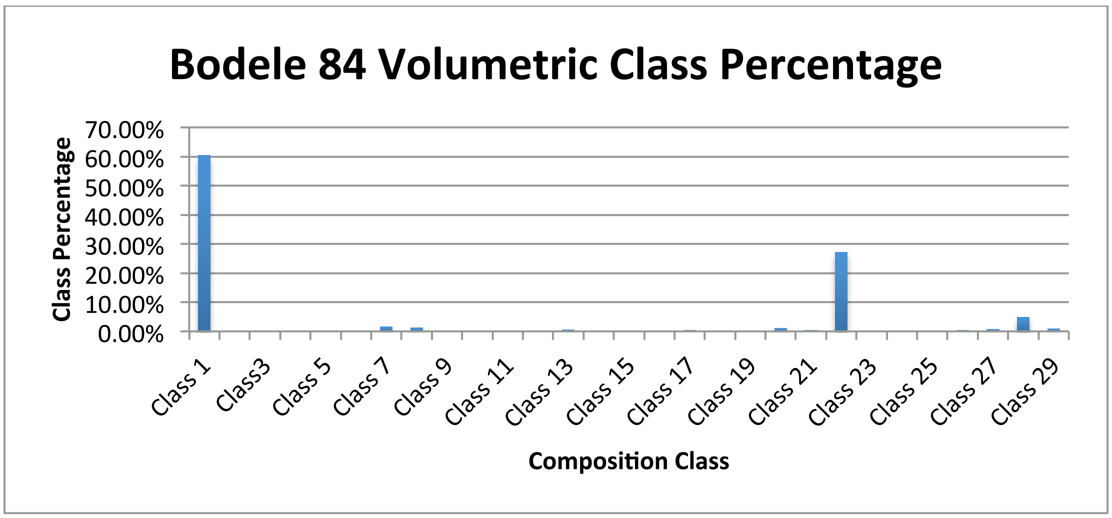

Figure 5-114: Volumetric percentage of elements within each respective class.

Table 5-10 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 1, 22, and 28, which is consistent with the numerical percentages. Class 1 has Silica greater than 99%. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica Greater than 60%. Class 28 has Aluminum less than 1%. This represents 92.41% of the entire sample and contains a total volume of 322998.54 μm^3. Class 29 represents the “unclassified” volume of particles and contains 0.85% of the entire sample.

Table 5-10: Graph of Bodele 84 showing the volume of each class within the sample. The three highest classes are highlighted along with the total volume and percentage of the sample.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
211062.73	111.20	7.64	309.00	0.20	138.86	5354.98	4169.98
60.38%	0.03%	0.00%	0.09%	0.00%	0.04%	1.53%	1.19%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
465.58	2.62	0.00	0.00	2039.70	9.19	0.00	13.70
0.13%	0.00%	0.00%	0.00%	0.58%	0.00%	0.00%	0.00%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
1101.19	274.27	192.88	3522.23	1262.80	94847.37	410.26	0.00
0.32%	0.08%	0.06%	1.01%	0.36%	27.14%	0.12%	0.00%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
262.75	1114.17	2798.62	17088.44	2975.33	349535.69		
0.08%	0.32%	0.80%	4.89%	0.85%	100.00%		

Analysis of class 29 showed no significant clusters of elements. The highest elements contained within Bodele 84 are Fe, Si, and Al. These elements are evenly distributed across the elements (Figure 5-115 and Figure 5-116). There are no significant clusters of particles to add additional classes to this sample.

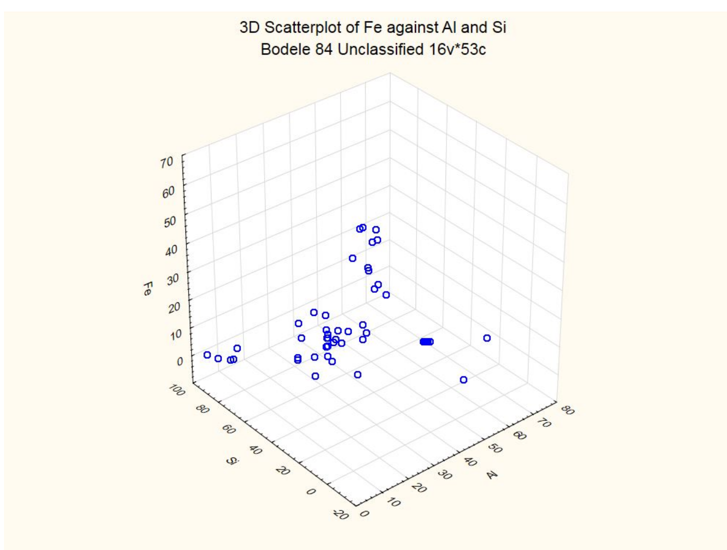

Figure 5-115: Scatterplot of Bodele 84 elements Al, Si and Fe, showing no clusters of particles

within the sample.

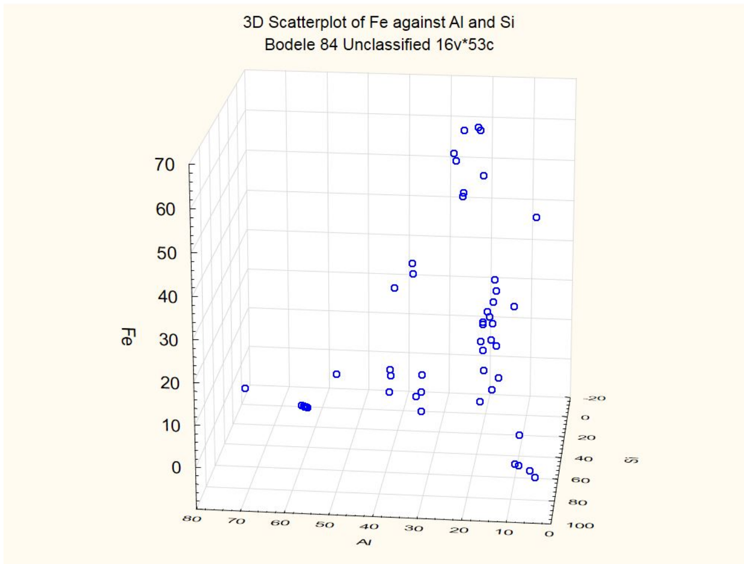

Figure 5-116: Scatterplot of Bodele 84 elements Al, Si and Fe, showing no clusters of particles within the sample.

Euclidean Distance

The Euclidean Distance for Class 1 of Bodele 84 is composed of greater than 99% Silica. There are a total of 1683 particles in this class (Figure 5-117).

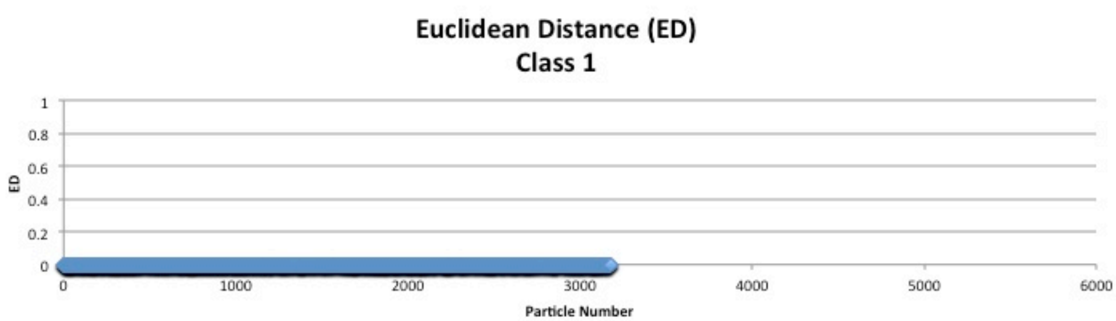

Figure 5-117: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 6 particles in this class (Figure 5-118).

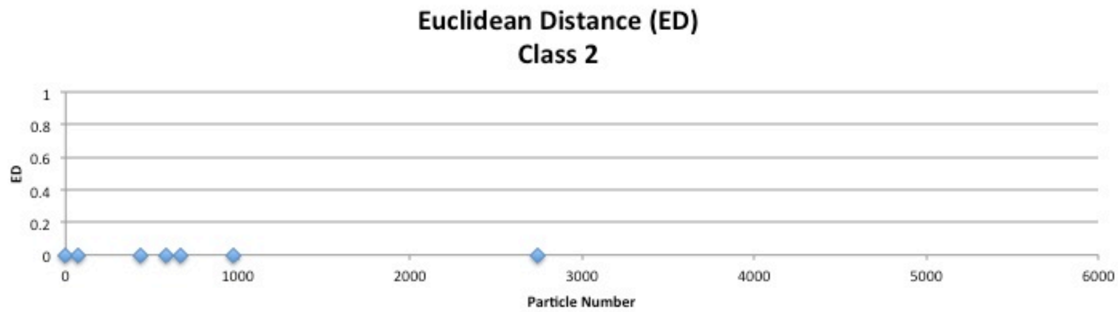

Figure 5-118: Euclidean Distance Class 2

Class 3 of Bodele 84 is composed of greater than 99% Calcium. There is a total of 1 particle in this class (Figure 5-119).

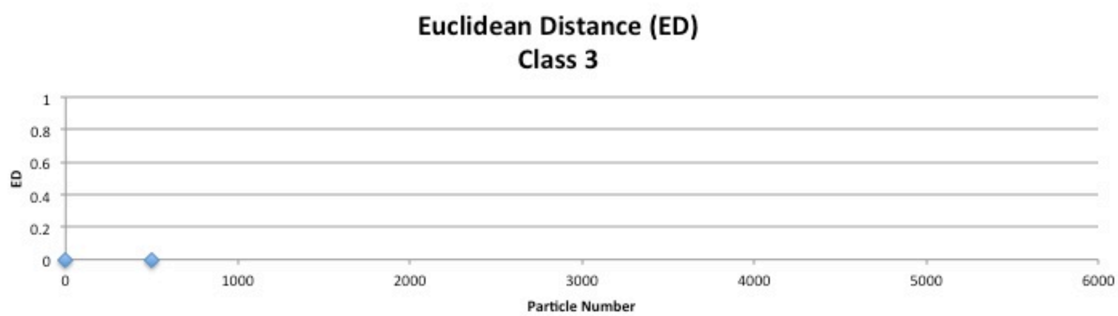

Figure 5-119: Euclidean Distance Class 3

Class 4 of Bodele 84 is composed of Titanium greater than 55% and Lead less than 5%. There are 30 particles in this class (Figure 5-120).

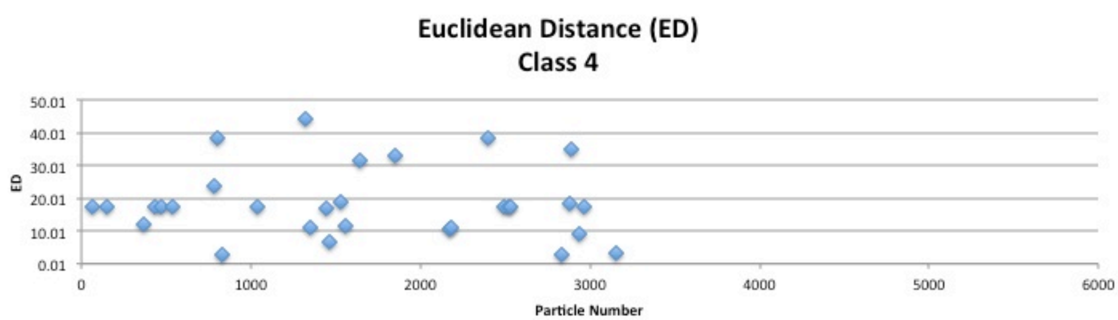

Figure 5-120: Euclidean Distance Class 4

Class 5 of Bodele 84 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There is 1 particle in this class (Figure 5-121).

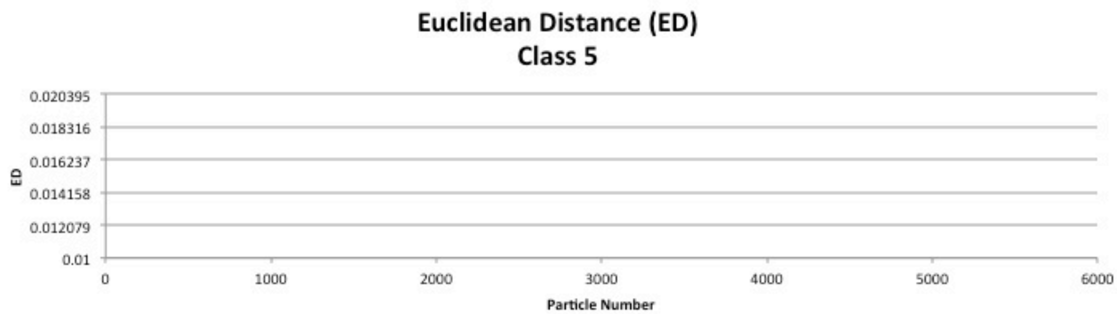

Figure 5-121: Euclidean Distance Class 1

Class 6 of Bodele 84 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 17 particles in this class (Figure 5-122).

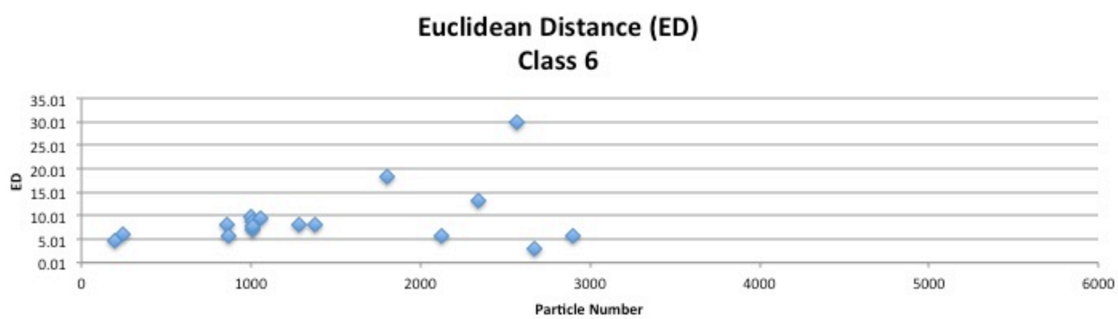

Figure 5-122: Euclidean Distance Class 6

Class 7 of Bodele 84 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 123 particles in this class (Figure 5-123).

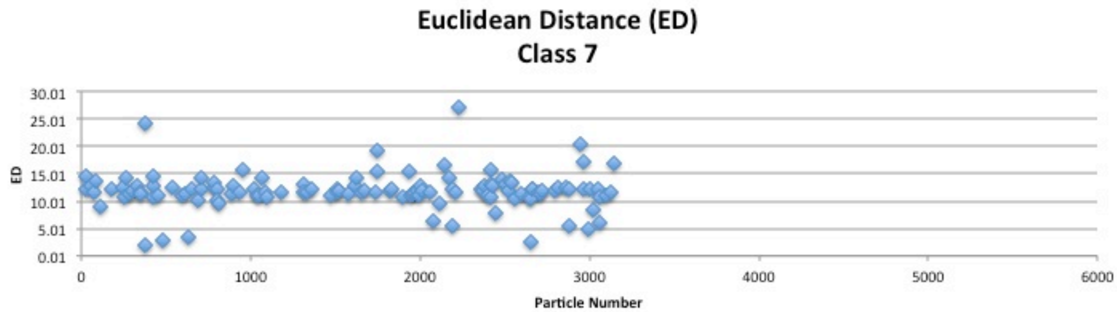

Figure 5-123: Euclidean Distance Class 7

Class 8 of Bodele 84 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 185 particles in this class (Figure 5-124).

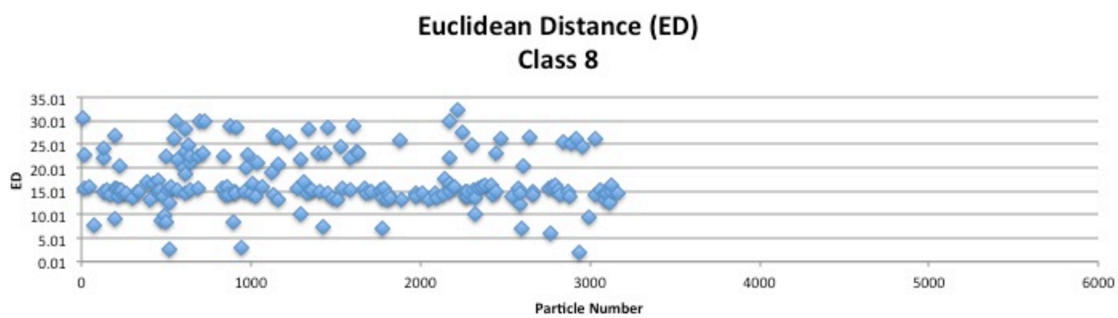

Figure 5-124: Euclidean Distance Class 8

Class 9 of Bodele 84 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There is 1 particle in this class (Figure 5-125).

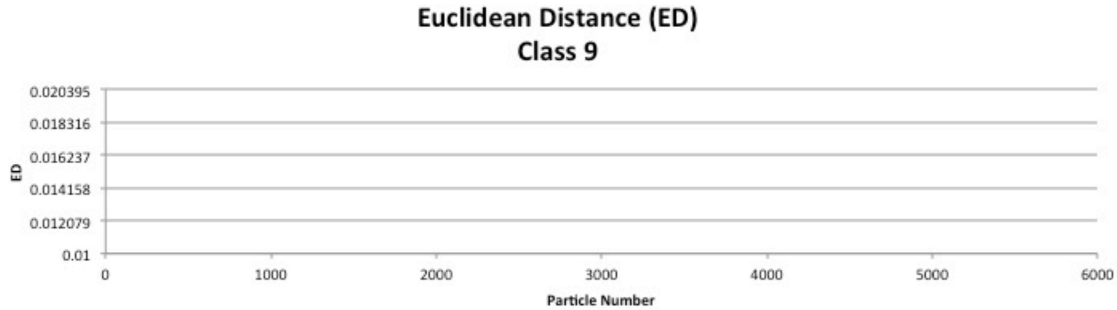

Figure 5-125: Euclidean Distance Class 9

Class 10 of Bodele 84 is composed of Calcium greater than 80% and Lead less than 5%. There is 1 particle in this class (Figure 5-126).

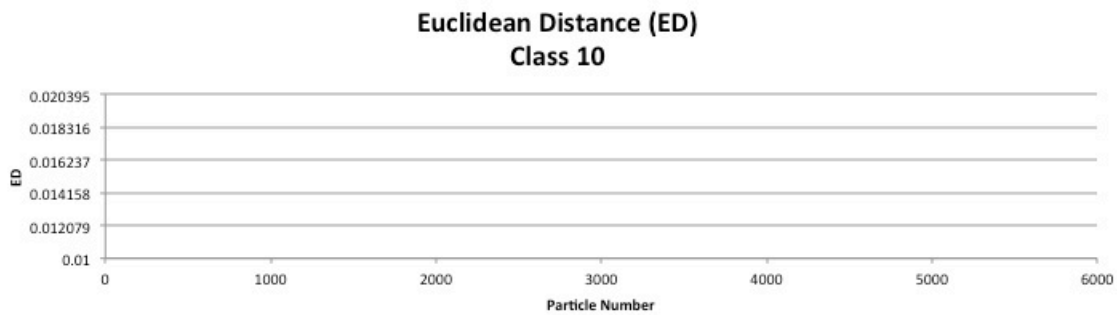

Figure 5-126: Euclidean Distance Class 10

Class 11 of Bodele 84 is composed of the total Calcium and Manganese greater than 90%. There are no particles in this class.

Class 12 of Bodele 84 is composed of the total Calcium and Phosphorus greater than 90%. There are no particles in this class.

Class 13 of Bodele 84 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 20 particles in this class (Figure 5-127).

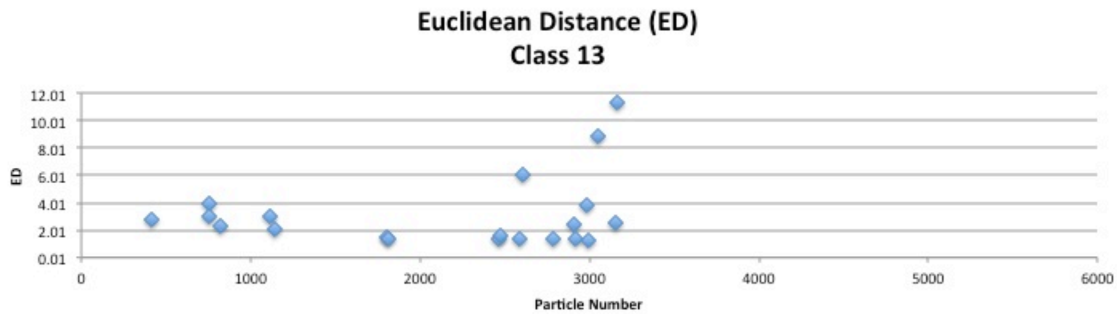

Figure 5-127: Euclidean Distance Class 13

Class 14 of Bodele 84 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There is a total of 1 particle in this class (Figure 5-128).

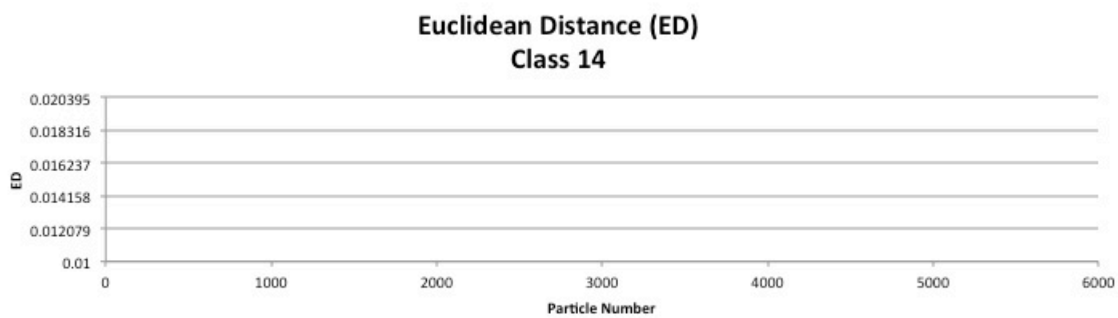

Figure 5-128: Euclidean Distance Class 14

Class 15 of Bodele 84 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Bodele 84 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 14 particles in this class (Figure 5-129).

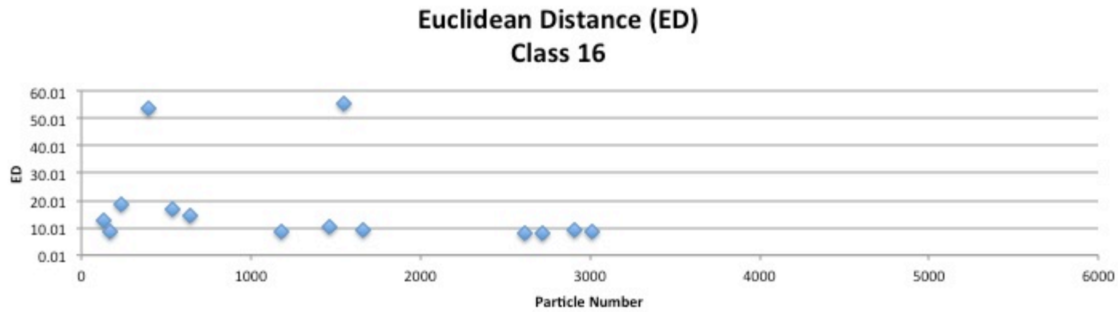

Figure 5-129: Euclidean Distance Class 16

Class 17 of Bodele 84 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 8 particles in this class (Figure 5-130).

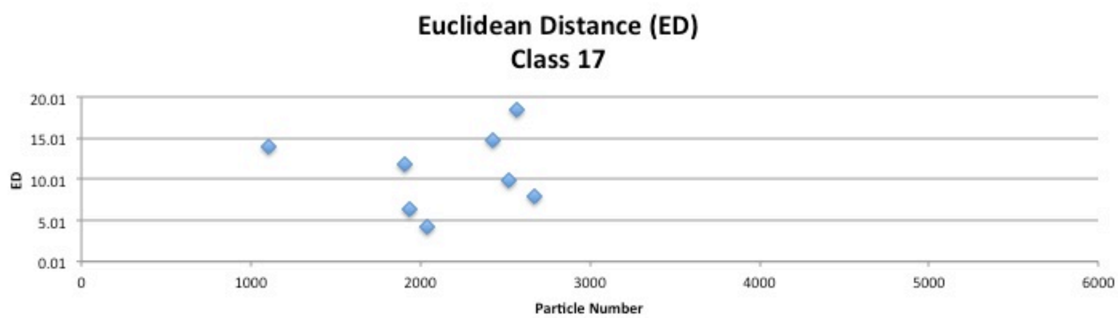

Figure 5-130: Euclidean Distance Class 17

Class 18 of Bodele 84 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 18 particles in this class (Figure 5-131).

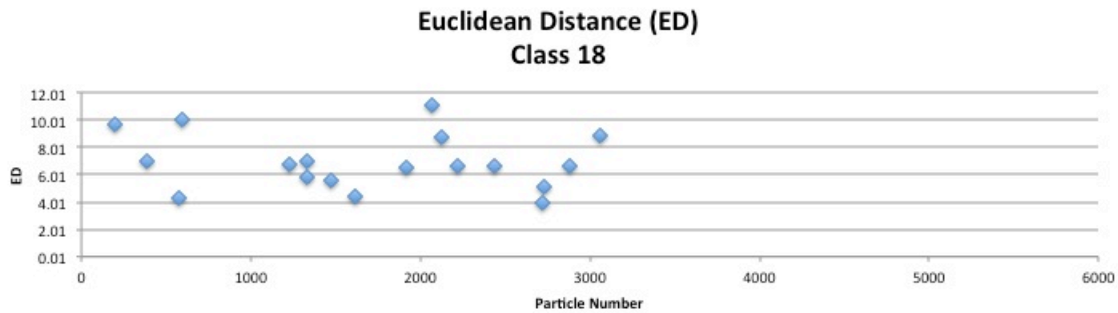

Figure 5-131: Euclidean Distance Class 18

Class 19 of Bodele 84 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 2 particles in this class (Figure 5-132).

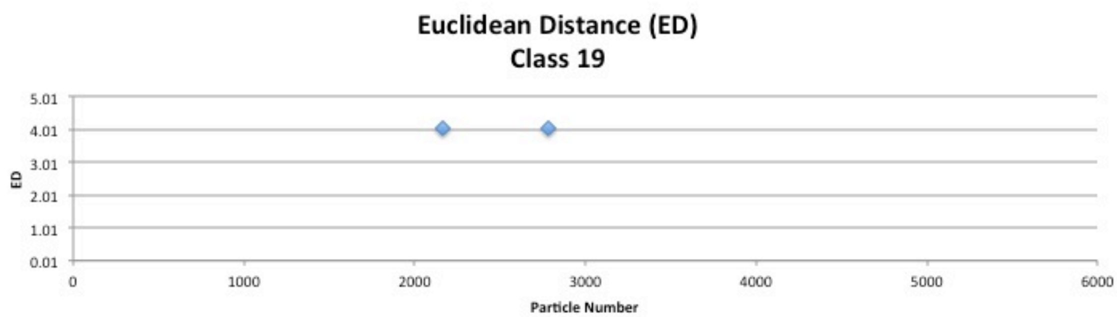

Figure 5-132: Euclidean Distance Class 19

Class 20 of Bodele 84 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 83 particles in this class (Figure 5-133).

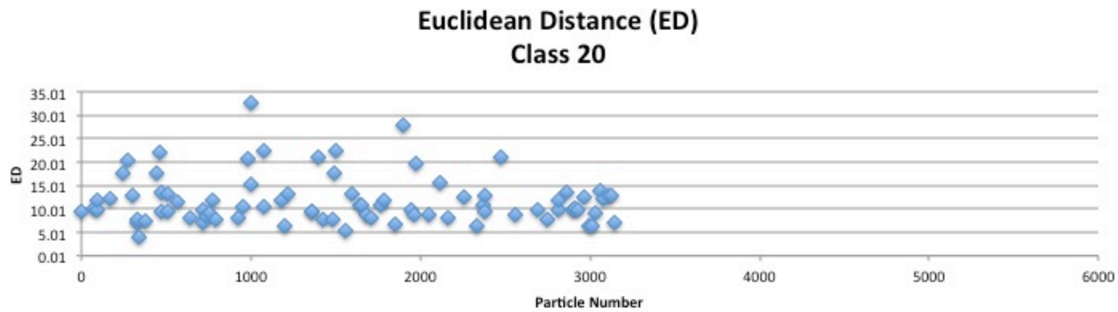

Figure 5-133: Euclidean Distance Class 20

Class 21 of Bodele 84 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 9 particles in this class (Figure 5-134).

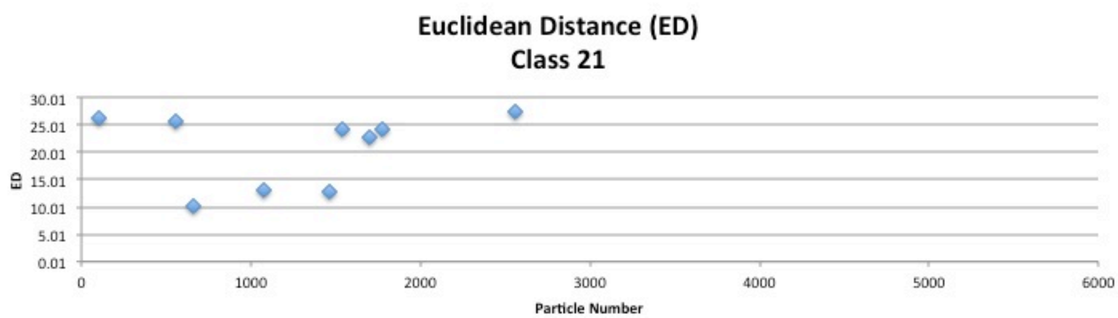

Figure 5-134: Euclidean Distance Class 21

Class 22 of Bodele 84 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 583 particles in this class (Figure 5-135).

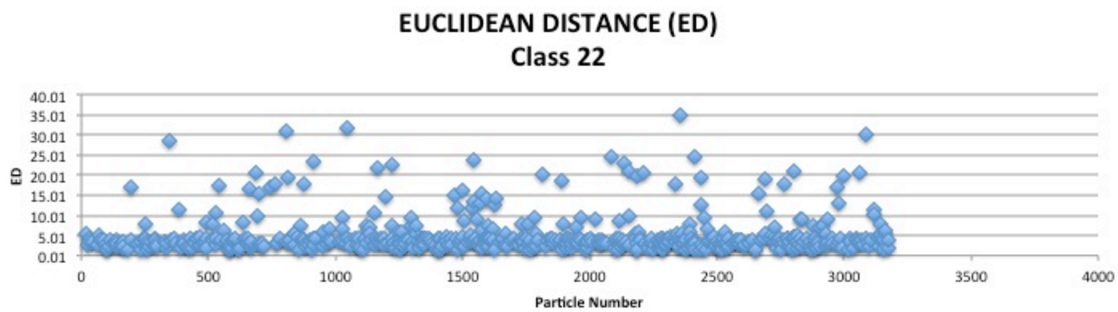

Figure 5-135: Euclidean Distance Class 22

Class 23 of Bodele 84 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 13 particles in this class (Figure 5-136).

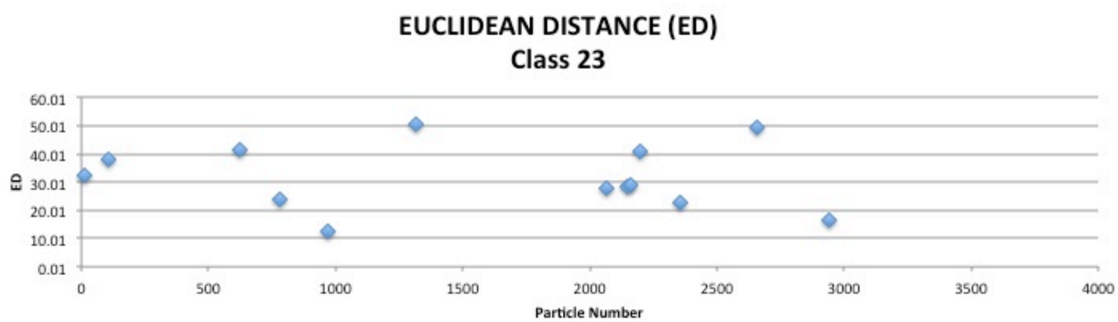

Figure 5-136: Euclidean Distance Class 23

Class 24 of Bodele 84 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are no particles in this class.

Class 25 of Bodele 84 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 20 particles in this class (Figure 5-137).

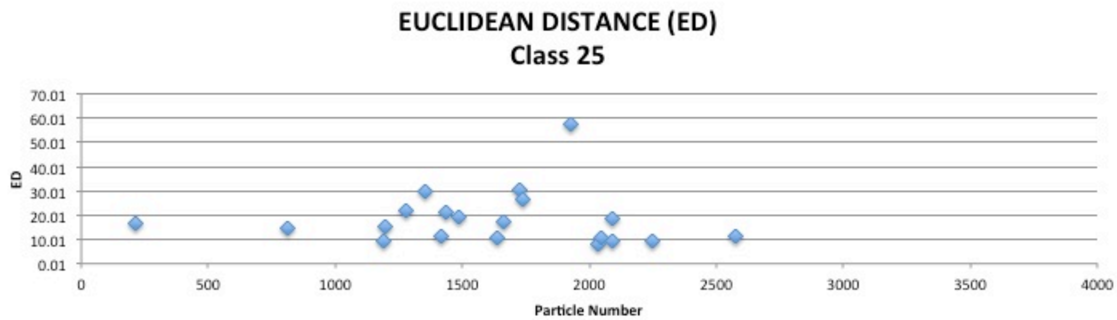

Figure 5-137: Euclidean Distance Class 25

Class 26 of Bodele 84 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 64 particles in this class (Figure 5-138).

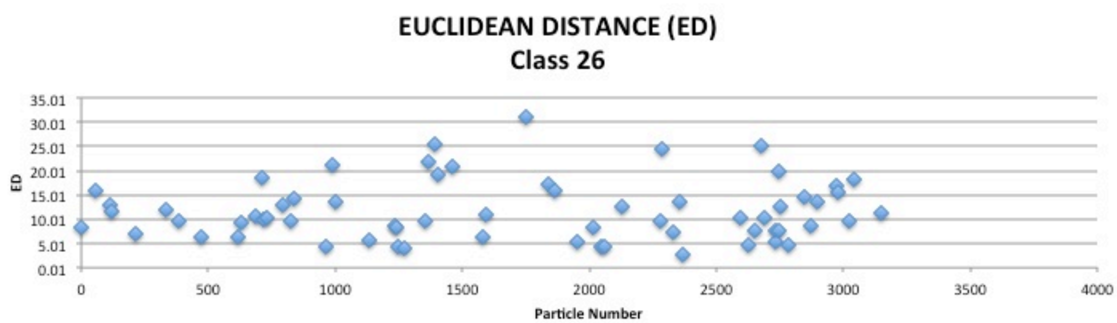

Figure 5-138: Euclidean Distance Class 26

Class 27 of Bodele 84 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 62 particles in this class (Figure 5-139).

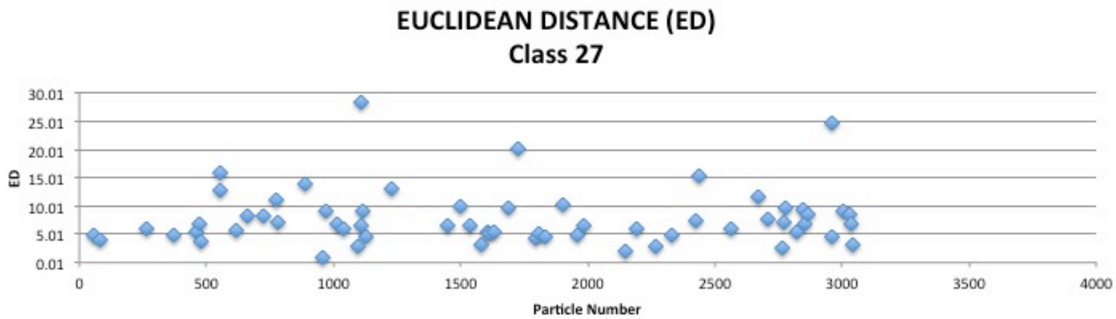

Figure 5-139: Euclidean Distance Class 27

Class 28 of Bodele 84 is composed of Aluminum less than 1%. There are a total of 177 particles in this class (Figure 5-140).

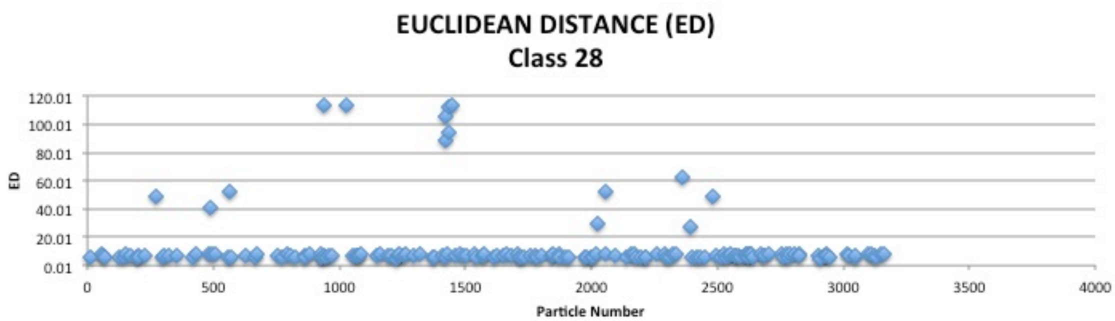

Figure 5-140: Euclidean Distance Class 28

Bodele 85

Numerical and Volumetric Analysis

Bodele 85, located at 16 09.190' N, 18 35.464' E in the same position as Bodele 86, was elementally separated into 29 separate classes (Figure 5-141). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-11).

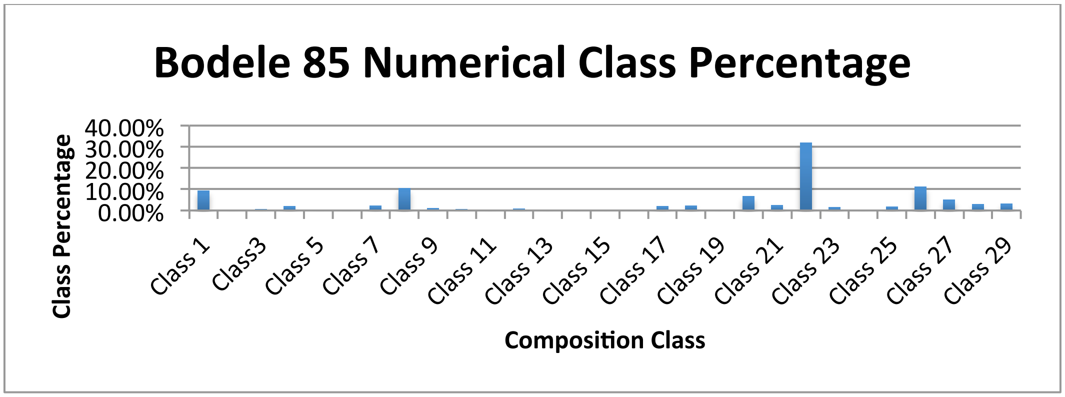

Figure 5-141: Bodele 85 showing the number of particles in percentages of elemental classes.

Table 5-11: Numerical Percentage showing the three highest class percentages and the total number of particles and percentages.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
375	13	23	76	0	16	93	417
9.38%	0.33%	0.58%	1.90%	0.00%	0.40%	2.33%	10.43%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
40	23	1	34	4	0	0	14
1.00%	0.58%	0.03%	0.85%	0.10%	0.00%	0.00%	0.35%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
79	94	7	268	102	1274	60	12
1.98%	2.35%	0.18%	6.70%	2.55%	31.85%	1.50%	0.30%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
74	450	203	119	129	4000		
1.85%	11.25%	5.08%	2.98%	3.23%	100.00%		

Table 5-11 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 8, 22, and 26. Class 8 has Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. Class 22 is composed of

Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica Greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. This represents 53.53% of the entire sample and contains a total of 2141 particles. Class 29 represents the “unclassified” particles and contains only 3.23% of the entire sample.

The volumetric percentage of Bodele 85 represents the volume of particles that are represented in each respective elemental class (Figure 5-142).

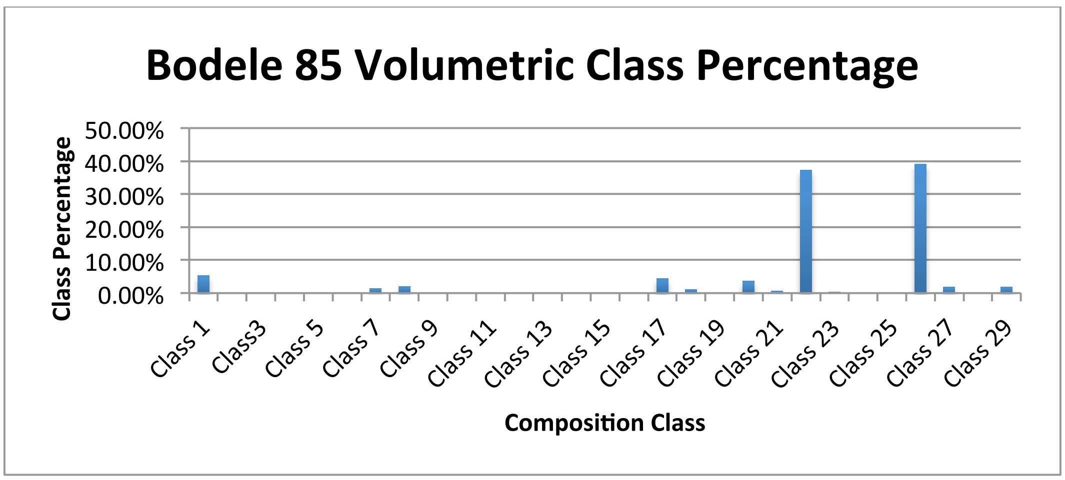

Figure 5-142: Volumetric percentage of elements within each respective class.

Table 5-12 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 1, 22, and 26, which is consistent with the numerical percentages. Class 1 has Silica greater than 99%. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica Greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. This represents 81.73% of the entire sample and contains a total volume of 49206.96 μm^3. Class 29 represents the “unclassified” volume of particles and contains 1.89% of the entire sample.

Table 5-12: Graph of Bodele 85 showing the volume of each class within the sample. The three highest classes are highlighted along with the total volume and percentage of the sample.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
3221.88	9.90	12.38	60.53	0.00	11.46	863.15	1242.21
5.35%	0.02%	0.02%	0.10%	0.00%	0.02%	1.43%	2.06%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
80.68	29.98	0.07	29.22	12.23	0.00	0.00	19.92
0.13%	0.05%	0.00%	0.05%	0.02%	0.00%	0.00%	0.03%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
2627.08	694.65	31.99	2187.38	368.69	22476.99	168.17	5.62
4.36%	1.15%	0.05%	3.63%	0.61%	37.33%	0.28%	0.01%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
158.03	23508.09	1130.86	118.75	1135.88	60205.78		
0.26%	39.05%	1.88%	0.20%	1.89%	100.00%		

Analysis of class 29 showed no significant clusters of elements. The highest elements contained within Bodele 85 are Fe, Si, and Al. These elements are evenly distributed across the elements (Figure 5-143 and Figure 5-144). There are no significant clusters of particles to add additional classes to this sample.

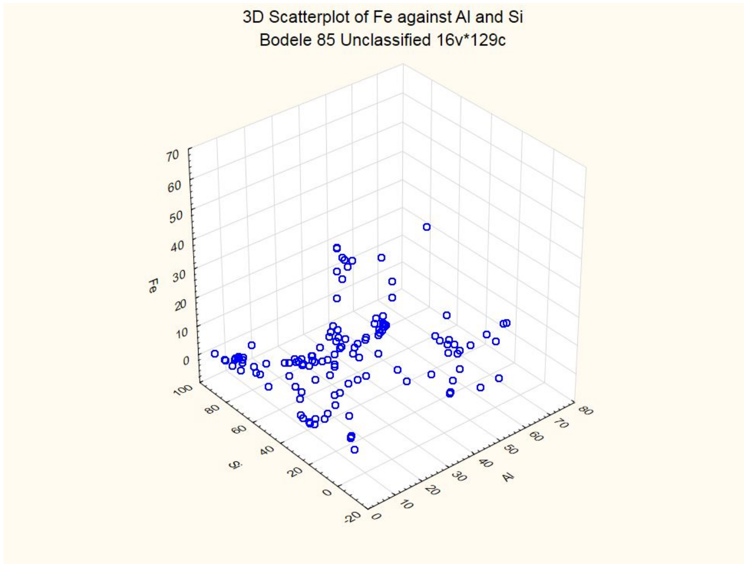

Figure 5-143: Scatterplot of Bodele 85 elements Al, Si and Fe, showing no clusters of particles within the sample.

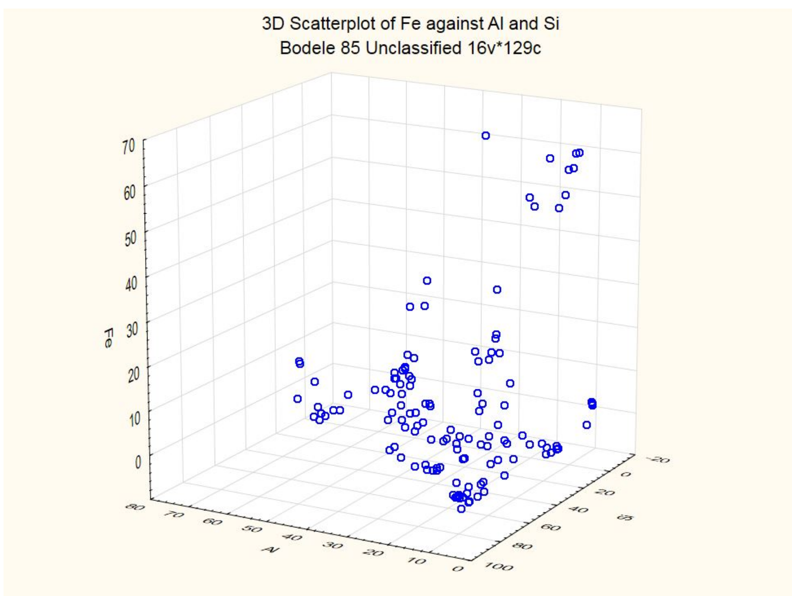

Figure 5-144: Scatterplot of Bodele 85 elements Al, Si and Fe, showing no clusters of particles within the sample.

Euclidean Distance

The Euclidean Distance for Class 1 of Bodele 85 is composed of greater than 99% Silica. There are a total of 375 particles in this class (Figure 5-145).

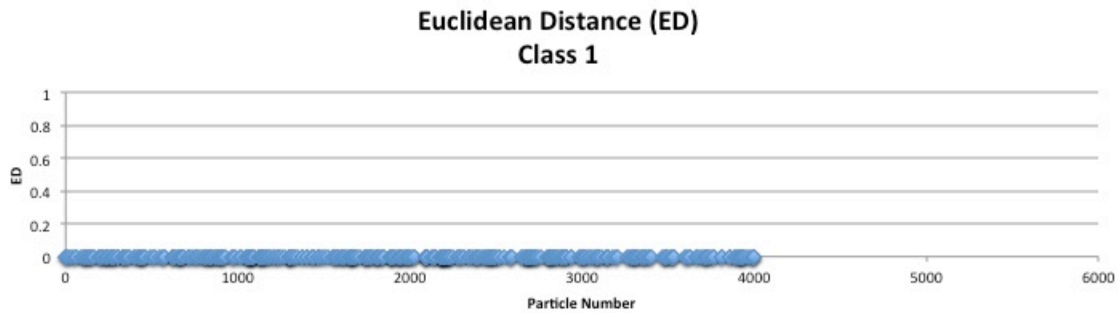

Figure 5-145: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 13 particles in this class (Figure 5-146).

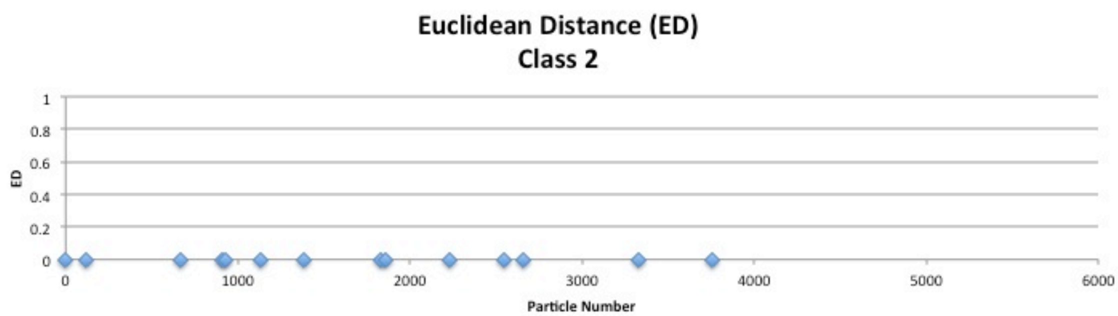

Figure 5-146: Euclidean Distance Class 2

Class 3 of Bodele 85 is composed of greater than 99% Calcium. There has a total of 23 particles in this class (Figure 5-147).

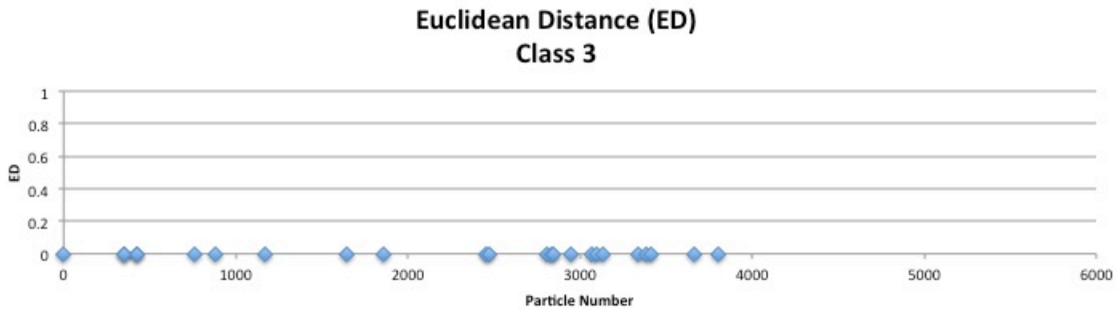

Figure 5-147: Euclidean Distance Class 3

Class 4 of Bodele 85 is composed of Titanium greater than 55% and Lead less than 5%. There are 76 particles in this class (Figure 5-148).

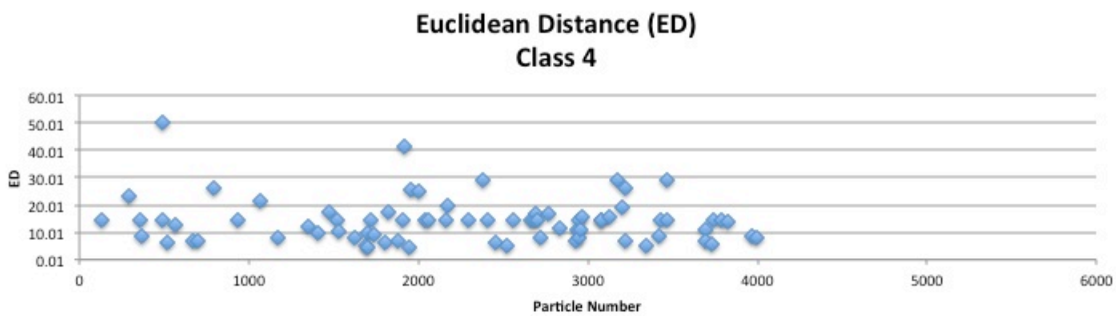

Figure 5-148: Euclidean Distance Class 4

Class 5 of Bodele 85 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Bodele 85 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 16 particles in this class (Figure 5-149).

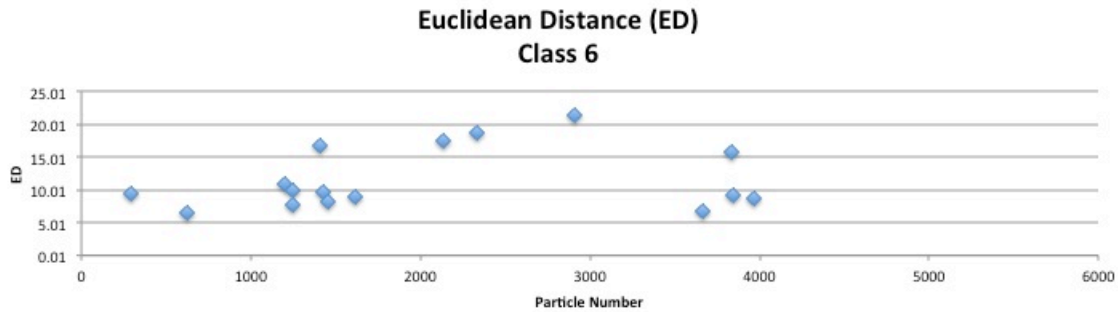

Figure 5-149: Euclidean Distance Class 6

Class 7 of Bodele 85 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 93 particles in this class (Figure 5-150).

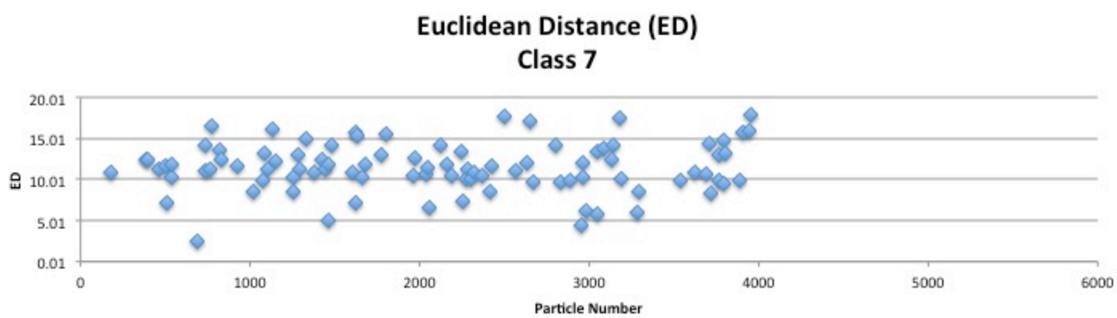

Figure 5-150: Euclidean Distance Class 7

Class 8 of Bodele 85 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 417 particles in this class (Figure 5-151).

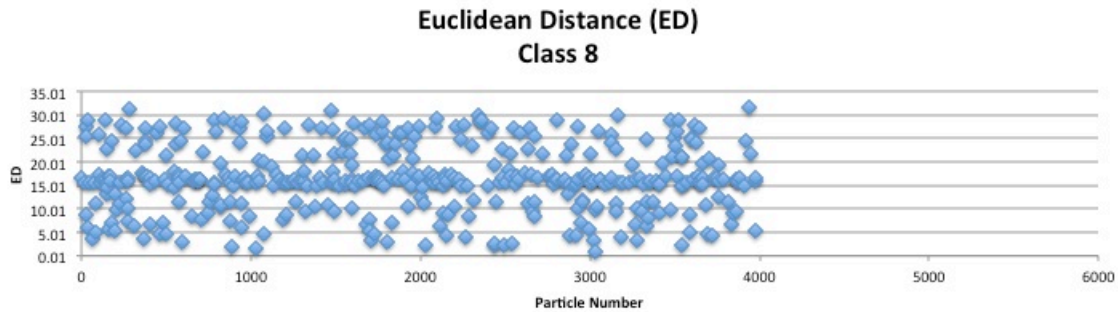

Figure 5-151: Euclidean Distance Class 8

Class 9 of Bodele 85 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 40 particles in this class (Figure 5-152).

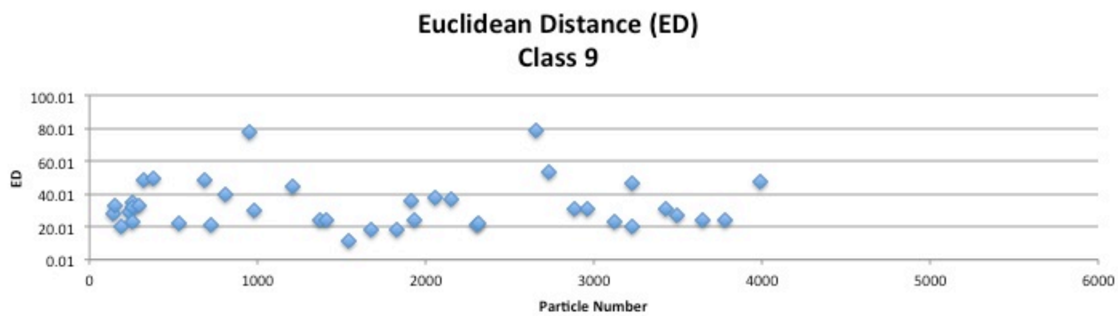

Figure 5-152: Euclidean Distance Class 9

Class 10 of Bodele 85 is composed of Calcium greater than 80% and Lead less than 5%. There are 23 particles in this class (Figure 5-153).

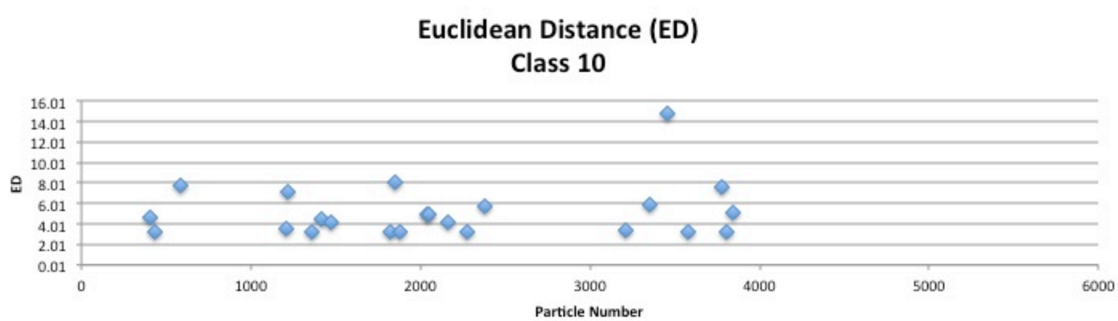

Figure 5-153: Euclidean Distance Class 10

Class 11 of Bodele 85 is composed of the total Calcium and Manganese greater than 90%. There is 1 particle in this class (Figure 5-154).

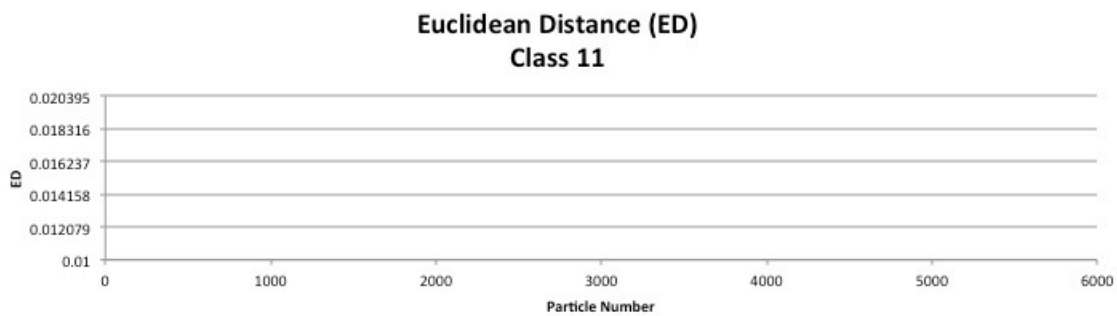

Figure 5-154: Euclidean Distance Class 11

Class 12 of Bodele 85 is composed of the total Calcium and Phosphorus greater than 90%. There are 34 particles in this class (Figure 5-155).

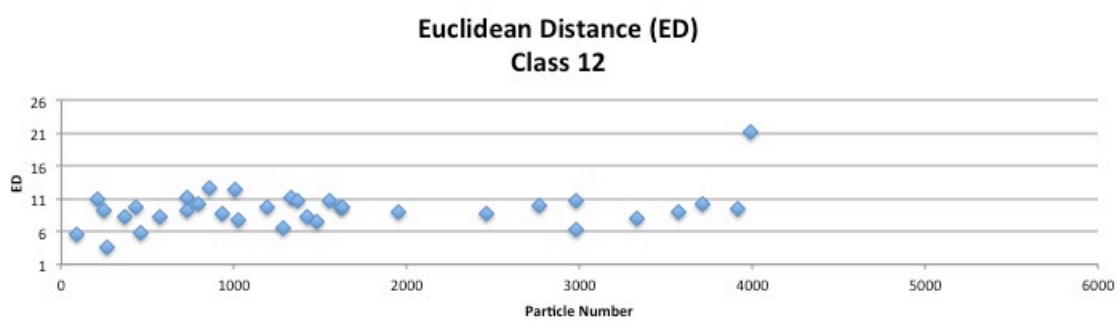

Figure 5-155: Euclidean Distance Class 12

Class 13 of Bodele 85 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 4 particles in this class (Figure 5-156).

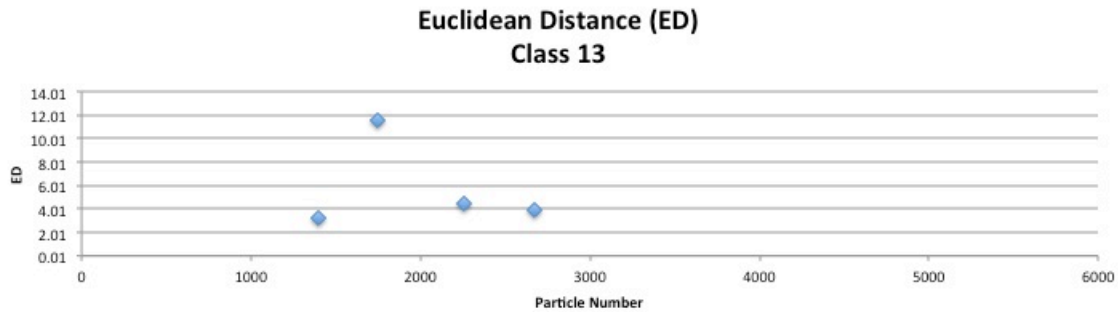

Figure 5-156: Euclidean Distance Class 13

Class 14 of Bodele 85 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are no particles in this class.

Class 15 of Bodele 85 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Bodele 85 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 14 particles in this class (Figure 5-157).

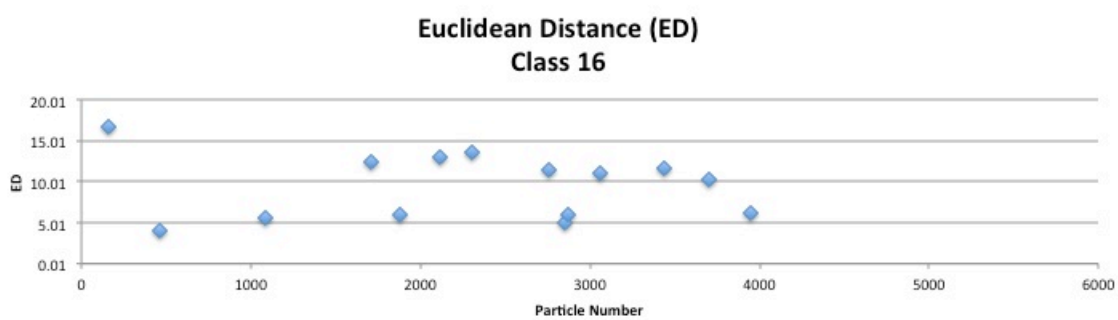

Figure 5-157: Euclidean Distance Class 16

Class 17 of Bodele 85 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 79 particles in this class (Figure 5-158).

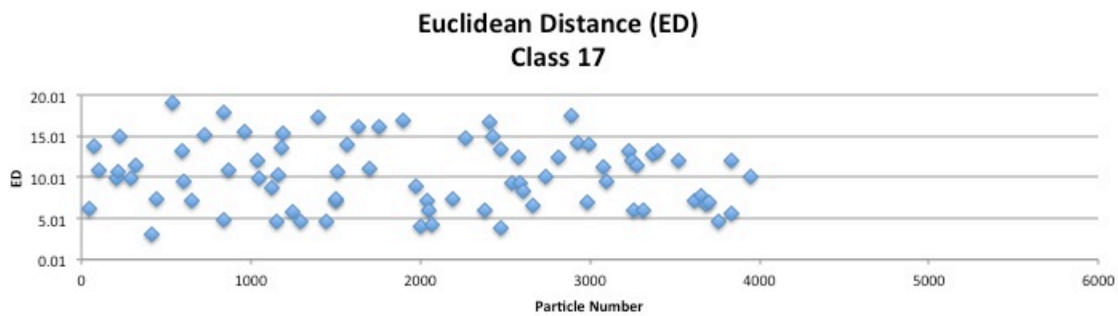

Figure 5-158: Euclidean Distance Class 17

Class 18 of Bodele 85 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 94 particles in this class (Figure 5-159).

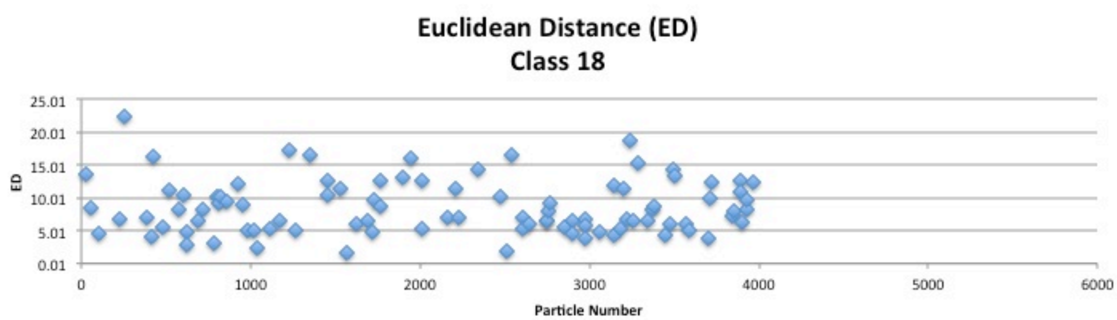

Figure 5-159: Euclidean Distance Class 18

Class 19 of Bodele 85 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 7 particles in this class (Figure 5-160).

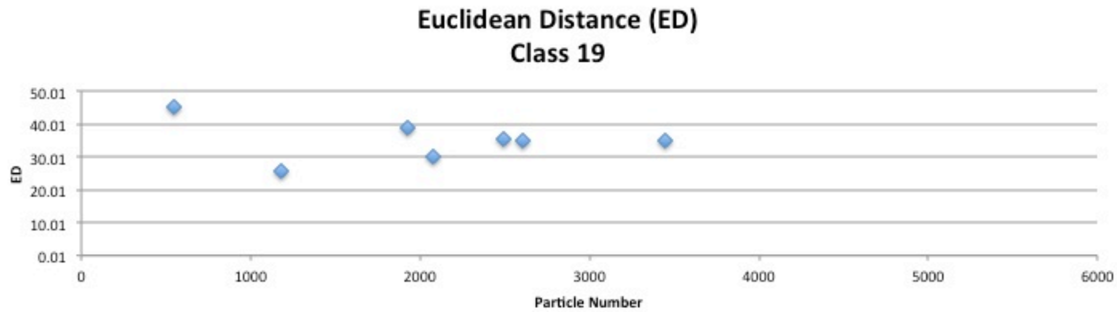

Figure 5-160: Euclidean Distance Class 19

Class 20 of Bodele 85 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 268 particles in this class (Figure 5-161).

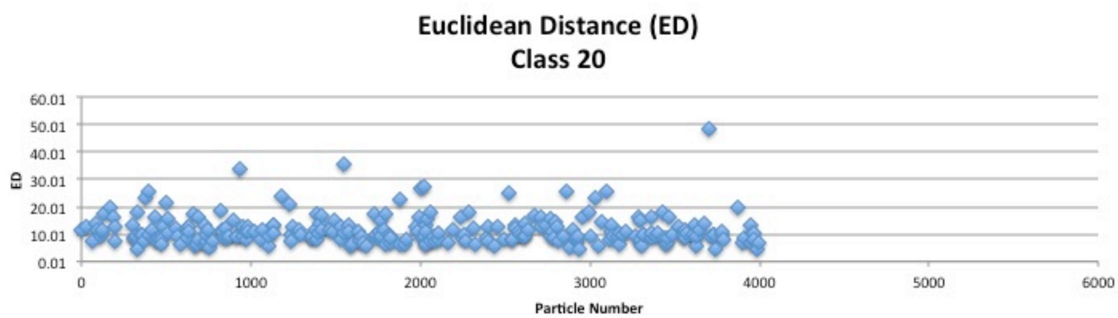

Figure 5-161: Euclidean Distance Class 20

Class 21 of Bodele 85 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 102 particles in this class (Figure 5-162).

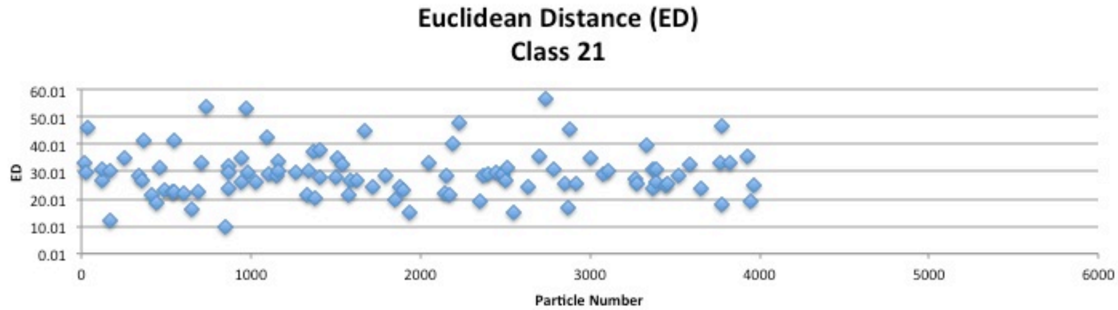

Figure 5-162: Euclidean Distance Class 21

Class 22 of Bodele 85 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 1274 particles in this class (Figure 5-163).

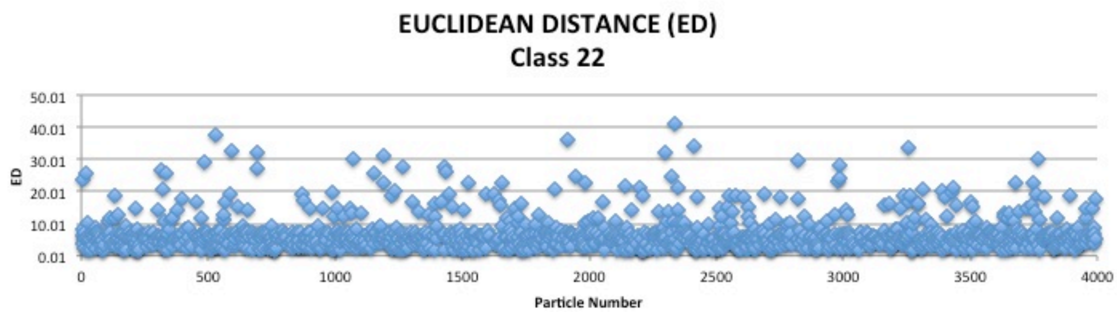

Figure 5-163: Euclidean Distance Class 22

Class 23 of Bodele 85 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 60 particles in this class (Figure 5-164).

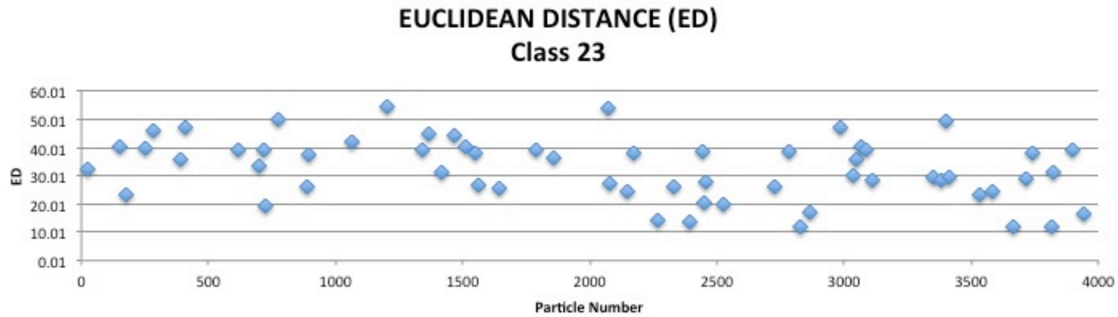

Figure 5-164: Euclidean Distance Class 23

Class 24 of Bodele 85 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are 12 particles in this class (Figure 5-165).

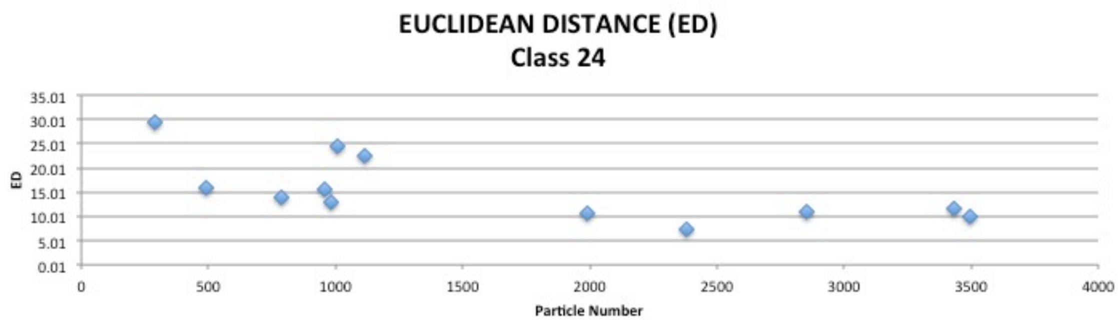

Figure 5-165: Euclidean Distance

Class 25 of Bodele 85 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 74 particles in this class (Figure 5-166).

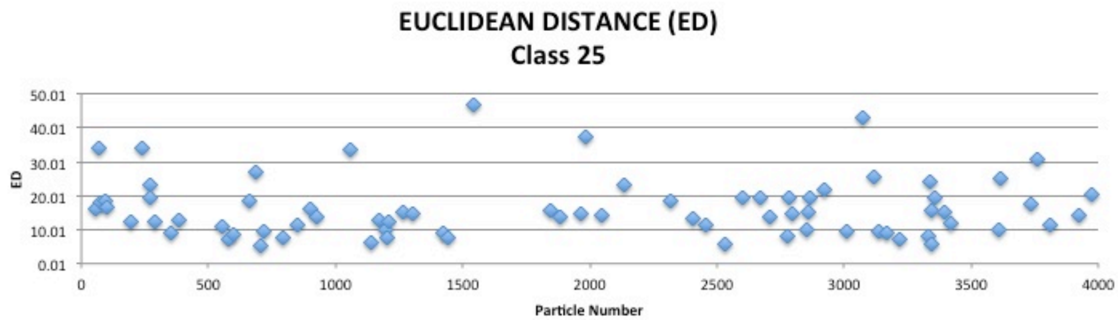

Figure 5-166: Euclidean Distance Class 25

Class 26 of Bodele 85 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 450 particles in this class (Figure 5-167).

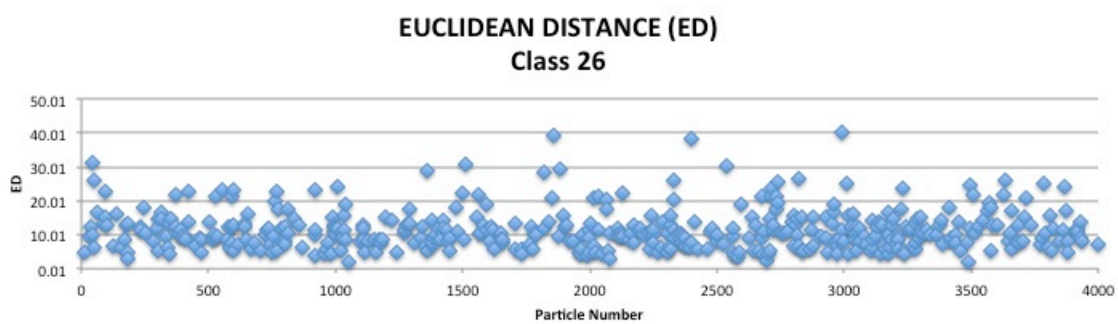

Figure 5-167: Euclidean Distance Class 26

Class 27 of Bodele 85 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 203 particles in this class (Figure 5-168).

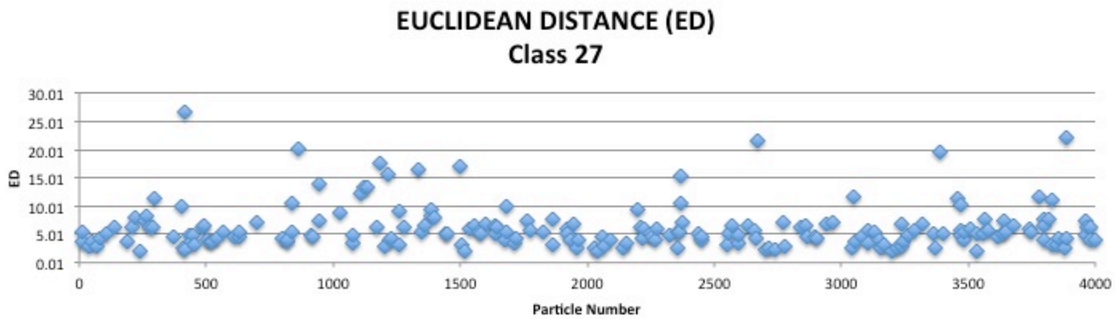

Figure 5-168: Euclidean Distance Class 27

Class 28 of Bodele 85 is composed of Aluminum less than 1%. There are a total of 119 particles in this class (Figure 5-169).

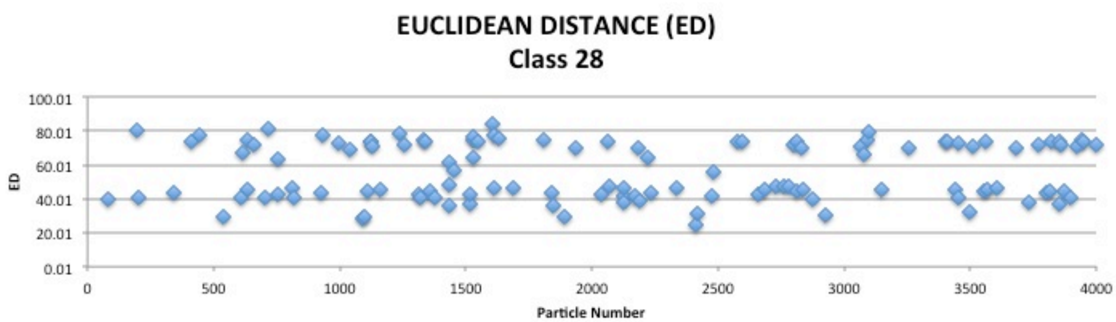

Figure 5-169: Euclidean Distance Class 28

Bodele 86

Numerical and Volumetric Analysis

Bodele 86, located at 16 09.190' N, 18 35.464' E, in the Bodele Depression was elementally separated into 29 separate classes (Figure 5-170). The numerical percentage shows the number of Particles in each class, and what percentage those particles represent to the entire class (Table 5-13)

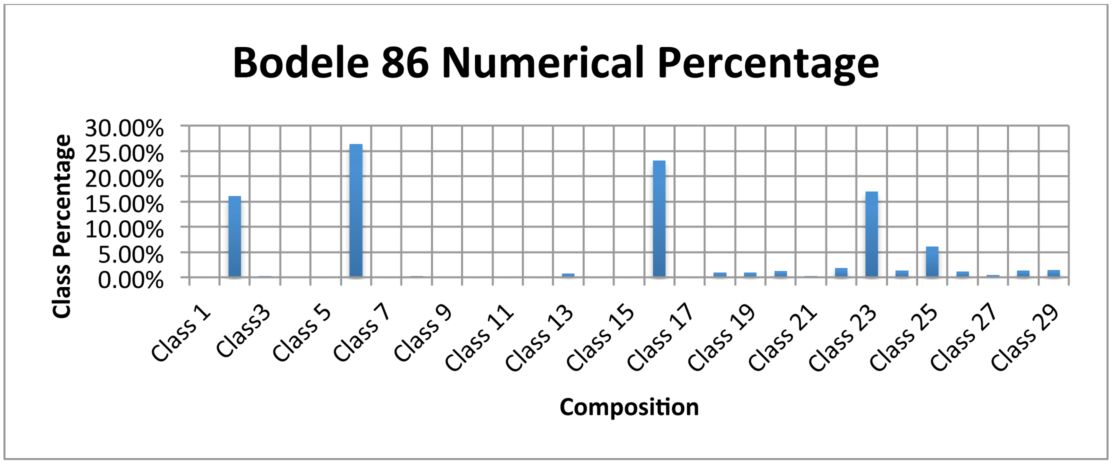

Figure 5-170: Bodele 86 showing the number of particles in percentages of elemental classes.

Table 5-13: Table Showing the Numerical Percentages of Bodele 86

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
3	603	6	0	0	992	0	9
0.08%	16.00%	0.16%	0.00%	0.00%	26.33%	0.00%	0.24%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	2	0	25	0	0	869
0.00%	0.00%	0.05%	0.00%	0.66%	0.00%	0.00%	23.06%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
0	33	32	44	6	68	639	49
0.00%	0.88%	0.85%	1.17%	0.16%	1.80%	16.96%	1.30%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
228	42	14	50	54	3768		
6.05%	1.11%	0.37%	1.33%	1.43%	100.00%		

Table 5-13 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 6, 16, and 23. Class 6 is composed of greater than 65% Iron and less than 1% Aluminum. Class 16 has Iron greater than 40% and the combination of Iron and Calcium totaling greater than 75%. Class 23 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. This represents 66.35% of the entire sample and contains a total of 2500 particles. Class 29 represents the “unclassified” particles and contains only 1.43% of the entire sample.

The volumetric percentage of Bodele 86 represents the volume of particles that are represented in each respective elemental class (figure 5-171). Table 5-14 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 6, 16, and 23, which is consistent with the numerical percentages. Class 6 is composed of greater than 65% Iron and less than 1% Aluminum. Class 16 has Iron greater than 40% and the combination of Iron and Calcium totaling greater than 75%. Class 23 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. This represents 62.84% of the entire sample and contains a total volume of 477380.31 μm^3. Class 29 represents the "unclassified" volume of particles and contains 1.43% of the entire sample.

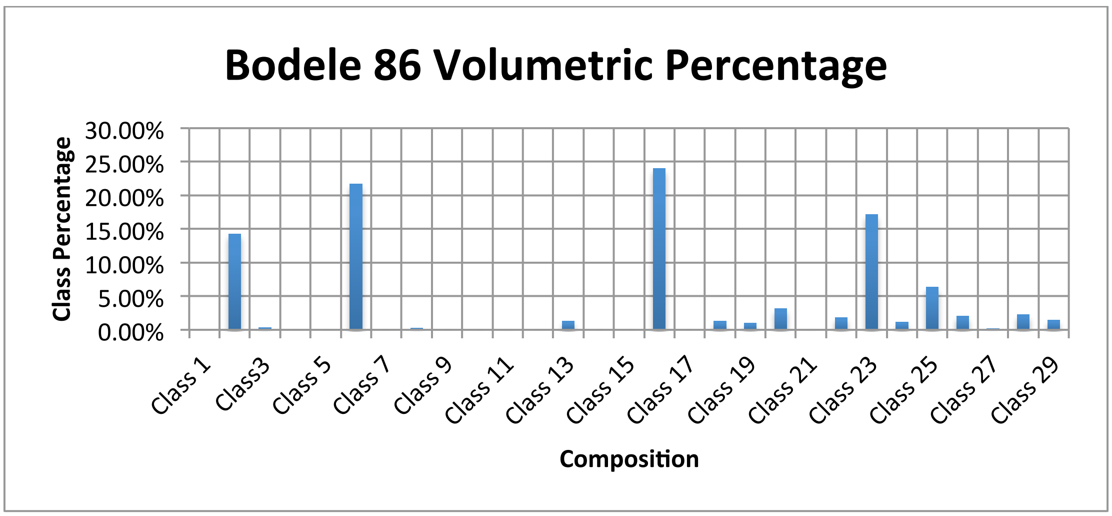

Figure 5-171: Volumetric percentage of elements within each respective class.

Table 5-14: Graph of Bodele 86 showing the volume of each class within the sample. The three highest classes are highlighted along with the total volume and percentage of the sample.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
576.55	108495.61	2394.81	0.00	0.00	164740.65	0.00	2248.23
0.08%	14.28%	0.32%	0.00%	0.00%	21.69%	0.00%	0.30%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	19.61	0.00	9632.39	0.00	0.00	182429.92
0.00%	0.00%	0.00%	0.00%	1.27%	0.00%	0.00%	24.01%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
0.00	9693.90	7863.72	24173.13	464.65	14077.51	130209.74	8800.32
0.00%	1.28%	1.04%	3.18%	0.06%	1.85%	17.14%	1.16%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
48433.59	15759.01	1533.99	17290.31	10859.95	759697.57		
6.38%	2.07%	0.20%	2.28%	1.43%	100.00%		

Analysis of class 29 showed no significant clusters of elements. The highest elements contained within Bodele 86 are Fe, Si, Al and Ca. These elements are relatively evenly distributed across the elements (Figure 5-172 and Figure 5-173). There are no significant clusters of particles to add additional classes to this sample.

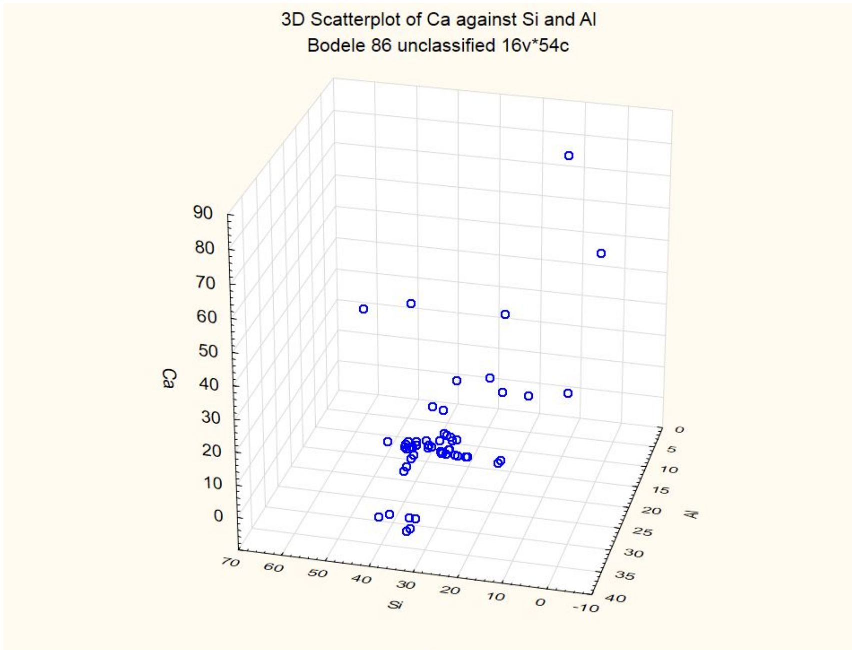

Figure 5-172: Scatterplot of Bodele 86 elements Al, Si and Ca, showing no clusters of particles within the sample.

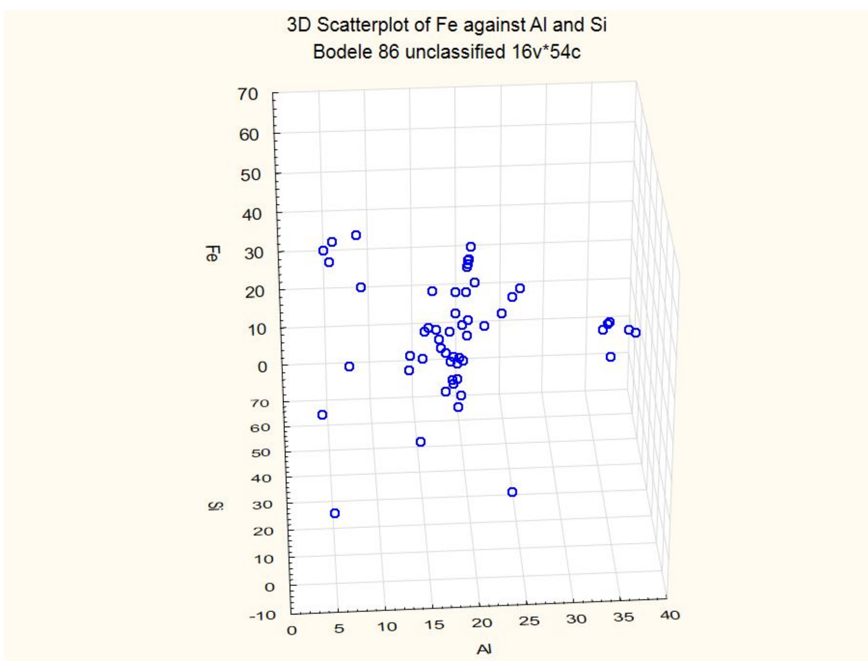

Figure 5-173: Scatterplot of Bodele 86 elements Al, Si and Si, showing no clusters of particles within the sample.

Euclidean Distance

The Euclidean Distance for Class 1 of Bodele 86 is composed of greater than 99% Silica. There are a total of 3 particles in this class (Figure 5-174).

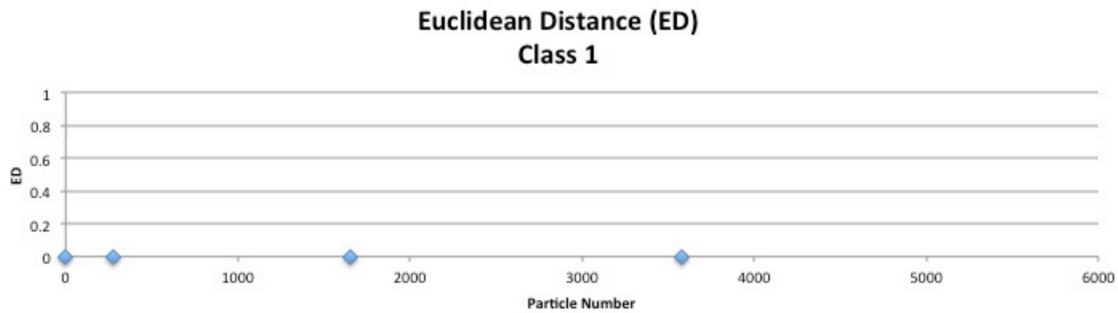

Figure 5-174: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 603 particles in this class (Figure 5-175).

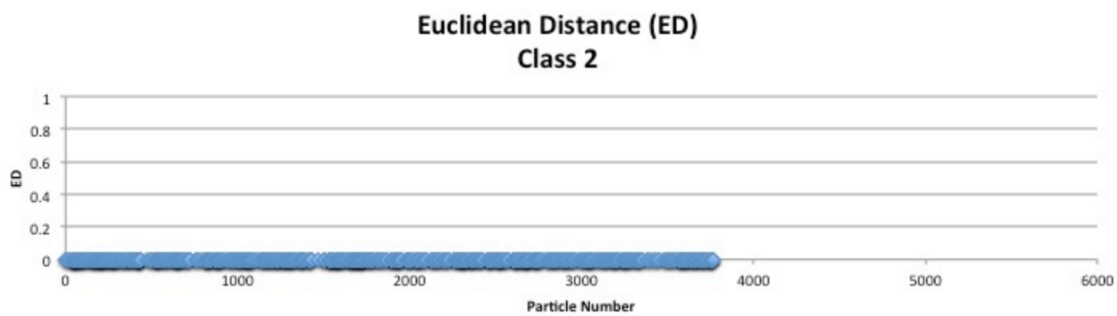

Figure 5-175: Euclidean Distance Class 2

Class 3 of Bodele 86 is composed of greater than 99% Calcium. There are a total of 6 particles in this class (Figure 5-176).

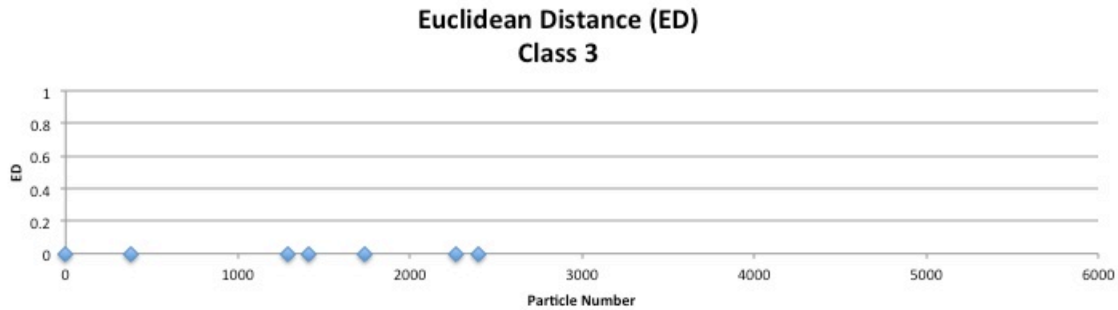

Figure 5-176: Euclidean Distance Class 3

Class 4 of Bodele 86 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Bodele 86 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Bodele 86 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 992 particles in this class (Figure 5-177).

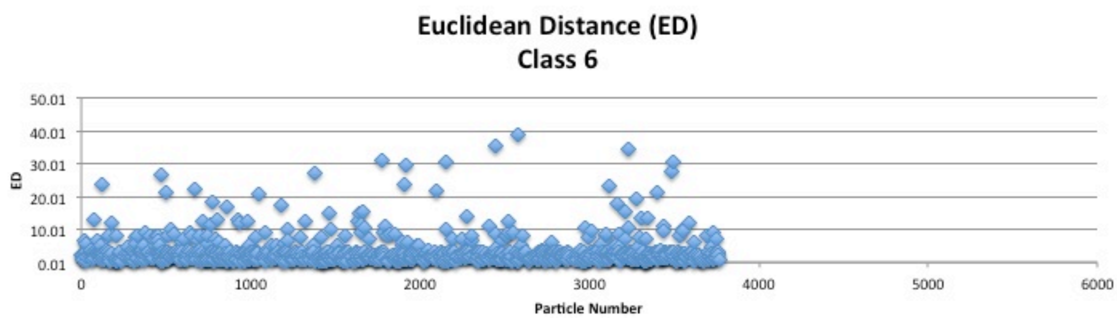

Figure 5-177: Euclidean Distance Class 6

Class 7 of Bodele 86 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are no particles in this class.

Class 8 of Bodele 86 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 9 particles in this class (Figure 5-178).

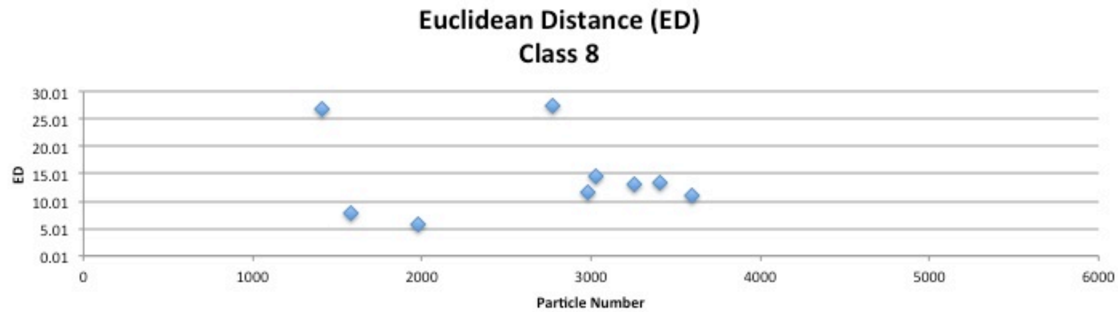

Figure 5-178: Euclidean Distance Class 8

Class 9 of Bodele 86 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Bodele 86 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Bodele 86 is composed of the total Calcium and Manganese greater than 90%. There are 2 particles in this class (Figure 5-179).

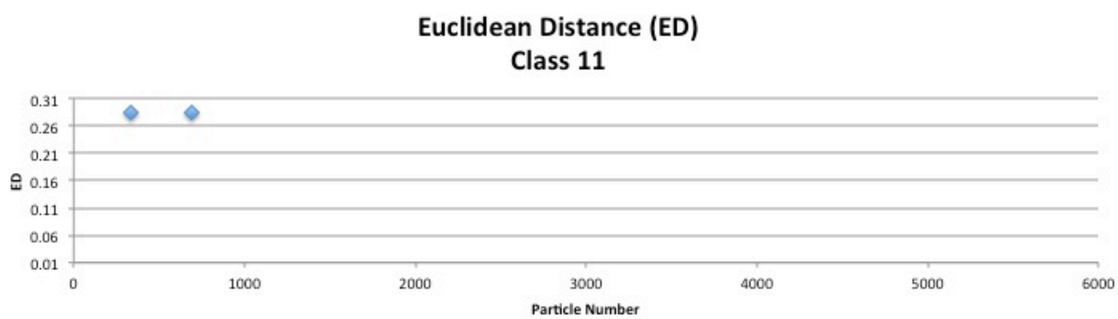

Figure 5-179: Euclidean Distance Class 11

Class 12 of Bodele 86 is composed of the total Calcium and Phosphorus greater than 90%. There is no particles in this class.

Class 13 of Bodele 86 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 25 particles in this class (Figure 5-180).

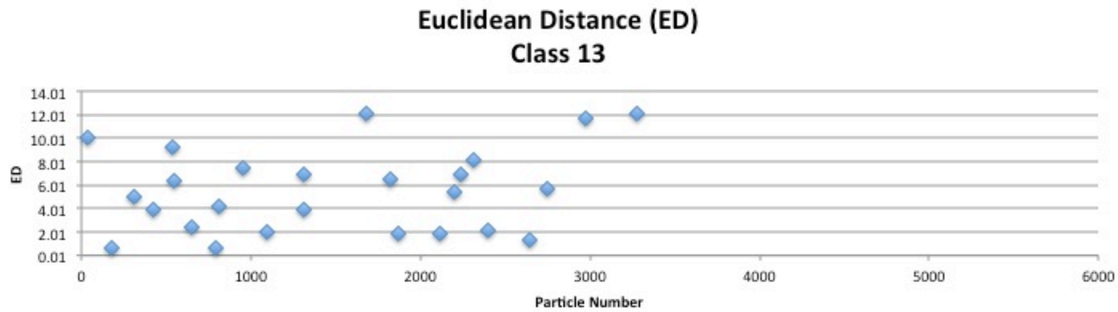

Figure 5-180: Euclidean Distance Class 13

Class 14 of Bodele 86 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are no particles in this class.

Class 15 of Bodele 83 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Bodele 86 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 869 particles in this class (Figure 5-181).

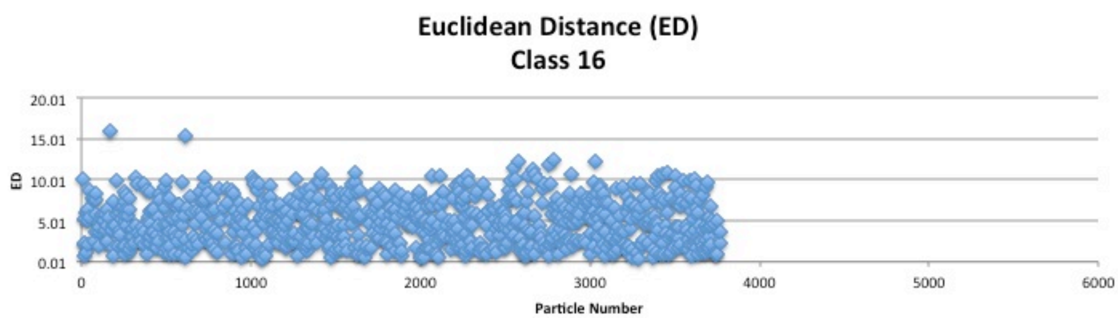

Figure 5-181: Euclidean Distance Class 16

Class 17 of Bodele 86 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are no particles in this class.

Class 18 of Bodele 86 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 33 particles in this class (Figure 5-182).

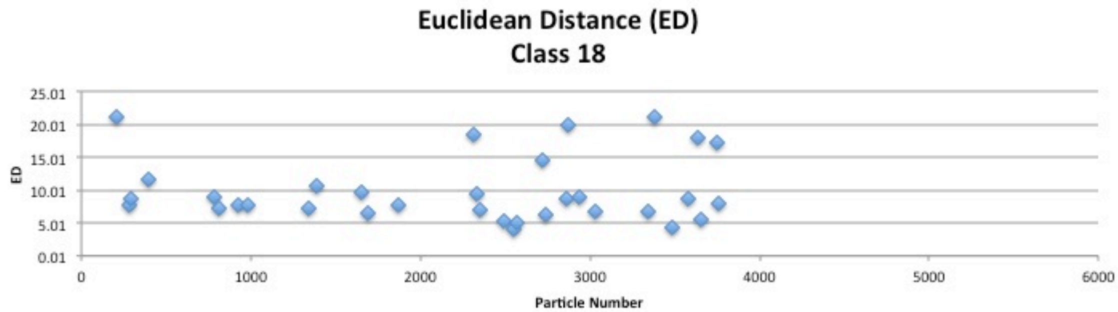

Figure 5-182: Euclidean Distance Class 18

Class 19 of Bodele 86 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 32 particles in this class (Figure 5-183).

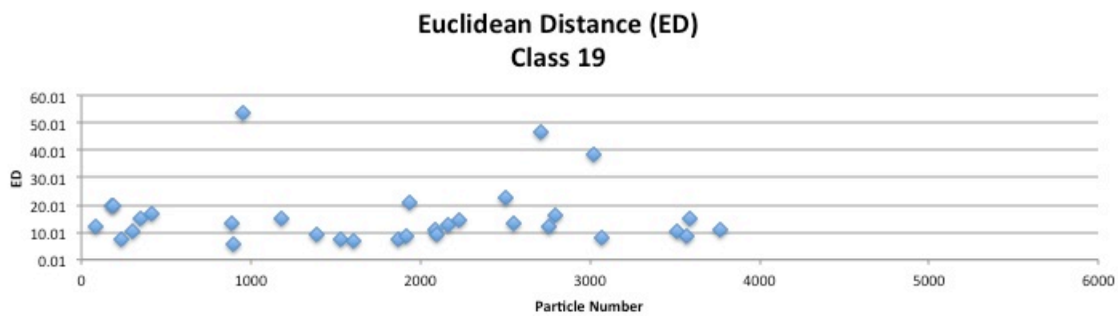

Figure 5-183: Euclidean Distance Class 19

Class 20 of Bodele 86 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 44 particles in this class (Figure 5-184).

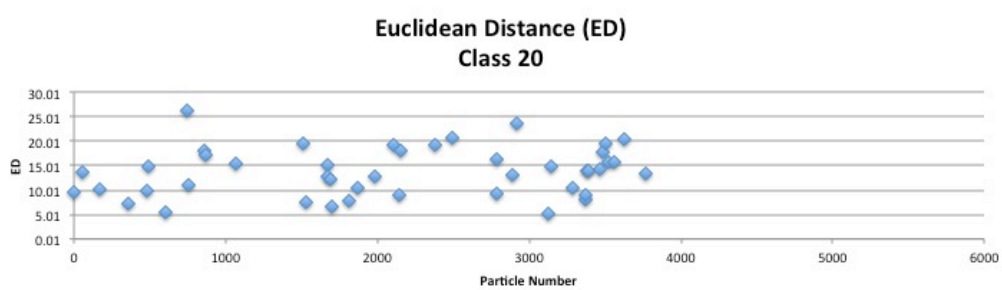

Figure 5-184: Euclidean Distance Class 20

Class 21 of Bodele 86 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 6 particles in this class (Figure 5-185).

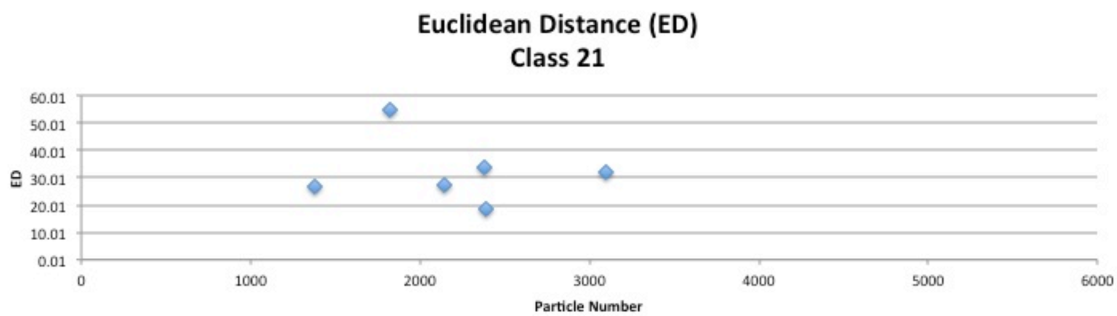

Figure 5-185: Euclidean Distance Class 21

Class 22 of Bodele 86 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 68 particles in this class (Figure 5-186).

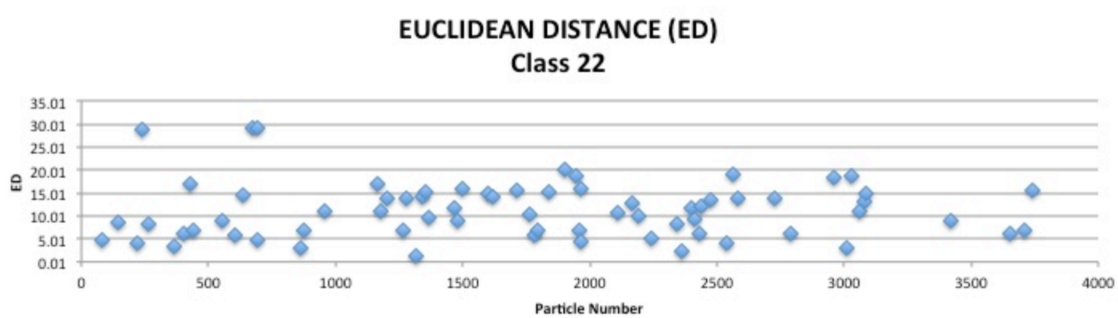

Figure 5-186: Euclidean Distance Class 22

Class 23 of Bodele 86 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 639 particles in this class (Figure 5-187).

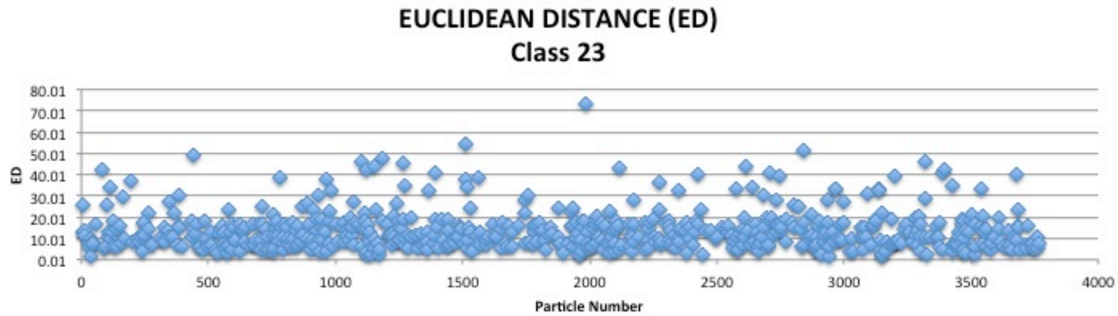

Figure 5-187: Euclidean Distance Class 23

Class 24 of Bodele 86 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 49 particles in this class (Figure 5-188).

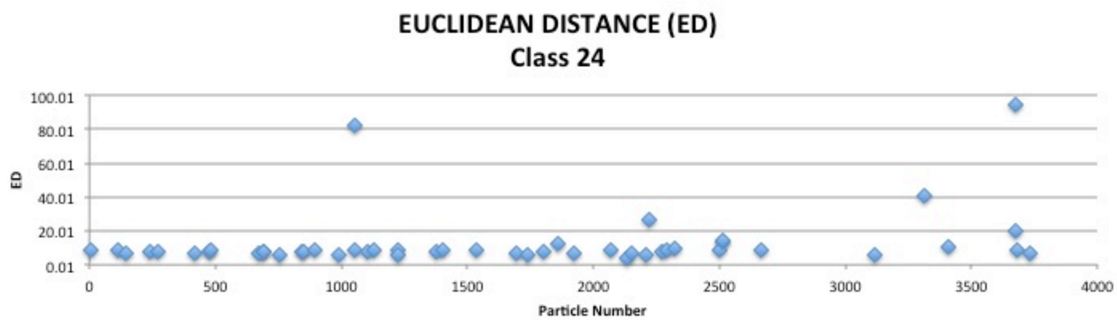

Figure 5-188: Euclidean Distance Class 24

Class 25 of Bodele 86 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 228 particles in this class (Figure 5-189).

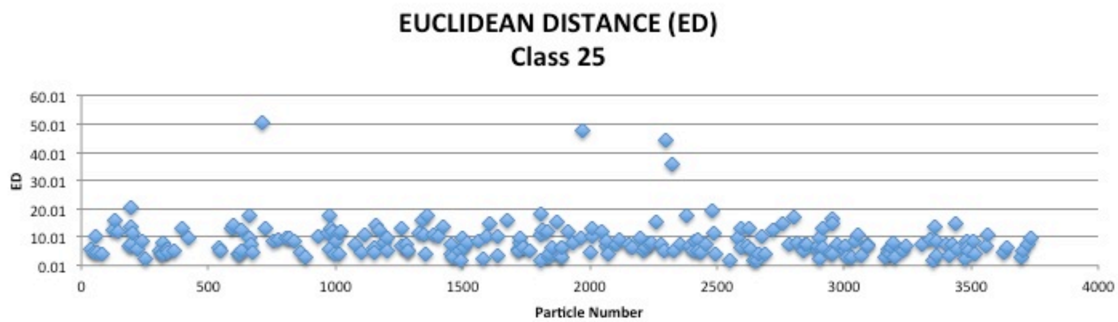

Figure 5-189: Euclidean Distance Class 25

Class 26 of Bodele 86 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 42 particles in this class (Figure 5-190).

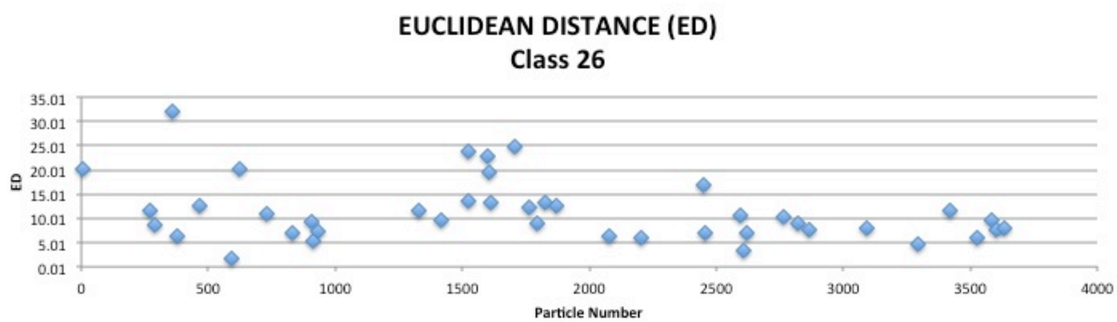

Figure 5-190: Euclidean Distance Class 26

Class 27 of Bodele 86 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 14 particles in this class (Figure 5-191).

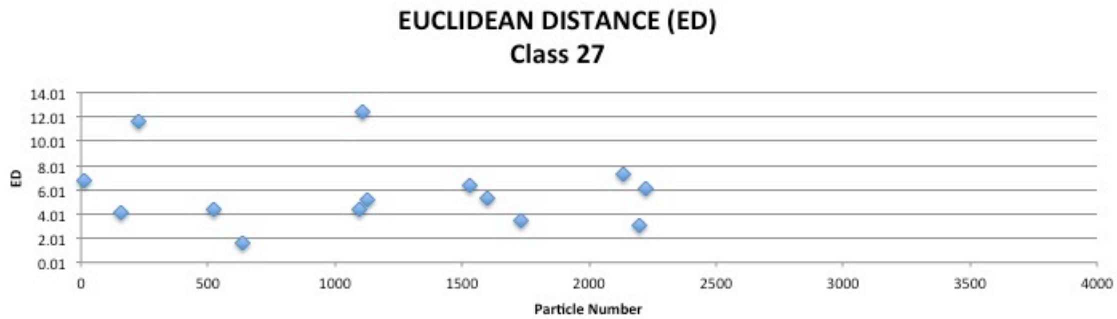

Figure 5-191: Euclidean Distance Class 27

Class 28 of Bodele 86 is composed of Aluminum less than 1%. There are a total of 50 particles in this class (Figure 5-192).

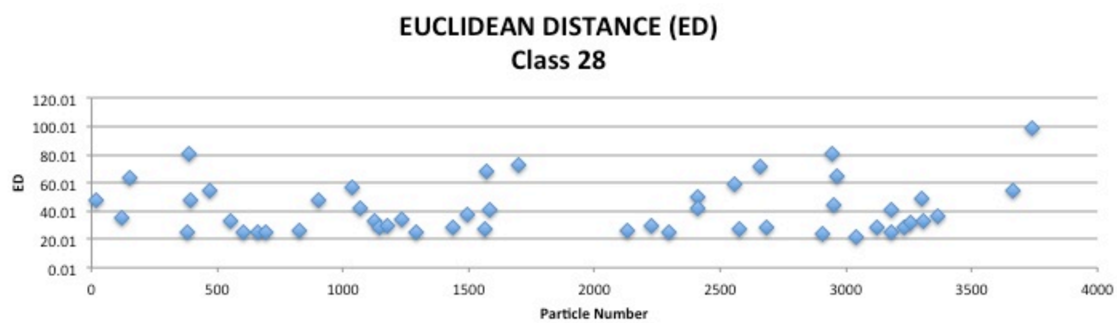

Figure 5-192: Euclidean Distance Class 28

Bodele Depression Summary

Located on the Southern edge of the Saharan Desert, the Bodele Depression was created by the dried-out Mega Lake Chad. Once evaporated, this freshwater lake left a large depression that is primarily filled with Siliceous Diatoms. These diatoms are able to be carried thousands of kilometers across the Atlantic Ocean and can be produced at a rate of around 700,000 tons a day (Todd et al., 2007).

The average number of particles in each class for all of the Bodele Depression samples gives a total class average of 5028.20 particles, which constitutes 100% of the sample (Table 5-15). Class 22 has the highest average number of particles with 18.98% or 954.20 particles (Figure 5-193). The most abundant elements within this class are Silica (Si>60%) and

Aluminum (4%<Al<20%), respectively. These particles are composed of both quartz fragments as well as broken pieces of diatoms that are composed of silica with aluminum impurities. Class 26 comes in as the second largest average particle class with 13.18% and 662.60 particles (Figure 5-194). The elements with the largest abundance are Silica (40%<Si<60%) and Aluminum (18%<Al<40%), respectively. This class contains Silica as well as larger amounts of Aluminum, which is consistent with clay type particles. Class 1 is the third largest average particle class with 12.91% and 649.20 particles (Figure 5-195). The only element represented in this class is Silica (Si>99%). These particles are primarily quartz due to the angular nature of the pieces, but also contain a number of Siliceous Diatoms.

Table 5-15: Class Average-Numerical Percentage

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
649.20	145.20	43.80	31.40	1.20	256.00	123.60	208.40
12.91%	2.89%	0.87%	0.62%	0.02%	5.09%	2.46%	4.14%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
20.20	17.80	44.60	7.60	20.00	5.40	0.00	246.80
0.40%	0.35%	0.89%	0.15%	0.40%	0.11%	0.00%	4.91%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
49.40	78.00	24.60	345.80	83.20	954.20	264.60	34.20
0.98%	1.55%	0.49%	6.88%	1.65%	18.98%	5.26%	0.68%
Class 25	Class 26	Class 27	Class 28	Class 29		Total	
144.00	662.60	233.00	161.40	172.00		5028.20	
2.86%	13.18%	4.63%	3.21%	3.42%		100.00%	

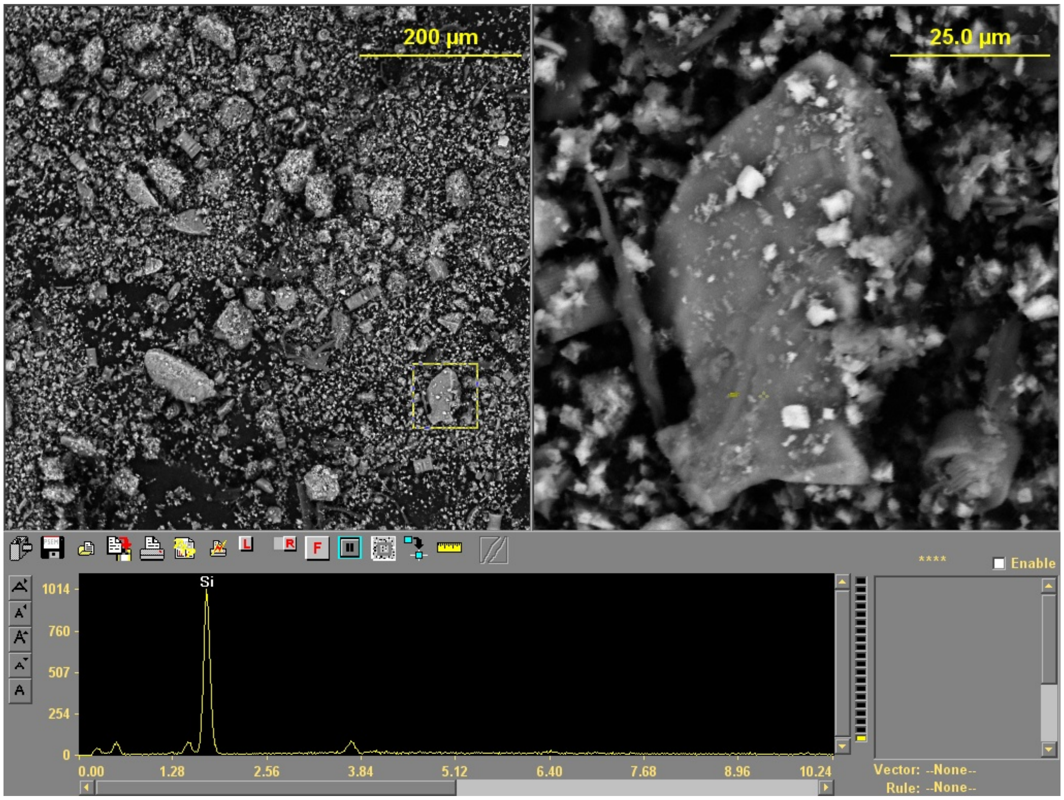

Figure 5-193: Class 22 Example showing high amounts of Si, low Al, and no Ca and K

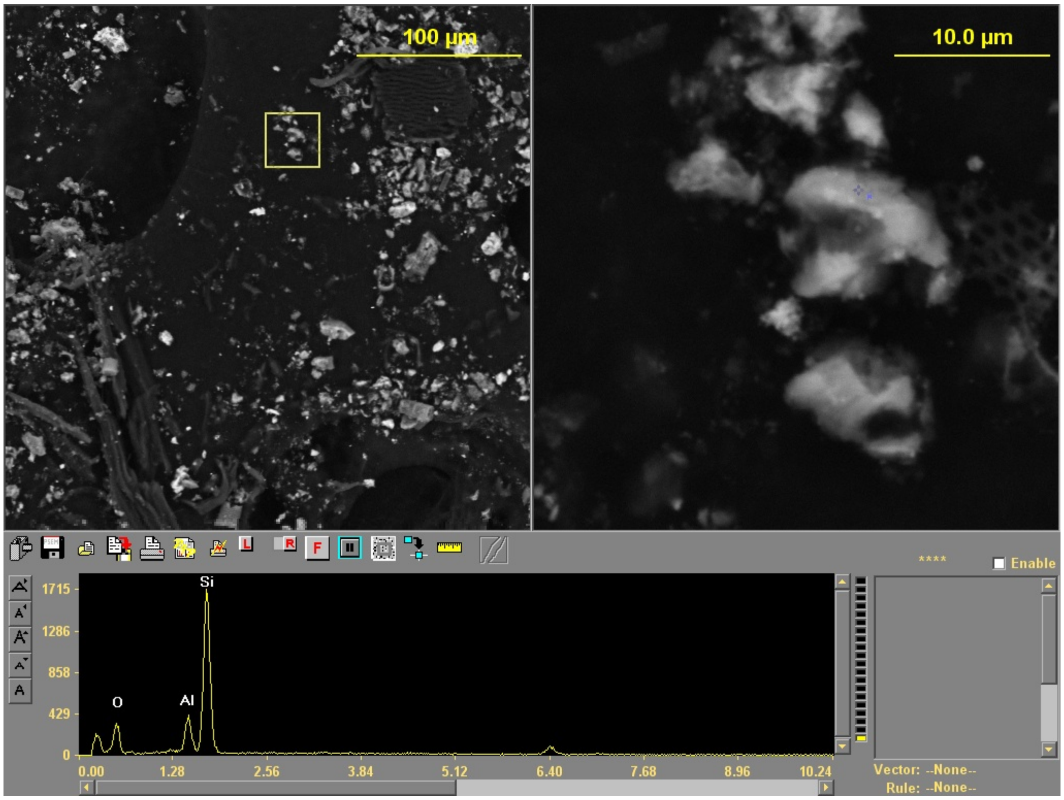

Figure 5-194: Class 26 example showing moderate Si and moderate Al

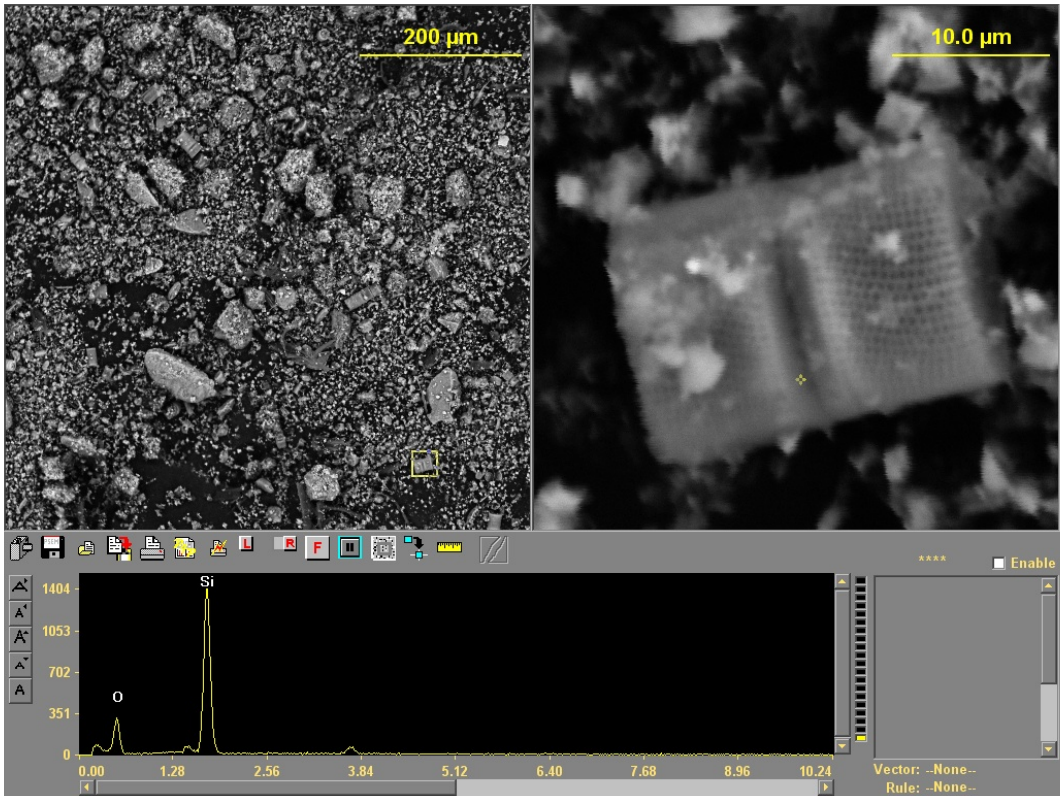

Figure 5-195: Class 1 showing Silicious Diatom

The average volume of particles in each class for all of the Bodele samples gives a total class volume average of 464131.90 µm^3, which constitutes 100% of the sample (Table 5-16). Class 26 has the highest volume of particles with 16.78% or a volume of 77882.66 µm^3. The elements with the largest abundance are Silica (40%<Si<60%) and Aluminum (18%<Al<40%), respectively. Class 22 comes in as the second largest average volume class with 14.85% and 68940.08 µm^3 average volume. The most abundant elements within this class are Silica (Si>60%) and Aluminum (4%<Al<20%), respectively. Similar to the numerical class average, class 1 is the third largest average volume class with 13.62% and a volume of 63226.49 µm^3. The only element represented in this class is Silica (Si>99%).

Table 5-16: Class Average-Volumetric Percentage

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
63226.49	21920.01	1324.71	96.73	0.06	33678.21	5349.89	4026.79
13.62%	4.72%	0.29%	0.02%	0.00%	7.26%	1.15%	0.87%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
1823.35	66.80	1038.28	99.21	2754.04	257.80	0.00	37213.19
0.39%	0.01%	0.22%	0.02%	0.59%	0.06%	0.00%	8.02%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
3652.01	4288.24	5248.81	17288.17	11704.92	68940.08	39742.11	1835.73
0.79%	0.92%	1.13%	3.72%	2.52%	14.85%	8.56%	0.40%
Class 25	Class 26	Class 27	Class 28	Class 29		Total	
11595.36	77882.66	5080.90	24132.33	19864.98		464131.90	
2.50%	16.78%	1.09%	5.20%	4.28%		100.00%	

Comparing both the numerical and volumetric average percentages, Class 26, 22, and 1 represent the highest percentages of all the Bodele samples. These three classes represent 45.07% of the numerical value and 45.25% for the volumetric value for all the Bodele Depression samples. The difference in the percentage between number of particles and volume of particle of the three highest classes is less than 1%. The small difference is caused by the value of classes 22 and 26. In the average numerical percentage class 22 is the highest, while in the average volumetric percentage class 26 is has the highest percentage. Silica and aluminum are, by far, the most abundant elements in the Bodele depression, with large amounts of Silica, which is consistent with a visual inspection of the particles during analysis

(Figure 5-196). Most of the Bodele Depression is composed of siliceous diatoms from its history as an inland freshwater sea. The exception, or outlier, in the Bodele Depression samples is sample 86. Bodele 86 is composed of Iron, Silica, Potassium, and Calcium, which is more characteristic of Chad Arid samples rather than Bodele samples (Figure 5-197). Because the location of the Bodele Depression is within the Chad area and the boundary varies, it can be hypothesized that Bodele 86 is actually mixing with some of the elements entrained within the Chad area. The characteristic siliceous diatoms are still present in Bodele 86, which means that it still distinguishable from the other samples, including those of Chad Arid.

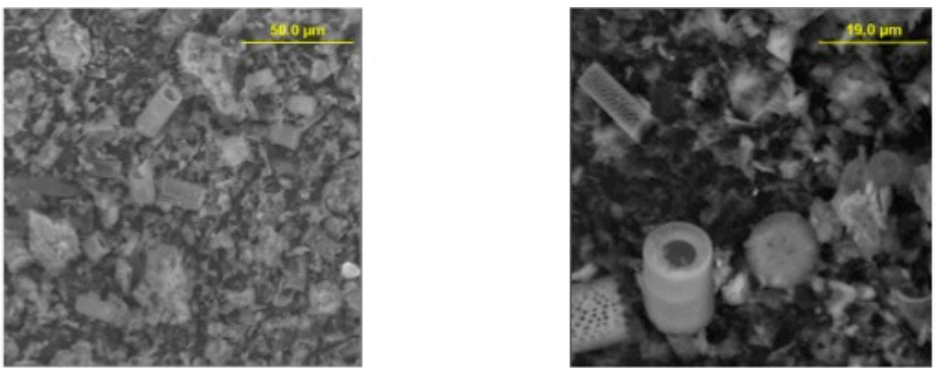

Figure 5-196: Si Diatoms: (Left) Bodele 82, (Right) Bodele 86.

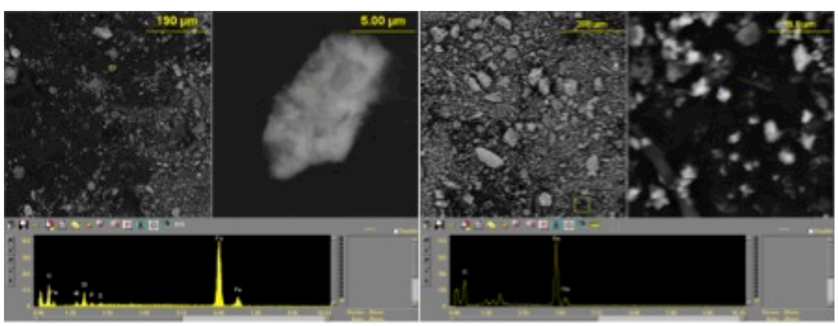

Figure 5-197: Bodele 86 showing Si, Al, Fe, Ca

The Euclidean distance for the all the Bodele Depression samples gives us an idea of the distribution of the particles and distance from the centroid of the cluster. While the Euclidean distance values themselves are arbitrary, the pattern of distribution is important for identification of sample types. Each sample class will have a unique distribution of particles around the centroid of the cluster, which can be a valuable tool for identification of samples. Some of the more notable Euclidean distance distribution tables are classes 8 and 28 (Figure 5-198). Class 28 shows two distinct clusters of particles that are away from the centroid of the cluster. Class 8 shows one distinct cluster of particles away from the centroid. This unique distributive pattern is a useful tool for identifying samples within the Bodele Depression.

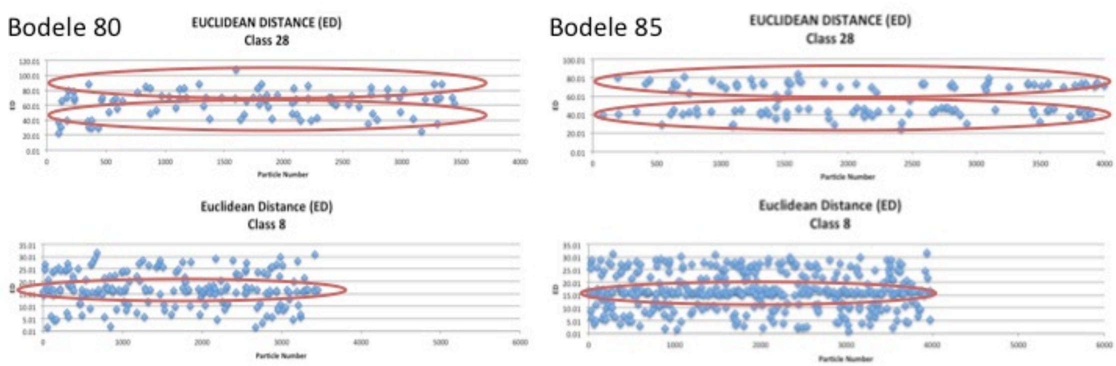

Figure 5-198: Examples of Class 8 and Class 28 Euclidean Distance Distribution.

Along with chemistry and Euclidean distance, the average particle size of each elemental class was identified (Table 5-17). The particles were separated into 4 size classes, with size 1 having particles with a diameter between 0-2.49μm, class 2 having a diameter between 2.5-4.9μm, class three having a diameter between 5-10μm, and class 4 having a diameter greater than 10μm. Size class 1 included 59.75% of all Bodele particles, size class 2 included 25.95%, size class 3 11.95%, and class 4 included 2.36%. This analysis showed an abundance of small particle sizes (Class 1) with no correlation between chemistry of the particles and size of the particles.

Table 5-17: Bodele Depression Particle Size Classes by Elemental Class.

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
Size Class 1	51.75%	0.00%	74.49%	51.40%	28.57%	77.53%	52.15%
Size Class 2	25.83%	100.00%	19.19%	5.27%	0.00%	14.82%	24.68%
Size Class 3	20.69%	0.00%	3.95%	0.48%	0.00%	6.09%	8.33%
Size Class 4	1.73%	0.00%	2.38%	0.00%	0.00%	1.56%	0.55%
	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	Class 14
Size Class 1	61.39%	29.23%	51.82%	37.79%	28.57%	66.91%	26.95%
Size Class 2	22.54%	8.82%	5.33%	32.60%	4.76%	18.31%	27.46%
Size Class 3	13.95%	18.27%	0.00%	1.04%	9.52%	11.40%	17.02%
Size Class 4	2.11%	0.82%	0.00%	0.00%	0.00%	3.38%	0.00%
	Class 15	Class 16	Class 17	Class 18	Class 19	Class 20	Class 21
Size Class 1	0.00%	64.00%	48.52%	58.72%	38.92%	57.22%	56.78%
Size Class 2	0.00%	14.27%	17.99%	25.79%	33.72%	24.34%	21.71%
Size Class 3	0.00%	5.99%	17.69%	12.81%	17.86%	14.29%	15.77%
Size Class 4	0.00%	1.45%	1.52%	2.67%	9.49%	4.15%	5.74%
	Class 22	Class 23	Class 24	Class 25	Class 26	Class 27	Class 28
Size Class 1	55.39%	64.52%	68.04%	66.13%	58.81%	57.63%	58.01%
Size Class 2	26.28%	21.75%	11.87%	20.24%	22.96%	29.66%	24.05%
Size Class 3	15.08%	10.62%	4.93%	12.36%	13.57%	12.13%	14.31%
Size Class 4	3.25%	3.11%	0.87%	1.27%	4.65%	0.58%	3.63%

Total Class %

Class 1	Class 2	Class 3	Class 4
59.75%	25.95%	11.95%	2.36%

Burkina Faso

Burkina Faso, Burkina for short, is located in central Africa and is dominated by a Precambrian massif that is bordered by cliffs (Figure 5-199). Burkina is bordered by the Sahara to the north and the Sudan to the south. Water shortages are often a problem for this region, which leads to increased desertification of the area and increased dust and dry sediment. This sediment is aerosolized by a hot dry wind that originates from the Sahara called the Harmattan.

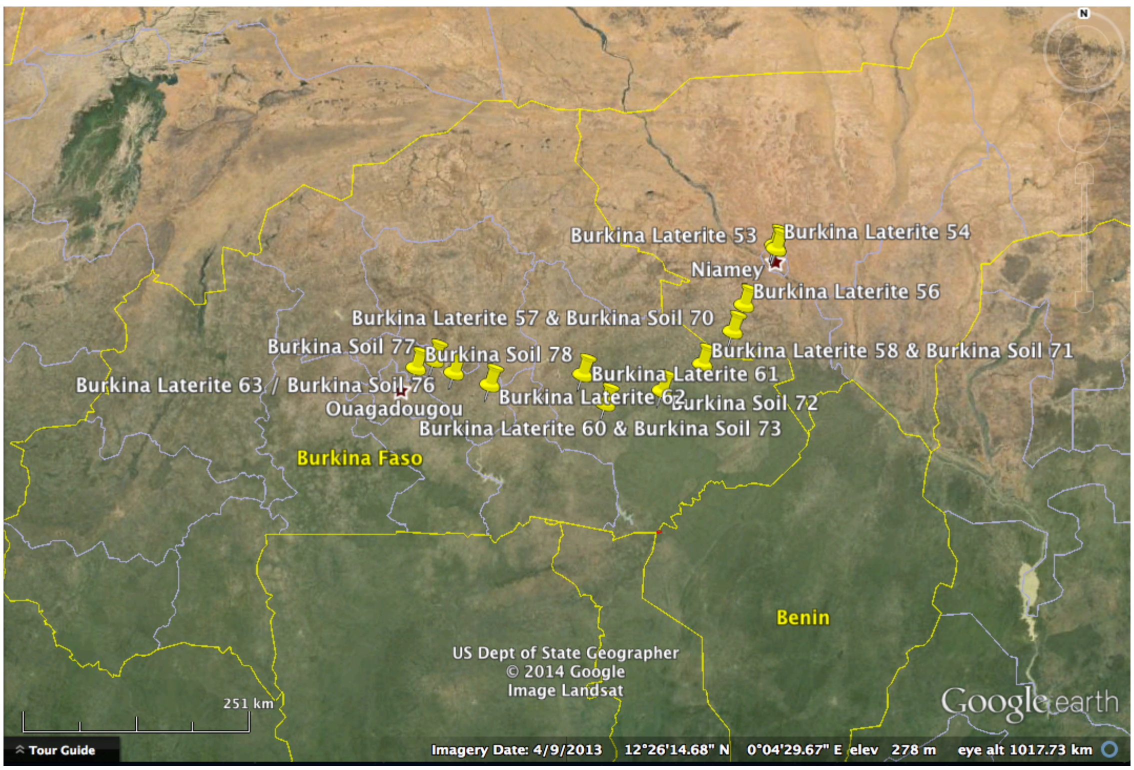

Figure 5-199: Location of both Burkina Laterites and Burkina Soils in Burkina Faso, Africa.

Burkina Faso has been split into two distinct categories for this experiment. The first is Burkina Laterite, which consists of laterites that have eroded from the parent rock and have been lithified into a clastic rock. These laterites were collected from consolidated material that was broken into small dust particles. The second are the Burkina Soils. These soils were unconsolidated dust already present on the ground. The thought behind collecting these two distinct types was the see the effects of wind transport on a region. The Burkina Laterites are slowing degrading into loose unconsolidated sediment, but wind blown material is being added to the collection of material on the ground and changing the elemental composition of the dust. Therefore, within the Burkina Faso region, there are two distinct types of dust, Burkina Laterites and Burkina Soils.

Burkina Laterite 53

Numerical and Volumetric Analysis

Burkina Laterite 53 is located at 13 29.809 N, 2 03.770 E and has been separated into 29 elemental classes (Figure 5-200). The numerical percentage shows the number of Particles in each class, and what percentage those particles represent to the entire class (Table 5-18).

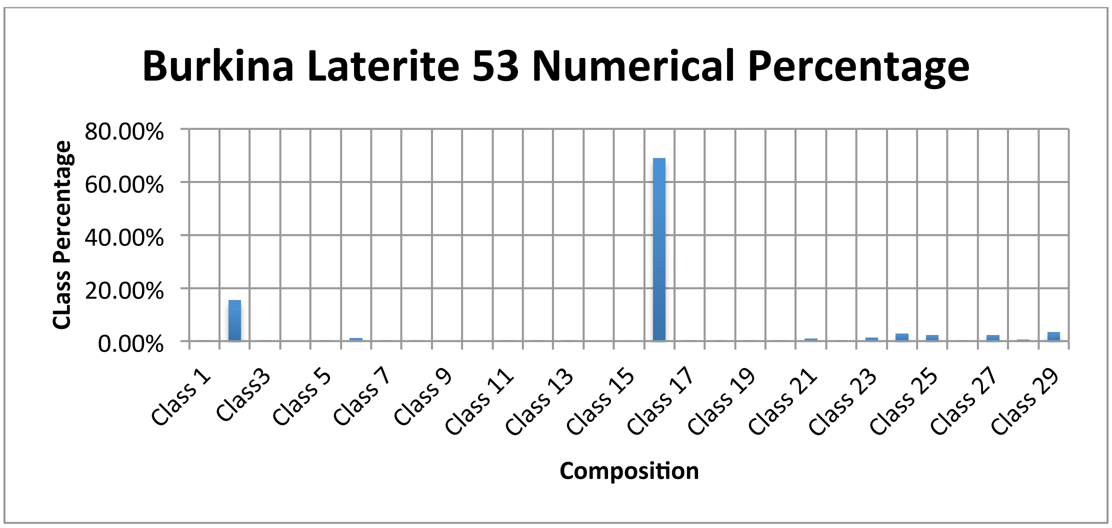

Figure 5-200: Burkina Laterite 53 showing the numerical percentages separated by class.

Table 5-18: Burkina Laterite 53 showing the three highest numerical percentages of particles per class and the total number of particles.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
4	1533	2	0	1	100	1	1
0.04%	15.33%	0.02%	0.00%	0.01%	1.00%	0.01%	0.01%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	4	1	36	0	0	6889
0.00%	0.00%	0.04%	0.01%	0.36%	0.00%	0.00%	68.90%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
1	6	16	21	87	40	133	273
0.01%	0.06%	0.16%	0.21%	0.87%	0.40%	1.33%	2.73%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
225	12	224	51	338	9999		
2.25%	0.12%	2.24%	0.51%	3.38%	1		

Table 5-18 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 2, 16, and 24. Class 2 is composed of Iron greater than 99%. Class 16 has greater than 40% Iron and the total Iron and Calcium combined greater than 75%. Class 24 has Potassium and Calcium less than 1%, Aluminum between 4% and 20% and Silica between 4% and 18%. This represents 86.96% of the entire sample and contains a total of 8695 particles. Class 29 represents the “unclassified” particles and contains only 3.38% of the entire sample.

The volumetric percentage of Burkina Laterite 53 represents the volume of particles that are represented in each respective elemental class (Figure 5-201). Table 5-19 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 2, 13, and 16. Class 2 is composed of Iron greater than 99%. Class 13 has Aluminum less than 1%, Iron greater than 4% and Silica greater than 80%. Class 16 has greater than 40% Iron and the total Iron and Calcium combined greater than 75%. This represents 83.56% of the entire sample and contains a total volume of 335769.99μm^3. Class 29 represents the “unclassified” volume of particles and contains 4.22% of the entire sample.

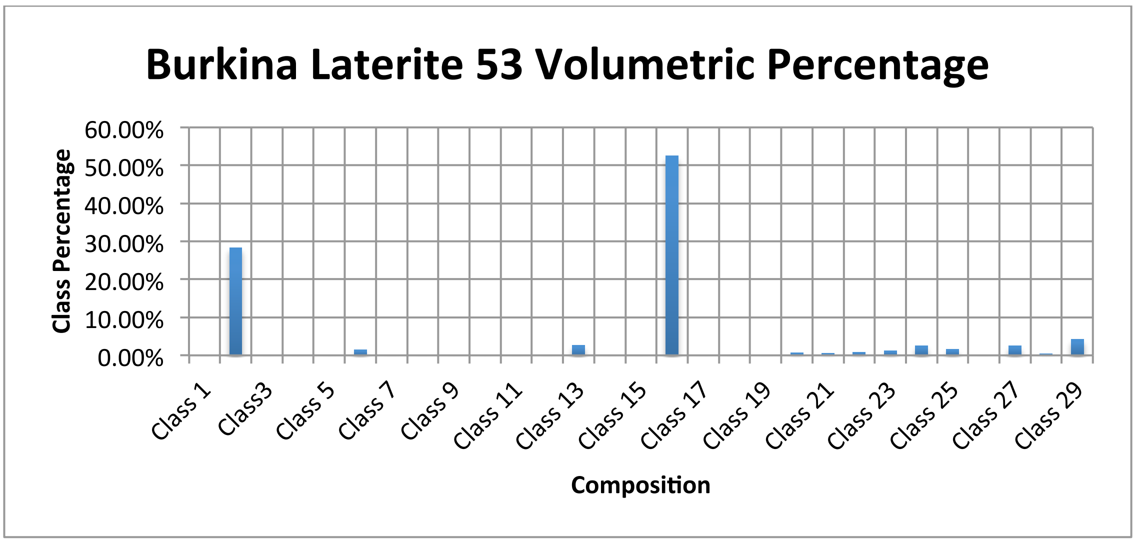

Figure 5-201: Volumetric percentage of elements per class.

Table 5-19: Volumetric percentages and volume per class including the three highest classes in the sample.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
375.92	113974.5	7.08	0.00	0.08	6017.48	3.29	103.93
0.09%	28.36%	0.00%	0.00%	0.00%	1.50%	0.00%	0.03%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	88.28	81.16	10494.34	0.00	0.00	211301.0
0.00%	0.00%	0.02%	0.02%	2.61%	0.00%	0.00%	52.59%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
7.46	177.21	438.59	2613.57	2251.33	3340.89	4703.86	10320.0
0.00%	0.04%	0.11%	0.65%	0.56%	0.83%	1.17%	2.57%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
6622.97	304.4	10167.34	1482.62	16946.94	401824.4138		
1.65%	0.08%	2.53%	0.37%	4.22%	1		

Analysis of class 29 showed two small clusters of elements. The highest elements contained within Burkina Laterite 53 unclassified are Fe, Si, Al, respectively, and only compose 4.22% of the entire sample. These elements are contained between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-202).

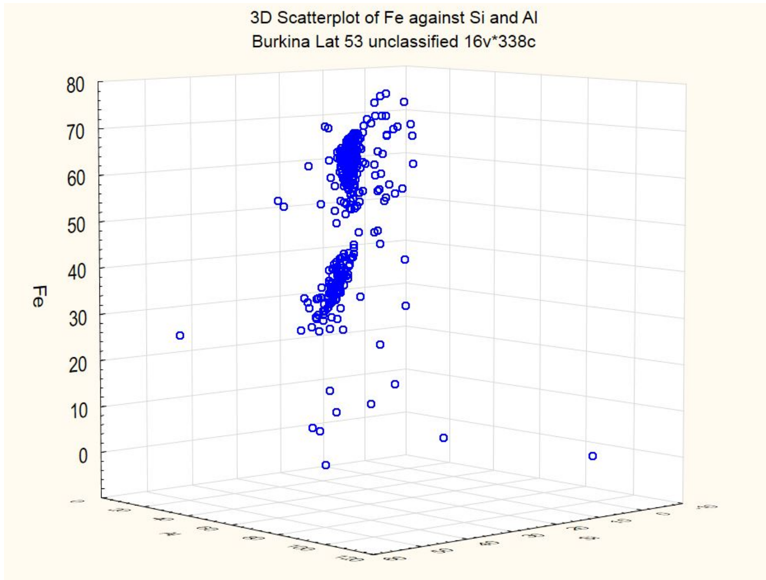

Figure 5-202: Scatterplot of Burkina Laterite 53 elements Al, Si and Fe, showing two distinct particle clusters. The unclassified particles only contain 4.22% of the particles in the sample.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Laterite 53 is composed of greater than 99% Silica. There are a total of 4 particles in this class (Figure 5-203).

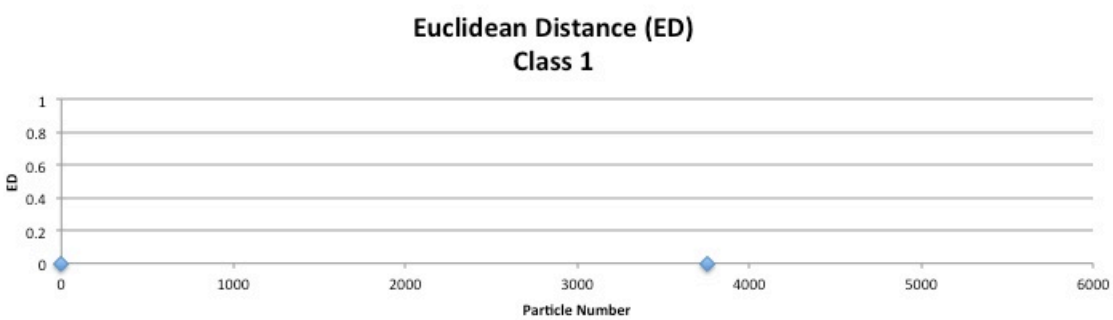

Figure 5-203: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 1533 particles in this class (Figure 5-204).

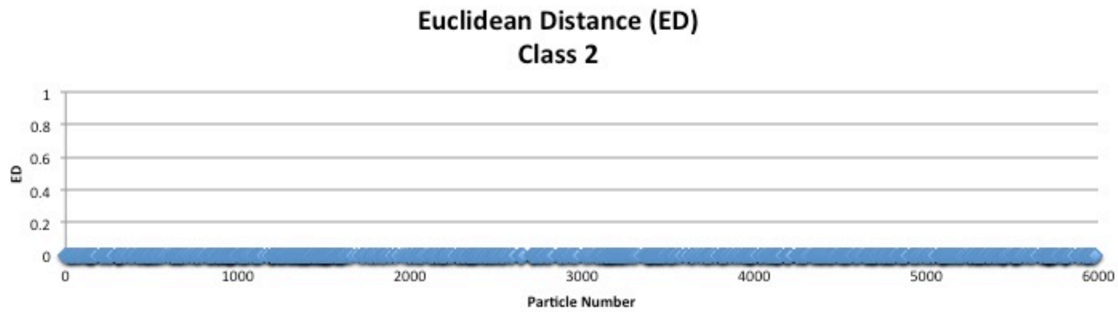

Figure 5-204: Euclidean Distance Class 2

Class 3 of Burkina Laterite 53 is composed of greater than 99% Calcium. There are a total of 2 particles in this class (Figure 5-205).

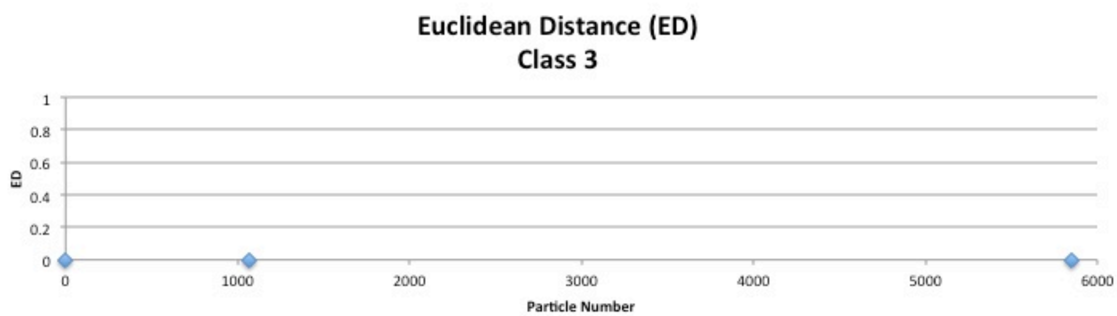

Figure 5-205: Euclidean Distance Class 3

Class 4 of Burkina Laterite 53 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Burkina Laterite 53 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There is 1 particle in this class (Figure 5-206).

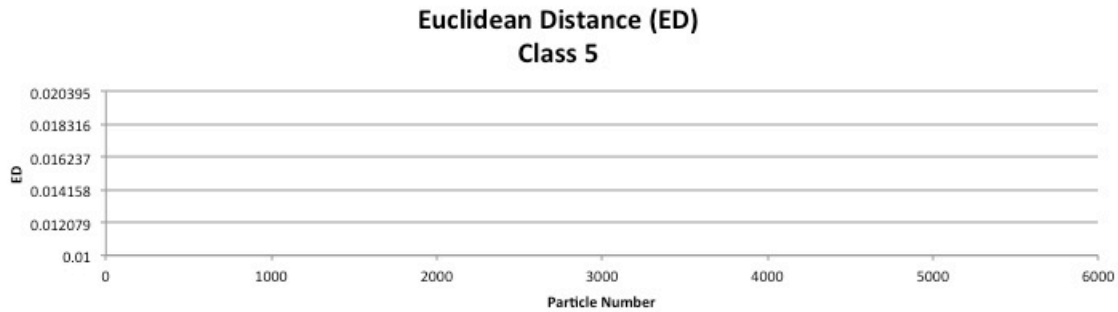

Figure 5-206: Euclidean Distance Class 5

Class 6 of Burkina Laterite 53 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 100 particles in this class (Figure 5-207).

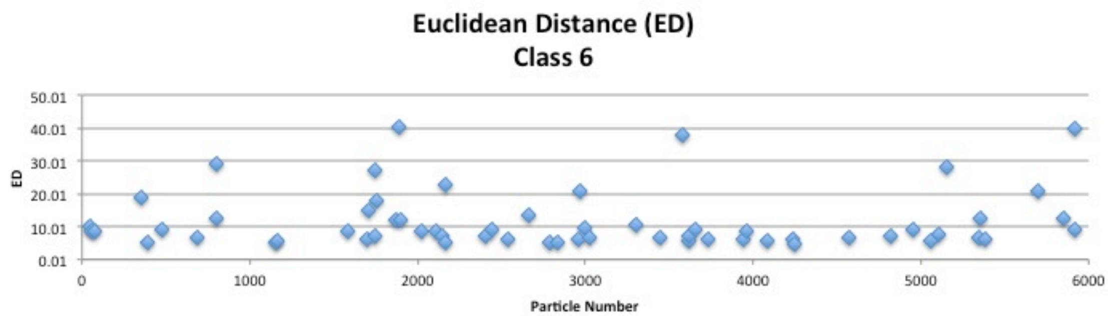

Figure 5-207: Euclidean Distance Class 6

Class 7 of Burkina Laterite 53 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There is a total of 1 particle in this class (Figure 5-208).

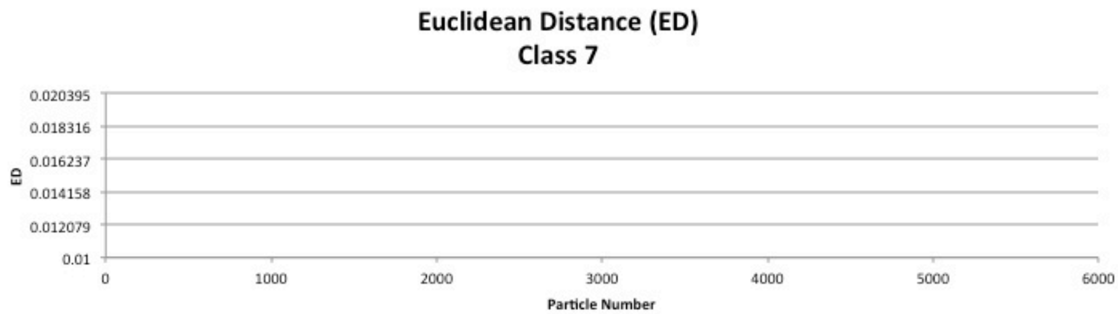

Figure 5-208: Euclidean Distance Class 7

Class 8 of Burkina Laterite 53 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There is a total of 1 particle in this class (Figure 5-209).

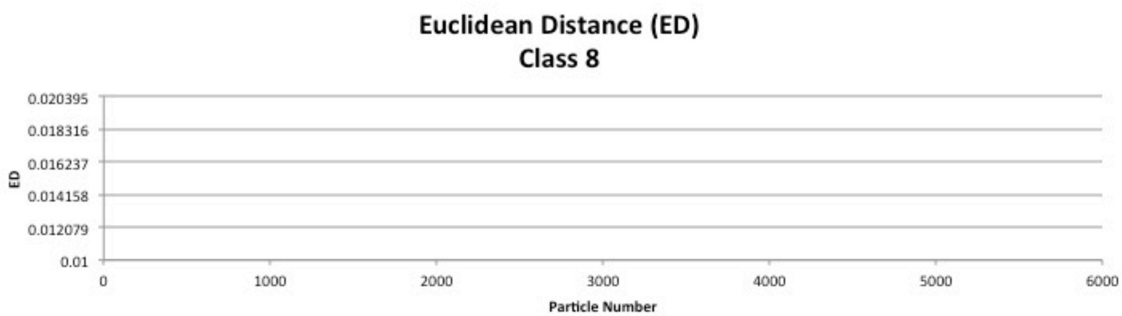

Figure 5-209: Euclidean Distance Class 8

Class 9 of Burkina Laterite 53 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Laterite 53 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Laterite 53 is composed of the total Calcium and Manganese greater than 90%. There are 4 particles in this class (Figure 5-210).

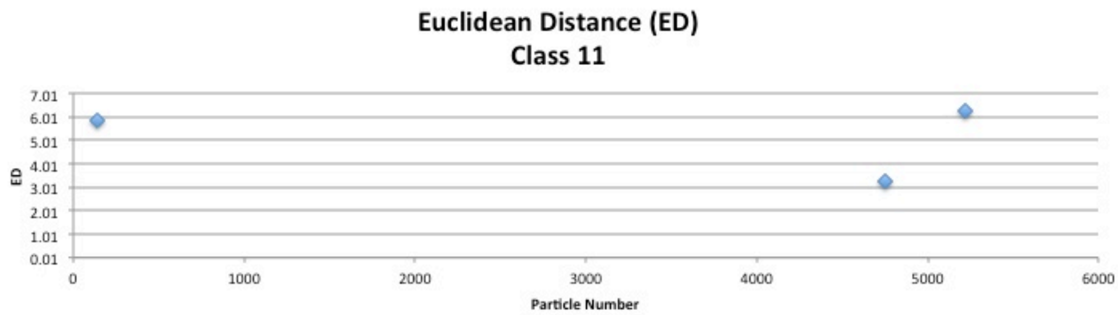

Figure 5-210: Euclidean Distance Class 11

Class 12 of Burkina Laterite 53 is composed of the total Calcium and Phosphorus greater than 90%. There is 1 particle in this class (Image 53-12).

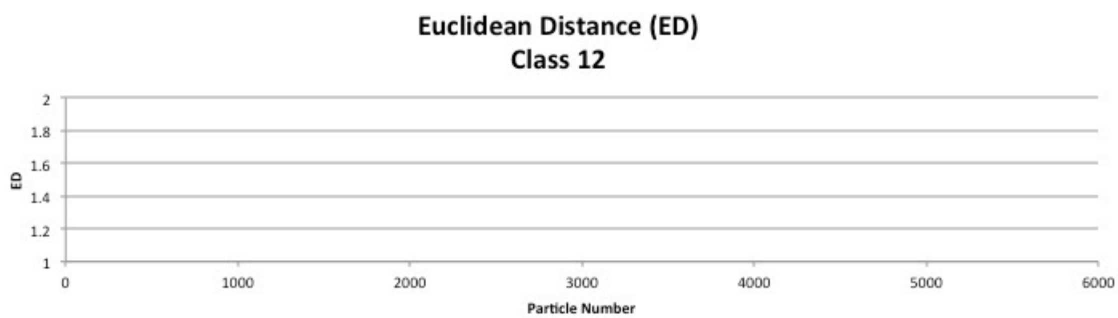

Figure 5-211: Euclidean Distance Class 12

Class 13 of Burkina Laterite 53 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 36 particles in this class (Figure 5-212).

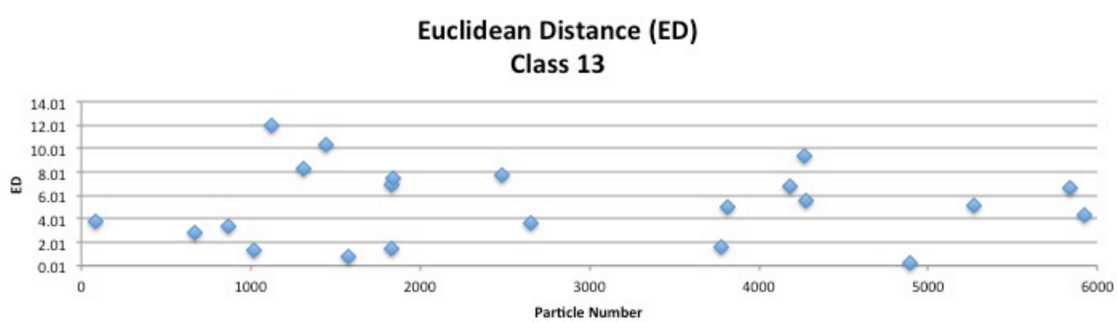

Figure 5-212: Euclidean Distance Class 13

Class 14 of Burkina Laterite 53 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are no particles in this class.

Class 15 of Burkina Laterite 53 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Laterite 53 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 6889 particles in this class (Figure 5-213).

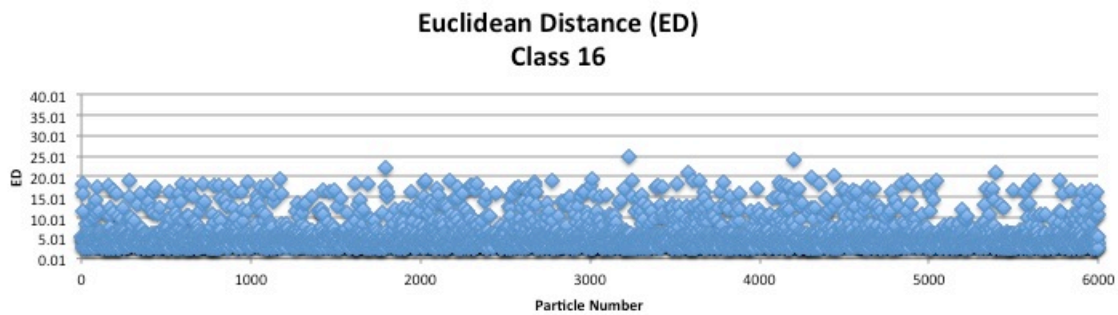

Figure 5-213: Euclidean Distance Class 16

Class 17 of Burkina Laterite 53 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There is a total of 1 particle in this class (Figure 5-214).

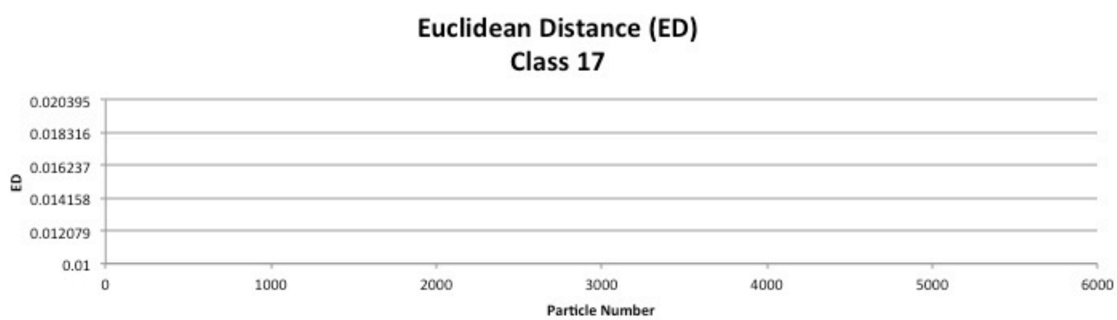

Figure 5-214: Euclidean Distance Class 17

Class 18 of Burkina Laterite 53 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 6 particles in this class (Figure 215).

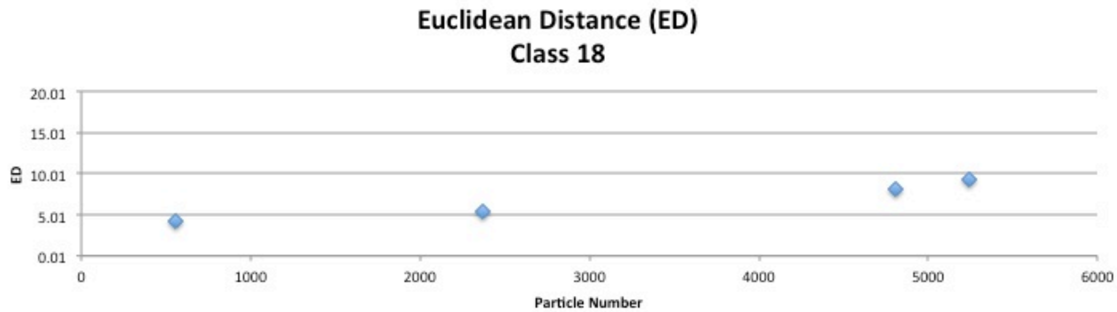

Figure 5-215: Euclidean Distance Class 18

Class 19 of Burkina Laterite 53 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 16 particles in this class (Figure 5-216).

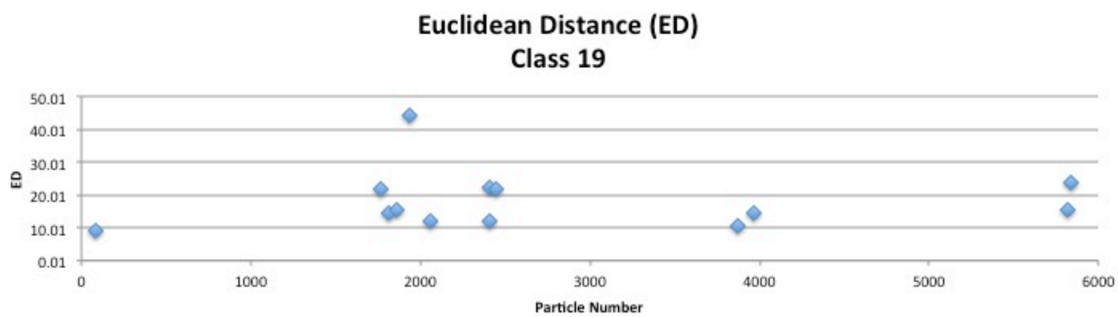

Figure 5-216: Euclidean Distance Class 19

Class 20 of Burkina Laterite 53 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 21 particles in this class (Figure 5-217).

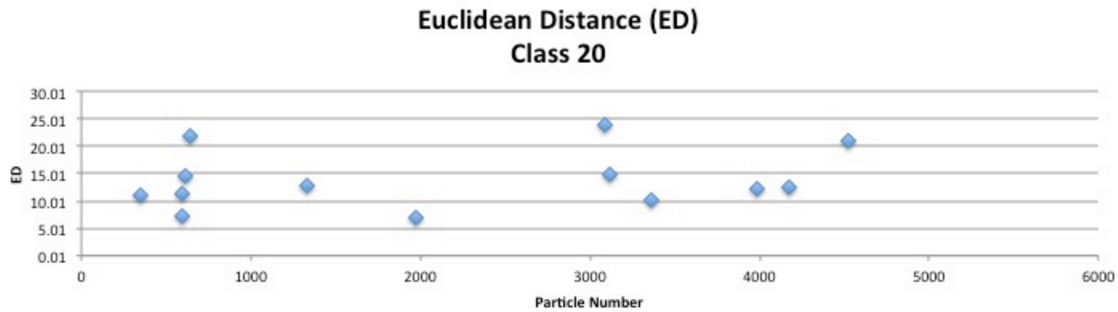

Figure 5-217: Euclidean Distance Class 20

Class 21 of Burkina Laterite 53 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 87 particles in this class (Figure 5-218).

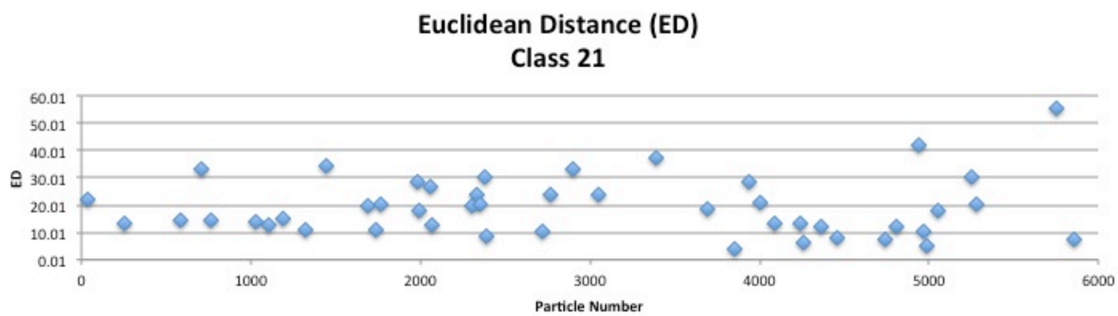

Figure 5-218: Euclidean Distance Class 21

Class 22 of Burkina Laterite 53 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 40 particles in this class (Figure 5-219).

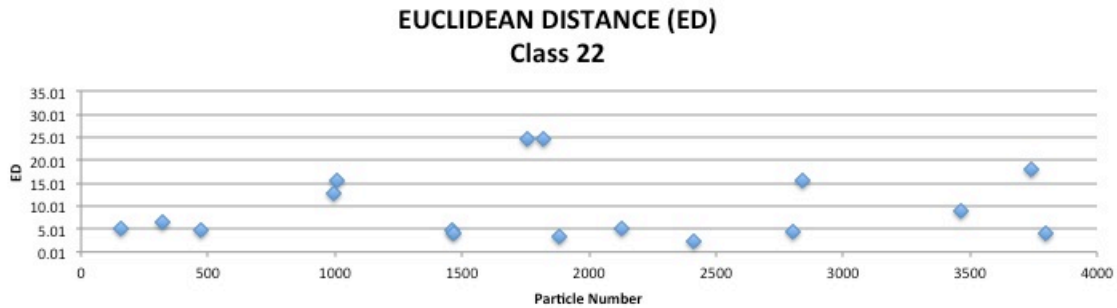

Figure 5-219: Euclidean Distance Class 22

Class 23 of Burkina Laterite 53 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 133 particles in this class (Figure 5-220).

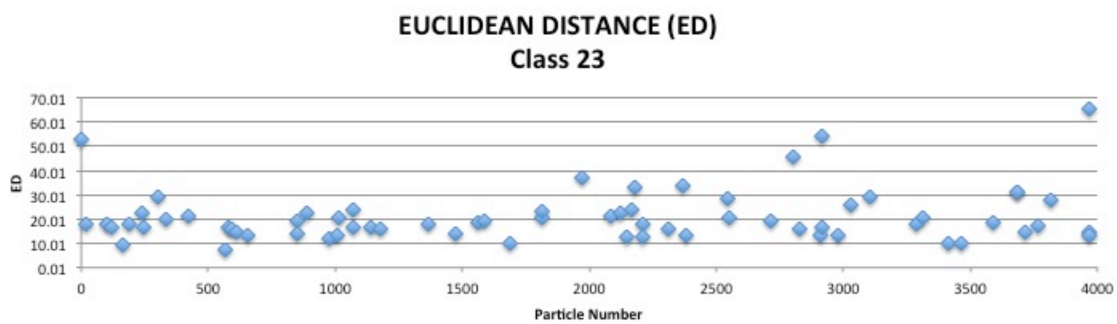

Figure 5-220: Euclidean Distance Class 23

Class 24 of Burkina Laterite 53 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 273 particles in this class (Figure 5-221).

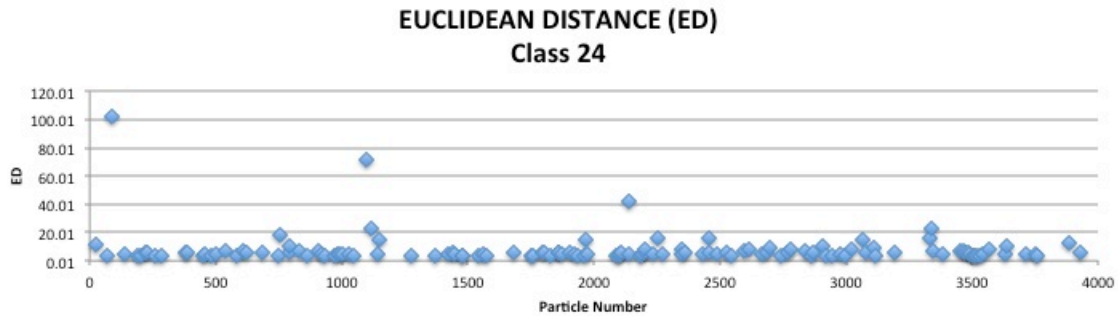

Figure 5-221: Euclidean Distance Class 24

Class 25 of Burkina Laterite 53 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 225 particles in this class (Figure 5-222).

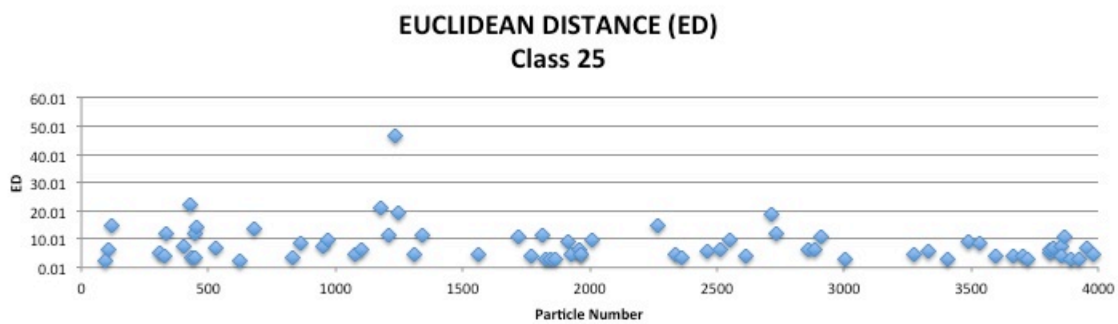

Figure 5-222: Euclidean Distance Class 25

Class 26 of Burkina Laterite 53 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 12 particles in this class (Figure 5-223).

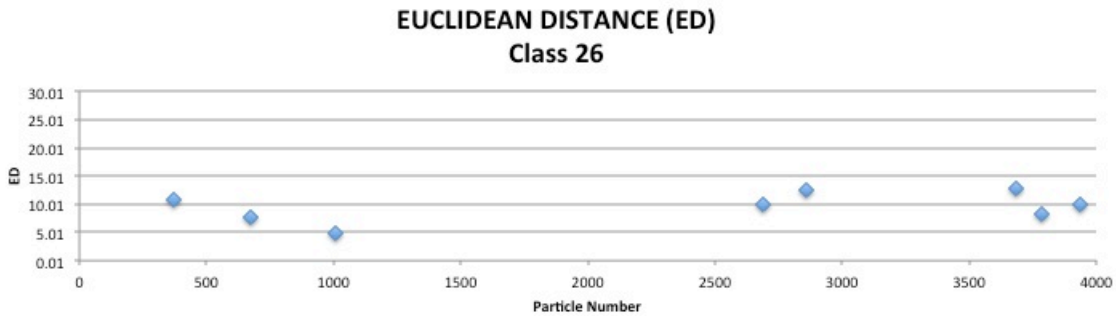

Figure 5-223: Euclidean Distance Class 26

Class 27 of Burkina Laterite 53 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 224 particles in this class (Figure 5-224).

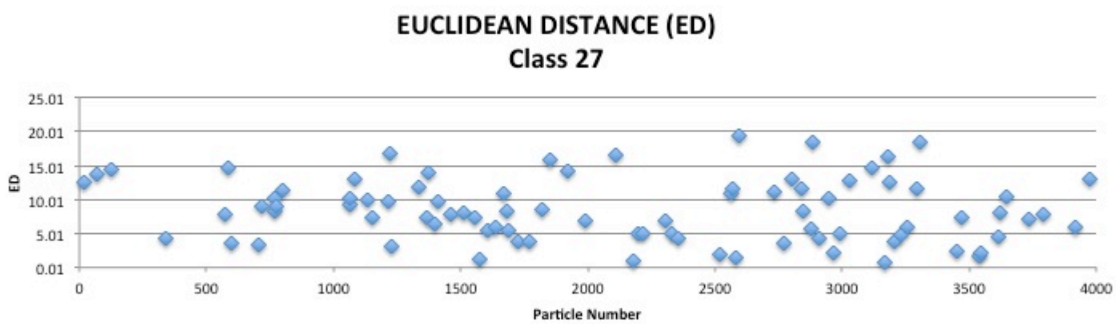

Figure 5-224: Euclidean Distance Class 27

Class 28 of Burkina Laterite 53 is composed of Aluminum less than 1%. There are a total of 338 particles in this class (Figure 5-225).

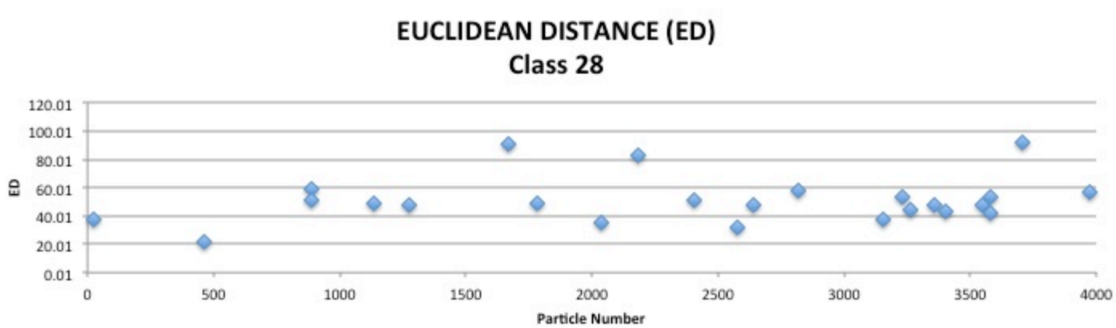

Figure 5-225: Euclidean Distance Class 28

Burkina Laterite 54

Numerical and Volumetric Analysis

Burkina Laterite 54 is located at 13 31.704’ N, 2 03.203’ E and has been separated into 29 elemental classes (Figure 5-226). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-20).

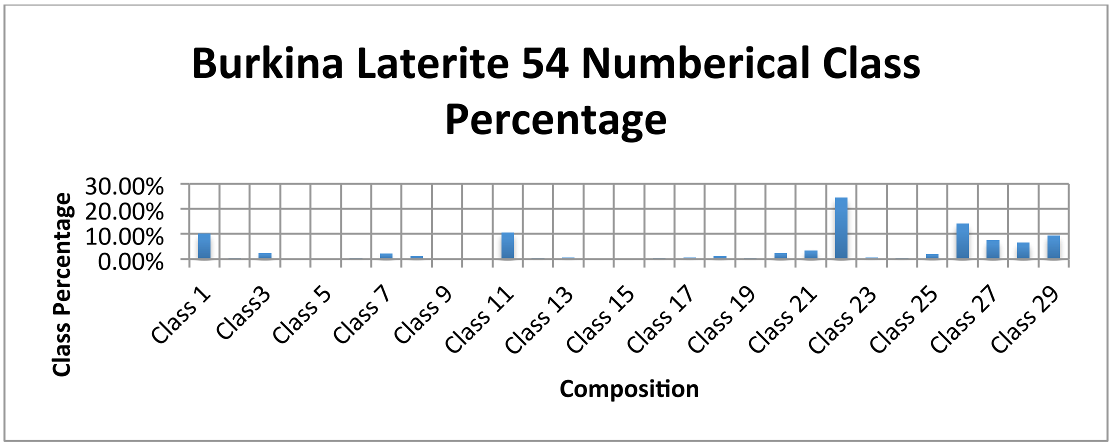

Figure 5-226: Number of particles contained within each elemental class.

Table 5-20: Percentage and number of particles contained within each class and three highest numerical elemental class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
552	1	125	0	0	7	112	68
10.10%	0.02%	2.29%	0.00%	0.00%	0.13%	2.05%	1.24%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	574	5	34	0	0	16
0.00%	0.00%	10.50%	0.09%	0.62%	0.00%	0.00%	0.29%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
28	65	9	133	181	1342	26	24
0.51%	1.19%	0.16%	2.43%	3.31%	24.56%	0.48%	0.44%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
109	773	408	359	514	5465		
1.99%	14.14%	7.47%	6.57%	9.41%	100.00%		

Table 5-20 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 11, 22, and 26. Class 11 has Calcium and Magnesium greater than 90% combined. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. This represents 49.2% of the entire sample and contains a total of 2689 particles. Class 29 represents the “unclassified” particles and contains only 9.41% of the entire sample.

The volumetric percentage of Burkina Laterite 54 represents the volume of particles that are represented in each respective elemental class (Figure 5-227). Table 5-21 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 1, 22, and 28. Class 1 has greater than 99% Silica. Class 22 is composed of less than 1% Calcium and Potassium, Aluminum between 4% and 20%, and Silica greater than 60%. Class 28 has Aluminum less than 1%. This represents 69.39% of the entire sample and contains a total volume of 105891.94 μm$^{3.}$ Class 29 represents the “unclassified” volume of particles and contains 10.31% of the entire sample.

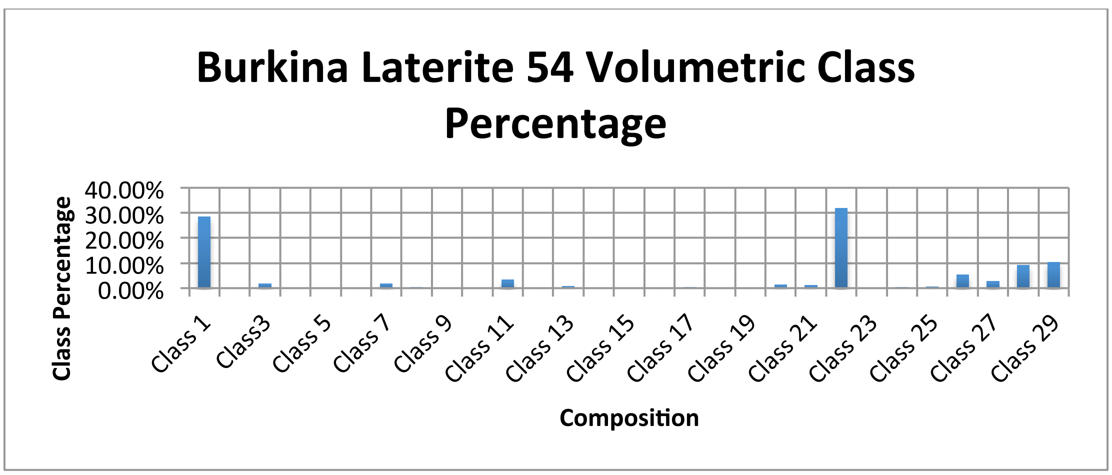

Figure 5-227: Volumetric percentage of classes contained within the sample.

Table 5-21: Volumetric percentage and volume of classes with the three highest classes highlighted with the total volume of the sample.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
43359.74	5.51	2785.09	0.00	0.00	45.46	2771.29	699.48
28.41%	0.00%	1.83%	0.00%	0.00%	0.03%	1.82%	0.46%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	5086.09	17.23	1134.90	0.00	0.00	49.31
0.00%	0.00%	3.33%	0.01%	0.74%	0.00%	0.00%	0.03%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
632.68	217.71	260.28	1955.24	1649.57	48509.73	261.33	469.72
0.41%	0.14%	0.17%	1.28%	1.08%	31.79%	0.17%	0.31%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
768.77	8016.83	4140.89	14022.47	15735.39	152594.71		
0.50%	5.25%	2.71%	9.19%	10.31%	100.00%		

Analysis of class 29 showed a slight cluster of elements similar to Burkina Laterite 53. The highest elements contained within Burkina Laterite 54 unclassified are Fe, Si, Al, respectively, and compose 10.31% of the entire sample. Most of the elements contained within class 29 are evenly distributed across the three elements Aluminum, Silica and Iron, and vary in percentages (Figure 5-228 and Figure 5-229). Not additional classes are necessary, but it is worth mentioning that there is a small cluster with Iron between 25% and 35%, Silica and Aluminum between 20% and 40%.

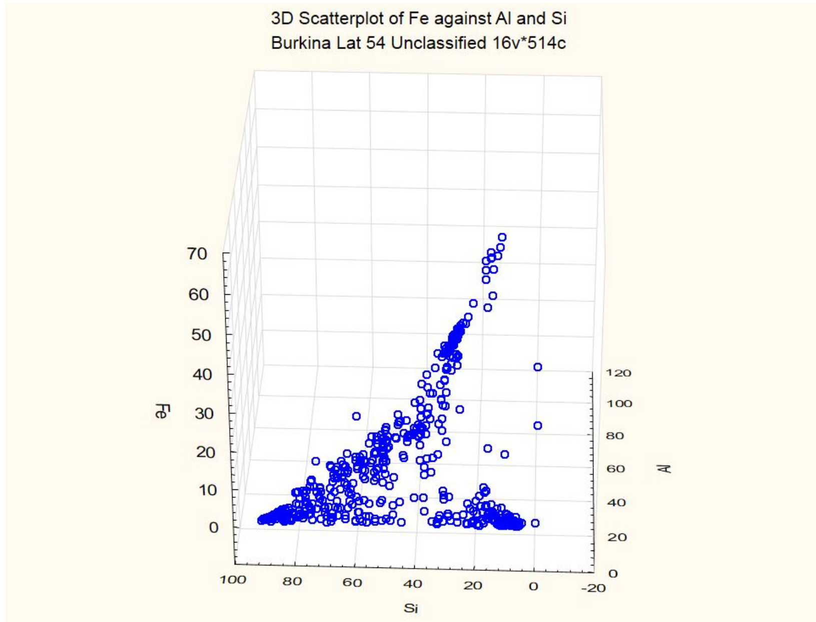

Figure 5-228: Scatterplot of Burkina Laterite 54 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles only contain 10.31% of the particles in the sample.

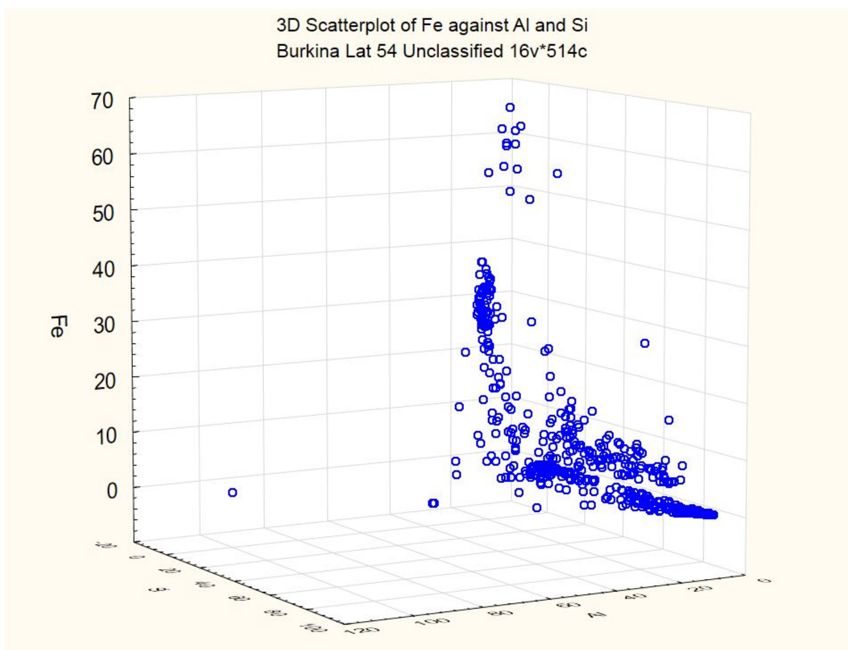

Figure 5-229: Different angle of Burkina Laterite 54 showing a slight cluster of Aluminum, Silica and Iron.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Laterite 54 is composed of greater than 99% Silica. There are a total of 552 particles in this class (Figure 5-230).

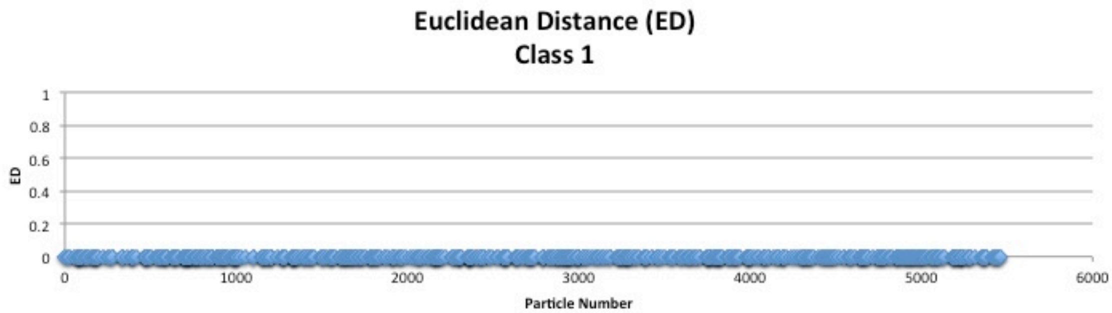

Figure 5-230: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There is a total of 1 particle in this class (Figure 5-231).

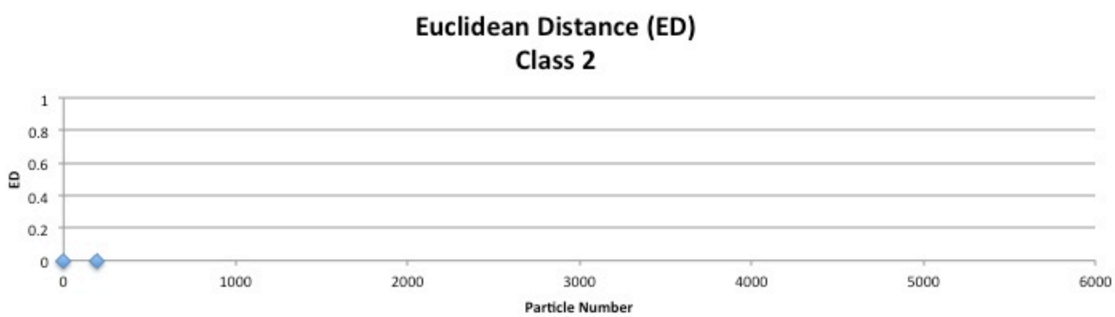

Figure 5-231: Euclidean Distance Class 2

Class 3 of Burkina Laterite 54 is composed of greater than 99% Calcium. There are a total of 125 particles in this class (Figure 5-232).

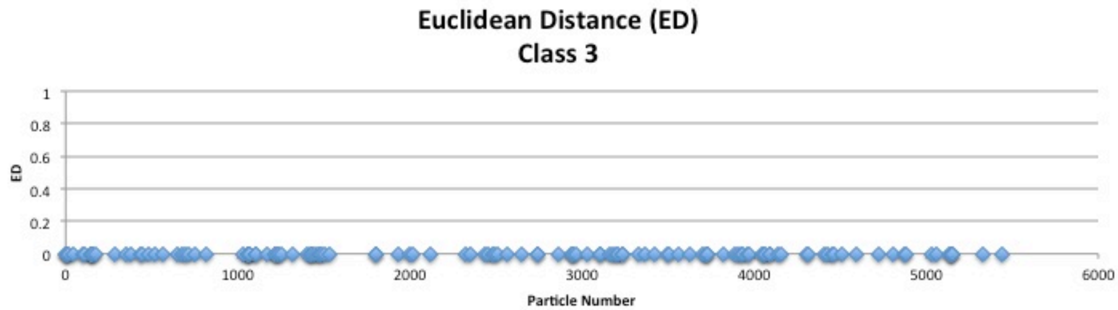

Figure 5-232: Euclidean Distance Class 3

Class 4 of Burkina Laterite 54 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Burkina Laterite 54 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Burkina Laterite 54 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 7 particles in this class (Figure 5-233).

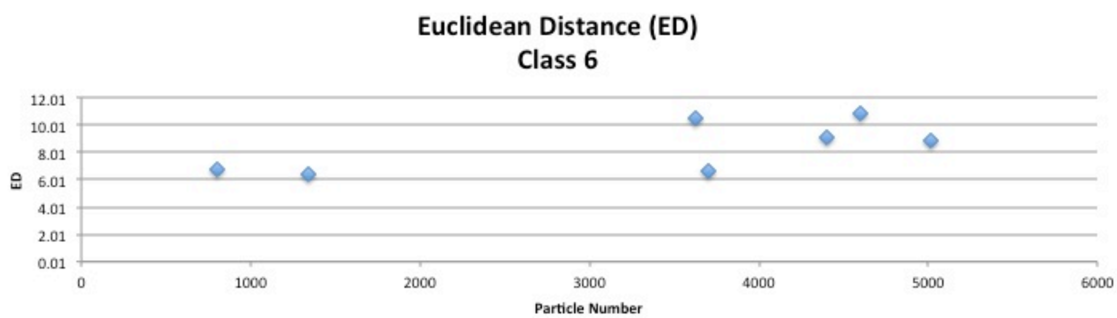

Figure 5-233: Euclidean Distance Class 6

Class 7 of Burkina Laterite 54 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 112 particles in this class (Figure 5-234).

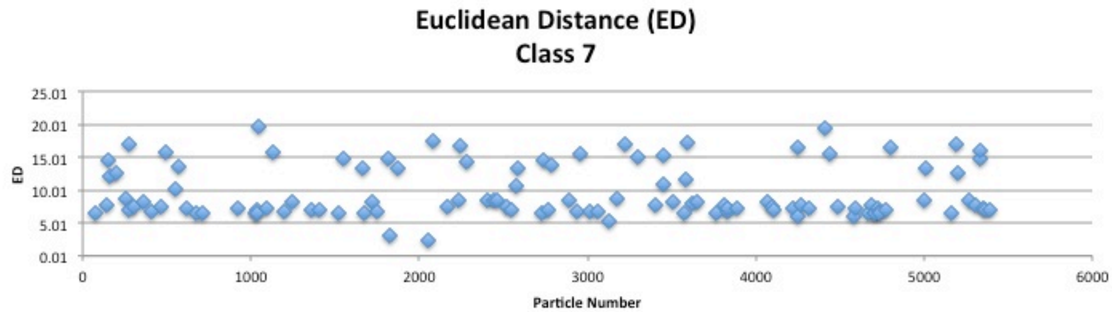

Figure 5-234: Euclidean Distance Class 7

Class 8 of Burkina Laterite 54 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 68 particles in this class (Figure 5-235).

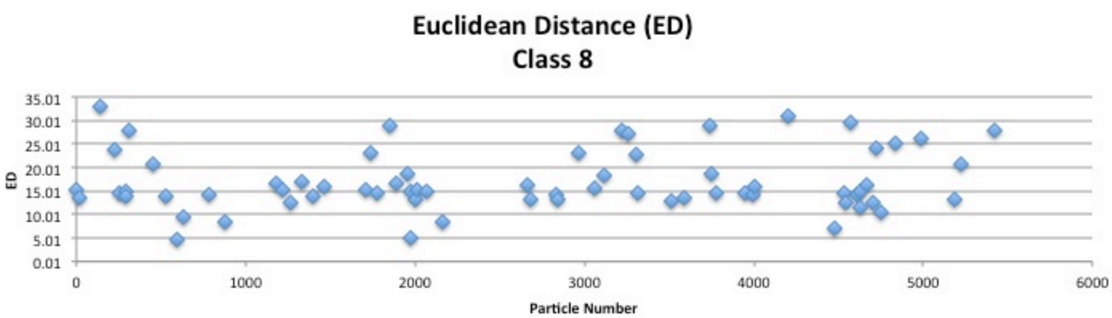

Figure 5-235: Euclidean Distance Class 8

Class 9 of Burkina Laterite 54 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Laterite 54 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Laterite 54 is composed of the total Calcium and Manganese greater than 90%. There are 574 particles in this class (Figure 5-236).

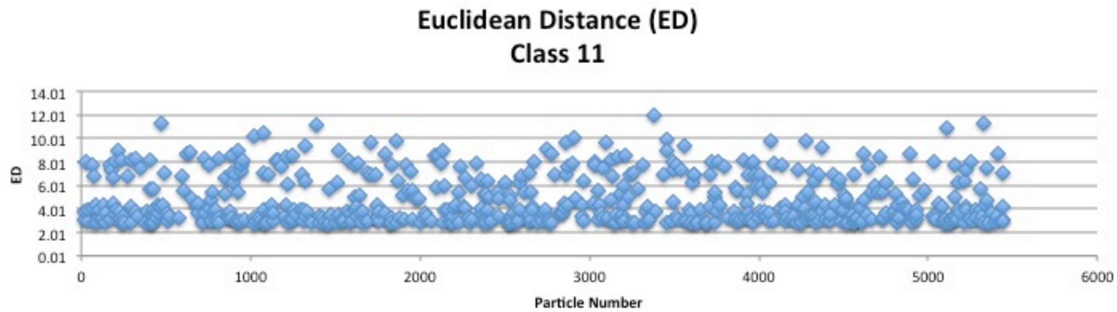

Figure 5-236: Euclidean Distance Class 11

Class 12 of Burkina Laterite 54 is composed of the total Calcium and Phosphorus greater than 90%. There are 5 particles in this class (Figure 5-237).

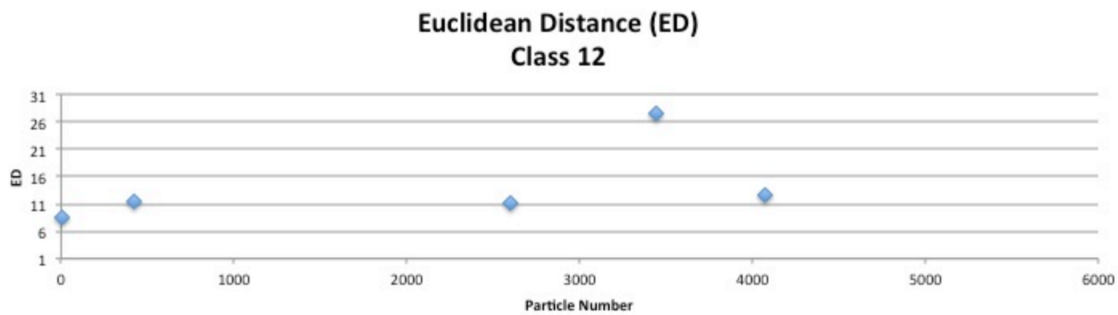

Figure 5-237: Euclidean Distance Class 12

Class 13 of Burkina Laterite 54 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 34 particles in this class (Figure 5-238).

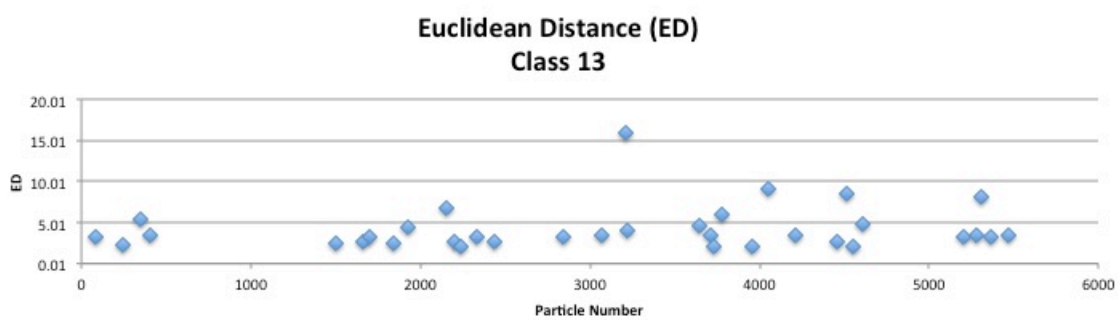

Figure 5-238: Euclidean Distance Class 13

Class 14 of Burkina Laterite 54 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are no particles in this class.

Class 15 of Burkina Laterite 54 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Laterite 54 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 16 particles in this class (Figure 5-239).

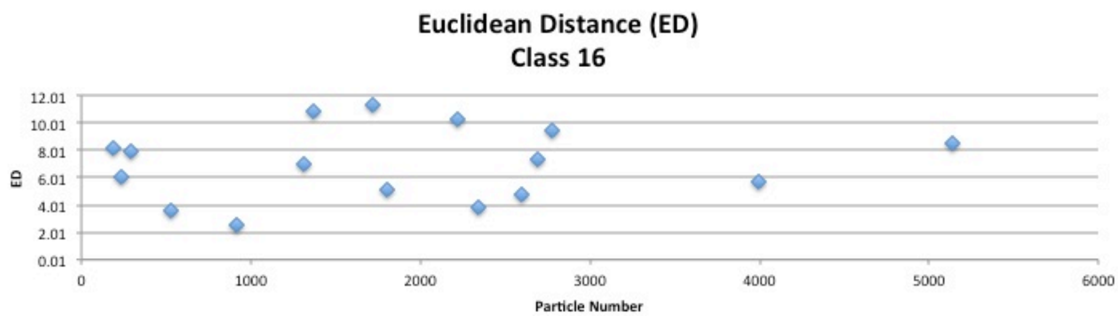

Figure 5-239: Euclidean Distance Class 16

Class 17 of Burkina Laterite 54 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 28 particles in this class (Figure 5-240).

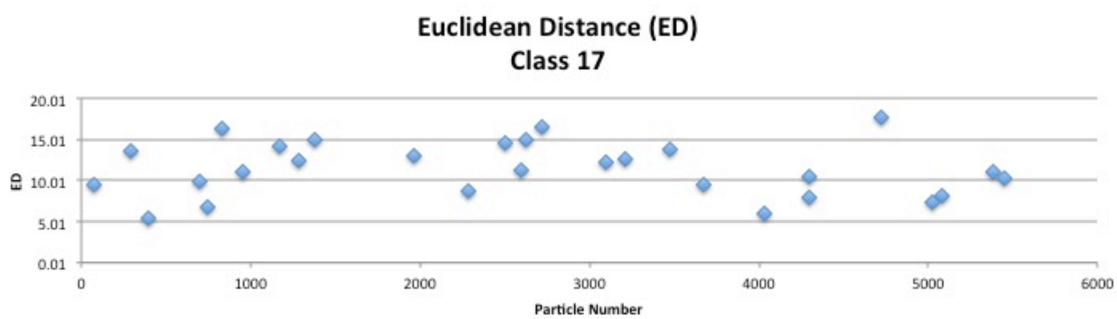

Figure 5-240: Euclidean Distance Class 17

Class 18 of Burkina Laterite 54 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 65 particles in this class (Figure 5-241).

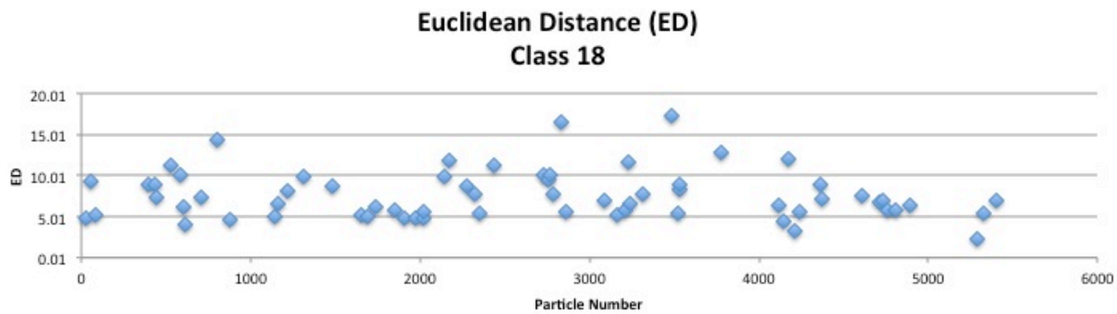

Figure 5-241: Euclidean Distance Class 18

Class 19 of Burkina Laterite 54 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 9 particles in this class (Figure 5-242).

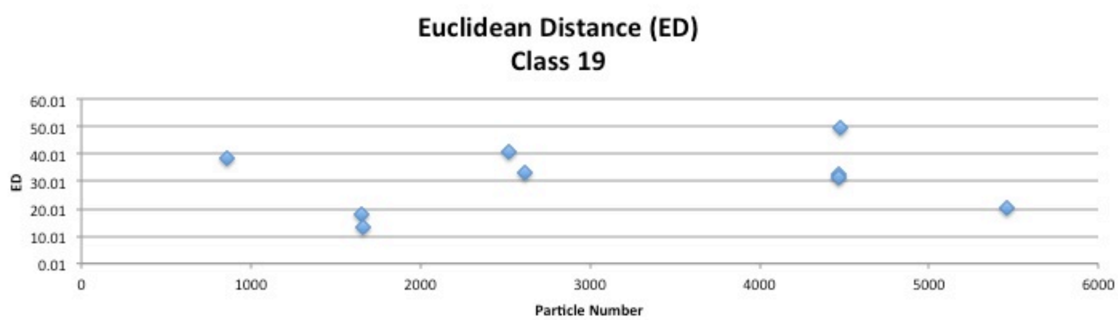

Figure 5-242: Euclidean Distance Class 19

Class 20 of Burkina Laterite 54 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 133 particles in this class (Figure 5-243).

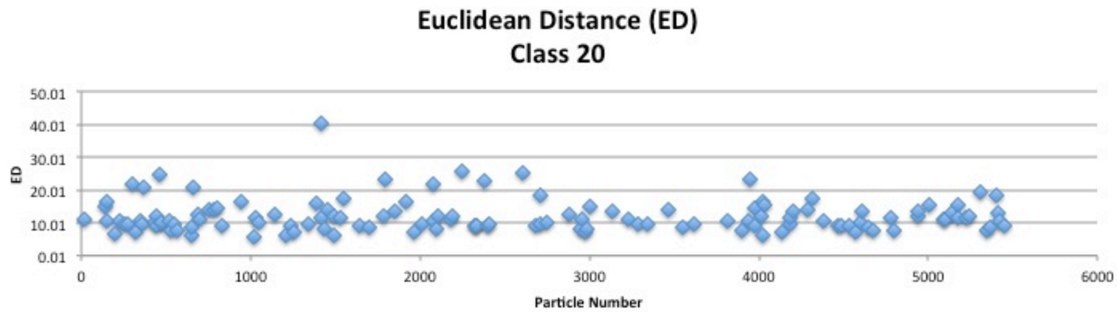

Figure 5-243: Euclidean Distance Class 20

Class 21 of Burkina Laterite 54 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 181 particles in this class (Figure 5-244).

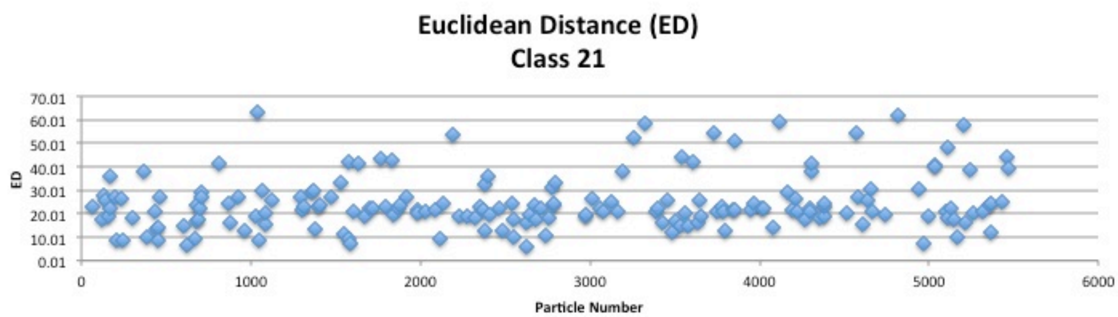

Figure 5-244: Euclidean Distance Class 21

Class 22 of Burkina Laterite 54 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 1342 particles in this class (Figure 5-245).

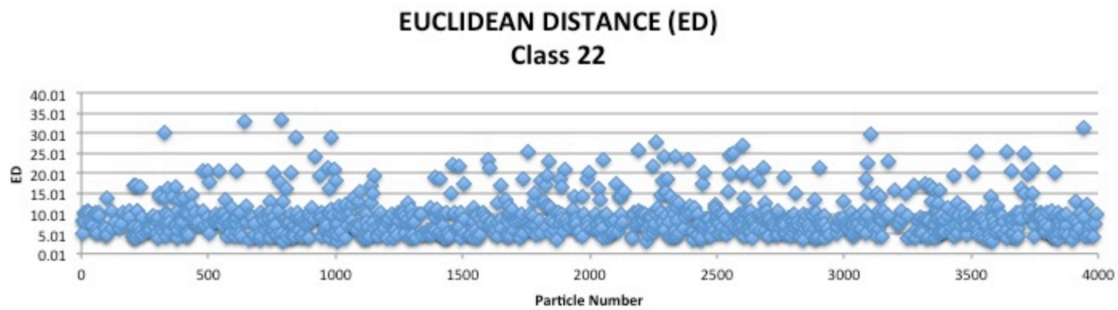

Figure 5-245: Euclidean Distance Class 22

Class 23 of Burkina Laterite 54 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 26 particles in this class (Figure 5-246).

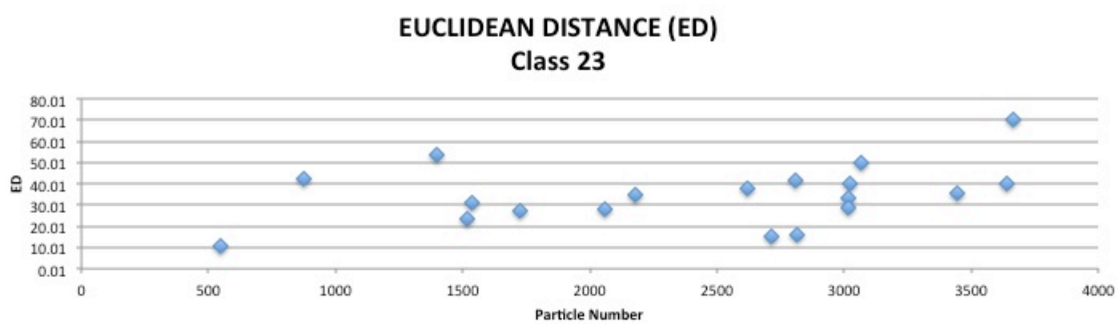

Image Figure 5-246: Euclidean Distance Class 23

Class 24 of Burkina Laterite 54 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 24 particles in this class (Figure 5-247).

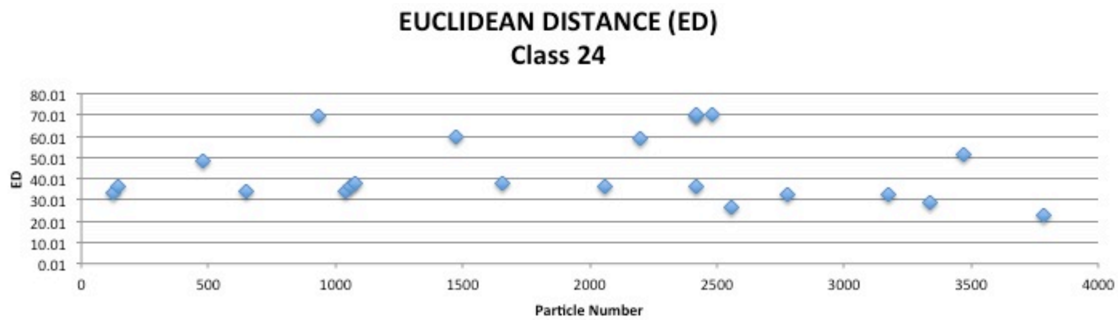

Figure 5-247: Euclidean Distance Class 24

Class 25 of Burkina Laterite 54 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 109 particles in this class (Figure 5-248).

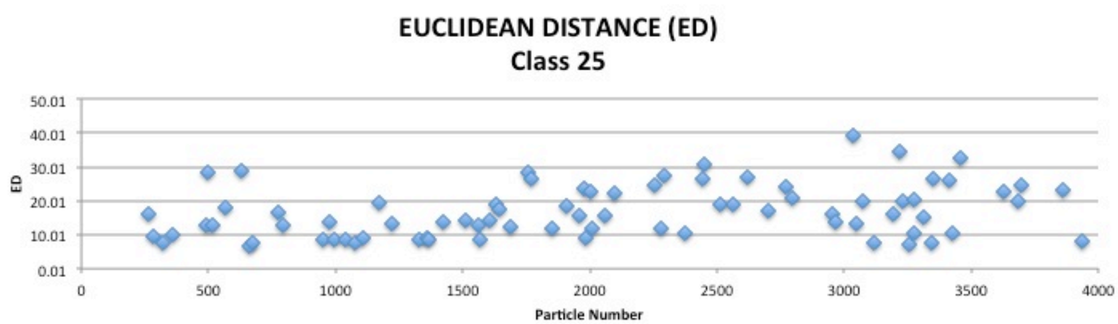

Figure 5-248: Euclidean Distance Class 25

Class 26 of Burkina Laterite 54 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 773 particles in this class (Figure 5-249).

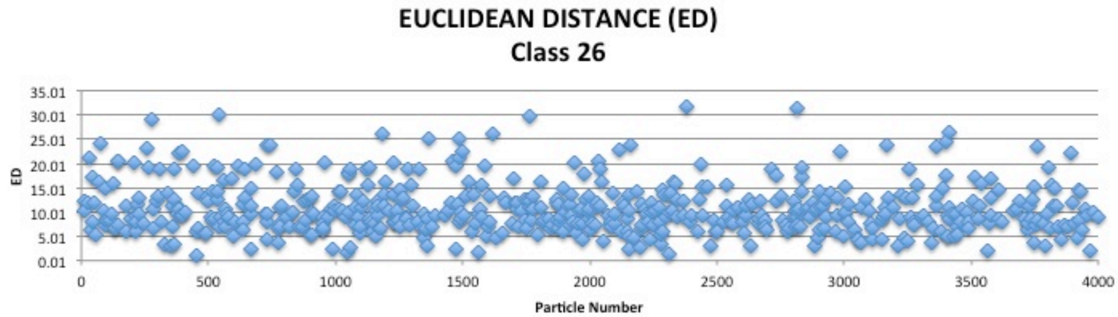

Figure 5-249: Euclidean Distance Class 26

Class 27 of Burkina Laterite 54 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 408 particles in this class (Figure 5-250).

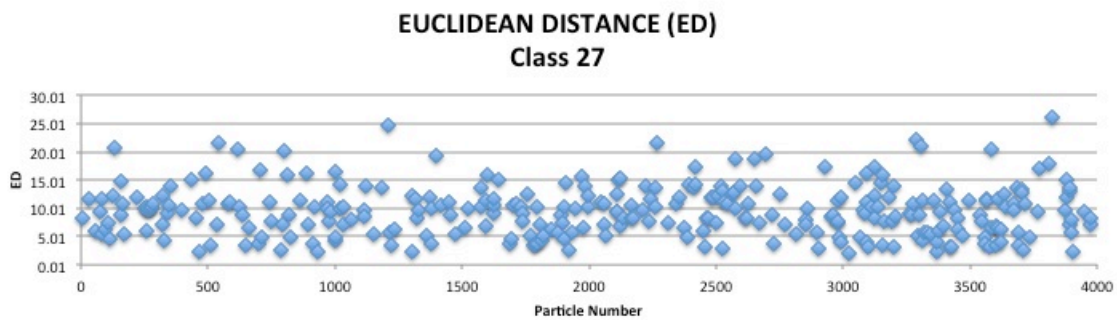

Figure 5-250: Euclidean Distance Class 27

Class 28 of Burkina Laterite 54 is composed of Aluminum less than 1%. There are a total of 514 particles in this class (Figure 5-251).

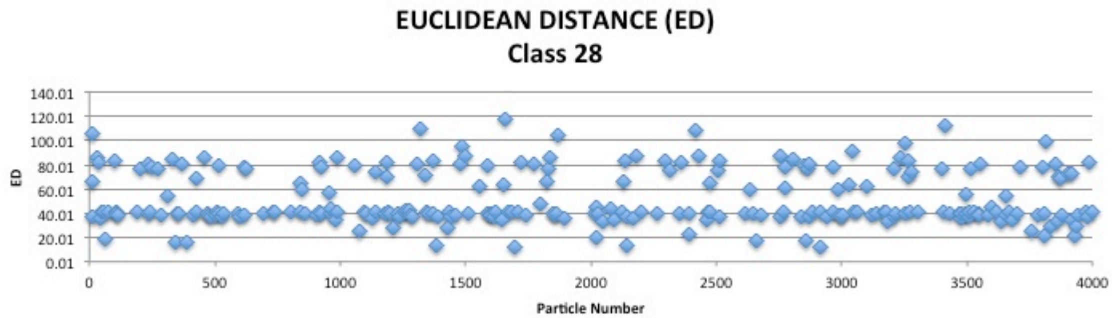

Figure 5-251: Euclidean Distance Class 28

Burkina Laterite 56

Numerical and Volumetric Analysis

Burkina Laterite 56 is located at 12 58.308’ N, 1 44.449’ E and has been separated into 29 elemental classes (Figure 5-252). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Figure 5-22).

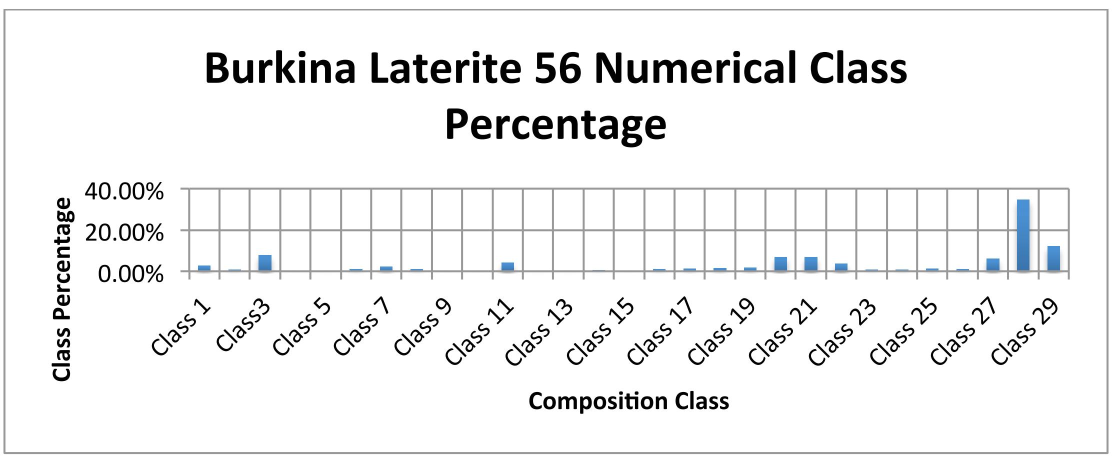

Figure 5-252: Numerical percentage of particles contained within each class.

Table 5-22: Numerical percentage and number of particles contained within each element class and three highest classes and total number of particles highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
83	26	241	0	6	33	72	29
2.65%	0.83%	7.68%	0.00%	0.19%	1.05%	2.30%	0.92%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	131	4	5	18	0	31
0.00%	0.00%	4.18%	0.13%	0.16%	0.57%	0.00%	0.99%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
37	48	51	216	216	117	23	25
1.18%	1.53%	1.63%	6.89%	6.89%	3.73%	0.73%	0.80%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
37	33	189	1088	377	3136		
1.18%	1.05%	6.03%	34.69%	12.02%	100.00%		

Table 5-22 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 3, 28, and equally 20 and 21. Class 3 contains greater than 99% Calcium. Class 28 contains Aluminum less than 1%. Class 20 has Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 21 is composed of Calcium between 4% and 80%, Potassium less than 1%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. This represents 56.16% of the entire sample and contains a total of 1761 particles. Class 29 represents the “unclassified” particles and contains only 12.02% of the entire sample.

The volumetric percentage of Burkina Laterite 56 represents the volume of particles that are represented in each respective elemental class (Figure 5-253). Table 5-23 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 21, 27, and 28. Class 21 is composed of Calcium between 4% and 80%, Potassium less than 1%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. Class 27 has less than 1% Potassium and Calcium, Aluminum between 40% and 60%, and Silica between 20% and 60%. Class 28 has less than 1% Aluminum. This represents 65.19% of the entire sample and contains a total volume of 67999.44μm. Class 29 represents the "unclassified" volume of particles and contains 12.94% of the entire sample.

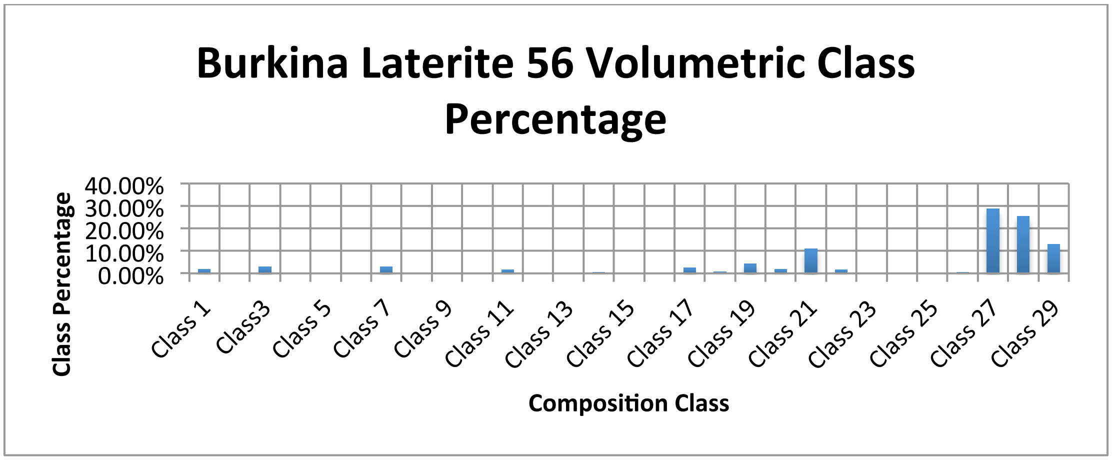

Figure 5-253: Burkina Laterite 56 volumetric percentage of each class.

Table 5-23: Volumetric percentage and volume of each class with three highest percentages and total volume highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
1956.35	57.10	3024.45	0.00	2.12	36.47	2971.19	217.78
1.88%	0.05%	2.90%	0.00%	0.00%	0.03%	2.85%	0.21%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	1665.31	1.47	4.57	420.77	0.00	91.90
0.00%	0.00%	1.60%	0.00%	0.00%	0.40%	0.00%	0.09%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
2528.63	724.72	4496.34	1981.02	11495.60	1642.41	72.42	316.69
2.42%	0.69%	4.31%	1.90%	11.02%	1.57%	0.07%	0.00
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
73.96	526.23	29980.61	26523.23	13494.35	104305.67		
0.07%	0.50%	28.74%	25.43%	12.94%	100.00%		

Analysis of class 29 showed a slight cluster of elements similar to Burkina Laterite 53 and

Burkina Laterite 54. The highest elements contained within Burkina Laterite 56 unclassified are Fe, Si, Al, respectively, and compose 12.94% of the entire sample. Most of the elements contained within class 29 are evenly distributed across the three elements Aluminum, Silica and Iron, and vary in percentages (Figure 5-254). Not additional classes are necessary, but it is worth mentioning that there is a small cluster with Iron between 25% and 35%, Silica and Aluminum between 20% and 40%.

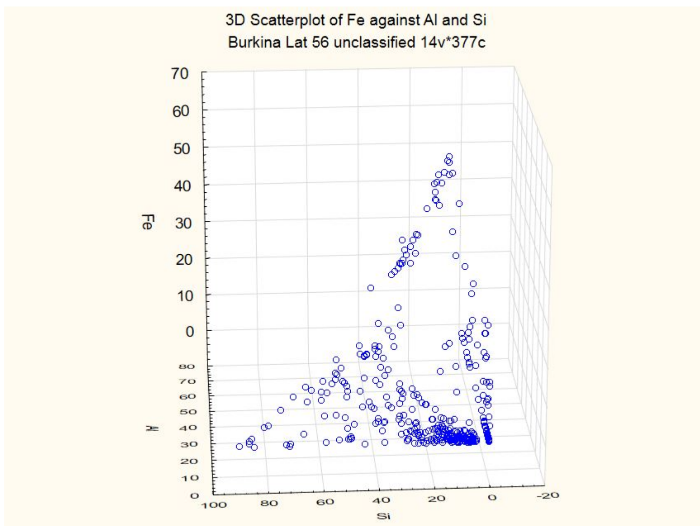

Figure 5-254: Burkina Laterite 56 showing a slight cluster of Aluminum, Silica and Iron.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Laterite 56 is composed of greater than 99% Silica. There are a total of 83 particles in this class (Figure 5-255).

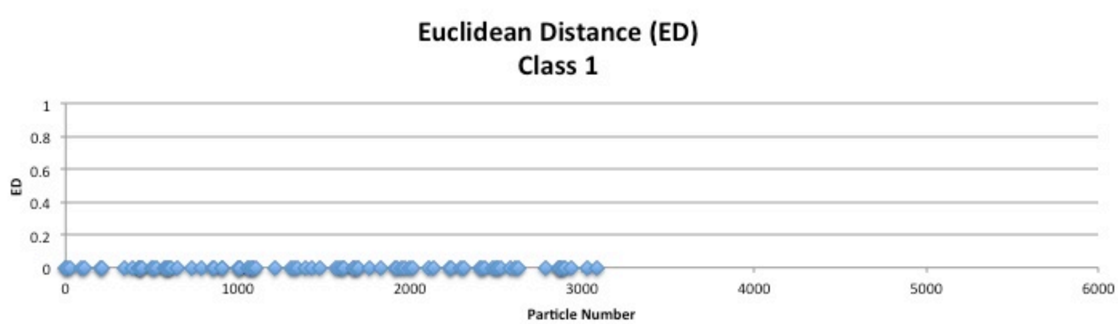

Figure 5-255: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 26 particles in this class (Figure 5-256).

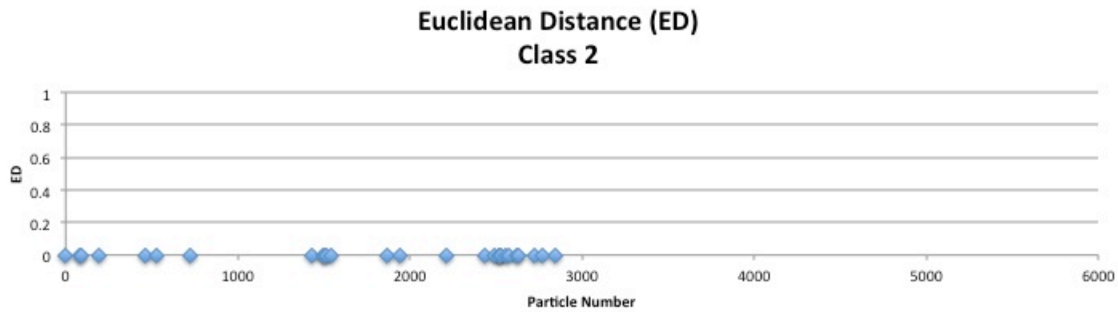

Figure 5-256: Euclidean Distance Class 2

Class 3 of Burkina Laterite 56 is composed of greater than 99% Calcium. There are a total of 241 particles in this class (Figure 5-257).

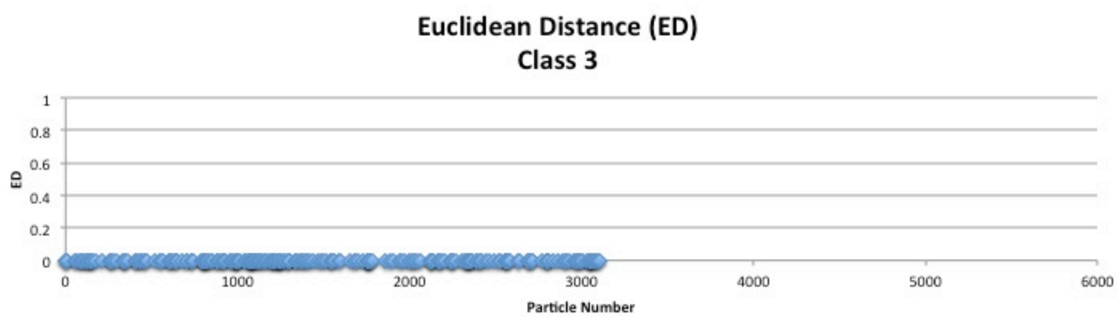

Figure 5-257: Euclidean Distance Class 3

Class 4 of Burkina Laterite 56 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Burkina Laterite 56 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are 6 particles in this class (Figure 5-258).

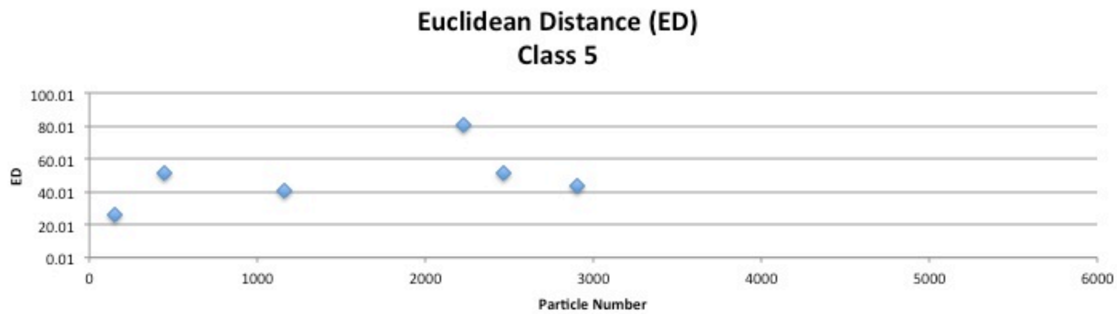

Figure 5-258: Euclidean Distance Class 5

Class 6 of Burkina Laterite 56 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 33 particles in this class (Figure 5-259).

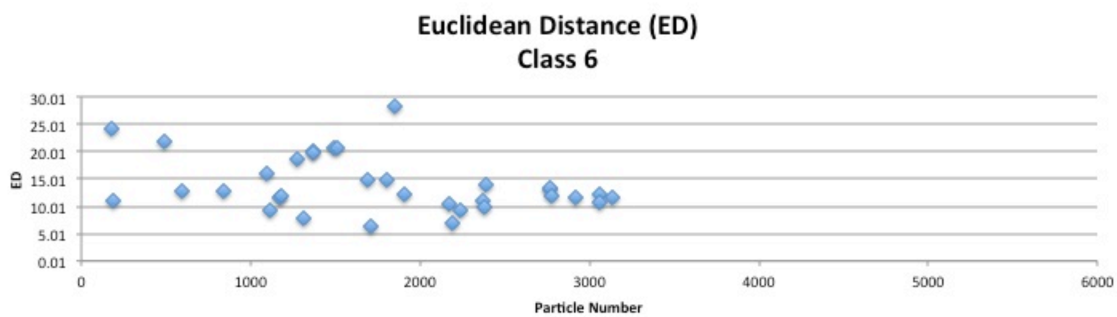

Figure 5-259: Euclidean Distance Class 6

Class 7 of Burkina Laterite 56 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 72 particles in this class (Figure 5-260).

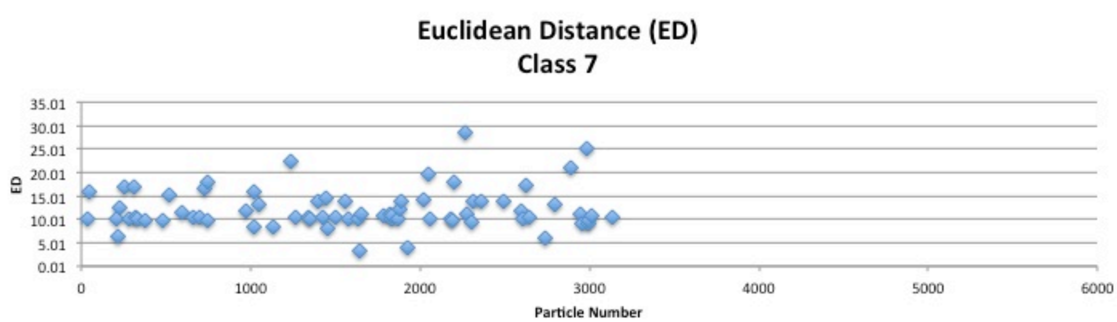

Figure 5-260: Euclidean Distance Class 7

Class 8 of Burkina Laterite 56 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 29 particles in this class (Figure 5-261).

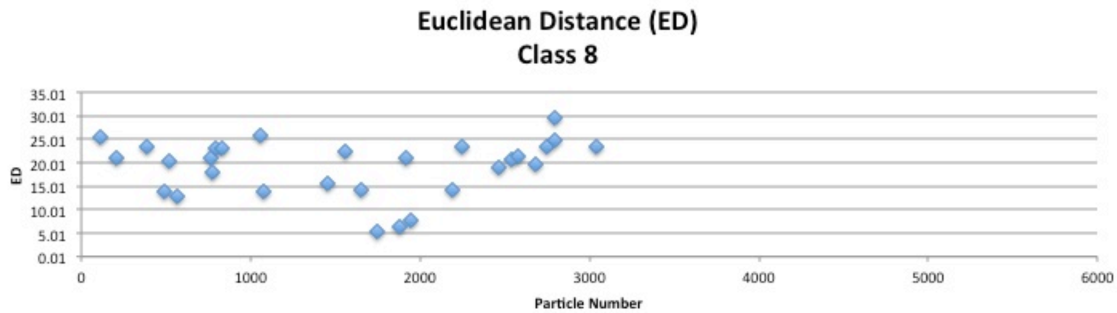

Figure 5-261: Euclidean Distance Class 8

Class 9 of Burkina Laterite 56 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Laterite 56 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Laterite 56 is composed of the total Calcium and Manganese greater than 90%. There are 131 particles in this class (Image Figure 5-262).

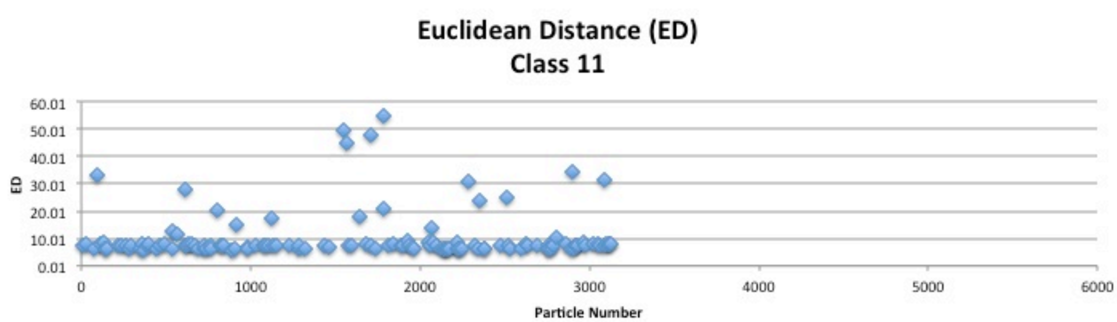

Figure 5-262: Euclidean Distance Class 11

Class 12 of Burkina Laterite 56 is composed of the total Calcium and Phosphorus greater than 90%. There are a total of 4 particles in this class (Figure 5-263).

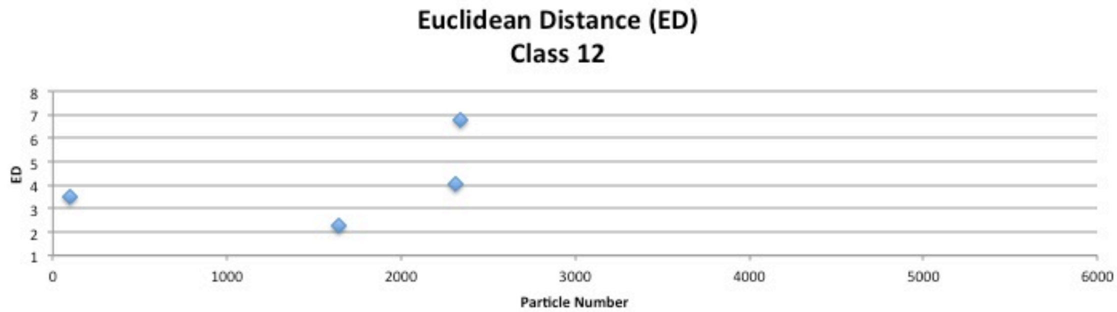

Figure 5-263: Euclidean Distance Class 12

Class 13 of Burkina Laterite 56 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 5 particles in this class (Figure 5-264).

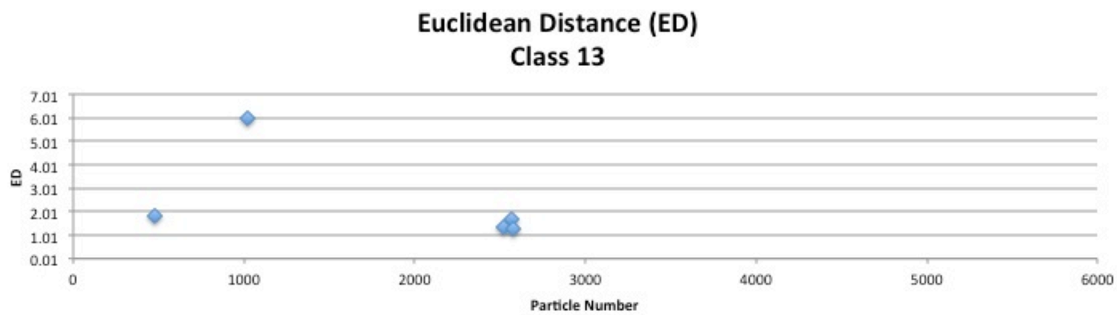

Figure 5-264: Euclidean Distance Class 13

Class 14 of Burkina Laterite 56 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are a total of 18 particles in this class (Figure 5-265).

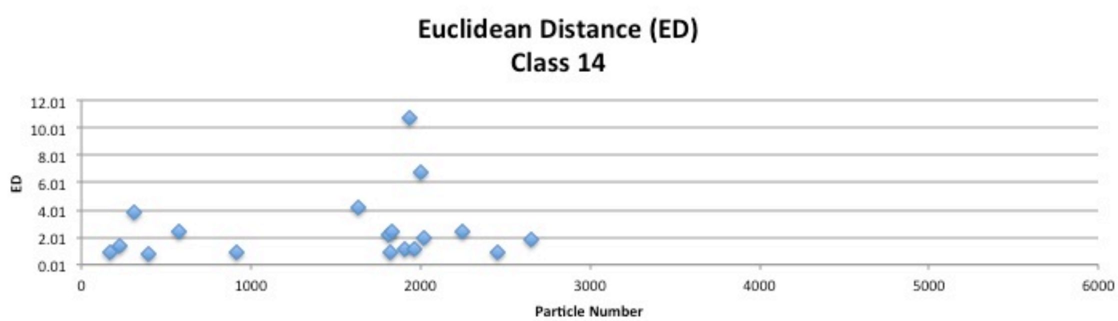

Figure 5-265: Euclidean Distance Class 14

Class 15 of Burkina Laterite 56 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Laterite 56 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 31 particles in this class (Figure 5-266).

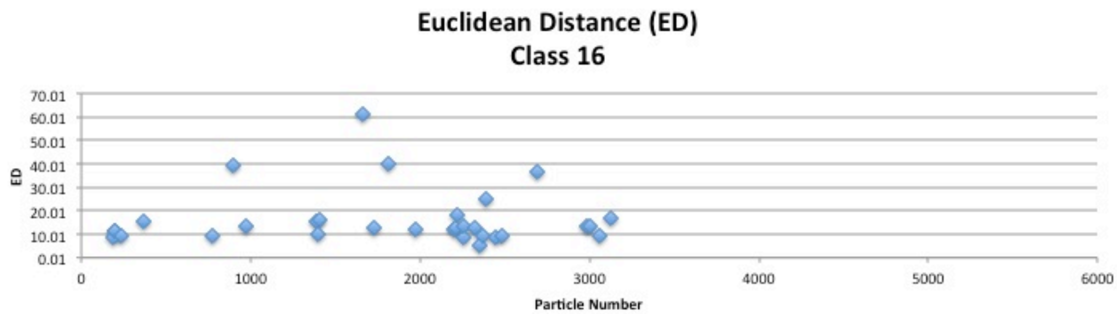

Figure 5-266: Euclidean Distance Class 16

Class 17 of Burkina Laterite 56 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 37 particles in this class (Figure 5-267).

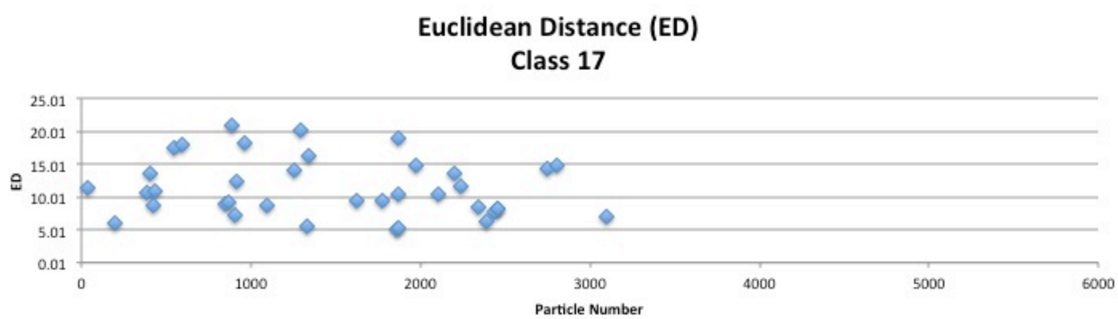

Figure 5-267: Euclidean Distance Class 17

Class 18 of Burkina Laterite 56 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 48 particles in this class (Figure 5-268).

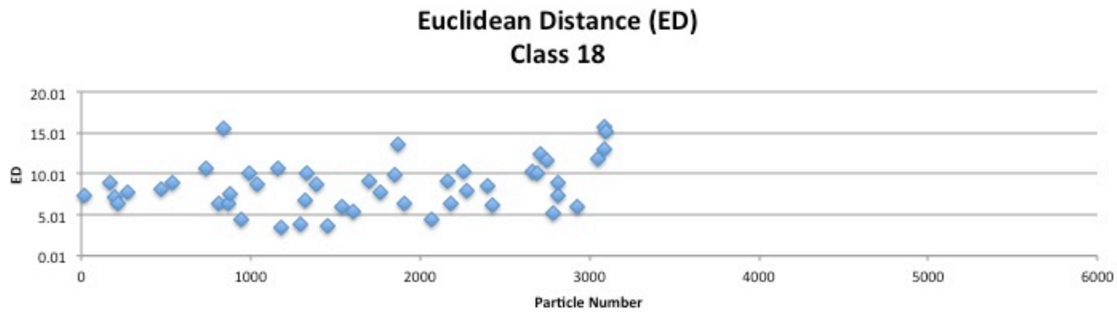

Figure 5-268: Euclidean Distance Class 18

Class 19 of Burkina Laterite 56 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 51 particles in this class (Figure 5-269).

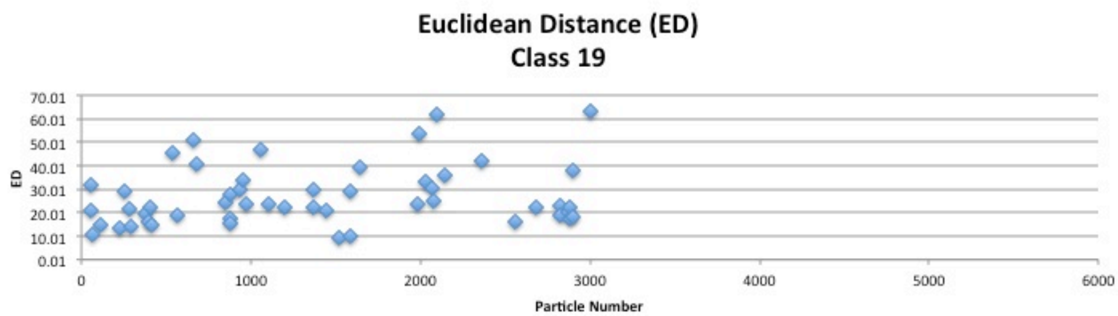

Figure 5-269: Euclidean Distance Class 19

Class 20 of Burkina Laterite 56 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 216 particles in this class (Figure 5-270).

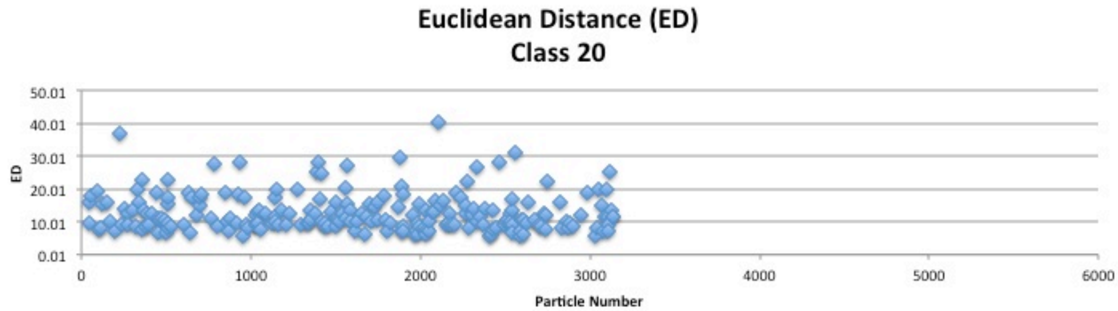

Figure 5-270: Euclidean Distance Class 20

Class 21 of Burkina Laterite 56 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 216 particles in this class (Figure 5-271).

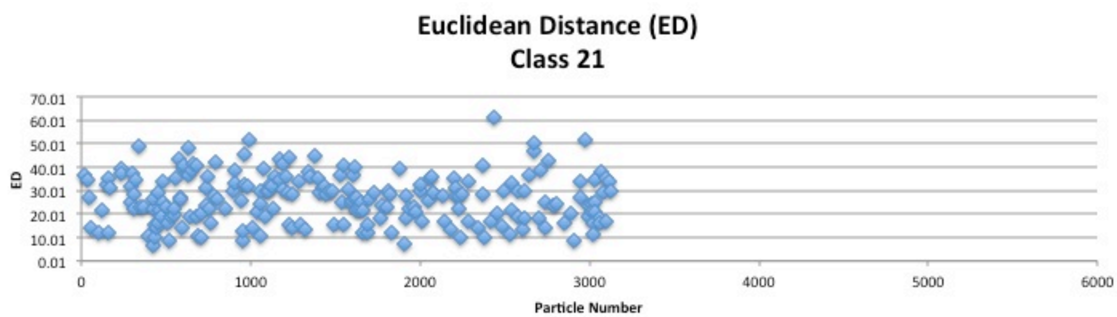

Figure 5-271: Euclidean Distance Class 21

Class 22 of Burkina Laterite 56 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 117 particles in this class (Figure 5-272).

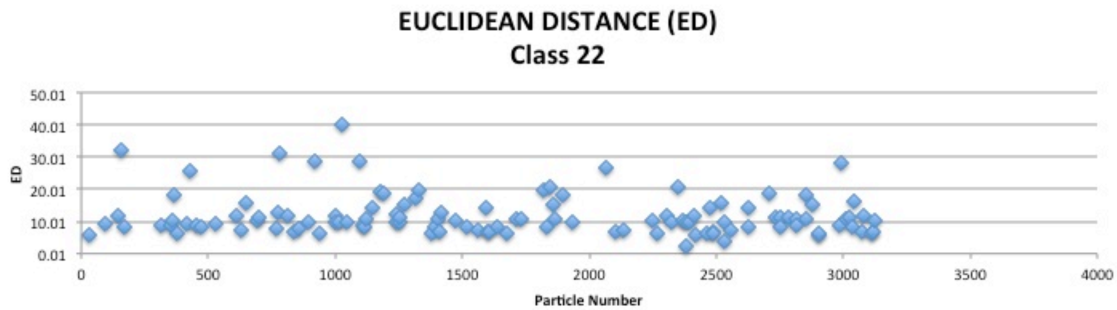

Figure 5-272: Euclidean Distance Class 22

Class 23 of Burkina Laterite 56 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 23 particles in this class (Figure 5-273).

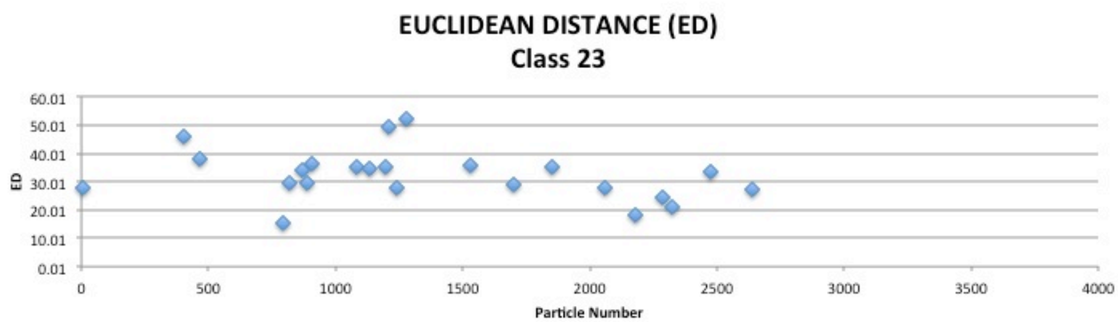

Figure 5-273: Euclidean Distance Class 23

Class 24 of Burkina Laterite 56 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 25 particles in this class (Figure 5-274).

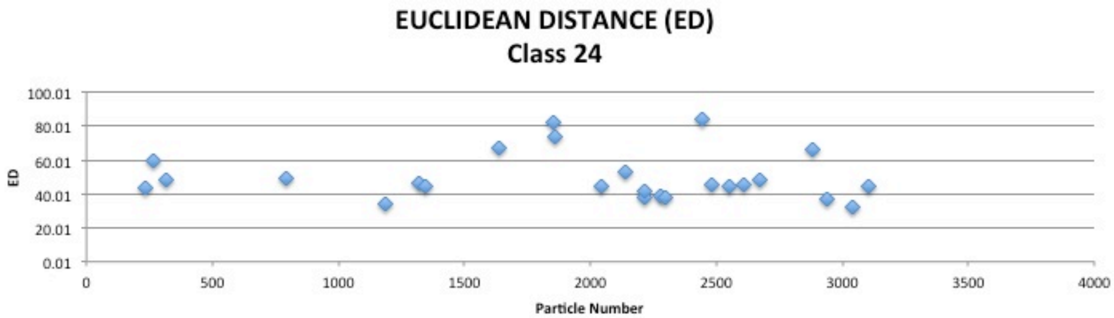

Figure 5-274: Euclidean Distance Class 24

Class 25 of Burkina Laterite 56 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 37 particles in this class (Figure 5-275).

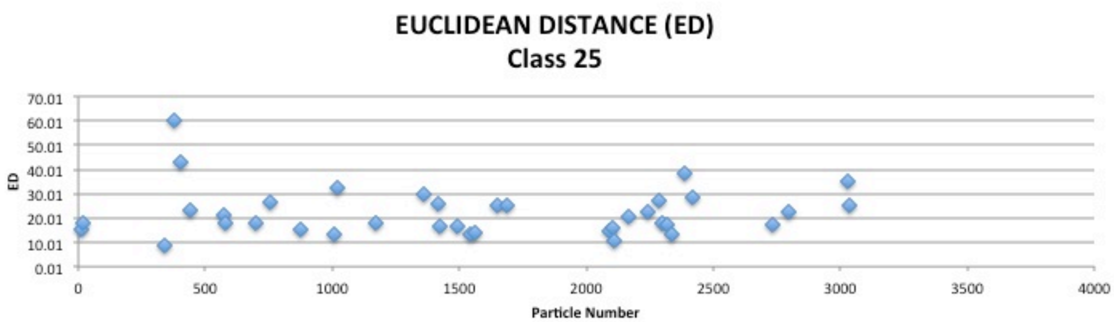

Figure 5-275: Euclidean Distance Class 25

Class 26 of Burkina Laterite 56 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 33 particles in this class (Figure 5-276).

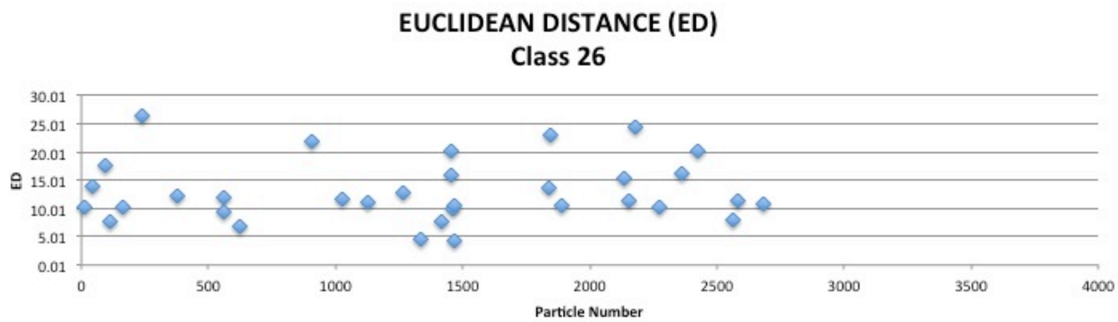

Figure 5-276: Euclidean Distance Class 26

Class 27 of Burkina Laterite 56 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 189 particles in this class (Figure 5-277).

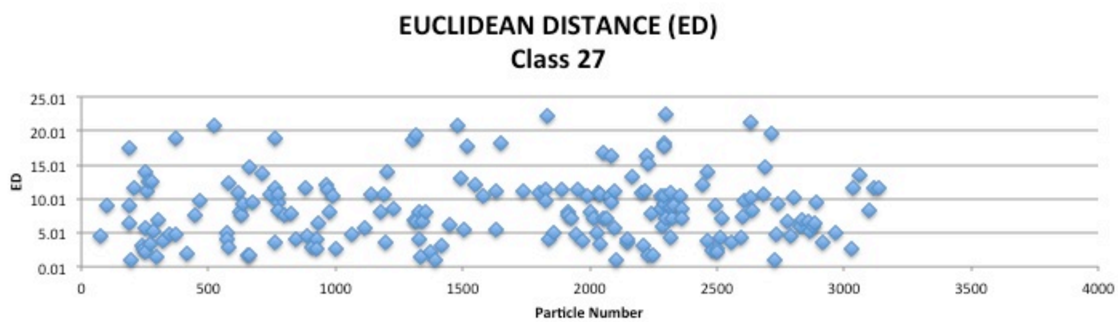

Figure 5-277: Euclidean Distance Class 27

Class 28 of Burkina Laterite 56 is composed of Aluminum less than 1%. There are a total of 1088 particles in this class (Figure 5-278).

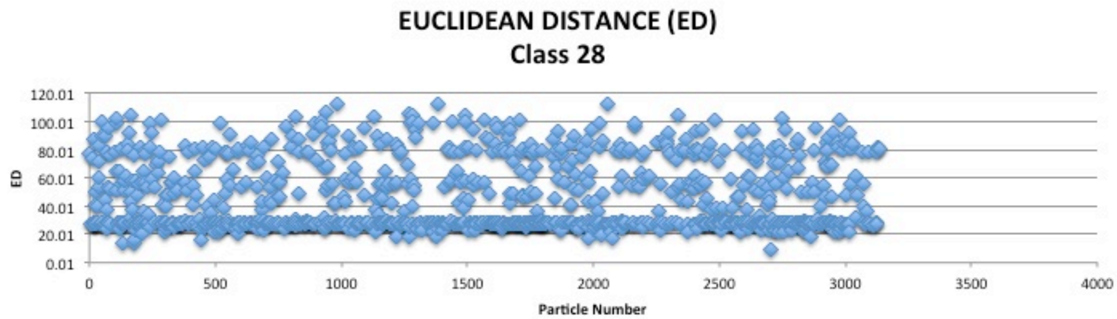

Figure 5-278: Euclidean Distance Class 28

Burkina Laterite 57

Numerical and Volumetric Analysis

Burkina Laterite 57 is located at 12 43.603' N, 1 37.670' E and has been separated into 29 elemental classes (Figure 5-279). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-24).

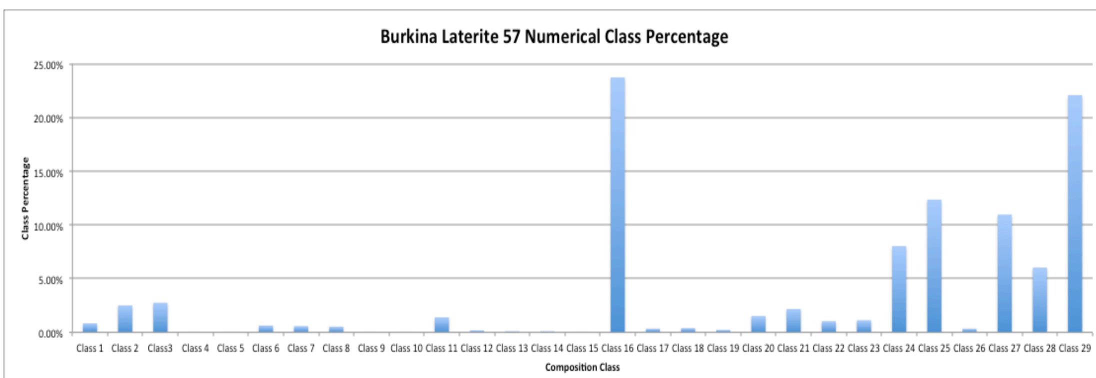

Figure 5-279: Numerical percentage of particles contained within each class.

Table 5-24: Numerical percentage and number of particles contained within each element class and three highest classes and total number of particles highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
48	142	156	0	0	36	33	30
0.85%	2.51%	2.76%	0.00%	0.00%	0.64%	0.58%	0.53%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	79	10	6	5	0	1342
0.00%	0.00%	1.40%	0.18%	0.11%	0.09%	0.00%	23.73%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
19	22	13	86	123	59	64	454
0.34%	0.39%	0.23%	1.52%	2.18%	1.04%	1.13%	8.03%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
699	19	620	341	1249	5655		
12.36%	0.34%	10.96%	6.03%	22.09%	100.00%		

Table 5-24 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 24, 25, and 27. Class 24 contains Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. Class 25 has Calcium and Potassium less than 1%, Aluminum between 20% and 35%, and between 18% and 40% Silica. Class 27 is composed of less than 1% Calcium and Potassium, between 40% and 60% Aluminum, and 20% to 60% Silica. This represents 31.35% of the entire sample and contains a total of 1773 particles. Class 29 represents the “unclassified” particles and contains only 22.09% of the entire sample.

The volumetric percentage of Burkina Laterite 57 represents the volume of particles that are represented in each respective elemental class (Figure 5-280). Table 5-25 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 24, 25, and 27, which is consistent with the numerical percentages. Class 24 contains Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. Class 25 has Calcium and Potassium less than 1%, Aluminum between 20% and 35%, and between 18% and 40% Silica. Class 27 is composed of less than 1% Calcium and Potassium, between 40% and 60% Aluminum, and 20% to 60% Silica. This represents 38.47% of the entire sample and contains a total volume of 68314µm. Class 29 represents the “unclassified” volume of particles and contains 25.47% of the entire sample.

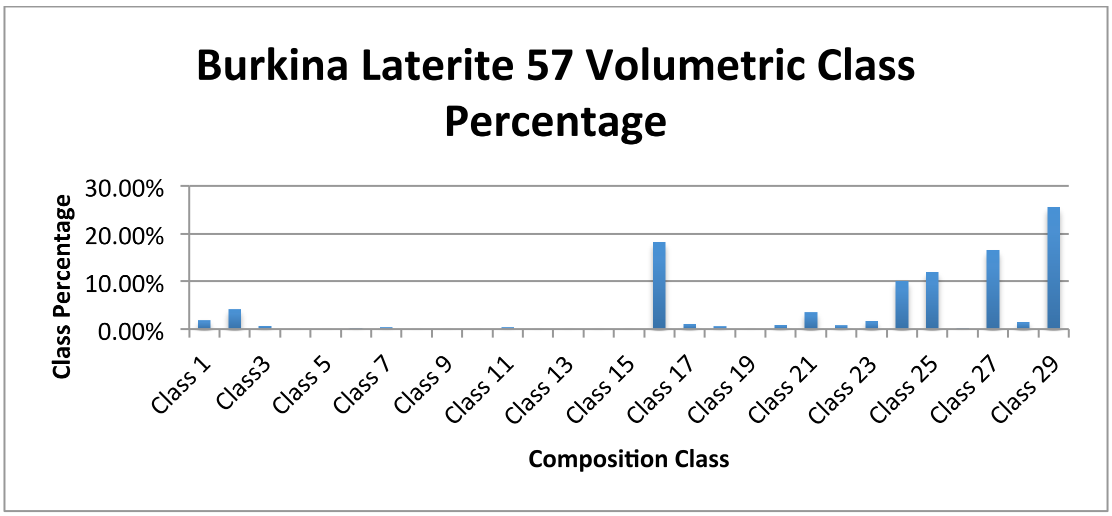

Figure 5-280: Burkina Laterite 57 volumetric percentage of each class.

Table 5-25: Volumetric percentage and volume of each class with three highest percentages and total volume highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
3253.39	7268.79	1081.30	0.00	0.00	482.47	516.06	125.48
1.83%	4.09%	0.61%	0.00%	0.00%	0.27%	0.29%	0.07%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	502.63	98.91	134.54	299.44	0.00	32137.27
0.00%	0.00%	0.28%	0.06%	0.08%	0.17%	0.00%	18.10%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
1896.89	966.25	113.02	1516.28	6209.36	1401.67	2939.29	17932.62
1.07%	0.54%	0.06%	0.85%	3.50%	0.79%	1.66%	10.10%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
21150.46	338.62	29231.07	2719.41	45226.45	177541.66		
11.91%	0.19%	16.46%	1.53%	25.47%	100.00%		

Analysis of class 29 showed a cluster of elements similar to Burkina Laterite 53, Burkina Laterite 54, and Burkina Laterite 56. The highest elements contained within Burkina Laterite 57 unclassified are Fe, Si, Al, respectively, and compose 22.09% of the entire sample. Most of the elements contained within class 29 are evenly distributed across the three elements Aluminum, Silica and Iron, or are contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-281 and Figure 5-282). Approximately 80% if the unclassified particles are contained within these two distinct clusters.

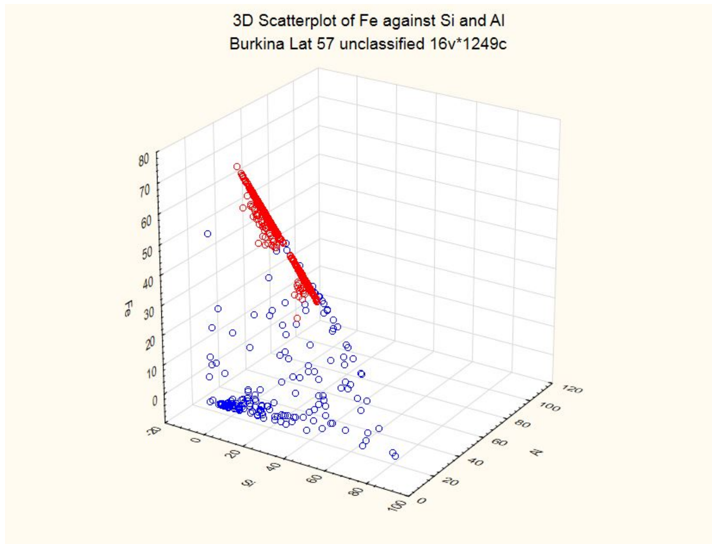

Figure 5-281: Scatterplot of Burkina Laterite 57 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 22.09% of the particles in the sample.

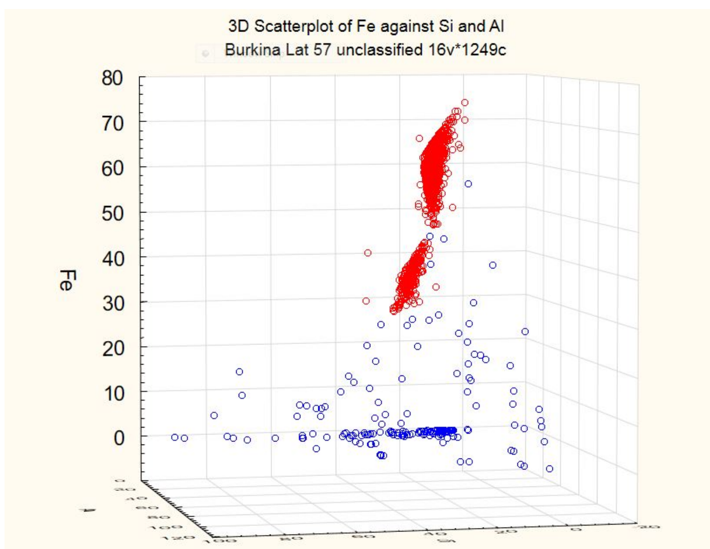

Figure 5-282: Different angle of Burkina Laterite 57 showing clusters of Aluminum, Silica and Iron.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Laterite 57 is composed of greater than 99% Silica. There are a total of 48 particles in this class (Figure 5-283).

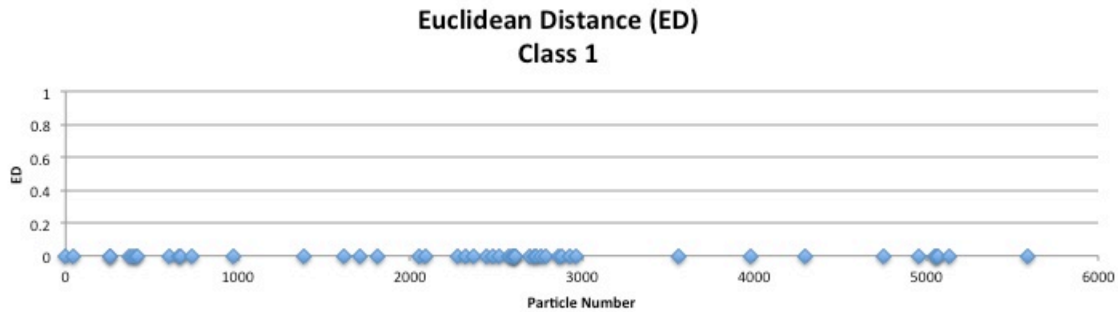

Figure 5-283: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 142 particles in this class (Figure 5-284).

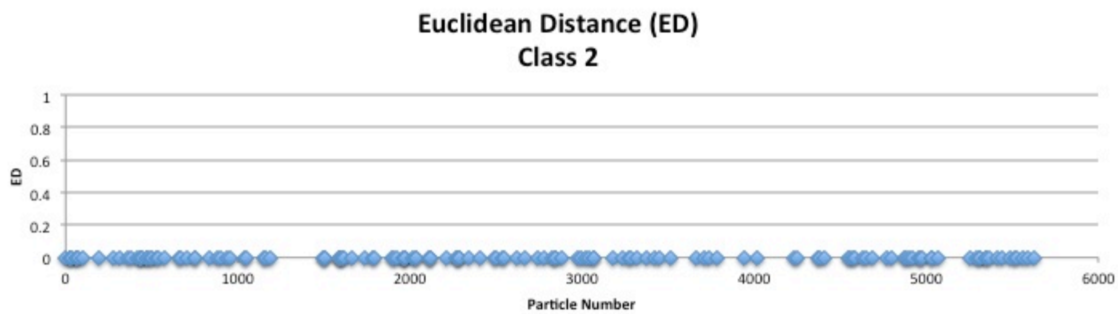

Figure 5-284: Euclidean Distance Class 2

Class 3 of Burkina Laterite 57 is composed of greater than 99% Calcium. There are a total of 156 particles in this class (Figure 5-285).

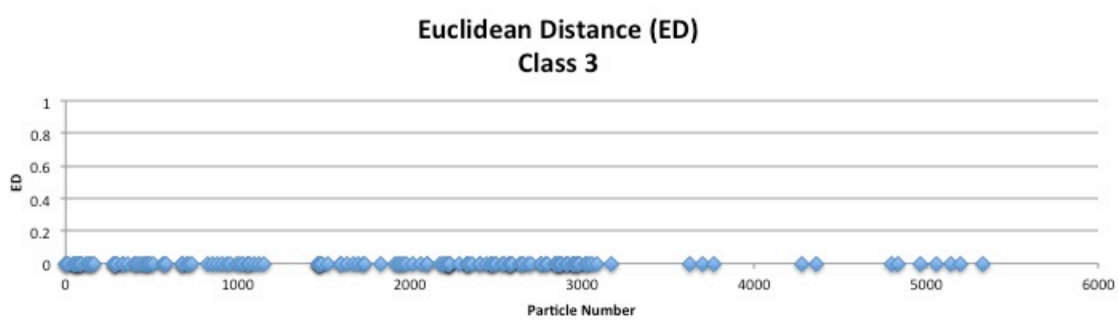

Figure 5-285: Euclidean Distance Class 3

Class 4 of Burkina Laterite 57 is composed of Titanium greater than 55% and Lead less

than 5%. There are no particles in this class.

Class 5 of Burkina Laterite 57 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Burkina Laterite 57 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 36 particles in this class (Figure 5-286).

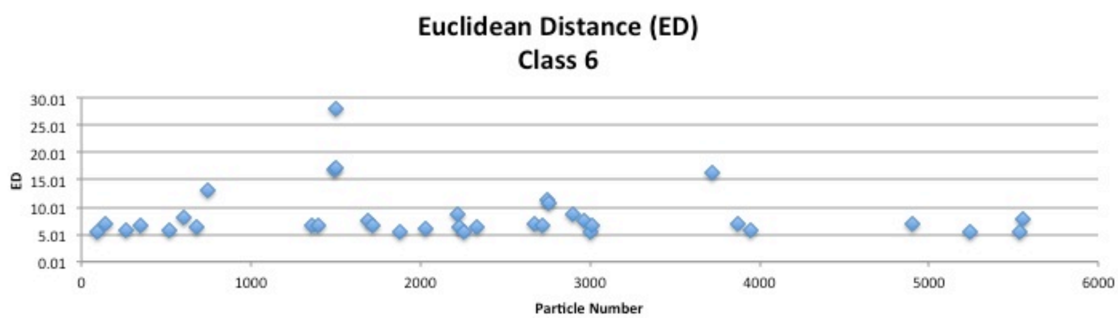

Figure 5-286: Euclidean Distance Class 6

Class 7 of Burkina Laterite 57 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 33 particles in this class (Figure 5-287).

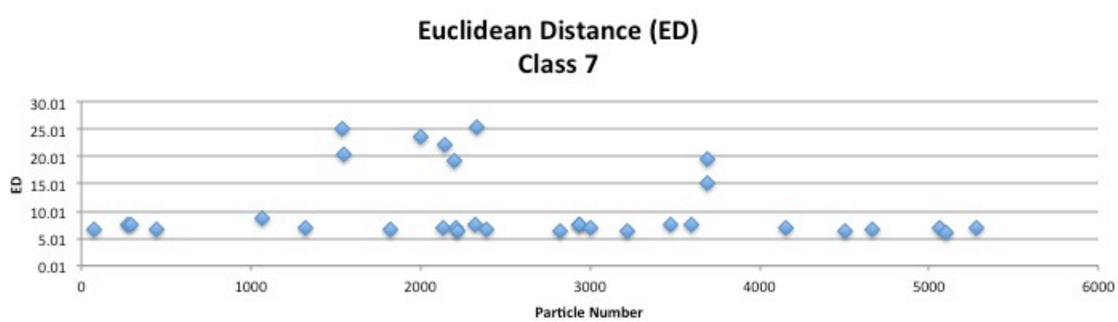

Figure 5-287: Euclidean Distance Class 7

Class 8 of Burkina Laterite 57 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 30 particles in this class (Figure 5-288).

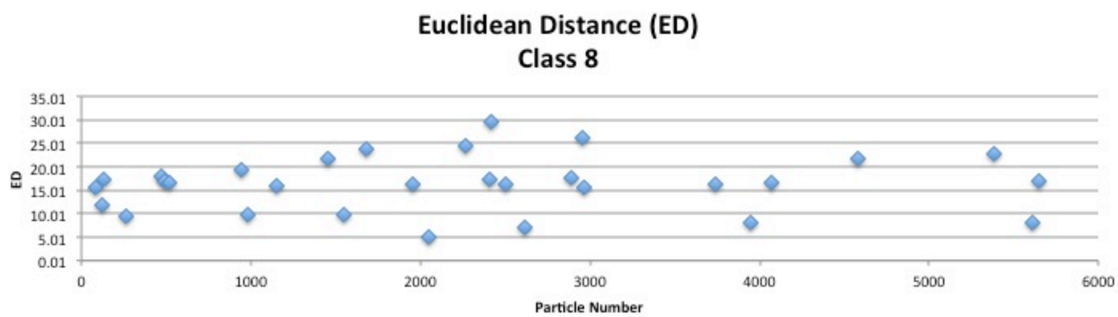

Figure 5-288: Euclidean Distance Class 8

Class 9 of Burkina Laterite 57 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Laterite 57 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Laterite 57 is composed of the total Calcium and Manganese greater than 90%. There are 79 particles in this class (Figure 5-289).

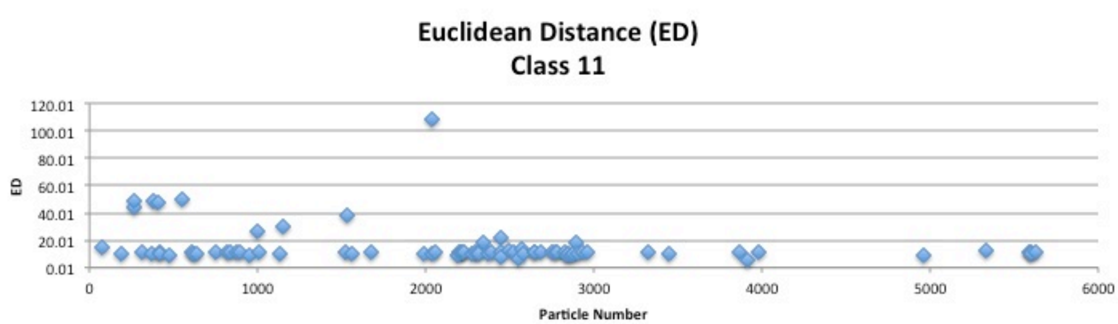

Figure 5-289: Euclidean Distance Class 11

Class 12 of Burkina Laterite 57 is composed of the total Calcium and Phosphorus greater than 90%. There are a total of 10 particles in this class (Figure 5-290).

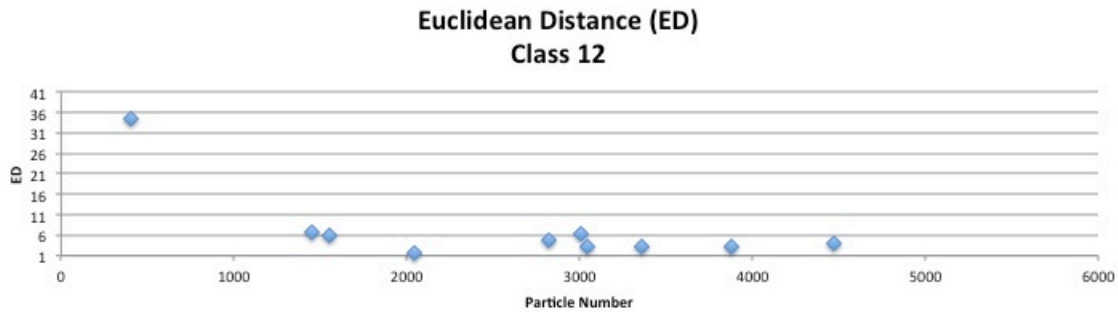

Figure 5-290: Euclidean Distance Class 12

Class 13 of Burkina Laterite 57 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 6 particles in this class (Figure 5-291).

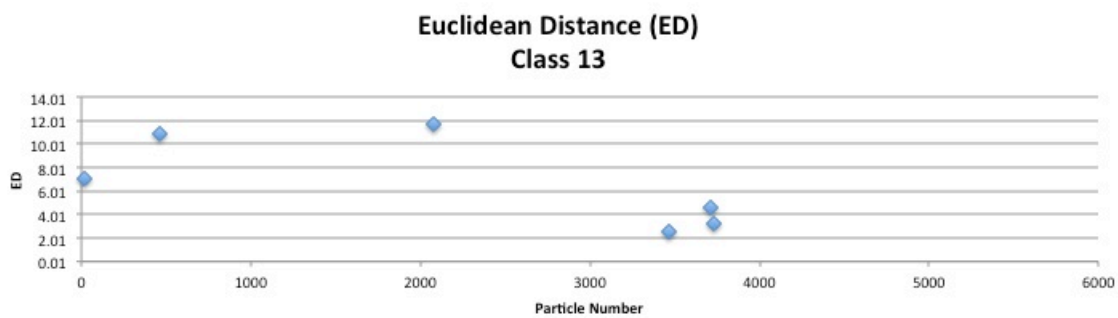

Figure 5-291: Euclidean Distance Class 13

Class 14 of Burkina Laterite 57 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are a total of 5 particles in this class (Figure 5-292).

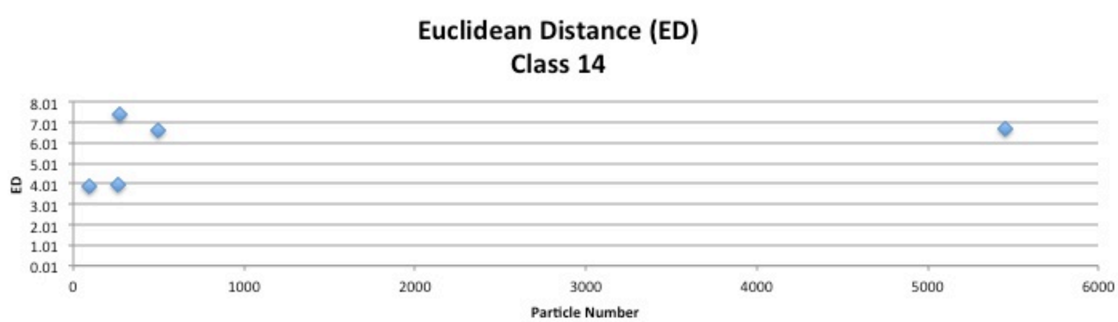

Figure 5-292: Euclidean Distance Class 14

Class 15 of Burkina Laterite 57 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Laterite 57 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 1342 particles in this class (Figure 5-293).

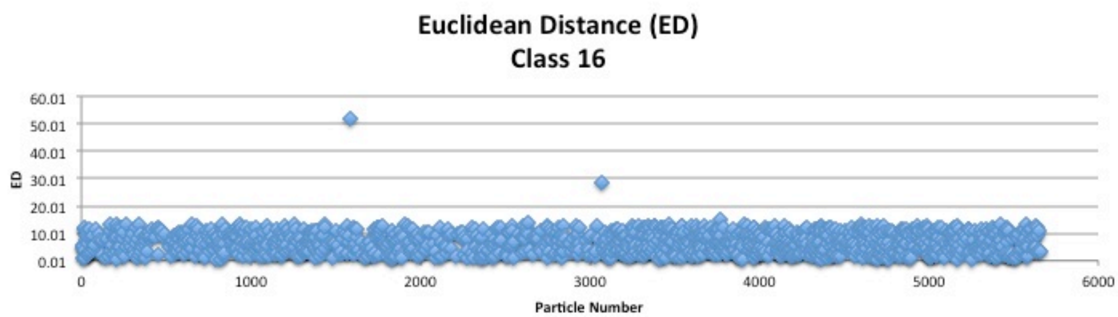

Figure 5-293: Euclidean Distance Class 16

Class 17 of Burkina Laterite 57 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 19 particles in this class (Figure 5-294).

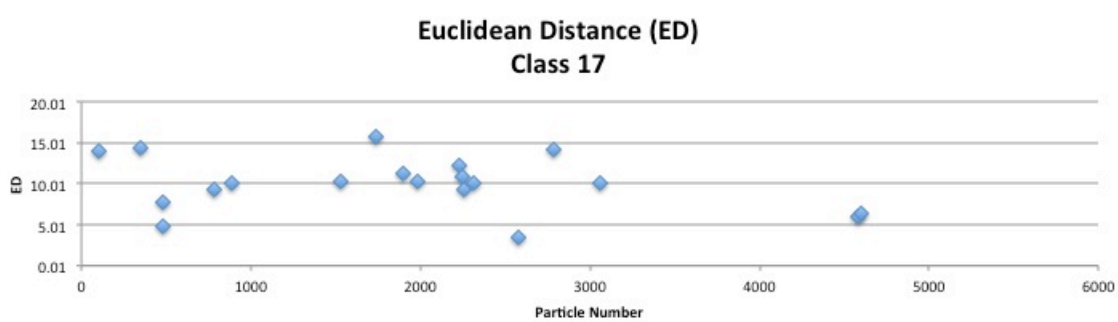

Figure 5-294: Euclidean Distance Class 17

Class 18 of Burkina Laterite 57 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 22 particles in this class (Figure 5-295).

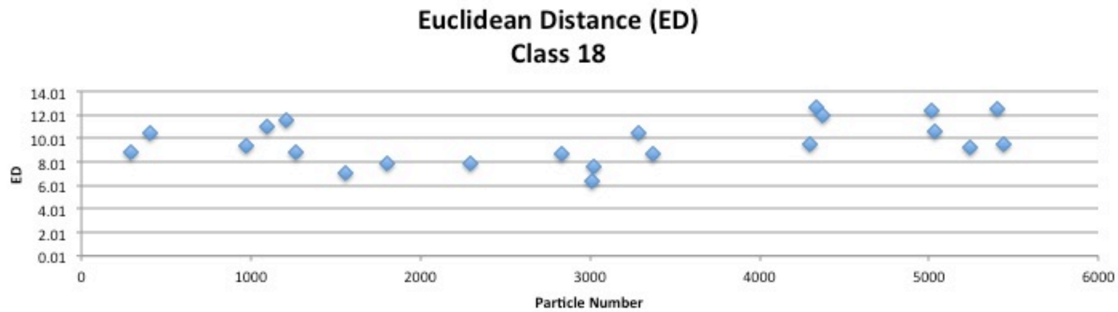

Figure 5-295: Euclidean Distance Class 18

Class 19 of Burkina Laterite 57 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 13 particles in this class (Figure 5-296).

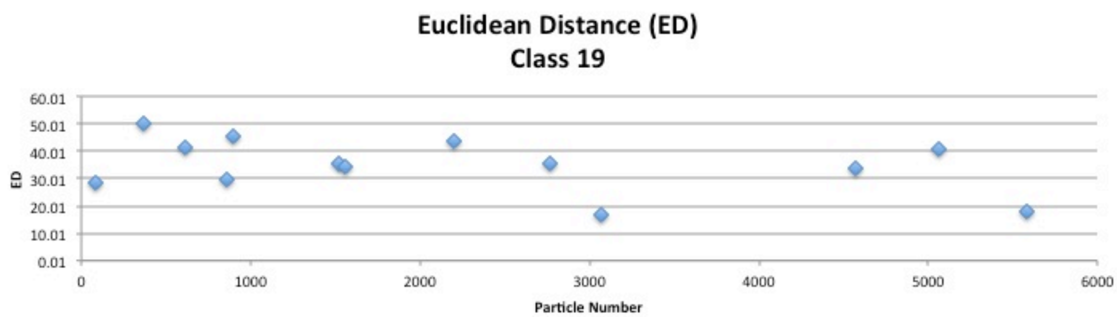

Figure 5-296: Euclidean Distance Class 19

Class 20 of Burkina Laterite 57 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 86 particles in this class (Figure 5-297).

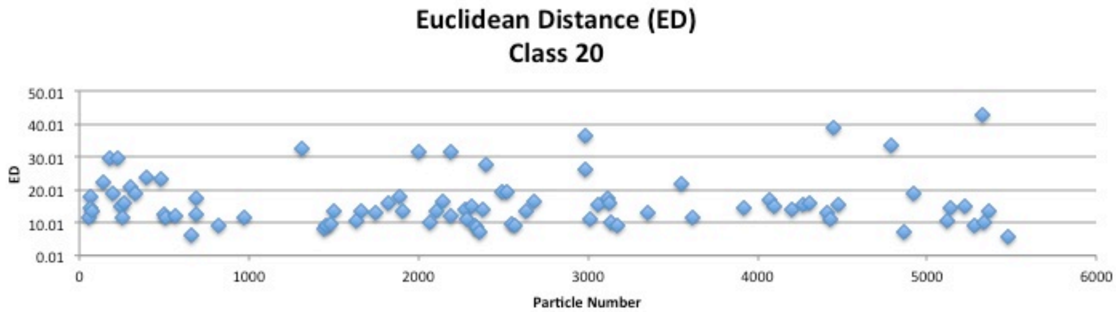

Figure 5-297: Euclidean Distance Class 20

Class 21 of Burkina Laterite 57 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 123 particles in this class (Figure 5-298).

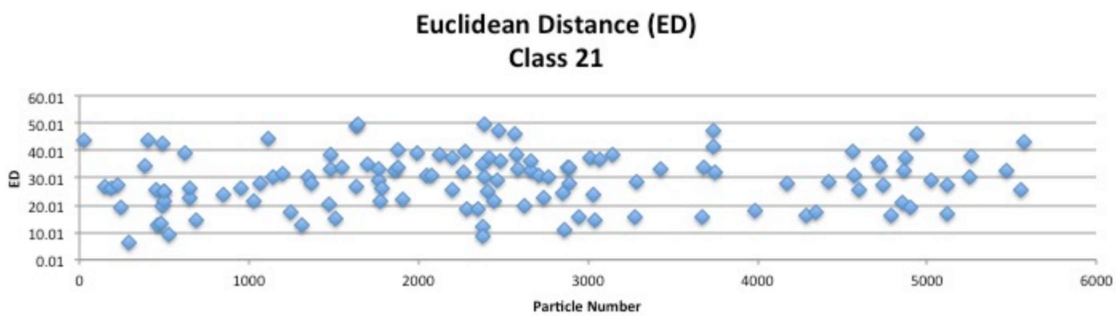

Figure 5-298: Euclidean Distance Class 21

Class 22 of Burkina Laterite 57 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 59 particles in this class (Figure 5-299).

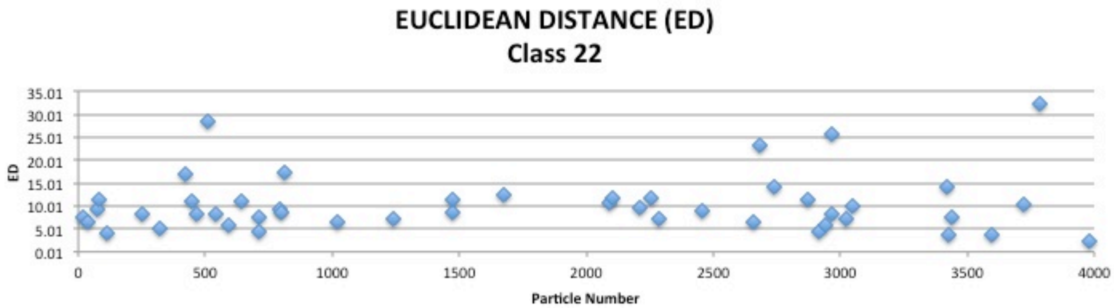

Figure 5-299: Euclidean Distance Class 22

Class 23 of Burkina Laterite 57 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 64 particles in this class (Figure 5-300).

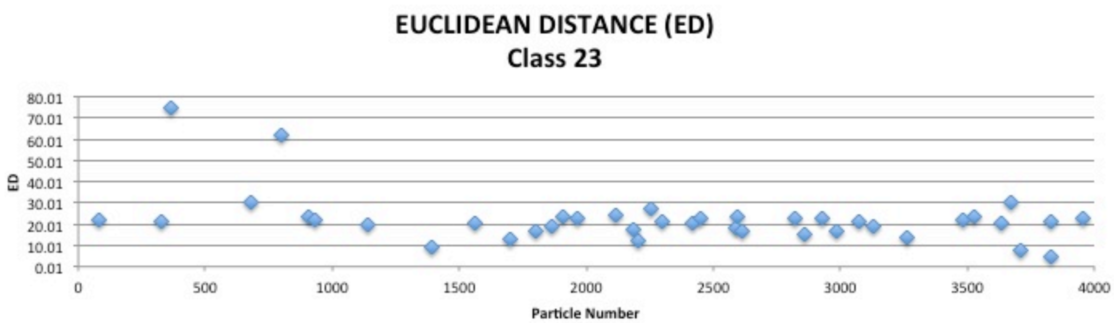

Figure 5-300: Euclidean Distance Class 23

Class 24 of Burkina Laterite 57 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 454 particles in this class (Figure 5-301).

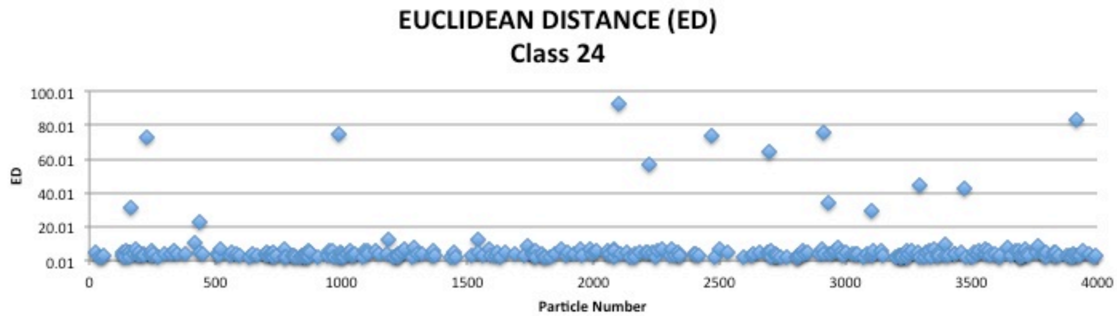

Figure 5-301: Euclidean Distance Class 24

Class 25 of Burkina Laterite 57 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 699 particles in this class (Figure 5-302).

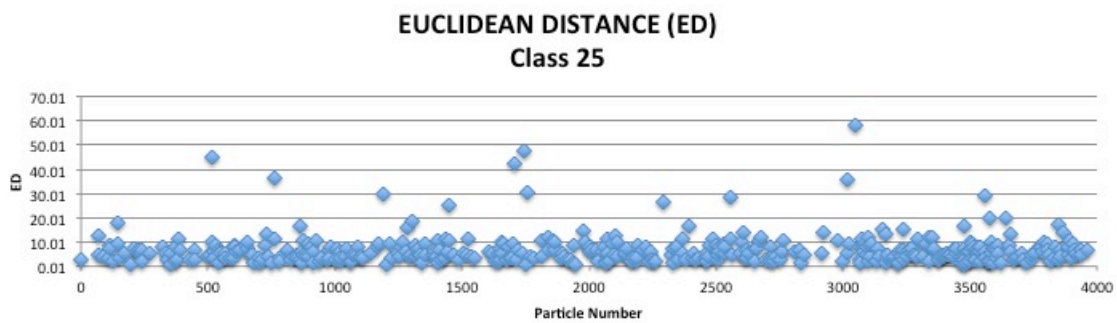

Figure 5-302: Euclidean Distance Class 25

Class 26 of Burkina Laterite 57 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 19 particles in this class (Figure 5-303).

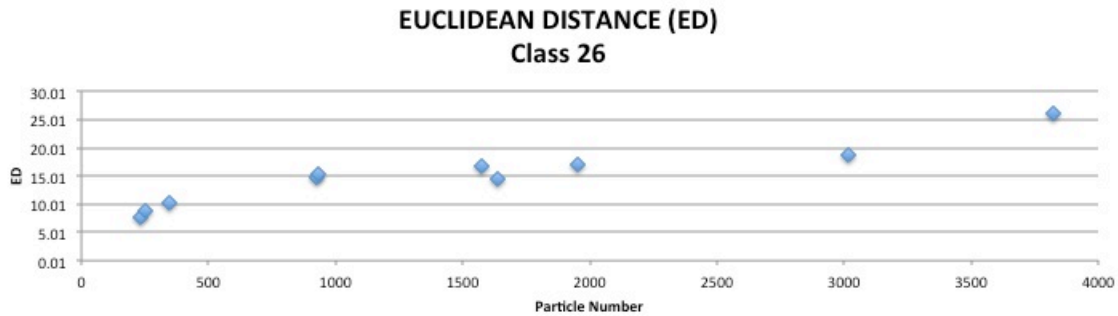

Figure 5-303: Euclidean Distance Class 26

Class 27 of Burkina Laterite 57 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 620 particles in this class (Figure 5-303).

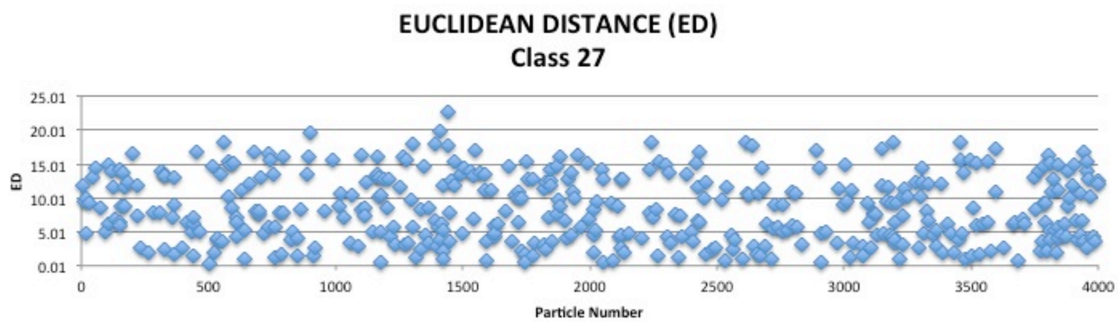

Figure 5-304: Euclidean Distance Class 27

Class 28 of Burkina Laterite 57 is composed of Aluminum less than 1%. There are a total of 341 particles in this class (Figure 5-305).

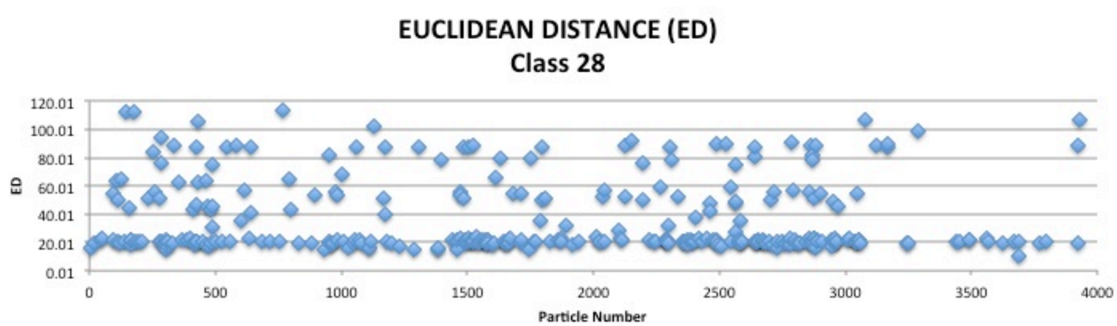

Figure 5-305: Euclidean Distance Class 28

Burkina Laterite 58

Numerical and Volumetric Analysis

Burkina Laterite 58 is located at 12 25.377' N, 1 19.837' E and has been separated into 29 elemental classes (Figure 5-306). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-26).

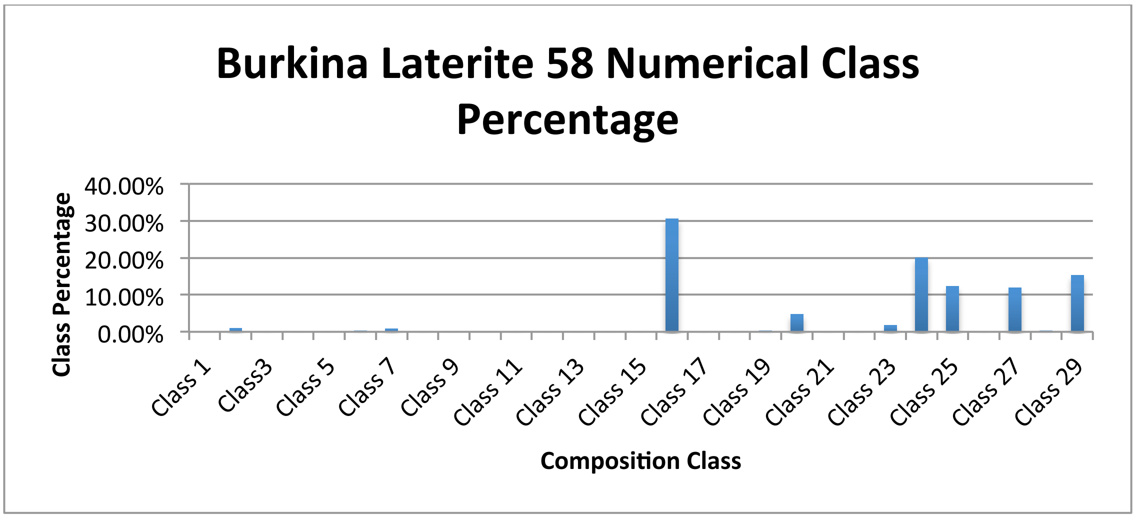

Figure 5-306: Numerical percentage of particles contained within each class.

Table 5-26: Numerical percentage and number of particles contained within each element class and three highest classes and total number of particles highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
0	41	7	0	0	14	36	4
0.00%	0.91%	0.16%	0.00%	0.00%	0.31%	0.80%	0.09%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	4	0	0	0	0	1377
0.00%	0.00%	0.09%	0.00%	0.00%	0.00%	0.00%	30.59%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
3	1	16	214	7	2	77	902
0.07%	0.02%	0.36%	4.75%	0.16%	0.04%	1.71%	20.04%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
556	1	538	11	691	4502		
12.35%	0.02%	11.95%	0.24%	15.35%	100.00%		

Table 5-26 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 16, 24 and 25. Class 16 is composed of Iron greater than 40% and the total of Iron and Calcium greater than 75%. Class 24 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. Class 25 has Potassium and Silica less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. This represents 62.98% of the entire sample and contains a total of 2835 particles. Class 29 represents the “unclassified” particles and contains only 15.35% of the entire sample.

The volumetric percentage of Burkina Laterite 58 represents the volume of particles that are represented in each respective elemental class (Figure 5-307). Table 5-27 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 16, 24, and 27. Class 16 is composed of Iron greater than 40% and the total of Iron and Calcium greater than 75%. Class 24 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 56.48% of the entire sample and contains a total volume of 81678.44µm. Class 29 represents the “unclassified” volume of particles and contains 15.35% of the entire sample.

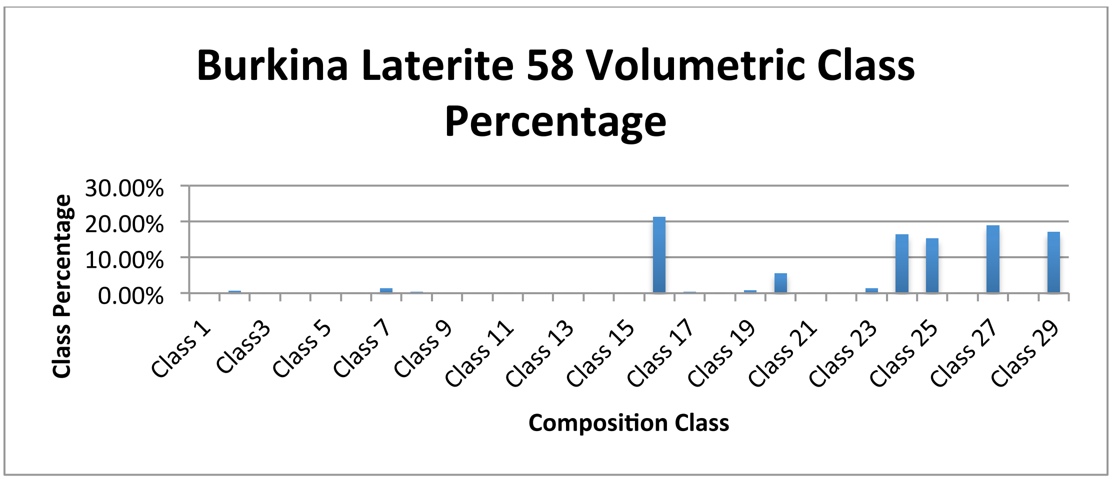

Figure 5-307: Burkina Laterite 58 volumetric percentage of each class.

Table 5-27: Volumetric percentage and volume of each class with three highest percentages and total volume highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
0.00	862.51	364.08	0.00	0.00	103.42	1978.01	423.49
0.00%	0.60%	0.25%	0.00%	0.00%	0.07%	1.37%	0.29%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	56.69	0.00	0.00	0.00	0.00	30661.3
0.00%	0.00%	0.04%	0.00%	0.00%	0.00%	0.00%	21.20%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
465.92	34.16	1134.85	8029.30	224.73	162.19	1941.78	23743.98
0.32%	0.02%	0.78%	5.55%	0.16%	0.11%	1.34%	16.42%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
22074.56	101.17	27273.13	327.01	24660.9	144623.27		
15.26%	0.07%	18.86%	0.23%	17.05%	100.00%		

Analysis of class 29 showed a cluster of elements similar to other Burkina Laterites. The highest elements contained within Burkina Laterite 59 unclassified are Fe, Si, Al, respectively, and compose 17.05% of the entire sample volume. Most of the elements contained within class 29 are evenly distributed across the three elements Aluminum, Silica and Iron, or are contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-308 and Figure 5-309). Approximately 70% if the unclassified particles are contained within these two distinct clusters.

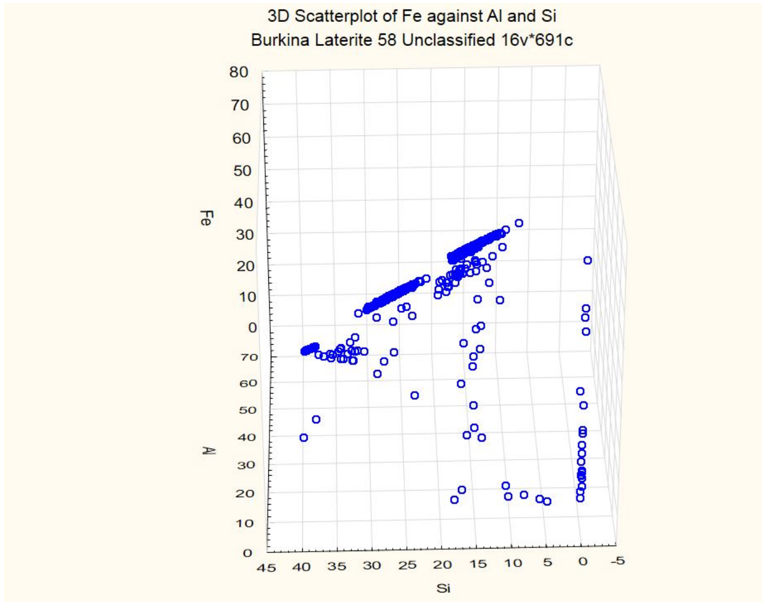

Figure 5-308: Scatterplot of Burkina Laterite 58 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 15.35% of the particles in the sample.

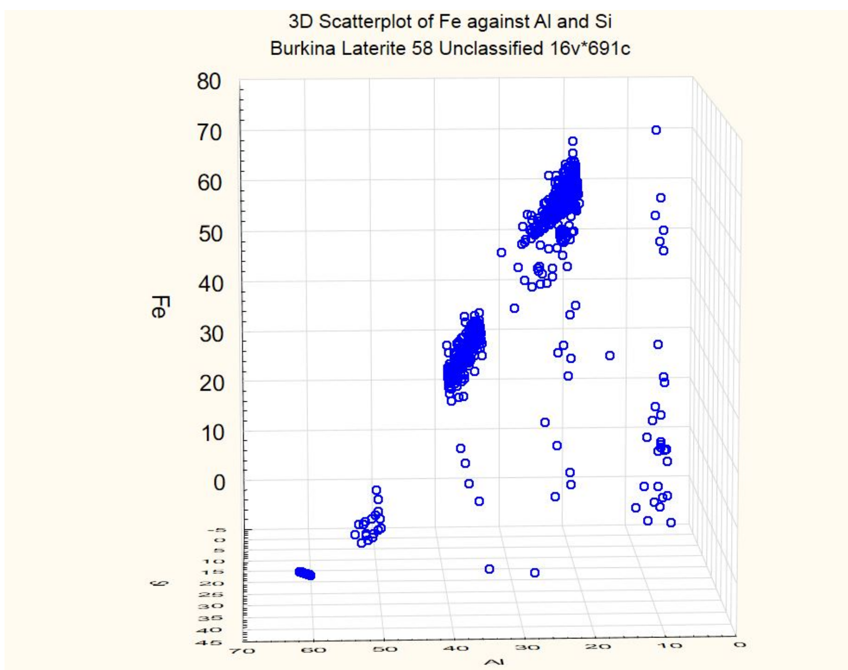

Figure 5-309: Different angle of Burkina Laterite 58 showing clusters of Aluminum, Silica and Iron.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Laterite 58 is composed of greater than 99% Silica. There are no particles in this class.

Class 2 is composed of greater than 99% Iron. There are a total of 41 particles in this class (Figure 5-310).

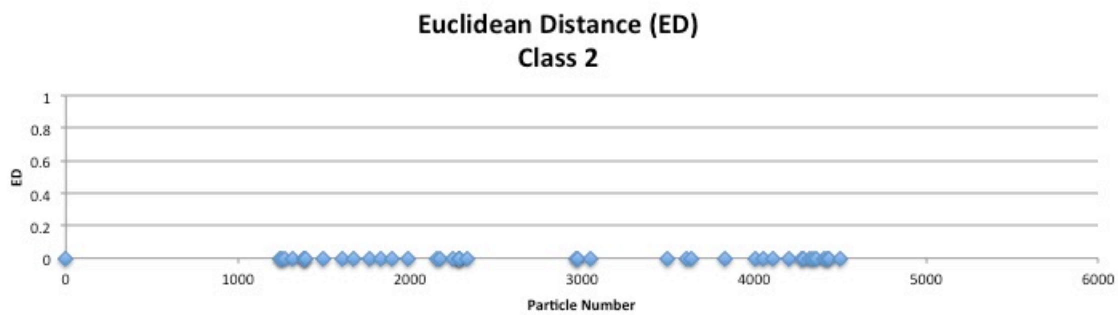

Figure 5-310: Euclidean Distance Class 2

Class 3 of Burkina Laterite 58 is composed of greater than 99% Calcium. There are a total of 7 particles in this class (Figure 5-311).

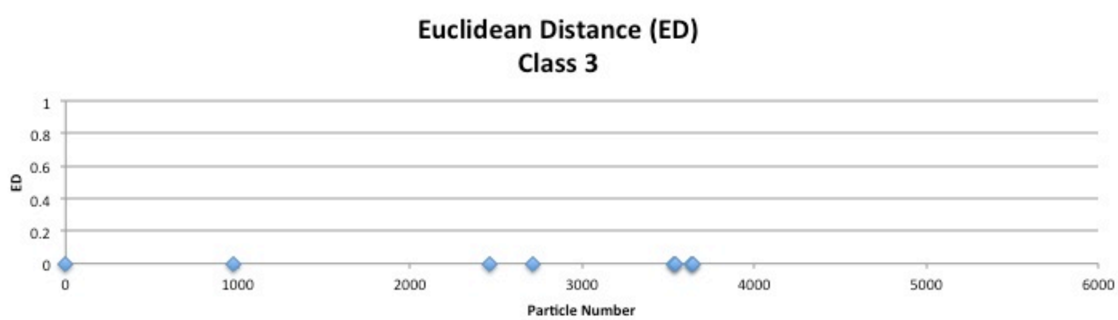

Figure 5-311: Euclidean Distance Class 3

Class 4 of Burkina Laterite 58 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Burkina Laterite 58 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Burkina Laterite 58 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 14 particles in this class (Figure 5-312).

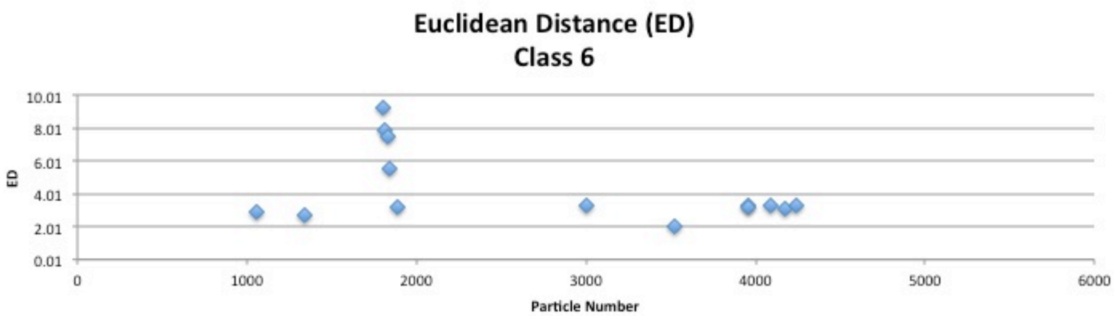

Figure 5-312: Euclidean Distance Class 6

Class 7 of Burkina Laterite 58 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 36 particles in this class (Figure 5-313).

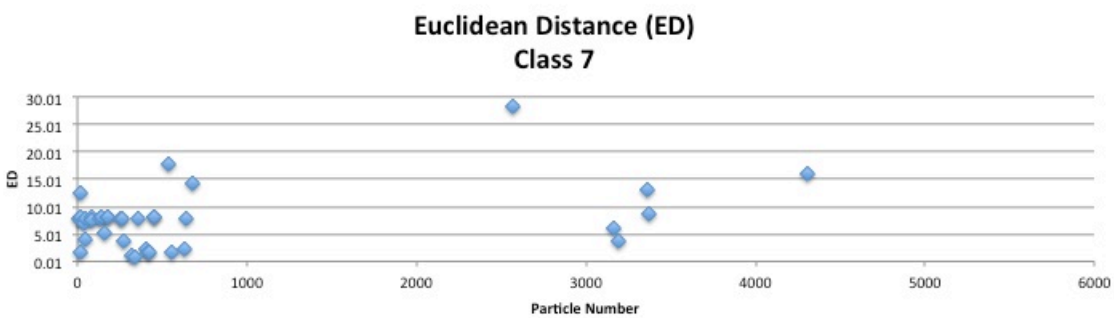

Figure 5-313: Euclidean Distance Class 7

Class 8 of Burkina Laterite 56 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 4 particles in this class (Figure 5-314).

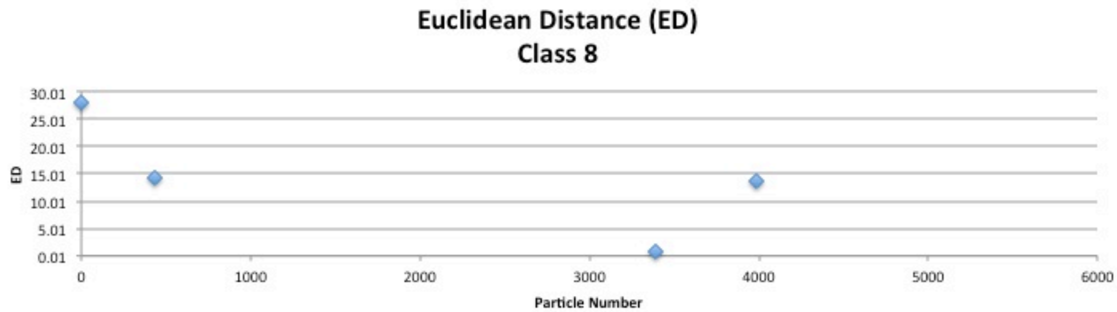

Figure 5-314: Euclidean Distance Class 8

Class 9 of Burkina Laterite 58 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Laterite 58 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Laterite 58 is composed of the total Calcium and Manganese greater than 90%. There are 4 particles in this class (Figure 5-315).

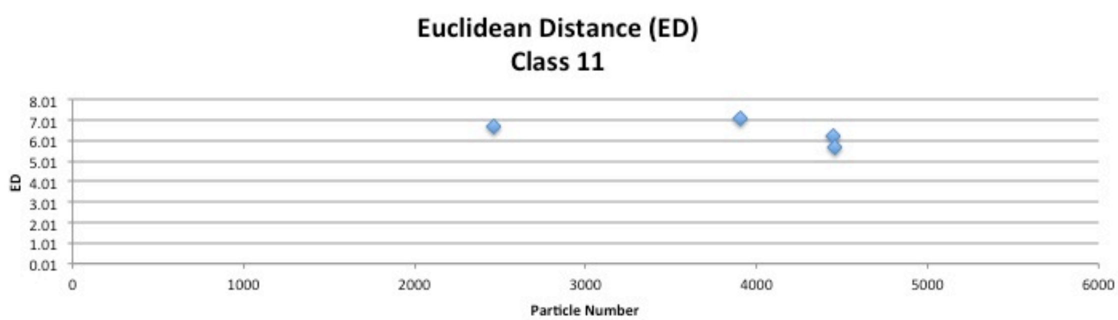

Figure 5-315: Euclidean Distance Class 11

Class 12 of Burkina Laterite 58 is composed of the total Calcium and Phosphorus greater than 90%. There are no particles in this class.

Class 13 of Burkina Laterite 58 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are no particles in this class.

Class 14 of Burkina Laterite 58 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are no particles in this class.

Class 15 of Burkina Laterite 58 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Laterite 58 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 1377 particles in this class (Figure 5-316).

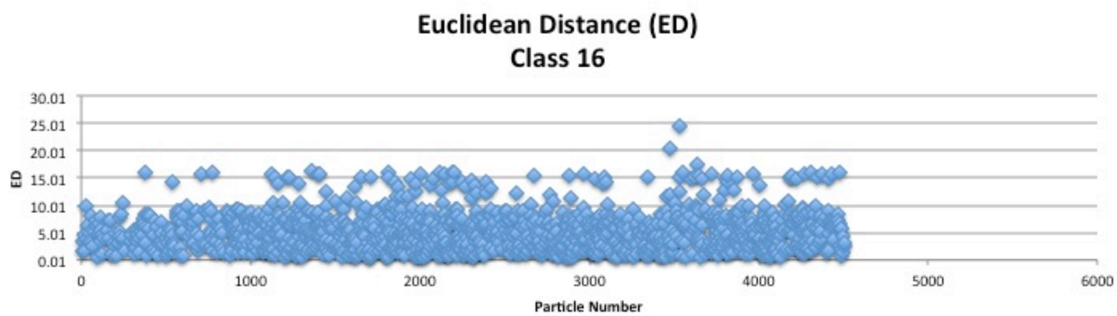

Figure 5-316: Euclidean Distance Class 16

Class 17 of Burkina Laterite 58 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 3 particles in this class (Figure 5-317).

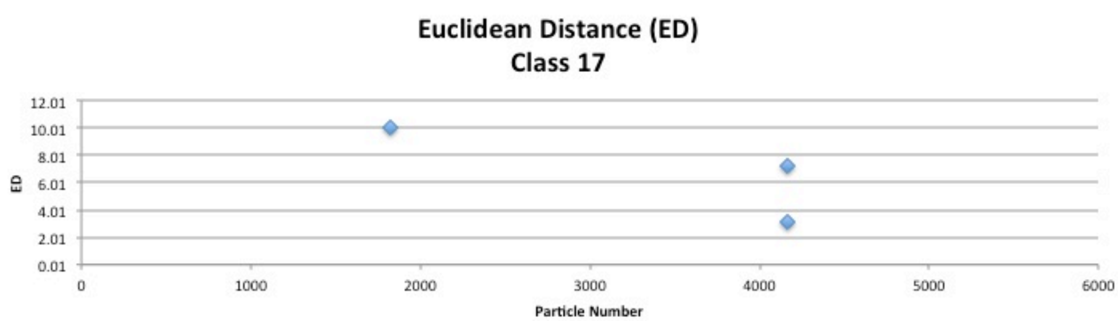

Figure 5-317: Euclidean Distance Class 17

Class 18 of Burkina Laterite 58 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There is a total of 1 particle in this class (Figure 5-318).

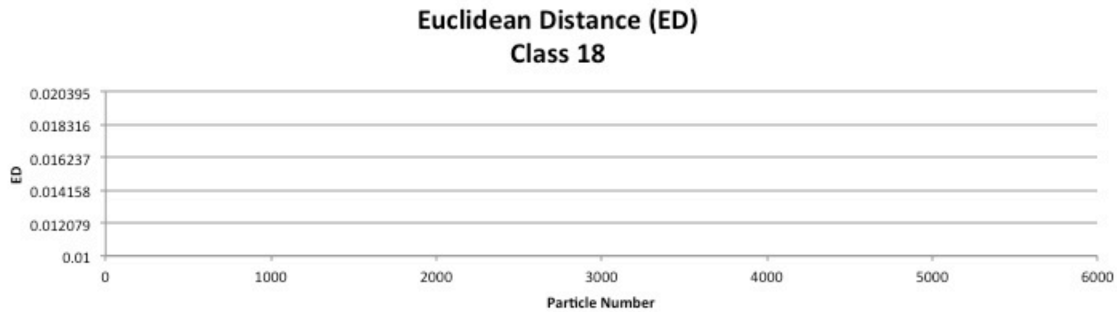

Figure 5-318: Euclidean Distance Class 18

Class 19 of Burkina Laterite 58 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 16 particles in this class (Figure 5-319).

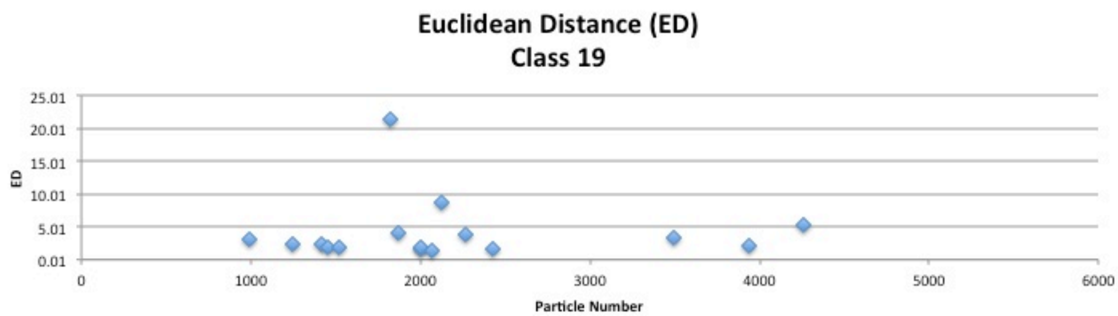

Figure 5-319: Euclidean Distance Class 19

Class 20 of Burkina Laterite 58 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 214 particles in this class (Figure 5-320).

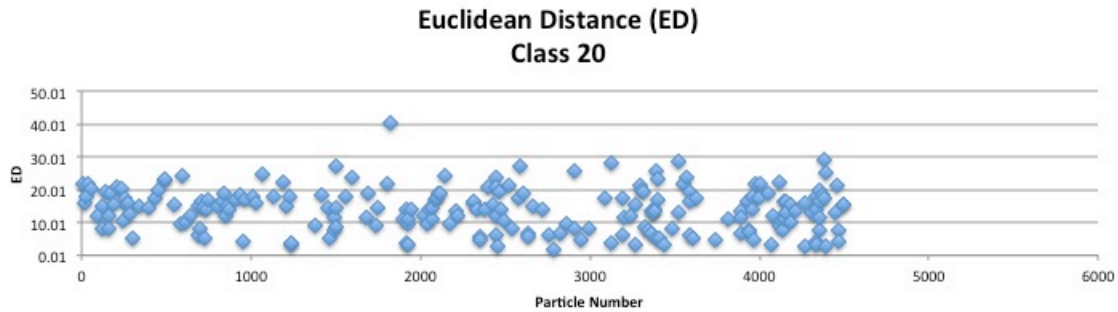

Figure 5-320: Euclidean Distance Class 20

Class 21 of Burkina Laterite 58 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 7 particles in this class (Figure 5-321).

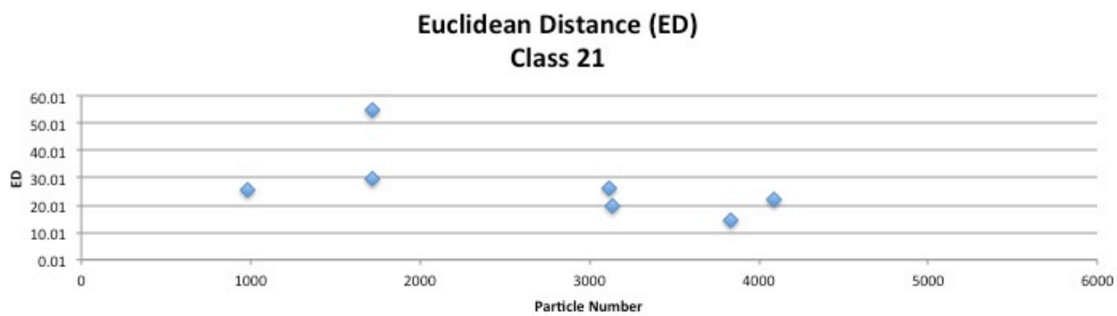

Figure 5-321: Euclidean Distance Class 21

Class 22 of Burkina Laterite 58 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 2 particles in this class (Figure 5-322).

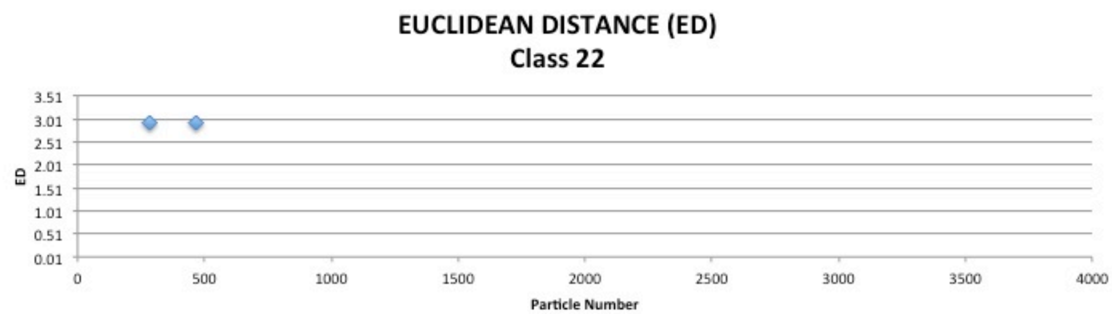

Figure 5-322: Euclidean Distance Class 22

Class 23 of Burkina Laterite 58 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 77 particles in this class (Figure 5-323).

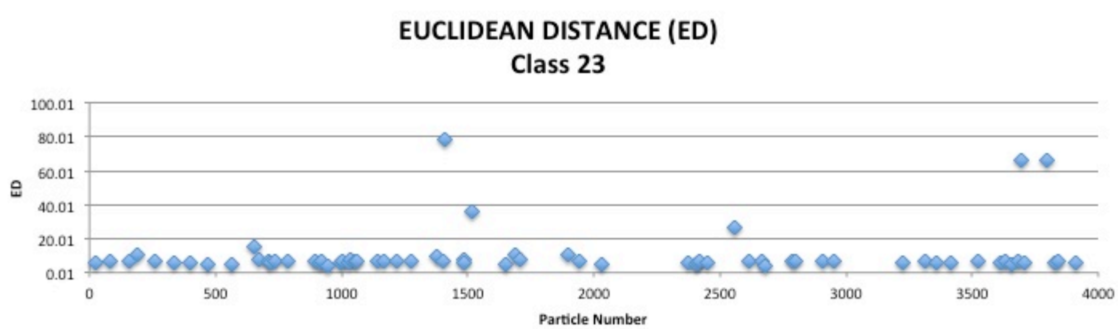

Figure 5-323: Euclidean Distance Class 23

Class 24 of Burkina Laterite 58 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 902 particles in this class (Figure 5-324).

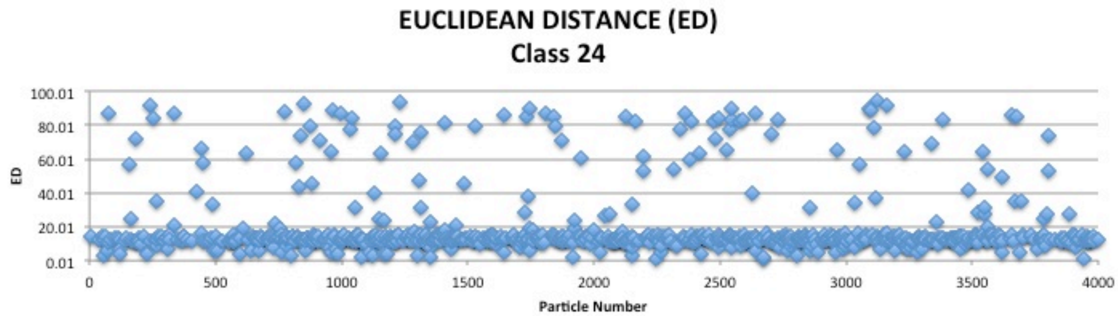

Figure 5-324: Euclidean Distance Class 24

Class 25 of Burkina Laterite 58 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 556 particles in this class (Figure 5-325).

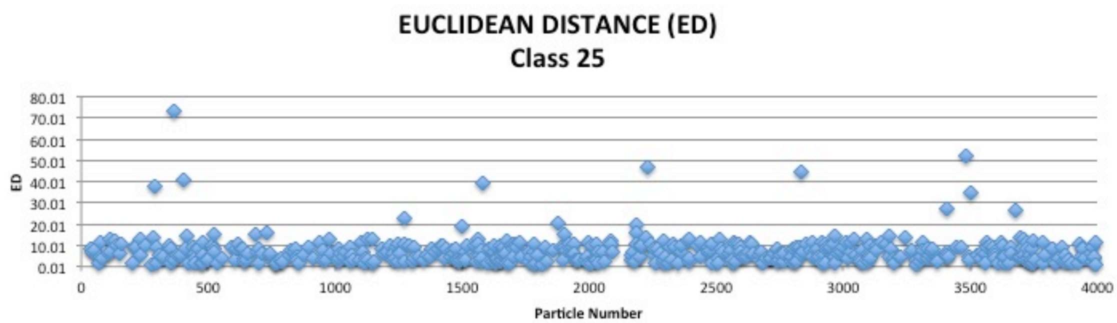

Figure 5-325: Euclidean Distance Class 25

Class 26 of Burkina Laterite 58 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There is a total of 1 particle in this class (Figure 5-326).

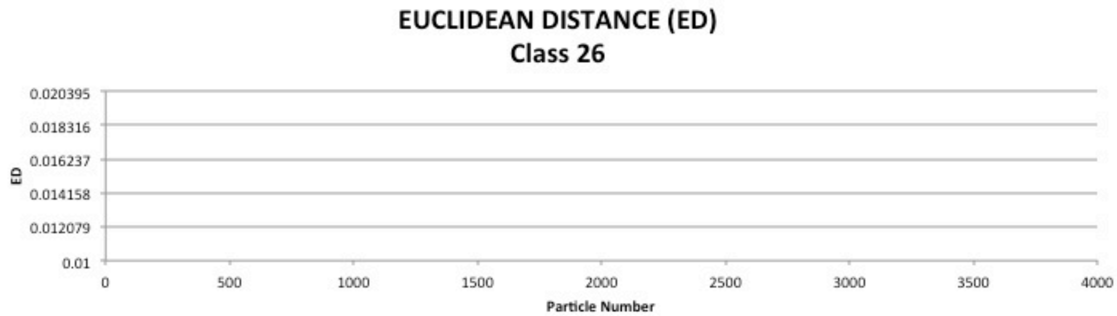

Figure 5-326: Euclidean Distance Class 26

Class 27 of Burkina Laterite 58 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 538 particles in this class (Figure 5-327).

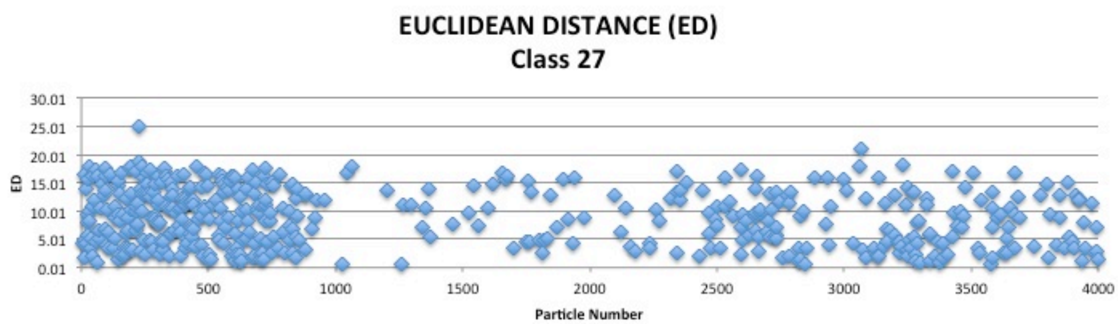

Figure 5-327: Euclidean Distance Class 27

Class 28 of Burkina Laterite 58 is composed of Aluminum less than 1%. There are a total of 11 particles in this class (Figure 5-328).

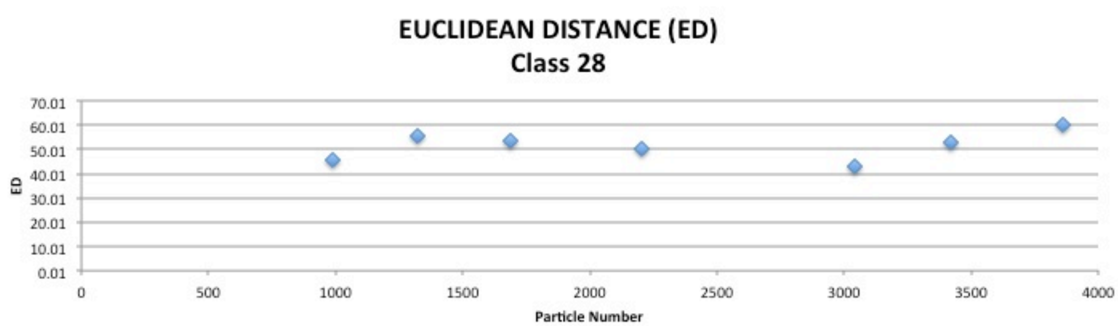

Figure 5-328: Euclidean Distance Class 28

Burkina Laterite 60

Numerical and Volumetric Analysis

Burkina Laterite 60 is located at 12 03.736' N, 0 23.608' and has been separated into 29 elemental classes (Figure 5-329). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-28).

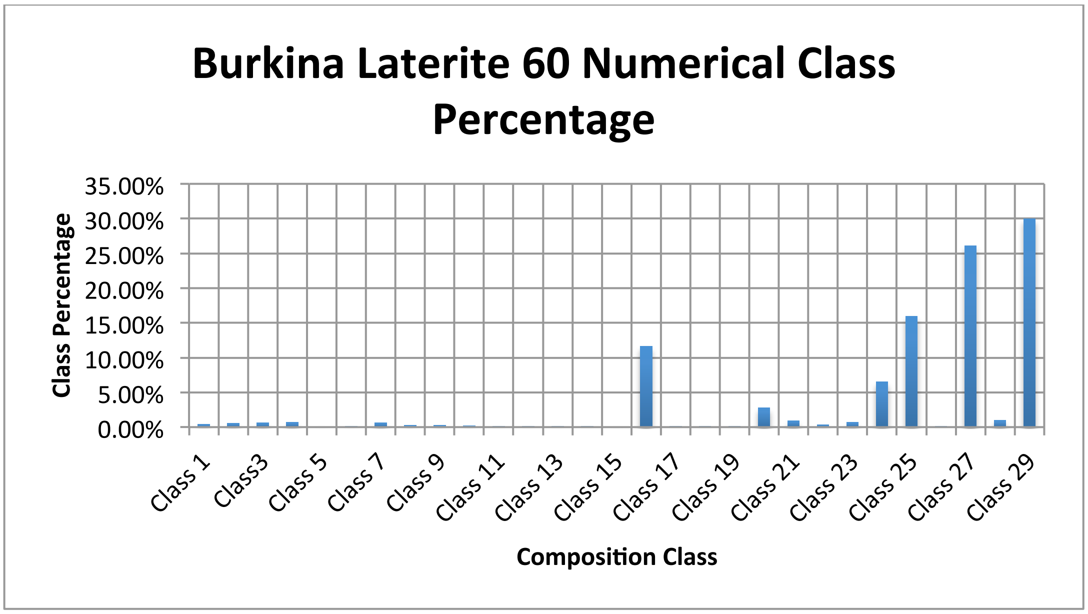

Figure 5-329: Numerical percentage of particles contained within each class.

Table 5-28: Numerical percentage and number of particles contained within each element class and three highest classes and total number of particles highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
12	17	19	21	0	4	20	8
0.38%	0.54%	0.60%	0.67%	0.00%	0.13%	0.64%	0.25%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
8	6	1	1	1	1	0	366
0.25%	0.19%	0.03%	0.03%	0.03%	0.03%	0.00%	11.65%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
2	3	1	88	29	11	21	206
0.06%	0.10%	0.03%	2.80%	0.92%	0.35%	0.67%	6.56%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
502	2	819	31	941	3141		
15.98%	0.06%	26.07%	0.99%	29.96%	100.00%		

Table 5-28 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 16, 25, and 27. Class 16 is composed of Iron greater than 40% and the total of Iron and Calcium greater than 75%. Class 25 has Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 53.70% of the entire sample and contains a total of 1687 particles. Class 29 represents the “unclassified” particles and contains only 29.96% of the entire sample.

The volumetric percentage of Burkina Laterite 60 represents the volume of particles that are represented in each respective elemental class (Figure 5-330). Table 5-29 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 25, 27, and 28. Class 25 has Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. Class 28 is composed of Aluminum less than 1%. This represents 39.89% of the entire sample and contains a total volume of 14580.66 μm3. Class 29 represents the "unclassified" volume of particles and contains 36.57% of the entire sample.

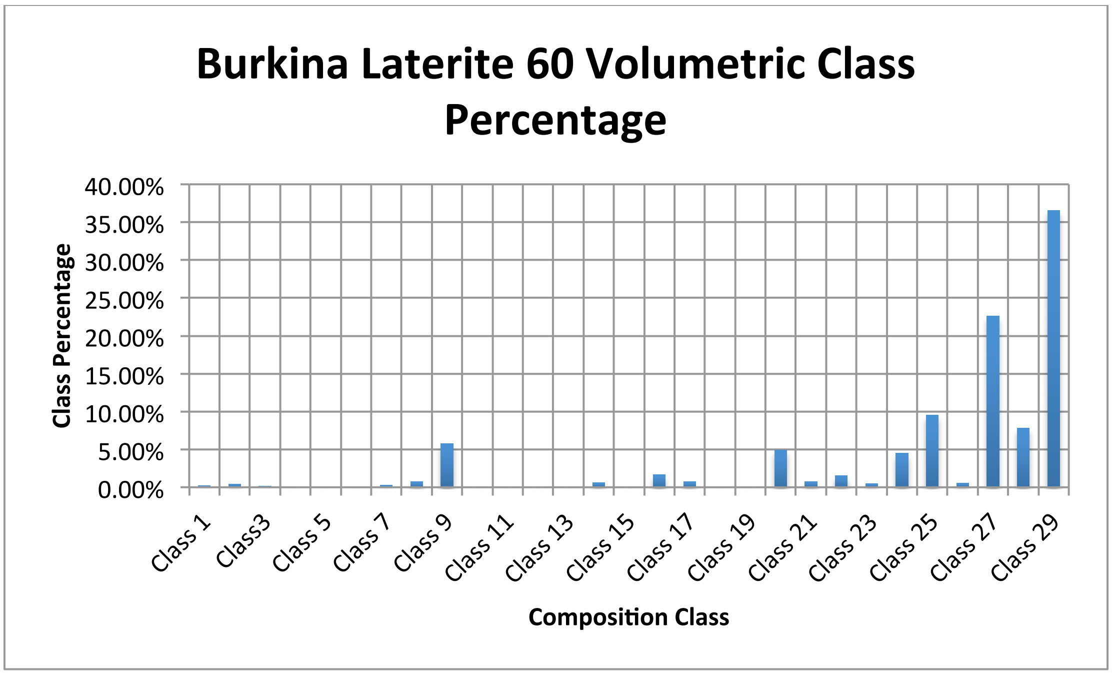

Figure 5-330: Burkina Laterite 60 volumetric percentage of each class.

Table 5-29: Volumetric percentage and volume of each class with three highest percentages and total volume highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
86.07	154.75	55.89	30.91	0.00	0.10	102.00	268.76
0.24%	0.42%	0.15%	0.08%	0.00%	0.00%	0.28%	0.74%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
2114.72	5.45	2.05	0.01	3.25	224.97	0.00	603.87
5.79%	0.01%	0.01%	0.00%	0.01%	0.62%	0.00%	1.65%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
275.14	7.68	0.13	1793.26	284.68	558.95	179.43	1638.87
0.75%	0.02%	0.00%	4.91%	0.78%	1.53%	0.49%	4.49%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
3476.50	206.10	8256.04	2848.12	13362.21	36539.90		
9.51%	0.56%	22.59%	7.79%	36.57%	100.00%		

Analysis of class 29 showed a cluster of elements similar to other Burkina Laterites. The highest elements contained within Burkina Laterite 60 unclassified are Fe, Si, Al, respectively, and compose 29.96% of the entire sample. Most of the elements contained within class 29 are evenly distributed across the three elements Aluminum, Silica and Iron, and are mostly contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-331 and Figure 5-332). Approximately 95% if the unclassified particles are contained within these two distinct clusters.

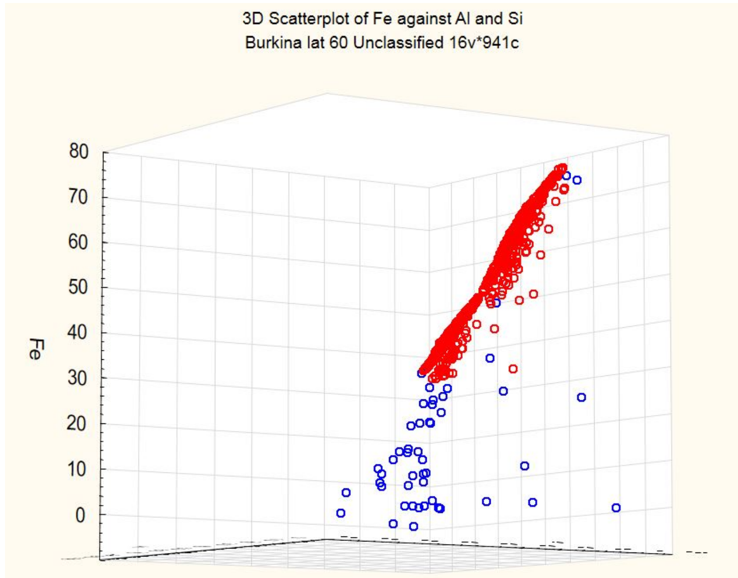

Figure 5-331: Scatterplot of Burkina Laterite 60 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 29.96% of the particles in the sample.

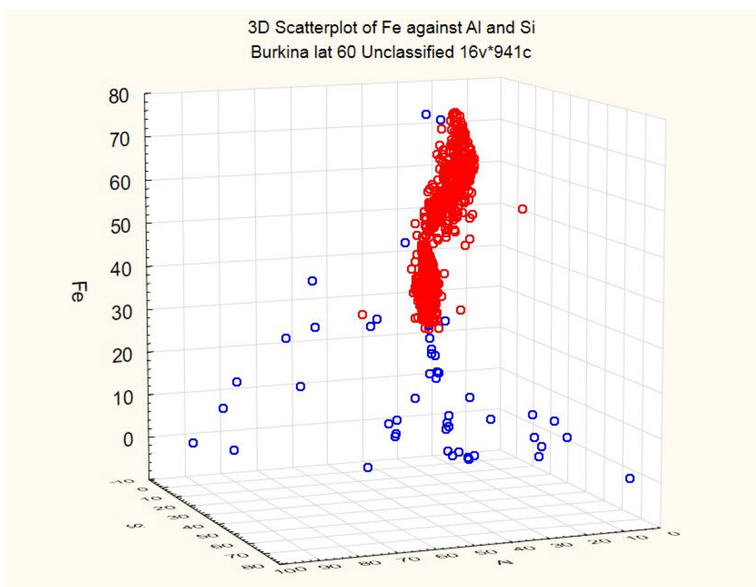

Figure 5-332: Alternate image of unclassified clusters.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Laterite 60 is composed of greater than 99% Silica. There are a total of 12 particles in this class (Figure 5-333).

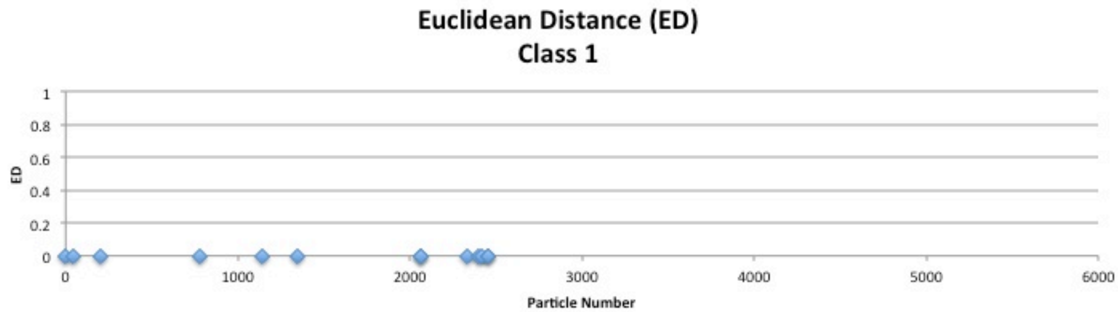

Figure 5-333: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 17 particles in this class (Figure 5-334).

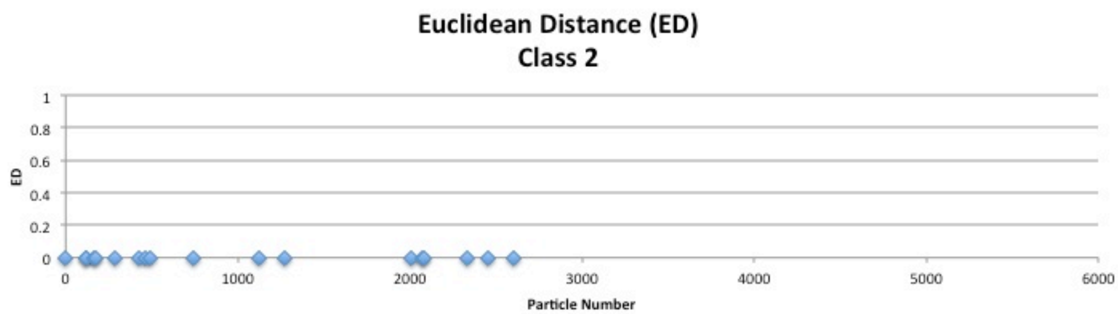

Figure 5-334: Euclidean Distance Class 2

Class 3 of Burkina Laterite 60 is composed of greater than 99% Calcium. There are a total of 19 particles in this class (Figure 5-335).

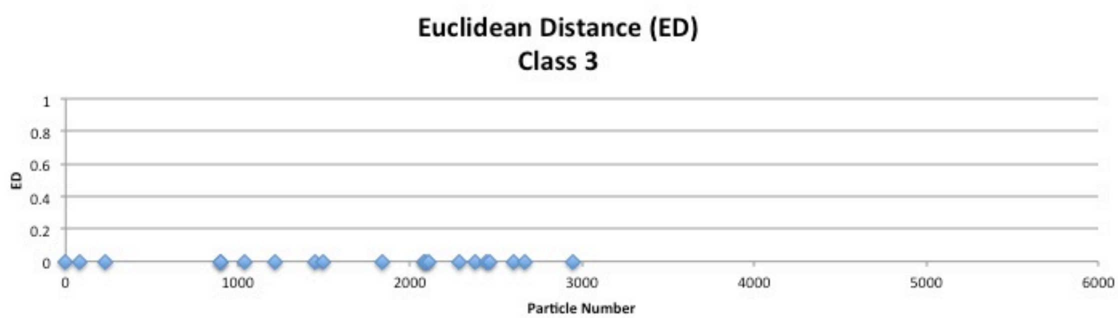

Figure 5-335: Euclidean Distance Class 3

Class 4 of Burkina Laterite 60 is composed of Titanium greater than 55% and Lead less

than 5%. There are 21 particles in this class (Figure 5-336).

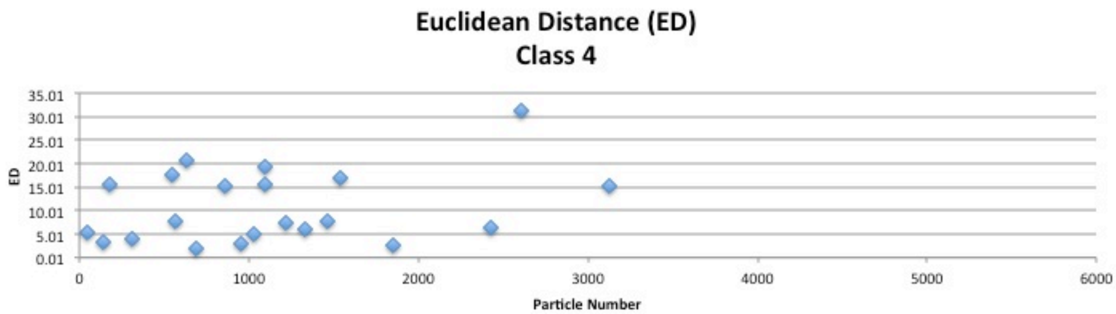

Figure 5-336: Euclidean Distance Class 4

Class 5 of Burkina Laterite 60 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Burkina Laterite 60 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 4 particles in this class (Figure 5-337).

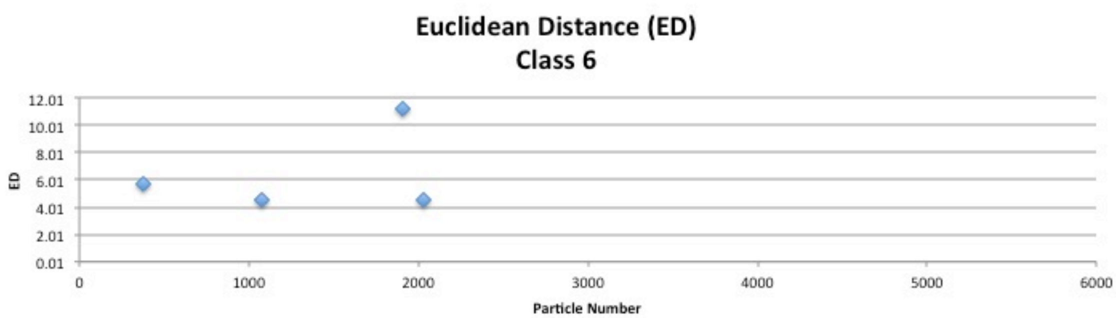

Figure 5-337: Euclidean Distance Class 6

Class 7 of Burkina Laterite 60 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 20 particles in this class (Figure 5-338).

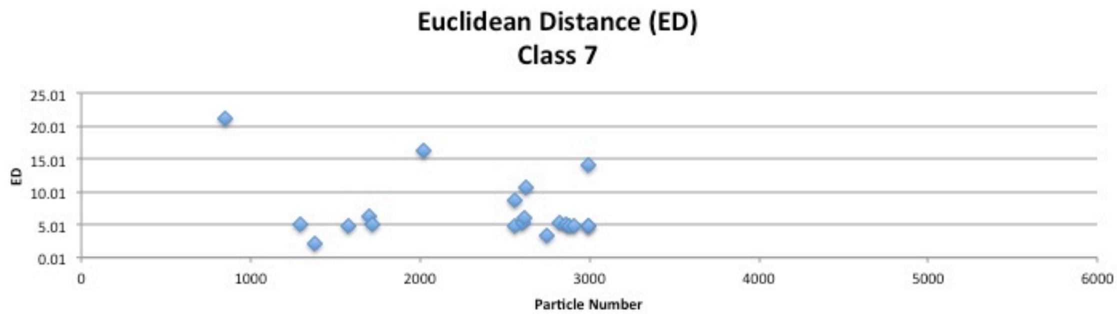

Figure 5-338: Euclidean Distance Class 7

Class 8 of Burkina Laterite 60 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 8 particles in this class (Figure 5-339).

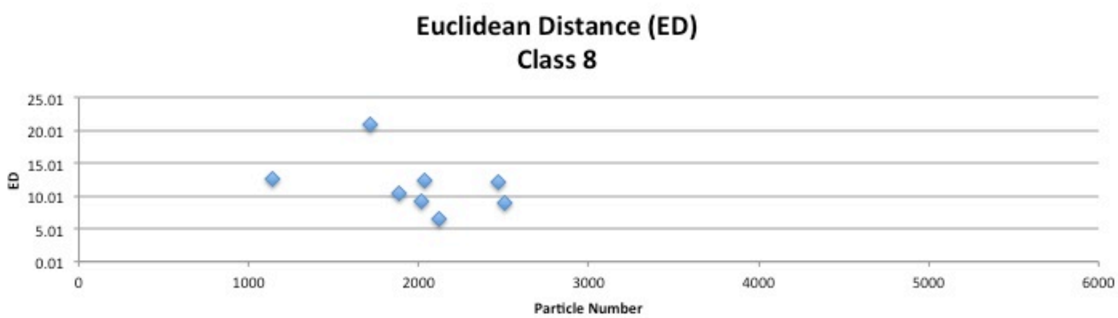

Figure 5-339: Euclidean Distance Class 8

Class 9 of Burkina Laterite 60 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 8 particles in this class (Figure 5-340).

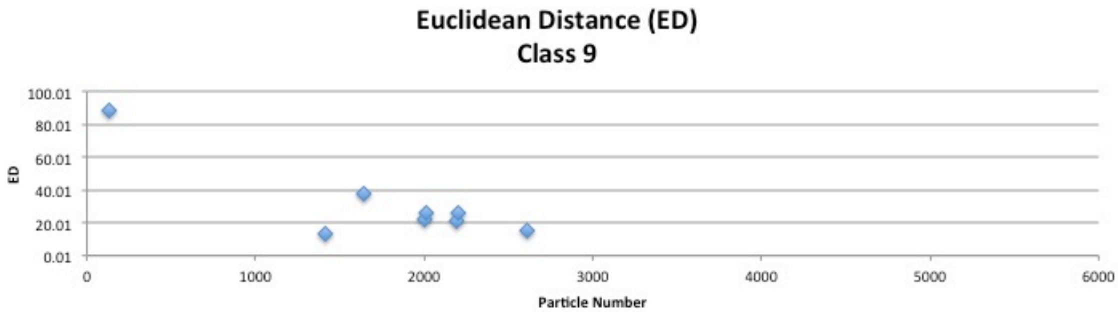

Figure 5-340: Euclidean Distance Class 9

Class 10 of Burkina Laterite 60 is composed of Calcium greater than 80% and Lead less than 5%. There are 6 particles in this class (Figure 5-341).

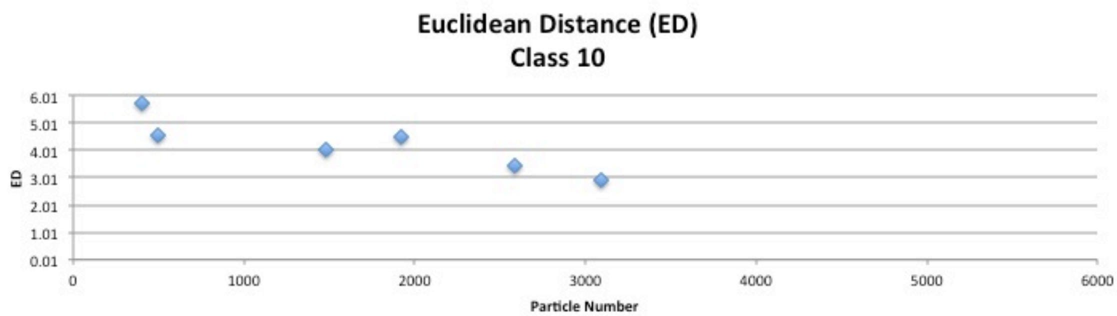

Figure 5-341: Euclidean Distance Class 10

Class 11 of Burkina Laterite 60 is composed of the total Calcium and Manganese greater than 90%. There is 1 particle in this class (Figure 5-342).

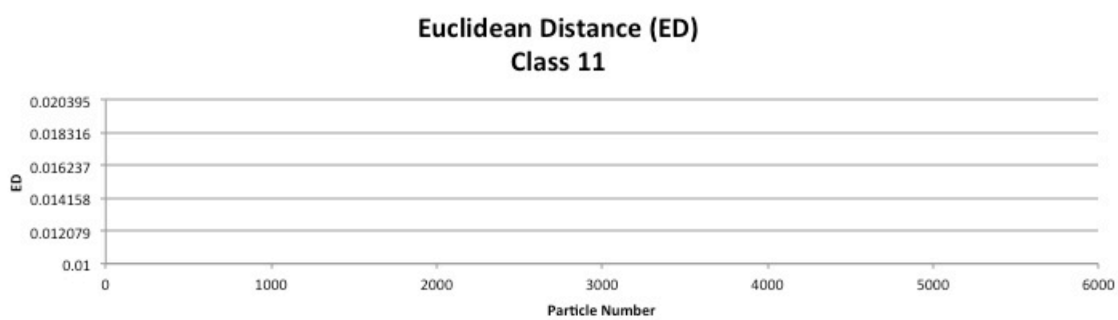

Figure 5-342: Euclidean Distance Class 11

Class 12 of Burkina Laterite 60 is composed of the total Calcium and Phosphorus greater than 90%. There is a total of 1 particle in this class (Figure 5-343).

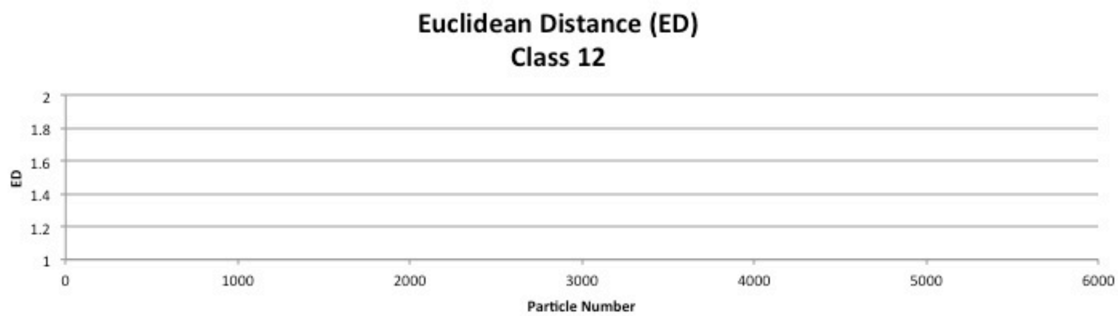

Figure 5-343: Euclidean Distance Class 12

Class 13 of Burkina Laterite 60 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There is 1 particle in this class (Figure 5-344).

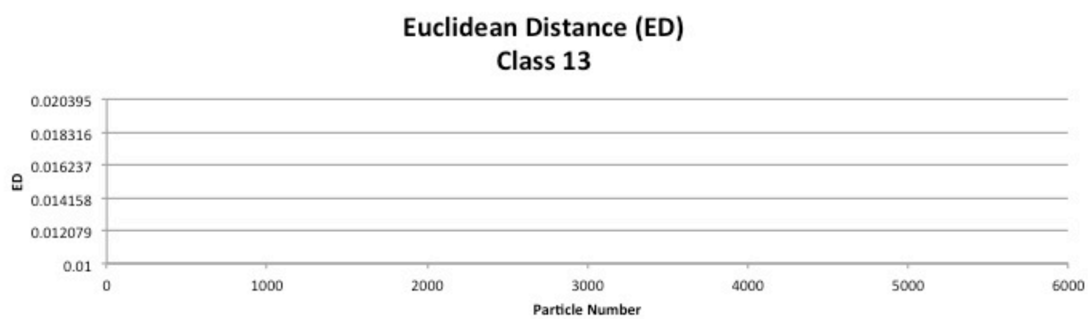

Figure 5-344: Euclidean Distance Class 13

Class 14 of Burkina Laterite 60 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There is a total of 1 particle in this class (Figure 5-345).

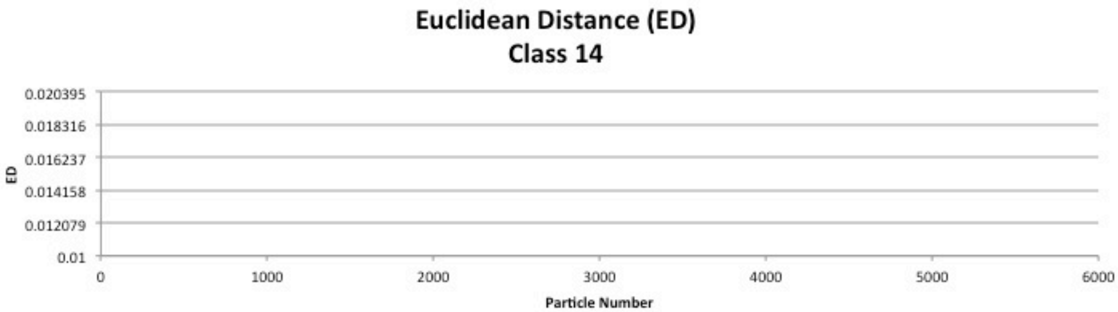

Figure 5-345: Euclidean Distance Class 14

Class 15 of Burkina Laterite 60 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class.

Class 16 of Burkina Laterite 60 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 366 particles in this class (Figure 5-346).

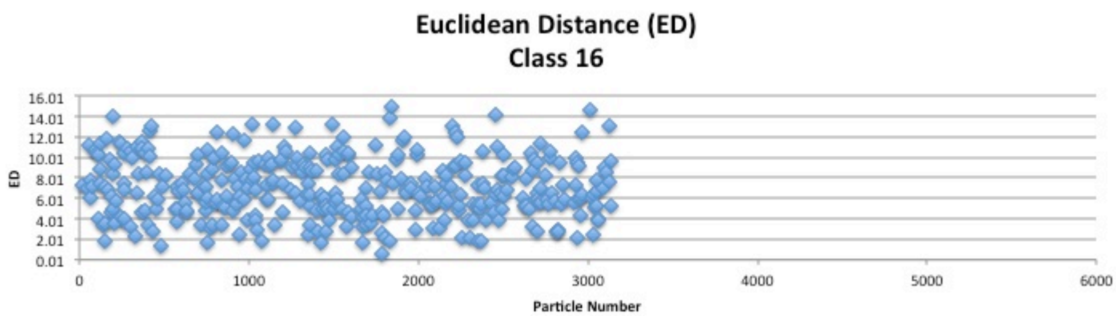

Figure 5-346: Euclidean Distance Class 16

Class 17 of Burkina Laterite 60 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 2 particles in this class (Figure 5-347).

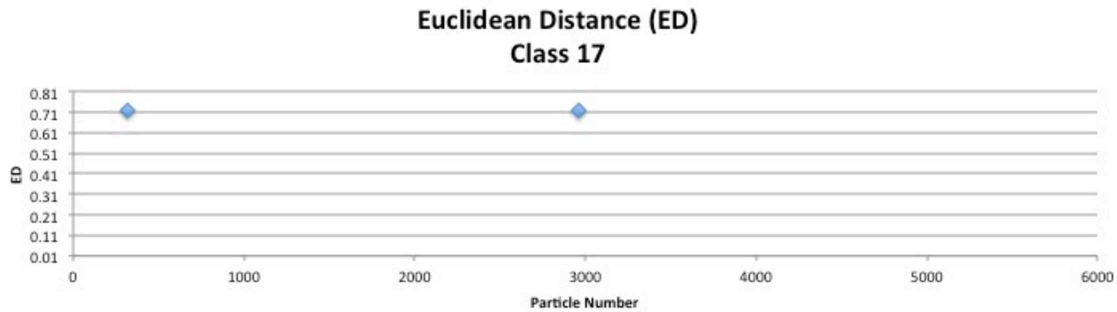

Figure 5-347: Euclidean Distance Class 17

Class 18 of Burkina Laterite 60 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 3 particles in this class (Figure 5-348).

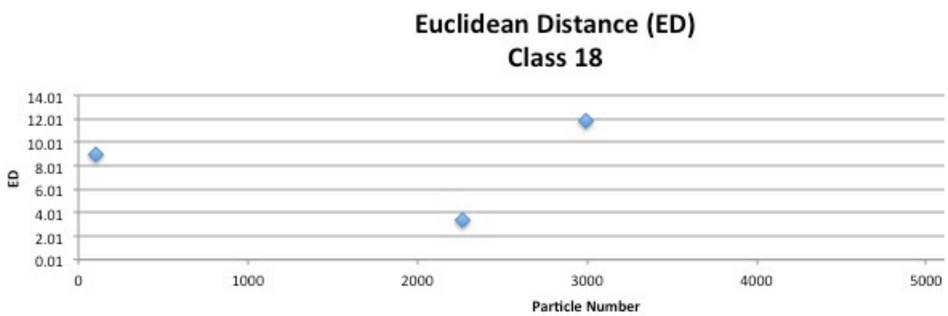

Figure 5-348: Euclidean Distance Class 18

Class 19 of Burkina Laterite 60 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There is a total of 1 particle in this class (Figure 5-349).

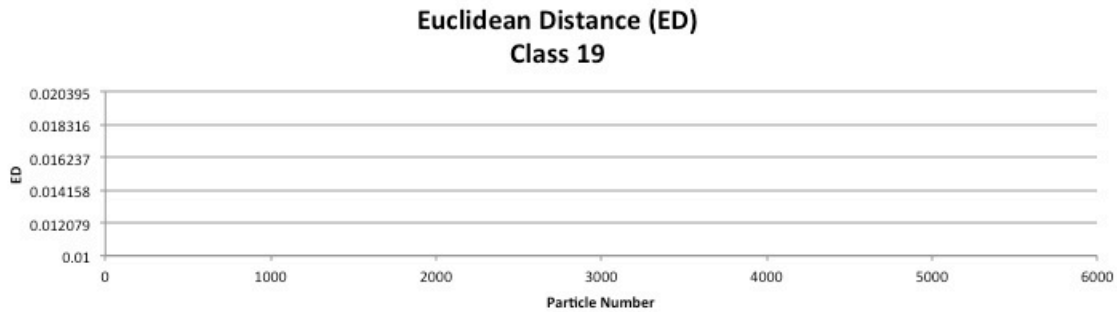

Figure 5-349: Euclidean Distance Class 19

Class 20 of Burkina Laterite 60 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 88 particles in this class (Figure 5-350).

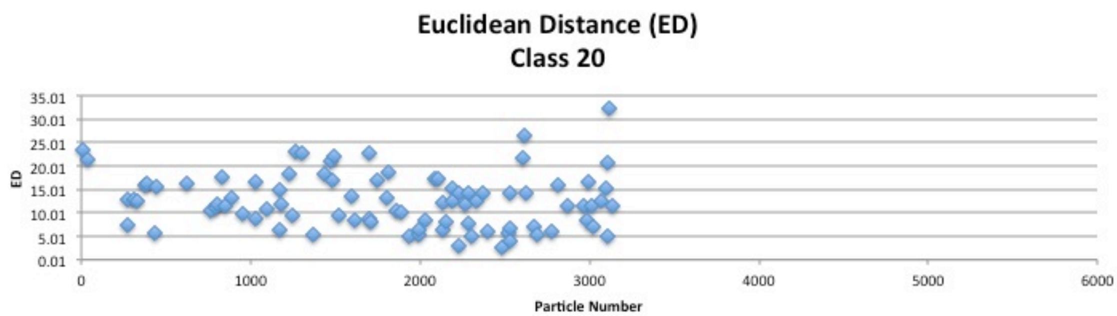

Figure 5-350: Euclidean Distance Class 20

Class 21 of Burkina Laterite 60 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 29 particles in this class (Figure 5-351).

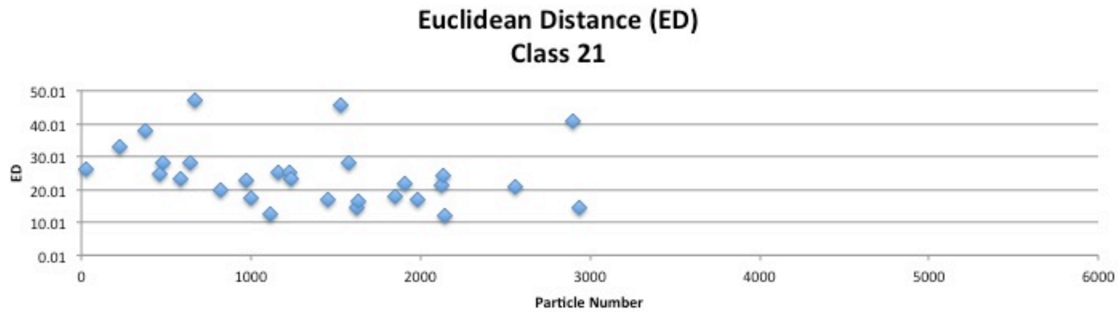

Figure 5-351: Euclidean Distance Class 21

Class 22 of Burkina Laterite 60 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 11 particles in this class (Figure 5-352).

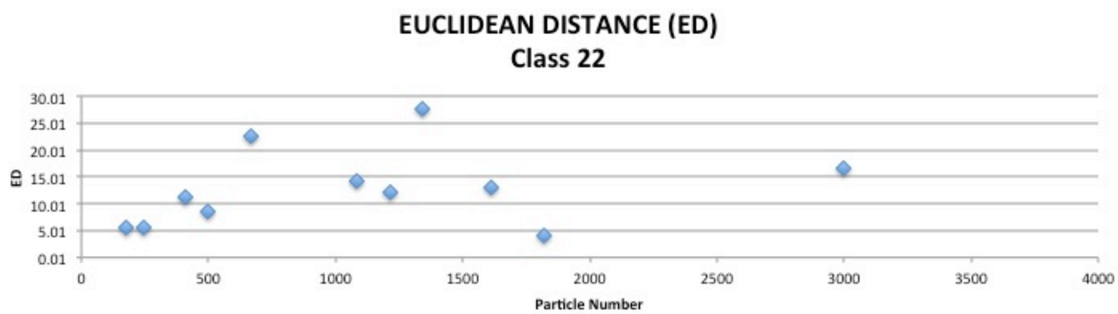

Figure 5-352: Euclidean Distance Class 22

Class 23 of Burkina Laterite 60 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 21 particles in this class (Figure 5-353).

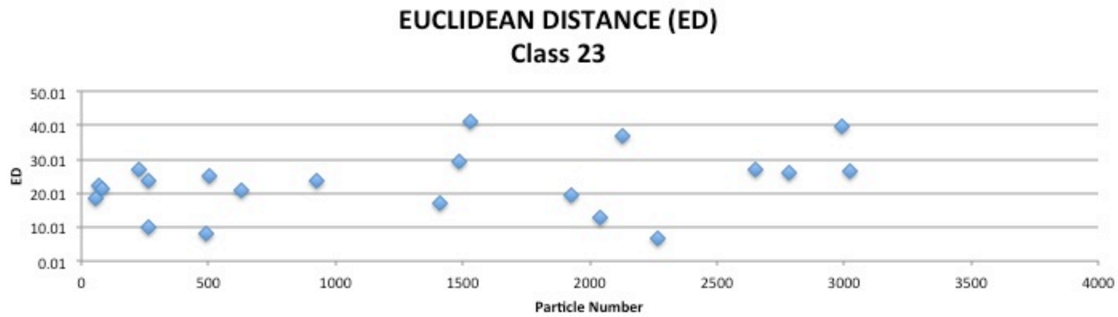

Figure 5-353: Euclidean Distance Class 23

Class 24 of Burkina Laterite 60 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 206 particles in this class (Figure 5-354).

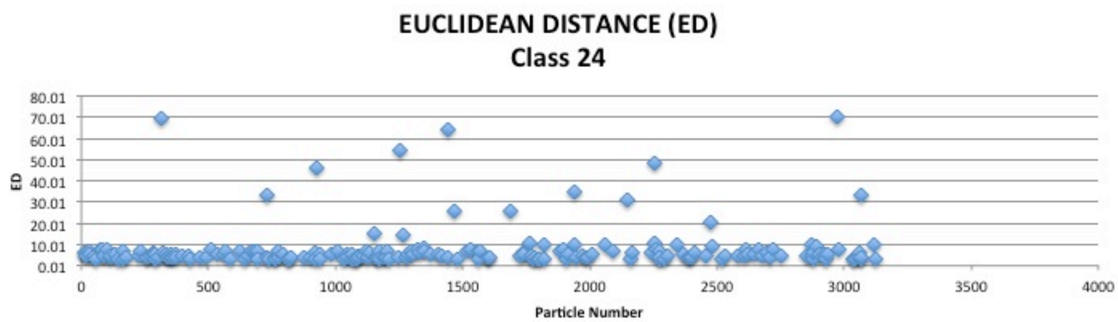

Figure 5-354: Euclidean Distance Class 24

Class 25 of Burkina Laterite 60 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 502 particles in this class (Figure 5-355).

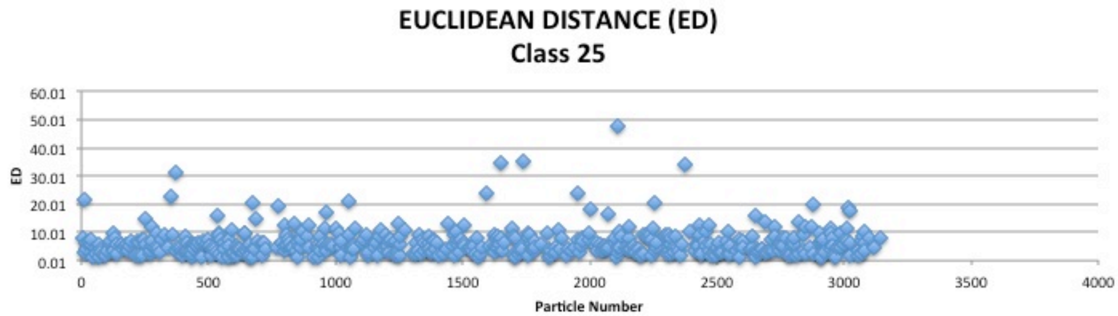

Figure 5-355: Euclidean Distance Class 25

Class 26 of Burkina Laterite 60 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 2 particles in this class (Figure 5-356).

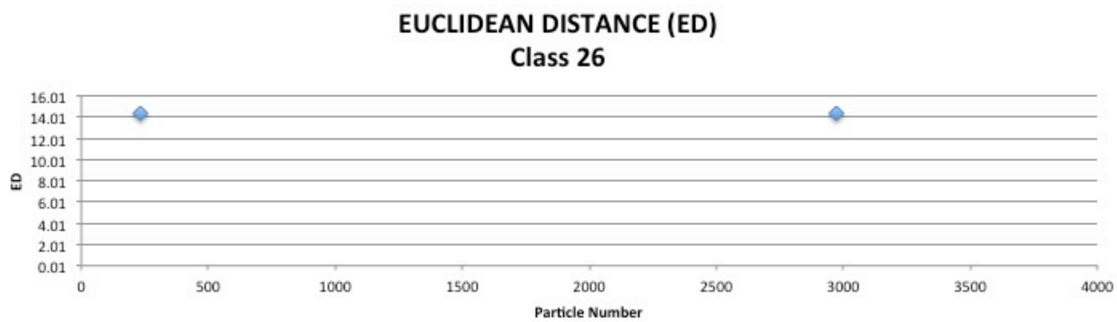

Figure 5-356: Euclidean Distance Class 26

Class 27 of Burkina Laterite 60 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 819 particles in this class (Figure 5-357).

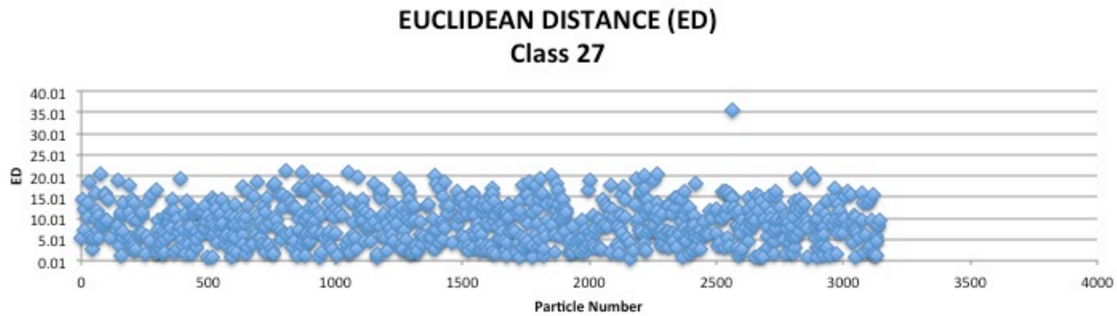

Figure 5-357: Euclidean Distance Class 27

Class 28 of Burkina Laterite 60 is composed of Aluminum less than 1%. There are a total of 31 particles in this class (Figure 5-358).

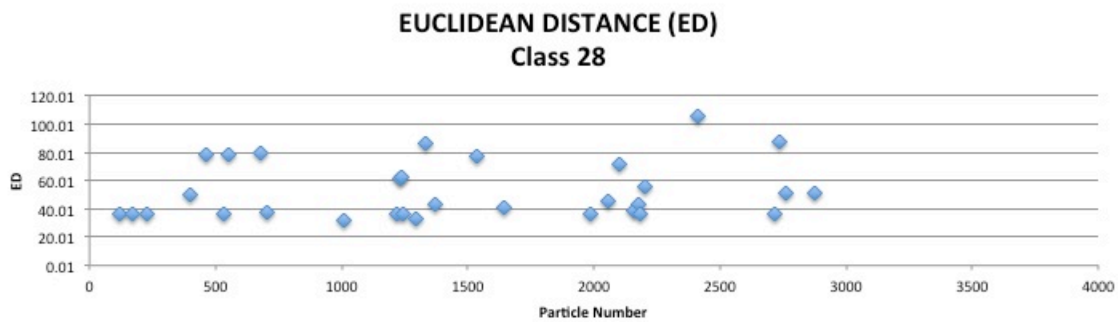

Figure 5-358: Euclidean Distance Class 28

Burkina Laterite 61

Numerical and Volumetric Analysis

Burkina Laterite 61 is located at 12 10.016' N, 0 08.378' E and has been separated into 29 elemental classes (Figure 5-359). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-30).

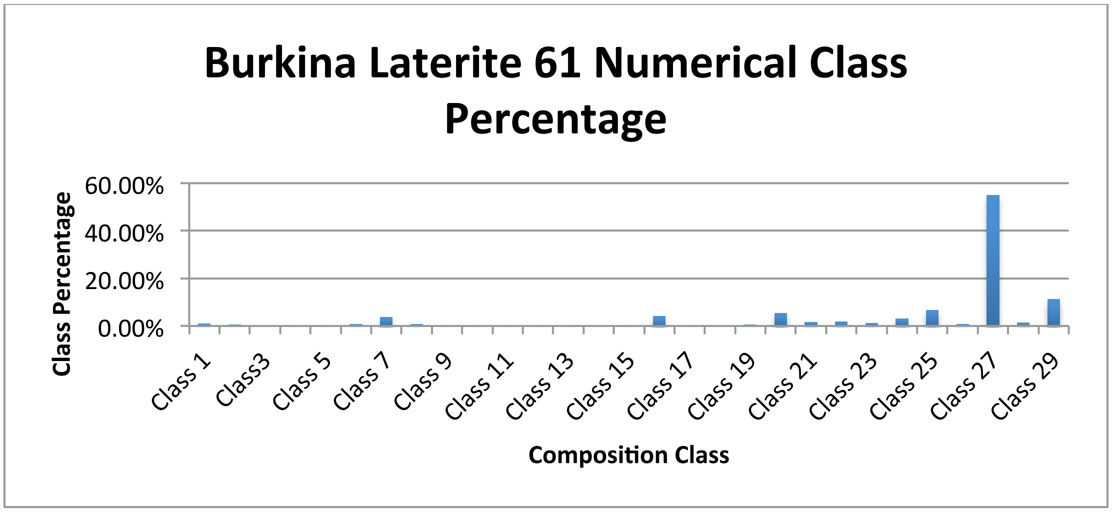

Figure 5-359: Numerical percentage of particles contained within each class.

Table 5-30: Numerical percentage and number of particles contained within each element class and three highest classes and total number of particles highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
35	21	13	0	0	27	146	30
0.88%	0.53%	0.33%	0.00%	0.00%	0.68%	3.65%	0.75%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	11	6	5	0	0	163
0.00%	0.00%	0.28%	0.15%	0.13%	0.00%	0.00%	4.08%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
0	14	20	217	59	68	49	125
0.00%	0.35%	0.50%	5.43%	1.48%	1.70%	1.23%	3.13%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
262	32	2194	52	449	3998		
6.55%	0.80%	54.88%	1.30%	11.23%	100.00%		

Table 5-30 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 20, 25, and 27. Class 20 is composed of Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 25 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 66.86% of the entire sample and contains a total of 2673 particles. Class 29 represents the "unclassified" particles and contains only 11.23% of the entire sample.

The volumetric percentage of Burkina Laterite 61 represents the volume of particles that are represented in each respective elemental class (Figure 5-360). Table 5-31 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 20, 25, and 27, which is consistent with the numerical percentages. Class 20 is composed of Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 25 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 69.96% of the entire sample and contains a total volume of 90342.4 μm^3. Class 29 represents the "unclassified" volume of particles and contains 8.52% of the entire sample.

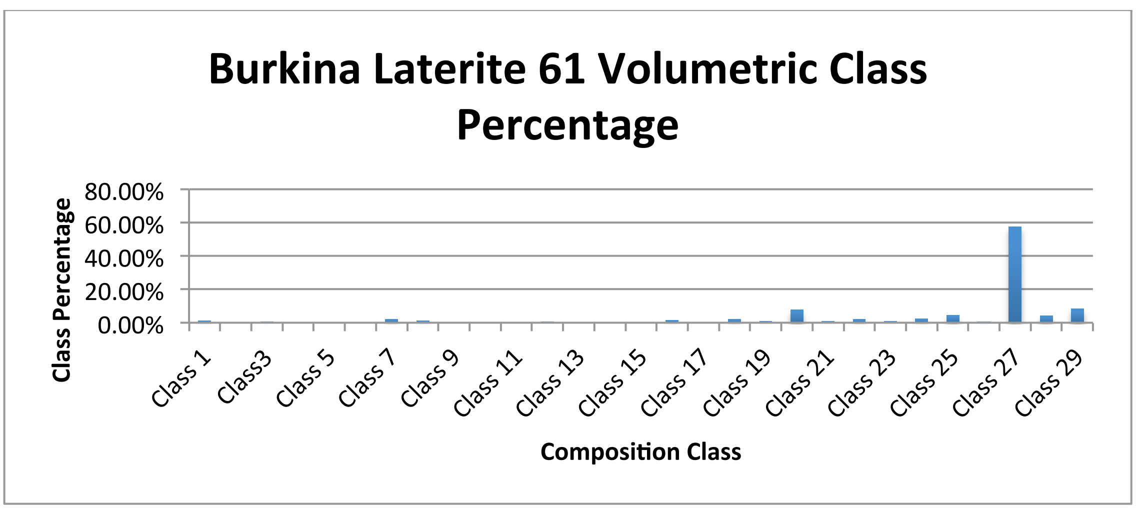

Figure 5-360: Burkina Laterite 61 volumetric percentage of each class.

Table 5-31: Volumetric percentage and volume of each class with three highest percentages and total volume highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
1509.50	128.36	595.08	0.00	0.00	505.62	2831.75	1708.70
1.17%	0.10%	0.46%	0.00%	0.00%	0.39%	2.19%	1.32%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	248.70	574.03	68.30	0.00	0.00	1727.59
0.00%	0.00%	0.19%	0.44%	0.05%	0.00%	0.00%	1.34%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
0.00	2841.56	1273.95	10153.89	1139.81	2698.01	948.39	3004.72
0.00%	2.20%	0.99%	7.86%	0.88%	2.09%	0.73%	2.33%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
5808.59	734.76	74379.92	5259.69	10998.76	129139.68		
4.50%	0.57%	57.60%	4.07%	8.52%	100.00%		

Analysis of class 29 showed a cluster of elements similar to other Burkina Laterites. The highest elements contained within Burkina Laterite 61 unclassified are Fe, Si, Al, respectively, and compose a volume of 8.52% of the entire sample. Most of the elements contained within class 29 are evenly distributed across the three elements Aluminum, Silica and Iron, or are mostly contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-361 and Figure 5-362). Approximately 60% if the unclassified particles are contained within these two distinct clusters.

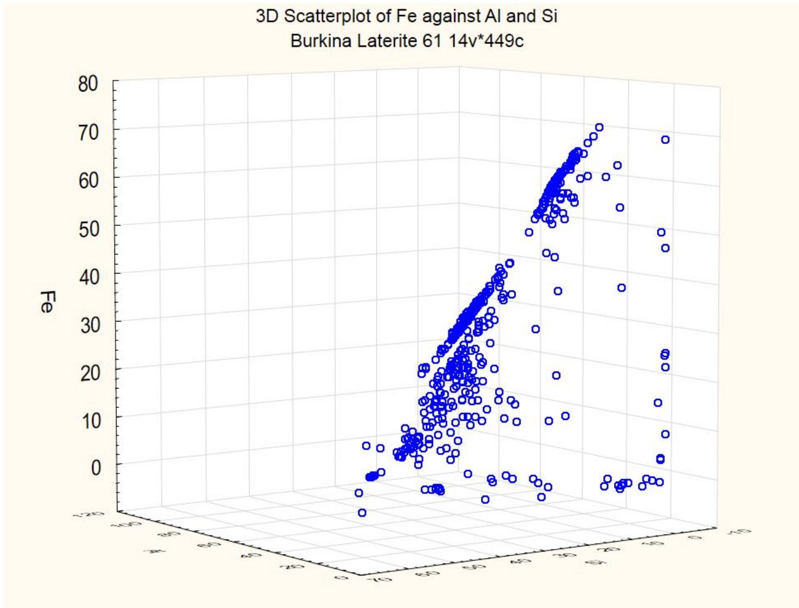

Figure 5-361: Scatterplot of Burkina Laterite 61 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 8.52% volume of the particles in the sample.

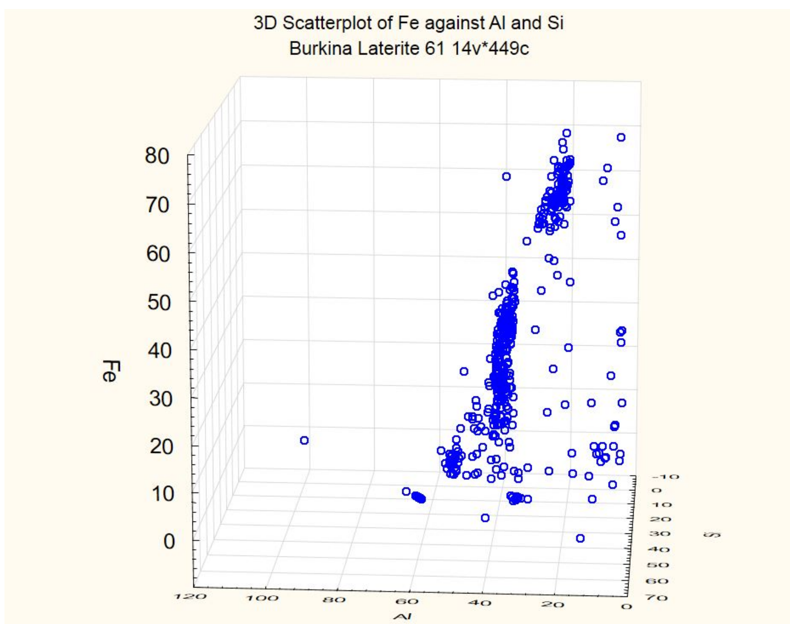

Figure 5-362: Alternate view of the class 29 particles.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Laterite 61 is composed of greater than

99% Silica. There are a total of 35 particles in this class (Figure 5-363).

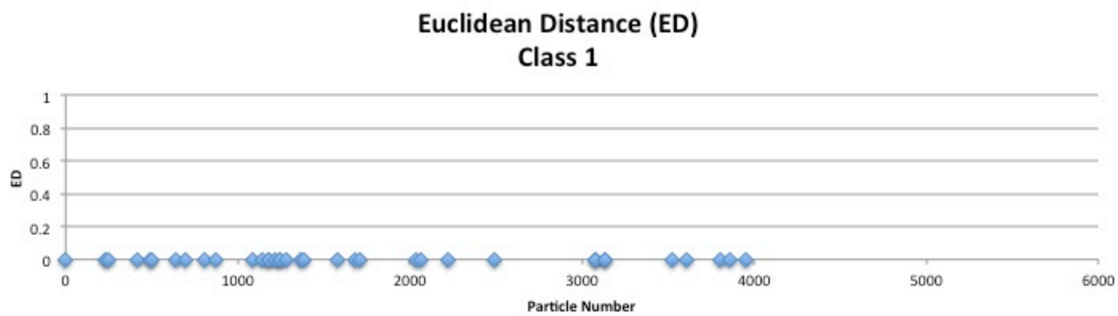

Figure 5-363: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 21 particles in this class (Figure 5-364).

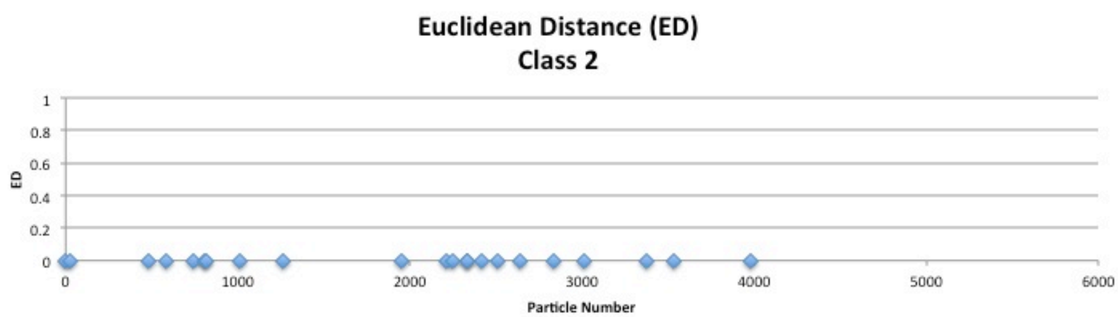

Figure 5-364: Euclidean Distance Class 2

Class 3 of Burkina Laterite 61 is composed of greater than 99% Calcium. There are a total of 13 particles in this class (Figure 5-365).

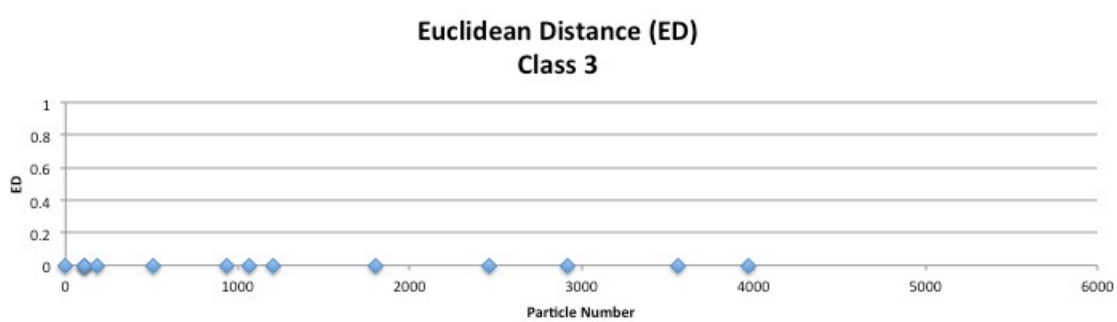

Figure 5-365: Euclidean Distance Class 3.

Class 4 of Burkina Laterite 61 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Burkina Laterite 61 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Burkina Laterite 61 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 27 particles in this class (Figure 5-366).

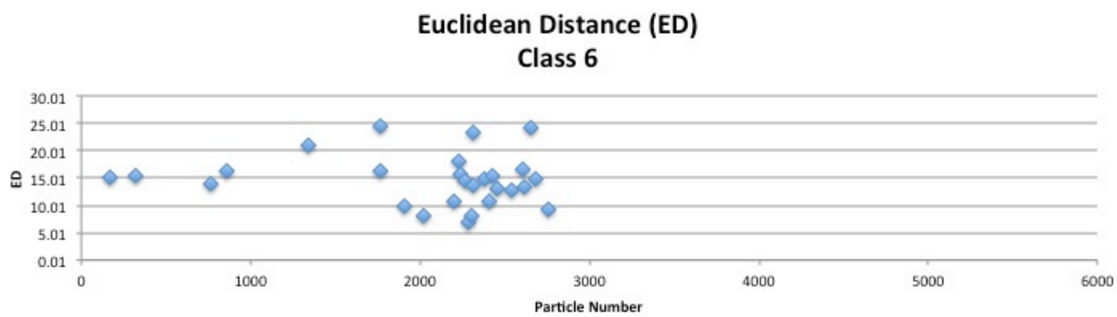

Figure 5-366: Euclidean Distance Class 6

Class 7 of Burkina Laterite 61 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 146 particles in this class (Figure 5-367).

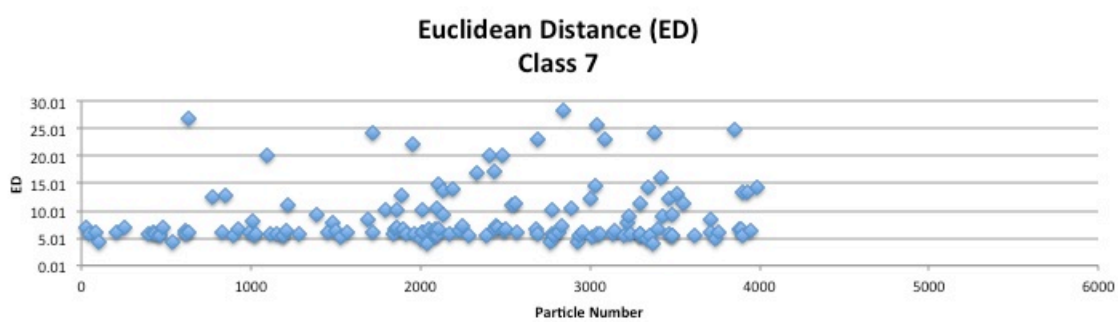

Figure 5-367: Euclidean Distance Class 7

Class 8 of Burkina Laterite 61 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 30 particles in this class (Figure 5-368).

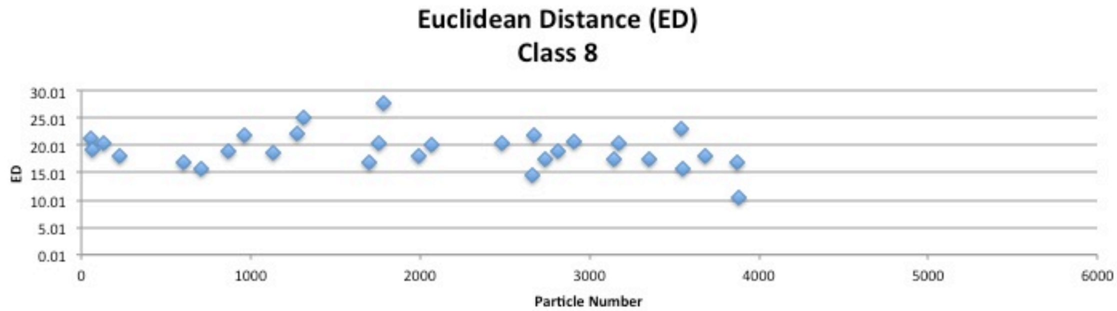

Figure 5-368: Euclidean Distance Class 8

Class 9 of Burkina Laterite 61 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Laterite 61 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Laterite 61 is composed of the total Calcium and Manganese greater than 90%. There are 11 particles in this class (Figure 5-369).

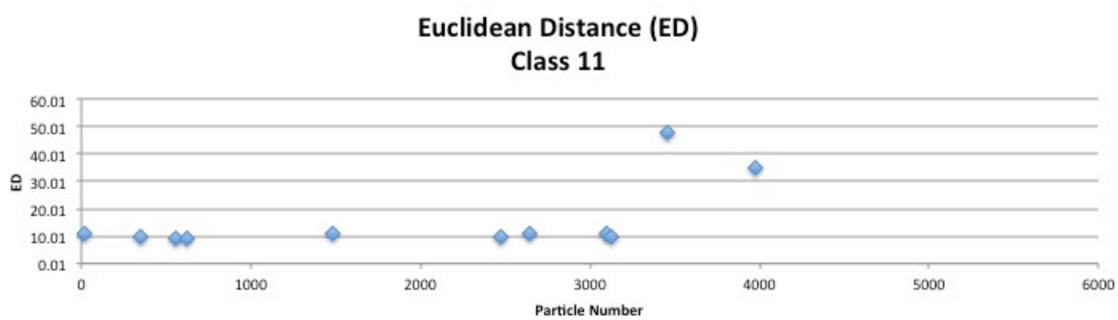

Figure 5-369: Euclidean Distance Class 11

Class 12 of Burkina Laterite 61 is composed of the total Calcium and Phosphorus greater than 90%. There are a total of 6 particles in this class (Figure 5-370).

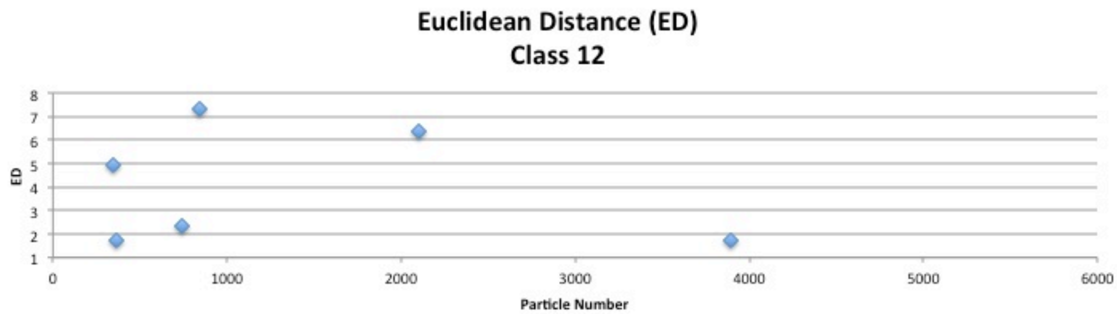

Figure 5-370: Euclidean Distance Class 12

Class 13 of Burkina Laterite 61 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 5 particles in this class (Figure 5-371).

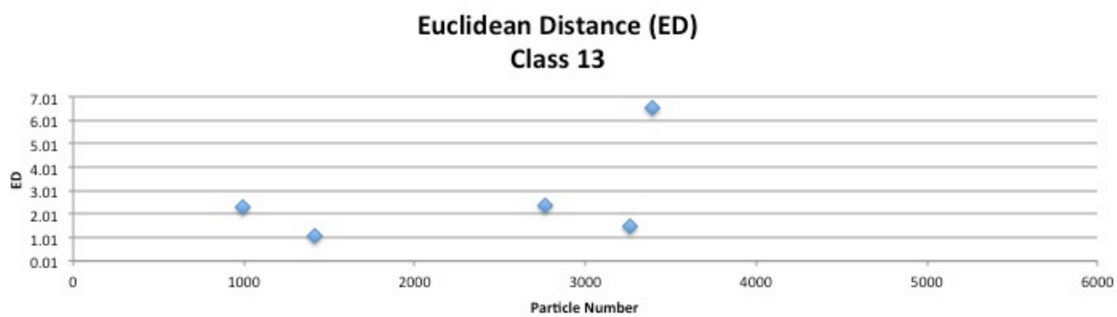

Figure 5-371: Euclidean Distance Class 13

Class 14 of Burkina Laterite 61 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are no particles in this class.

Class 15 of Burkina Laterite 61 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Laterite 61 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 163 particles in this class (Figure 5-372).

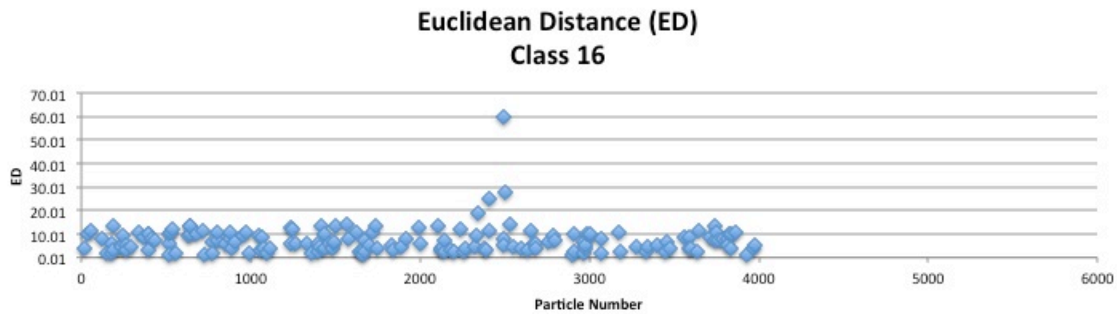

Figure 5-372: Euclidean Distance Class 16

Class 17 of Burkina Laterite 61 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are no particles in this class.

Class 18 of Burkina Laterite 61 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 14 particles in this class (Figure 5-373).

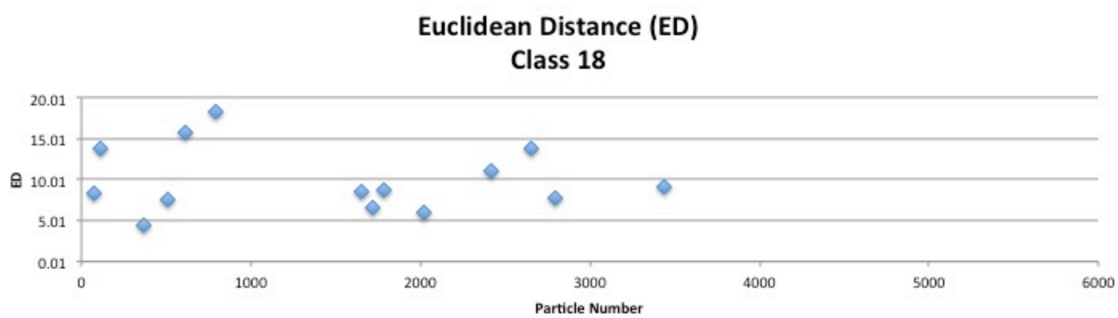

Figure 5-373: Euclidean Distance Class 18

Class 19 of Burkina Laterite 61 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 20 particles in this class (Figure 5-374).

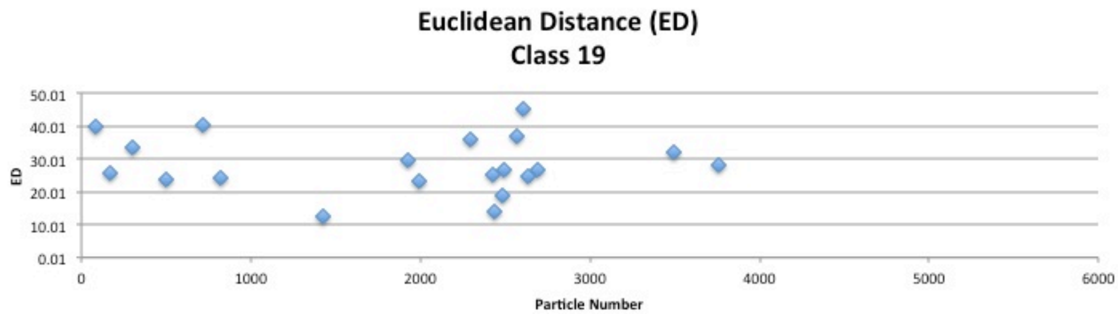

Figure 5-374: Euclidean Distance Class 19

Class 20 of Burkina Laterite 61 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 217 particles in this class (Figure 5-375).

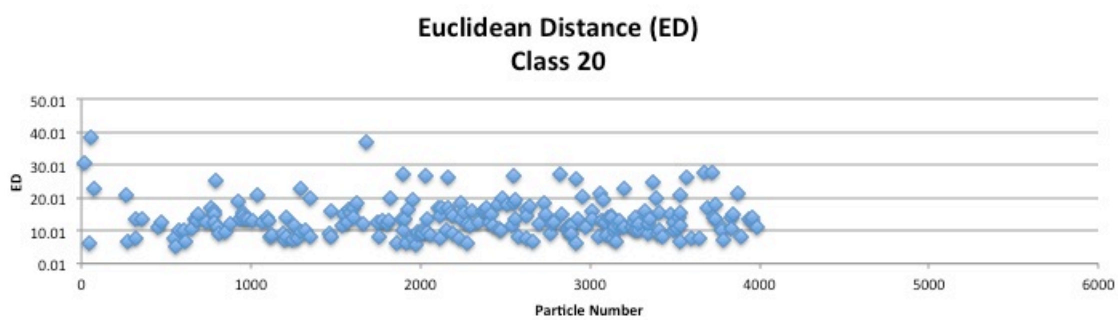

Figure 5-375: Euclidean Distance Class 20

Class 21 of Burkina Laterite 61 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 59 particles in this class (Figure 5-376).

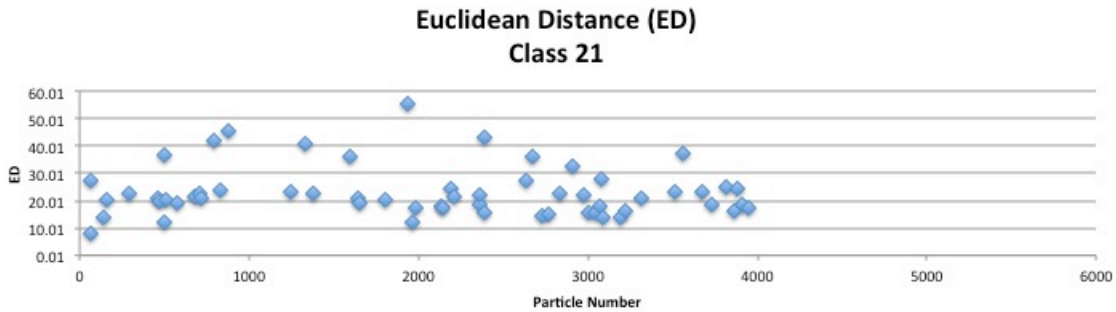

Figure 5-376: Euclidean Distance Class 21

Class 22 of Burkina Laterite 61 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 68 particles in this class (Figure 5-377).

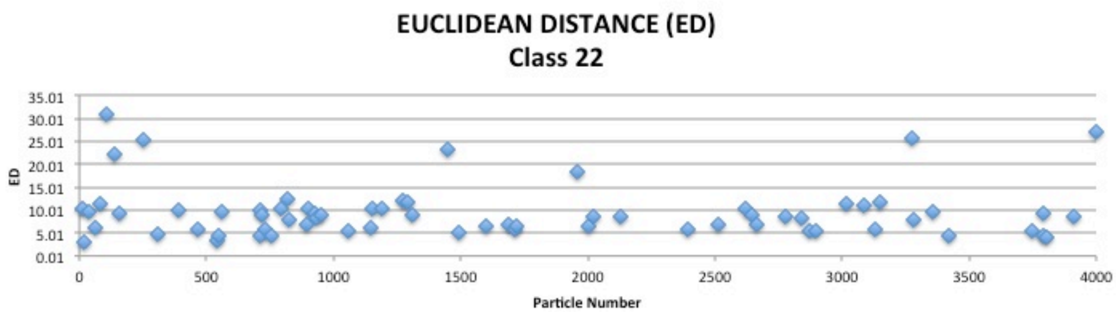

Figure 5-377: Euclidean Distance Class 22

Class 23 of Burkina Laterite 61 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 49 particles in this class (Figure 5-378).

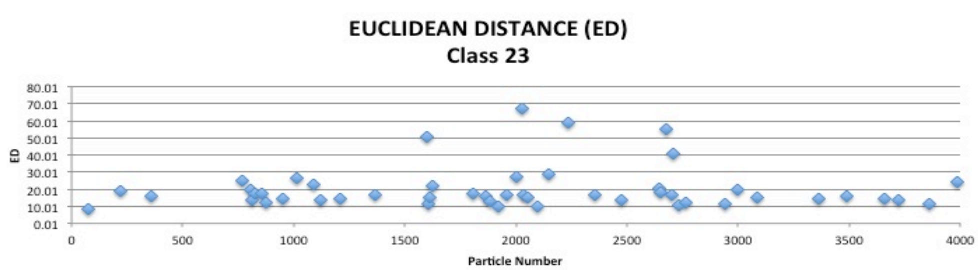

Figure 5-378: Euclidean Distance Class 23

Class 24 of Burkina Laterite 61 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 125 particles in this class (Figure 5-379).

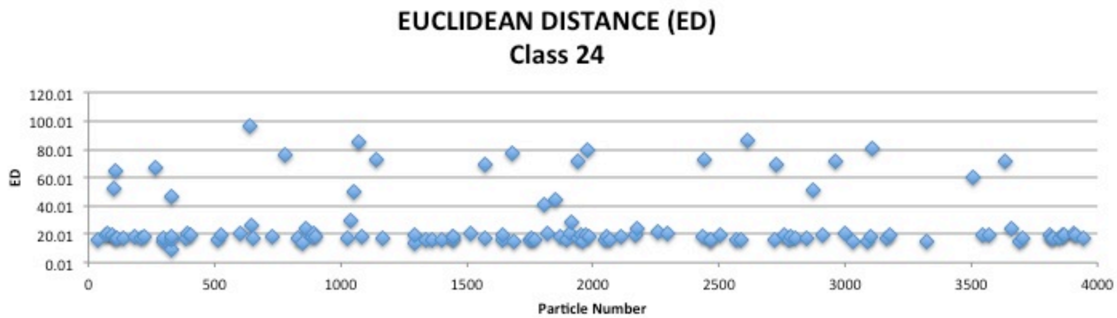

Figure 5-379: Euclidean Distance Class 24.

Class 25 of Burkina Laterite 61 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 262 particles in this class (Figure 5-380).

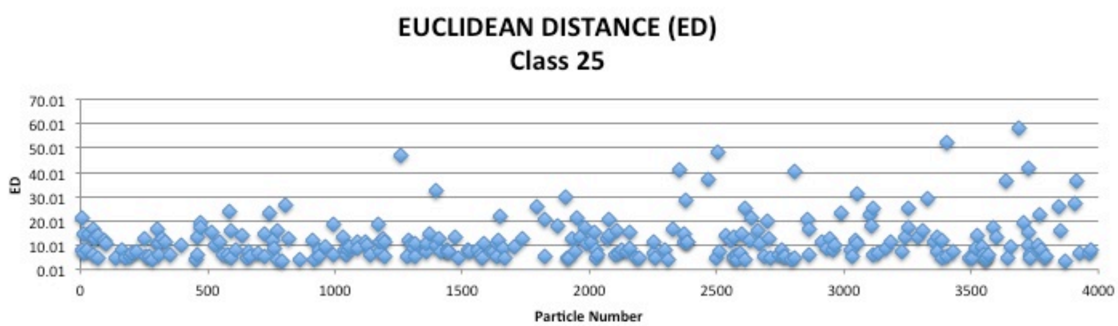

Figure 5-380: Euclidean Distance Class 25.

Class 26 of Burkina Laterite 61 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 32 particles in this class (Figure 5-381).

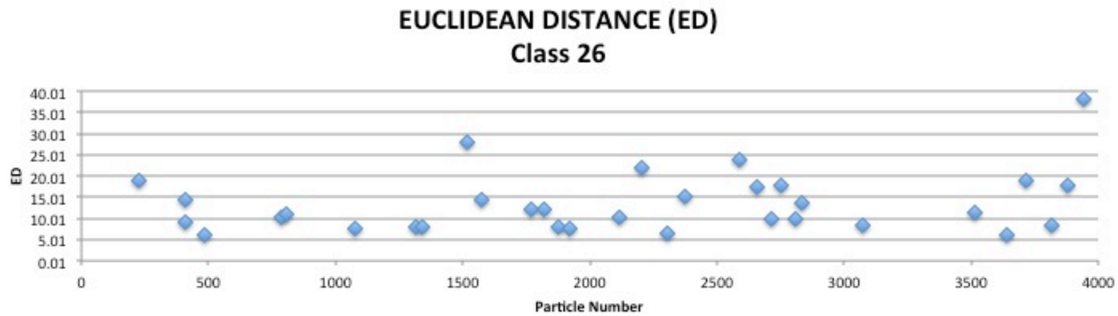

Figure 5-381: Euclidean Distance Class 26

Class 27 of Burkina Laterite 61 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 2194 particles in this class (Figure 5-382).

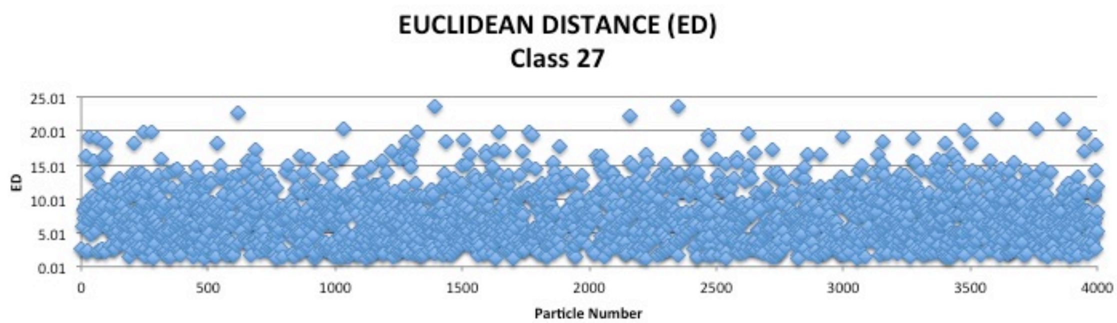

Figure 5-382: Euclidean Distance Class 27

Class 28 of Burkina Laterite 61 is composed of Aluminum less than 1%. There are a total of 52 particles in this class (Figure 5-383).

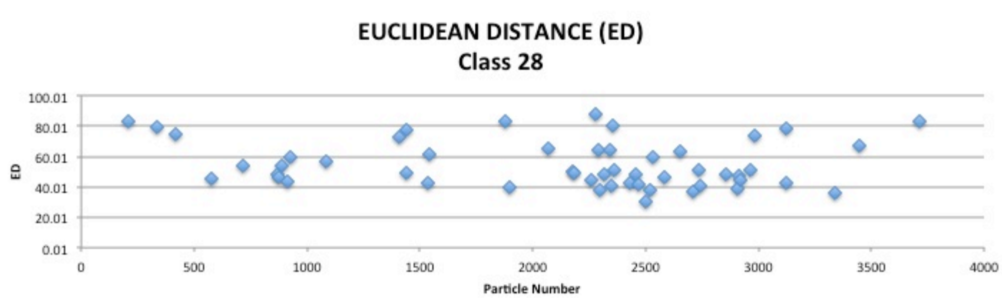

Figure 5-383: Euclidean Distance Class 28.

Burkina Laterite 62

Numerical and Volumetric Analysis

Burkina Laterite 62 is located at 12 15.016' N, 0 42.725' W and has been separated into 29 elemental classes (Figure 5-384). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-32).

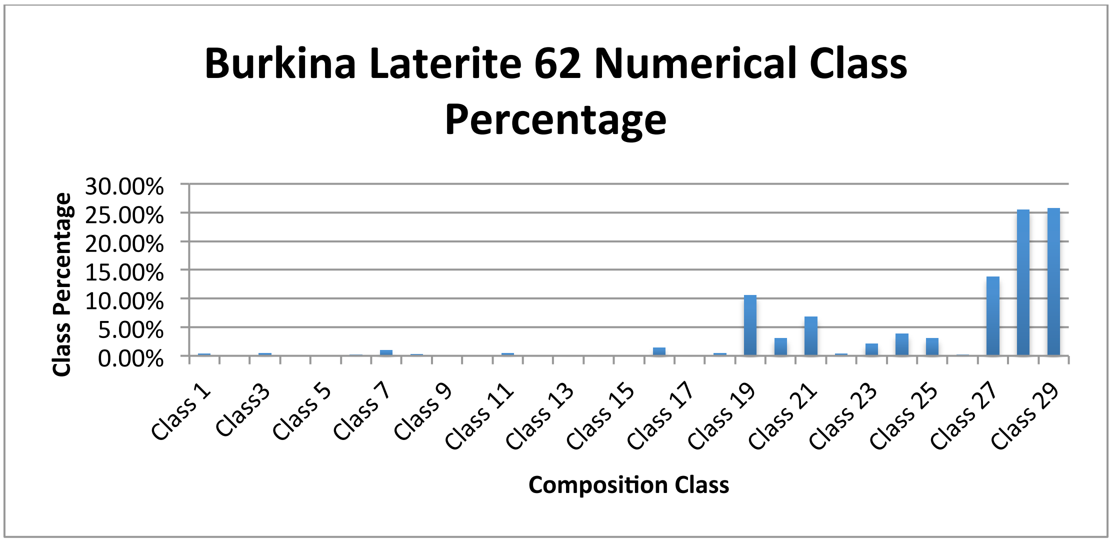

Figure 5-384: Numerical percentage of particles contained within each class.

Table 5-32: Numerical percentage and number of particles contained within each element class and three highest classes and total number of particles highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
418.34	0.00	493.82	0.00	0.00	68.92	76.23	129.19
0.36%	0.00%	0.46%	0.00%	0.00%	0.23%	0.94%	0.29%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	410.56	24.24	39.10	4.80	0.00	69.66
0.00%	0.00%	0.46%	0.03%	0.03%	0.03%	0.00%	1.43%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
3.86	85.90	1250.25	681.85	1212.27	99.24	181.37	381.10
0.07%	0.42%	10.57%	3.09%	6.83%	0.39%	2.11%	3.84%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
342.18	107.51	2881.51	11838.17	4220.18	25020.24		
3.09%	0.23%	13.83%	25.50%	25.76%	100.00%		

Table 5-32 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 19, 27, and 28. Class 19 has Potassium between 45 and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. Class 27 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60% and Silica between 20% and 60%. Class 28 has Aluminum less than 1%. This represents 49.90% of the entire sample and contains a total of 1534 particles. Class 29 represents the "unclassified" particles and contains only 25.76% of the entire sample.

The volumetric percentage of Burkina Laterite 62 represents the volume of particles that are represented in each respective elemental class (Figure 5-385). Table 5-33 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 19, 27, and 28, which is consistent with the numerical percentages. Class 19 has Potassium between 45 and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. Class 27 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60% and Silica between 20% and 60%. This represents 63.83% of the entire sample and contains a total volume of 15969.93 μm^3. Class 29 represents the "unclassified" volume of particles and contains 16.87% of the entire sample.

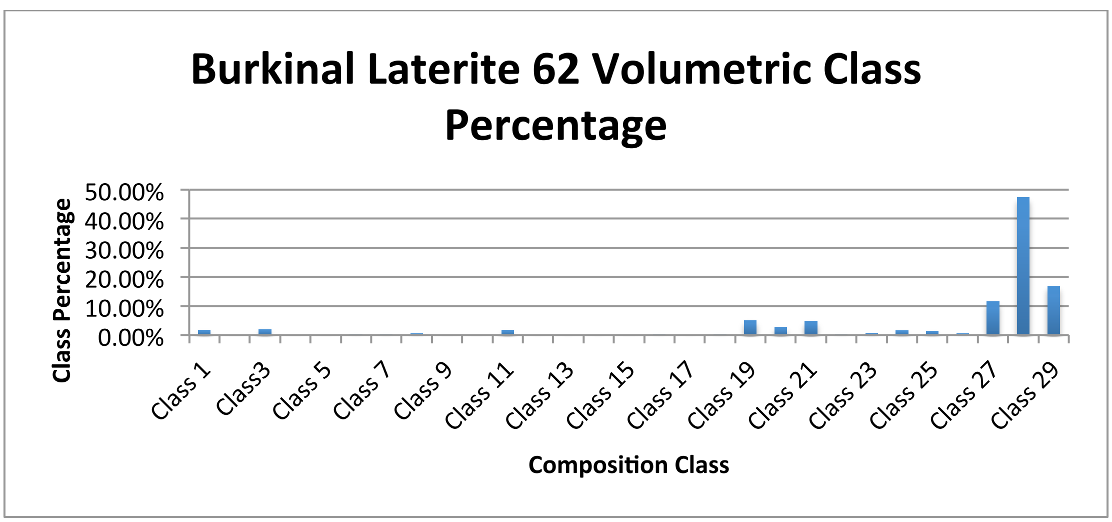

Figure 5-385: Burkina Laterite 62 volumetric percentage of each class.

Table 5-33: Volumetric percentage and volume of each class with three highest percentages and total volume highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
418.34	0.00	493.82	0.00	0.00	68.92	76.23	129.19
1.67%	0.00%	1.97%	0.00%	0.00%	0.28%	0.30%	0.52%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	410.56	24.24	39.10	4.80	0.00	69.66
0.00%	0.00%	1.64%	0.10%	0.16%	0.02%	0.00%	0.28%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
3.86	85.90	1250.25	681.85	1212.27	99.24	181.37	381.10
0.02%	0.34%	5.00%	2.73%	4.85%	0.40%	0.72%	1.52%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
342.18	107.51	2881.51	11838.17	4220.18	25020.24		
1.37%	0.43%	11.52%	47.31%	16.87%	100.00%		

Analysis of class 29 showed a cluster of elements similar to other Burkina Laterites. The highest elements contained within Burkina Laterite 62 unclassified are Fe, Si, Al, respectively, and compose a volume of 16.87% of the entire sample. Most of the elements contained within class 29 are evenly distributed across the three elements Aluminum, Silica and Iron, but some are contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-386 and Figure 5-387). Approximately 60% if the unclassified particles are contained within these two distinct clusters.

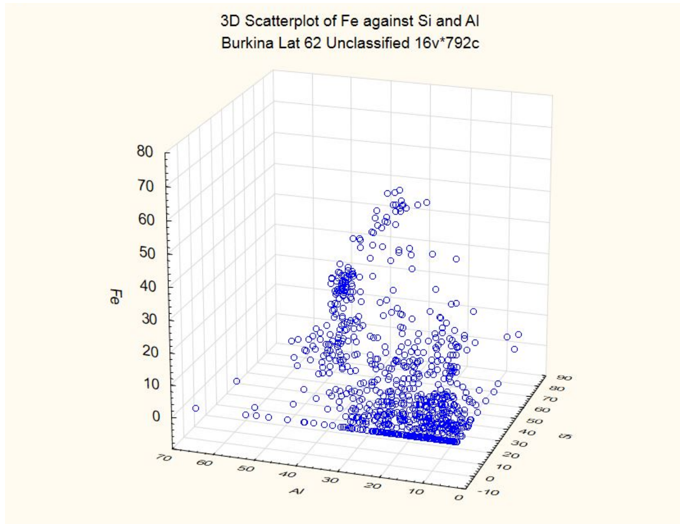

Figure 5-386: Scatterplot of Burkina Laterite 62 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 16.87% volume of the particles in the sample.

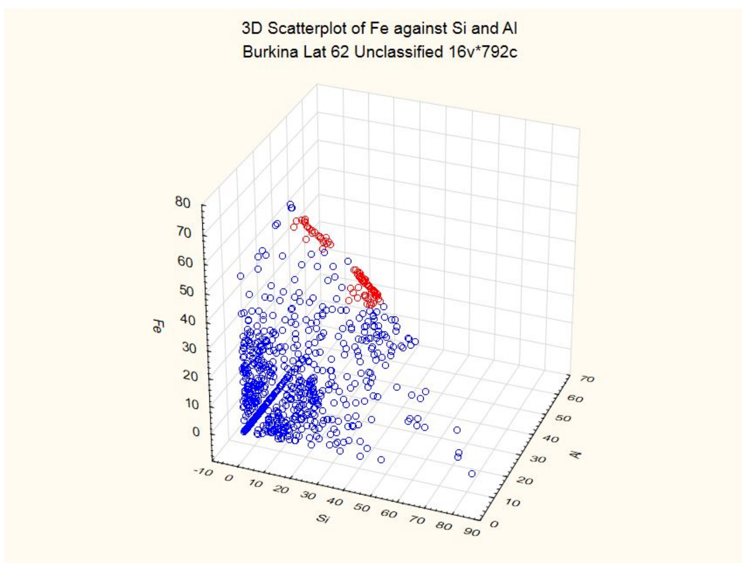

Figure 5-387: Alternate figure of unclassified particles showing slight clustering of particles.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Laterite 62 is composed of greater than 99% Silica. There are a total of 11 particles in this class (Figure 5-388).

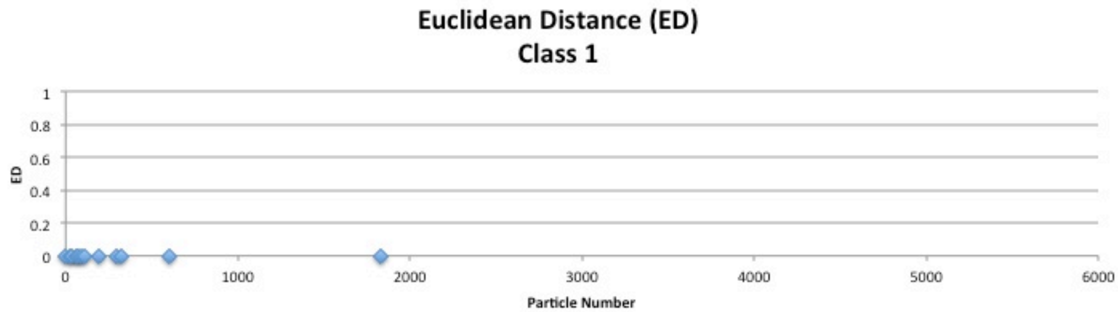

Figure 5-388: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are no particles in this class.

Class 3 of Burkina Laterite 62 is composed of greater than 99% Calcium. There are a total of 14 particles in this class (Figure 5-389).

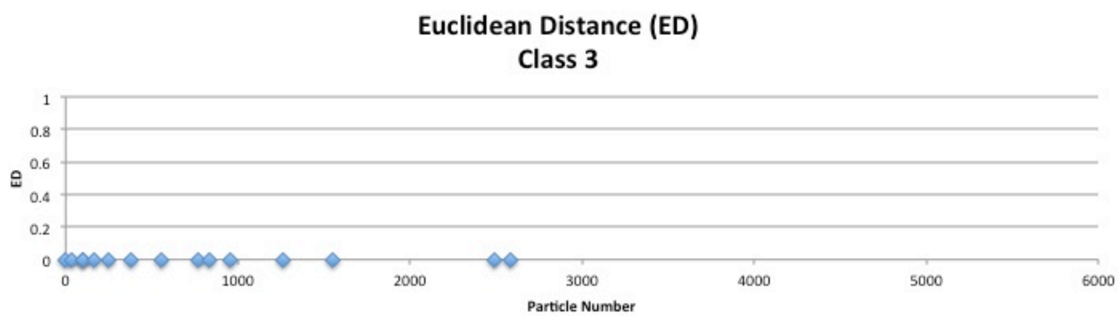

Figure 5-389: Euclidean Distance Class 3

Class 4 of Burkina Laterite 62 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Burkina Laterite 62 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Burkina Laterite 62 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 7 particles in this class (Figure 5-390).

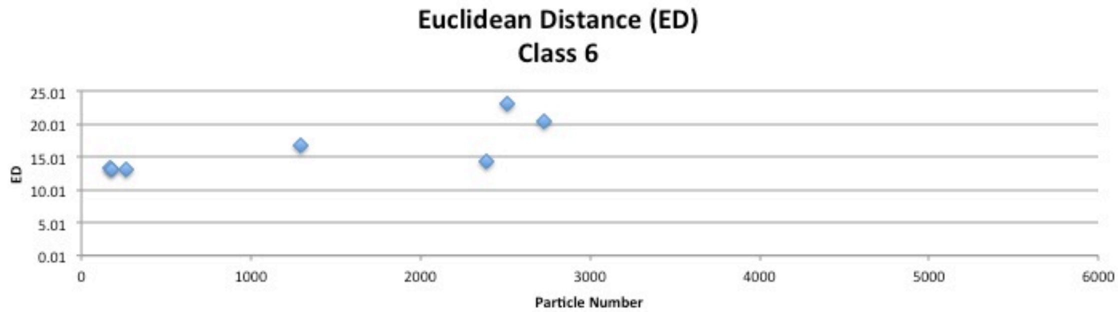

Figure 5-390: Euclidean Distance Class 6

Class 7 of Burkina Laterite 62 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 29 particles in this class (Figure 5-391).

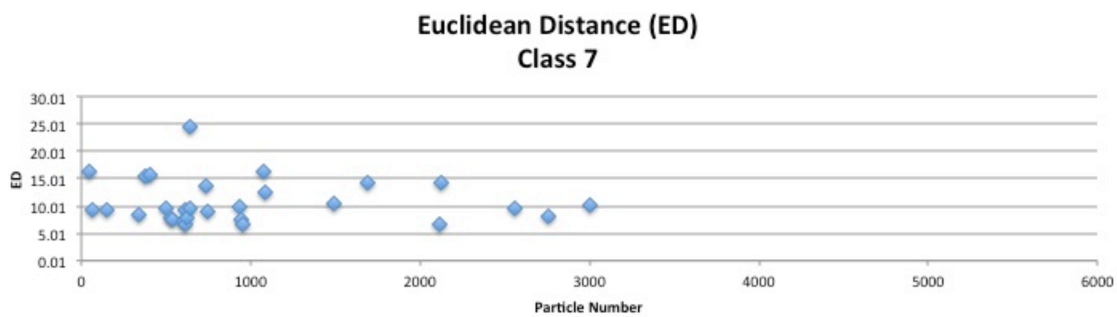

Figure 5-391: Euclidean Distance Class 7

Class 8 of Burkina Laterite 62 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 9 particles in this class (Figure 5-392).

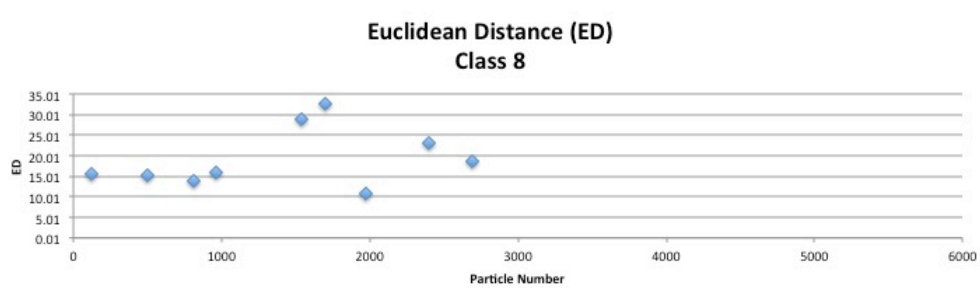

Figure 5-392: Euclidean Distance Class 8

Class 9 of Burkina Laterite 62 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Laterite 62 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Laterite 62 is composed of the total Calcium and Manganese greater than 90%. There are 14 particles in this class (Figure 5-393).

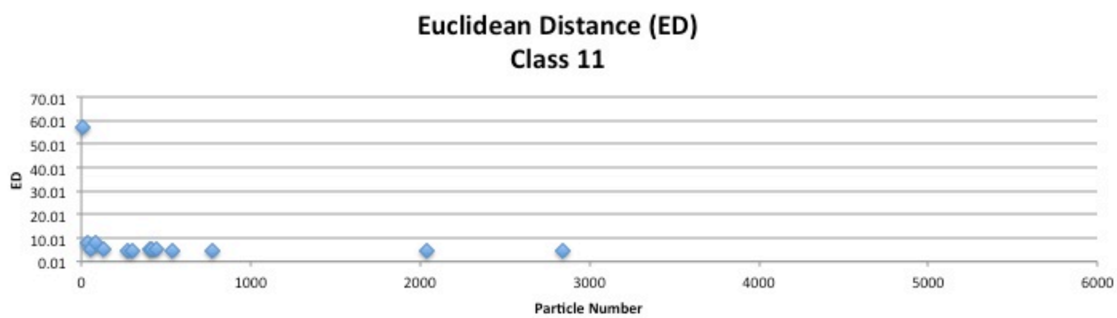

Figure 5-393: Euclidean Distance Class 11

Class 12 of Burkina Laterite 62 is composed of the total Calcium and Phosphorus greater than 90%. There is a total of 1 particle in this class (Figure 5-394).

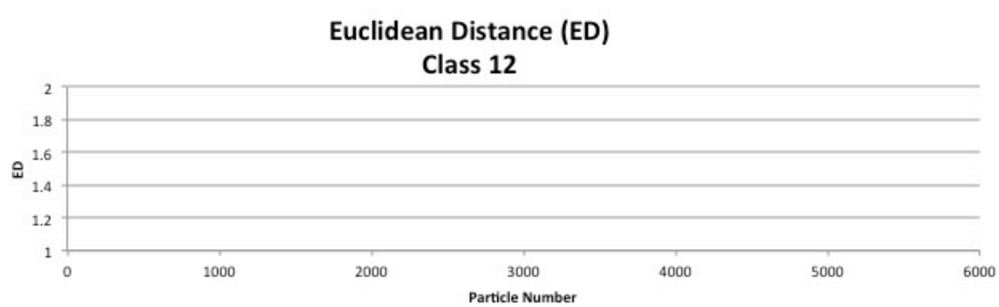

Figure 5-394: Euclidean Distance Class 12

Class 13 of Burkina Laterite 62 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There is 1 particle in this class (Figure 5-395).

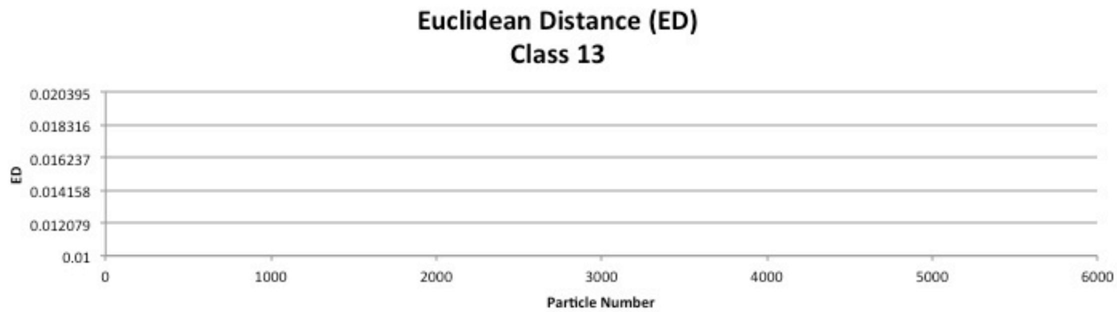

Figure 5-395: Euclidean Distance Class 13

Class 14 of Burkina Laterite 62 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There is a total of 1 particle in this class (Figure 5-396).

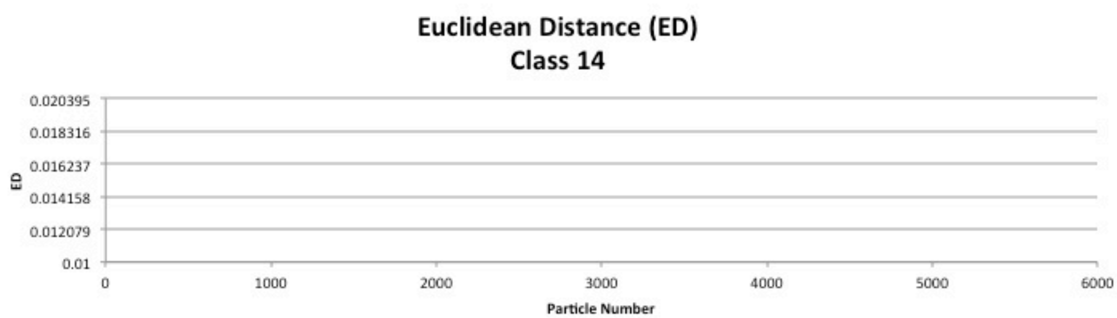

Figure 5-396: Euclidean Distance Class 14

Class 15 of Burkina Laterite 62 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Laterite 62 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 44 particles in this class (Figure 5-397).

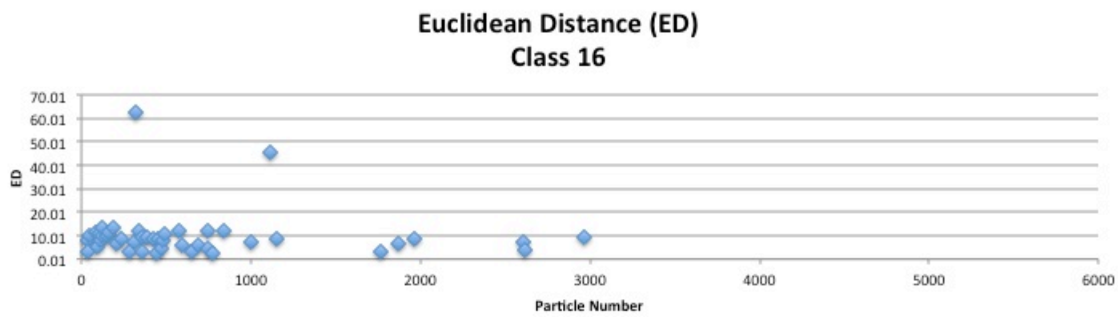

Figure 5-397: Euclidean Distance Class 16

Class 17 of Burkina Laterite 62 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 2 particles in this class (Figure 5-398).

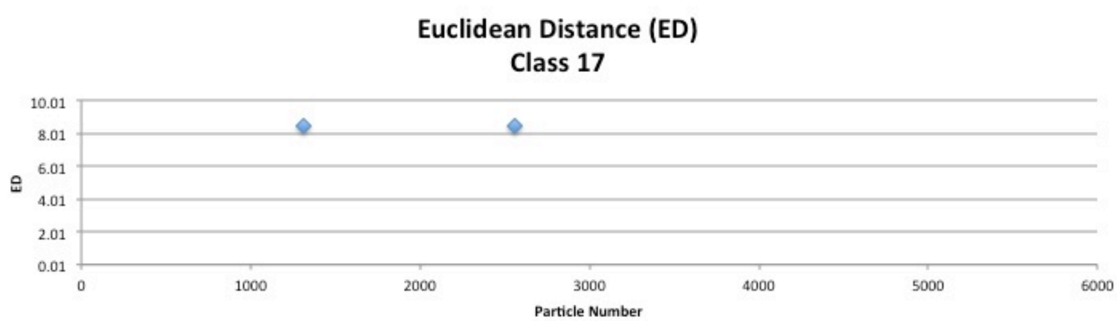

Figure 5-398: Euclidean Distance Class 17

Class 18 of Burkina Laterite 62 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 13 particles in this class (Figure 5-399).

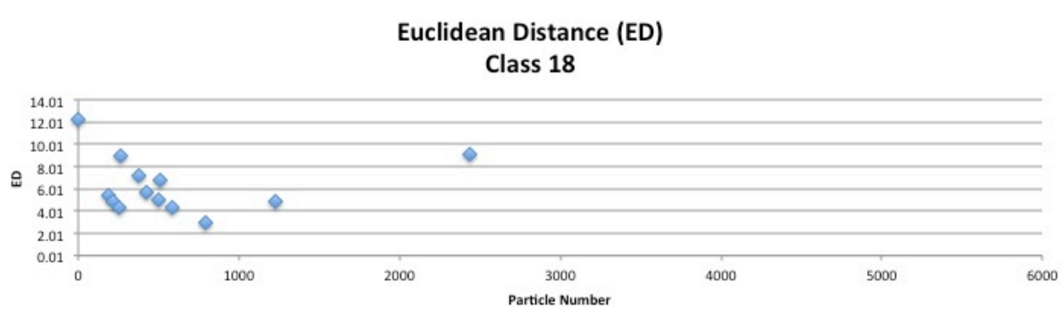

Figure 5-399: Euclidean Distance Class 18

Class 19 of Burkina Laterite 62 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are a total of 325 particles in this class (Figure 5-400).

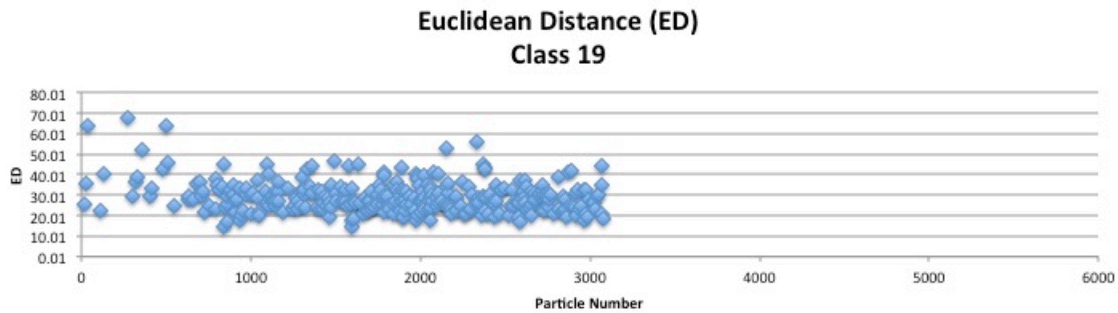

Figure 5-400: Euclidean Distance Class 19

Class 20 of Burkina Laterite 62 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 95 particles in this class (Figure 5-401).

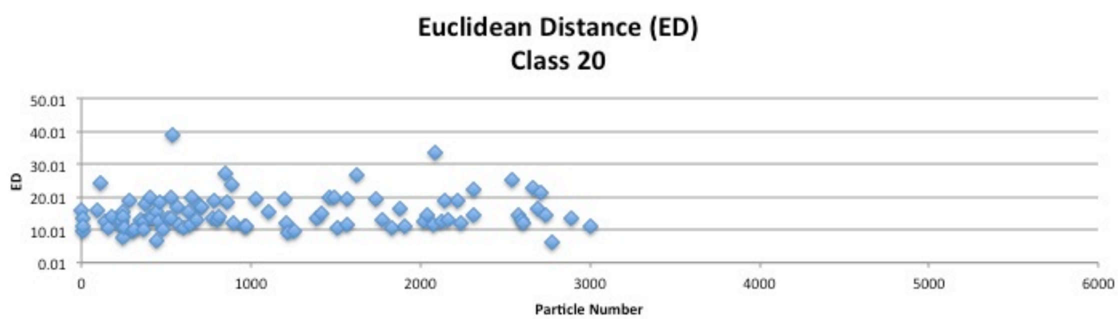

Figure 5-401: Euclidean Distance Class 20

Class 21 of Burkina Laterite 62 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 210 particles in this class (Figure 5-402).

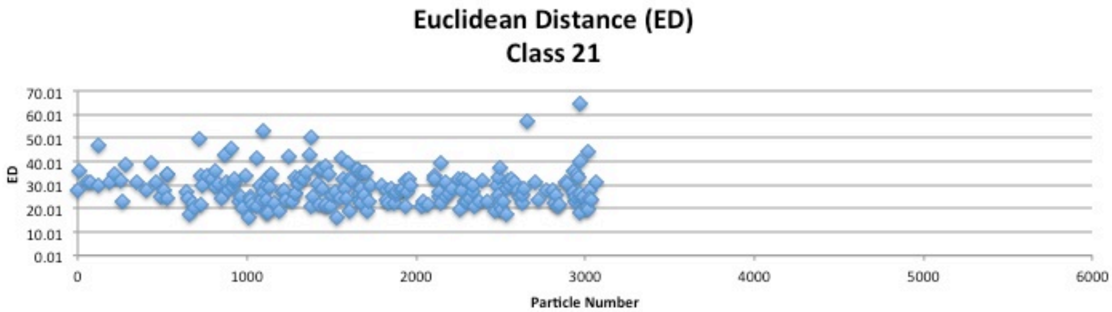

Figure 5-402: Euclidean Distance Class 21

Class 22 of Burkina Laterite 62 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 12 particles in this class (Figure 5-403).

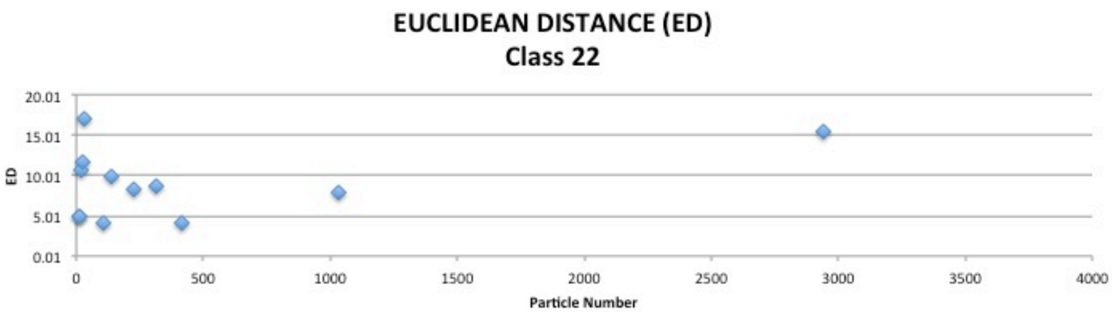

Figure 5-403: Euclidean Distance Class 22

Class 23 of Burkina Laterite 62 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 65 particles in this class (Figure 5-404).

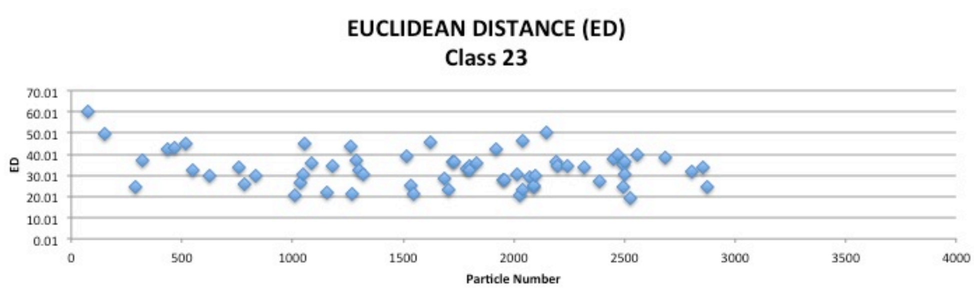

Figure 5-404: Euclidean Distance Class 23

Class 24 of Burkina Laterite 62 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 118 particles in this class (Figure 5-405).

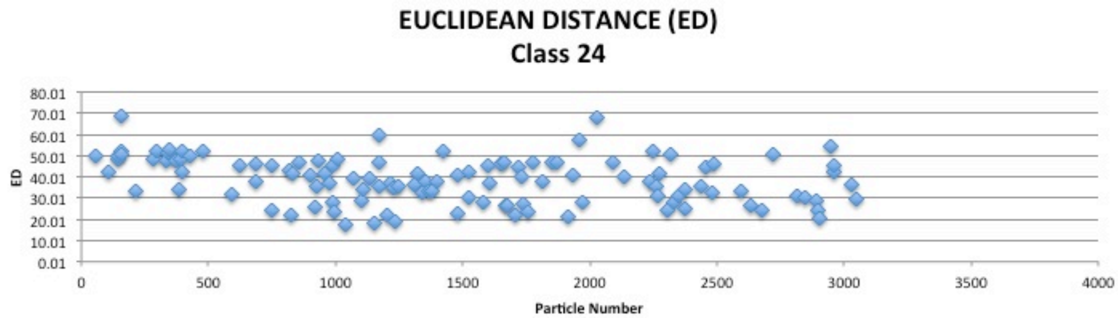

Figure 5-405: Euclidean Distance Class 24

Class 25 of Burkina Laterite 62 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 95 particles in this class (Figure 5-406).

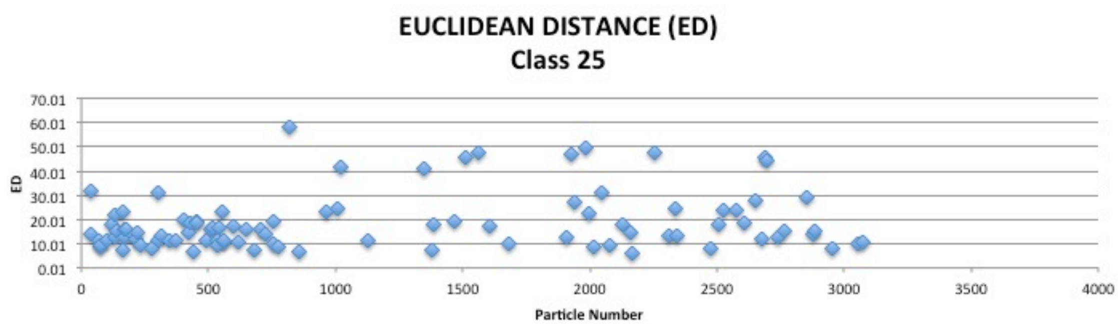

Figure 5-406: Euclidean Distance Class 25

Class 26 of Burkina Laterite 62 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 7 particles in this class (Figure 5-407).

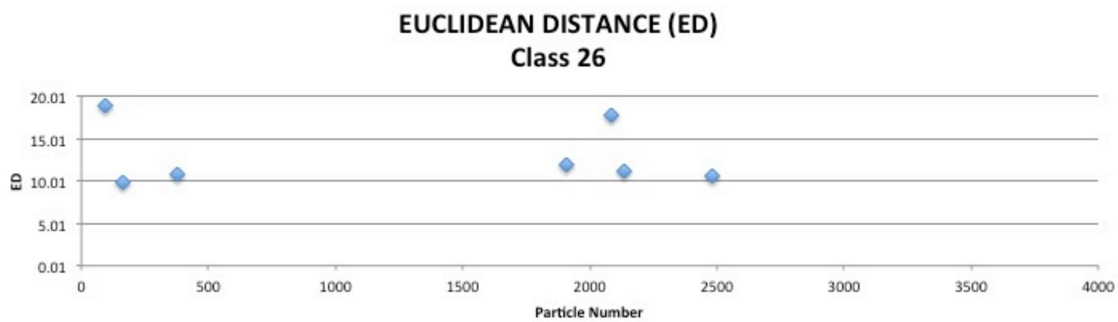

Figure 5-407: Euclidean Distance Class 26

Class 27 of Burkina Laterite 62 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 425 particles in this class (Figure 5-408).

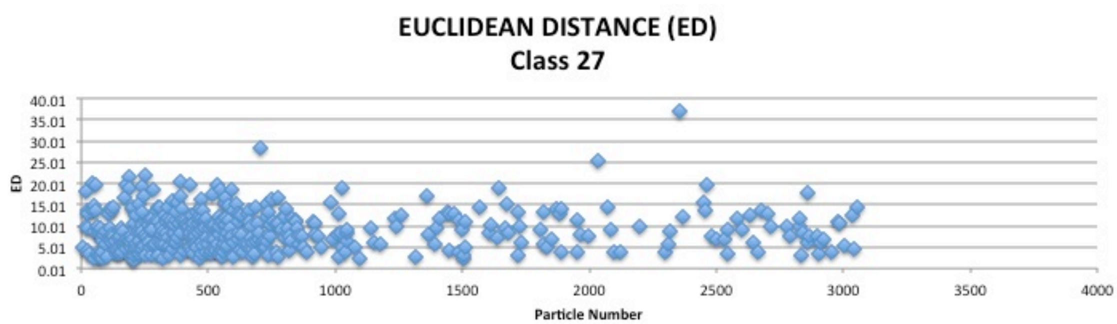

Figure 5-408: Euclidean Distance Class 27

Class 28 of Burkina Laterite 62 is composed of Aluminum less than 1%. There are a total of 784 particles in this class (Figure 5-409).

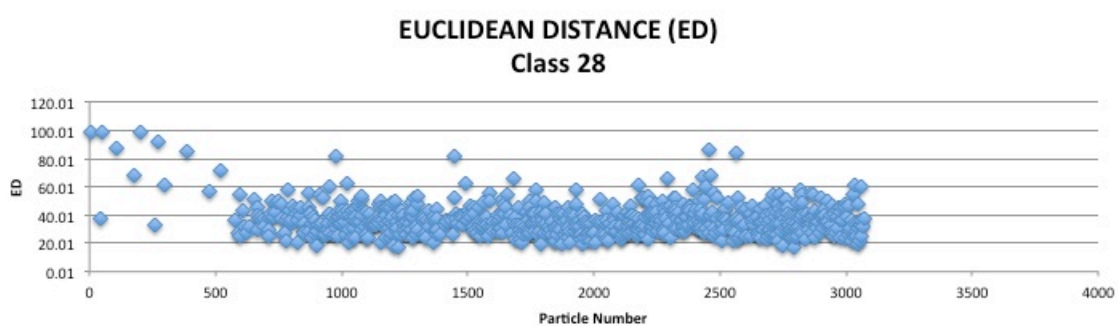

Figure 5-409: Euclidean Distance Class 28

Burkina Laterite 63

Numerical and Volumetric Analysis

Burkina Laterite 63, located at 12 21.801' N, 1 03.116' W, has been separated into 29 elemental classes (Figure 5-410). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-34).

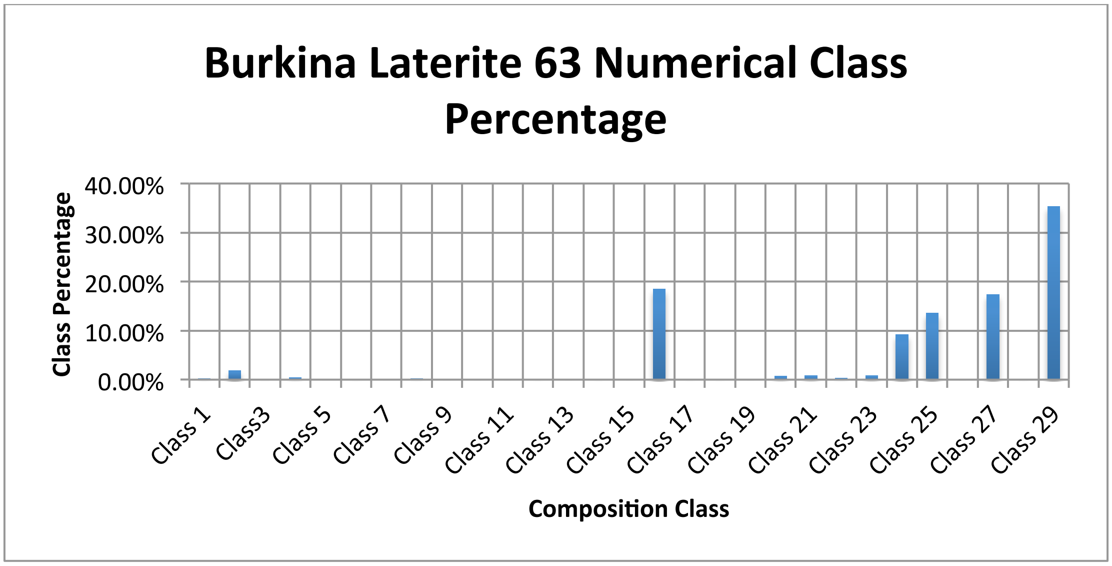

Figure 5-410: Numerical percentage of particles in each class.

Table 5-34: Numerical percentages and number of particles in each class with total number of particles in sample.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
8	65	1	14	0	5	0	6
0.23%	1.90%	0.03%	0.41%	0.00%	0.15%	0.00%	0.18%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	0	1	0	2	0	633
0.00%	0.00%	0.00%	0.03%	0.00%	0.06%	0.00%	18.50%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
3	2	0	24	28	10	29	316
0.09%	0.06%	0.00%	0.70%	0.82%	0.29%	0.85%	9.23%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
465	0	595	5	1210	3422		
13.59%	0.00%	17.39%	0.15%	35.36%	100.00%		

Table 5-34 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 16, 25, and 27. Class 16 has Iron greater than 40% and a combination of Iron and Calcium totaling greater than 75%. Class 25 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 49.48% of the entire sample and contains a total of 1693 particles. Class 29 represents the "unclassified" particles and contains only 35.36% of the entire sample.

The volumetric percentage of Burkina Laterite 63 represents the volume of particles that are represented in each respective elemental class (Figure 5-411). Table 5-35 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 16, 20, and 27. Class 16 has Iron greater than 40% and a combination of Iron and Calcium totaling greater than 75%. Class 20 is composed of Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 42.40% of the entire sample and contains a total volume of 5816.83 μm^3. Class 29 represents the "unclassified" volume of particles and contains 25.97% of the entire sample.

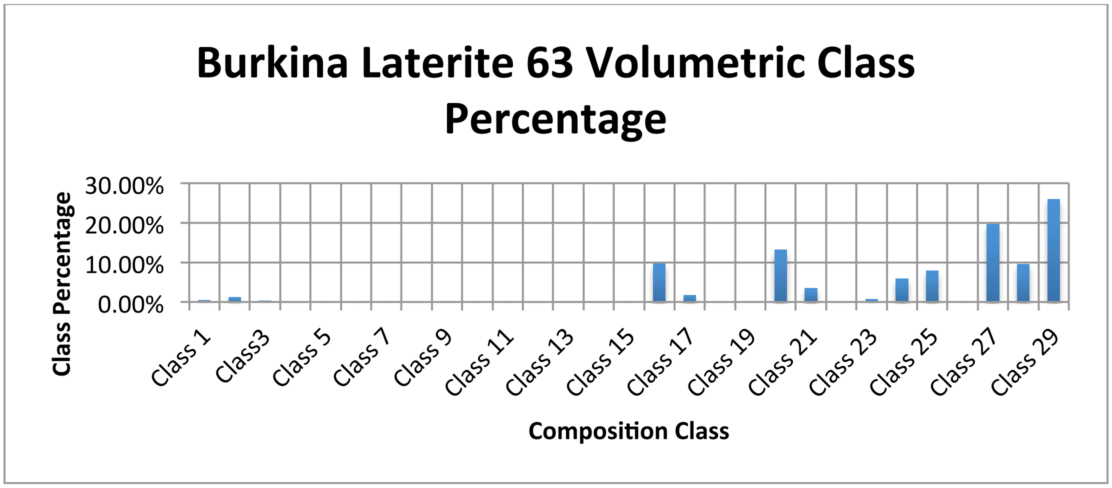

Figure 5-411: Volumetric percentages in sample per class.

Table 5-35: Volumetric percentage and volume per class and total volume of particles. Highlighted cells are the highest classes.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
54.85	160.49	36.89	2.95	0.00	0.09	0.00	18.05
0.40%	1.17%	0.27%	0.02%	0.00%	0.00%	0.00%	0.13%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	0.00	0.33	0.00	19.78	0.00	1321.21
0.00%	0.00%	0.00%	0.00%	0.00%	0.14%	0.00%	9.63%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
240.97	0.16	0.00	1803.40	474.01	30.25	96.58	809.37
1.76%	0.00%	0.00%	13.15%	3.46%	0.22%	0.70%	5.90%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
1080.02	0.00	2692.22	1314.16	3563.21	13718.99		
7.87%	0.00%	19.62%	9.58%	25.97%	100.00%		

Analysis of class 29 showed a cluster of elements similar to other Burkina Laterites. The highest elements contained within Burkina Laterite 63 unclassified are Fe, Si, Al, respectively, and compose a volume of 25.97% of the entire sample. Most of the unclassified elements are contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-412 and Figure 5-413). Approximately 95% if the unclassified particles are contained within these two distinct clusters.

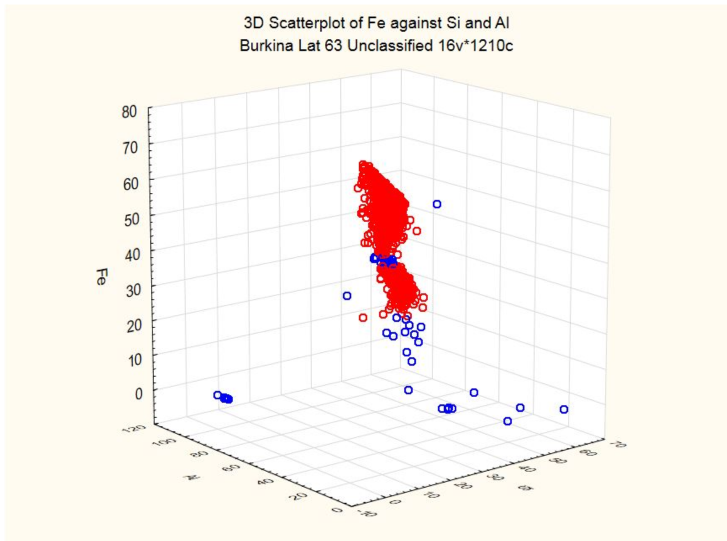

Figure 5-412: Scatterplot of Burkina Laterite 63 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 25.97% volume of the particles in the sample.

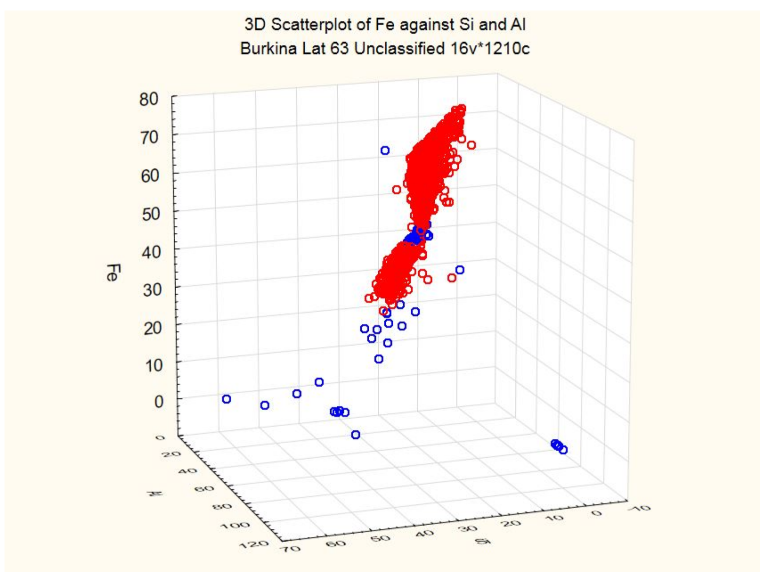

Figure 5-413: Alternate view of unclassified particles contained within two clusters.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Laterite 63 is composed of greater than 99% Silica. There are a total of 8 particles in this class (Figure 5-414).

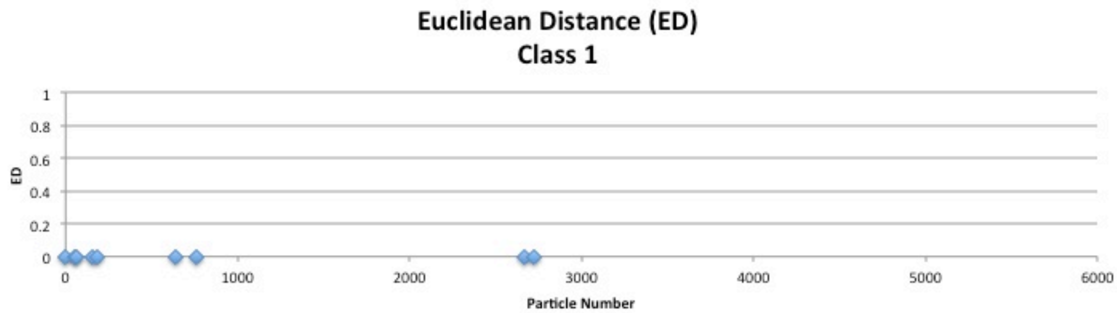

Figure 5-414: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 65 particles in this class (Figure 5-415).

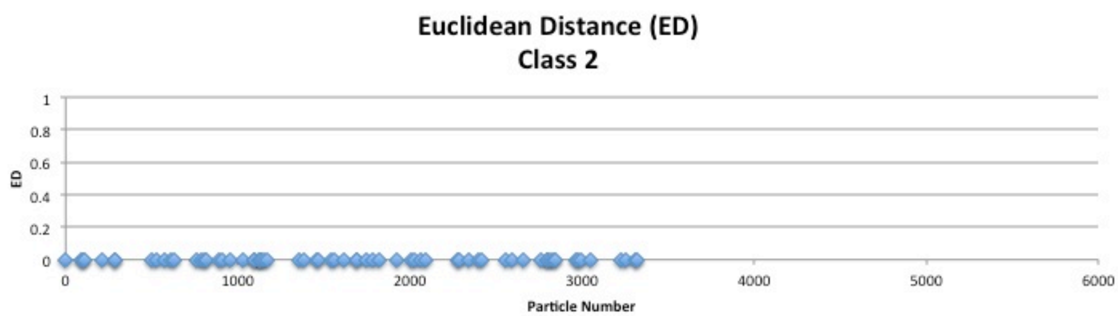

Figure 5-415: Euclidean Distance Class 2

Class 3 of Burkina Laterite 63 is composed of greater than 99% Calcium. There is a total of 1 particle in this class (Figure 5-416).

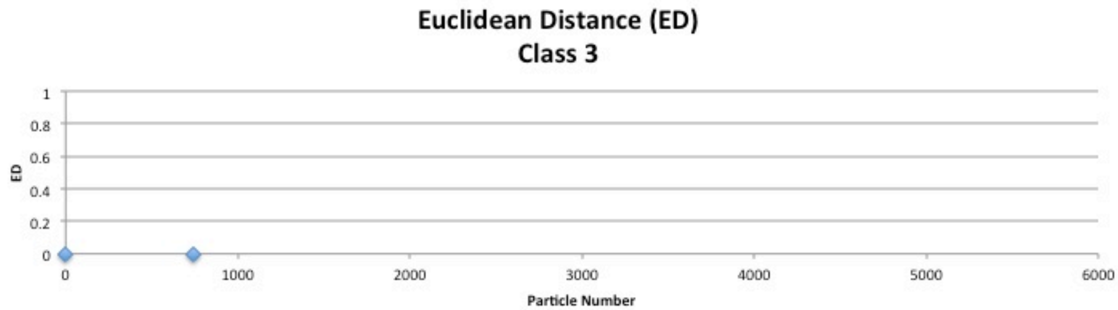

Figure 5-416: Euclidean Distance Class 3

Class 4 of Burkina Laterite 63 is composed of Titanium greater than 55% and Lead less than 5%. There is 1 particle in this class (Figure 5-417).

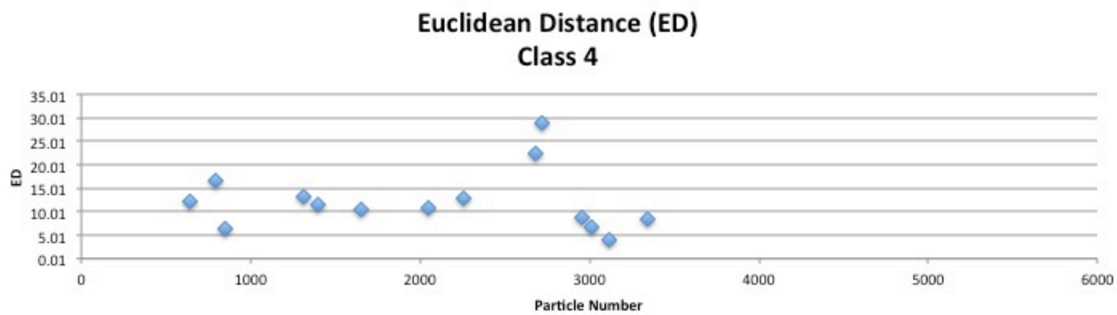

Figure 5-417: Euclidean Distance Class 4

Class 5 of Burkina Laterite 63 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Burkina Laterite 63 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 5 particles in this class (Figure 5-418).

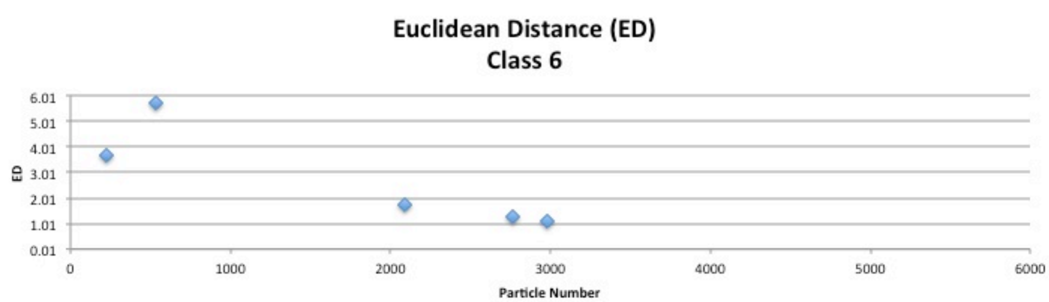

Figure 5-418: Euclidean Distance Class 6

Class 7 of Burkina Laterite 63 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are no particles in this class.

Class 8 of Burkina Laterite 63 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 6 particles in this class (Figure 5-419).

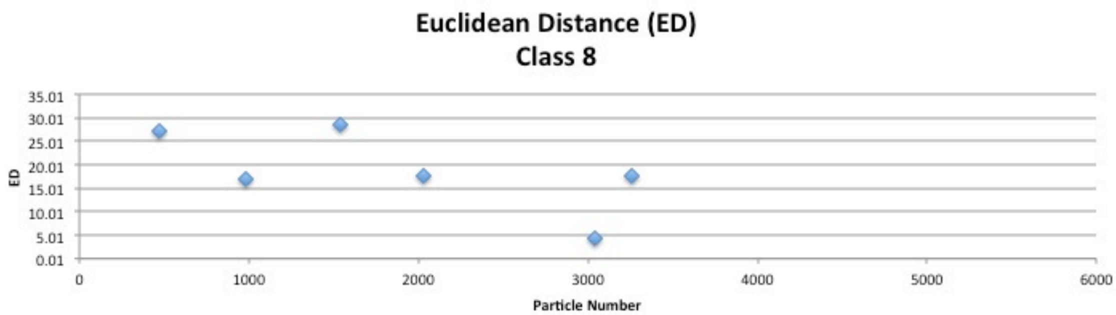

Figure 5-419: Euclidean Distance Class 8

Class 9 of Burkina Laterite 63 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Laterite 63 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Laterite 63 is composed of the total Calcium and Manganese greater than 90%. There are no particles in this class.

Class 12 of Burkina Laterite 63 is composed of the total Calcium and Phosphorus greater than 90%. There is a total of 1 particle in this class (Figure 5-420).

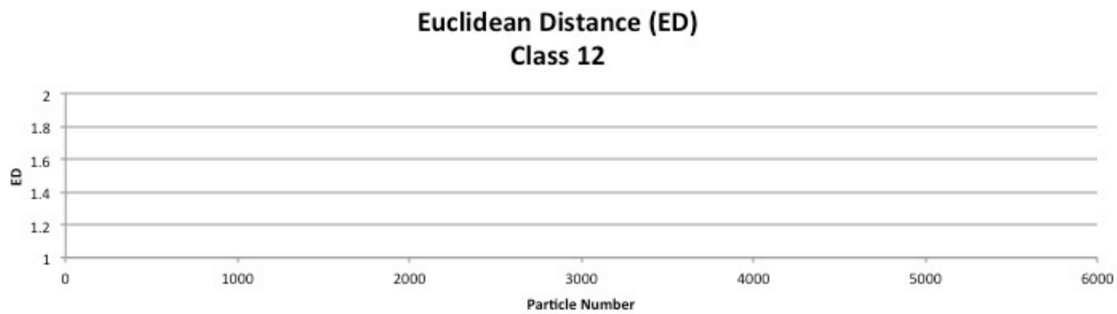

Figure 5-420: Euclidean Distance Class 12

Class 13 of Burkina Laterite 63 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are no particles in this class.

Class 14 of Burkina Laterite 63 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are a total of 2 particles in this class (Figure 5-421).

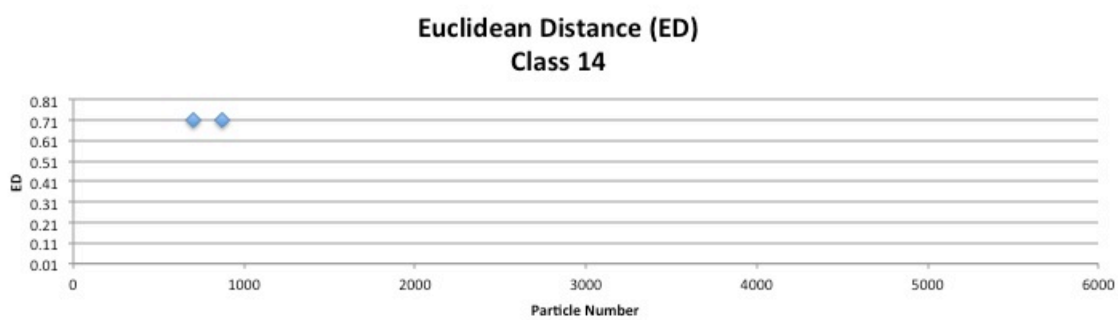

Figure 5-421: Euclidean Distance Class 14

Class 15 of Burkina Laterite 63 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Laterite 63 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 633 particles in this class (Figure 5-422).

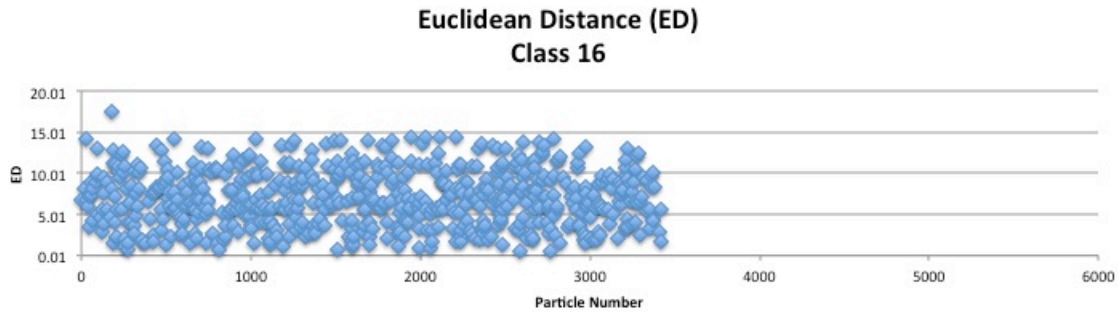

Figure 5-422: Euclidean Distance Class 16

Class 17 of Burkina Laterite 63 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 3 particles in this class (Figure 5-423).

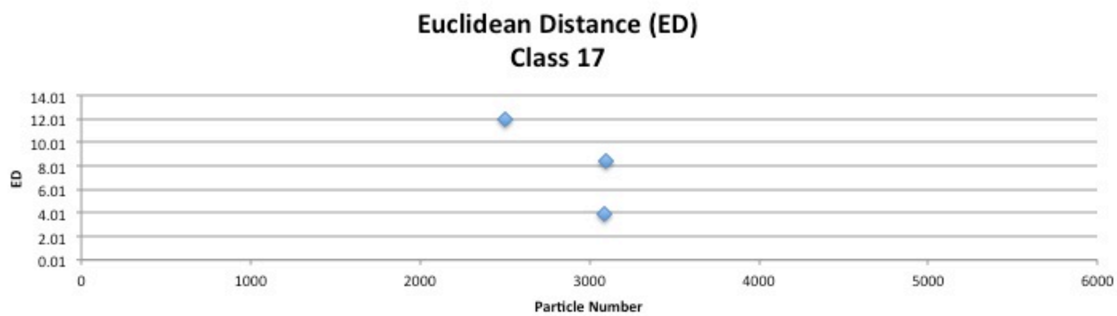

Figure 5-423: Euclidean Distance Class 17

Class 18 of Burkina Laterite 63 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 2 particles in this class (Figure 5-424).

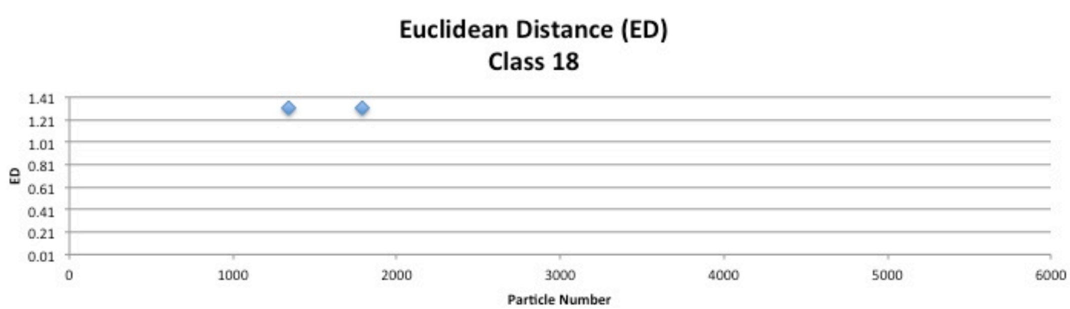

Figure 5-424: Euclidean Distance Class 18

Class 19 of Burkina Laterite 63 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are no particles in this class.

Class 20 of Burkina Laterite 63 is composed of Potassium between 4% and 30#, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 24 particles in this class (Figure 5-425).

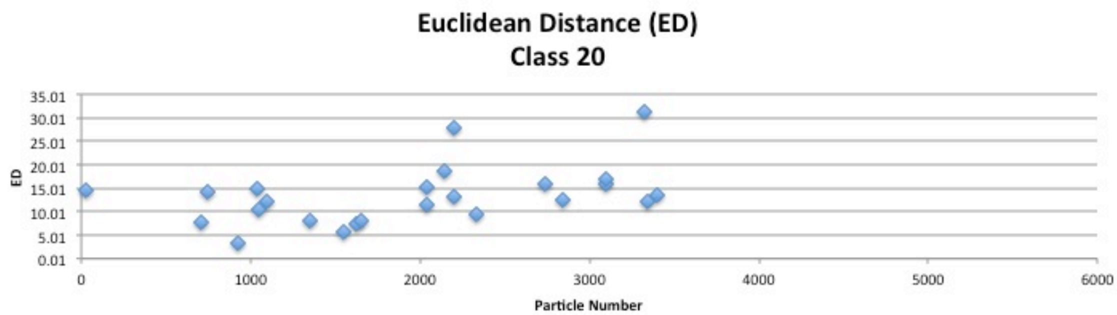

Figure 5-425: Euclidean Distance Class 20

Class 21 of Burkina Laterite 63 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 28 particles in this class (Figure 5-426).

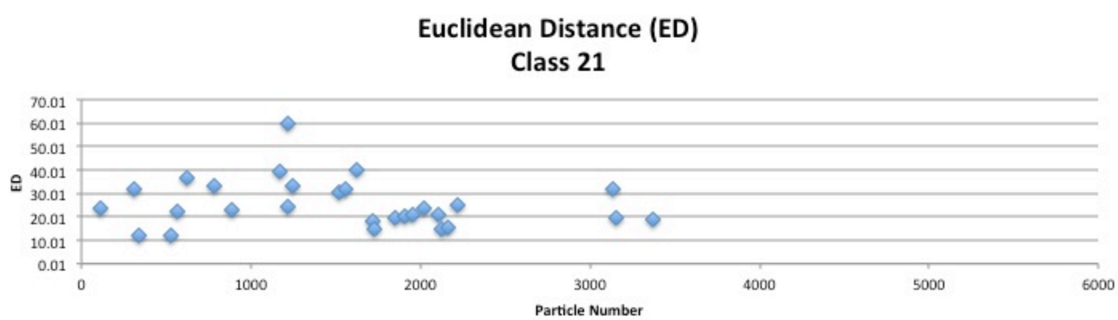

Figure 5-426: Euclidean Distance Class 21

Class 22 of Burkina Laterite 63 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 10 particles in this class (Figure 5-427).

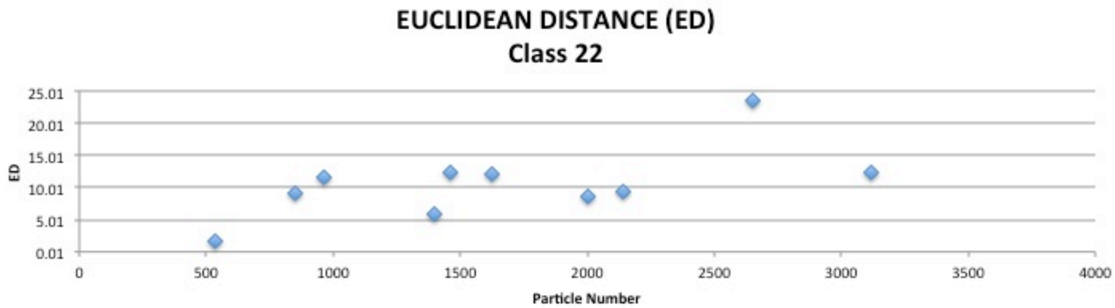

Figure 5-427: Euclidean Distance Class 22

Class 23 of Burkina Laterite 63 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 29 particles in this class (Figure 5-428).

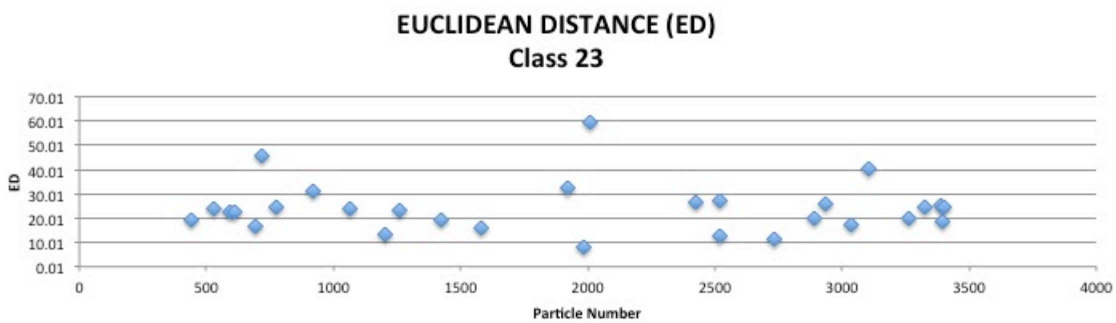

Figure 5-428: Euclidean Distance Class 23

Class 24 of Burkina Laterite 63 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 316 particles in this class (Figure 5-429).

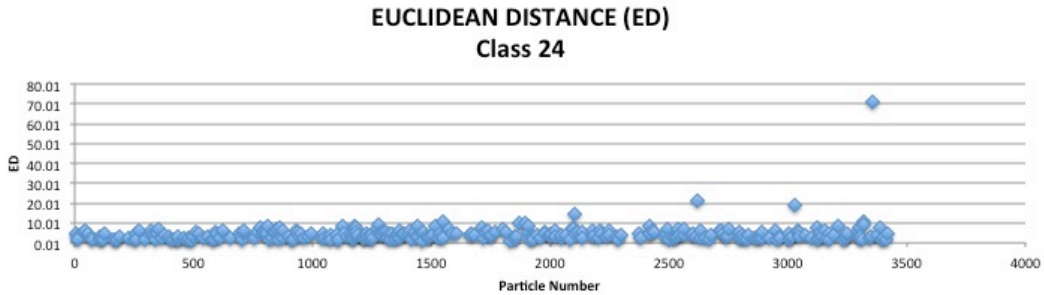

Figure 5-429: Euclidean Distance Class 24

Class 25 of Burkina Laterite 63 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 465 particles in this class (Figure 5-430).

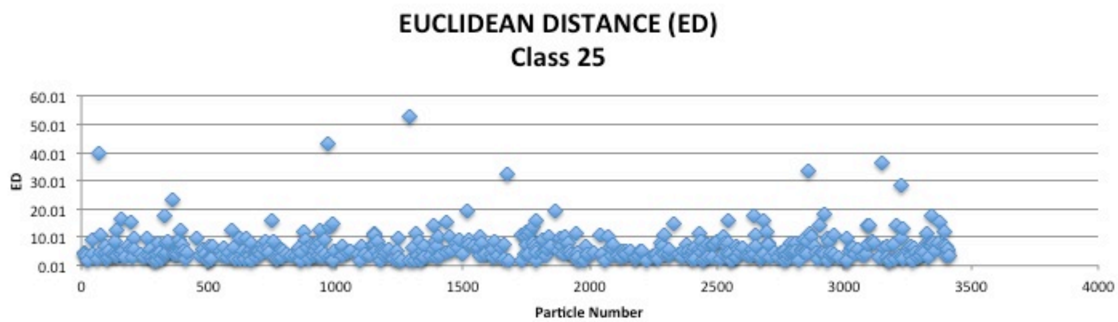

Figure 5-430: Euclidean Distance Class 25

Class 26 of Burkina Laterite 63 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are no particles in this class.

Class 27 of Burkina Laterite 63 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 595 particles in this class (Figure 5-431).

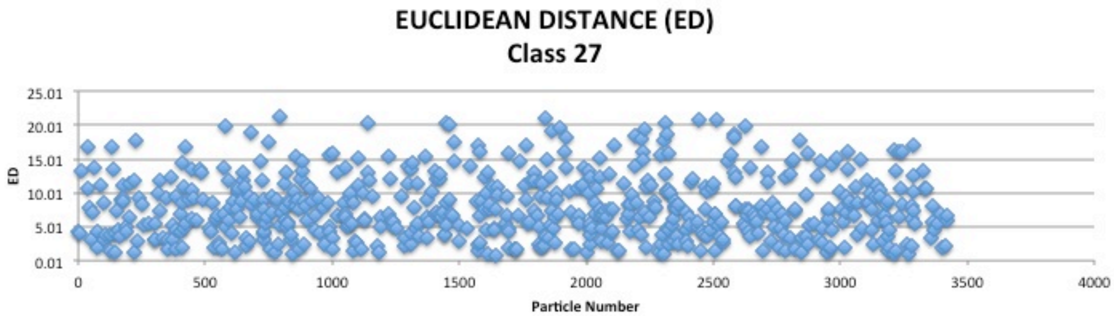

Figure 5-431: Euclidean Distance Class 27

Class 28 of Burkina Laterite 63 is composed of Aluminum less than 1%. There are a total of 5 particles in this class (Figure 5-432).

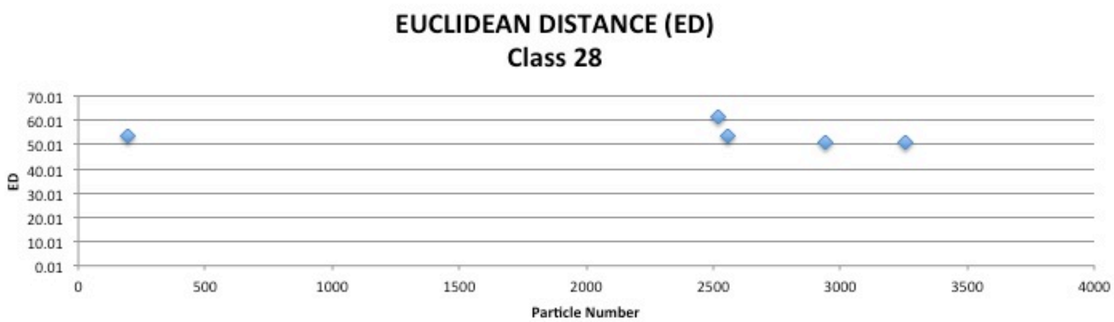

Figure 5-432: Euclidean Distance Class 28

Burkina Laterite Summary

Laterites are formed when minerals are leached from the parent sedimentary rocks that underlie the area. The most commonly leached elements consist of sodium, potassium, calcium and magnesium. This leaves more insoluble ions such as iron and aluminum to form the laterites. It is to be expected that the Burkina Laterites will be dominated by these two elements along with trace amounts of titanium, manganese and zircon.

The average number of particles in each class for all of the Burkina Laterite samples gives a total class average of 4710.22 particles, which constitutes 100% of the sample (Table 5-36). Class 16 has the highest average number of particles with 25.62% or 1206.78 particles

(Figure 5-433). The most abundant element within this class is Iron (Fe>40%, with the total Iron and Calcium totaling greater than 75%). This class is consistent with the formation of laterites and only contains trace amounts of Calcium due to the leaching process during the creation of the laterites. Class 27 comes in as the second largest average particle class with 14.18% and 668.00 particles (Figure 5-434. The elements with the largest abundance are Silica (20%<Si<60%) and Aluminum (40%<Al<60%). Due to the resistance to erosion, the silica particles are still present, but in small quantities. The Aluminum dominates most of these samples, which is consistent with laterites. Class 25 is the third largest average particle class, with 6.96% and 327.78 particles (Figure 5-435). The elements with the largest abundance are Silica (20%<Si<35%) and Aluminum (20%<Al<35%). While this class is dominated by the Silica and Aluminum, it is still in moderate amounts due to the leaching process of laterites.

Table 5-36: Class Average-Numerical Percentage

Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
83.67	205.11	64.22	3.89	0.78	25.89	49.89	20.56
1.78%	4.35%	1.36%	0.08%	0.02%	0.55%	1.06%	0.44%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.89	0.67	90.89	3.22	9.78	3.00	0.00	1206.78
0.02%	0.01%	1.93%	0.07%	0.21%	0.06%	0.00%	25.62%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
10.56	19.33	50.11	121.56	104.44	184.56	54.11	271.44
0.22%	0.41%	1.06%	2.58%	2.22%	3.92%	1.15%	5.76%
Class 25	Class 26	Class 27	Class 28	Class 29		Total	
327.78	97.67	668.00	302.44	729.00		4710.22	
6.96%	2.07%	14.18%	6.42%	15.48%		100.00%	

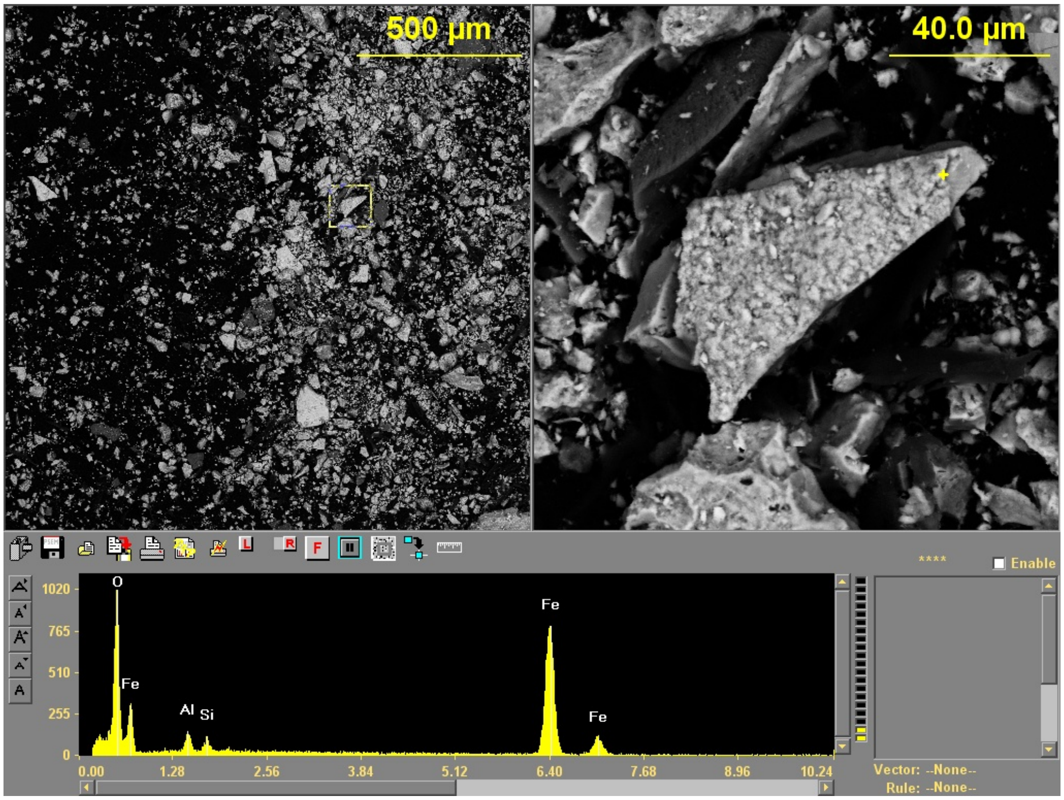

Figure 5-433: Burkina Laterite Class 16 composed of large amounts of Fe.

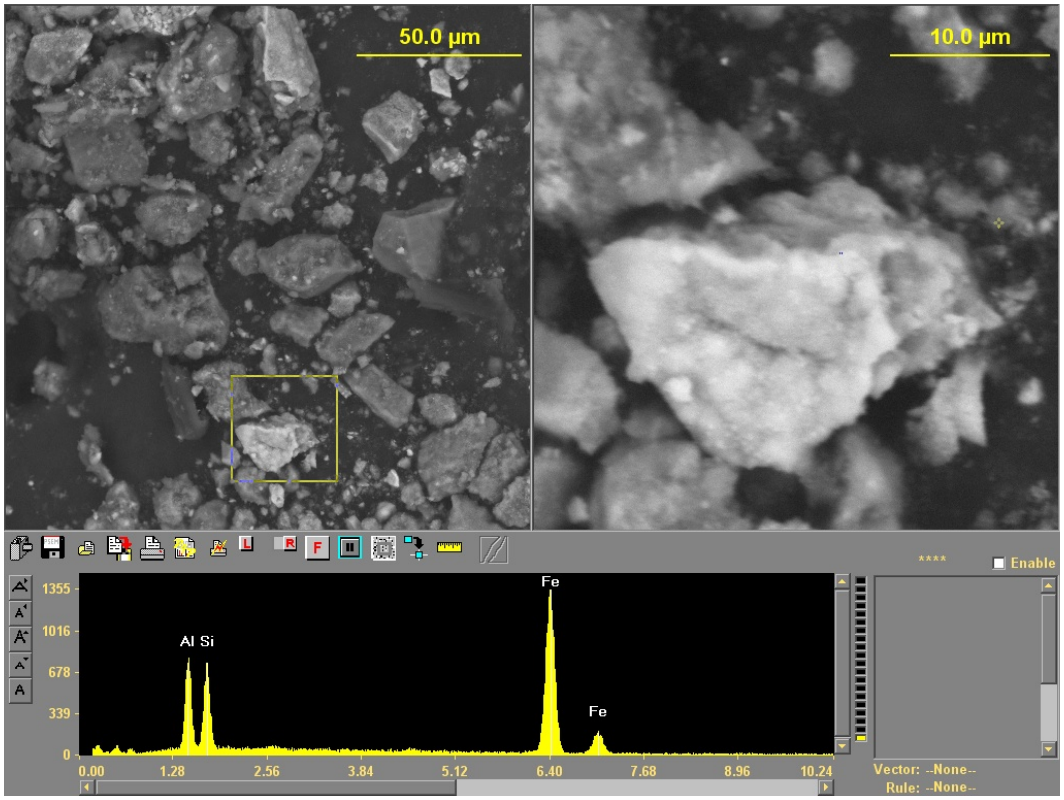

Figure 5-434: Class 27 showing Al, Si, Fe

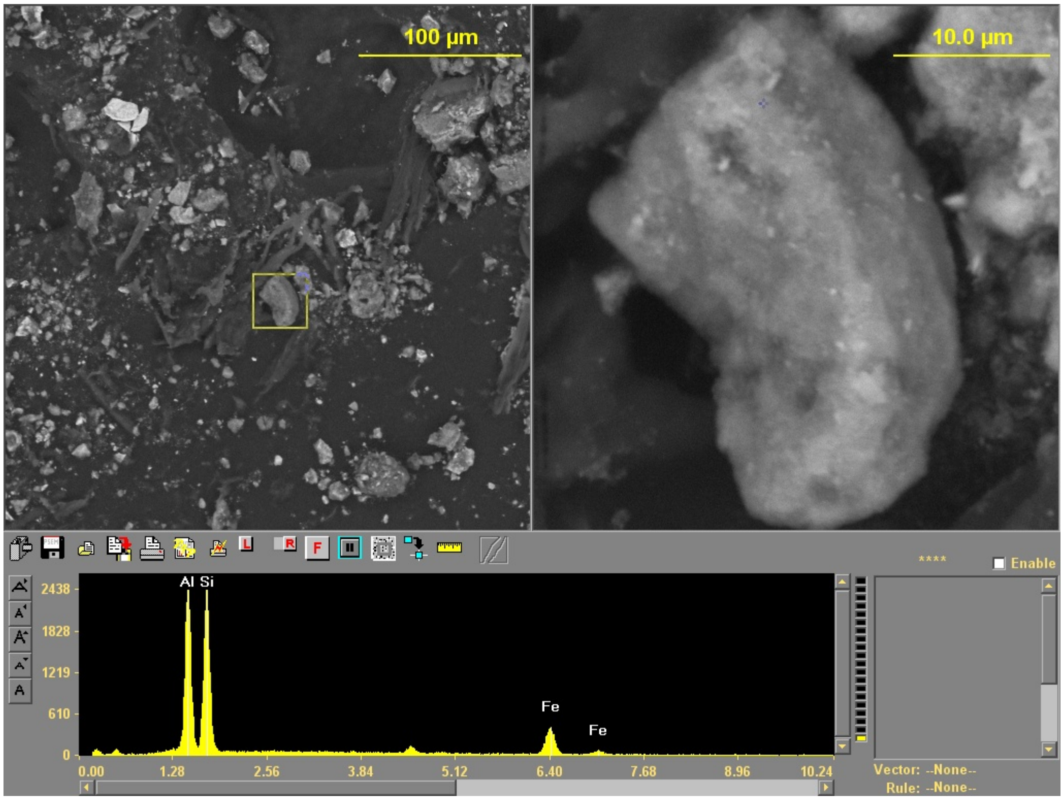

Figure 5-435: Class 25 showing Al and Si.

The average volume of particles in each class for all of the Burkina Laterite samples gives a total class volume average of 131700.95 µm^3, which constitutes 100% of the sample (Table 5-37). Class 16 has the highest volume of particles with 23.45% or a volume of 30884.80 µm^3. The most abundant element within this class is Iron (Fe>40%, with the total Iron and Calcium totaling greater than 75%). Class 27 comes in as the second largest average volume class with 15.95% and 21000.30 µm^3 average volume. The elements with the largest abundance are Silica (20%<Si<60%) and Aluminum (40%<Al<60%). Different from the numerical class average, Class 2 is the third largest average volume class with 10.34% and a volume of 13623.57 µm^3. The only element represented in this class is Iron (Si>99%).

Table 5-37: Class Average-Volumetric Percentage

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
5668.24	13623.57	938.18	3.76	0.24	806.67	1249.98	410.54
4.30%	10.34%	0.71%	0.00%	0.00%	0.61%	0.95%	0.31%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
234.97	0.61	895.59	88.60	1319.89	107.75	0.00	30884.80
0.18%	0.00%	0.68%	0.07%	1.00%	0.08%	0.00%	23.45%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
672.39	561.71	996.38	3391.98	2771.26	6493.70	1258.27	6513.01
0.51%	0.43%	0.76%	2.58%	2.10%	4.93%	0.96%	4.95%
Class 25	Class 26	Class 27	Class 28	Class 29		Total	
6822.00	1148.41	21000.30	7370.54	16467.61		131700.95	
5.18%	0.87%	15.95%	5.60%	12.50%		100.00%	

Comparing the average numerical percentages, Class 16, 27, and 25, and volumetric average percentages, Class 16, 27, and 2, the three highest classes represent 46.76% of the numerical value and 49.74% for the volumetric value for all the Burkina Laterite samples. The difference in the percentage between number of particles and volume of particle of the three highest classes is 2.98%. The third highest class for each average sample causes the small difference. Class 25 is characterized by high Silica and Aluminum, while class 2 is characterized by high Iron. By looking at the other high-class values, the Iron content is determined to be the most abundant element in the Burkina Laterite samples. The difference in the three highest element classes is caused by the average volume of the Iron particles being larger than the average volume of Silica and Aluminum particles. Regardless of the difference in the third largest element class percentage, Iron dominates the Burkina Laterite samples (Figure 5-436).

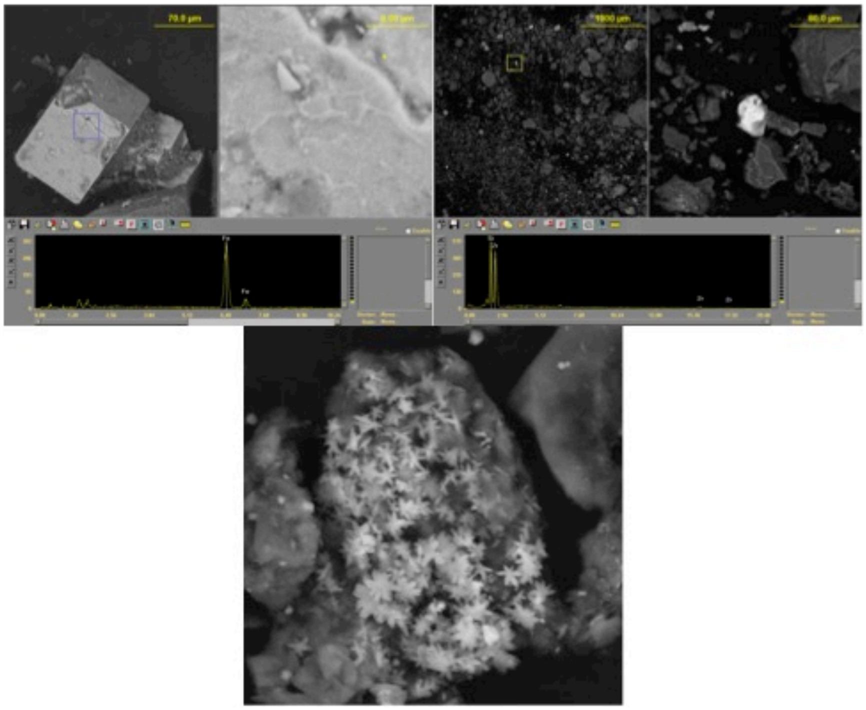

Figure 5-436: Burkina Soil 77 (Top Left) Cubic Fe, (Top Right) High Si Zr, (Bottom) Snowflake Fe_2O_3.

A notable feature to recognize in the Burkina Laterite samples are the additional cluster of particles that is created from the unclassified particles in class 29. Most of the unclassified elements are contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-437).

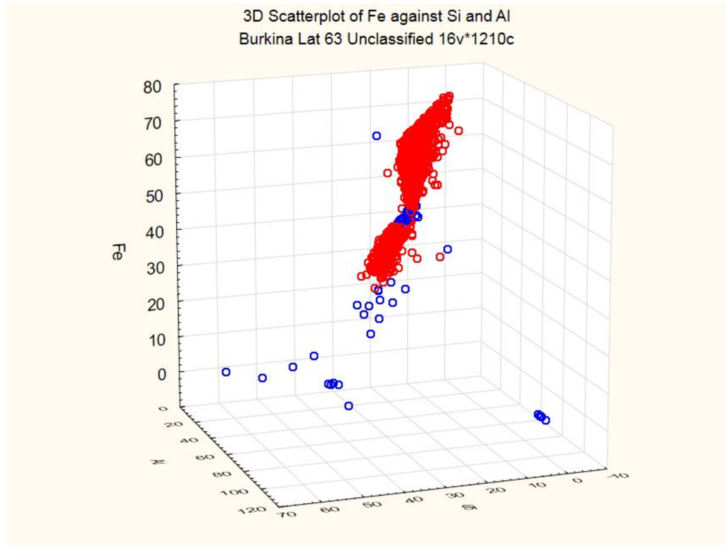

Figure 5-437: Scatterplot of Burkina Laterite 63 unclassified elements Al, Si and Fe, showing a cluster of particles.

The Euclidean distance for the all the Burkina Laterite samples gives us an idea of the distribution of the particles and distance from the centroid of the cluster. While the Euclidean distance values themselves are arbitrary, the pattern of distribution is important for identification of sample types. Each sample class will have a unique distribution of particles around the centroid of the cluster, which can be a valuable tool for identification of samples. Some of the more notable Euclidean distance distribution tables are the Iron-rich element classes.

Along with chemistry and Euclidean distance, the average particle size of each elemental class was identified (Table 5-38). The particles were separated into 4 size classes, with size 1 having particles with a diameter between 0-2.49µm, class 2 having a diameter between 2.5-4.9µm, class three having a diameter between 5-10µm, and class 4 having a diameter greater than 10µm. Size class 1 included 62.15% of all Bodele particles, size class 2 included 27.39%, size class 3 contains 9.71%, and class 4 included 0.75%. This analysis showed an abundance of small particle sizes (Class 1) with no correlation between chemistry of the particles and size of the particles.

Table 5-38: Burkina Laterite Particle Size Classes by Elemental Class.

Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
49.57%	0.00%	54.05%	21.69%	22.22%	78.48%	59.99%
27.16%	88.89%	36.02%	0.53%	0.00%	18.50%	23.36%
11.56%	0.00%	9.89%	0.00%	0.00%	2.58%	5.23%
0.61%	0.00%	0.05%	0.00%	0.00%	0.44%	0.31%
Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	Class 14
56.66%	5.56%	11.11%	63.54%	56.67%	40.50%	23.46%
21.33%	1.39%	0.00%	17.78%	17.41%	31.92%	15.93%
21.64%	2.78%	0.00%	7.48%	14.81%	3.50%	16.17%
0.37%	1.39%	0.00%	0.08%	0.00%	1.85%	0.00%
Class 15	Class 16	Class 17	Class 18	Class 19	Class 20	Class 21
0.00%	83.87%	43.46%	66.04%	57.76%	62.72%	66.03%
0.00%	12.85%	22.38%	27.81%	17.79%	29.08%	25.93%
0.00%	3.05%	22.76%	5.36%	12.35%	6.35%	7.57%
0.00%	0.23%	0.30%	0.79%	0.99%	1.86%	0.48%
Class 22	Class 23	Class 24	Class 25	Class 26	Class 27	Class 28
60.22%	70.44%	75.54%	73.11%	41.47%	67.07%	63.07%
27.55%	23.64%	18.98%	22.36%	26.71%	25.13%	25.22%
10.34%	5.83%	5.04%	4.17%	20.70%	7.04%	8.48%
1.89%	0.08%	0.44%	0.36%	0.00%	0.75%	3.23%

Total Class %

Class 1	Class 2	Class 3	Class 4
62.15%	27.39%	9.71%	0.75%

Burkina Soil 70

Numerical and Volumetric Analysis

Burkina Soil 70, which is located in the same location as Burkina Laterite 57, at 12 43.603’ N, 1 37.670’ E and has been separated into 29 elemental classes (Figure 5-438). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-39).

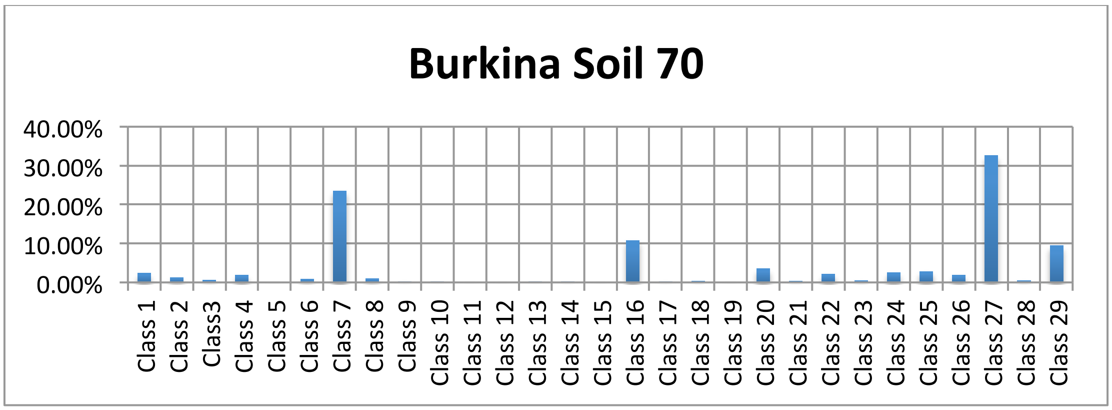

Figure 5-438: Numerical percentages of each class.

Table 5-39: Numerical percentage and number of particles per class. Three highest classes are highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
76	42	20	60	0	29	763	31
2.35%	1.30%	0.62%	1.85%	0.00%	0.90%	23.55%	0.96%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
9	1	0	0	2	8	0	350
0.28%	0.03%	0.00%	0.00%	0.06%	0.25%	0.00%	10.80%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
9	11	0	114	12	71	17	83
0.28%	0.34%	0.00%	3.52%	0.37%	2.19%	0.52%	2.56%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
92	60	1057	17	306	3240		
2.84%	1.85%	32.62%	0.52%	9.44%	100.00%		

Table 5-39 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 7, 16, and 27. Class 7 is composed of less than 1% Iron, between 30% and 50% Silica and between 35% and 60% Aluminum. Class 16 has Iron greater than 60% and the combination of Iron and Calcium totaling more than 75%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 66.97% of the entire sample and contains a total of 1534 particles. Class 29 represents the "unclassified" particles and contains only 9.44% of the entire sample.

The volumetric percentage of Burkina Laterite 70 represents the volume of particles that are represented in each respective elemental class (Figure 5-439). Table 5-40 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 22, 25, and 27. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 25 has Potassium and Calcium less 1%, Aluminum between 20% and 35% and Silica between 18% and 40%. Class 27 is represented by Potassium and Calcium less than 1%, between 40% and 60% Aluminum, and 20% to 60% Silica. This represents 81.64% of the entire sample and contains a total volume of 258143.53 μm^3. Class 29 represents the "unclassified" volume of particles and contains 13.44% of the entire sample.

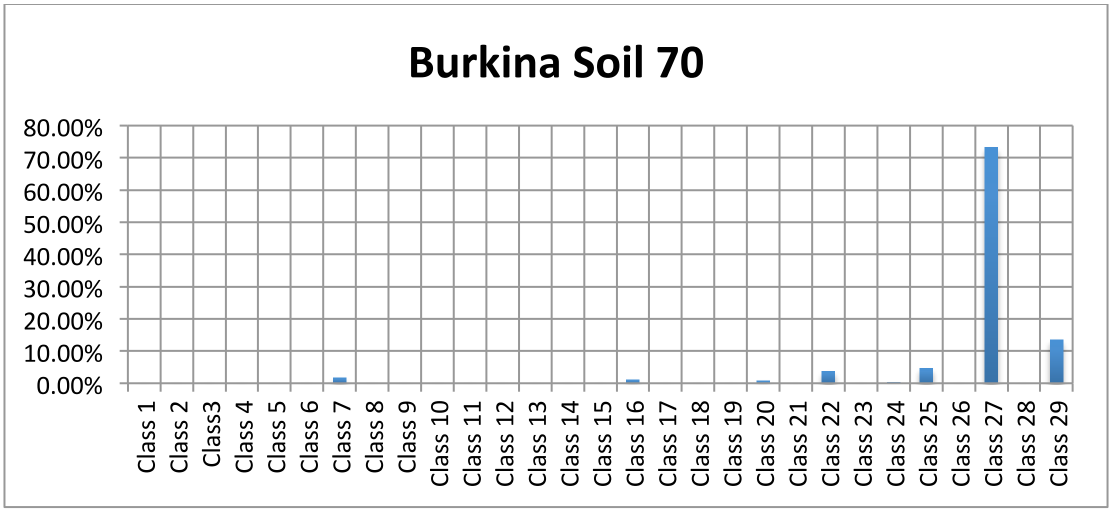

Figure 5-439: Volumetric percentages by class.

Table 5-40: Volumetric percentages and volumes per class. Three highest classes are highlighted.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
136.27	182.07	557.84	603.14	0.00	26.13	5373.77	271.94
0.04%	0.06%	0.18%	0.19%	0.00%	0.01%	1.70%	0.09%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
84.97	0.35	0.00	0.00	0.40	314.23	0.00	3330.80
0.03%	0.00%	0.00%	0.00%	0.00%	0.10%	0.00%	1.05%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
70.20	61.79	0.00	2466.72	375.48	11850.87	175.94	893.15
0.02%	0.02%	0.00%	0.78%	0.12%	3.75%	0.06%	0.28%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
14686.89	614.19	231605.77	15.39	42501.72	316200.03		
4.64%	0.19%	73.25%	0.00%	13.44%	100.00%		

Analysis of class 29 showed a cluster of elements similar to the Burkina Laterites. The highest elements contained within Burkina Soil 70 unclassified are Fe, Si, Al, respectively, and compose 9.44% of the entire sample particles. Most of the unclassified elements are contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-440 and Figure and Figure 5-441). Approximately 85% if the unclassified particles are contained within these two distinct clusters.

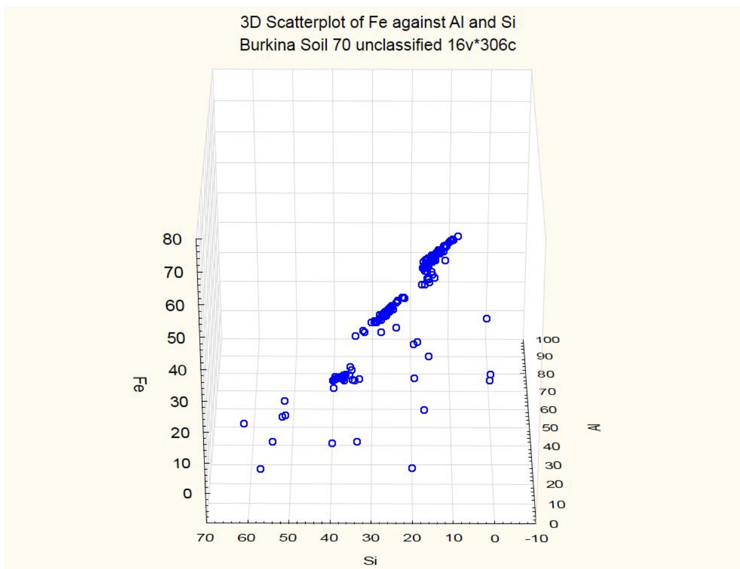

Figure 5-440: Scatterplot of Burkina Soil 70 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 13.44% volume of the particles in the sample.

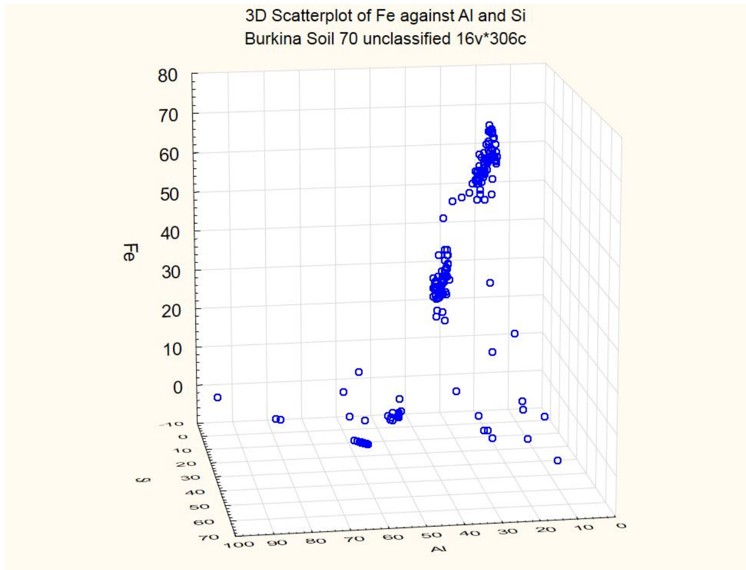

Figure 5-441: Alternate view of Burkina 70 unclassified particles.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Soil 70 is composed of greater than 99% Silica. There are a total of 76 particles in this class (Figure 5-442).

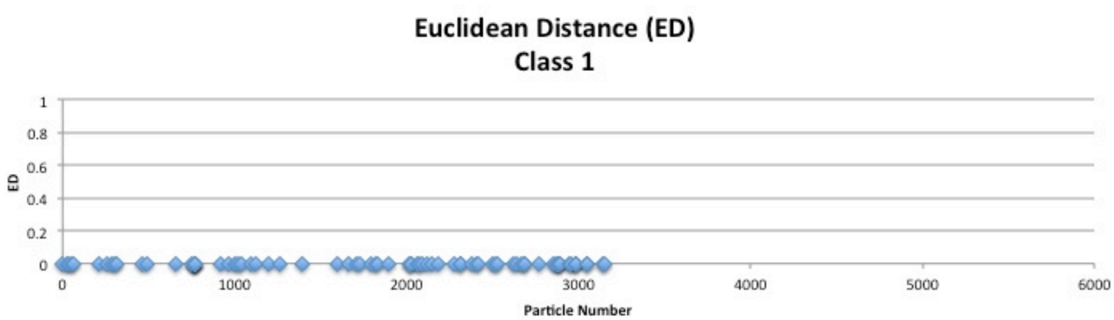

Figure 5-442: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 42 particles in this class (Figure 5-443).

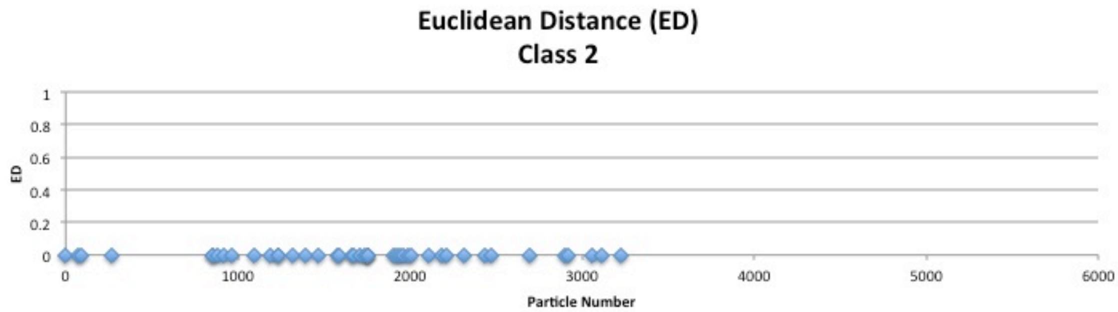

Figure 5-443: Euclidean Distance Class 2

Class 3 of Burkina Soil 70 is composed of greater than 99% Calcium. There are a total of 20 particles in this class (Figure 5-444).

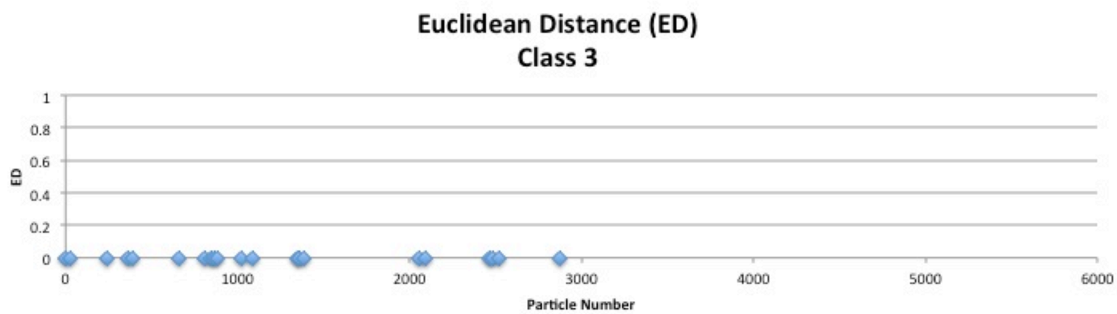

Figure 5-444: Euclidean Distance Class 3

Class 4 of Burkina Soil 70 is composed of Titanium greater than 55% and Lead less than 5%. There are 60 particles in this class (Figure 5-445).

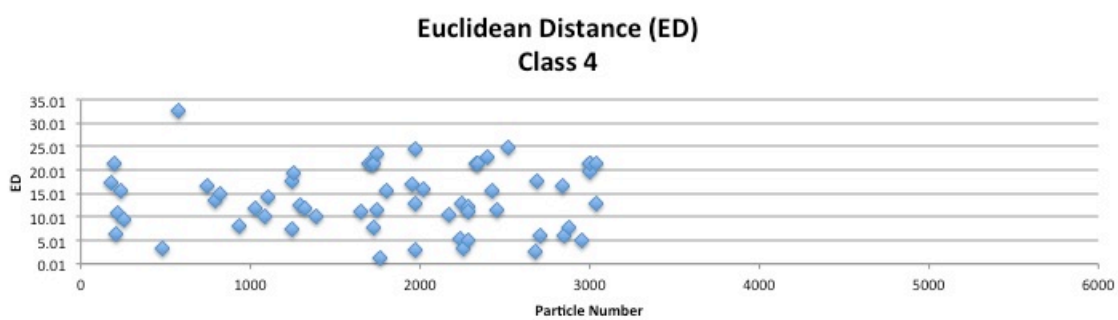

Figure 5-445: Euclidean Distance Class 4

Class 5 of Burkina Soil 70 is composed of Iron and Sulfur totaling greater than 95% with

Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Burkina Soil 70 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 29 particles in this class (Figure 5-446).

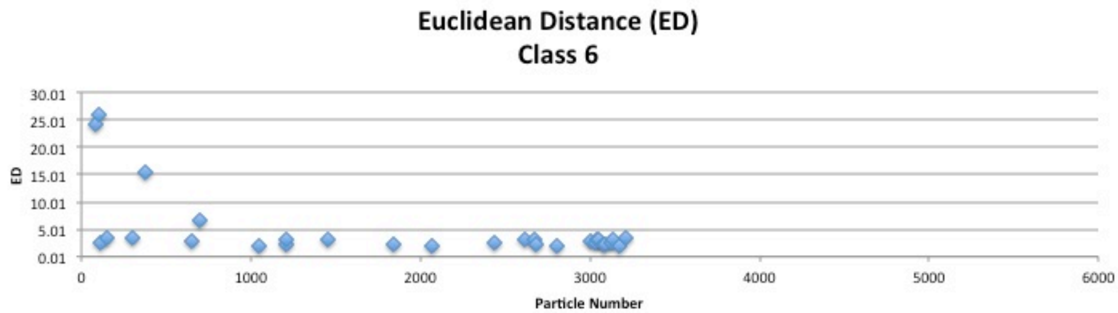

Figure 5-446: Euclidean Distance Class 6

Class 7 of Burkina Soil 70 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 763 particles in this class (Figure 5-447).

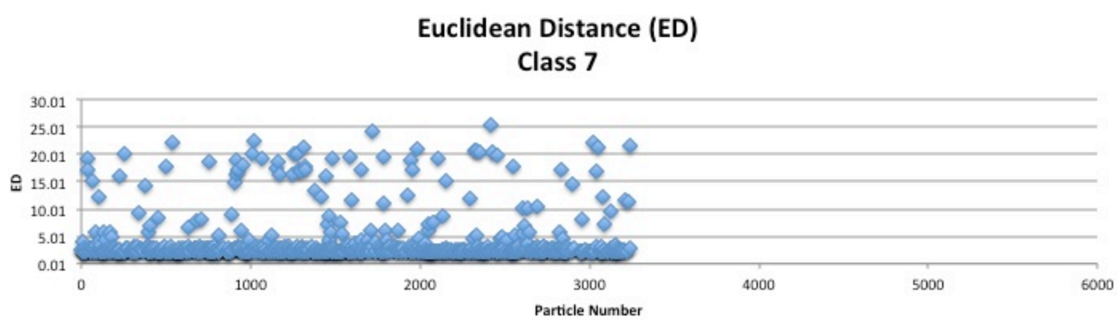

Figure 5-447: Euclidean Distance Class 7

Class 8 of Burkina Soil 70 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 31 particles in this class (Figure 5-448).

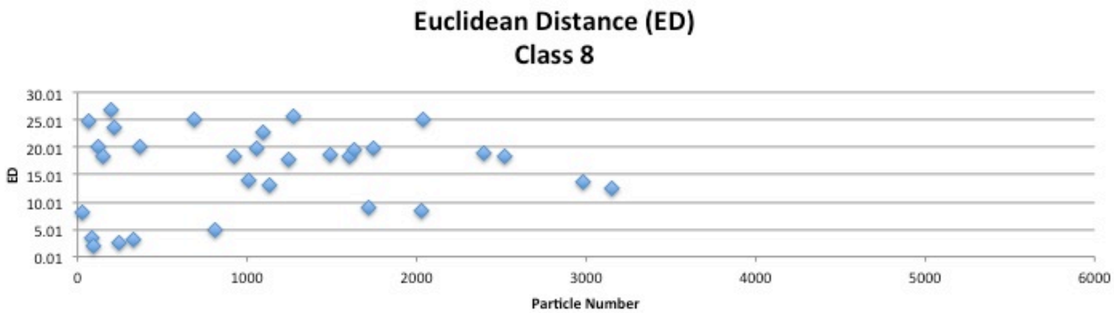

Figure 5-448: Euclidean Distance Class 8

Class 9 of Burkina Soil 70 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 9 particles in this class (Figure 5-449).

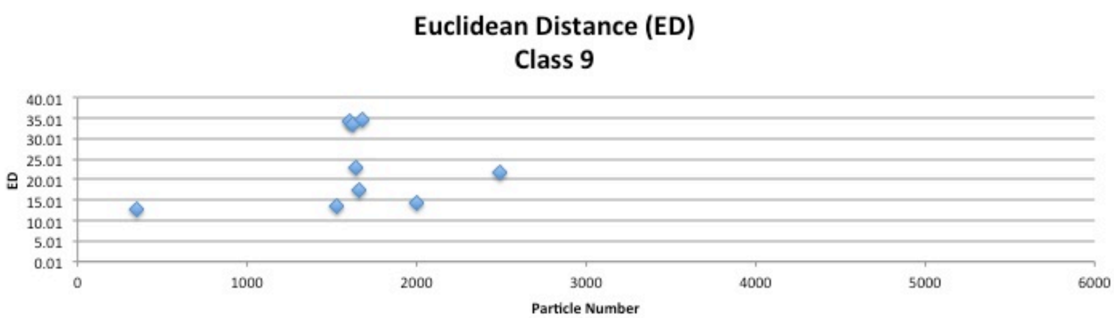

Figure 5-449: Euclidean Distance Class 9

Class 10 of Burkina Soil 70 is composed of Calcium greater than 80% and Lead less than 5%. There is 1 particle in this class (Figure 5-450).

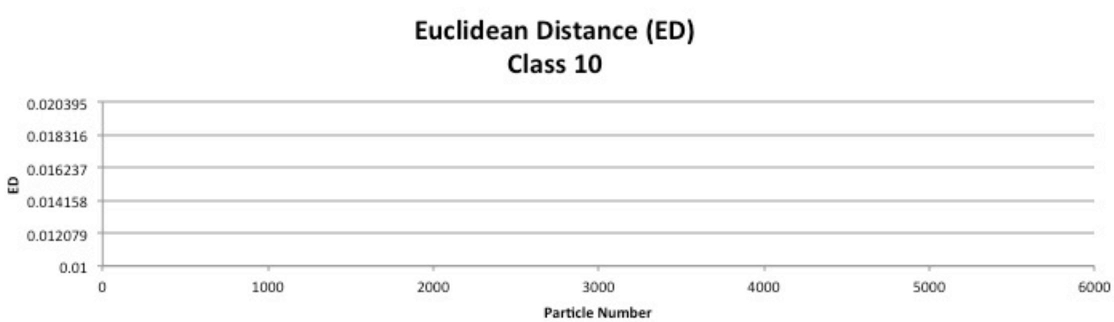

Figure 5-450: Euclidean Distance Class 10

Class 11 of Burkina Soil 70 is composed of the total Calcium and Manganese greater than 90%. There are no particles in this class.

Class 12 of Burkina Soil is composed of the total Calcium and Phosphorus greater than 90%. There are no particles in this class.

Class 13 of Burkina Soil 70 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 2 particles in this class (Figure 5-451).

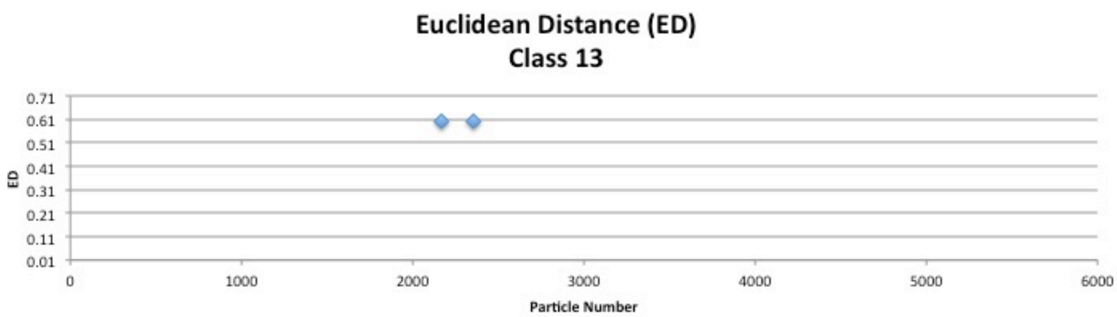

Figure 5-451: Euclidean Distance Class 13

Class 14 of Burkina Soil 70 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are a total of 8 particles in this class (Figure 5-452).

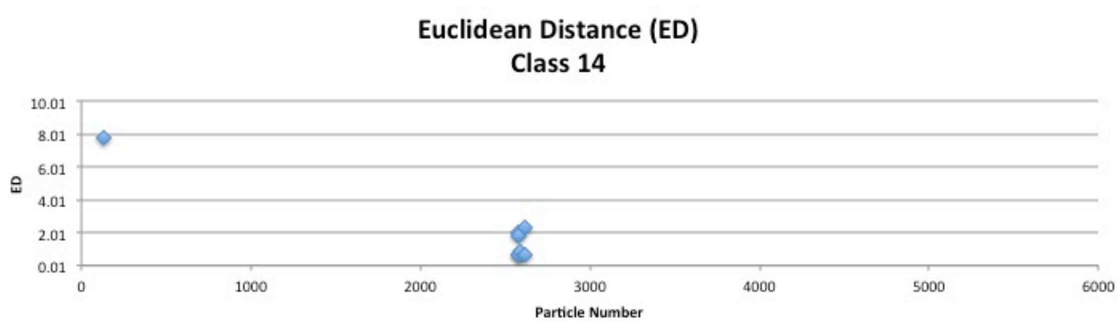

Figure 5-452: Euclidean Distance Class 14

Class 15 of Burkina Soil 70 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Soil 70 is composed of Iron greater than 40% and the total Iron and

Calcium greater than 75%. There are 350 particles in this class (Figure 5-453).

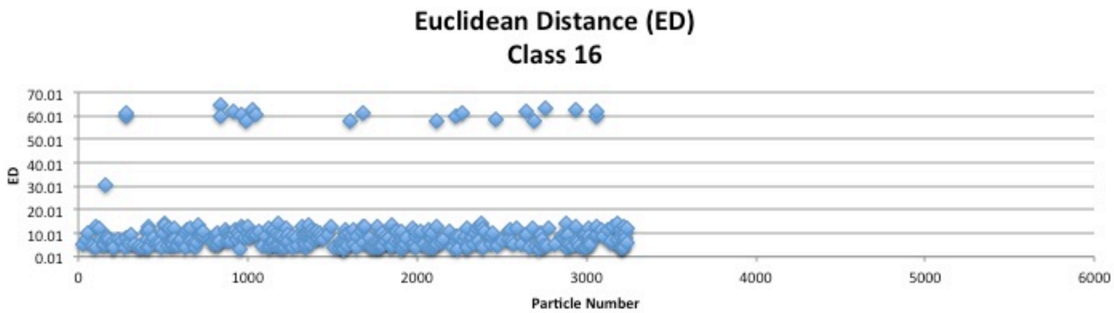

Figure 5-453: Euclidean Distance Class 16

Class 17 of Burkina Soil 70 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 9 particles in this class (Figure 5-454).

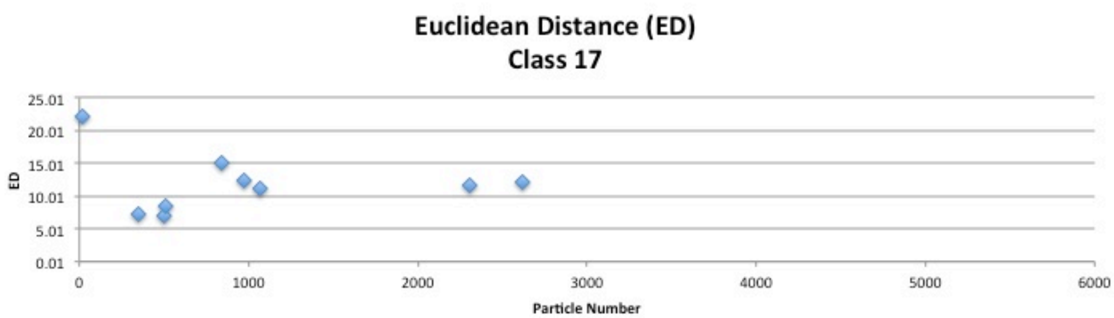

Figure 5-454: Euclidean Distance Class 17

Class 18 of Burkina Soil 70 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 11 particles in this class (Figure 5-455).

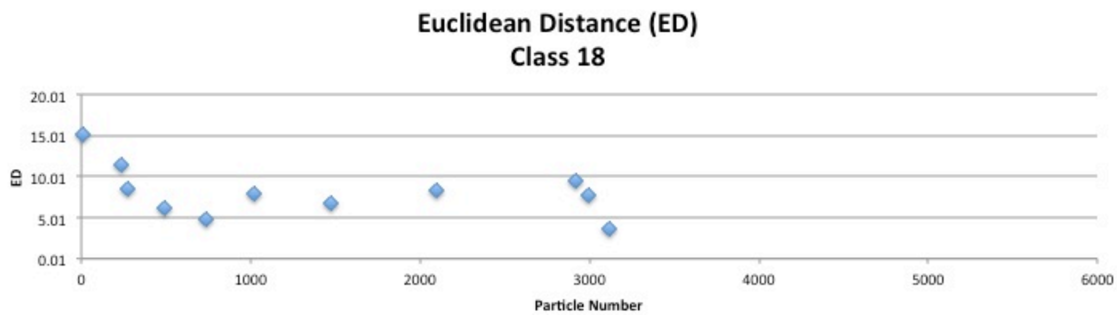

Figure 5-455: Euclidean Distance Class 18

Class 19 of Burkina Soil 70 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are no particles in this class.

Class 20 of Burkina Soil 70 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 114 particles in this class (Figure 5-456).

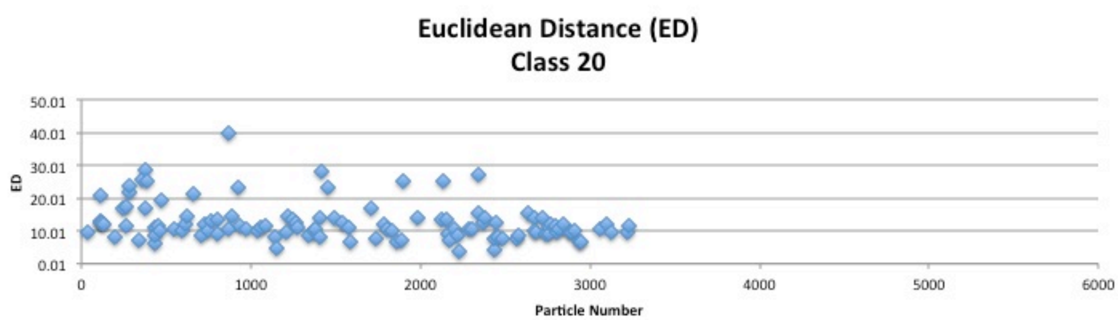

Figure 5-456: Euclidean Distance Class 20

Class 21 of Burkina Soil 70 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 12 particles in this class (Figure 5-457).

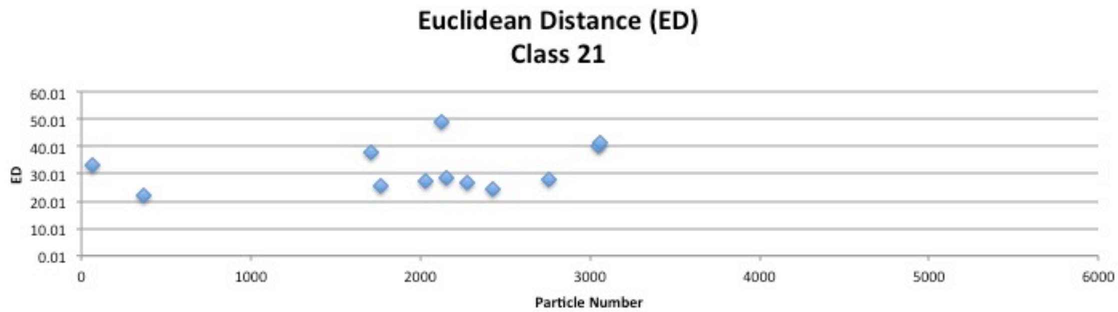

Figure 5-457: Euclidean Distance Class 21

Class 22 of Burkina Soil 70 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 71 particles in this class (Figure 5-458).

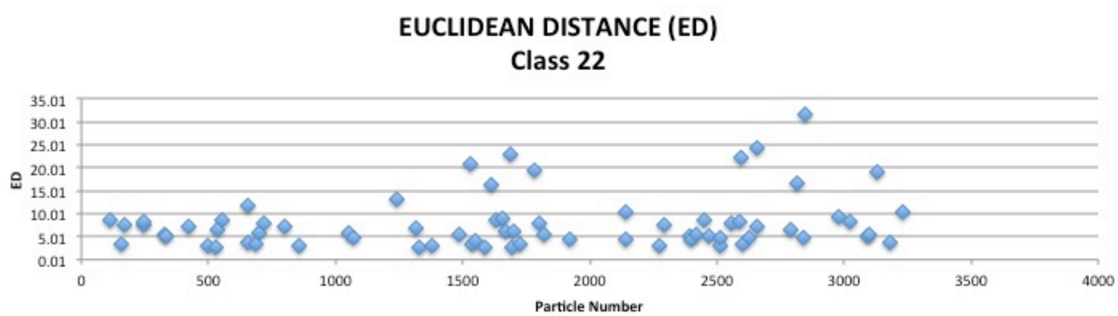

Figure 5-458: Euclidean Distance Class 22

Class 23 of Burkina Soil 70 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 17 particles in this class (Figure 5-459).

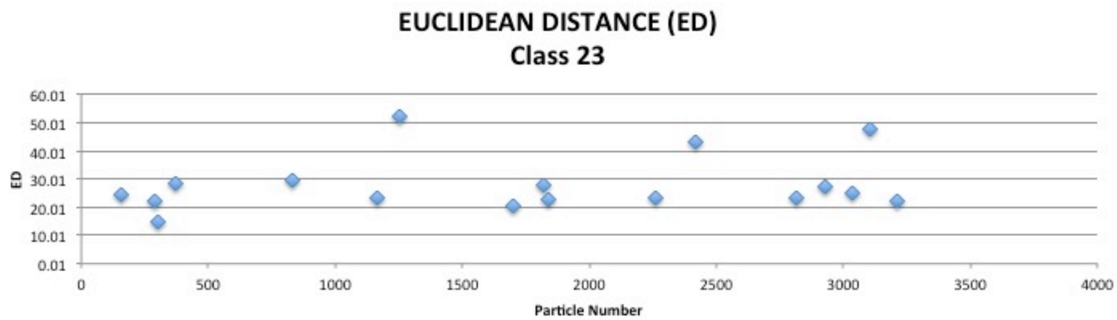

Figure 5-459: Euclidean Distance Class 23

Class 24 of Burkina Soil 70 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 83 particles in this class (Figure 5-460).

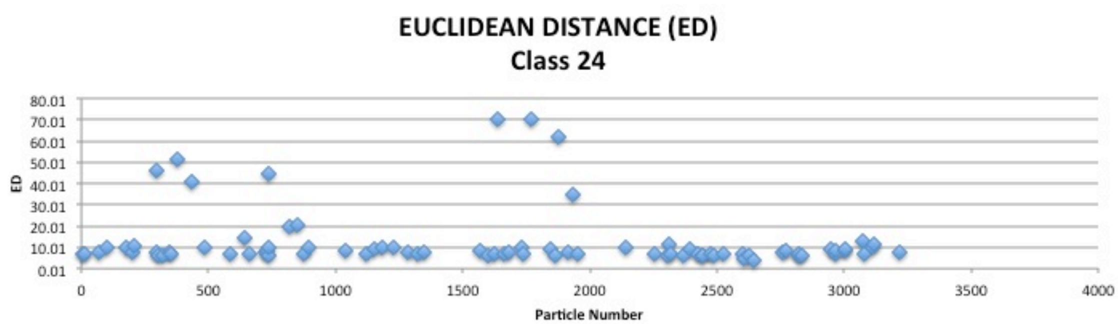

Figure 5-460: Euclidean Distance Class 24

Class 25 of Burkina Soil 70 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 92 particles in this class (Figure 5-461).

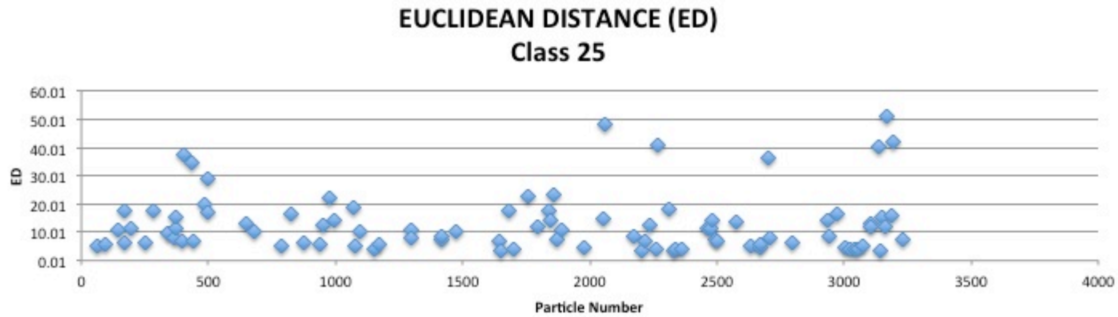

Figure 5-461: Euclidean Distance Class 25

Class 26 of Burkina Soil 70 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 60 particles in this class (Figure 5-462).

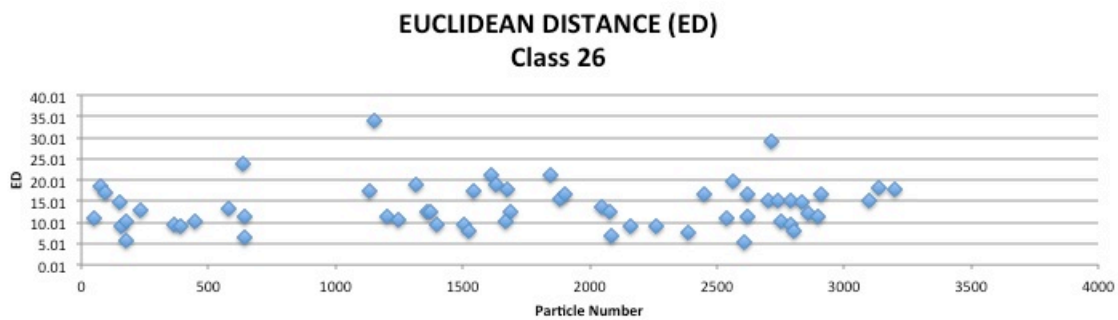

Figure 5-462: Euclidean Distance Class 26

Class 27 of Burkina Soil 70 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 1057 particles in this class (Figure 5-463).

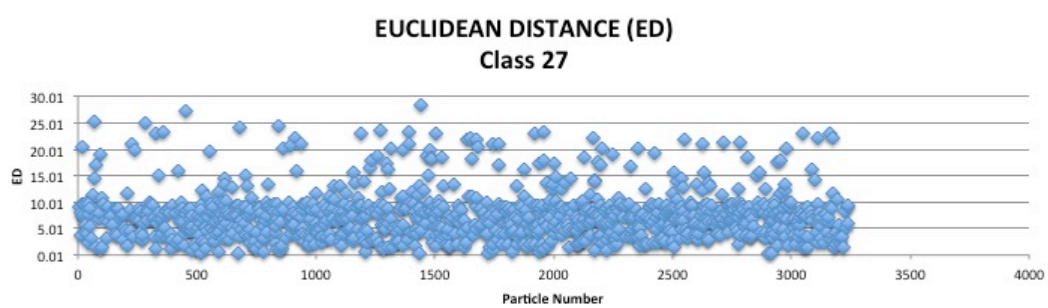

Figure 5-463: Euclidean Distance Class 27

Class 28 of Burkina Soil 70 is composed of Aluminum less than 1%. There are a total of 17 particles in this class (Figure 5-464).

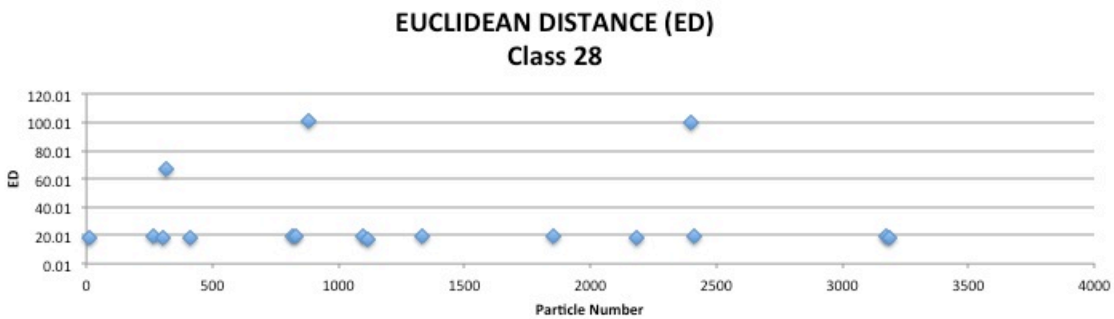

Figure 5-464: Euclidean Distance Class 28

Burkina Soil 71

Numerical and Volumetric Analysis

Burkina Soil 71, which is located in the same location as Burkina Laterite 58, at 12 25.377' N, 1 19.837' E and has been separated into 29 elemental classes (Figure 5-465). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-41).

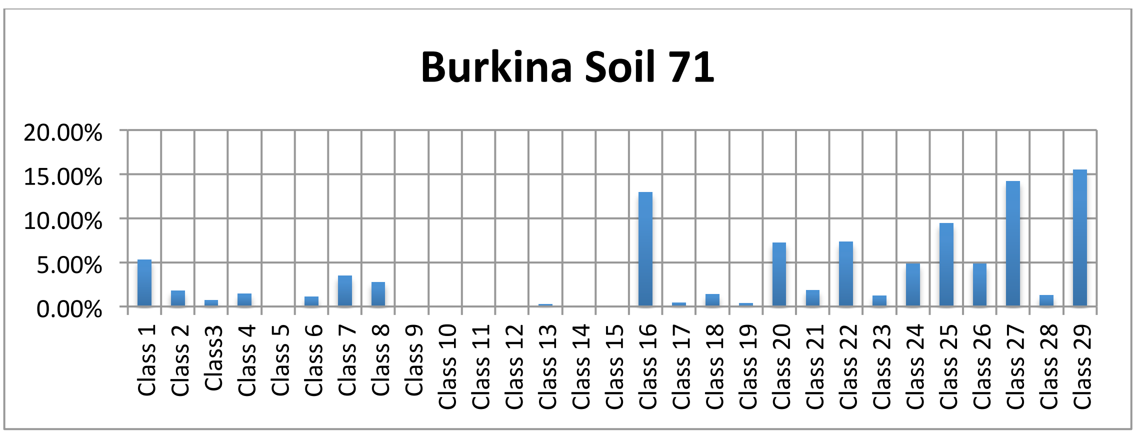

Figure 5-465: Numerical Percentage of classes.

Table 5-41: Numerical percentages and number of particles per class. Highlighted cells are the three highest classes.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
155	52	20	42	2	33	102	80
5.30%	1.78%	0.68%	1.44%	0.07%	1.13%	3.49%	2.74%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
3	3	1	1	8	0	0	378
0.10%	0.10%	0.03%	0.03%	0.27%	0.00%	0.00%	12.92%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
13	40	10	212	54	214	36	142
0.44%	1.37%	0.34%	7.25%	1.85%	7.32%	1.23%	4.85%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
276	141	416	37	454	2925		
9.44%	4.82%	14.22%	1.26%	15.52%	100.00%		

Table 5-41 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 16, 25, and 27. Class 16 is composed of Iron greater than 40%, and the total Iron and Calcium greater than 75%. Class 25 has Potassium and Calcium less 1%, Aluminum between 20% and 35% and Silica between 18% and 40%. Class 27 is represented by Potassium and Calcium less than 1%, between 40% and 60% Aluminum, and 20% to 60% Silica. This represents 36.58% of the entire sample and contains a total of 1070 particles. Class 29 represents the “unclassified” particles and contains only 15.52% of the entire sample.

The volumetric percentage of Burkina Laterite 71 represents the volume of particles that are represented in each respective elemental class (Figure 5-466). Table 5-42 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 1, 22, and 27. Class 1 is composed of greater than 99% Silica. Class 22 has less than 1% Calcium and Potassium, 4% to 20% Aluminum, and greater than 60% Silica. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 62.38% of the entire sample and contains a total volume of 237707.41 μm^3. Class 29 represents the "unclassified" volume of particles and contains 7.26% of the entire sample.

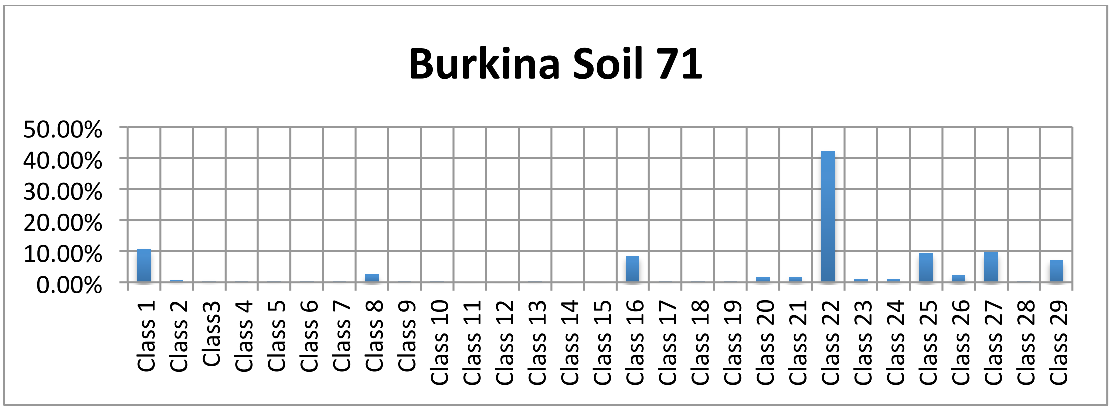

Figure 5-466: Volumetric percentage per class.

Table 5-42: Volumetric percentage and volume per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
40667.23	2137.14	1877.18	221.79	0.15	157.95	1215.99	9729.00
10.67%	0.56%	0.49%	0.06%	0.00%	0.04%	0.32%	2.55%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
303.36	80.74	0.01	0.06	54.93	0.00	0.00	32487.37
0.08%	0.02%	0.00%	0.00%	0.01%	0.00%	0.00%	8.53%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
95.50	1011.58	186.46	5770.08	6765.29	160305.60	4029.47	3741.41
0.03%	0.27%	0.05%	1.51%	1.78%	42.07%	1.06%	0.98%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
36161.20	9053.64	36734.58	608.76	27657.48	381053.96		
9.49%	2.38%	9.64%	0.16%	7.26%	100.00%		

Analysis of class 29 showed a cluster of elements similar to the Burkina Laterites. The highest elements contained within Burkina Soil 71 unclassified are Fe, Si, Al, respectively, and compose a volume of 7.26% of the entire sample particles. Most of the unclassified elements are contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-467 and Figure 5-468). Approximately 90% if the unclassified particles are contained within these two distinct clusters.

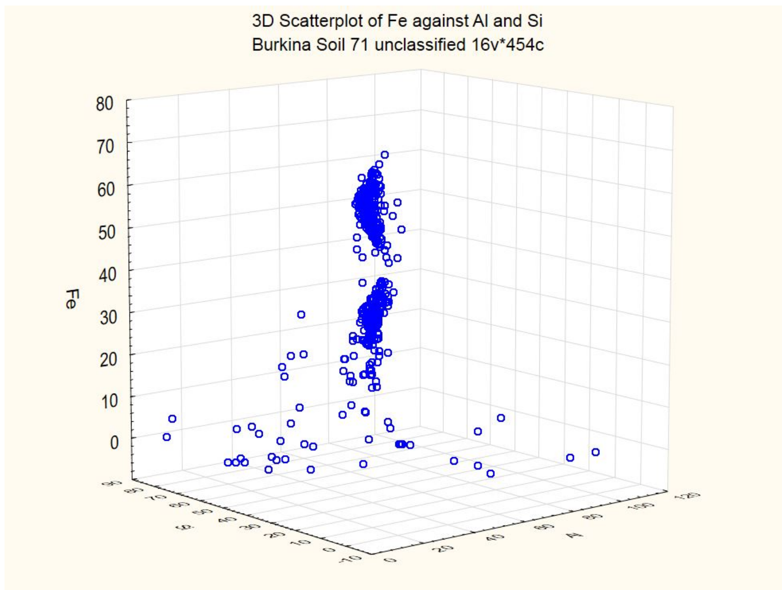

Figure 5-467: Scatterplot of Burkina Soil 71 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 7.26% volume of the particles in the sample.

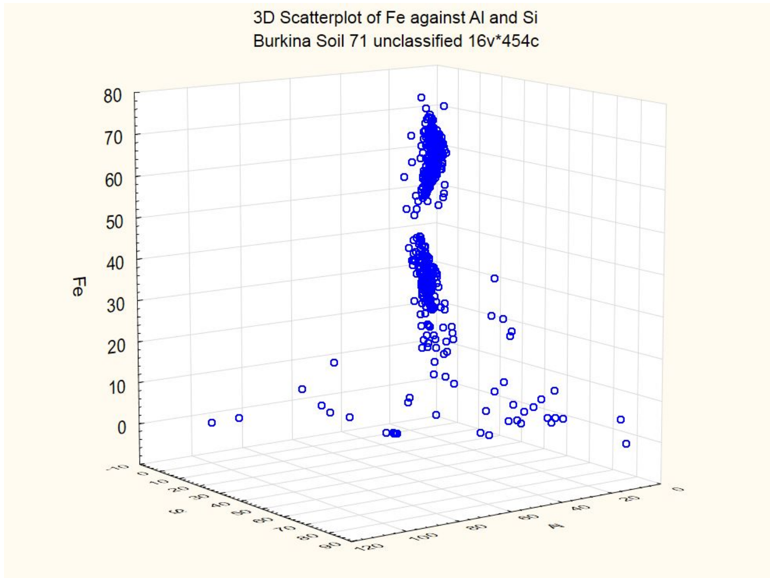

Figure 5-468: Alternate view of unclassified particles for Burkina Soil 71.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Soil 71 is composed of greater than 99% Silica. There are a total of 155 particles in this class (Figure 5-469).

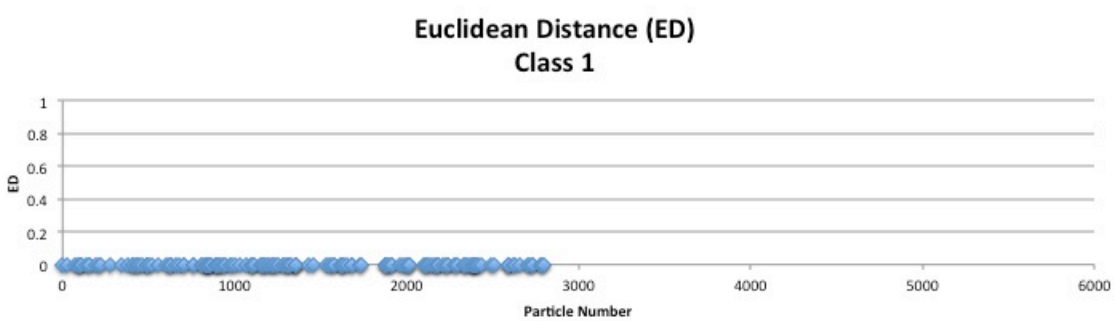

Figure 5-469: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 52 particles in this class (Figure 5-470).

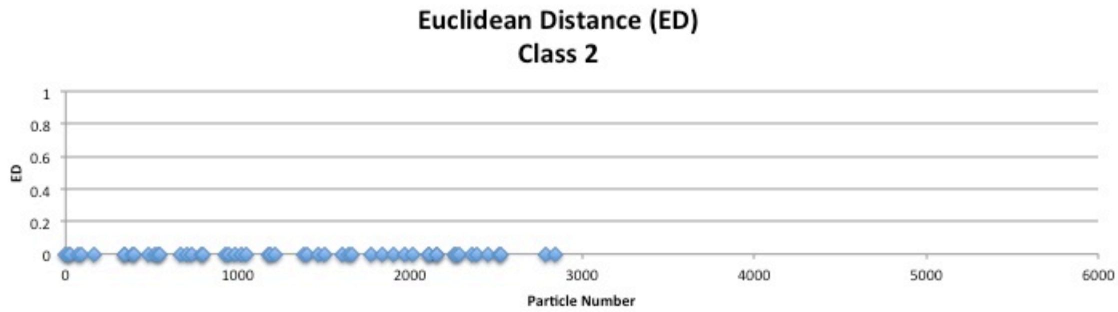

Figure 5-470: Euclidean Distance Class 2

Class 3 of Burkina Soil 71 is composed of greater than 99% Calcium. There are a total of 20 particles in this class (Figure 5-471).

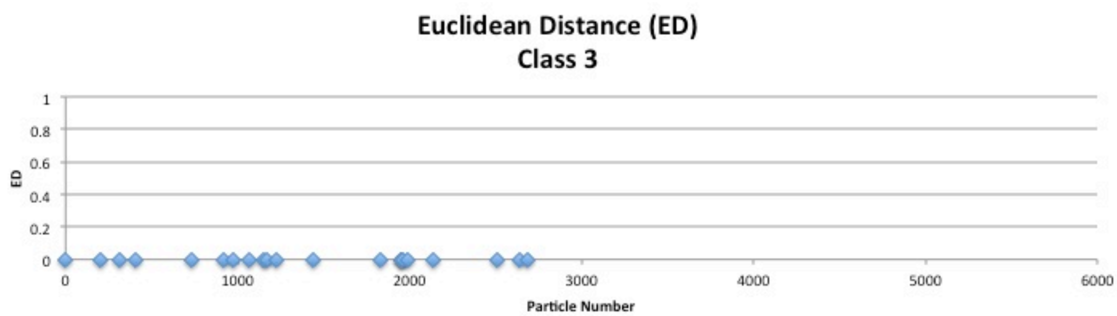

Figure 5-471: Euclidean Distance Class 3

Class 4 of Burkina Soil 71 is composed of Titanium greater than 55% and Lead less than 5%. There are 42 particles in this class (Figure 5-472).

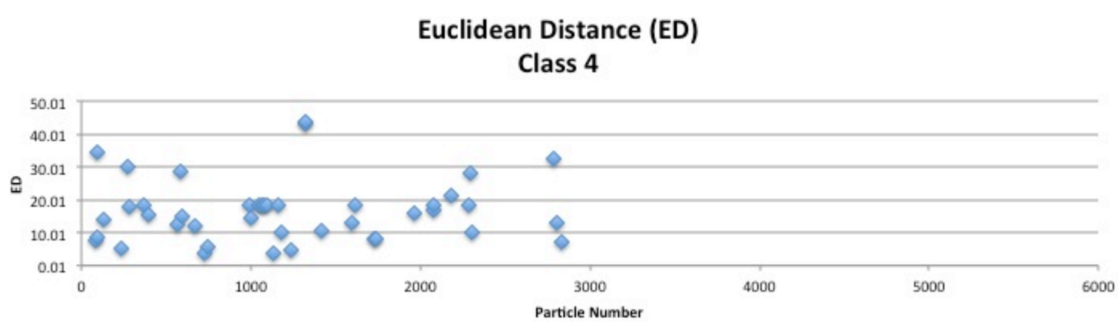

Figure 5-472: Euclidean Distance Class 4

Class 5 of Burkina Soil 71 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are 2 particles in this class (Figure 5-473).

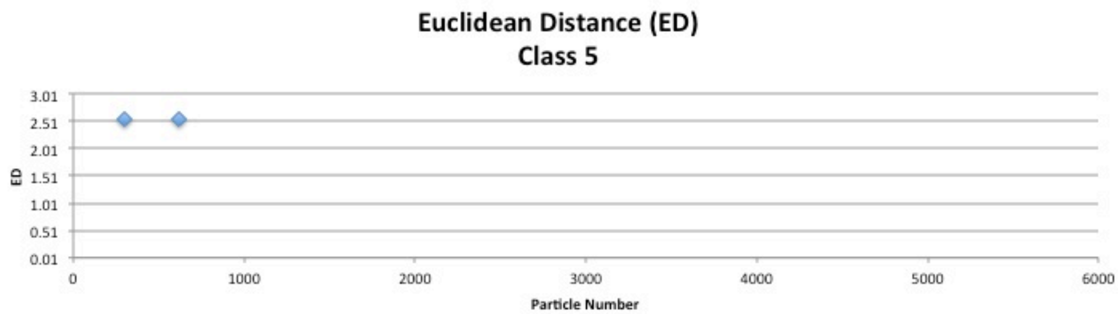

Figure 5-473: Euclidean Distance Class 5

Class 6 of Burkina Soil 71 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 33 particles in this class (Figure 5-474).

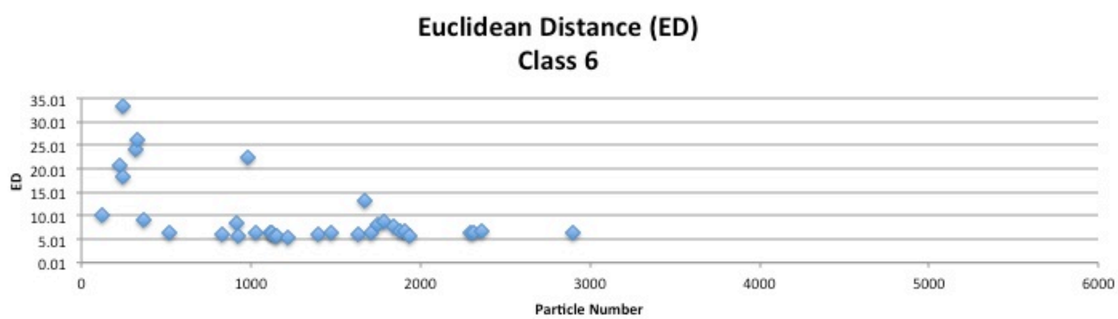

Figure 5-474: Euclidean Distance Class 6

Class 7 of Burkina Soil 71 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 102 particles in this class (Figure 5-475).

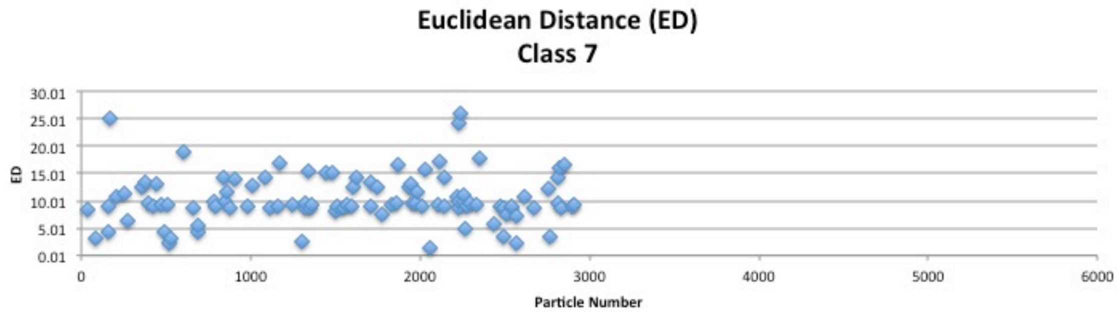

Figure 5-475: Euclidean Distance Class 7

Class 8 of Burkina Soil 71 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 80 particles in this class (Figure 5-476).

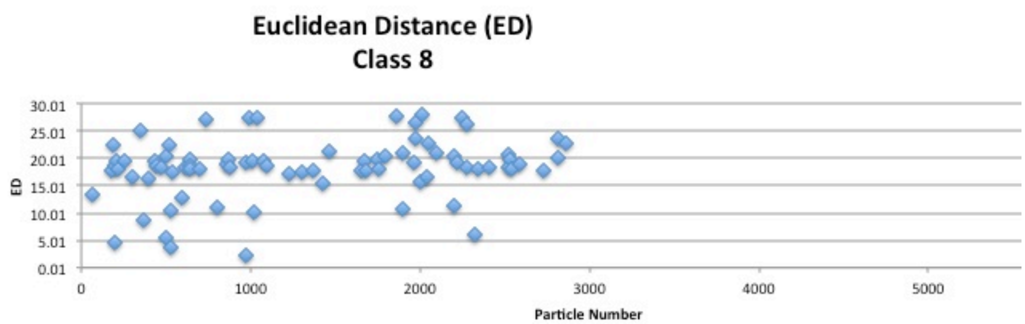

Figure 5-476: Euclidean Distance Class 8

Class 9 of Burkina Soil 71 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 3 particles in this class (Figure 5-477).

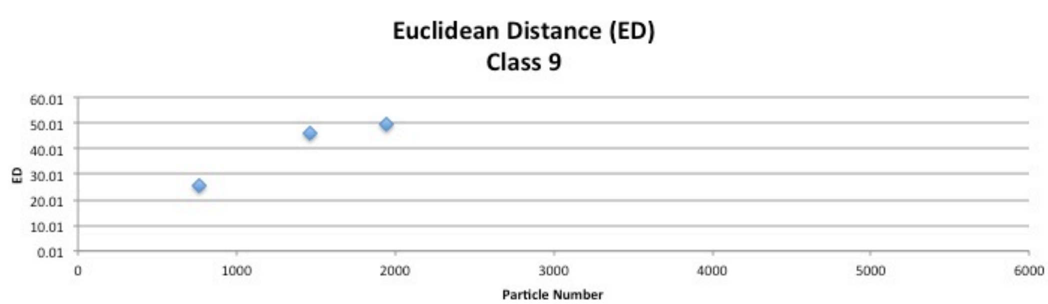

Figure 5-477: Euclidean Distance Class 9

Class 10 of Burkina Soil 71 is composed of Calcium greater than 80% and Lead less than 5%. There are 3 particles in this class (Figure 5-478).

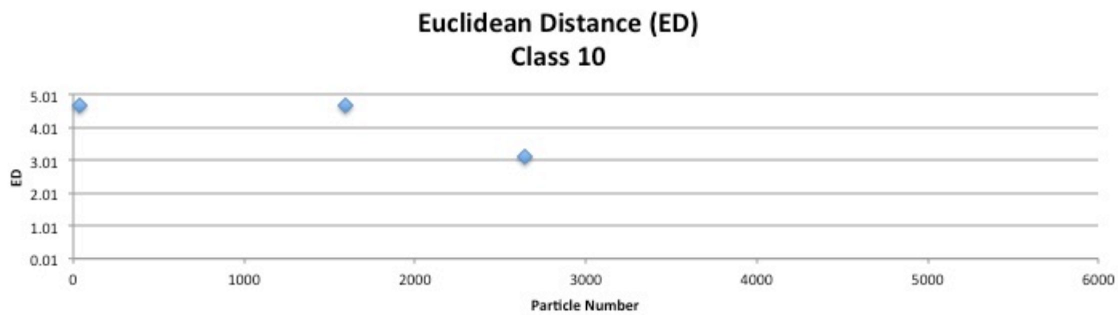

Figure 5-478: Euclidean Distance Class 10

Class 11 of Burkina Soil 71 is composed of the total Calcium and Manganese greater than 90%. There is 1 particle in this class (Figure 5-479).

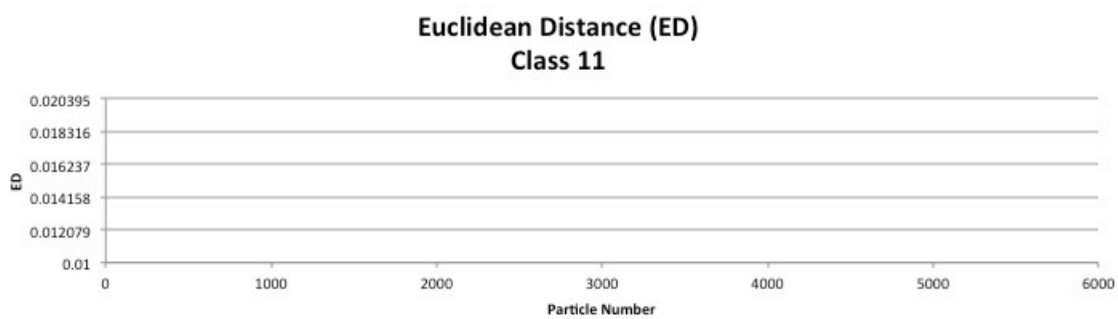

Figure 5-479: Euclidean Distance Class 11

Class 12 of Burkina Soil is composed of the total Calcium and Phosphorus greater than 90%. There is 1 particle in this class (Figure 5-480).

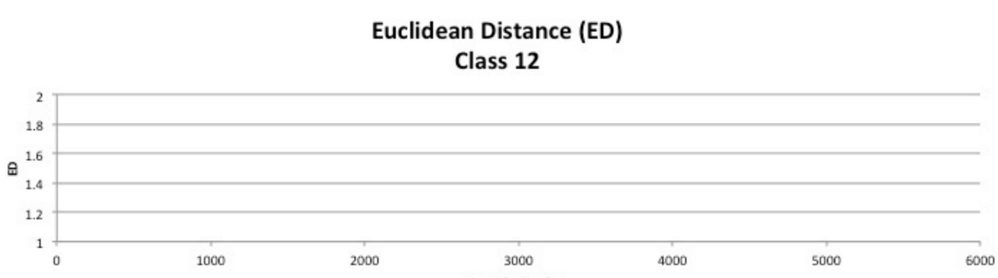

Figure 5-480: Euclidean Distance Class 12

Class 13 of Burkina Soil 71 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 8 particles in this class (Figure 5-481).

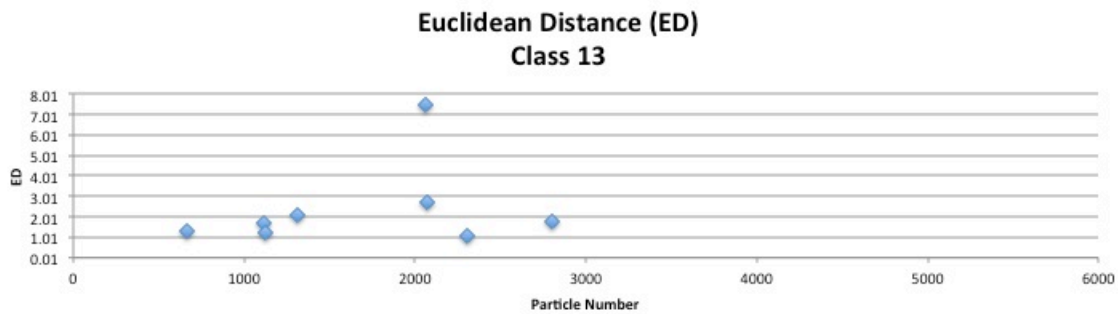

Figure 5-481: Euclidean Distance Class 13

Class 14 of Burkina Soil 71 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are no particles in this class.

Class 15 of Burkina Soil 71 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Soil 71 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 378 particles in this class (Figure 5-482).

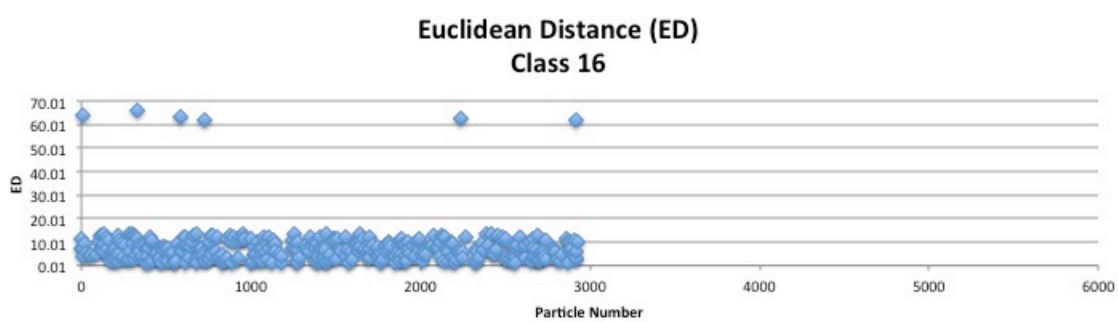

Figure 5-482: Euclidean Distance Class 16

Class 17 of Burkina Soil 71 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 13 particles in this class (Figure 5-483).

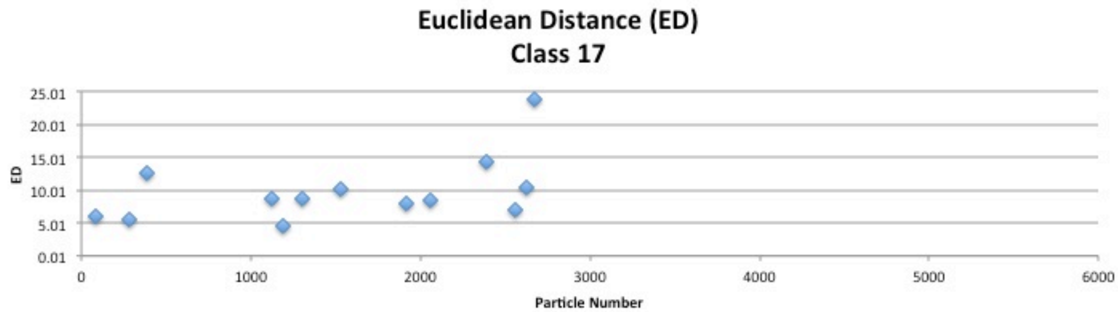

Figure 5-483: Euclidean Distance Class 17

Class 18 of Burkina Soil 71 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 40 particles in this class (Figure 5-484).

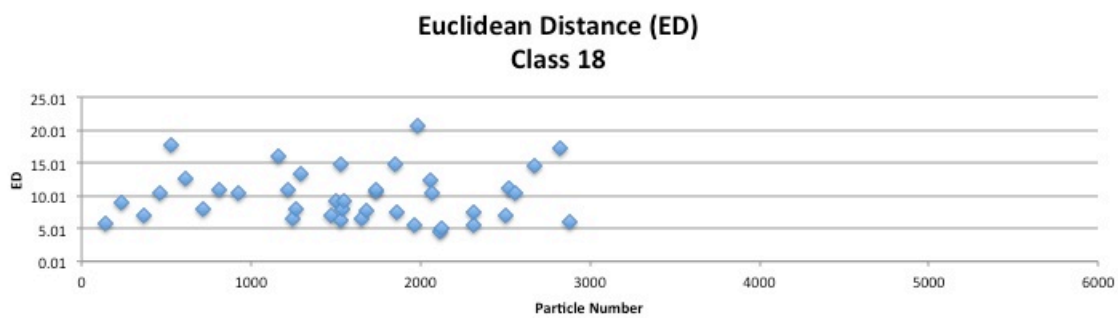

Figure 5-484: Euclidean Distance Class 18

Class 19 of Burkina Soil 71 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are 10 particles in this class (Figure 5-485).

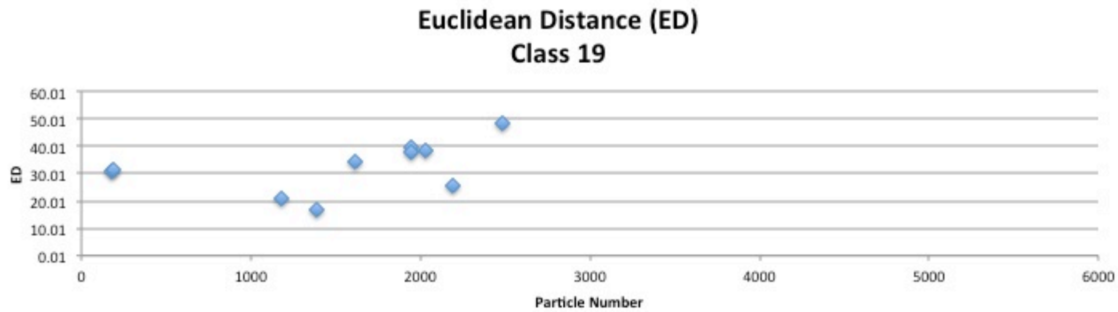

Figure 5-485: Euclidean Distance Class 19

Class 20 of Burkina Soil 71 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 212 particles in this class (Figure 5-486).

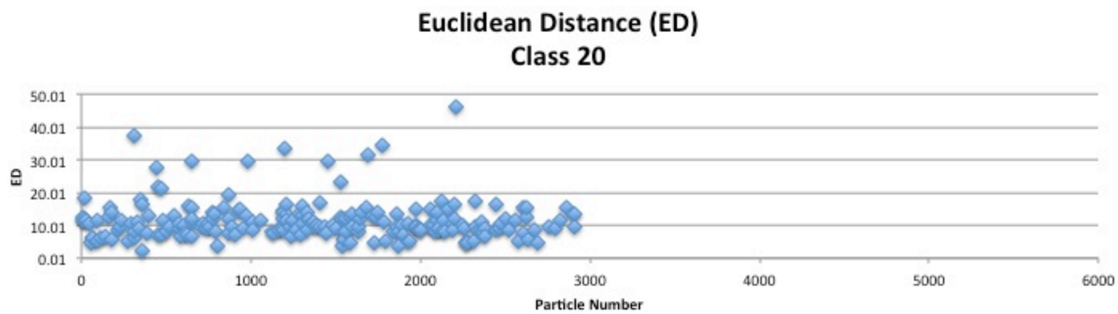

Figure 5-486: Euclidean Distance Class 20

Class 21 of Burkina Soil 71 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 54 particles in this class (Figure 5-487).

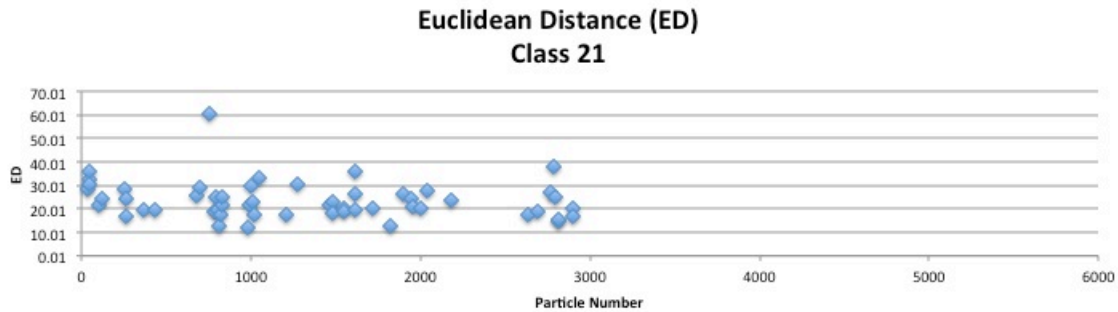

Figure 5-487: Euclidean Distance Class 21

Class 22 of Burkina Soil 71 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 214 particles in this class (Figure 5-488).

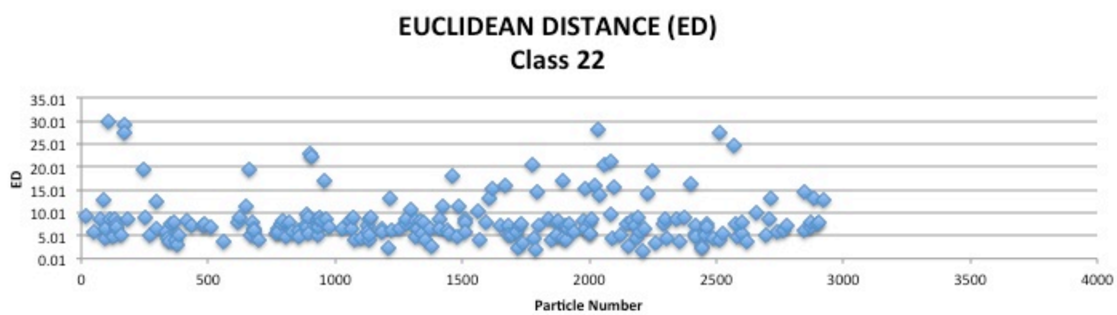

Figure 5-488: Euclidean Distance Class 22

Class 23 of Burkina Soil 71 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 36 particles in this class (Figure 5-489).

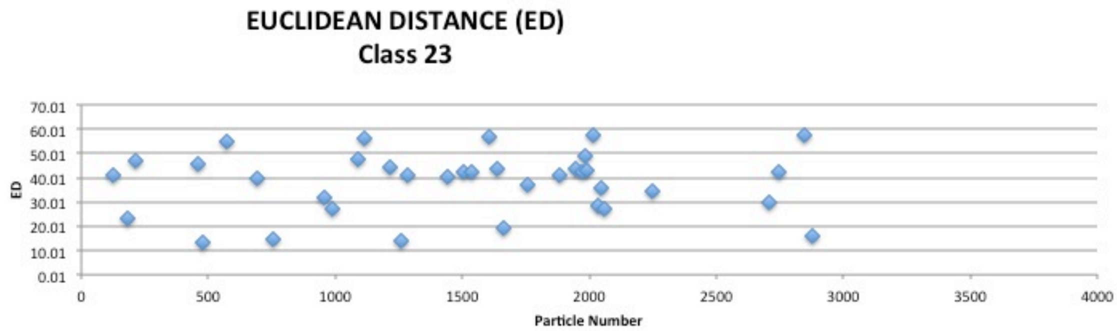

Figure 5-489: Euclidean Distance Class 23

Class 24 of Burkina Soil 71 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 142 particles in this class (Figure 5-490).

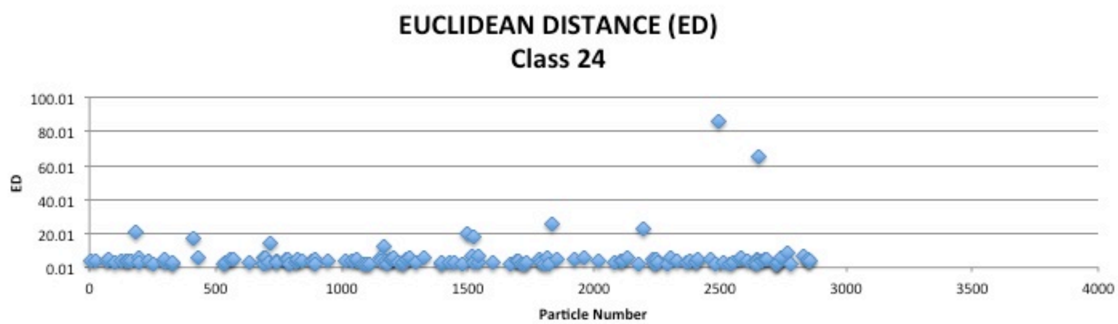

Figure 5-490: Euclidean Distance Class 24

Class 25 of Burkina Soil 71 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 276 particles in this class (Figure 5-491).

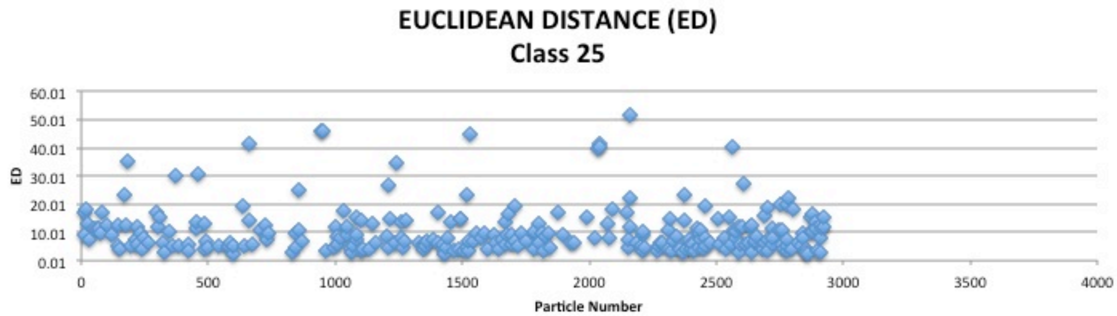

Figure 5-491: Euclidean Distance Class 25

Class 26 of Burkina Soil 71 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 141 particles in this class (Figure 5-492).

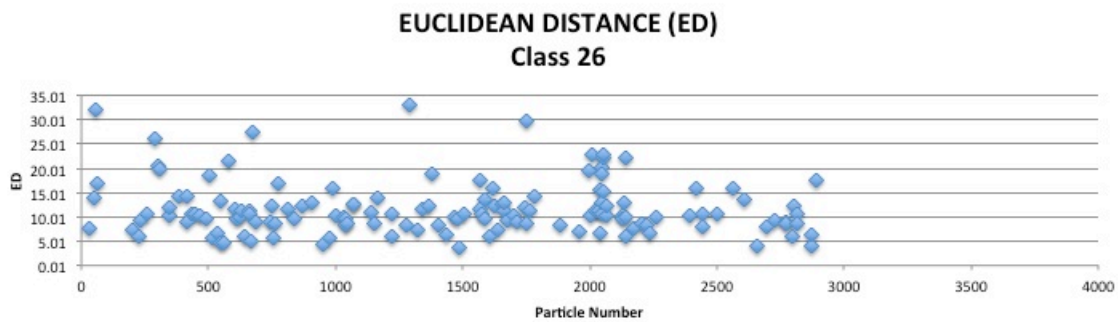

Figure 5-492: Euclidean Distance Class 26

Class 27 of Burkina Soil 71 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 416 particles in this class (Figure 5-493).

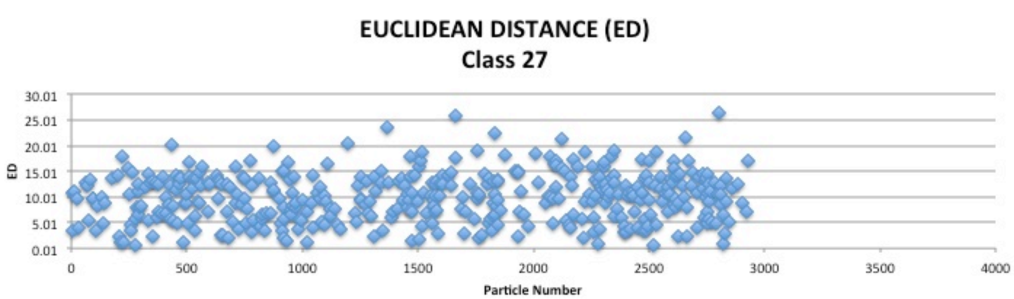

Figure 5-493: Euclidean Distance Class 27

Class 28 of Burkina Soil 71 is composed of Aluminum less than 1%. There are a total of 37 particles in this class (Figure 5-494).

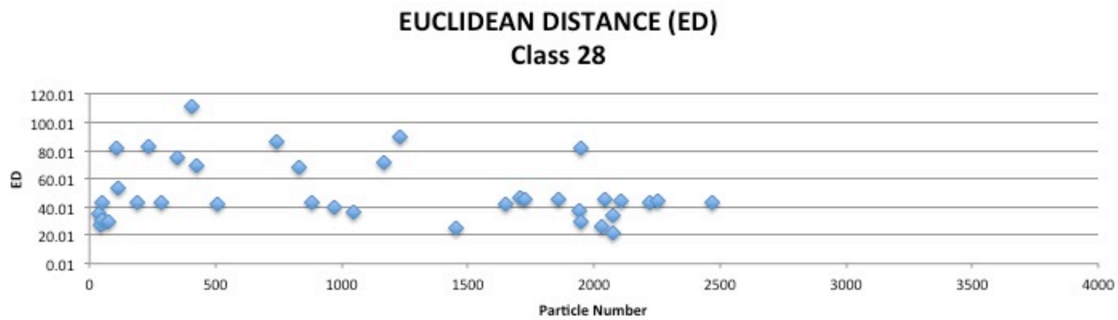

Figure 5-494: Euclidean Distance Class 28

Burkina Soil 72

Numerical and Volumetric Analysis

Burkina Soil 72 is located at 12 10.737' N, 0 56.326' E and has been separated into 29 elemental classes (Figure 5-495). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-43).

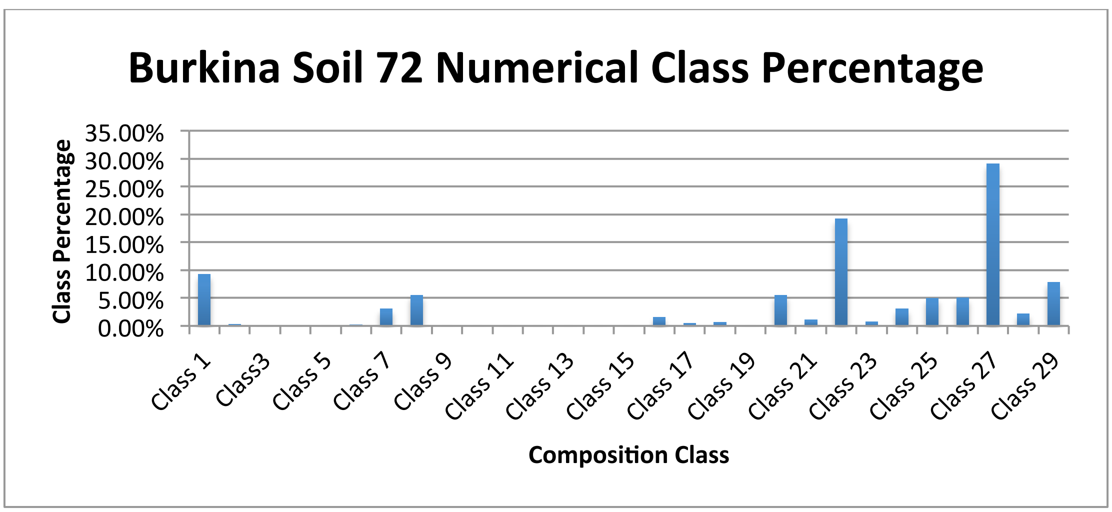

Figure 5-495: Numerical Percentages of classes in Burkina Soil 72

Table 5-43: Numerical Percentages and number of particles per class. Highlighted cells are the three highest classes.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
479	14	4	0	1	12	158	284
9.22%	0.27%	0.08%	0.00%	0.02%	0.23%	3.04%	5.47%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	1	2	2	1	0	82
0.00%	0.00%	0.02%	0.04%	0.04%	0.02%	0.00%	1.58%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
26	34	7	286	59	997	37	160
0.50%	0.65%	0.13%	5.51%	1.14%	19.20%	0.71%	3.08%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
258	260	1510	112	408	5194		
4.97%	5.01%	29.07%	2.16%	7.86%	100.00%		

Table 5-43 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 1, 22, and 27. Class 1 is composed of greater than 99% Silica. Class 22 has less than 1% Calcium and Potassium, 4% to 20% Aluminum, and greater than 60% Silica. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 57.49% of the entire sample and contains a total of 2986 particles. Class 29 represents the “unclassified” particles and contains only 7.86% of the entire sample.

The volumetric percentage of Burkina Laterite 72 represents the volume of particles that are represented in each respective elemental class (Figure 5-496). Table 5-44 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 1, 22, and 27, which is consistent with the numerical percentages. Class 1 is composed of greater than 99% Silica. Class 22 has less than 1% Calcium and Potassium, 4% to 20% Aluminum, and greater than 60% Silica. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 61.36% of the entire sample and contains a total volume of 498201.73 μm^3. Class 29 represents the "unclassified" volume of particles and contains 5.89% of the entire sample.

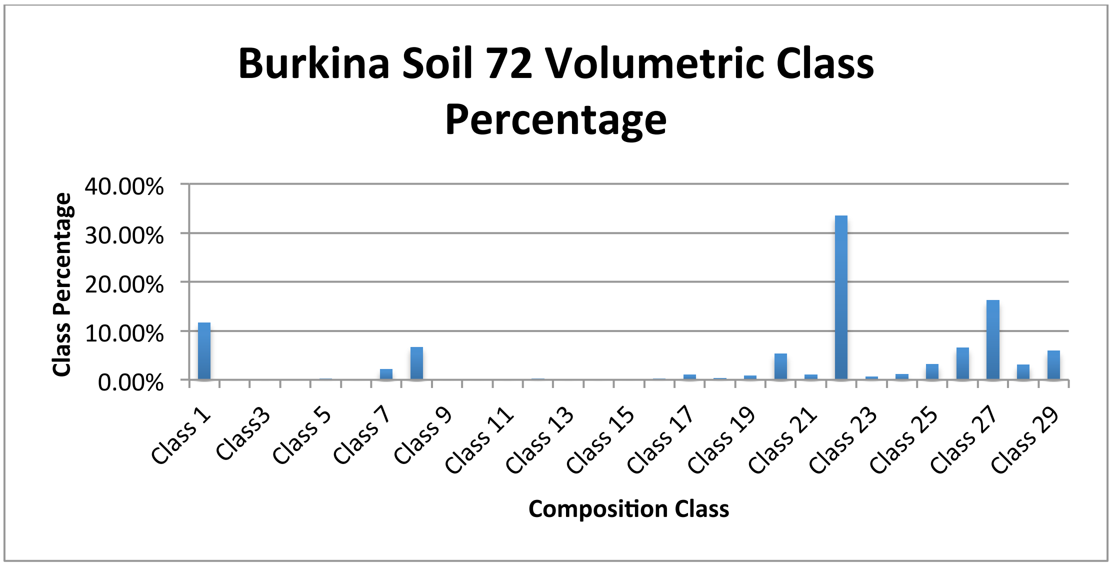

Figure 5-496: Volumetric percentages per class.

Table 5-44: Volumetric percentages and volume per class. Highlighted cells are the largest class categories.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
94524.9	124.61	202.18	0.00	1612.32	263.44	17171.96	54317.94
11.64%	0.02%	0.02%	0.00%	0.20%	0.03%	2.12%	6.69%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	49.32	2151.12	725.91	13.61	0.00	1423.34
0.00%	0.00%	0.01%	0.26%	0.09%	0.00%	0.00%	0.18%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
8435.8	2876.6	6629.48	43170.0	8328.20	271893.2	5165.59	9355.05
1.04%	0.35%	0.82%	5.32%	1.03%	33.49%	0.64%	1.15%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
25678.1	53337.3	131783.5	24853.0	47798.16	811885.10		
3.16%	6.57%	16.23%	3.06%	5.89%	100.00%		

Analysis of class 29 showed a cluster of elements similar to the Burkina Laterites. The highest elements contained within Burkina Soil 72 unclassified are Fe, Si, Al, respectively, and compose a volume of 5.89% of the entire sample particles. Most of the unclassified elements are contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-497 and Figure 5-498). Approximately 65% of the unclassified particles are contained within these two distinct clusters.

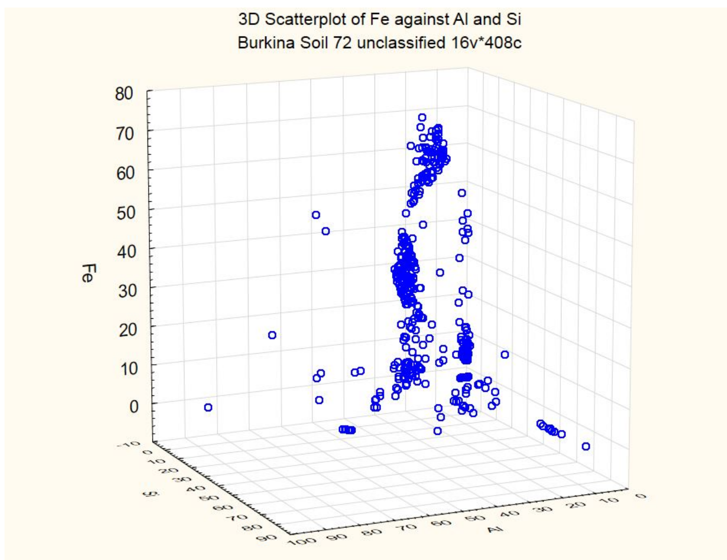

Figure 5-497: Scatterplot of Burkina Soil 72 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 5.89% volume of the particles in the sample.

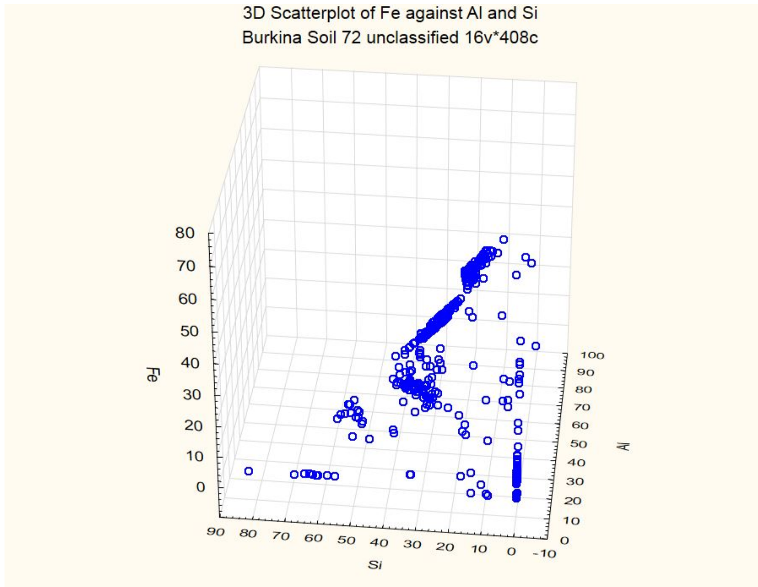

Figure 5-498: Alternate view of 3D scatterplot.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Soil 72 is composed of greater than 99% Silica. There are a total of 479 particles in this class (Figure 5-499).

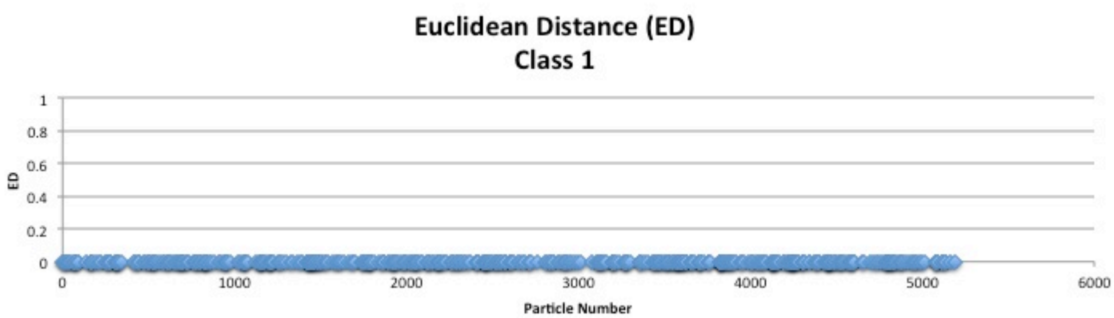

Figure 5-499: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 14 particles in this class (Figure 5-500).

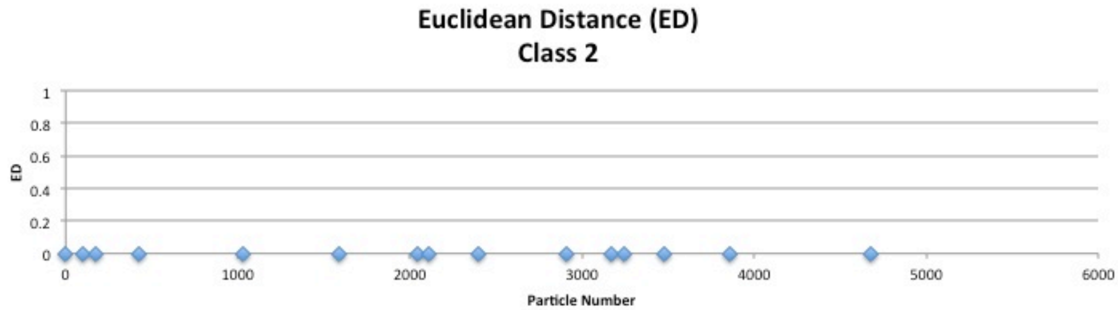

Figure 5-500: Euclidean Distance Class 2

Class 3 of Burkina Soil 72 is composed of greater than 99% Calcium. There are a total of 4 particles in this class (Figure 5-501).

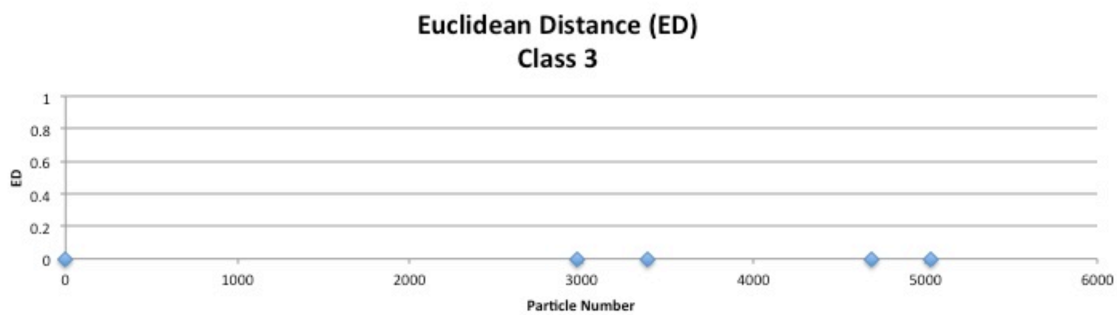

Figure 5-501: Euclidean Distance Class 3

Class 4 of Burkina Soil 72 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Burkina Soil 72 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There is 1 particle in this class (Figure 5-502).

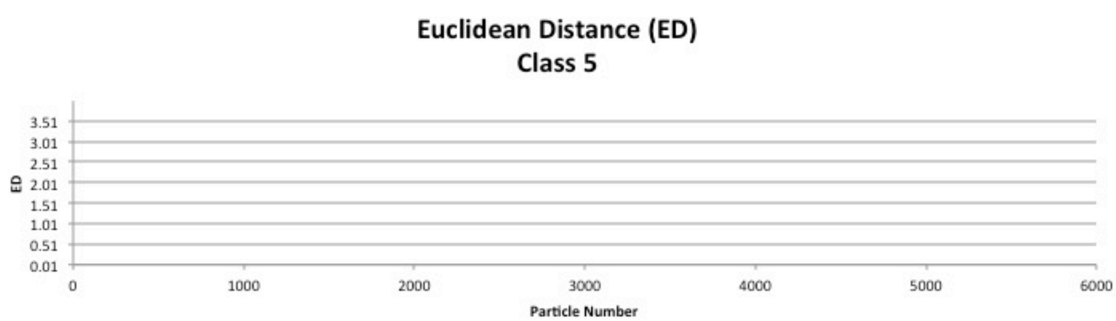

Figure 5-502: Euclidean Distance Class 5

Class 6 of Burkina Soil 72 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 12 particles in this class (Figure 5-503).

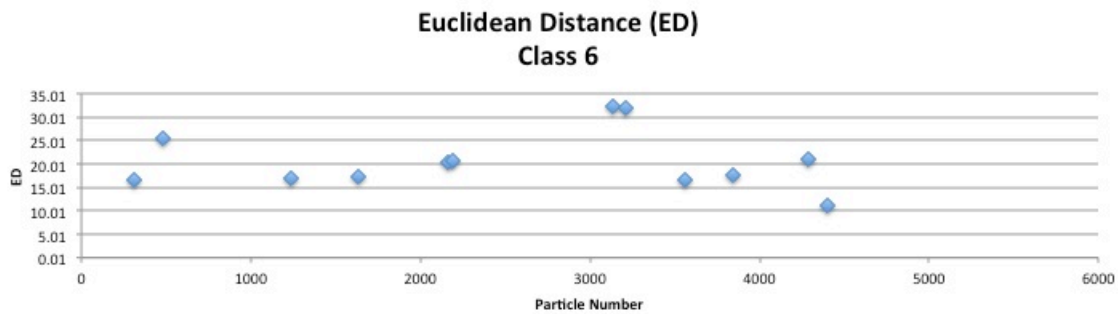

Figure 5-503: Euclidean Distance Class 6

Class 7 of Burkina Soil 72 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 158 particles in this class (Figure 5-504).

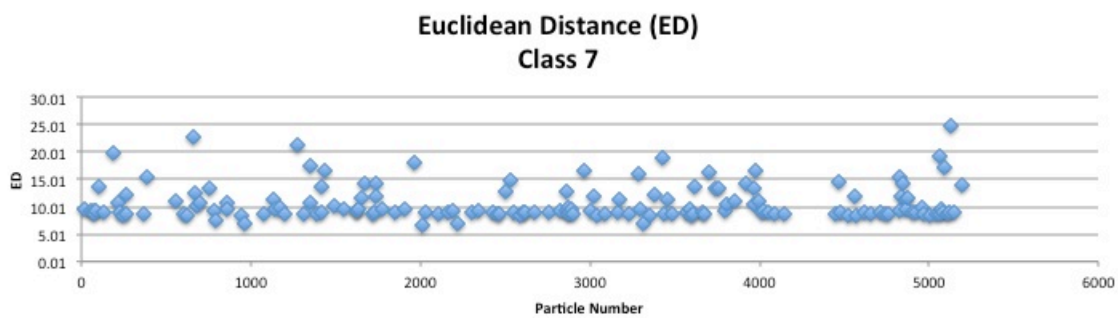

Figure 5-504: Euclidean Distance Class 7

Class 8 of Burkina Soil 72 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 284 particles in this class (Figure 5-505).

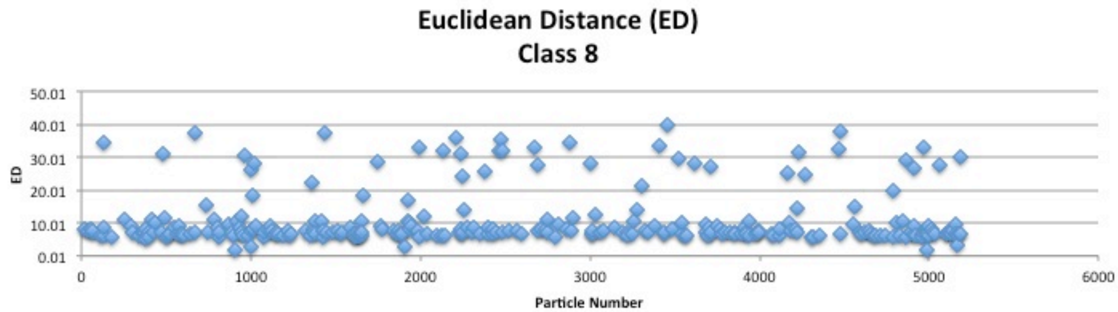

Figure 5-505: Euclidean Distance Class 8

Class 9 of Burkina Soil 72 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Soil 72 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Soil 72 is composed of the total Calcium and Manganese greater than 90%. There is 1 particle in this class (Figure 5-506).

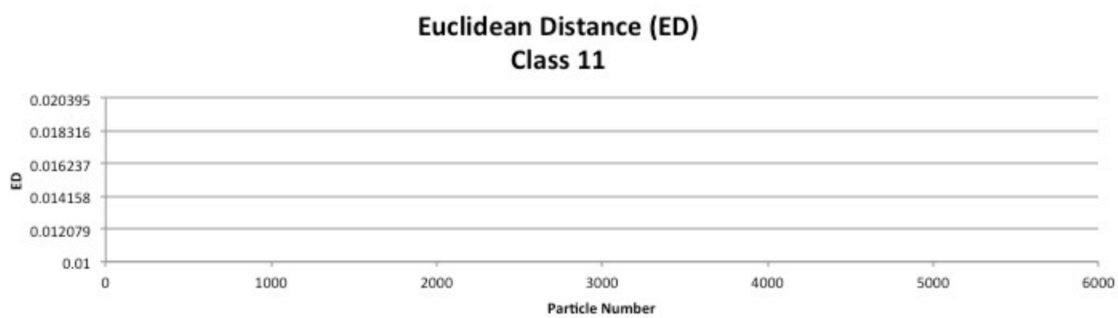

Figure 5-506: Euclidean Distance Class 11

Class 12 of Burkina Soil 72 is composed of the total Calcium and Phosphorus greater than 90%. There are 2 particles in this class (Figure 5-507).

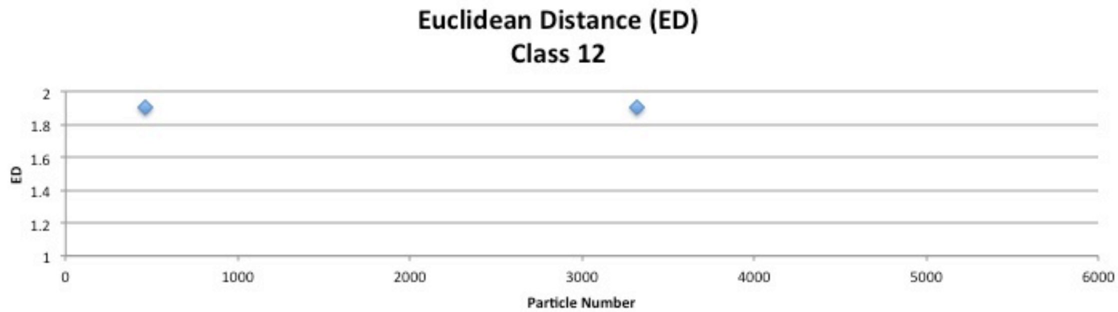

Figure 5-507: Euclidean Distance Class 12

Class 13 of Burkina Soil 72 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 2 particles in this class (Figure 5-508).

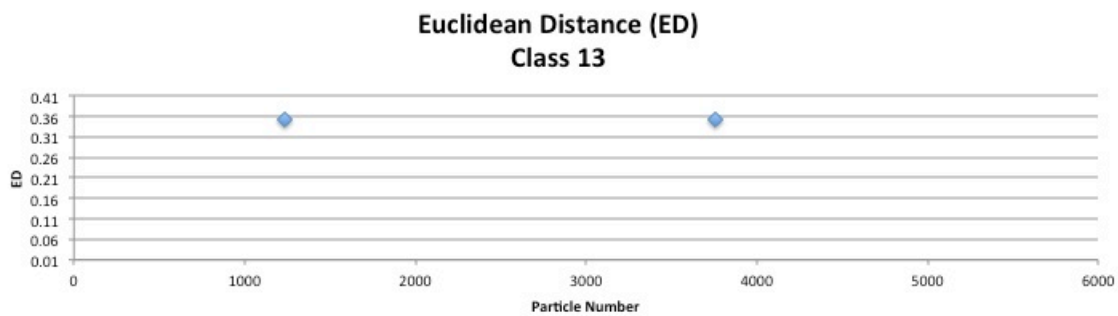

Figure 5-508: Euclidean Distance Class 13

Class 14 of Burkina Soil 72 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There is 2 particle2 in this class (Figure 5-509).

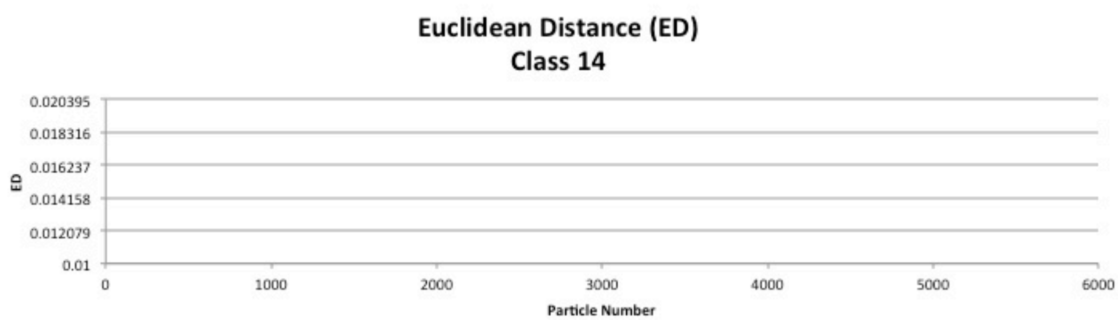

Figure 5-509: Euclidean Distance Class 14

Class 15 of Burkina Soil 72 is composed of Aluminum less than 1%, Iron greater than

64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Soil 72 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 82 particles in this class (Figure 5-510).

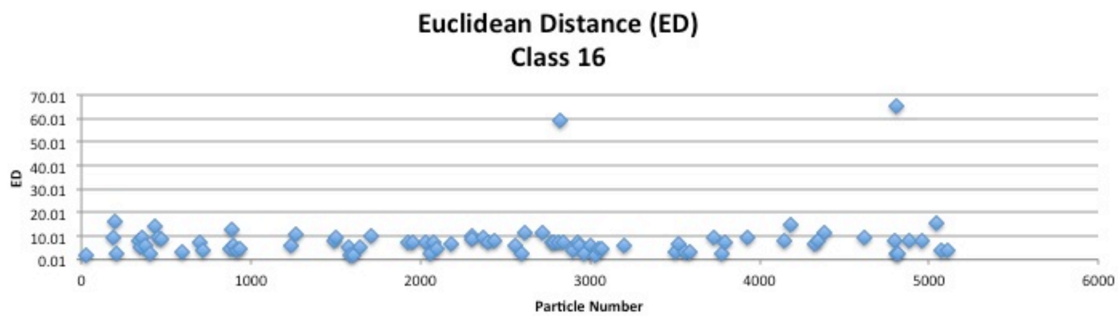

Figure 5-510: Euclidean Distance Class 16

Class 17 of Burkina Soil 72 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 26 particles in this class (Figure 5-511).

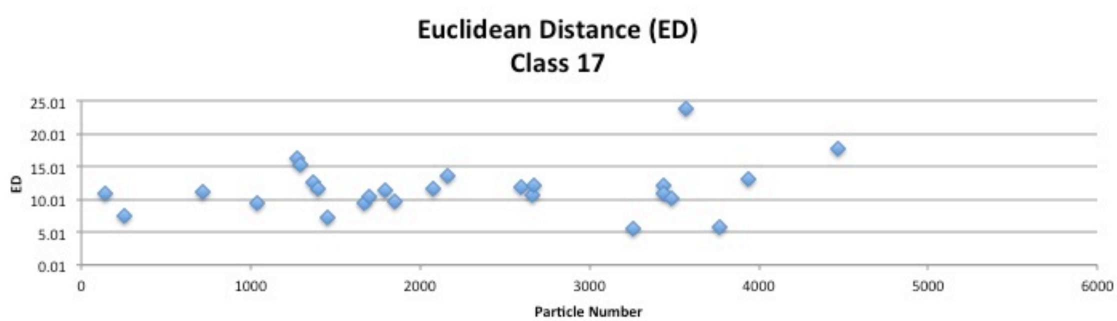

Figure 5-511: Euclidean Distance Class 17

Class 18 of Burkina Soil 72 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 34 particles in this class (Figure 5-512).

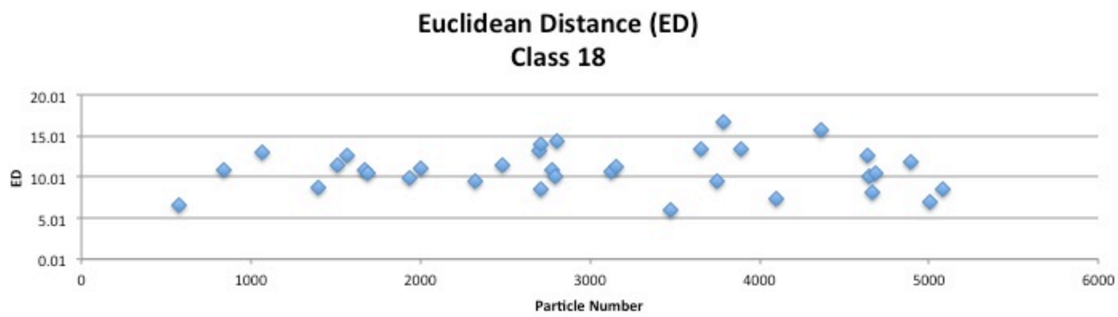

Figure 5-512: Euclidean Distance Class 18

Class 19 of Burkina Soil 72 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are 7 particles in this class (Figure 5-513).

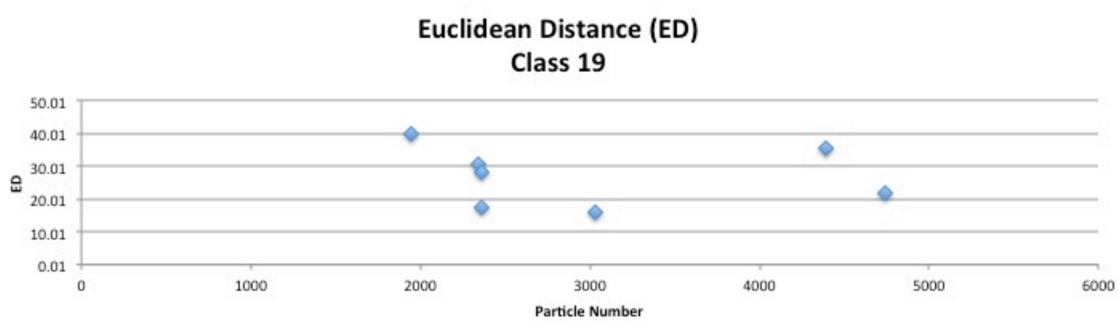

Figure 5-513: Euclidean Distance Class 19

Class 20 of Burkina Soil 72 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 286 particles in this class (Figure 5-514).

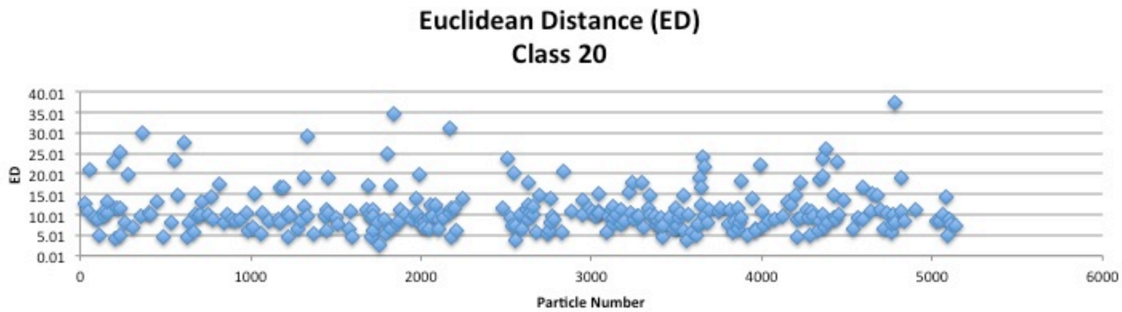

Figure 5-514: Euclidean Distance Class 20

Class 21 of Burkina Soil 72 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 59 particles in this class (Figure 5-515).

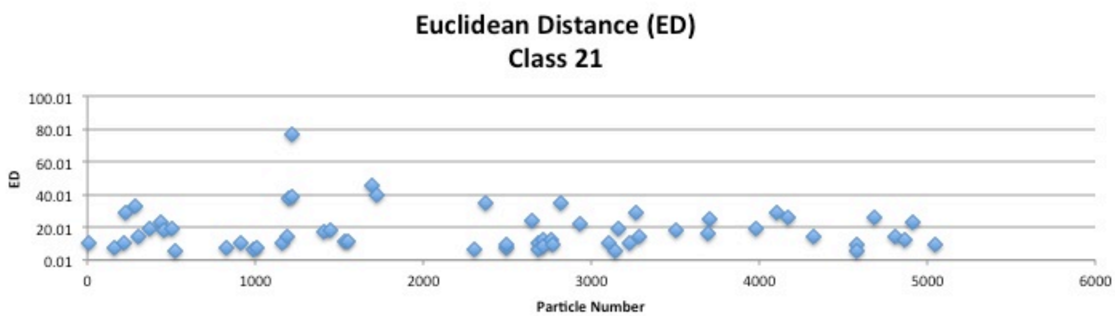

Figure 5-515: Euclidean Distance Class 21

Class 22 of Burkina Soil 72 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 997 particles in this class (Figure 5-516).

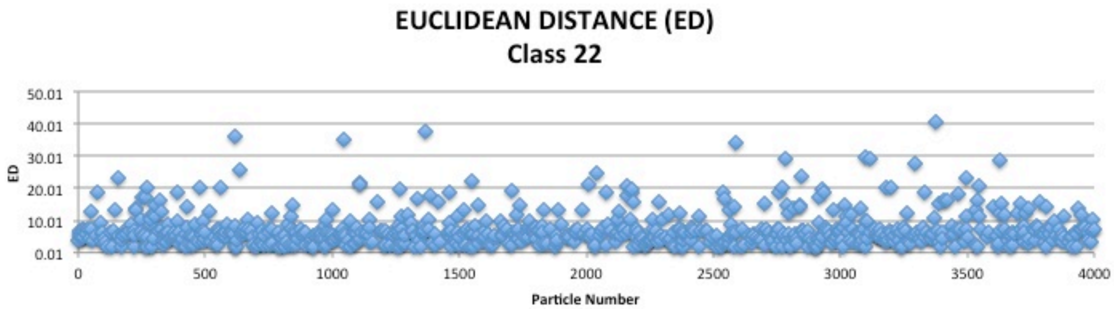

Figure 5-516: Euclidean Distance Class 22

Class 23 of Burkina Soil 72 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 37 particles in this class (Figure 5-517).

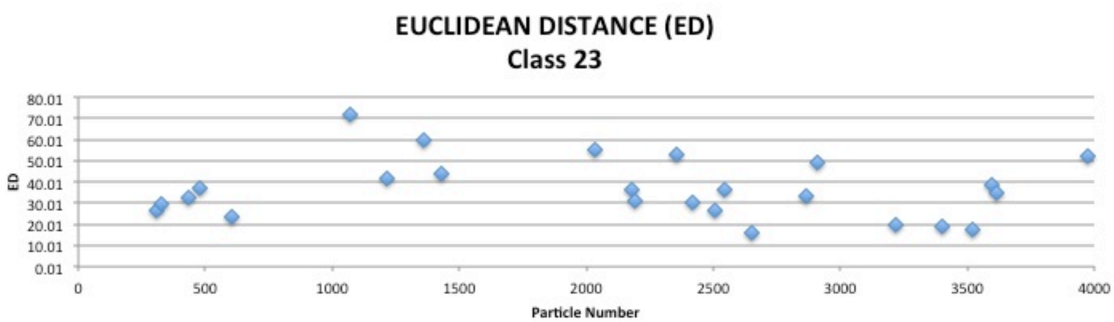

Figure 5-517: Euclidean Distance Class 23

Class 24 of Burkina Soil 72 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 160 particles in this class (Figure 5-518).

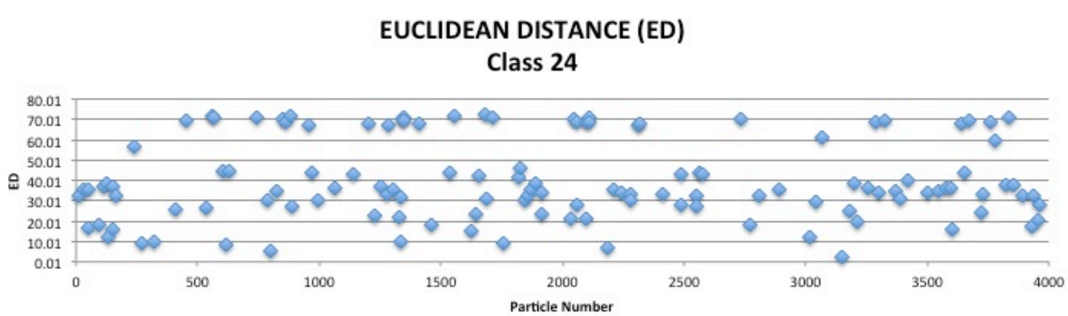

Figure 5-518: Euclidean Distance Class 24

Class 25 of Burkina Soil 72 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 258 particles in this class (Figure 5-519).

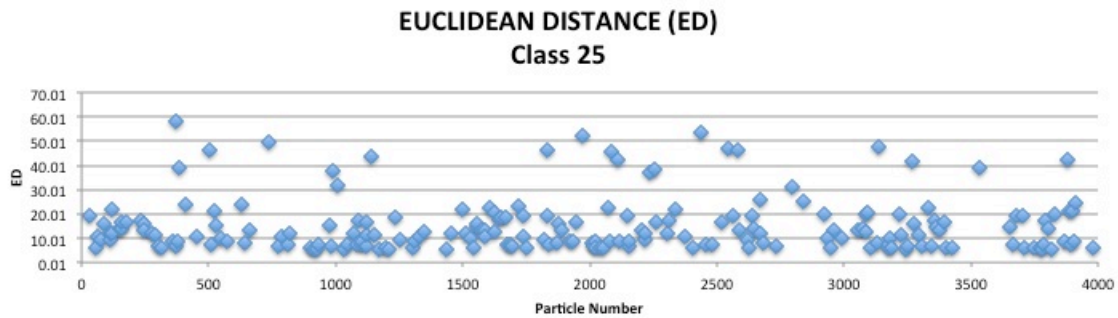

Figure 5-519: Euclidean Distance Class 25

Class 26 of Burkina Soil 72 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 260 particles in this class (Figure 5-520).

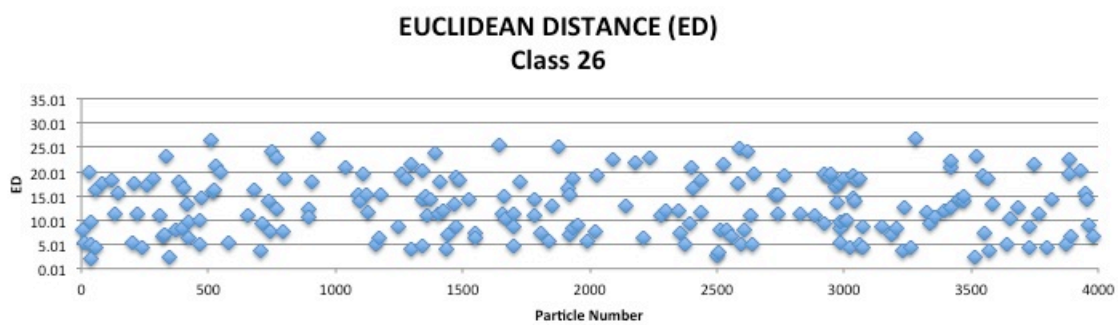

Figure 5-520: Euclidean Distance Class 26

Class 27 of Burkina Soil 72 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 1510 particles in this class (Figure 5-521).

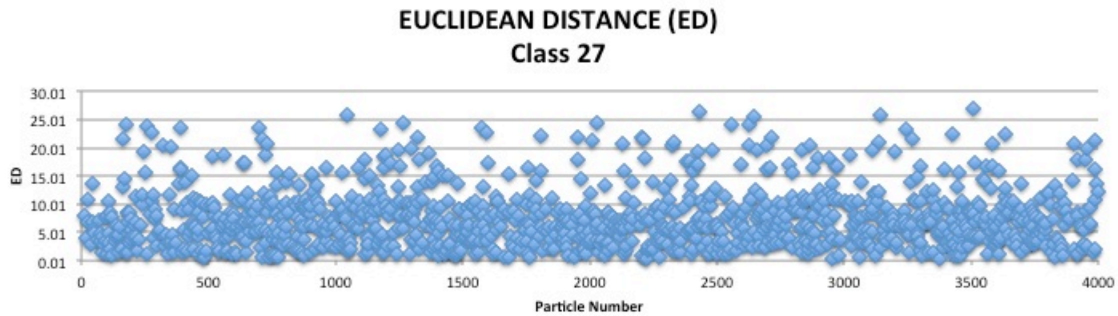

Figure 5-521: Euclidean Distance Class 27

Class 28 of Burkina Soil 72 is composed of Aluminum less than 1%. There are a total of 112 particles in this class (Figure 5-522).

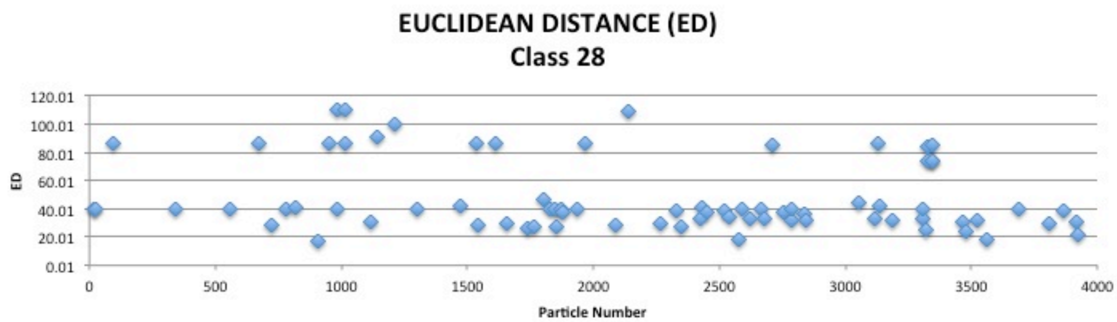

Figure 5-522: Euclidean Distance Class 28

Burkina Soil 73

Numerical and Volumetric Analysis

Burkina Soil 73, which is located in the same location as Burkina Laterite 60, is located at 12 03.736' N, 0 23.608' E and has been separated into 29 elemental classes (Figure 5-523). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-45).

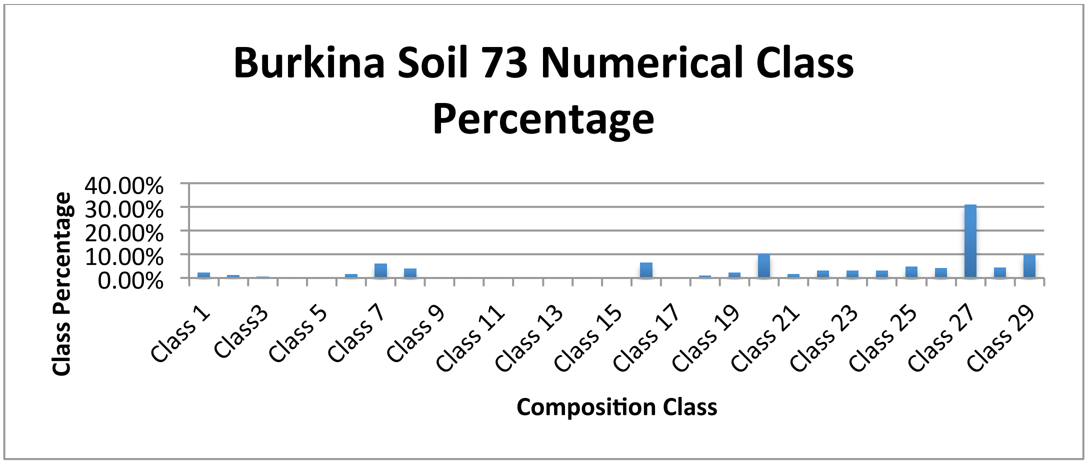

Figure 5-523: Burkina Soil 73 numerical percentage per class.

Table 5-45: Burkina Soil 73 numerical percentage and number of particles per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
68	37	16	0	2	49	186	122
2.17%	1.18%	0.51%	0.00%	0.06%	1.56%	5.94%	3.90%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	7	2	2	1	0	198
0.00%	0.00%	0.22%	0.06%	0.06%	0.03%	0.00%	6.32%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
10	32	69	314	46	96	93	96
0.32%	1.02%	2.20%	10.03%	1.47%	3.07%	2.97%	3.07%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
146	131	967	138	304	3132		
4.66%	4.18%	30.87%	4.41%	9.71%	100.00%		

Table 5-45 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 16, 20, and 27. Class 16 is composed of Iron greater than 40%, and the total Iron and Calcium greater than 75%. Class 20 has Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 27 is represented by Potassium and Calcium less than 1%, between 40% and 60% Aluminum, and 20% to 60% Silica. This represents 47.22% of the entire sample and contains a total of 1479 particles. Class 29 represents the "unclassified" particles and contains only 9.71% of the entire sample.

The volumetric percentage of Burkina Laterite 73 represents the volume of particles that are represented in each respective elemental class (Figure 5-524). Table 5-46 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 19, 25, and 27. Class 19 consists of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. Class 25 has Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. Class 27 is represented by Potassium and Calcium less than 1%, between 40% and 60% Aluminum, and 20% to 60% Silica. This represents 63.48% of the entire sample and contains a total volume of 244275.43 μm^3. Class 29 represents the "unclassified" volume of particles and contains 9.71% of the entire sample.

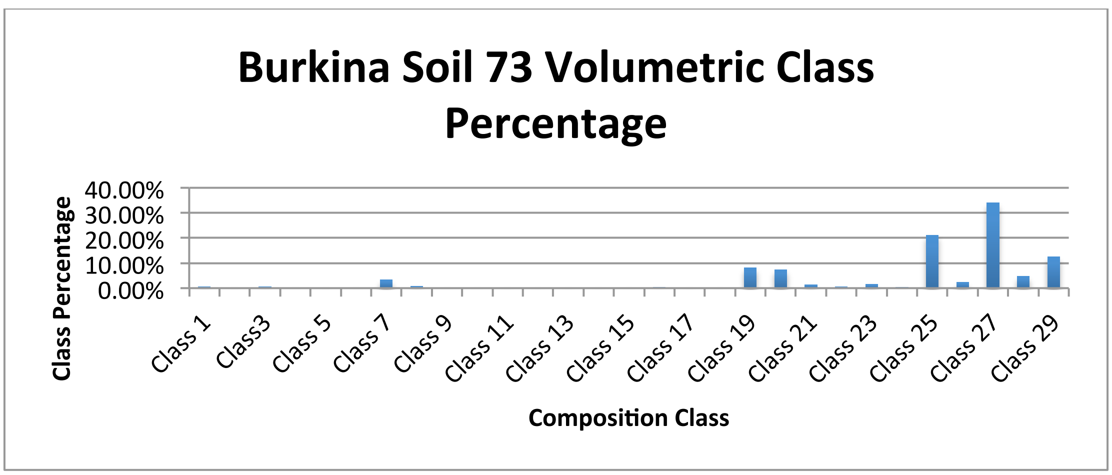

Figure 5-524: Volumetric percentages per class.

Table 5-46: Volumetric percentages and volume per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
2304.78	162.18	1861.07	0.00	8.03	43.17	12554.66	3287.43
0.60%	0.04%	0.48%	0.00%	0.00%	0.01%	3.26%	0.85%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	10.86	1.05	0.79	8.97	0.00	1223.39
0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.32%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
257.07	149.26	31449.03	28557.62	5254.51	1864.10	5736.10	1570.74
0.07%	0.04%	8.17%	7.42%	1.37%	0.48%	1.49%	0.41%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
81506.92	9054.19	131319.48	18297.08	48285.05	384767.51		
21.18%	2.35%	34.13%	4.76%	12.55%	100.00%		

Analysis of class 29 showed a cluster of elements similar to the Burkina Laterites. The highest elements contained within Burkina Soil 73 unclassified are Fe, Si, Al, respectively, and compose a volume of 12.55% of the entire sample particles. Most of the unclassified elements are contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-525 and Figure 5-526). Approximately 65% of the unclassified particles are contained within these two distinct clusters.

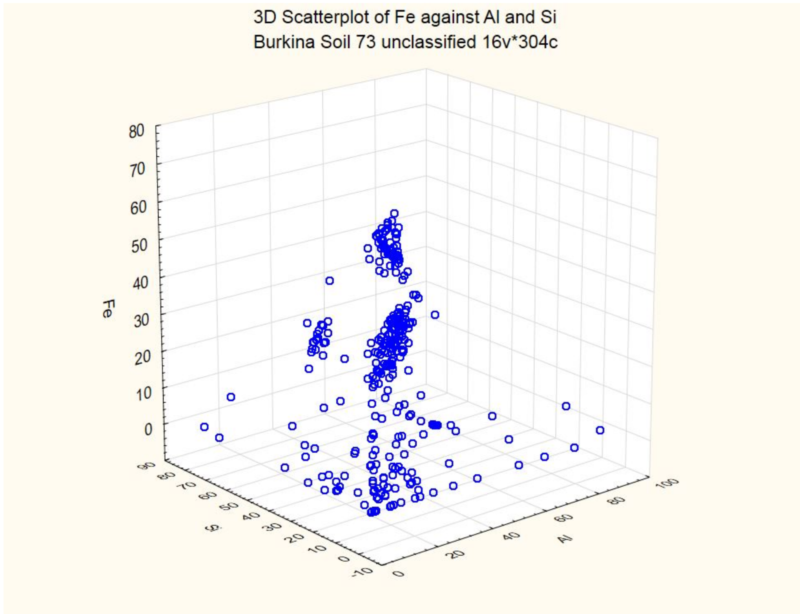

Figure 5-525: Scatterplot of Burkina Soil 73 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 12.55% volume of the particles in the sample.

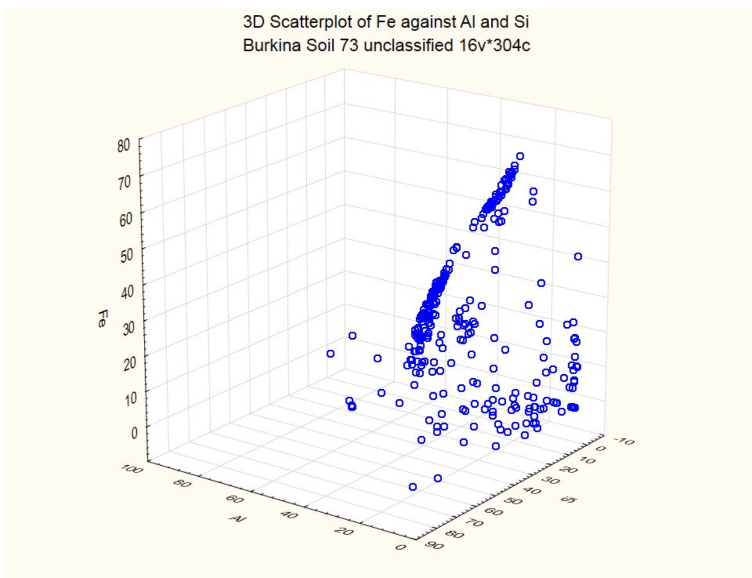

Figure 5-526: Burkina Soil 73 alternate 3D scatterplot view.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Soil 73 is composed of greater than 99% Silica. There are a total of 68 particles in this class (Figure 5-527).

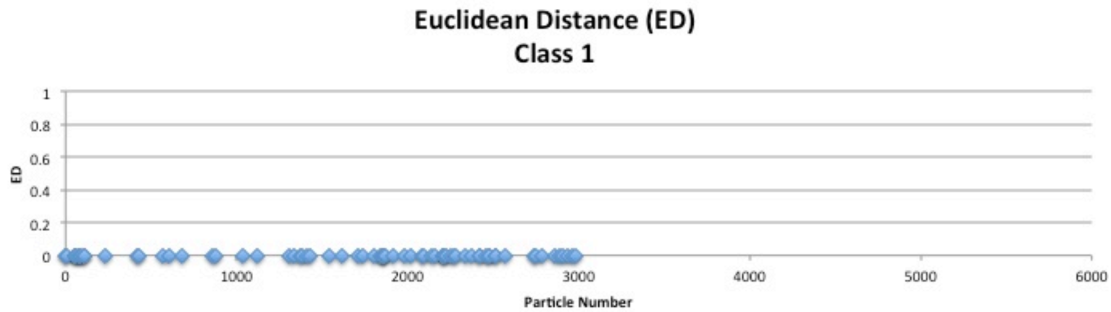

Figure 5-527: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 37 particles in this class (Figure 5-528).

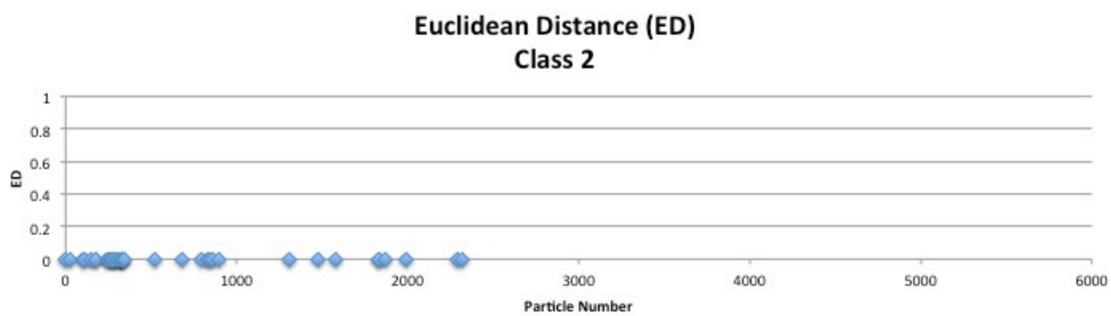

Figure 5-528: Euclidean Distance Class 2

Class 3 of Burkina Soil 73 is composed of greater than 99% Calcium. There are a total of 16 particles in this class (Figure 5-529).

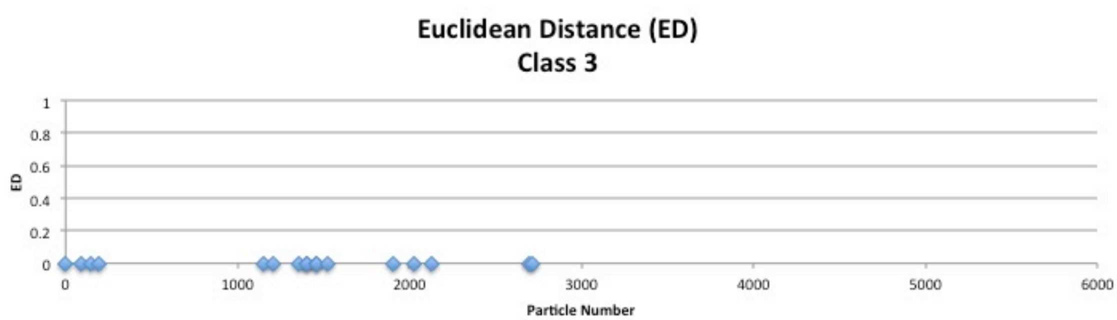

Figure 5-529: Euclidean Distance Class 3

Class 4 of Burkina Soil 73 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in class 4.

Class 5 of Burkina Soil 73 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are 2 particles in this class (Figure 5-530).

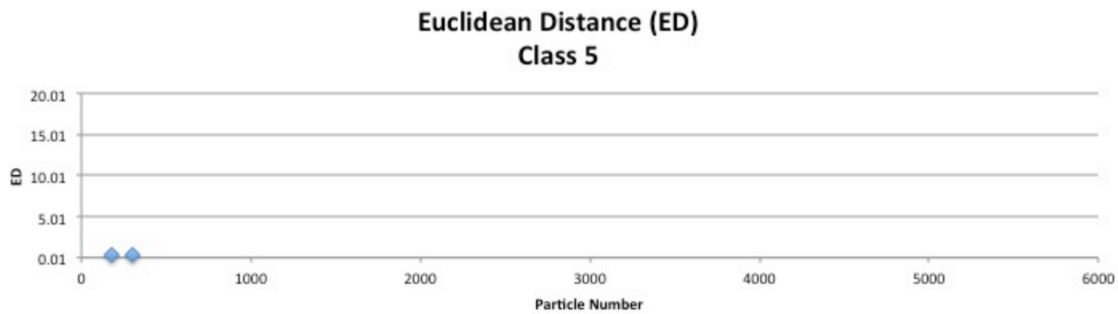

Figure 5-530: Euclidean Distance Class 5

Class 6 of Burkina Soil 73 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 49 particles in this class (Figure 5-531).

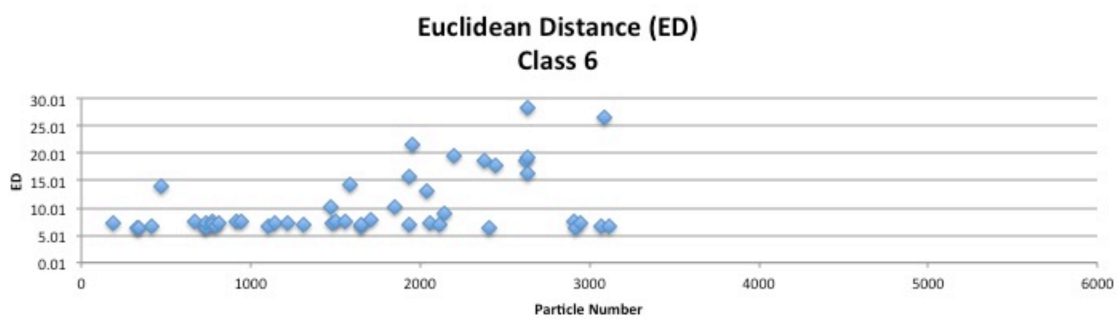

Figure 5-531: Euclidean Distance Class 6

Class 7 of Burkina Soil 73 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 186 particles in this class (Figure 5-532).

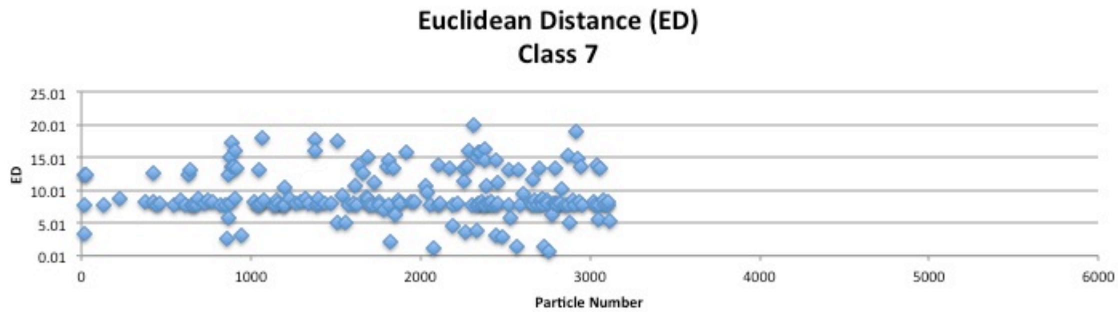

Figure 5-532: Euclidean Distance Class 7

Class 8 of Burkina Soil 73 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 122 particles in this class (Figure 5-533).

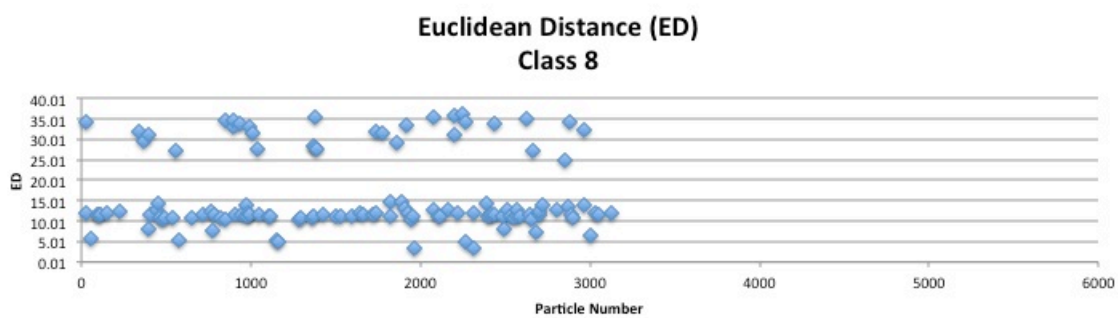

Figure 5-533: Euclidean Distance Class 8

Class 9 of Burkina Soil 73 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in class 9.

Class 10 of Burkina Soil 73 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in class 10.

Class 11 of Burkina Soil 73 is composed of the total Calcium and Manganese greater than 90%. There are 7 particles in this class (Figure 5-534).

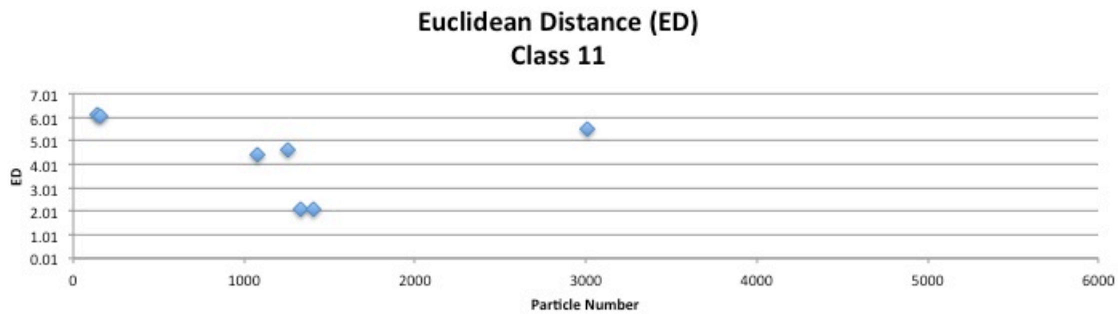

Figure 5-534: Euclidean Distance Class 11

Class 12 of Burkina Soil 73 is composed of the total Calcium and Phosphorus greater than 90%. There are 2 particles in this class (Figure 5-535).

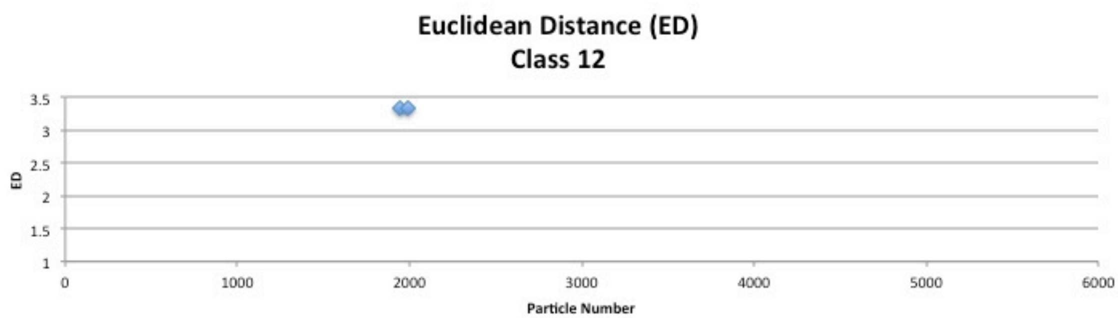

Figure 5-535: Euclidean Distance Class 12

Class 13 of Burkina Soil 73 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 2 particles in this class (Figure 5-536).

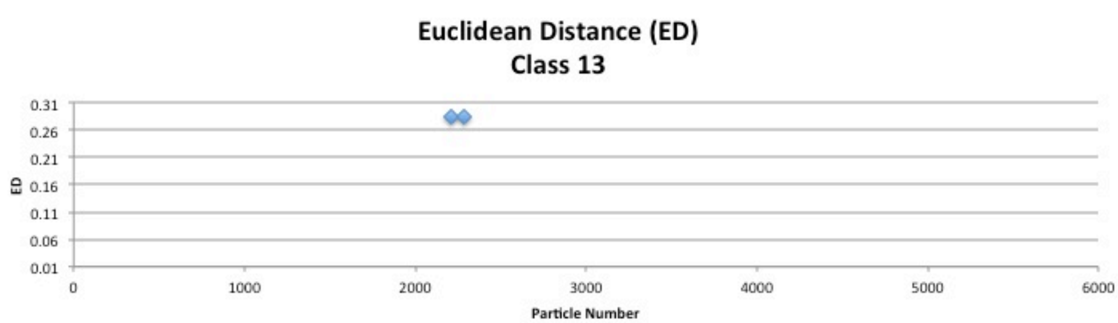

Figure 5-536: Euclidean Distance Class 13

Class 14 of Burkina Soil 73 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There is 1 particle in this class (Figure 5-537).

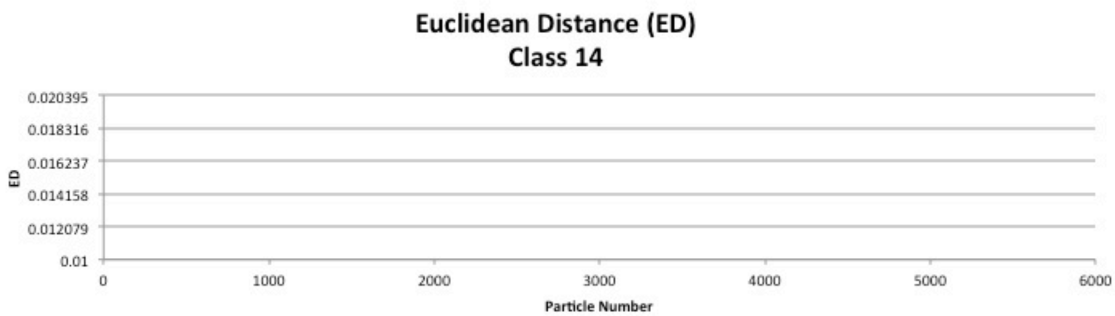

Figure 5-537: Euclidean Distance Class 14

Class 15 of Burkina Soil 73 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Soil 73 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 198 particles in this class (Figure 5-538).

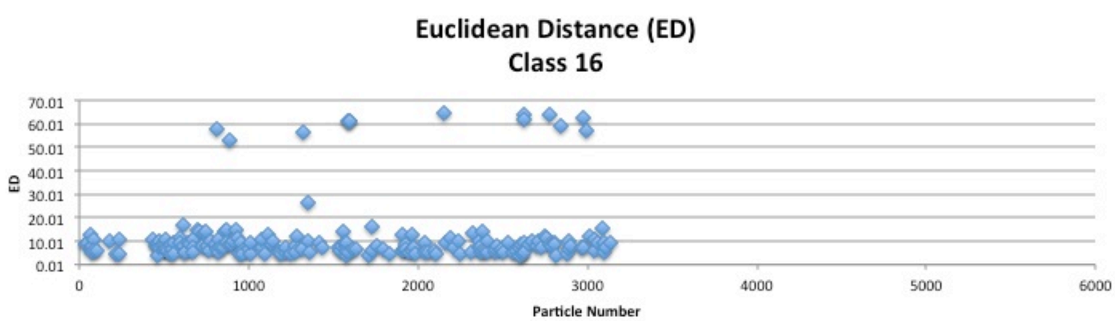

Figure 5-538: Euclidean Distance Class 16

Class 17 of Burkina Soil 73 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 10 particles in this class (Figure 5-539).

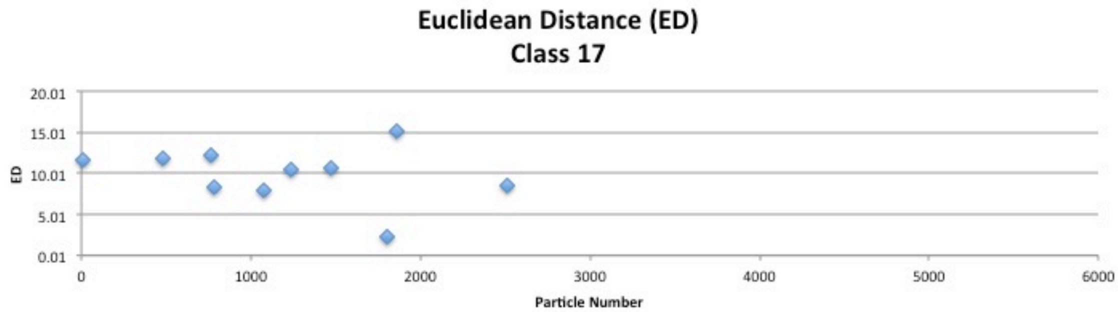

Figure 5-539: Euclidean Distance Class 17

Class 18 of Burkina Soil 73 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 32 particles in this class (Figure 5-540).

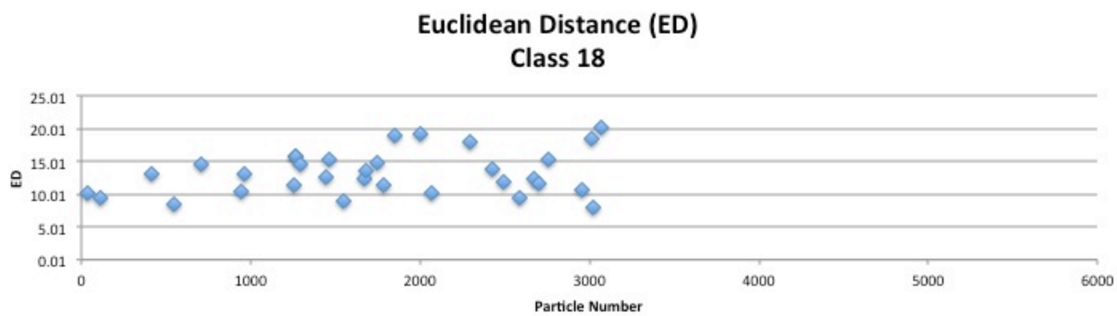

Figure 5-540: Euclidean Distance Class 18

Class 19 of Burkina Soil 73 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are 69 particles in this class (Figure 5-541).

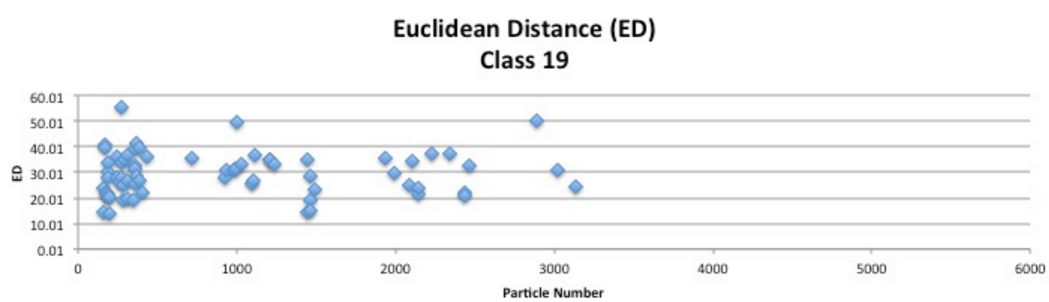

Figure 5-541: Euclidean Distance Class 19

Class 20 of Burkina Soil 73 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 314 particles in this class (Figure 5-542).

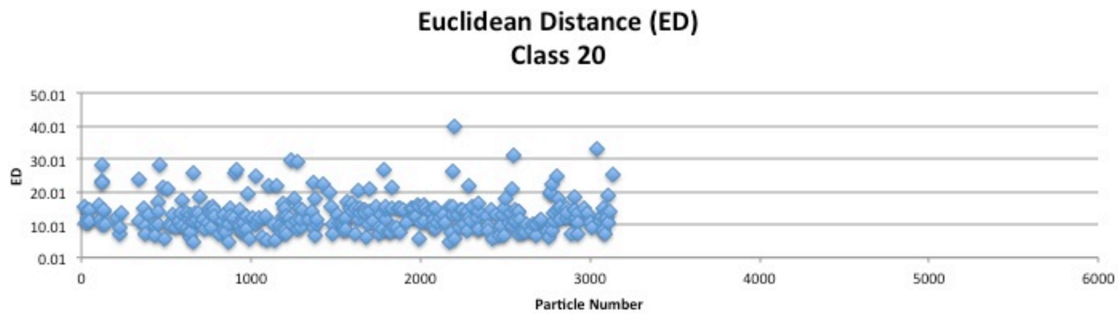

Figure 5-542: Euclidean Distance Class 20

Class 21 of Burkina Soil 73 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 46 particles in this class (Figure 5-543).

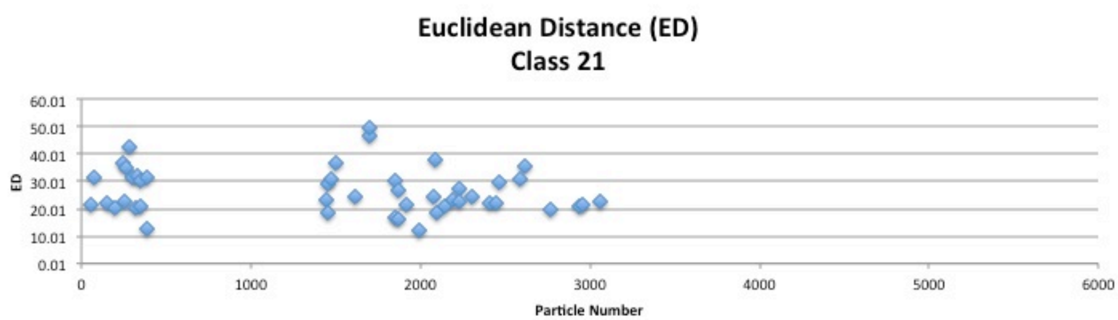

Figure 5-543: Euclidean Distance Class 21

Class 22 of Burkina Soil 73 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 96 particles in this class (Figure 5-544).

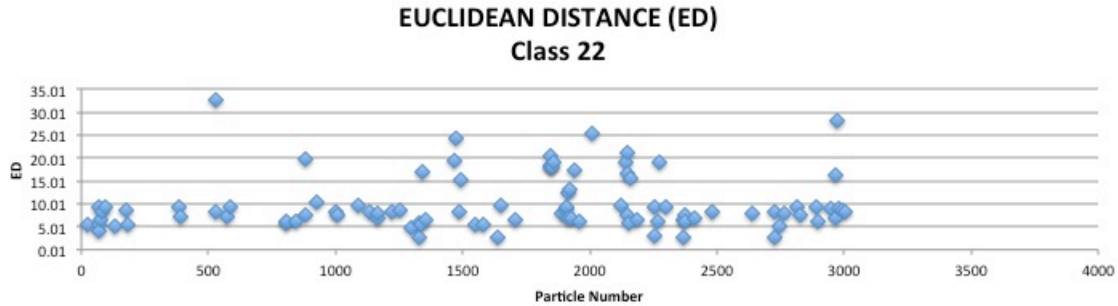

Figure 5-544: Euclidean Distance Class 22

Class 23 of Burkina Soil 73 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 93 particles in this class (Figure 5-545).

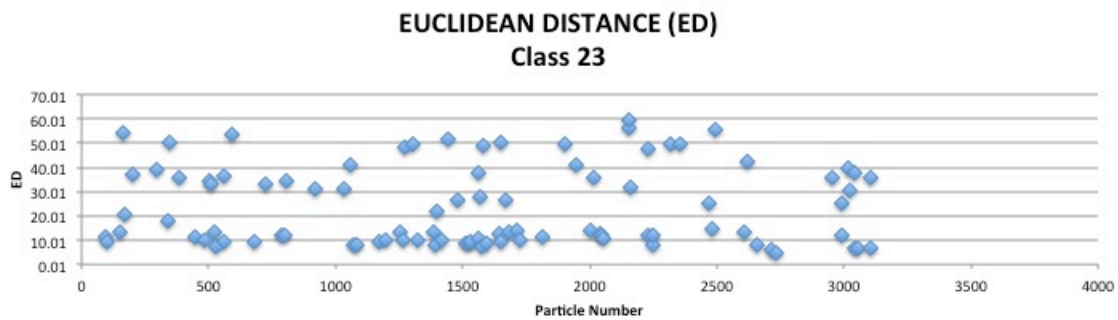

Figure 5-545: Euclidean Distance Class 23

Class 24 of Burkina Soil 73 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 96 particles in this class (Figure 5-546).

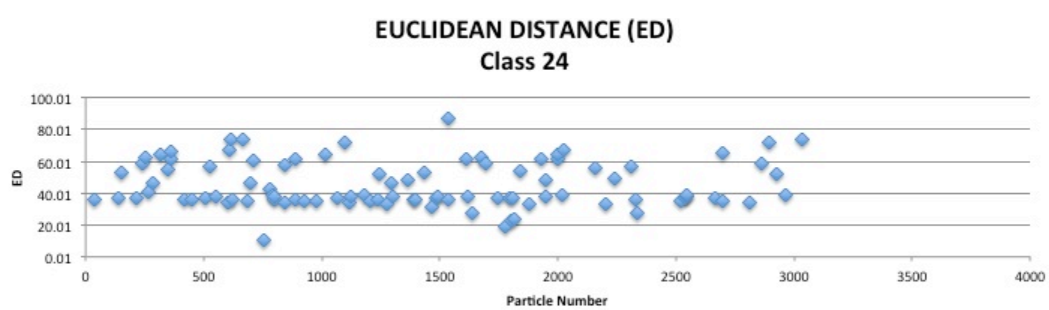

Figure 5-546: Euclidean Distance Class 24

Class 25 of Burkina Soil 73 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 146 particles in this class (Figure 5-547).

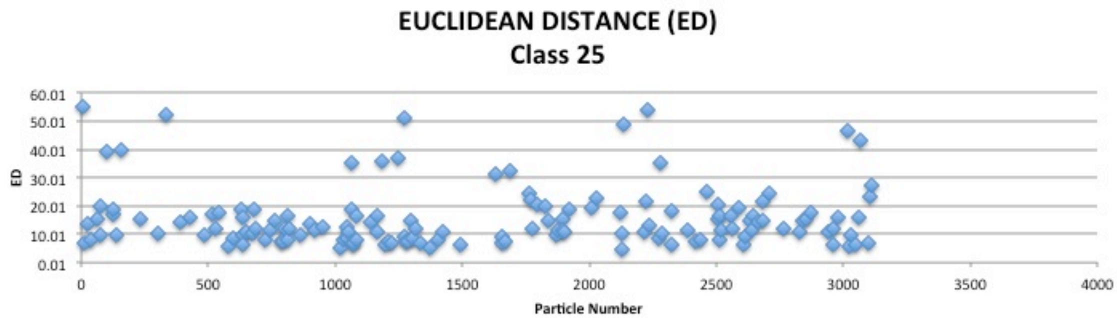

Figure 5-547: Euclidean Distance Class 25

Class 26 of Burkina Soil 73 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 131 particles in this class (Figure 5-548).

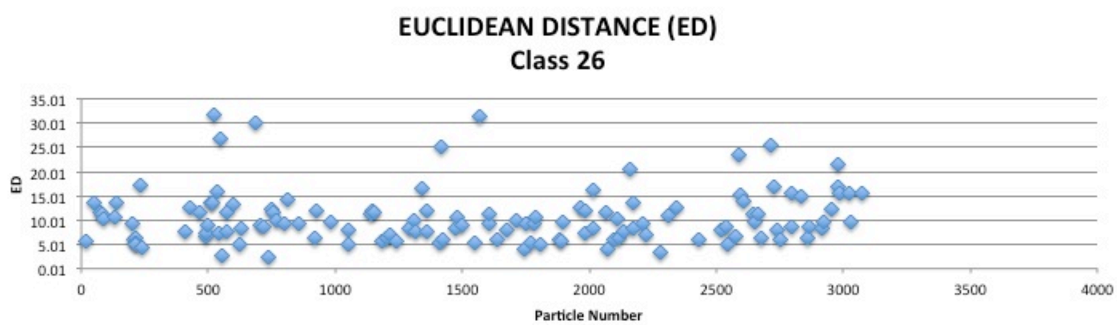

Figure 5-548: Euclidean Distance Class 26

Class 27 of Burkina Soil 73 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 967 particles in this class (Figure 5-549).

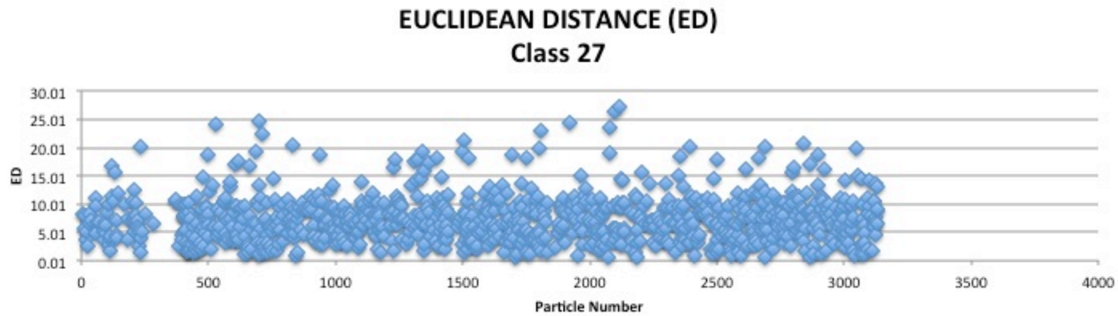

Figure 5-549: Euclidean Distance Class 27

Class 28 of Burkina Soil 73 is composed of Aluminum less than 1%. There are a total of 138 particles in this class (Figure 5-550).

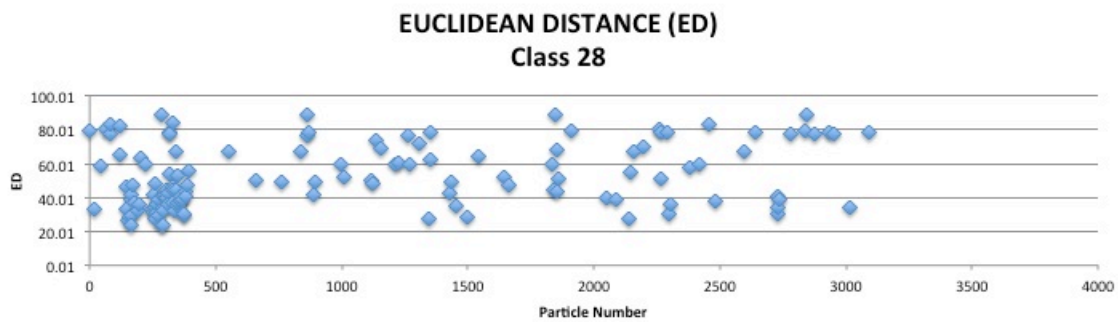

Figure 5-550: Euclidean Distance Class 28

Burkina Soil 76

Numerical and Volumetric Analysis

Burkina Soil 76 is located at 12 21.801' N, 1 03.116' W and has been separated into 29 elemental classes (Figure 5-551). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-47).

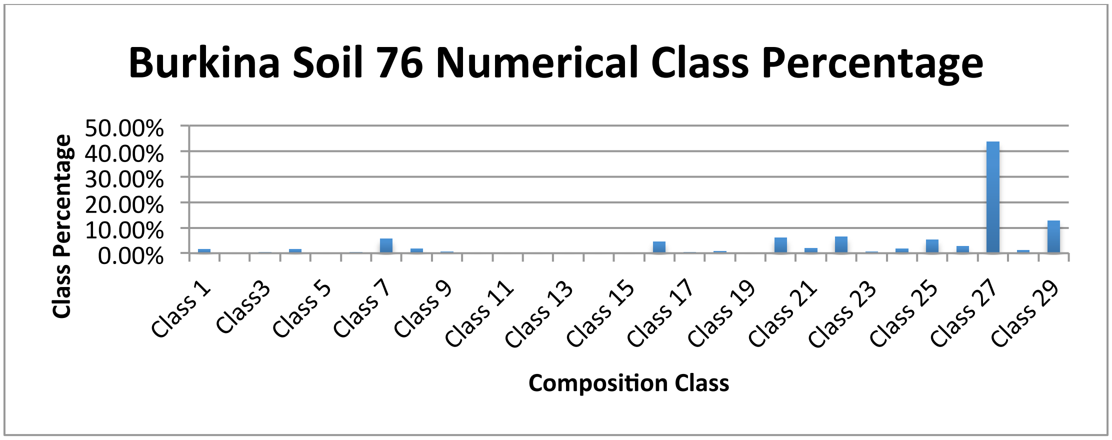

Figure 5-551: Burkina Soil 76 numerical percentage per class.

Table 5-47: Burkina Soil 76 numerical percentage and number of particles per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
31	3	6	30	1	6	115	35
1.50%	0.15%	0.29%	1.46%	0.05%	0.29%	5.58%	1.70%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
12	4	1	0	0	4	0	93
0.58%	0.19%	0.05%	0.00%	0.00%	0.19%	0.00%	4.51%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
6	17	0	123	42	133	13	35
0.29%	0.82%	0.00%	5.97%	2.04%	6.45%	0.63%	1.70%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
110	55	900	23	263	2061		
5.34%	2.67%	43.67%	1.12%	12.76%	100.00%		

Table 5-47 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 20, 22, and 27. Class 20 has Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 22 has

Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 27 is represented by Potassium and Calcium less than 1%, between 40% and 60% Aluminum, and 20% to 60% Silica. This represents 56.09% of the entire sample and contains a total of 1156 particles. Class 29 represents the "unclassified" particles and contains only 12.76% of the entire sample.

The volumetric percentage of Burkina Laterite 76 represents the volume of particles that are represented in each respective elemental class (Figure 5-552). Table 5-48 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 20, 22, and 27. Class 20 has Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 22 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 27 is represented by Potassium and Calcium less than 1%, between 40% and 60% Aluminum, and 20% to 60% Silica. This represents 72.04% of the entire sample and contains a total volume of 236212.44 μm^3. Class 29 represents the "unclassified" volume of particles and contains 10.82% of the entire sample.

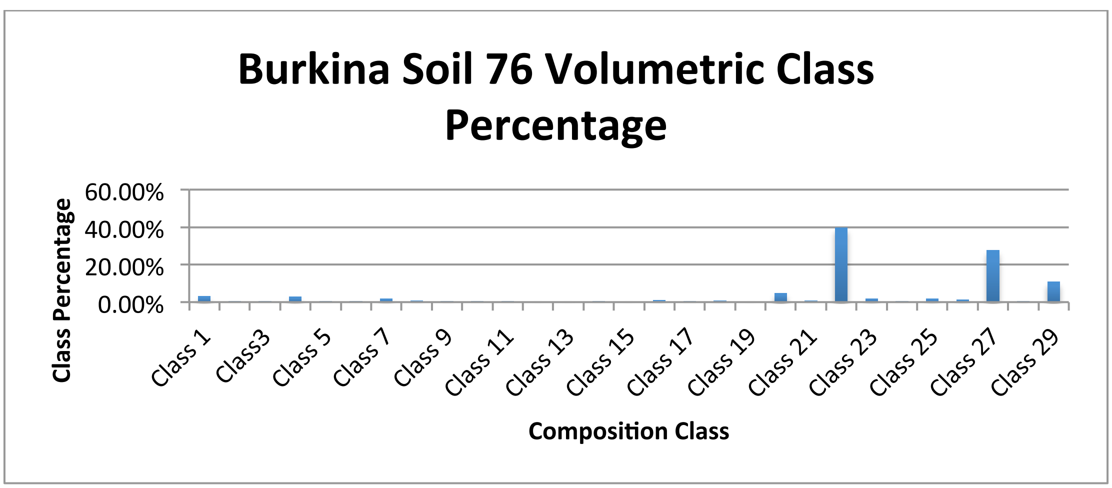

Figure 5-552: Volumetric percentages per class.

Table 5-48: Volumetric percentages and volume per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
9849.38	14.72	103.51	9005.07	0.50	5.53	5746.86	2092.79
3.00%	0.00%	0.03%	2.75%	0.00%	0.00%	1.75%	0.64%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
1870.24	7.62	17.56	0.00	0.00	145.10	0.00	2903.31
0.57%	0.00%	0.01%	0.00%	0.00%	0.04%	0.00%	0.89%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
581.60	2546.38	0.00	15785.36	2028.75	129779.46	6347.39	1231.30
0.18%	0.78%	0.00%	4.81%	0.62%	39.58%	1.94%	0.38%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
5522.84	4341.62	90647.62	1827.71	35462.33	327864.57		
1.68%	1.32%	27.65%	0.56%	10.82%	100.00%		

Analysis of class 29 showed a cluster of elements similar to the Burkina Laterites. The highest elements contained within Burkina Soil 76 unclassified are Fe, Si, Al, respectively, and compose a volume of 10.82% of the entire sample particles. Most of the unclassified elements are contained within the two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-553 and Figure 5-554). Approximately 75% of the unclassified particles are contained within these two distinct clusters.

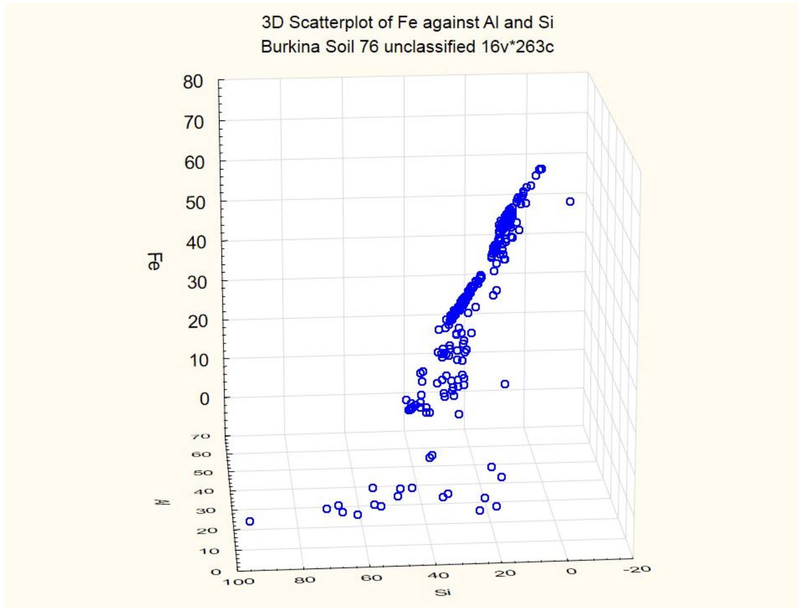

Figure 5-553: Scatterplot of Burkina Soil 76 elements Al, Si and Fe, showing a slight cluster of particles. The unclassified particles contain 10.82% volume of the particles in the sample.

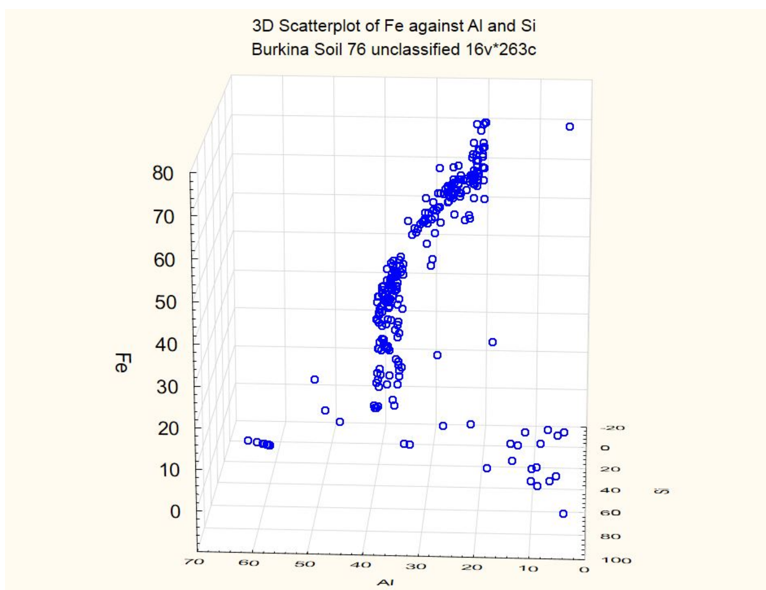

Figure 5-554: Burkina Soil 76 alternate 3D scatterplot view.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Soil 76 is composed of greater than 99% Silica. There are a total of 31 particles in this class (Figure 5-555).

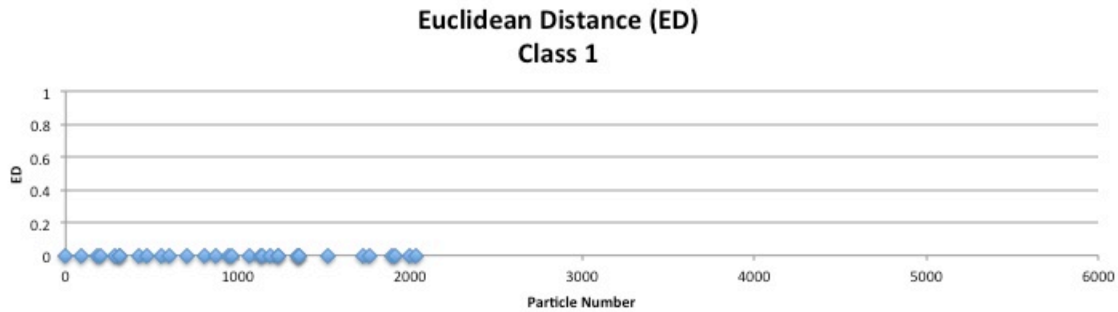

Figure 5-555: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 3 particles in this class (Figure 5-556).

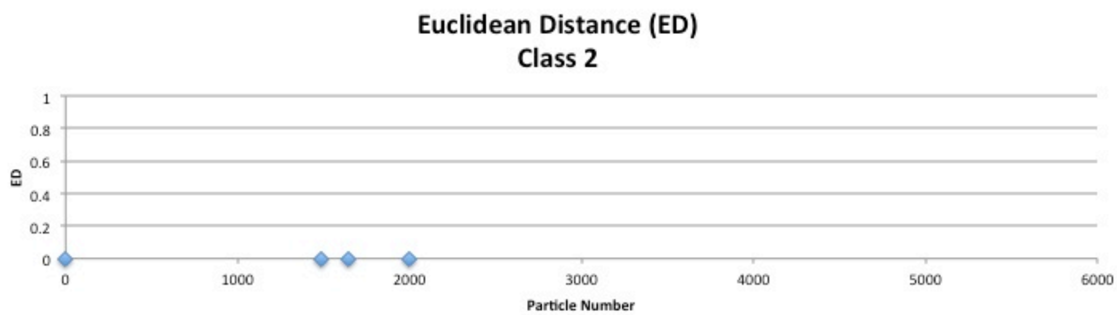

Figure 5-556: Euclidean Distance Class 2

Class 3 of Burkina Soil 76 is composed of greater than 99% Calcium. There are a total of 6 particles in this class (Figure 5-557).

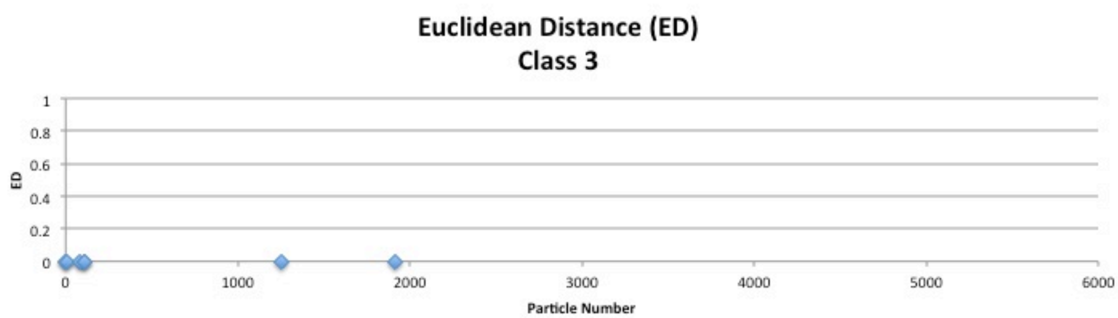

Figure 5-557: Euclidean Distance Class 3

Class 4 of Burkina Soil 76 is composed of Titanium greater than 55% and Lead less

than 5%. There are 30 particles in this class (Figure 5-558).

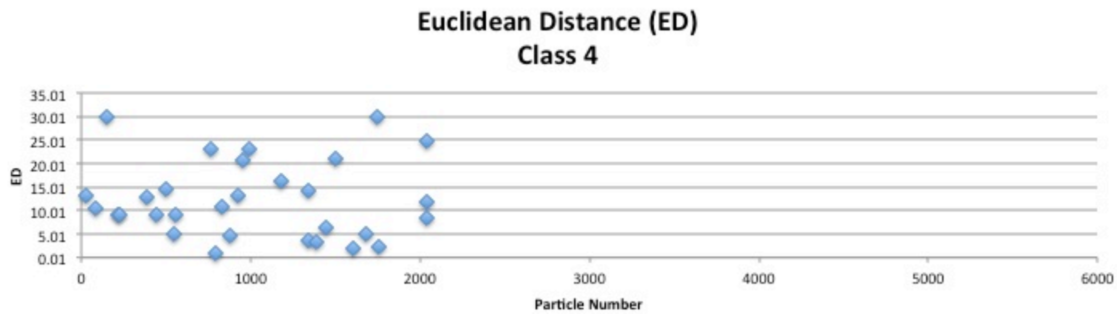

Figure 5-558: Euclidean Distance Class 4

Class 5 of Burkina Soil 76 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There is 1 particle in this class (Figure 5-559).

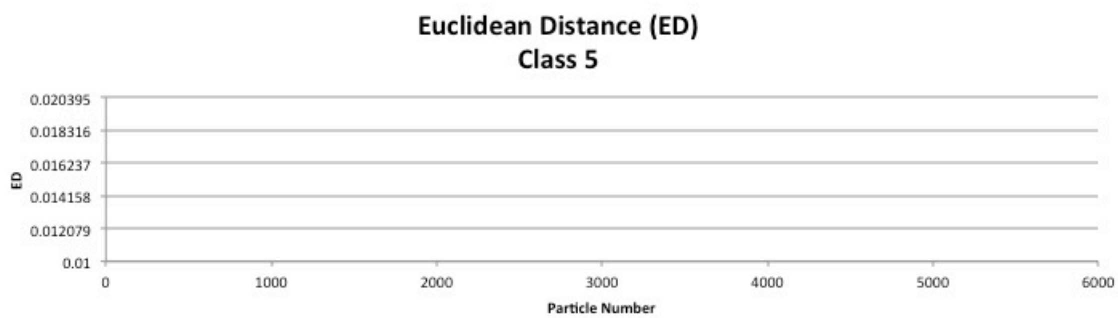

Figure 5-559: Euclidean Distance Class 5

Class 6 of Burkina Soil 76 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 6 particles in this class (Figure 5-560).

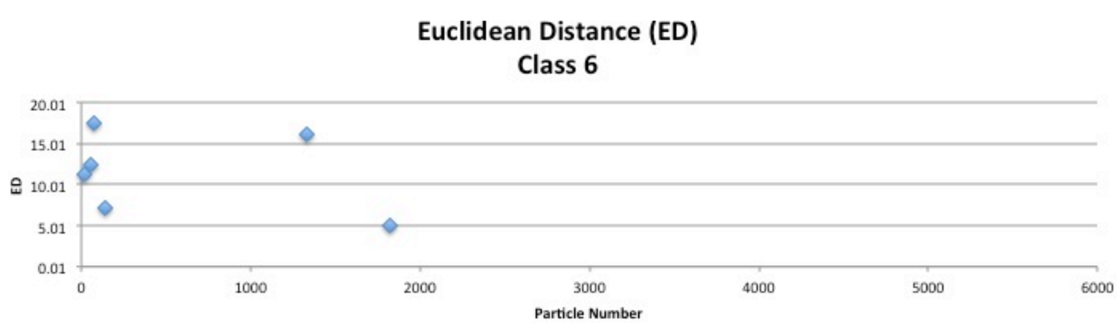

Figure 5-560: Euclidean Distance Class 6

Class 7 of Burkina Soil 76 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 115 particles in this class (Figure 5-561).

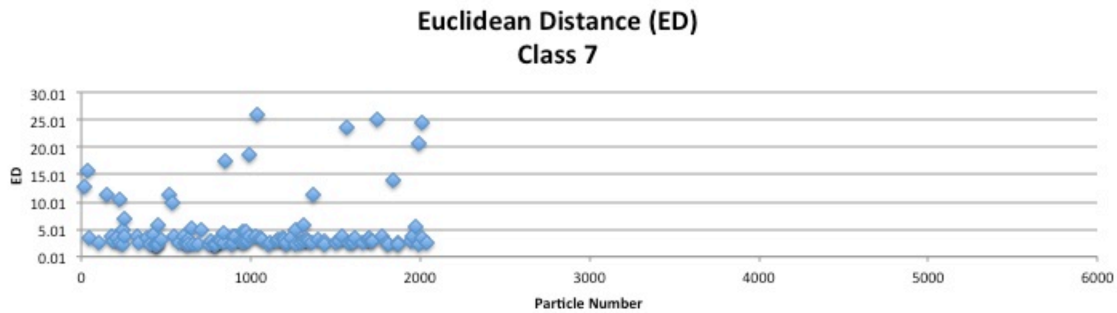

Figure 5-561: Euclidean Distance Class 7

Class 8 of Burkina Soil 76 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 35 particles in this class (Figure 5-562).

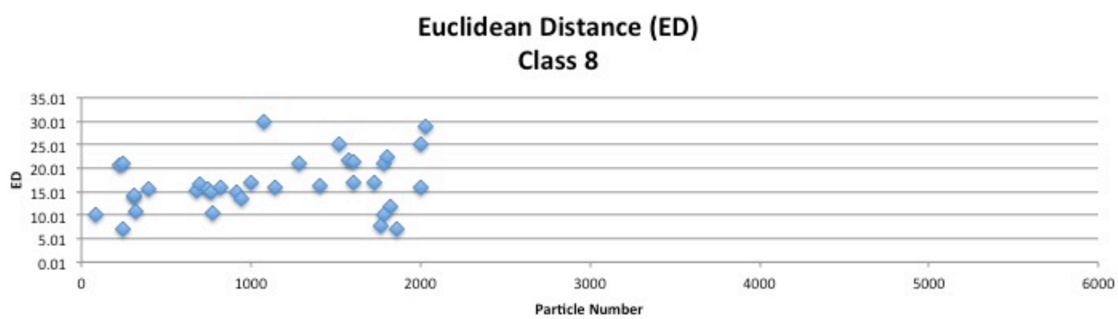

Figure 5-562: Euclidean Distance Class 8

Class 9 of Burkina Soil 76 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 12 particles in this class (Figure 5-563).

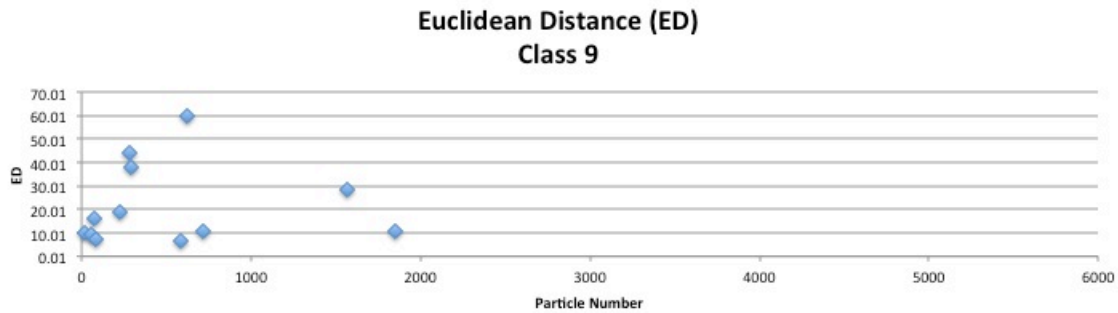

Figure 5-563: Euclidean Distance Class 9

Class 10 of Burkina Soil 76 is composed of Calcium greater than 80% and Lead less than 5%. There are 4 particles in this class (Figure 5-564).

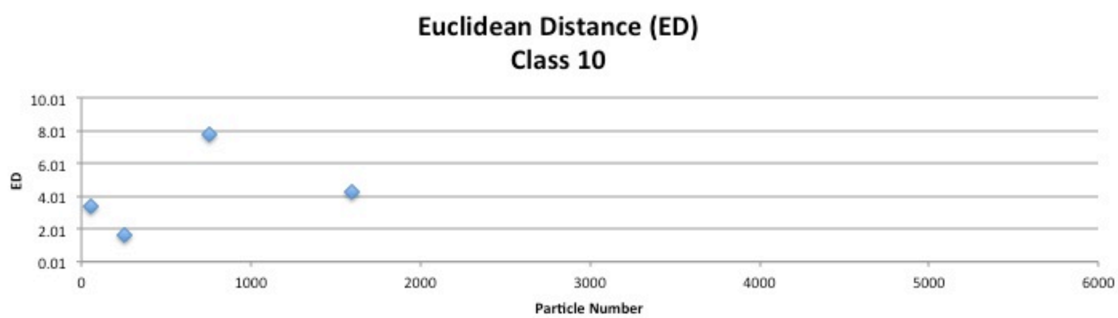

Figure 5-564: Euclidean Distance Class 10

Class 11 of Burkina Soil 76 is composed of the total Calcium and Manganese greater than 90%. There is 1 particle in this class (Figure 5-565).

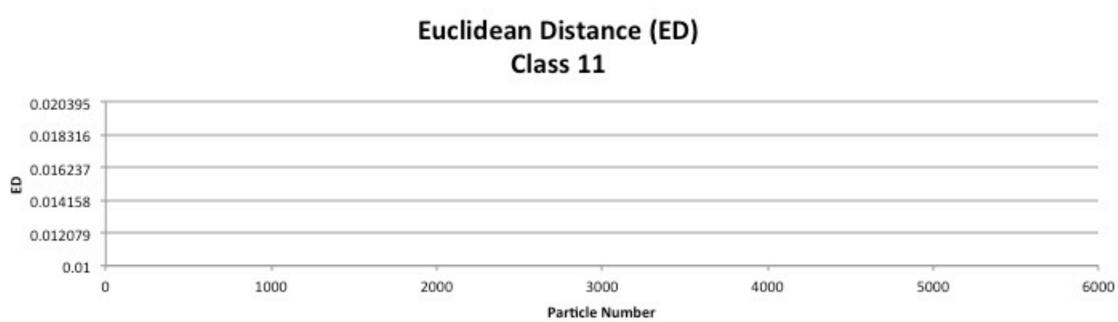

Figure 5-565: Euclidean Distance Class 11

Class 12 of Burkina Soil 76 is composed of the total Calcium and Phosphorus greater

than 90%. There are no particles in this class.

Class 13 of Burkina Soil 76 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are no particles in this class.

Class 14 of Burkina Soil 76 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are 4 particles in this class (Figure 5-566).

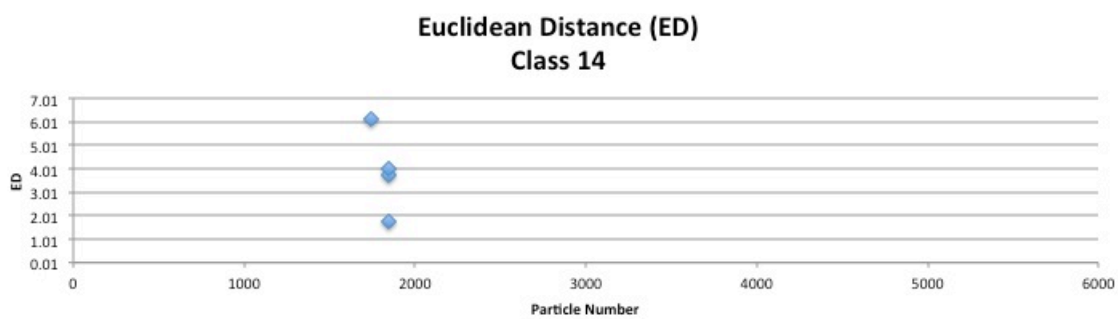

Figure 5-566: Euclidean Distance Class 14

Class 15 of Burkina Soil 76 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Soil 76 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 93 particles in this class (Figure 5-567).

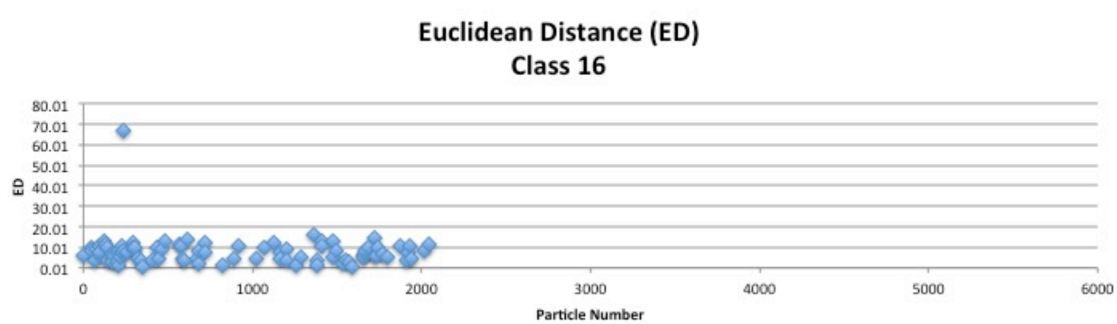

Figure 5-567: Euclidean Distance Class 16

Class 17 of Burkina Soil 76 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 6 particles in this class (Figure 5-568).

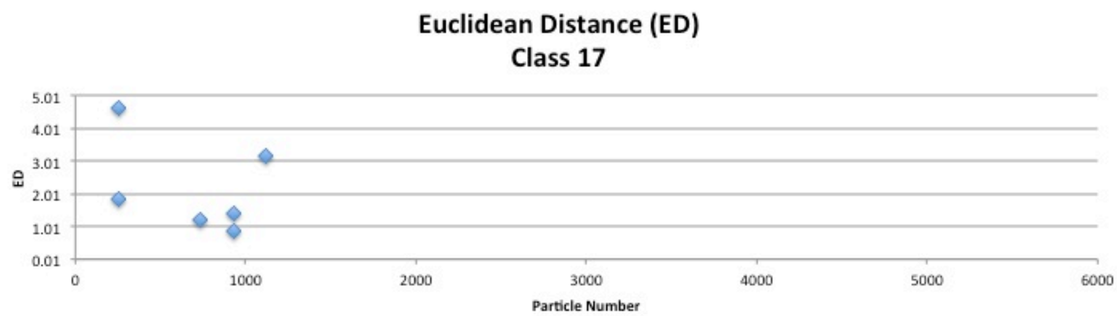

Figure 5-568: Euclidean Distance Class 17

Class 18 of Burkina Soil 76 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 17 particles in this class (Figure 5-569).

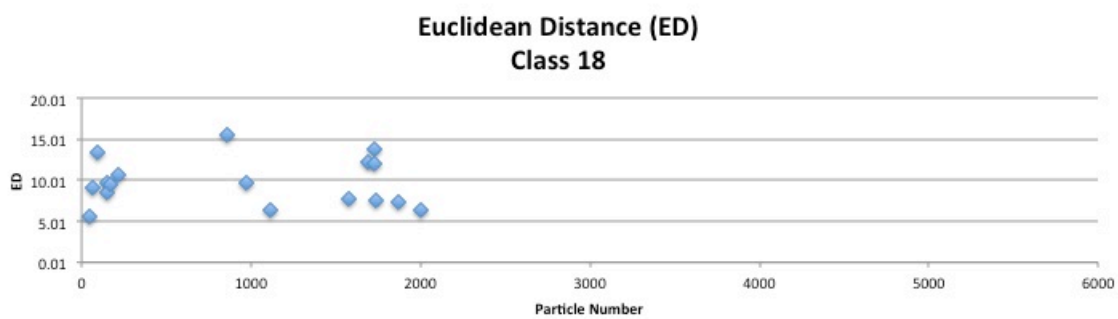

Figure 5-569: Euclidean Distance Class 18

Class 19 of Burkina Soil 76 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are no particles in this class.

Class 20 of Burkina Soil 76 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 123 particles in this class (Figure 5-570).

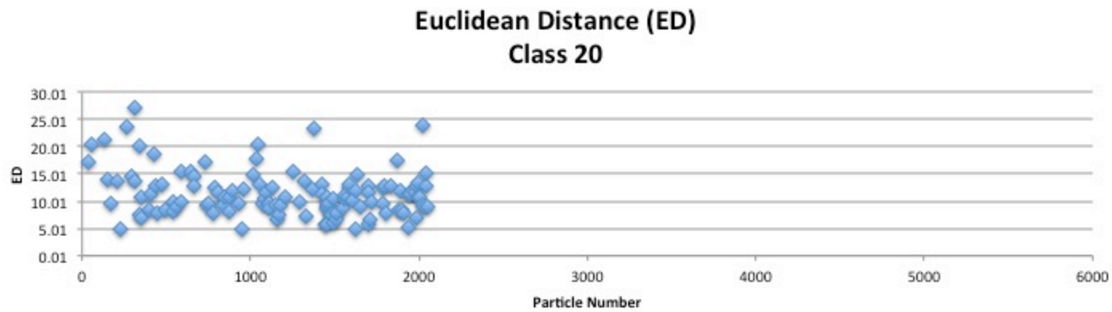

Figure 5-570: Euclidean Distance Class 20

Class 21 of Burkina Soil 76 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 42 particles in this class (Figure 5-571).

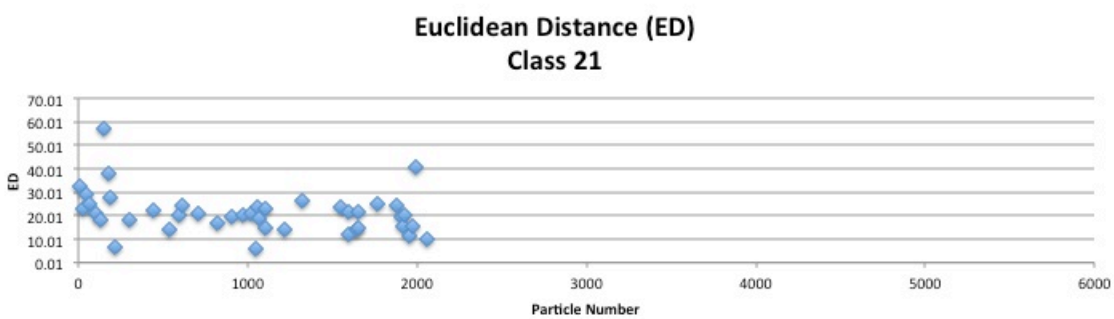

Figure 5-571: Euclidean Distance Class 21

Class 22 of Burkina Soil 76 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 133 particles in this class (Figure 5-572).

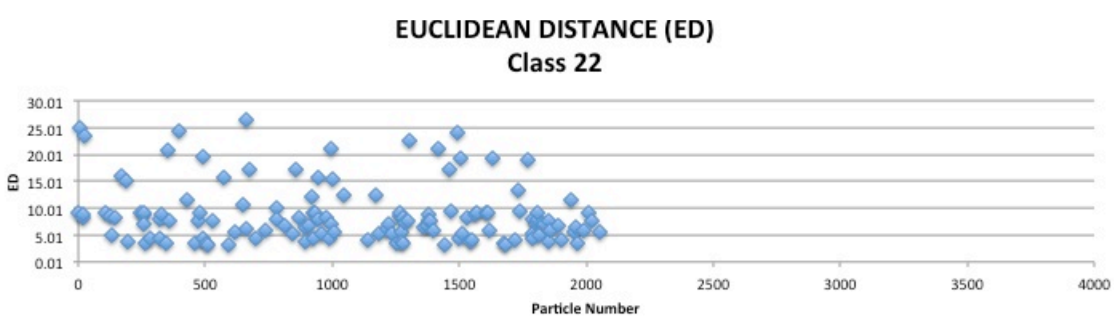

Figure 5-572: Euclidean Distance Class 22

Class 23 of Burkina Soil 76 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 13 particles in this class (Figure 5-573).

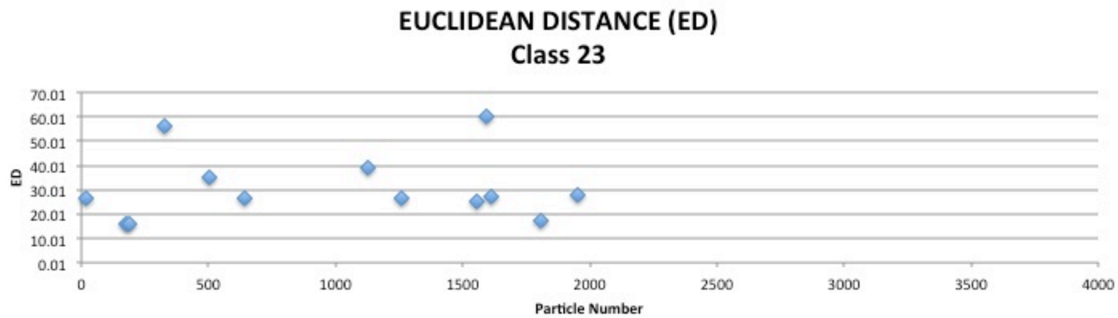

Figure 5-573: Euclidean Distance Class 23

Class 24 of Burkina Soil 76 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 35 particles in this class (Figure 5-574).

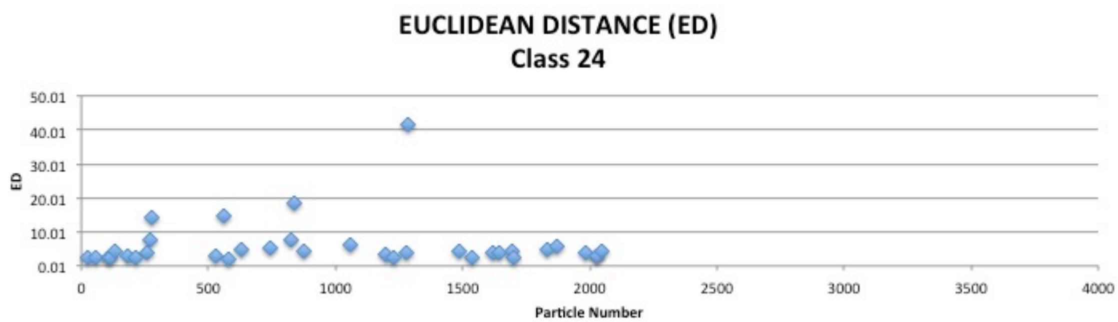

Figure 5-574: Euclidean Distance Class 24

Class 25 of Burkina Soil 76 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 110 particles in this class (Figure 5-575).

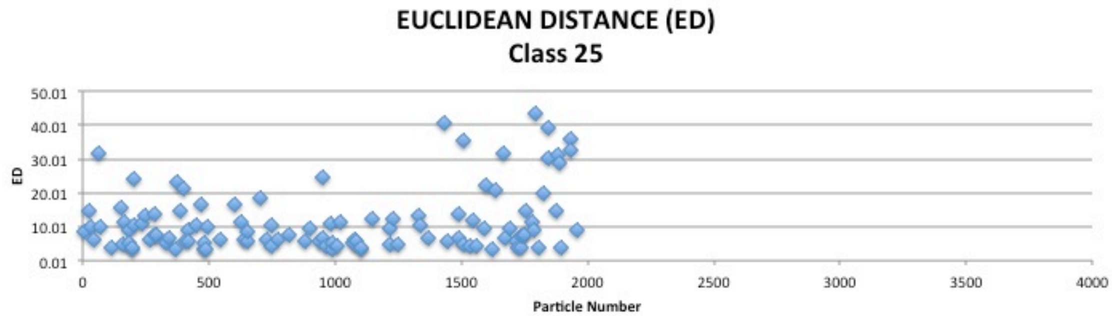

Figure 5-575: Euclidean Distance Class 25

Class 26 of Burkina Soil 76 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 55 particles in this class (Figure 5-576).

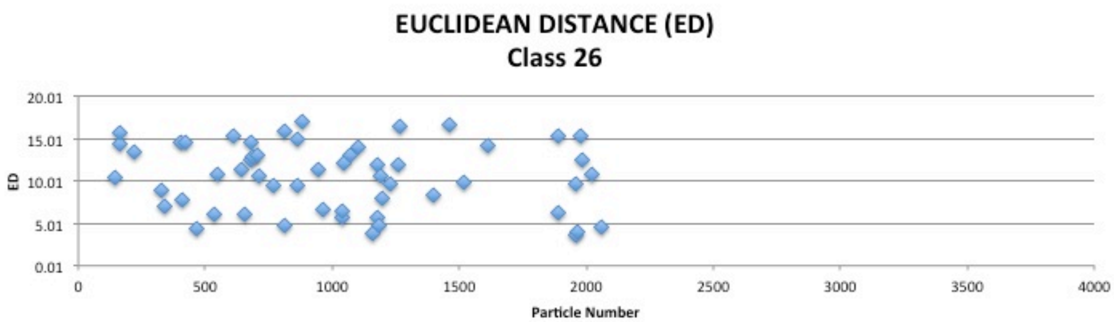

Figure 5-576: Euclidean Distance Class 26

Class 27 of Burkina Soil 76 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 900 particles in this class (Figure 5-577).

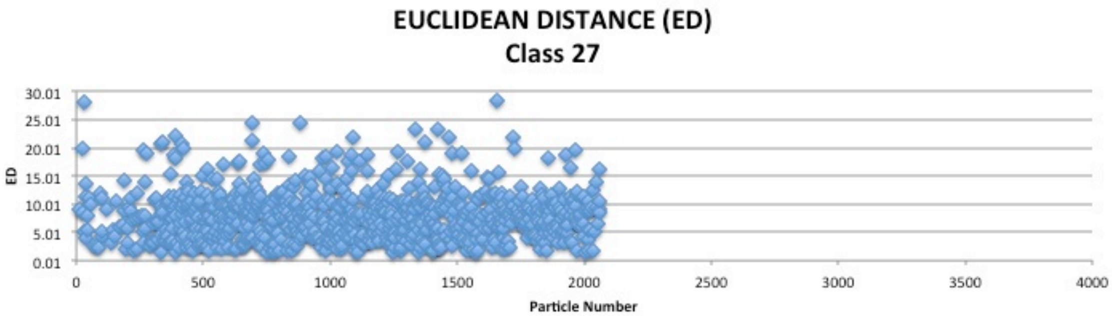

Figure 5-577: Euclidean Distance Class 27

Class 28 of Burkina Soil 76 is composed of Aluminum less than 1%. There are a total of 23 particles in this class (Figure 5-578).

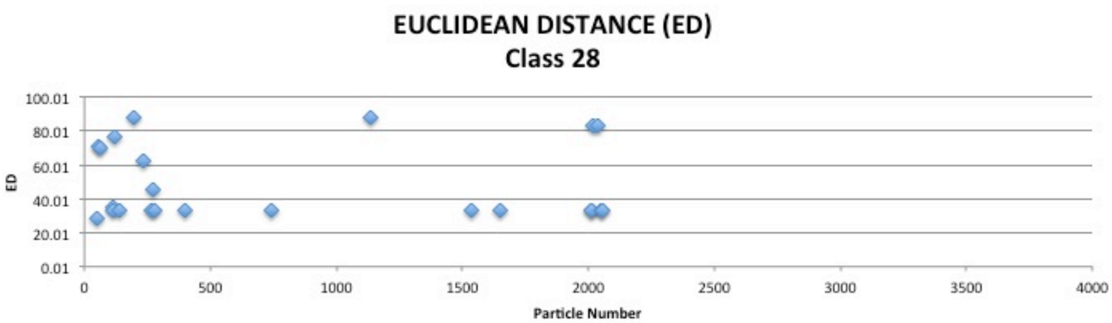

Figure 5-578: Euclidean Distance Class 28

Burkina Soil 77

Numerical and Volumetric Analysis

Burkina Soil 77 is located at 12 29.038’ N, 1 14.738’ W and has been separated into 29 elemental classes (Figure 5-579). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-49).

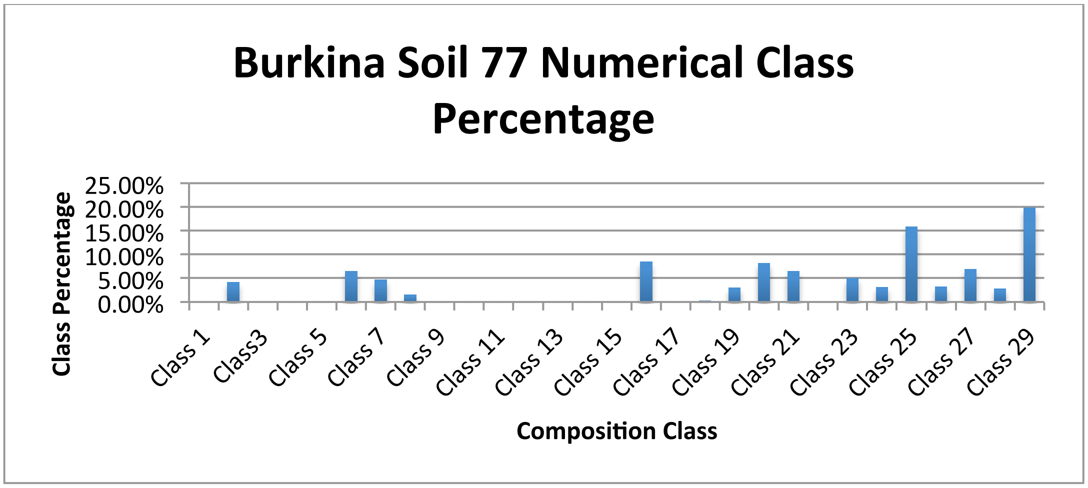

Figure 5-579: Numerical percentage per class.

Table 5-49: Numerical Percentage and Number of particles per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
0	165	0	0	1	258	185	59
0.00%	4.13%	0.00%	0.00%	0.03%	6.45%	4.63%	1.48%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	0	0	0	0	0	339
0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	8.48%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
1	12	120	327	258	7	199	124
0.03%	0.30%	3.00%	8.18%	6.45%	0.18%	4.98%	3.10%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
634	128	277	112	793	3999		
15.85%	3.20%	6.93%	2.80%	19.83%	100.00%		

Table 5-49 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 16, 20, and 25. Class 16 has Iron greater than 40% and the total Iron and Calcium greater than 75%. Class 20 has Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 25 has Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. This represents 32.51% of the entire sample and contains a total of 1300 particles. Class 29 represents the “unclassified” particles and contains only 19.56% of the entire sample.

The volumetric percentage of Burkina Laterite 77 represents the volume of particles that are represented in each respective elemental class (Figure 5-580). Table 5-50 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 25, 26, and 27. Class 25 has Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. Class 26 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. Class 27 contains Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 43.37% of the entire sample and contains a total volume of 23427.64 μm^3. Class 29 represents the “unclassified” volume of particles and contains 19.56% of the entire sample

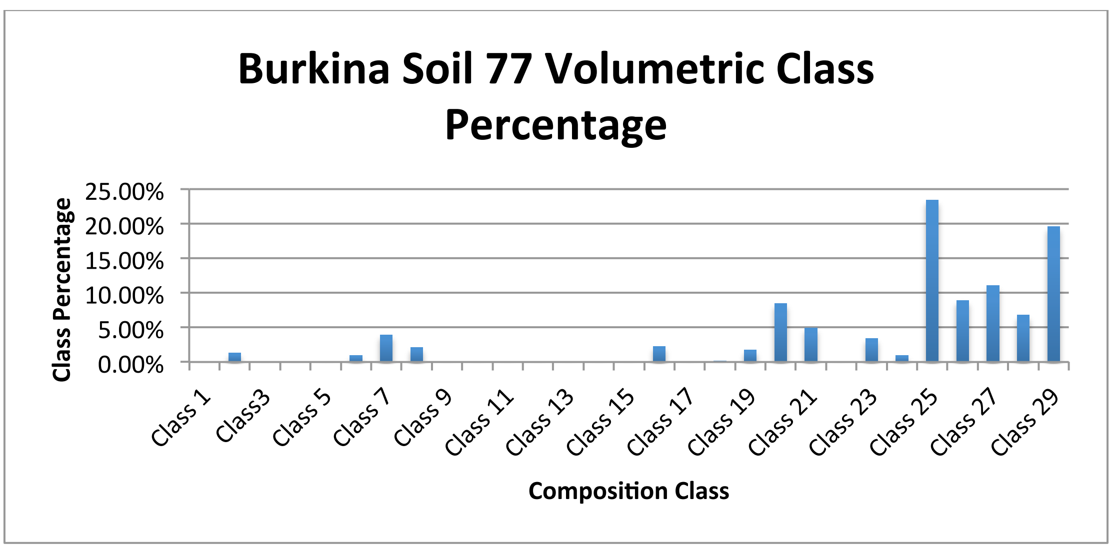

Figure 5-580: Volumetric percentage per class.

Table 5-50: Volumetric Percentage and volume per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
0.00	703.19	0.00	0.00	0.14	524.71	2130.55	1126.13
0.00%	1.30%	0.00%	0.00%	0.00%	0.97%	3.94%	2.08%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1218.10
0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.25%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
17.25	75.53	946.19	4585.42	2670.99	13.56	1846.25	511.35
0.03%	0.14%	1.75%	8.49%	4.94%	0.03%	3.42%	0.95%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
12650.63	4806.09	5970.92	3661.13	10566.76	54024.89		
23.42%	8.90%	11.05%	6.78%	19.56%	100.00%		

Analysis of class 29 showed a cluster of elements similar to the Burkina Laterites. The highest elements contained within Burkina Soil 77 unclassified are Fe, Si, Al, respectively, and compose a volume of 19.56% of the entire sample particles. The unclassified elements are evenly spread between the elements Iron, Silica and Aluminum (Figure 5-581 and Figure 5-582).

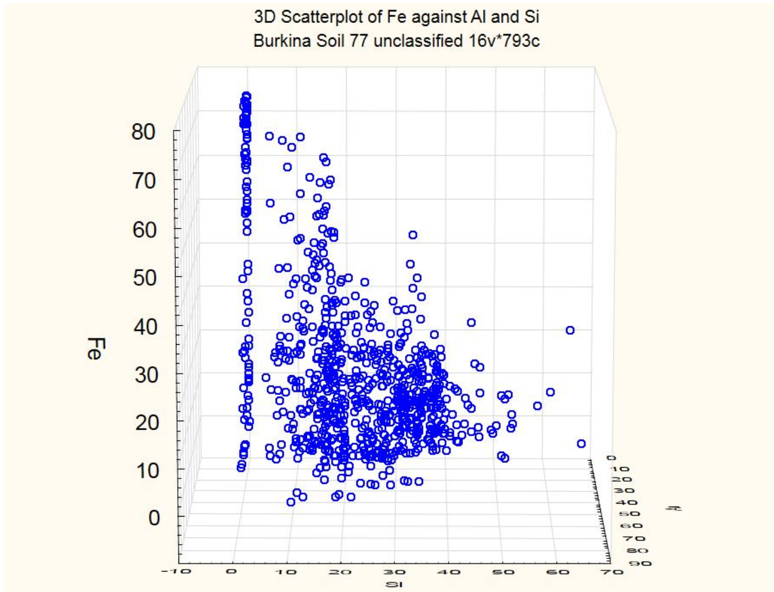

Figure 5-581: Scatterplot of Burkina Soil 77 elements Al, Si and Fe. The unclassified particles contain 19.56% volume of the particles in the sample.

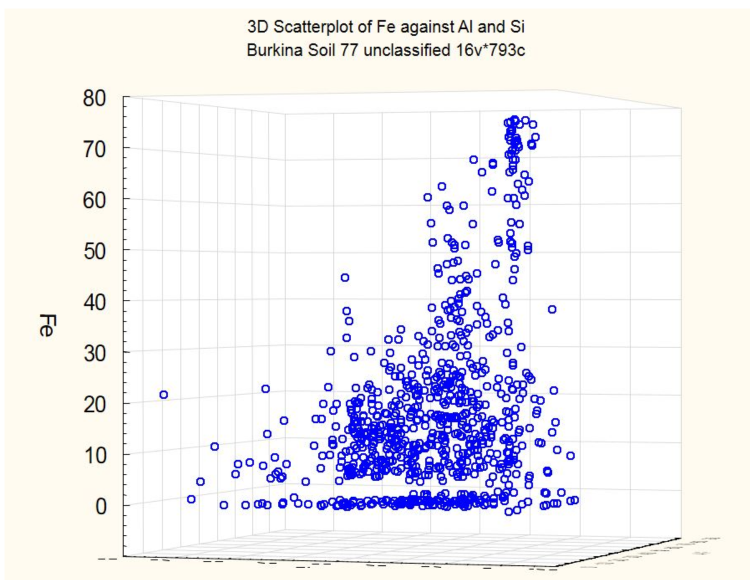

Figure 5-582: Burkina Soil 77 alternate 3D scatterplot view.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Soil 77 is composed of greater than 99% Silica. There are no particles in this class.

Class 2 is composed of greater than 99% Iron. There are a total of 165 particles in this class (Figure 5-583).

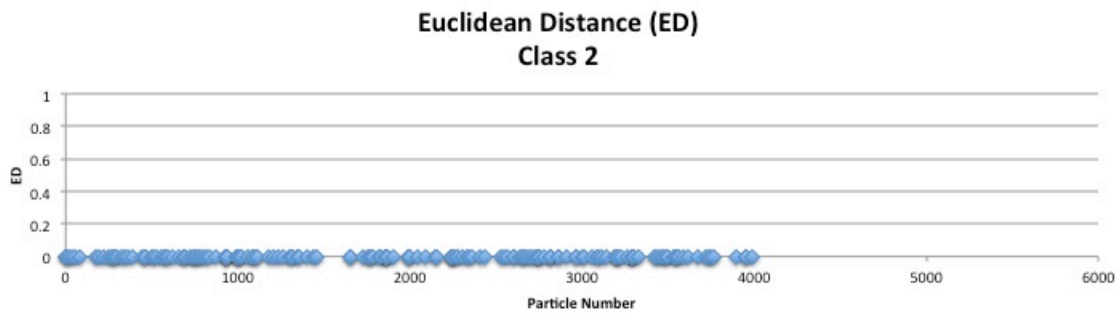

Figure 5-583: Euclidean Distance Class 2

Class 3 of Burkina Soil 77 is composed of greater than 99% Calcium. There are no particles in this class.

Class 4 of Burkina Soil 77 is composed of Titanium greater than 55% and Lead less than 5%. There are no particles in this class.

Class 5 of Burkina Soil 77 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There is 1 particle in this class (Figure 5-584).

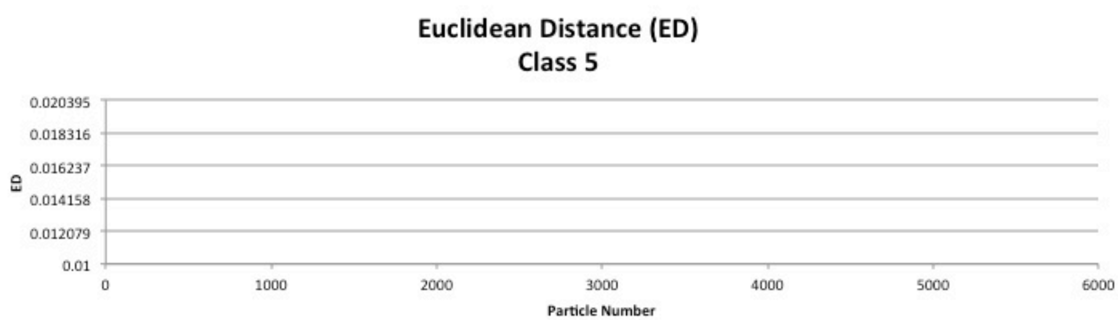

Figure 5-584: Euclidean Distance Class 5

Class 6 of Burkina Soil 77 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 258 particles in this class (Figure 5-585).

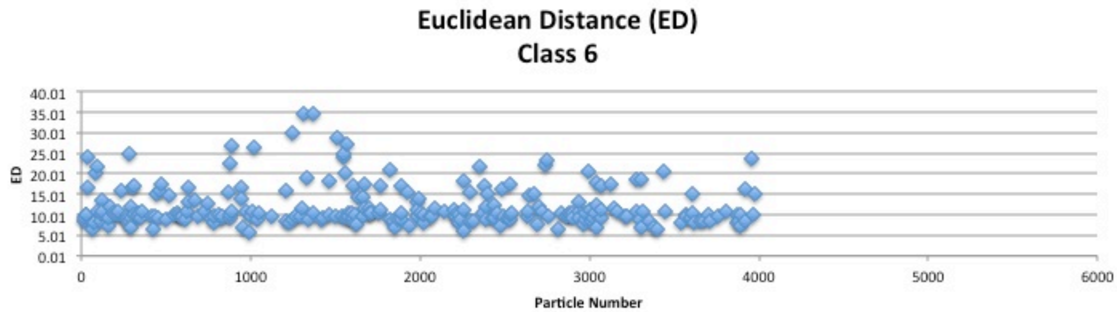

Figure 5-585: Euclidean Distance Class 6

Class 7 of Burkina Soil 77 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 185 particles in this class (Figure 5-586).

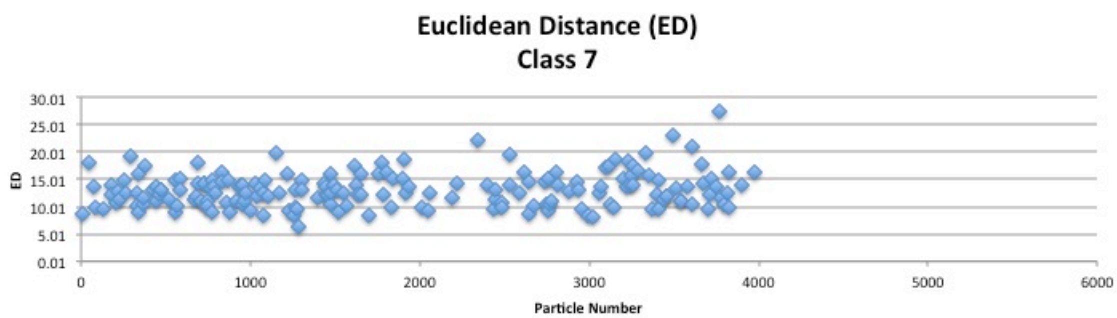

Figure 5-586: Euclidean Distance Class 7

Class 8 of Burkina Soil 77 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 59 particles in this class (Figure 5-587).

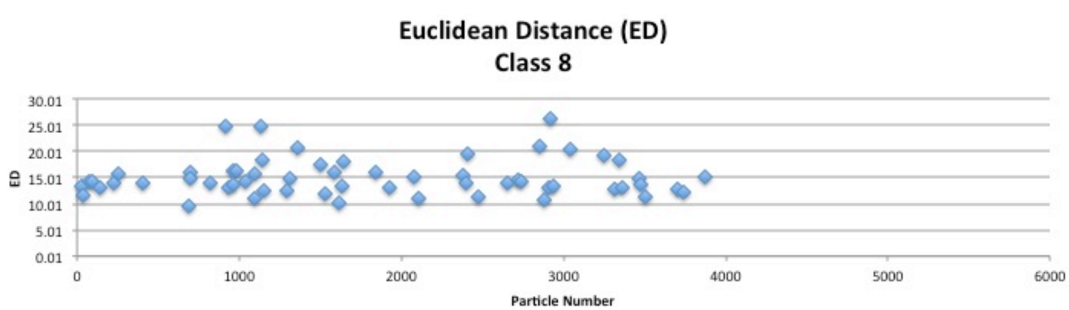

Figure 5-587: Euclidean Distance Class 8

Class 9 of Burkina Soil 77 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Soil 77 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Soil 77 is composed of the total Calcium and Manganese greater than 90%. There are no particles in this class.

Class 12 of Burkina Soil 77 is composed of the total Calcium and Phosphorus greater than 90%. There are no particles in this class.

Class 13 of Burkina Soil 77 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are no particles in this class.

Class 14 of Burkina Soil 77 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are no particles in this class.

Class 15 of Burkina Soil 77 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Soil 77 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 339 particles in this class (Figure 5-588).

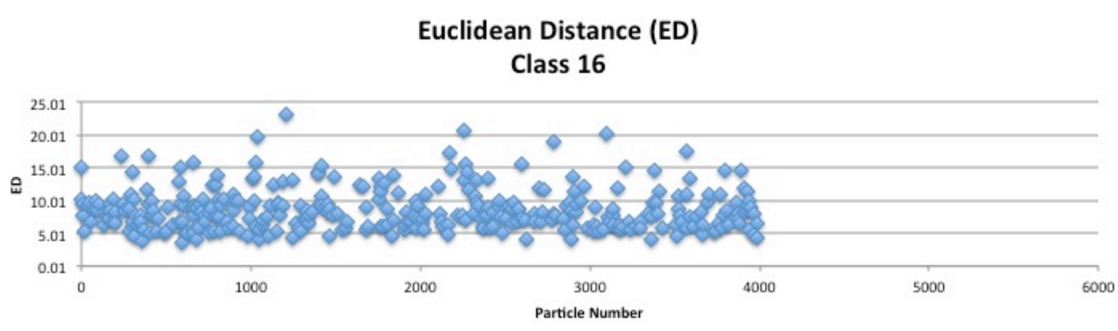

Figure 5-588: Euclidean Distance Class 16

Class 17 of Burkina Soil 77 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There is 1 particle in this class (Figure 5-589).

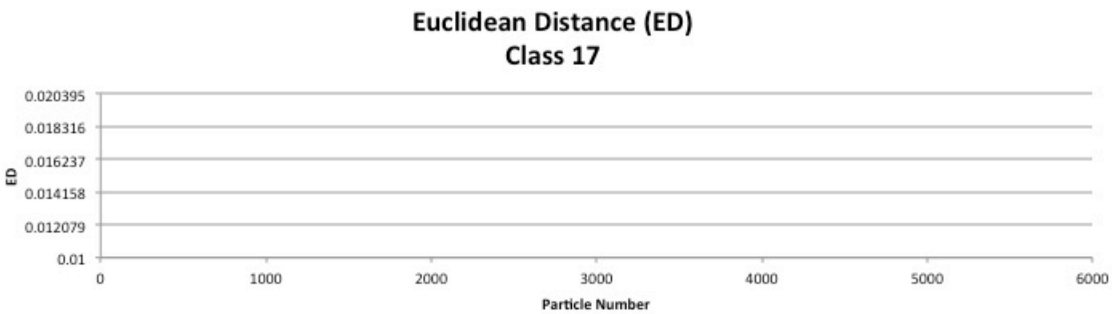

Figure 5-589: Euclidean Distance Class 17

Class 18 of Burkina Soil 77 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 12 particles in this class (Figure 5-590).

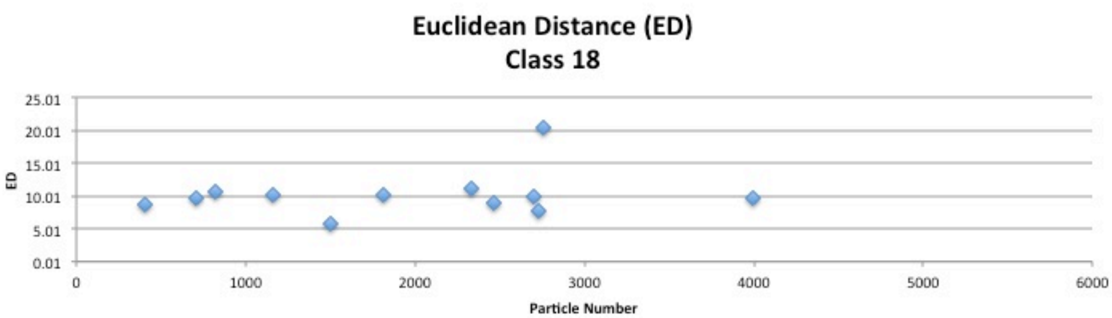

Figure 5-590: Euclidean Distance Class 18

Class 19 of Burkina Soil 77 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are 120 particles in this class (Figure 5-591).

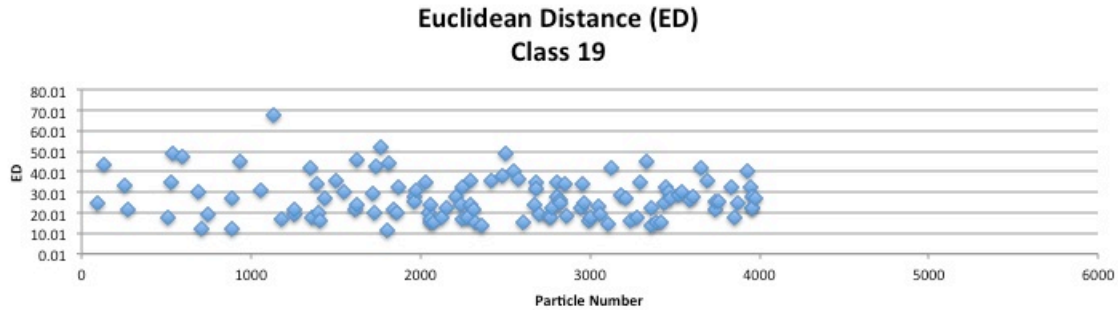

Figure 5-591: Euclidean Distance Class 19

Class 20 of Burkina Soil 77 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 327 particles in this class (Figure 5-592).

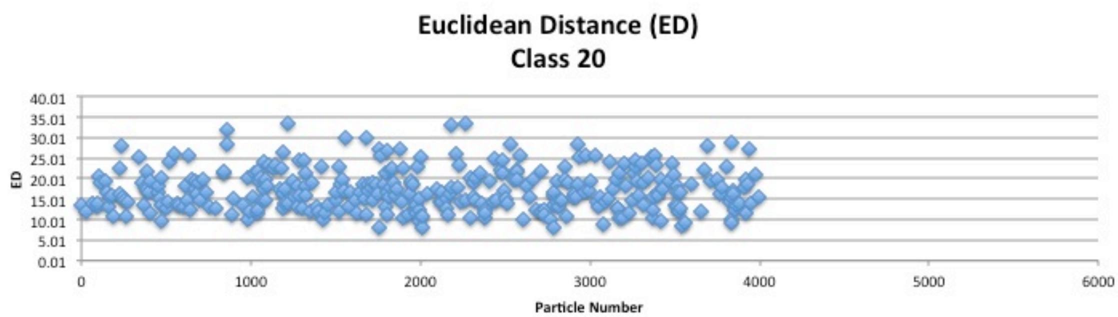

Figure 5-592: Euclidean Distance Class 20

Class 21 of Burkina Soil 77 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 258 particles in this class (Figure 5-593).

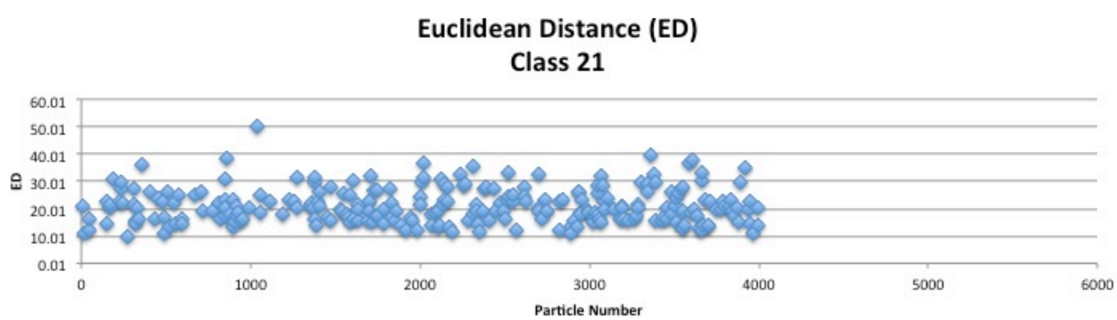

Figure 5-593: Euclidean Distance Class 21

Class 22 of Burkina Soil 77 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 7 particles in this class (Figure 5-594).

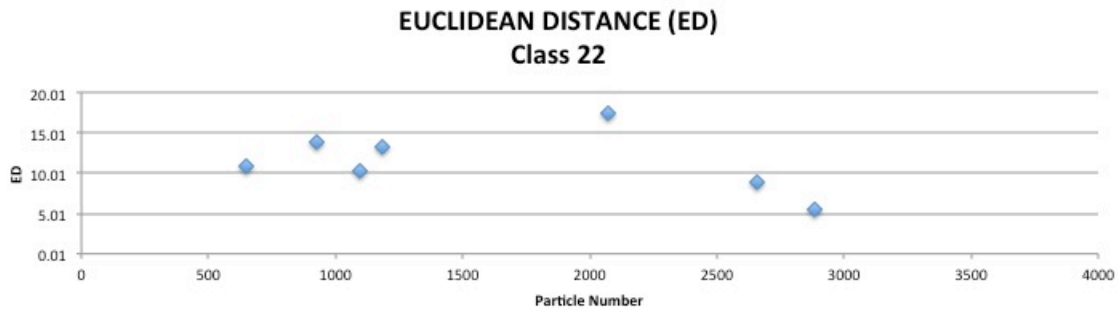

Figure 5-594: Euclidean Distance Class 22

Class 23 of Burkina Soil 77 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 199 particles in this class (Figure 5-595).

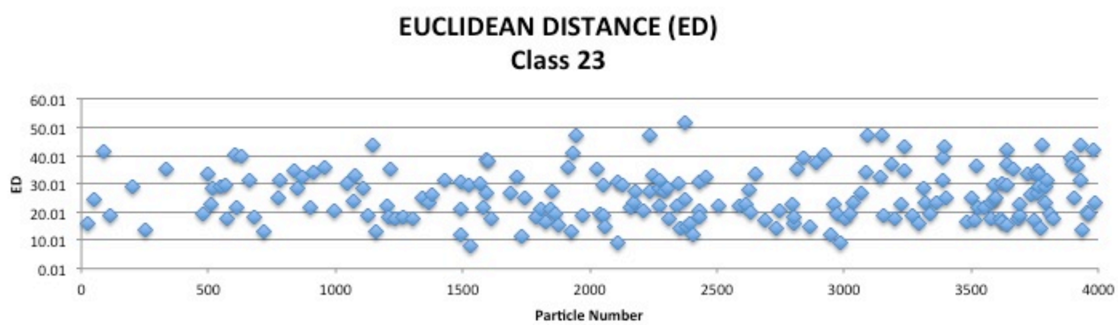

Figure 5-595: Euclidean Distance Class 23

Class 24 of Burkina Soil 77 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 124 particles in this class (Figure 5-596).

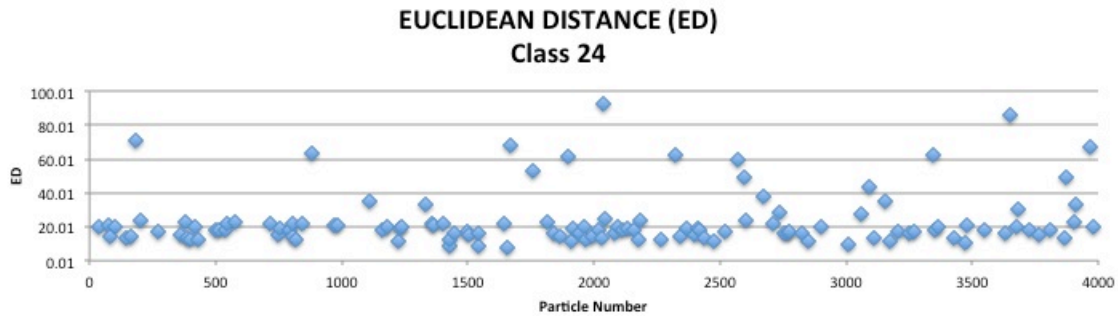

Figure 5-596: Euclidean Distance Class 24

Class 25 of Burkina Soil 77 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 634 particles in this class (Figure 5-597).

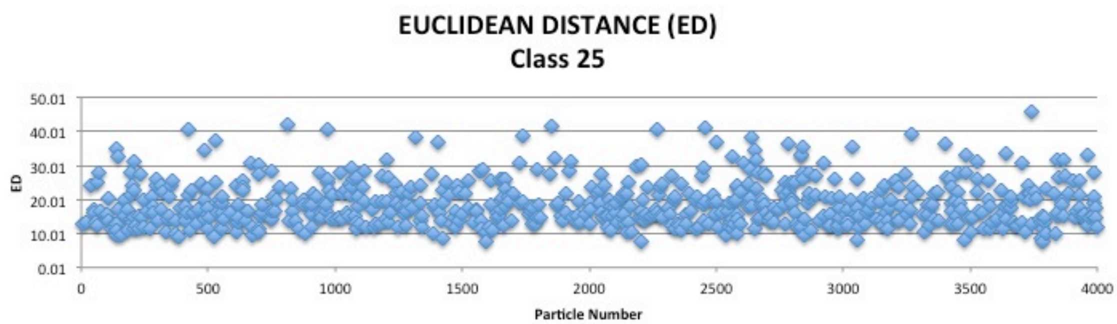

Figure 5-597: Euclidean Distance Class 25

Class 26 of Burkina Soil 77 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 128 particles in this class (Figure 5-598).

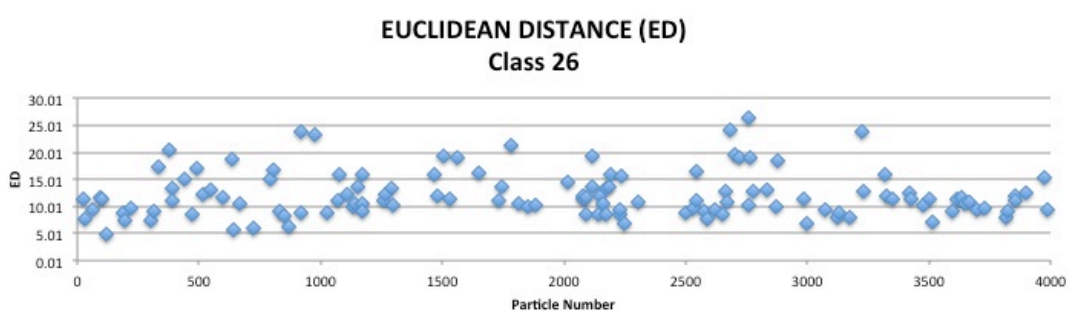

Figure 5-598: Euclidean Distance Class 26

Class 27 of Burkina Soil 77 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 277 particles in this class (Figure 5-599).

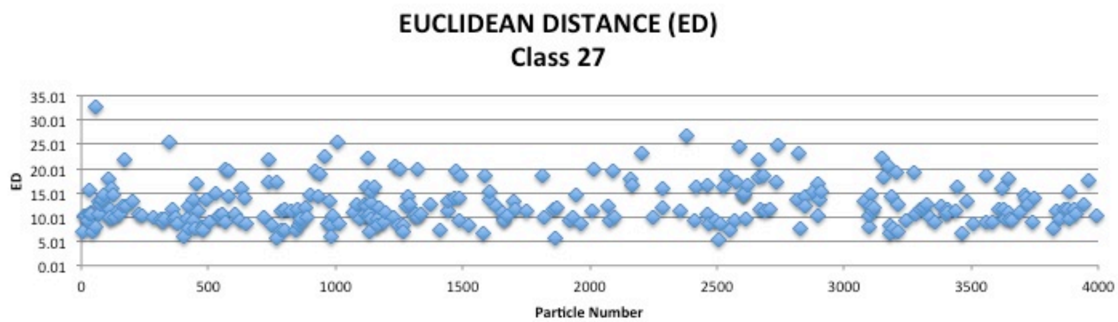

Figure 5-599: Euclidean Distance Class 27

Class 28 of Burkina Soil 77 is composed of Aluminum less than 1%. There are a total of 112 particles in this class (Figure 5-600).

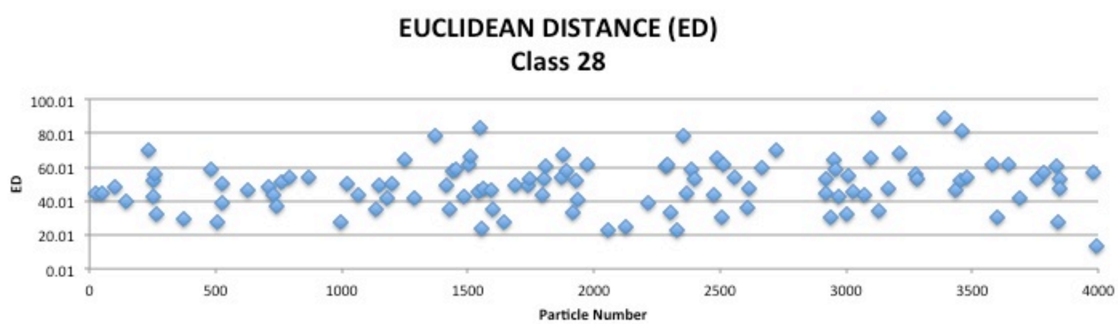

Figure 5-600: Euclidean Distance Class 28

Burkina Soil 78

Numerical and Volumetric Analysis

Burkina Soil 78 is located at 12 24.672' N, 1 25.207' W and has been separated into 29 elemental classes (Figure 5-601). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-51).

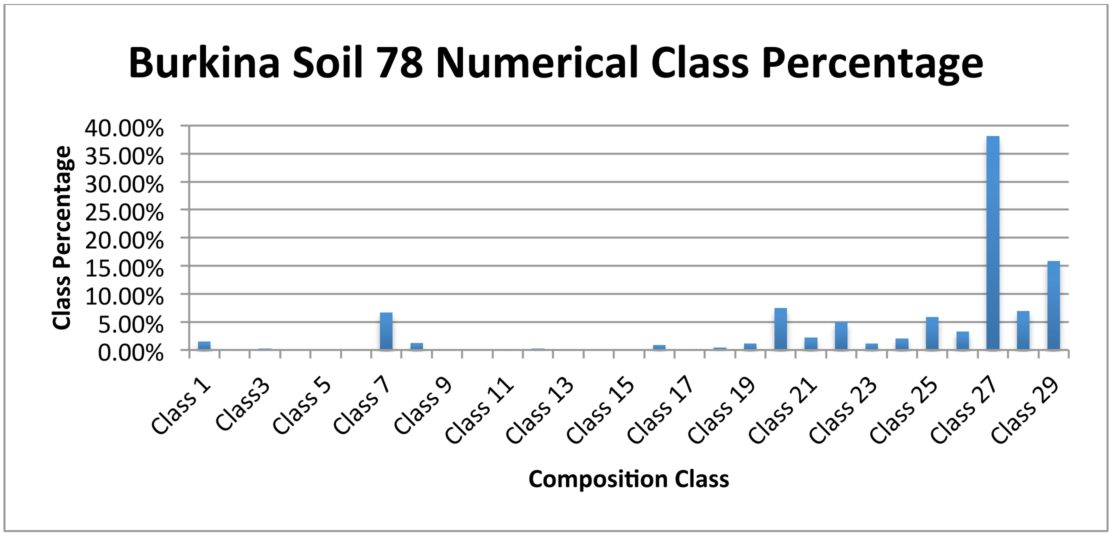

Figure 5-601: Numerical Percentage per class.

Table 5-51: Numerical percentage and number of particles per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
58	2	7	0	0	3	266	47
1.45%	0.05%	0.18%	0.00%	0.00%	0.08%	6.65%	1.18%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0	0	4	8	3	0	0	33
0.00%	0.00%	0.10%	0.20%	0.08%	0.00%	0.00%	0.83%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
1	17	46	299	87	197	45	81
0.03%	0.43%	1.15%	7.48%	2.18%	4.93%	1.13%	2.03%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
234	130	1523	276	632	3999		
5.85%	3.25%	38.08%	6.90%	15.80%	100.00%		

Table 5-51 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 20, 27, and 28. Class 20 is composed of Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60% and Silica between 20% and 60%. Class 28 has less than 1% Aluminum. This represents 52.46% of the entire sample and contains a total of 2098 particles. Class 29 represents the “unclassified” particles and contains only 15.80% of the entire sample.

The volumetric percentage of Burkina Laterite 78 represents the volume of particles that are represented in each respective elemental class (Figure 5-602). Table 5-52 shows the breakdown of each class volumetric percentage and shows the majority of the particles are contained in classes 22, 25, and 27. Class 22 contains Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 25 has Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. Class 27 contains Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 59.98% of the entire sample and contains a total volume of 87805.53 μm^3. Class 29 represents the “unclassified” volume of particles and contains 13.16% of the entire sample.

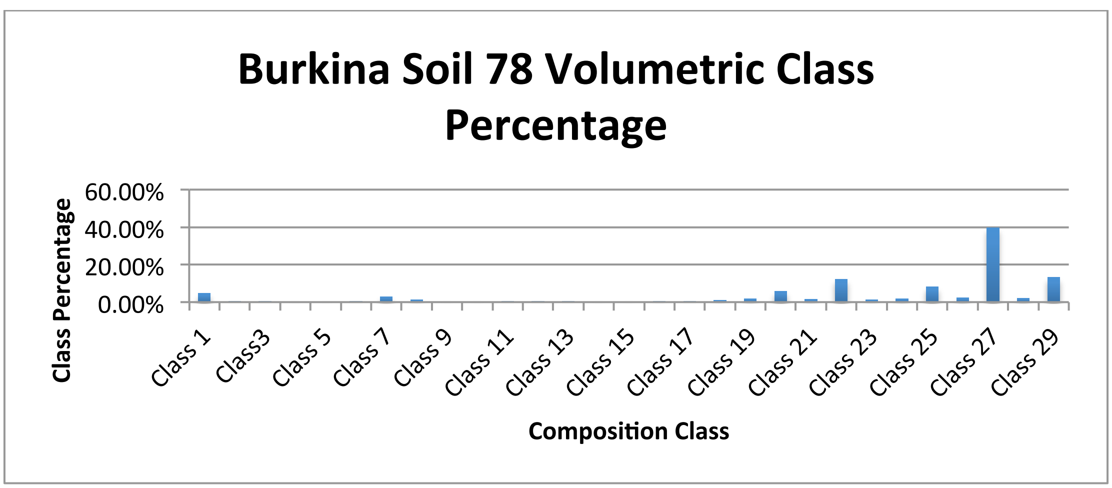

Figure 5-602: Volumetric percentage per class.

Table 5-52: Volumetric percentage and volume of each class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
6797.86	3.87	79.45	0.00	0.00	8.34	4262.99	1861.93
4.64%	0.00%	0.05%	0.00%	0.00%	0.01%	2.91%	1.27%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.00	0.00	47.65	36.49	23.62	0.00	0.00	704.55
0.00%	0.00%	0.03%	0.02%	0.02%	0.00%	0.00%	0.48%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
6.50	1552.03	2683.39	8458.92	2146.82	17869.57	1817.46	2459.36
0.00%	1.06%	1.83%	5.78%	1.47%	12.21%	1.24%	1.68%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
11891.87	3241.22	58044.09	3107.02	19268.86	146373.87		
8.12%	2.21%	39.65%	2.12%	13.16%	100.00%		

Analysis of class 29 showed a cluster of elements similar to the Burkina Laterites. The highest elements contained within Burkina Soil 78 unclassified are Fe, Si, Al, respectively, and compose a volume of 13.16% of the entire sample particles. The unclassified elements are evenly spread between the elements Iron, Silica and Aluminum, with 40% of the unclassified particles being contained within two clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum (Figure 5-603 and Figure 5-604).

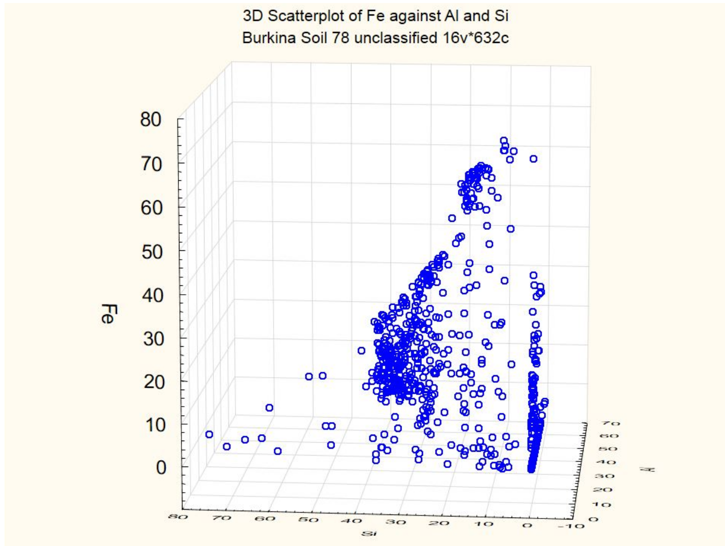

Figure 5-603: Scatterplot of Burkina Soil 78 elements Al, Si and Fe. The unclassified particles contain 13.78% volume of the particles in the sample.

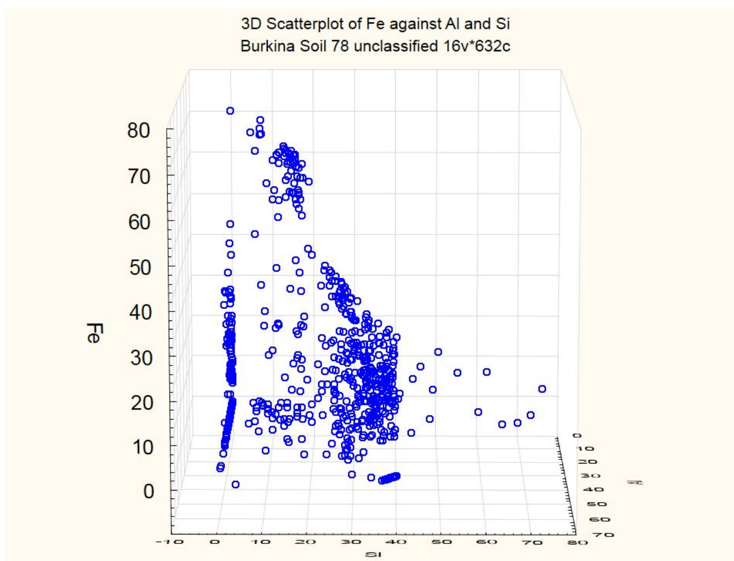

Figure 5-604: Burkina Soil 78 alternate 3D scatterplot view.

Euclidean Distance

The Euclidean Distance for Class 1 of Burkina Soil 78 is composed of greater than 99% Silica. There are a total of 58 particles in this class (Figure 5-605).

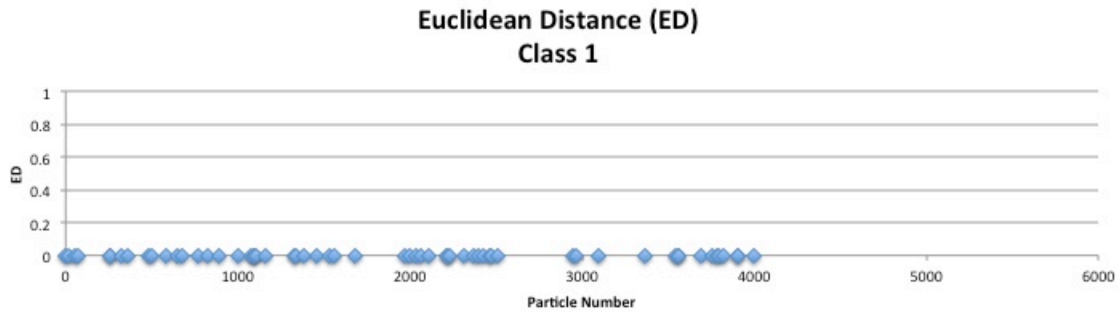

Figure 5-605: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 2 particles in this class (Figure 5-606).

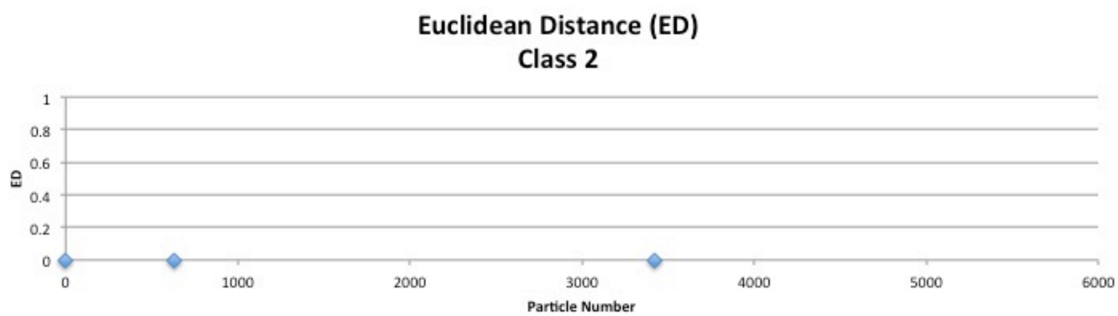

Figure 5-606: Euclidean Distance Class 2

Class 3 of Burkina Soil 78 is composed of greater than 99% Calcium. There are a total of 7 particles in this class (Figure 5-607).

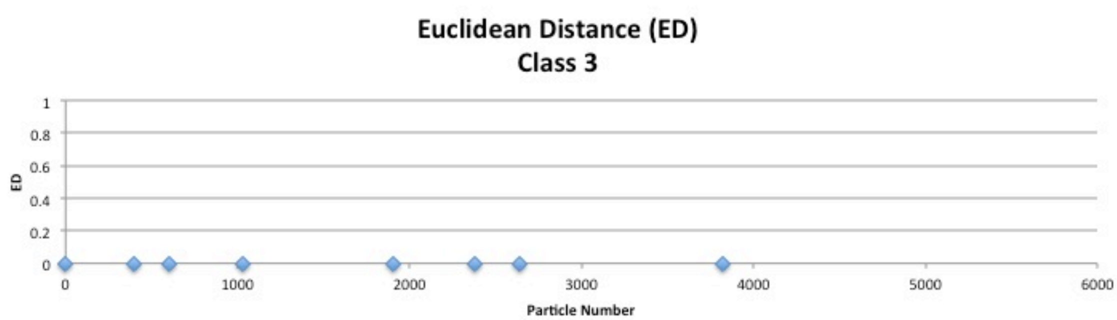

Figure 5-607: Euclidean Distance Class 3

Class 4 of Burkina Soil 78 is composed of Titanium greater than 55% and Lead less

than 5%. There are no particles in this class.

Class 5 of Burkina Soil 78 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Burkina Soil 78 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 3 particles in this class (Figure 5-608).

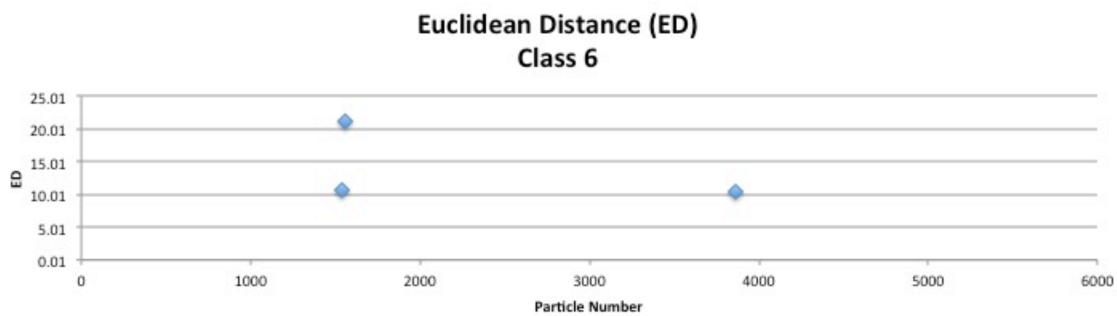

Figure 5-608: Euclidean Distance Class 6

Class 7 of Burkina Soil 78 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 266 particles in this class (Figure 5-609).

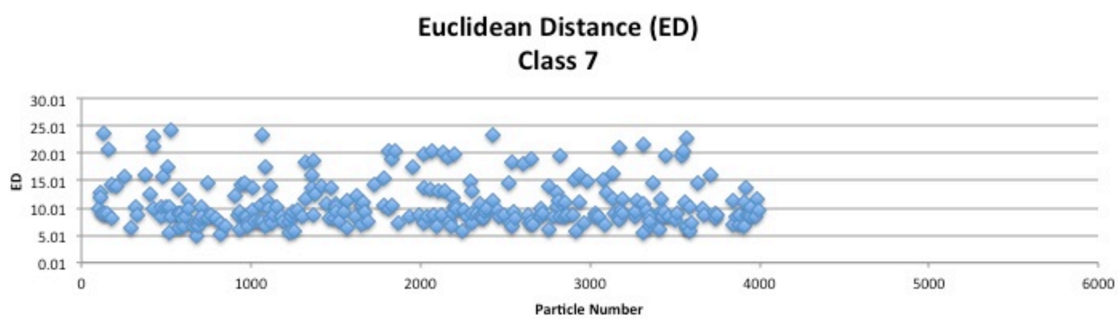

Figure 5-609: Euclidean Distance Class 7

Class 8 of Burkina Soil 78 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 47 particles in this class (Figure 5-610).

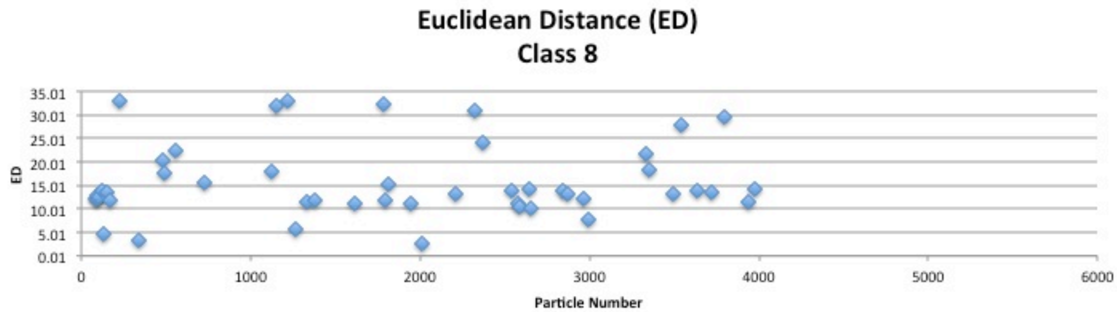

Figure 5-610: Euclidean Distance Class 8

Class 9 of Burkina Soil 78 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are no particles in this class.

Class 10 of Burkina Soil 76 is composed of Calcium greater than 80% and Lead less than 5%. There are no particles in this class.

Class 11 of Burkina Soil 78 is composed of the total Calcium and Manganese greater than 90%. There are 4 particles in this class (Figure 5-611).

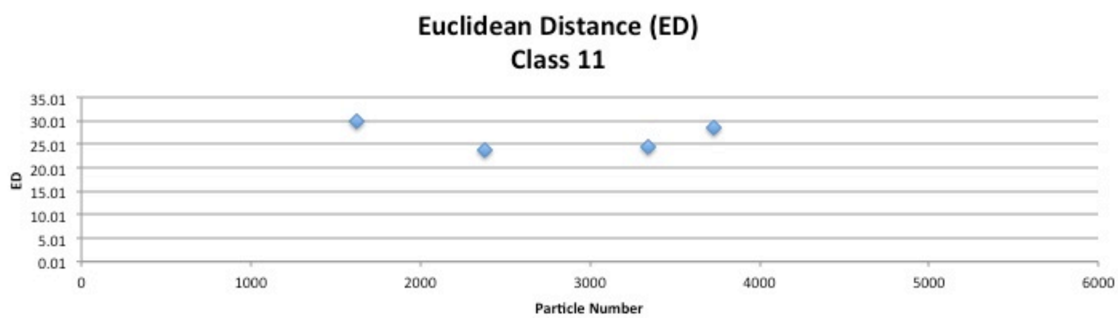

Figure 5-611: Euclidean Distance Class 11

Class 12 of Burkina Soil 78 is composed of the total Calcium and Phosphorus greater than 90%. There are 8 particles in this class (Figure 5-612).

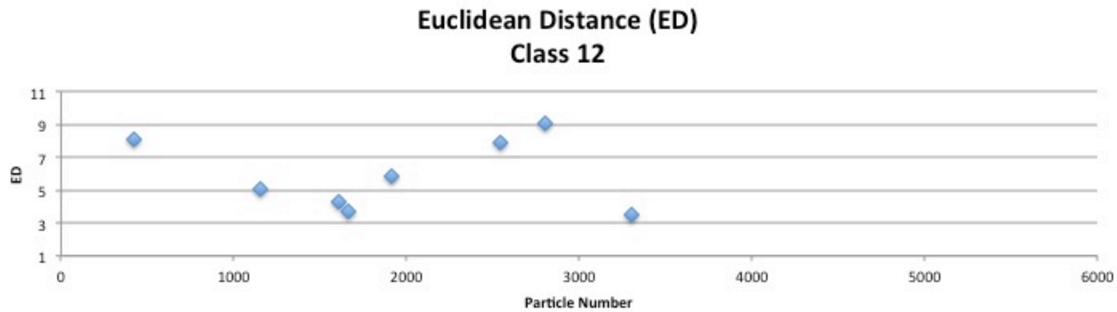

Figure 5-612: Euclidean Distance Class 12

Class 13 of Burkina Soil 78 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 3 particles in this class (Figure 5-613).

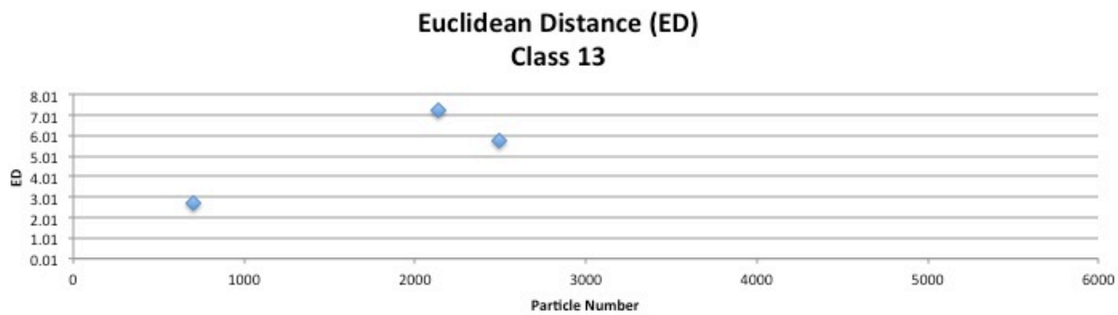

Figure 5-613: Euclidean Distance Class 13

Class 14 of Burkina Soil 78 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are no particles in this class.

Class 15 of Burkina Soil 78 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Burkina Soil 78 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 33 particles in this class (Figure 5-614).

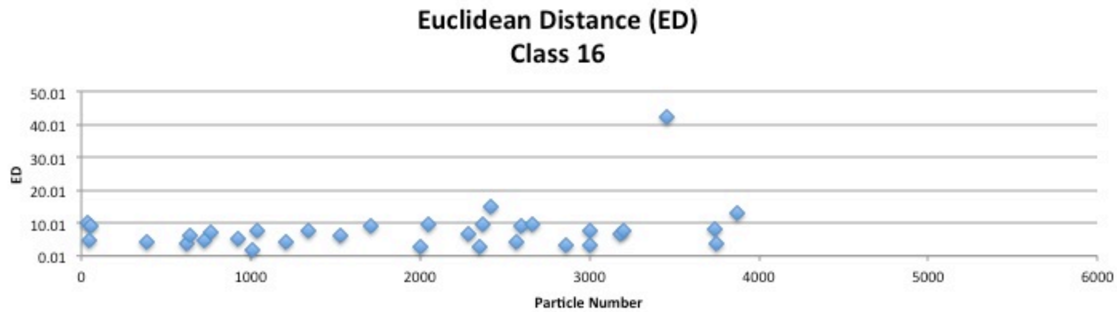

Figure 5-614: Euclidean Distance Class 16

Class 17 of Burkina Soil 78 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There is a total of 1 particle in this class (Figure 5-615).

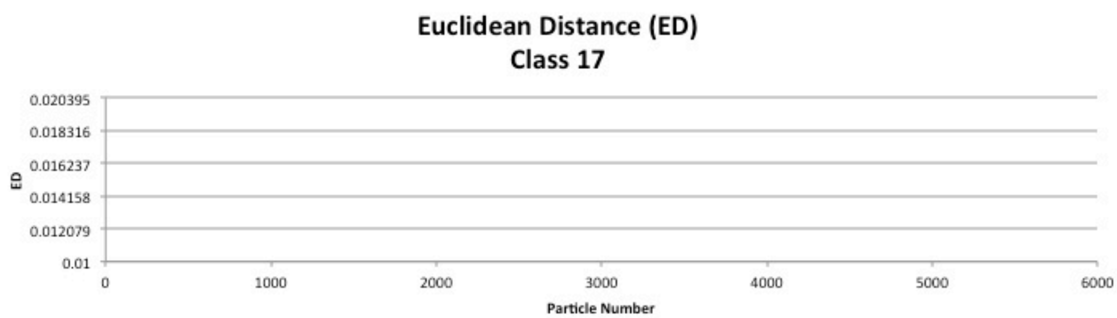

Figure 5-615: Euclidean Distance Class 17

Class 18 of Burkina Soil 78 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 17 particles in this class (Figure 5-616).

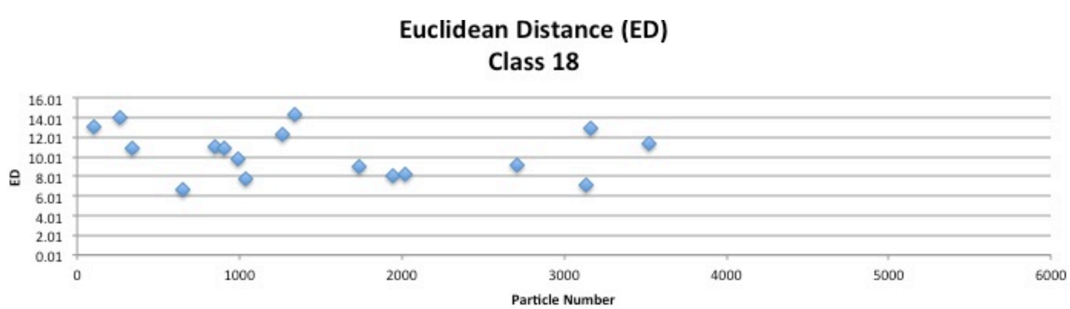

Figure 5-616: Euclidean Distance Class 18

Class 19 of Burkina Soil 78 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are 46 particles in this class (Figure 5-617).

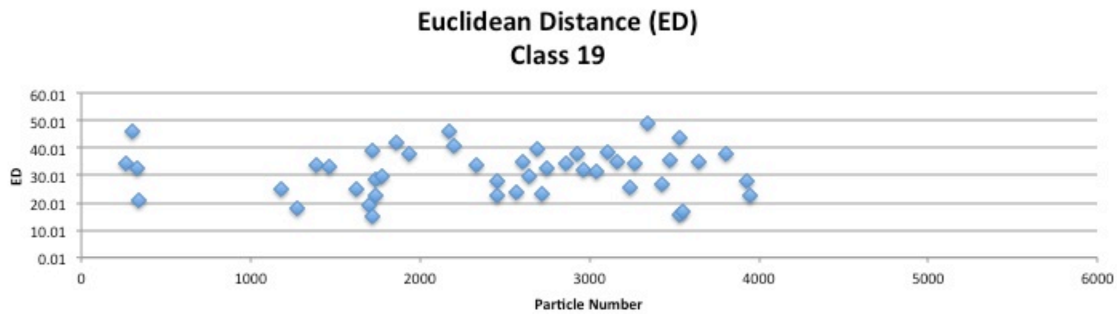

Figure 5-617: Euclidean Distance Class 19

Class 20 of Burkina Soil 78 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 299 particles in this class (Figure 5-618).

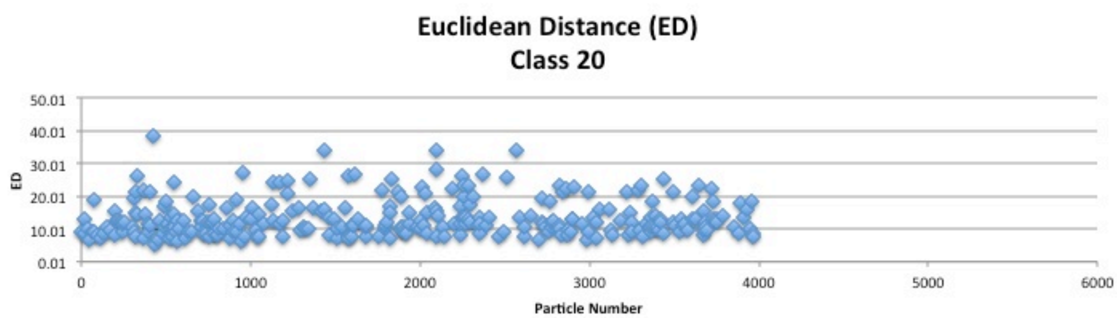

Figure 5-618: Euclidean Distance Class 20

Class 21 of Burkina Soil 78 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 87 particles in this class (Figure 5-619).

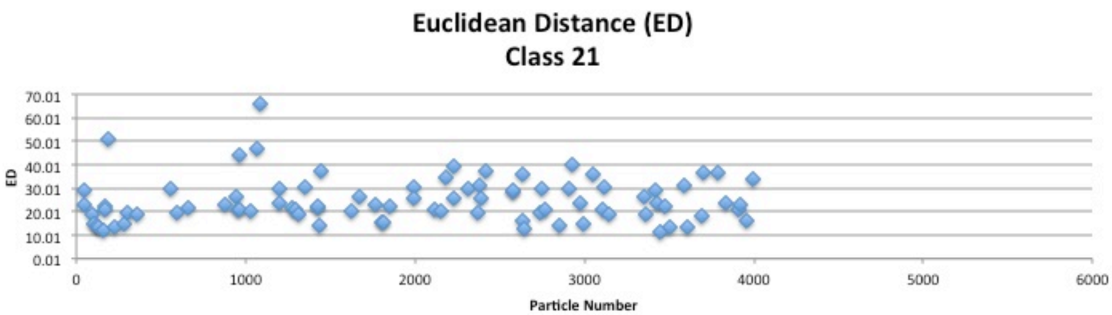

Figure 5-619: Euclidean Distance Class 21

Class 22 of Burkina Soil 78 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 197 particles in this class (Figure 5-620).

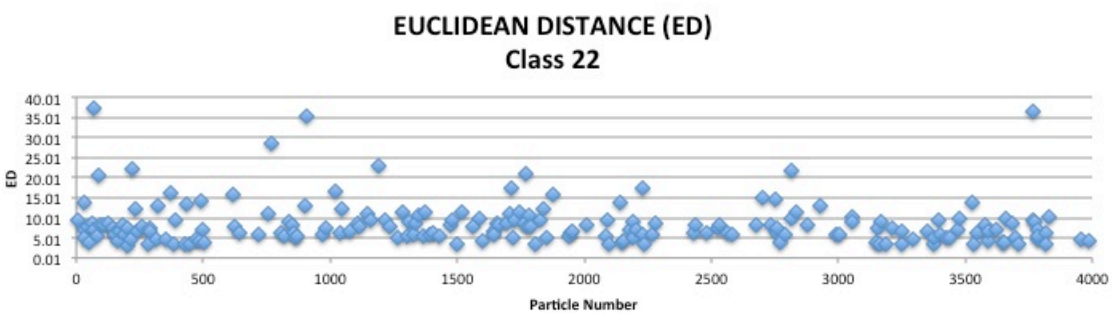

Figure 5-620: Euclidean Distance Class 22

Class 23 of Burkina Soil 78 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 45 particles in this class (Figure 5-621).

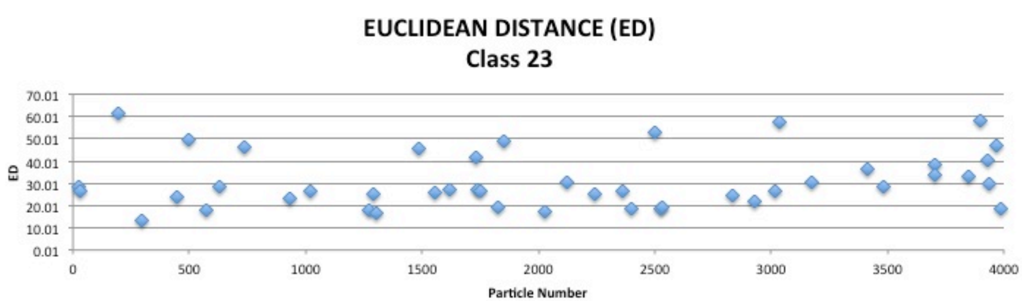

Figure 5-621: Euclidean Distance Class 23

Class 24 of Burkina Soil 78 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 81 particles in this class (Figure 5-622).

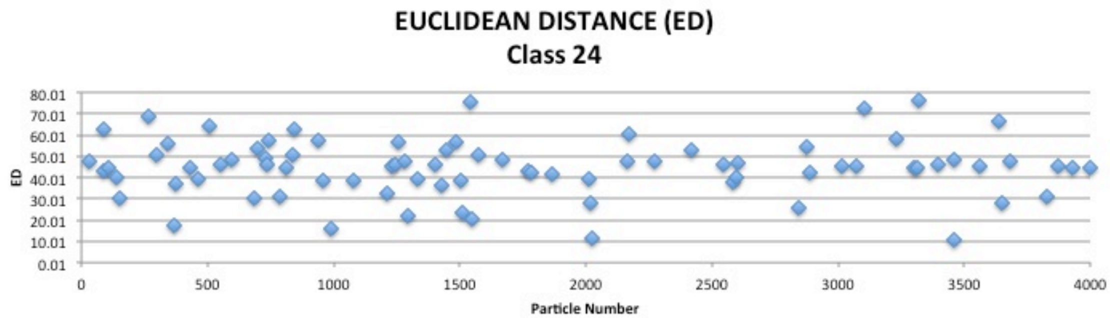

Figure 5-622: Euclidean Distance Class 24

Class 25 of Burkina Soil 78 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 234 particles in this class (Figure 5-623).

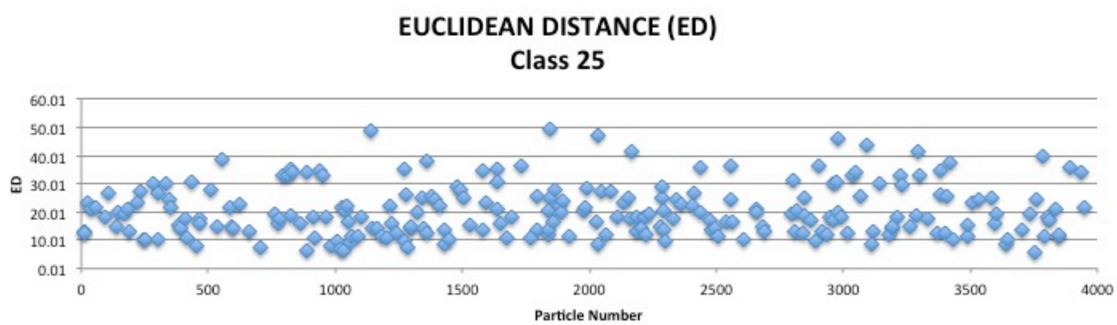

Figure 5-623: Euclidean Distance Class 25

Class 26 of Burkina Soil 78 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 130 particles in this class (Figure 5-624).

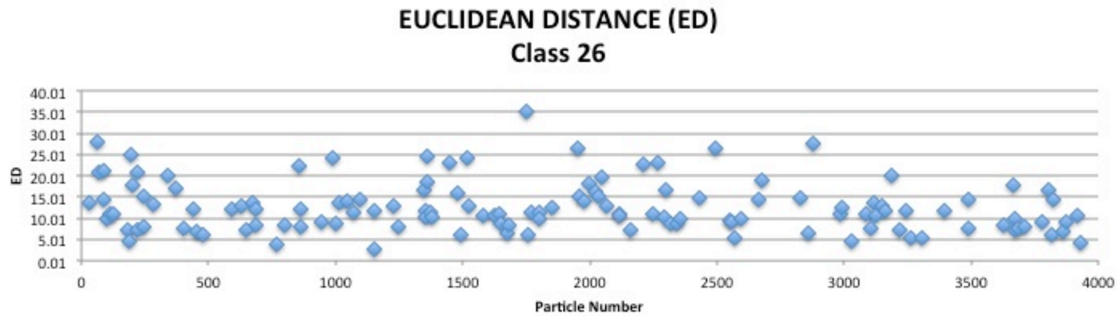

Figure 5-624: Euclidean Distance Class 26

Class 27 of Burkina Soil 78 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 1523 particles in this class (Figure 5-625).

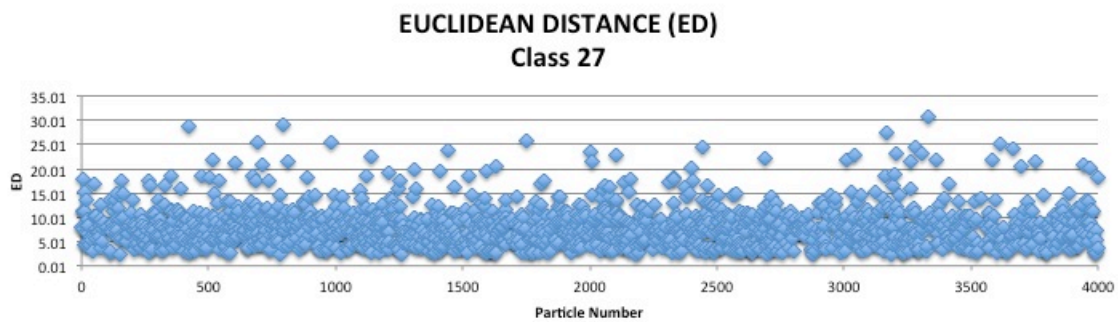

Figure 5-625: Euclidean Distance Class 27

Class 28 of Burkina Soil 78 is composed of Aluminum less than 1%. There are a total of 276 particles in this class (Figure 5-626).

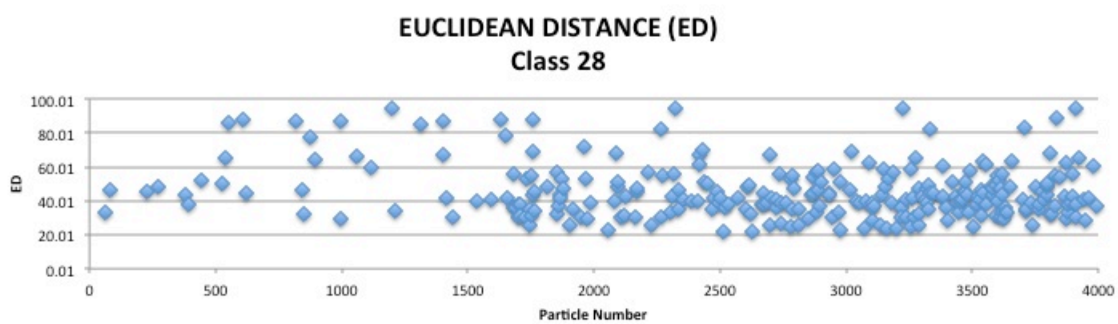

Figure 5-626: Euclidean Distance Class 28

Burkina Soil Summary

The average number of particles in each class for all of the Burkina Soil samples gives a total class average of 3507.14 particles, which constitutes 100% of the sample (Table 5-53). Class 27 has the largest average particle class with 27.09% and 950.00 particles (Figure 5-627). The elements with the largest abundance are Silica (20%<Si<60%) and Aluminum (40%<Al<60%). Class 7 is the second largest average particle class, with 7.23% and 253.57 particles (Figure 5-628). The elements with the largest abundance are Silica (30%<Si<50%) and Aluminum (35%<Al<60%), with Iron being less than 1%. Class 25 is the third largest average particle class, with 6.96% and 327.78 particles (Figure 5-629). The elements with the largest abundance are Silica (20%<Si<35%) and Aluminum (20%<Al<35%). All classes contain varying amounts of Al and Si with small amounts of Fe, Mg, Ca, and Na.

Table 5-53: Class Average-Numerical Percentage

Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
123.86	45.00	10.43	18.86	1.00	55.71	253.57	94.00
3.53%	1.28%	0.30%	0.54%	0.03%	1.59%	7.23%	2.68%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
3.43	1.14	2.00	1.86	2.43	2.00	0.00	210.43
0.10%	0.03%	0.06%	0.05%	0.07%	0.06%	0.00%	6.00%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
9.43	23.29	36.00	239.29	79.71	245.00	62.86	103.00
0.27%	0.66%	1.03%	6.82%	2.27%	6.99%	1.79%	2.94%
Class 25	Class 26	Class 27	Class 28	Class 29		Total	
250.00	129.29	950.00	102.14	451.43		3507.14	
7.13%	3.69%	27.09%	2.91%	12.87%		100.00%	

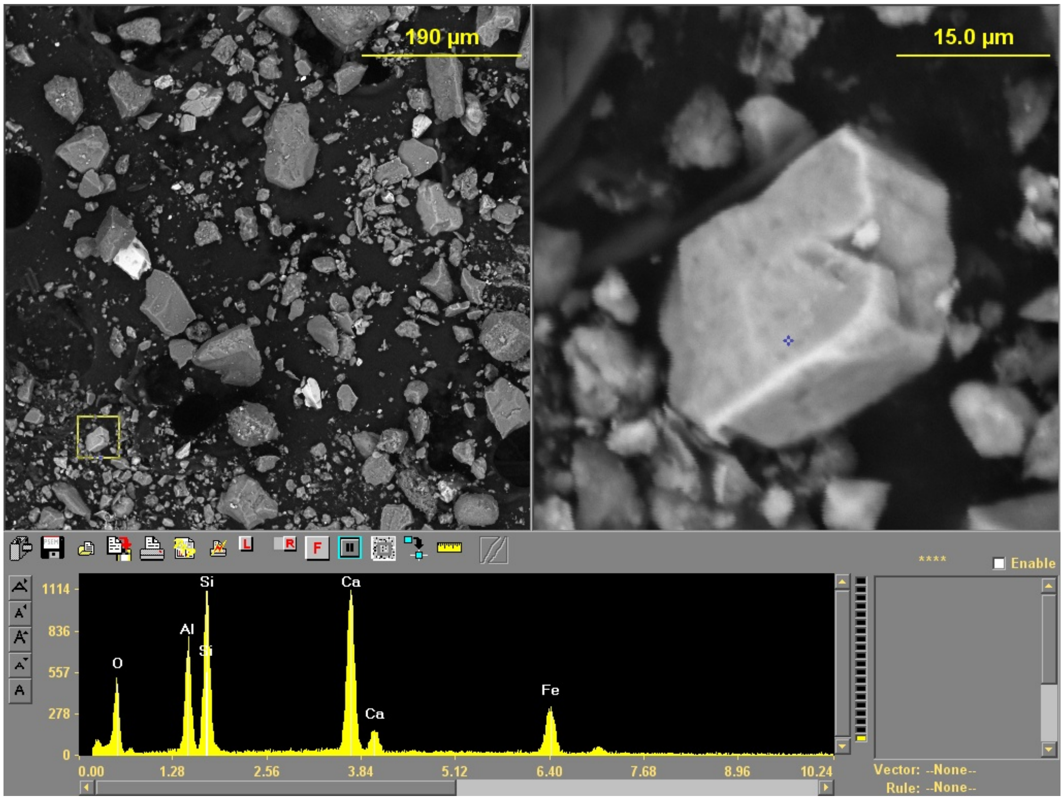

Figure 5-627: Burkina Soil class 27 showing Ca, Fe, Al, Si.

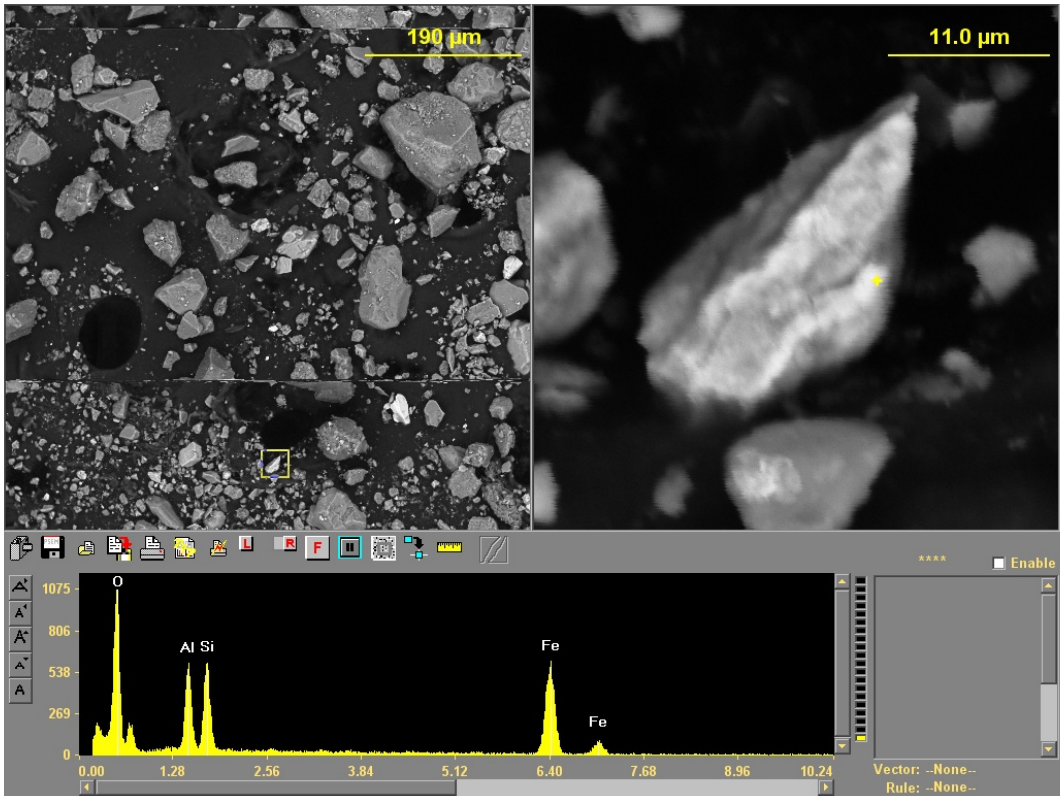

Figure 5-628: Burkina Soil Class 7 showing Al, Si, Fe.

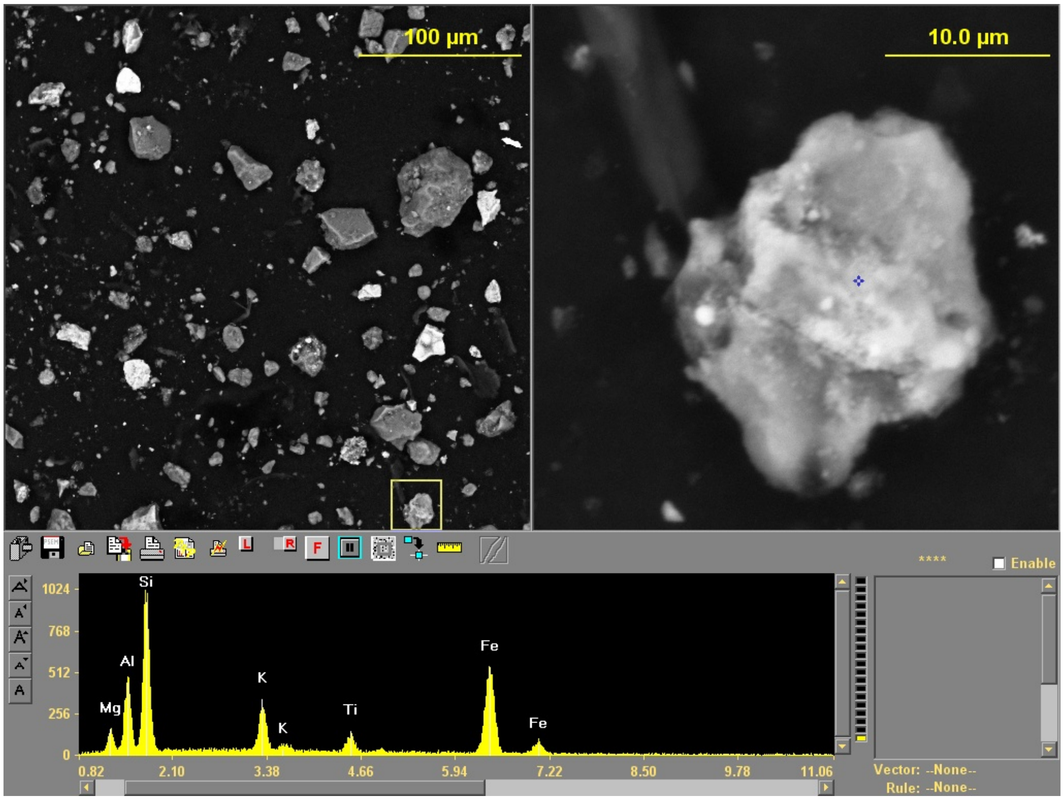

Figure 5-629: Class 25 Showing Si, Al, Fe.

The average volume of particles in each class for all of the Burkina Soil samples gives a total class volume average of 346024.28 µm^3, which constitutes 100% of the sample (Table 5-54). Class 27 has the highest volume of particles with 28.33% or a volume of 98015.14 µm^3. The elements with the largest abundance are Silica (20%<Si<60%) and Aluminum (40%<Al<60%). Different from the numerical class average, class 22 comes in as the second largest average volume class with 24.51% and 84796.63 µm^3 average volume. The elements with the largest abundance are Silica (Si>60%) and Aluminum (4%<Al<20%), with Calcium and Potassium being less than 1%. Class 25 is the third largest average volume class with 7.77% and a volume of 26871.21 µm^3. The elements with the largest abundance are Silica (20%<Si<35%) and Aluminum (20%<Al<35%).

Table 5-54: Class Average-Volumetric Percentage

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
22040.07	475.40	668.75	1404.29	231.59	147.04	6922.40	10383.88
6.37%	0.14%	0.19%	0.41%	0.07%	0.04%	2.00%	3.00%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
322.65	12.67	17.91	312.67	115.09	68.84	0.00	6184.41
0.09%	0.00%	0.01%	0.09%	0.03%	0.02%	0.00%	1.79%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
1352.00	1181.90	5984.94	15542.02	3938.57	84796.63	3588.32	2823.19
0.39%	0.34%	1.73%	4.49%	1.14%	24.51%	1.04%	0.82%
Class 25	Class 26	Class 27	Class 28	Class 29		Total	
26871.21	12064.04	98015.14	7481.45	33077.19		346024.28	
7.77%	3.49%	28.33%	2.16%	9.56%		100.00%	

Comparing the average numerical percentages, Class 27, 7, and 25, and volumetric average percentages, Class 27, 22, and 25, the three highest classes represent 41.45% of the numerical value and 60.61% for the volumetric value for all the Burkina Soil samples. The difference in the percentage between number of particles and volume of particle of the three highest classes is 19.15%. The second highest class for each average sample causes the difference between the numerical and volumetric average percentages. Class 7 is characterized by high Silica and moderate Aluminum with very low Iron, while class 22 is characterized by high Silica with low amounts Aluminum and virtually no Potassium or Calcium. By looking at the other high-class values, the Silica content is determined to be the most abundant element in the Burkina Soil samples. The average volume of the Silica particles being larger than the Aluminum or Iron particles causes the difference in the three highest element classes. Regardless of the difference in the second largest element class percentage, Silica dominates the Burkina Soil samples (Figure 5-630).

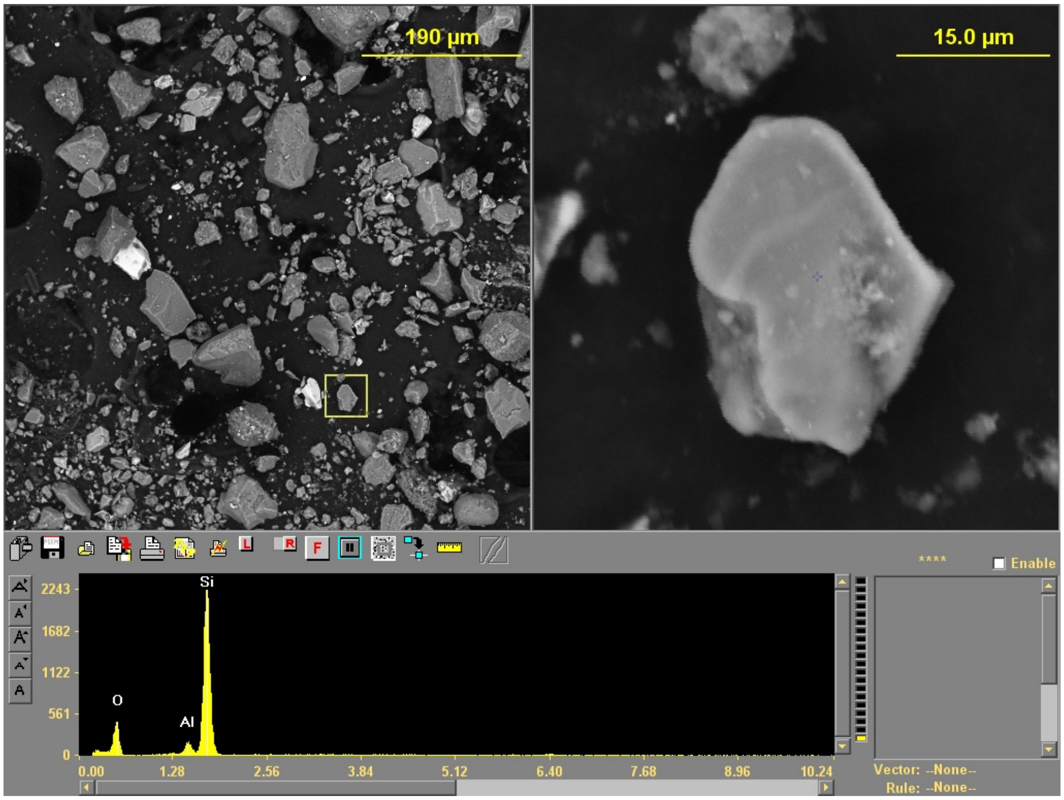

Figure 5-630: Silica Dominated Particle in the Burkina Soils.

The Euclidean distance for the all the Burkina Soil samples gives us an idea of the distribution of the particles and distance from the centroid of the cluster. While the Euclidean distance values themselves are arbitrary, the pattern of distribution is important for identification of sample types. Each sample class will have a unique distribution of particles around the centroid of the cluster, which can be a valuable tool for identification of samples. Some of the more notable Euclidean distance distribution tables are the Silica-rich element classes.

Along with chemistry and Euclidean distance, the average particle size of each elemental class was identified (Table 5-55). The particles were separated into 4 size classes, with size 1 having particles with a diameter between 0-2.49µm, class 2 having a diameter between 2.5-4.9µm, class three having a diameter between 5-10µm, and class 4 having a diameter greater than 10μm. Size class 1 included 62.36% of all Burkina Soil particles, size class 2 included 25.98%, size class 3 contains 7.99%, and class 4 included 3.67%. This analysis showed an abundance of small particle sizes (Class 1) with no correlation between chemistry of the particles and size of the particles.

Table 5-55: Burkina Soil Particle Size Classes by Elemental Class.

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
Size Class 1	51.78%	0.00%	52.09%	35.31%	57.14%	94.06%	61.67%
Size Class 2	17.77%	100.00%	22.49%	4.25%	0.00%	3.07%	29.06%
Size Class 3	12.21%	0.00%	8.81%	2.35%	0.00%	2.87%	8.25%
Size Class 4	3.96%	0.00%	2.32%	0.95%	14.29%	0.00%	1.01%
	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	Class 14
Size Class 1	60.25%	26.19%	38.10%	37.24%	39.29%	54.17%	21.43%
Size Class 2	26.02%	5.95%	0.00%	34.18%	10.71%	10.12%	30.36%
Size Class 3	11.00%	9.52%	4.76%	0.00%	0.00%	0.00%	5.36%
Size Class 4	2.73%	1.19%	0.00%	0.00%	7.14%	7.14%	0.00%
	Class 15	Class 16	Class 17	Class 18	Class 19	Class 20	Class 21
Size Class 1	0.00%	81.82%	55.40%	62.52%	42.41%	59.39%	50.02%
Size Class 2	0.00%	13.93%	27.79%	26.20%	14.33%	26.79%	35.07%
Size Class 3	0.00%	3.75%	14.62%	7.98%	6.38%	11.51%	12.00%
Size Class 4	0.00%	0.50%	2.20%	3.30%	8.30%	2.31%	2.91%
	Class 22	Class 23	Class 24	Class 25	Class 26	Class 27	Class 28
Size Class 1	65.07%	63.65%	76.73%	63.85%	53.83%	52.16%	78.67%
Size Class 2	19.93%	21.41%	17.40%	24.75%	30.33%	32.64%	13.05%
Size Class 3	9.40%	9.87%	5.14%	8.06%	12.83%	12.40%	4.70%
Size Class 4	5.61%	5.08%	0.73%	3.34%	3.01%	2.80%	3.58%

Total Class %

Class 1	Class 2	Class 3	Class 4
62.36%	25.98%	7.99%	3.67%

Origin of Soils and Laterites

Laterites are defined as a type of soil that is rich in Iron and originate from weathering of the parent rock under strong oxidation or leaching. Laterites generally form in tropical and subtropical, humid regions and are usually composed of Iron-rich minerals, such as Pyrite, Goethite, and Hematite. Along with Iron-rich minerals, Laterites also contain Aluminum Oxides such as Bauxite and Kaolinite. As previously stated in the summary of the Burkina Laterites, the most abundant mineral in the Burkina Laterites is Iron, which is constant with the composition of Laterites. Along with Iron, the Burkina Laterites also contain lesser amounts of Aluminum, and Silica. Both SEM and XRD analysis confirmed the mineralogy of the Burkina laterites. Burkina Laterite 54, 56, 62, and 64 were sent off for XRD analysis to confirm the mineralogy was consistent with laterites. The XRD results showed the presence of Pyrite, Kaolinite, and Quartz (Figure 5-631, Figure 5-632, Figure 5-633, Figure 5-634).

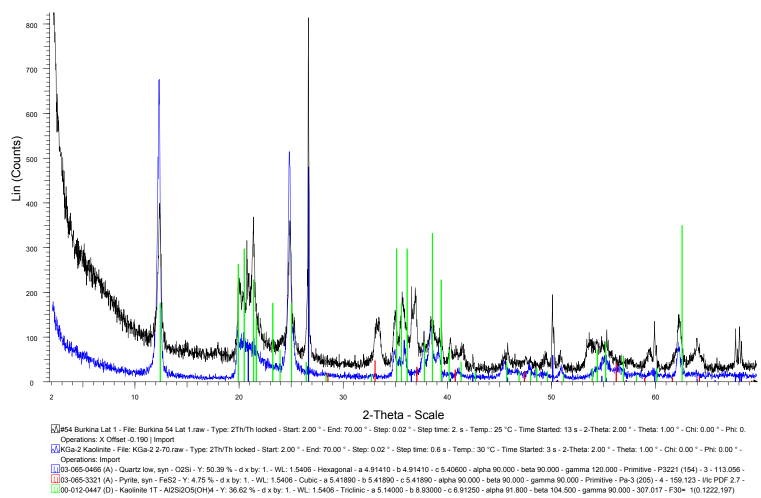

Figure 5-631: Burkina Laterite 54 Showing Kaolinite (36.62%), Pyrite (4.75%), and Quartz (50.39%).

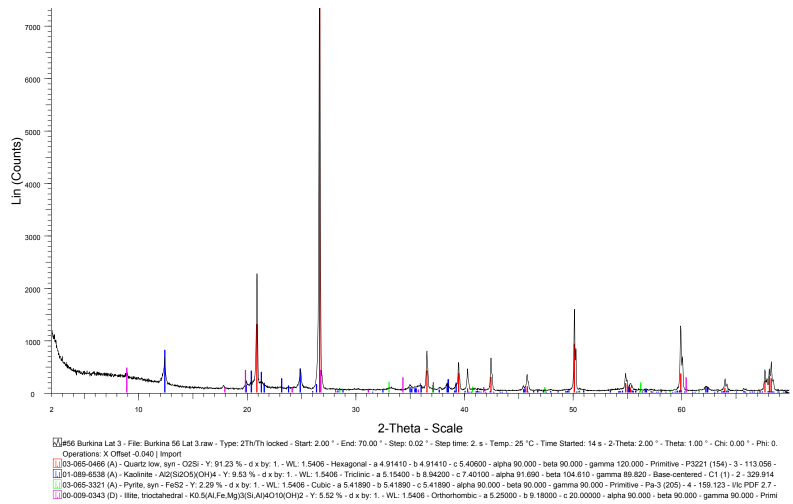

Figure 5-632: Burkina Laterite 56 showing Kaolinite (9.53%), Pyrite (2.29%), and Quartz (91.23).

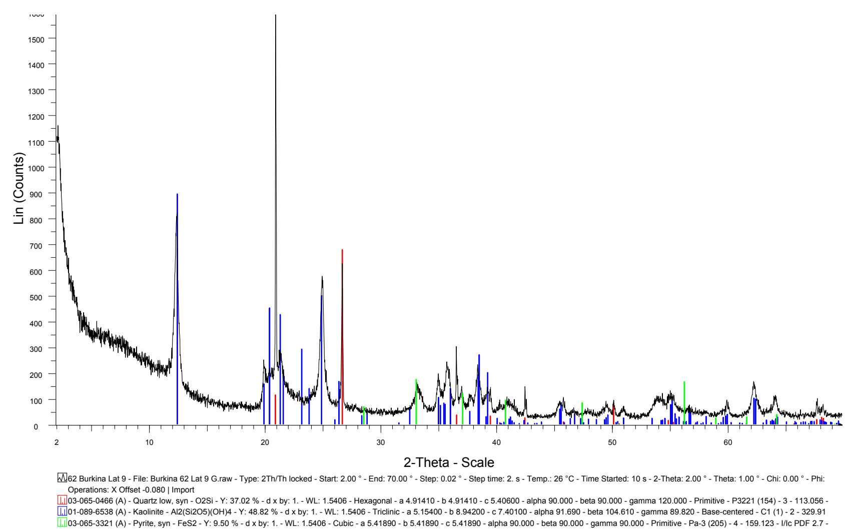

Figure 5-633: Burkina Laterite 62 showing Kaolinite (48.82%), Pyrite (9.50%), and Quartz (37.02%).

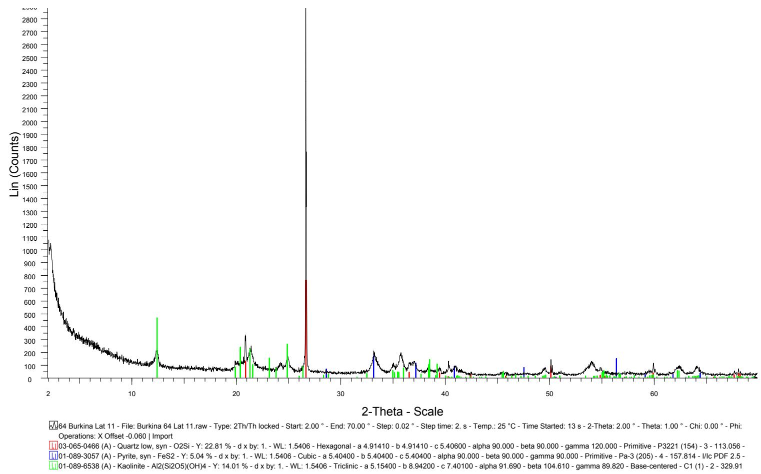

Figure 5-634: Burkina Laterite 64 showing Kaolinite (14.01%), Pyrite (5.04%), and Quartz (22.81%).

The Burkina Soils, as previously shown, are composed primarily of Silica, Aluminum and Iron, respectively. These three elements are consistent with what is found in the laterites, but in different percentages. The Burkina Laterites have class 16 as the most abundant class, which is characterized by high amounts of Iron, while Burkina Soils have class 27 as the most abundant class, which is characterized by high amounts of Silica. Both the laterites and the soils were collected from the same area in Africa, with three of each samples being collected from the exact same location. Burkina Laterite 57 was collected at the same location as Burkina Soil 70. Burkina Laterite 58 was collected at the same location as Burkina Soil 71. Burkina Laterite 60 was collected at the same location as Burkina Soil 73. Patches of red-colored soils are defined as the Burkina Laterites and the Burkina soils are defined as tan-colored soils (Figure 5-635). The thought behind collecting the two different types of soils from the same area was the red-colored Burkina Laterites were being eroded from the parent rock, and the Burkina Soils were a combination of the abundant Quartz present in the Sahel and Saharan region of Africa and the Burkina Laterites that were interspersed between the loose soils. The findings from this analysis show that the Laterites are abundant in Iron and the Soils are abundant in Silica, but the Soils also seem to be eroded from the parent rock below (Figure 5-636). This leads to the conclusion that both Laterites and Soils are elementally distinguishable, but there is a large amount mixing between both the Burkina Soils and the Burkina Laterites.

Figure 5-635: Image of Laterites (red) and Soils (tan). Image from Sprott Global Resources.

Figure 5-636: Image showing Burkina Laterites and Soils, both consolidated. Image from Indigo Exploration, Inc.

Chad Arid

The Chad area of Africa is located in central Africa (Figure 5-637) is dominated by a low-lying basin, aptly called the Chad Basin, which is the remains of an immense late that occupied approximately 330,000 square kilometers of the Chad Basin 7000 years ago. A large mountain that rises approximately 3100 meters above sea level defines the northern border of Chad and to the east; there is the Ennedi Plateau and the Ouaddai highlands that gradually slope down to the Chad Basin. These geologic features create prime conditions for the collection of unconsolidated soils and sands.

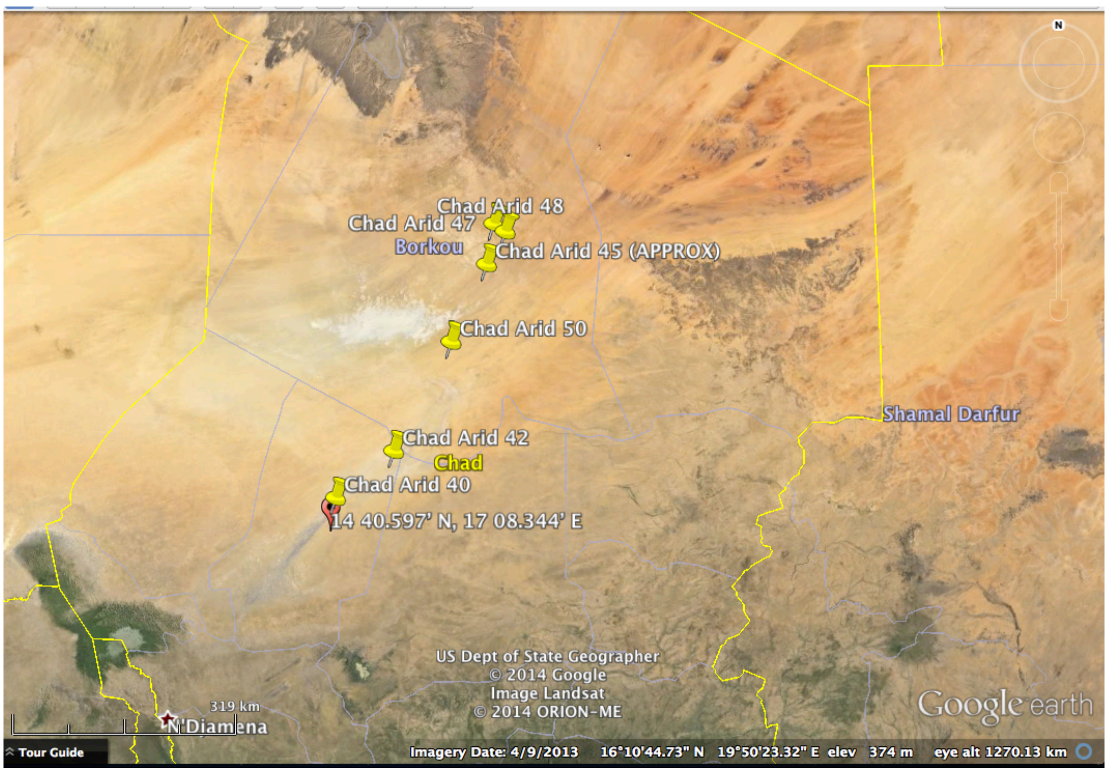

Figure 5-637: Location of Chad Arid Samples in Chad, Africa.

Chad Arid 40

Chad Arid 40 is located at 14 40.597' N, 17 08.344' E and has been separated into 29 elemental classes (Figure 5-638). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-56).

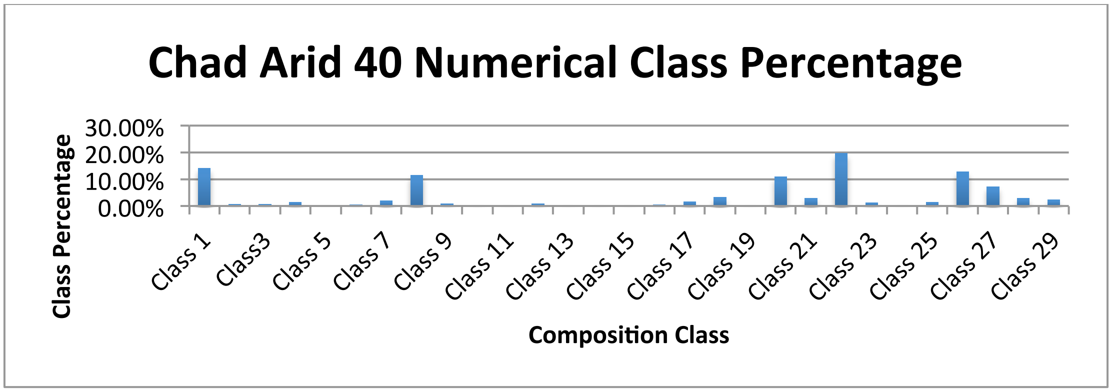

Figure 5-638: Numerical percentage per class.

Table 5-56: Numerical percentage and number of particles per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
566	23	29	57	0	18	76	459
14.15%	0.58%	0.73%	1.43%	0.00%	0.45%	1.90%	11.48%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
34	13	1	36	4	1	2	18
0.85%	0.33%	0.03%	0.90%	0.10%	0.03%	0.05%	0.45%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
65	127	8	439	118	785	49	9
1.63%	3.18%	0.20%	10.98%	2.95%	19.63%	1.23%	0.23%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
55	514	288	113	93	4000		
1.38%	12.85%	7.20%	2.83%	2.33%	100.00%		

Table 5-56 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 1, 22, and 26. Class 1 is composed of greater than 99% Silica. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. Class 28 has less than 1% Aluminum. This represents 46.63% of the entire sample and contains 1865 particles. Class 29 represents the "unclassified" particles and contains only 2.33% of the entire sample.

The volumetric percentage of Chad Arid 40 represents the volume of particles that are represented in each respective elemental class (Figure 5-639). Table 5-57 shows the breakdown of each class volumetric percentage and, as with the numerical percentage, shows the majority of the particles are contained in classes 8, 17, and 22. Class 8 has Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. Class 17 is composed of Potassium between 4% and 30%, Silica between 55% and 90%, and Aluminum between 10% and 30%. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. This represents 65.06% of the entire sample and contains an average volume of 349513.70 μm^3. Class 29 represents the "unclassified" volume of particles and contains 0.34% of the entire sample.

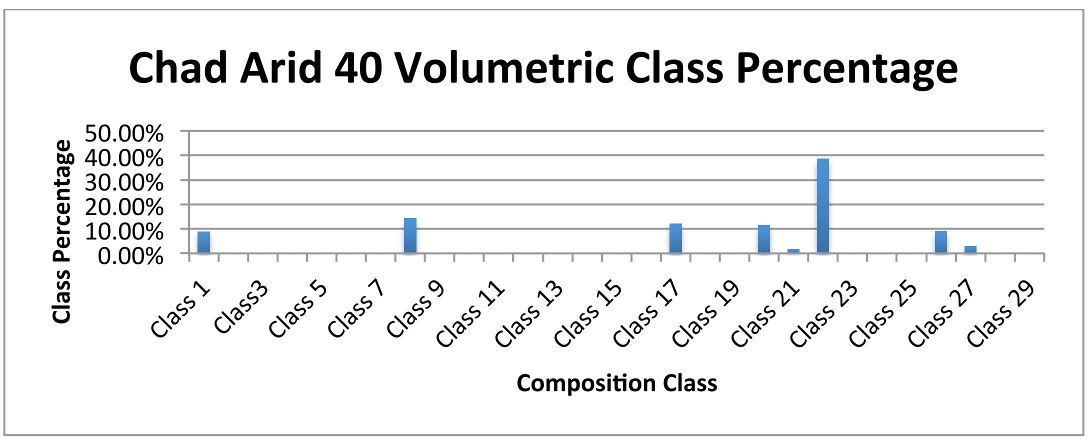

Figure 5-639: Volumetric percentage per class.

Table 5-57: Volumetric percentage and volume of each class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
47631.43	25.76	44.38	371.18	0.00	59.84	578.65	76480.29
8.87%	0.00%	0.01%	0.07%	0.00%	0.01%	0.11%	14.24%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
570.68	46.39	4.80	75.61	2.88	0.15	15.26	49.65
0.11%	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.01%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
65325.60	1349.72	574.94	61403.81	8735.51	207707.81	299.07	5.36
12.16%	0.25%	0.11%	11.43%	1.63%	38.66%	0.06%	0.00%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
277.85	47975.63	15579.20	191.14	1842.86	537225.44		
0.05%	8.93%	2.90%	0.04%	0.34%	100.00%		

Analysis of class 29 showed a diverse spread across three elements. The highest elements contained within Chad Arid 40 unclassified are Fe, Si, Al, and only compose a volume of 0.34% of the entire sample particles. The unclassified elements are evenly spread between the elements Iron, Silica and Aluminum, with most of the particles being high in Iron and lower in Silica and Aluminum (Figure 5-640 and Figure 5-641).

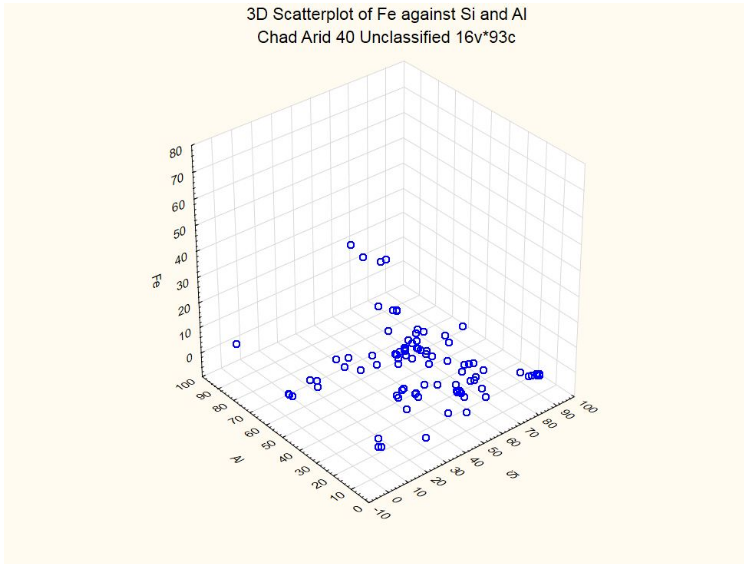

Figure 5-640: Scatterplot of Chad Arid 40 elements Al, Si and Fe. The unclassified particles contain 0.34% volume of the particles in the sample.

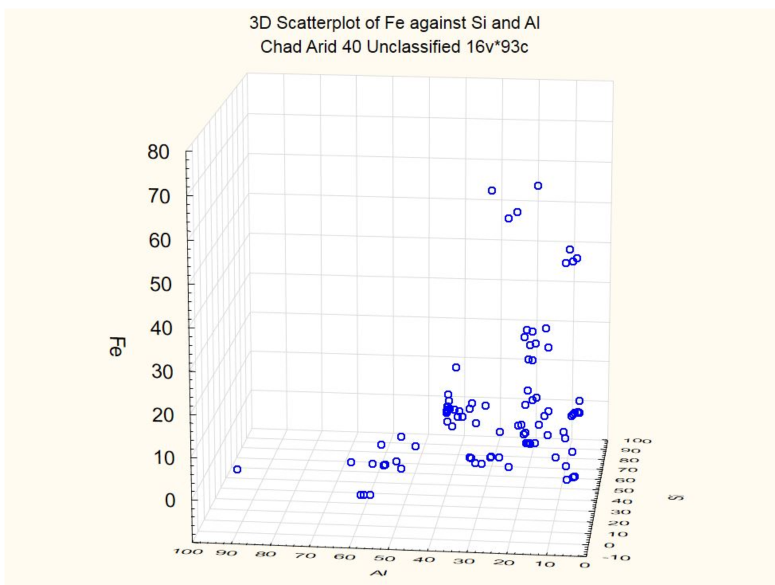

Figure 5-641: Chad Arid 40 alternate 3D scatterplot view.

Euclidean Distance

The Euclidean Distance for Class 1 of Chad Arid 40 is composed of greater than 99% Silica. There are a total of 566 particles in this class (Figure 5-642).

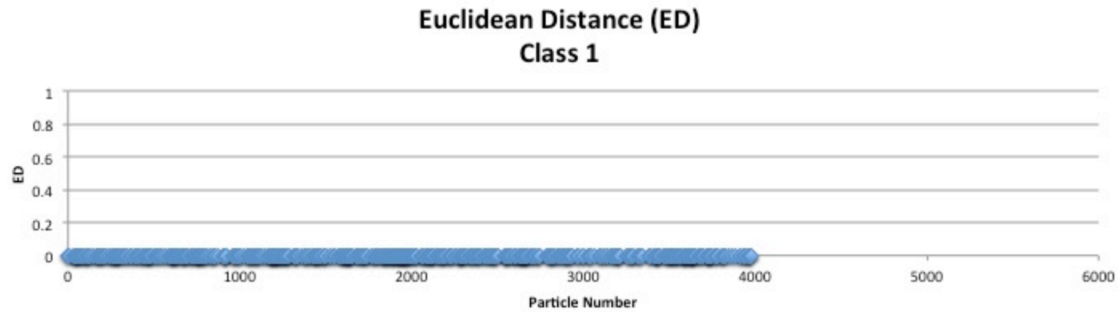

Figure 5-642: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 23 particles in this class (Figure 5-643).

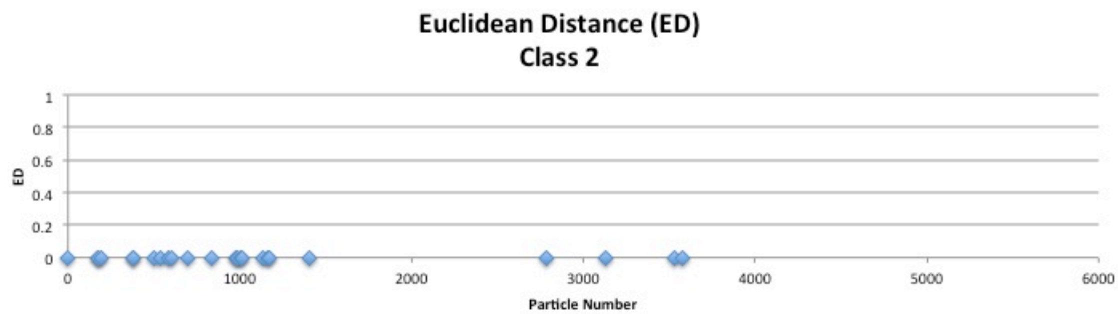

Figure 5-643: Euclidean Distance Class 2

Class 3 of Chad Arid 40 is composed of greater than 99% Calcium. There are a total of 29 particles in this class (Figure 5-644).

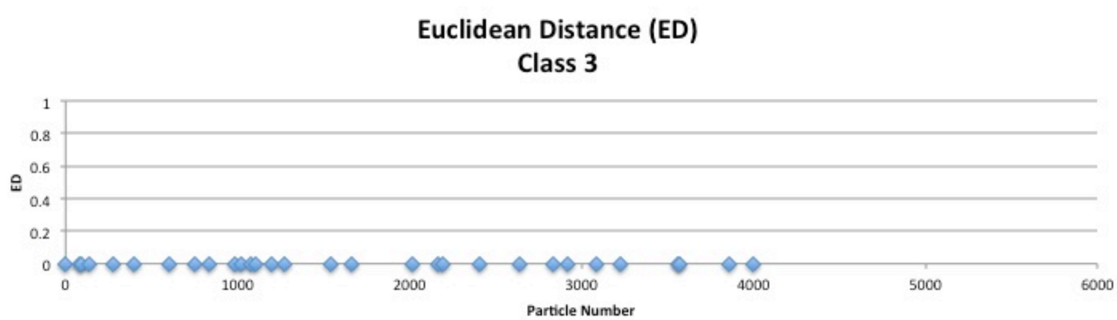

Figure 5-644: Euclidean Distance Class 3

Class 4 of Chad Arid 40 is composed of Titanium greater than 55% and Lead less than

5%. There are 57 particles in this class (Figure 5-645).

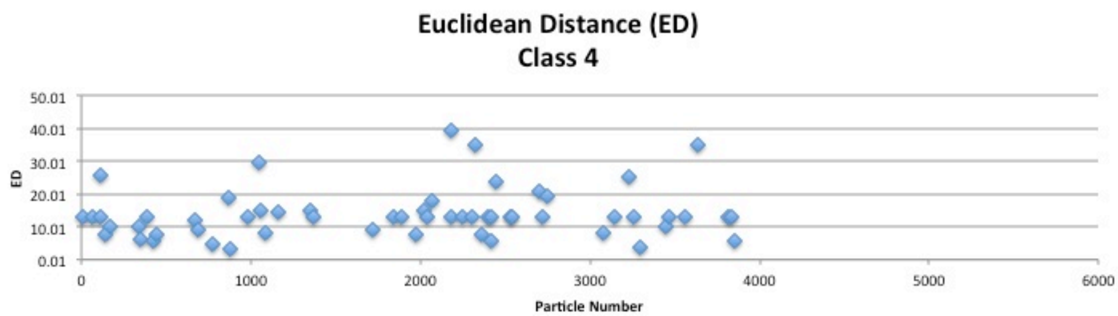

Figure 5-645: Euclidean Distance Class 4

Class 5 of Chad Arid 40 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Chad Arid 40 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 18 particles in this class (Figure 5-646).

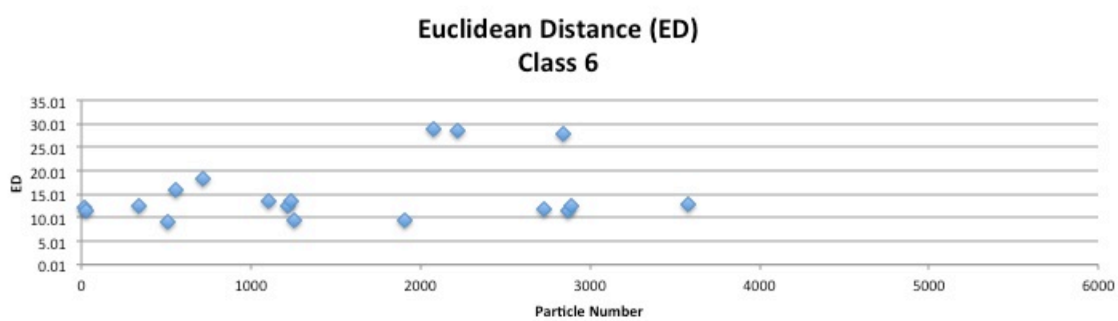

Figure 5-646: Euclidean Distance Class 6

Class 7 of Chad Arid 40 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 76 particles in this class (Figure 5-647).

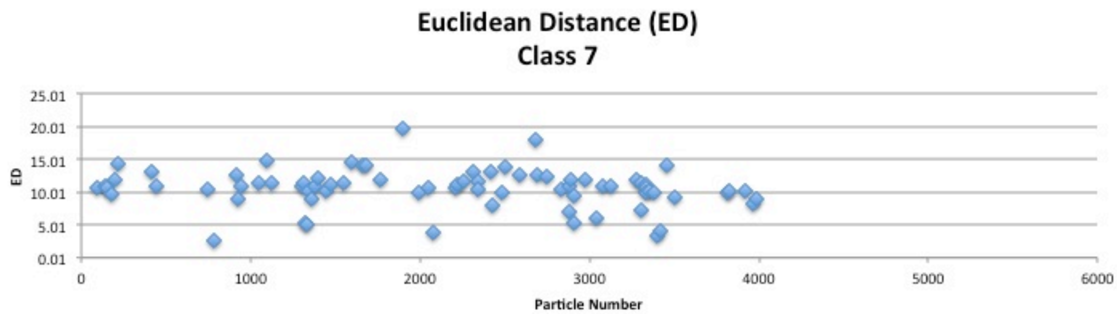

Figure 5-647: Euclidean Distance Class 7

Class 8 of Chad Arid 40 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 459 particles in this class (Figure 5-648).

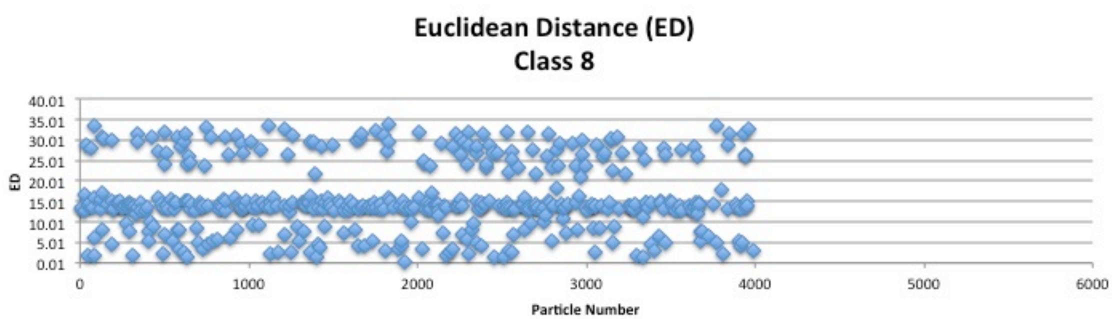

Figure 5-648: Euclidean Distance Class 8

Class 9 of Chad Arid 40 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 34 particles in this class (Figure 5-649).

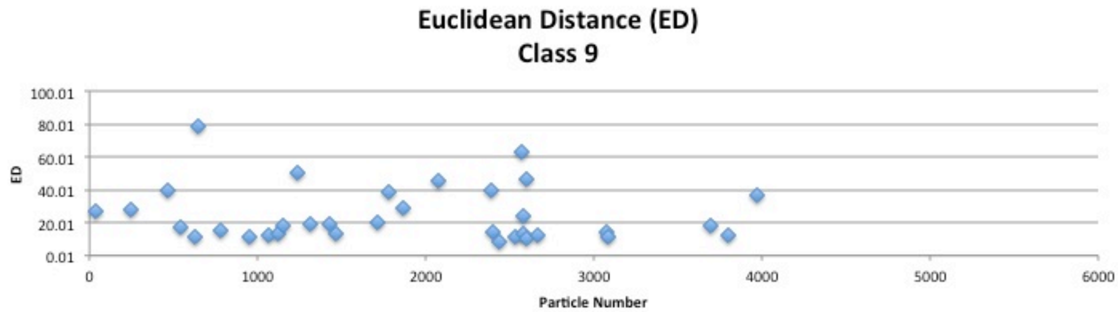

Figure 5-649: Euclidean Distance Class 9

Class 10 of Chad Arid 40 is composed of Calcium greater than 80% and Lead less than 5%. There are 13 particles in this class (Figure 5-650).

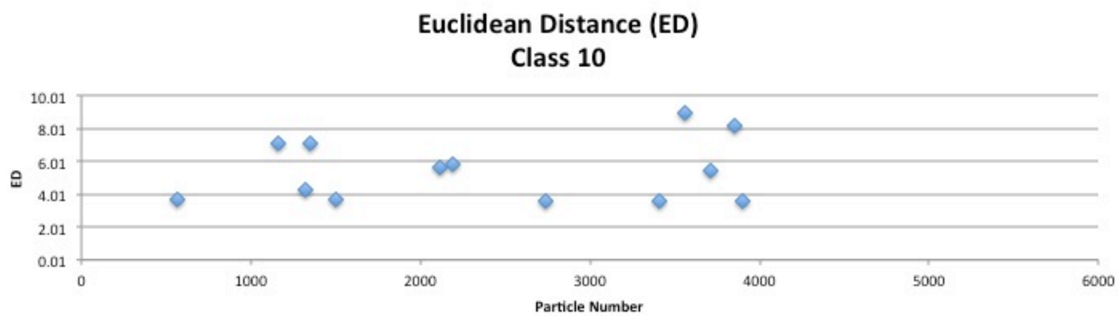

Figure 5-650: Euclidean Distance Class 10

Class 11 of Chad Arid 40 is composed of the total Calcium and Manganese greater than 90%. There is 1 particle in this class (Figure 5-651).

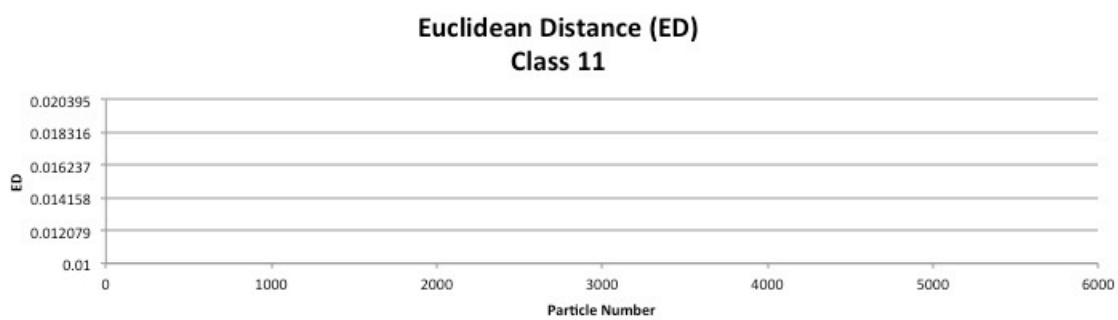

Figure 5-651: Euclidean Distance Class 11

Class 12 of Chad Arid 40 is composed of the total Calcium and Phosphorus greater

than 90%. There are 36 particles in this class (Figure 5-652).

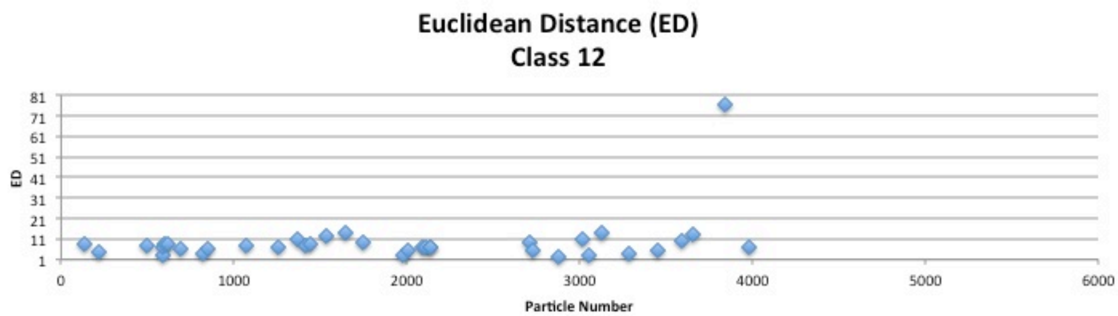

Figure 5-652: Euclidean Distance Class 12

Class 13 of Chad Arid 40 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 4 particles in this class (Figure 5-653).

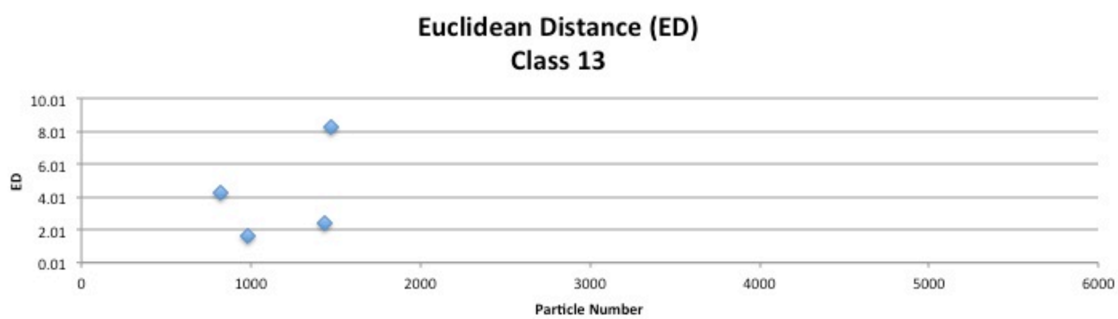

Figure 5-653: Euclidean Distance Class 13

Class 14 of Chad Arid 40 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There is 1 particle in this class (Figure 5-654).

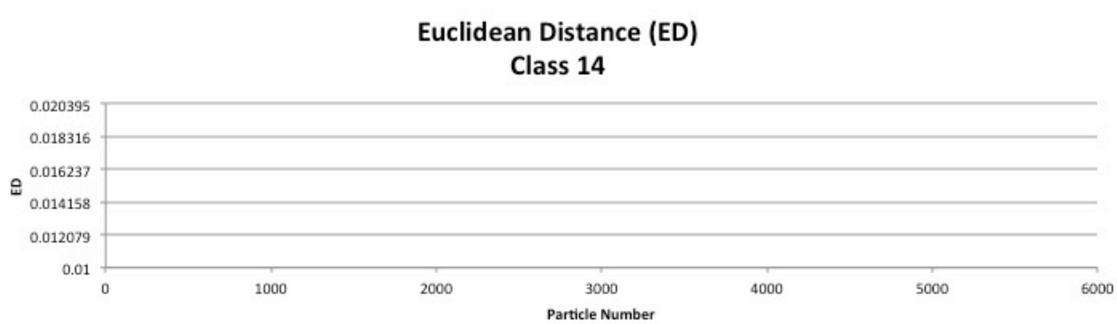

Figure 5-654: Euclidean Distance Class 14

Class 15 of Chad Arid 40 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are 2 particles in this class (Figure 5-655).

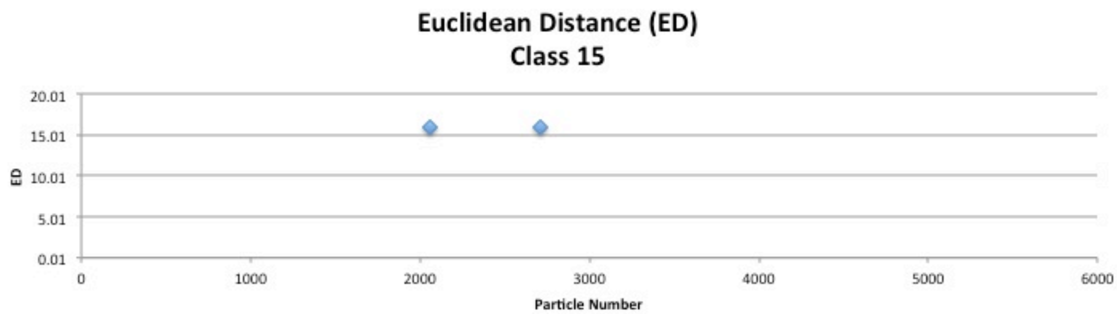

Figure 5-655: Euclidean Distance Class 15

Class 16 of Chad Arid 40 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 18 particles in this class (Figure 5-656).

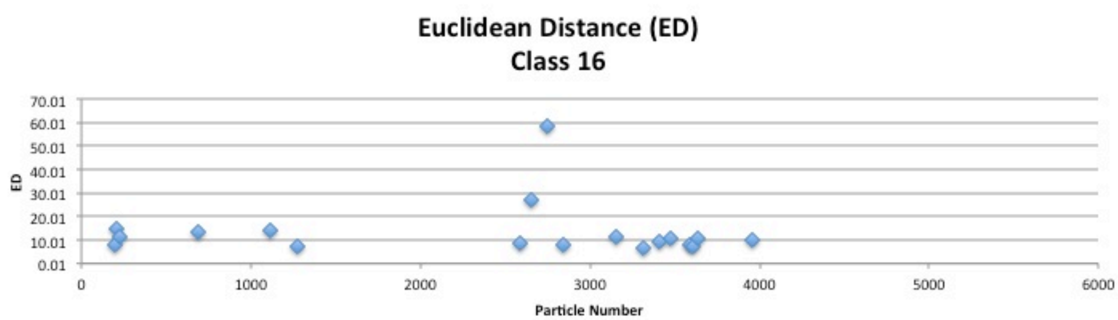

Figure 5-656: Euclidean Distance Class 16

Class 17 of Chad Arid 40 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 65 particles in this class (Figure 5-657).

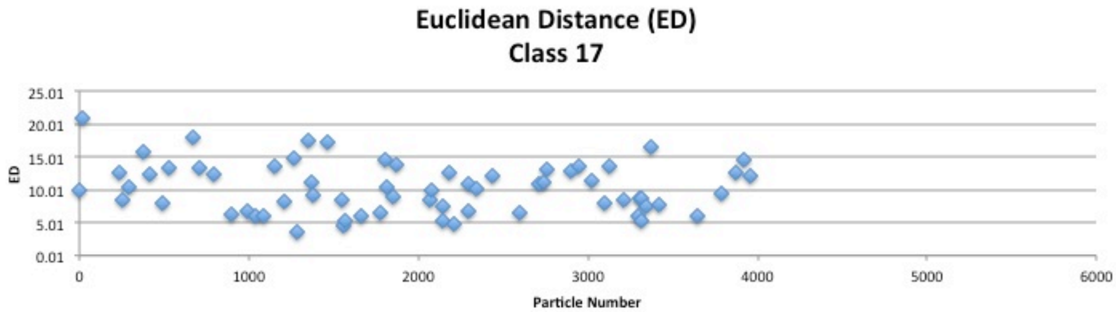

Figure 5-657: Euclidean Distance Class 17

Class 18 of Chad Arid 40 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 127 particles in this class (Figure 5-658).

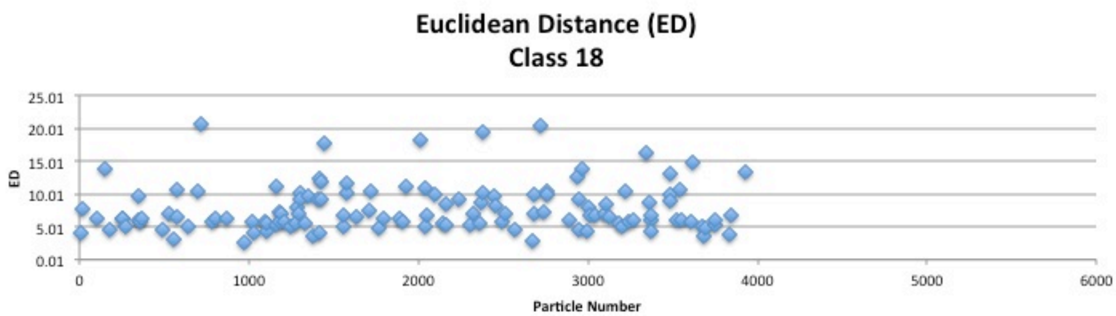

Figure 5-658: Euclidean Distance Class 18

Class 19 of Chad Arid 40 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are 8 particles in this class (Figure 5-659).

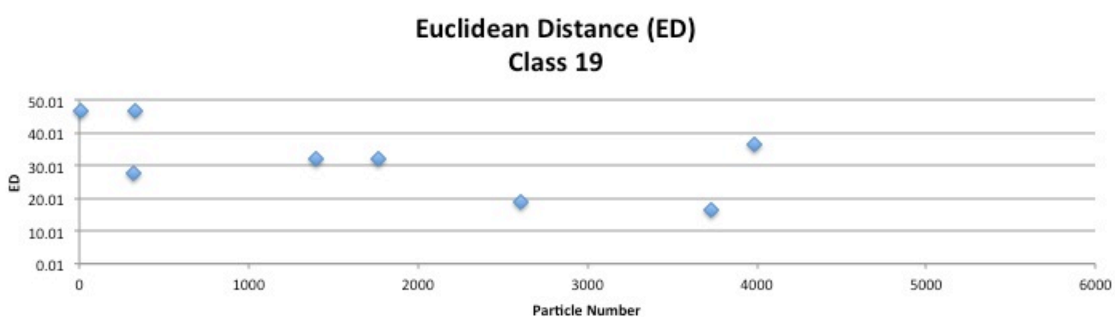

Figure 5-659: Euclidean Distance Class 19

Class 20 of Chad Arid 40 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 439 particles in this class (Figure 5-660).

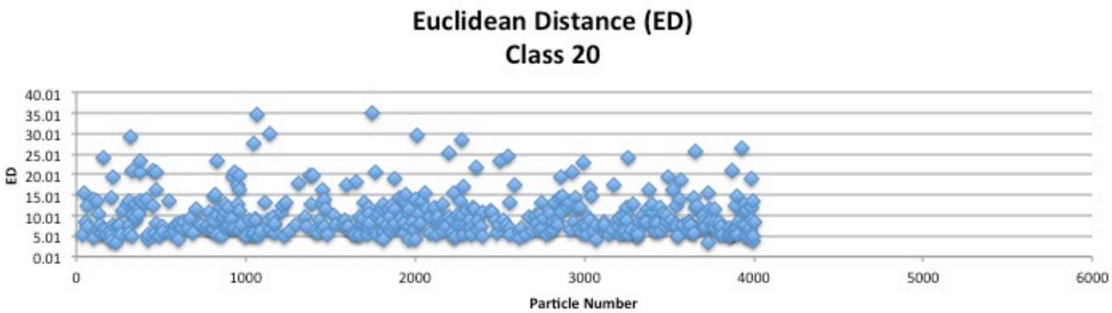

Figure 5-660: Euclidean Distance Class 20

Class 21 of Chad Arid 40 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 118 particles in this class (Figure 5-661).

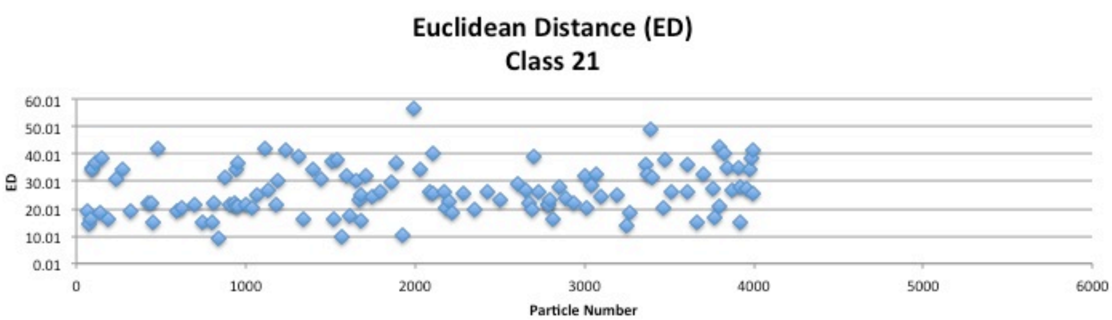

Figure 5-661: Euclidean Distance Class 21

Class 22 of Chad Arid 40 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 785 particles in this class (Figure 5-662).

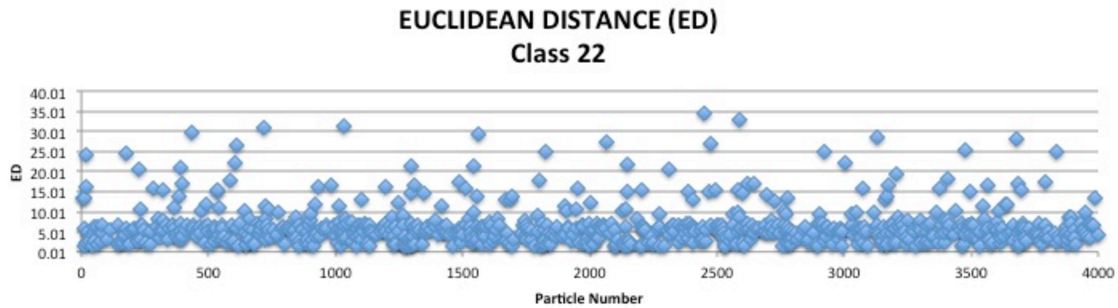

Figure 5-662: Euclidean Distance Class 22

Class 23 of Chad Arid 40 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 49 particles in this class (Figure 5-663).

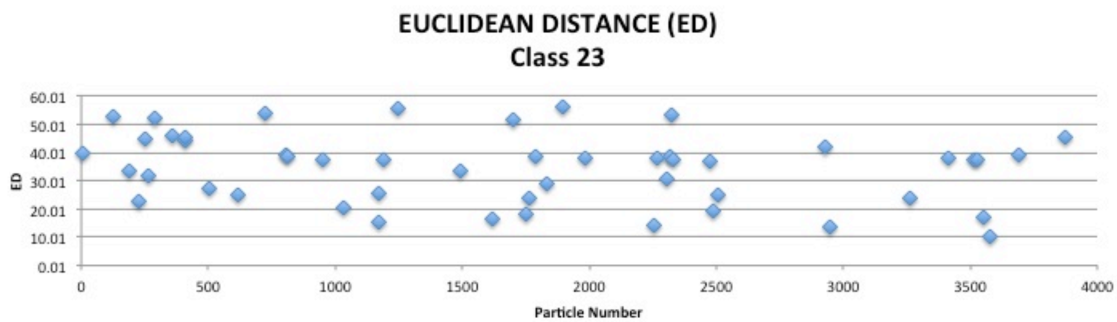

Figure 5-663: Euclidean Distance Class 23

Class 24 of Chad Arid 40 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 9 particles in this class (Figure 5-664).

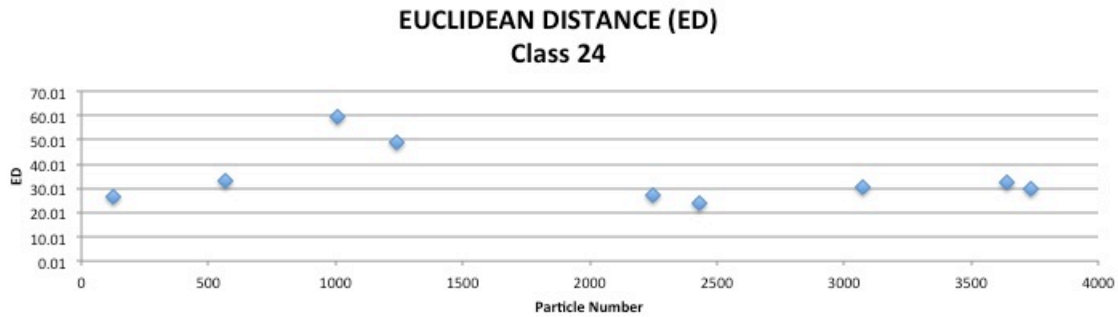

Figure 5-664: Euclidean Distance Class 24

Class 25 of Chad Arid 40 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 55 particles in this class (Figure 5-665).

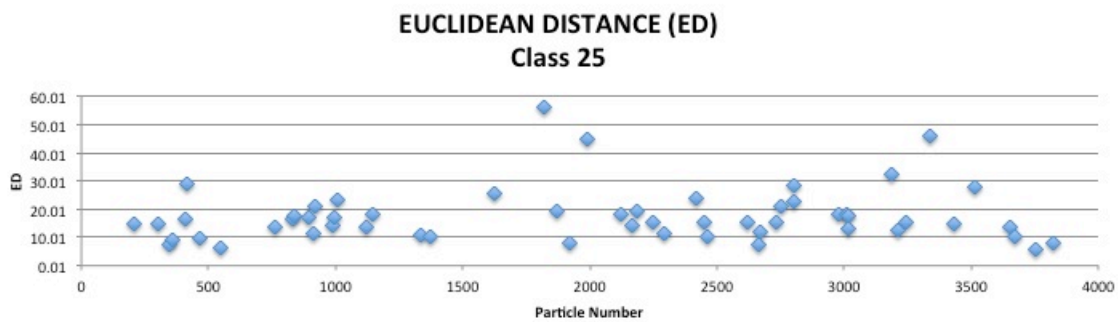

Figure 5-665: Euclidean Distance Class 25

Class 26 of Chad Arid 40 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 514 particles in this class (Figure 5-666).

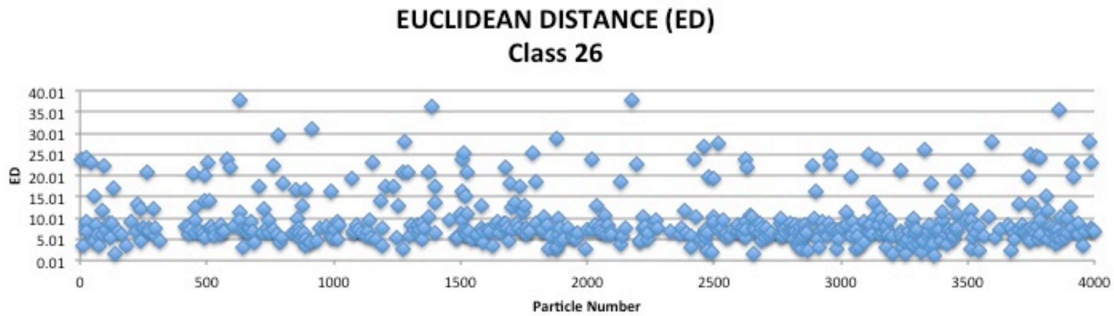

Figure 5-666: Euclidean Distance Class 26

Class 27 of Chad Arid 40 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 288 particles in this class (Figure 5-667).

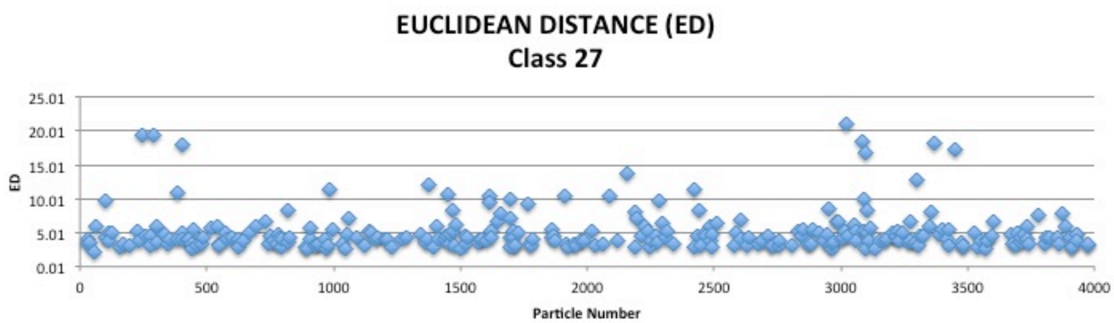

Figure 5-667: Euclidean Distance Class 27

Class 28 of Chad Arid 40 is composed of Aluminum less than 1%. There are a total of 113 particles in this class (Figure 5-668).

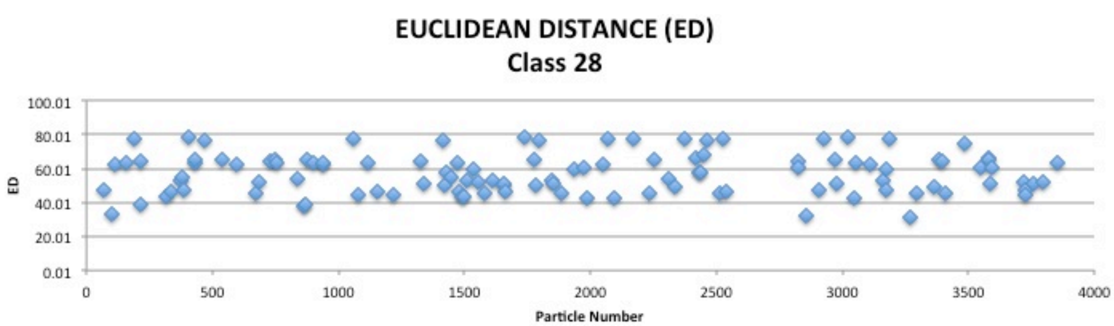

Figure 5-668: Euclidean Distance Class 28

Chad Arid 42

Chad Arid 42 is located at 15 14.332' N, 17 51.786' E and has been separated into 29 elemental classes (Figure 5-669). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-58).

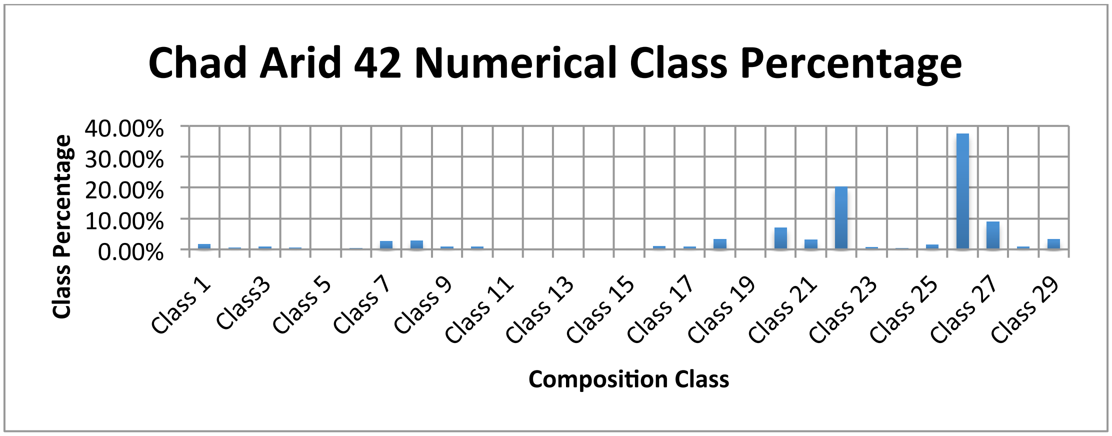

Figure 5-669: Numerical percentage per class.

Table 5-58: Numerical percentage and number of particles per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
82	23	43	24	0	16	134	141
1.65%	0.46%	0.86%	0.48%	0.00%	0.32%	2.69%	2.83%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
45	44	5	1	0	3	0	52
0.90%	0.88%	0.10%	0.02%	0.00%	0.06%	0.00%	1.05%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
40	162	7	349	152	1008	31	19
0.80%	3.26%	0.14%	7.01%	3.05%	20.26%	0.62%	0.38%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
75	1868	448	41	163	4976		
1.51%	37.54%	9.00%	0.82%	3.28%	100.00%		

Table 5-58 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 22, 26, and 28. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. Class 28 has less than 1% Aluminum. This represents 66.80% of the entire sample and contains 3324 particles. Class 29 represents the “unclassified” particles and contains only 3.28% of the entire sample.

The volumetric percentage of Chad Arid 42 represents the volume of particles that are represented in each respective elemental class (Figure 5-670). Table 5-59 shows the breakdown of each class volumetric percentage and, as with the numerical percentage, shows the majority of the particles are contained in classes 22, 26, and 28. Class 22 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. Class 28 has less than 1% Aluminum. This represents 69.11% of the entire sample and contains an average volume of 420740.13 μm^3. Class 29 represents the “unclassified” volume of particles and contains 2.25% of the entire sample.

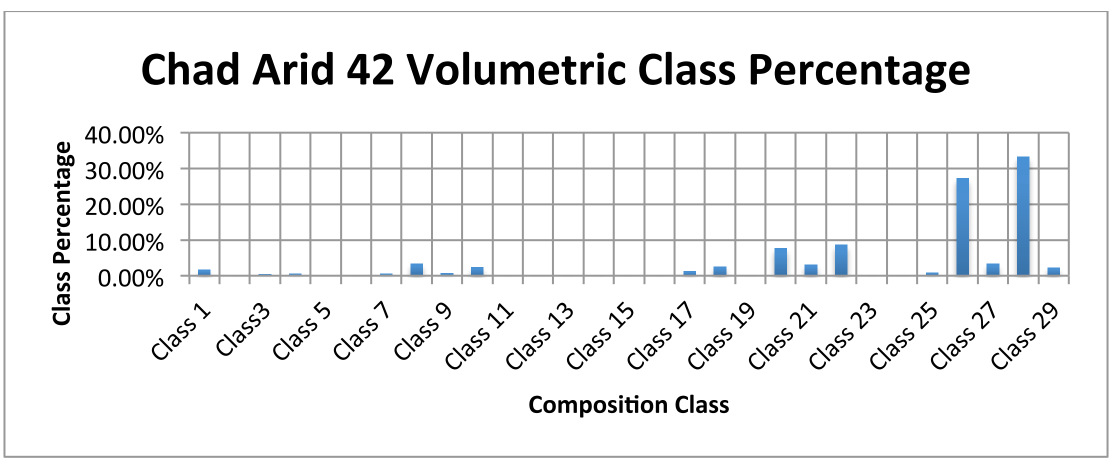

Figure 5-670: Volumetric percentage per class.

Table 5-59: Volumetric percentage and volume of each class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
9757.24	35.52	2122.24	3544.84	0.00	28.93	3405.11	20117.73
1.60%	0.01%	0.35%	0.58%	0.00%	0.00%	0.56%	3.30%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
3874.01	14508.58	779.02	28.76	0.00	674.69	0.00	757.40
0.64%	2.38%	0.13%	0.00%	0.00%	0.11%	0.00%	0.12%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
7218.83	15522.92	215.97	46453.78	19057.23	52356.69	1103.55	60.30
1.19%	2.55%	0.04%	7.63%	3.13%	8.60%	0.18%	0.01%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
5125.29	165903.19	19974.06	202480.25	13677.40	608783.55		
0.84%	27.25%	3.28%	33.26%	2.25%	100.00%		

Analysis of class 29 showed a diverse spread across three elements. The highest elements contained within Chad Arid 42 unclassified are Fe, Si, Al, and only compose a volume of 2.25% of the entire sample particles. The unclassified elements are evenly spread between the elements Iron, Silica and Aluminum, with most of the particles being high in Iron and lower in Silica and Aluminum (Figure 5-671 and Figure 5-672).

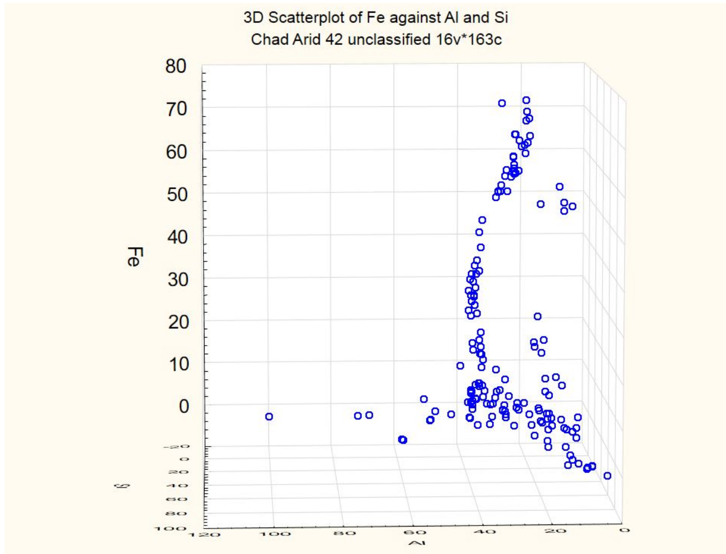

Figure 5-671: Scatterplot of Chad Arid 42 elements Al, Si and Fe. The unclassified particles contain 2.25% volume of the particles in the sample.

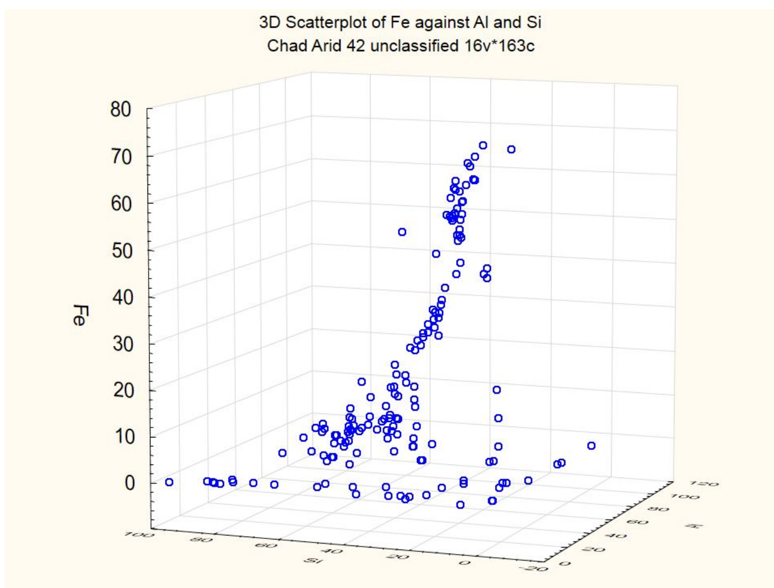

Figure 5-672: Chad Arid 42 alternate 3D scatterplot view.

Euclidean Distance

The Euclidean Distance for Class 1 of Chad Arid 42 is composed of greater than 99% Silica. There are a total of 82 particles in this class (Figure 5-673).

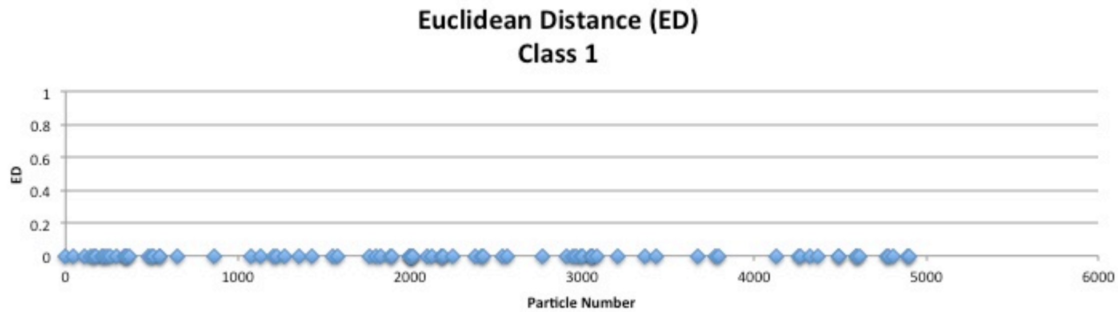

Figure 5-673: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 23 particles in this class (Figure 5-674).

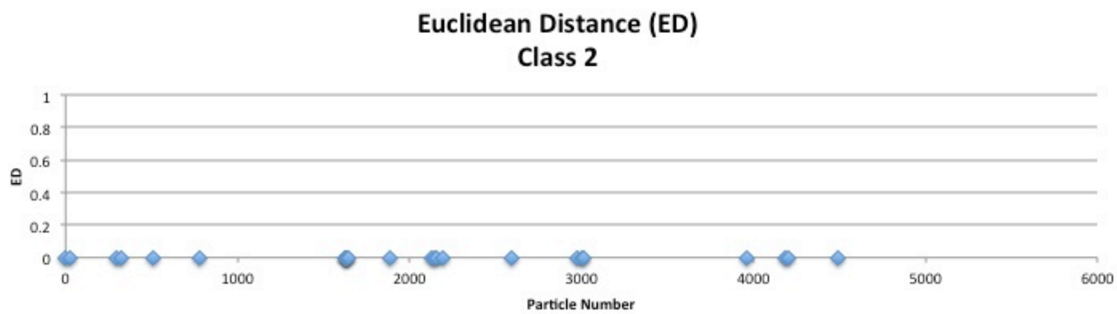

Figure 5-674: Euclidean Distance Class 2

Class 3 of Chad Arid 42 is composed of greater than 99% Calcium. There are a total of 43 particles in this class (Figure 5-675).

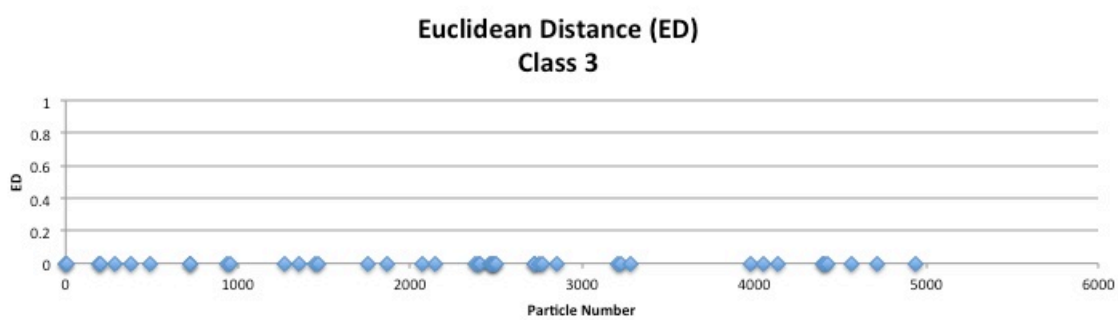

Figure 5-675: Euclidean Distance Class 3

Class 4 of Chad Arid 42 is composed of Titanium greater than 55% and Lead less than

5%. There are 24 particles in this class (Figure 5-676)

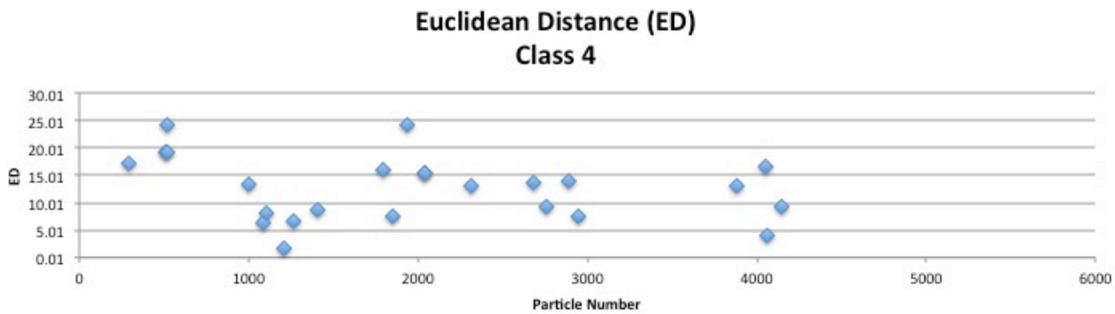

Figure 5-676: Euclidean Distance Class 4

Class 5 of Chad Arid 42 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Chad Arid 42 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 16 particles in this class (Figure 5-677).

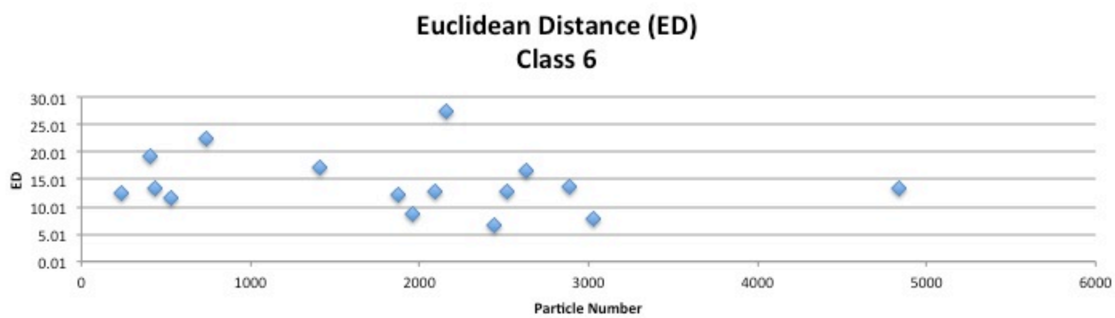

Figure 5-677: Euclidean Distance Class 6

Class 7 of Chad Arid 42 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 134 particles in this class (Figure 5-678).

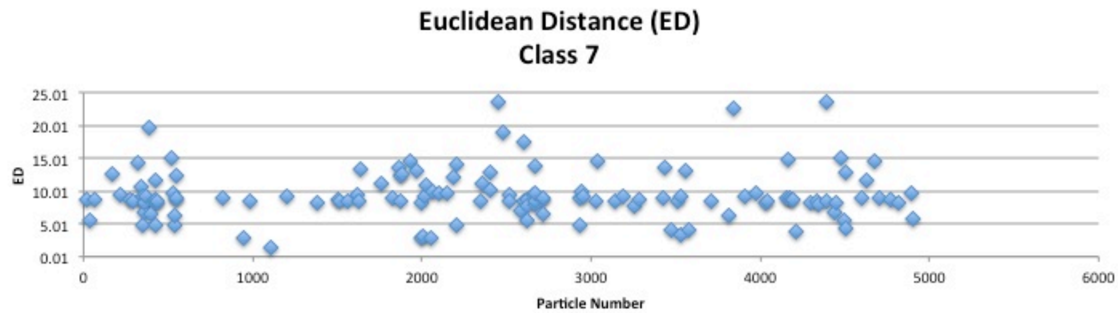

Figure 5-678: Euclidean Distance Class 7

Class 8 of Chad Arid 42 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 141 particles in this class (Figure 5-679).

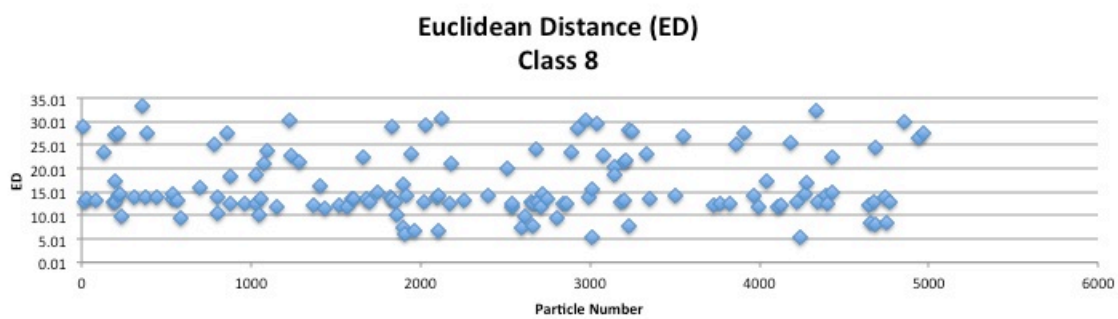

Figure 5-679: Euclidean Distance Class 8

Class 9 of Chad Arid 42 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 45 particles in this class (Figure 5-680).

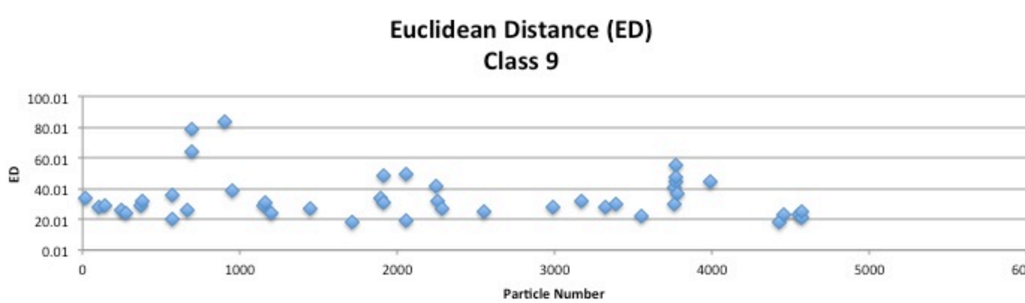

Figure 5-680: Euclidean Distance Class 9

Class 10 of Chad Arid 42 is composed of Calcium greater than 80% and Lead less than 5%. There are 44 particles in this class (Figure 5-681).

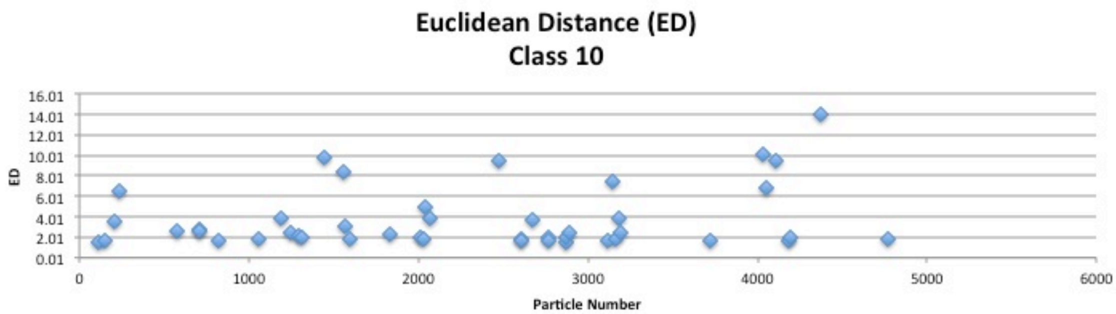

Figure 5-681: Euclidean Distance Class 10

Class 11 of Chad Arid 42 is composed of the total Calcium and Manganese greater than 90%. There are 5 particles in this class (Figure 5-682).

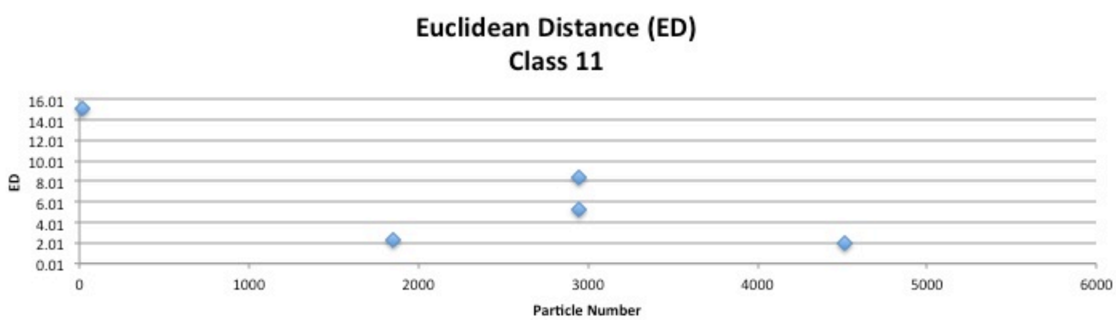

Figure 5-682: Euclidean Distance Class 11

Class 12 of Chad Arid 42 is composed of the total Calcium and Phosphorus greater than 90%. There is 1 particle in this class (Figure 5-683).

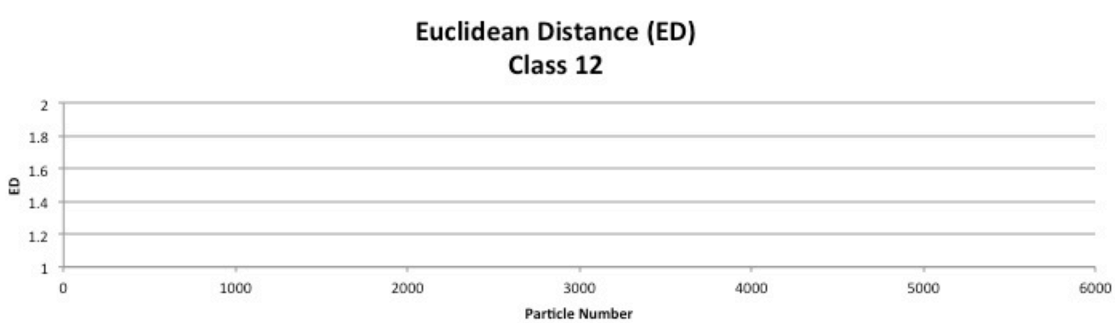

Figure 5-683: Euclidean Distance Class 12

Class 13 of Chad Arid 42 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are no particles in this class.

Class 14 of Chad Arid 42 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are 3 particles in this class (Figure 5-684).

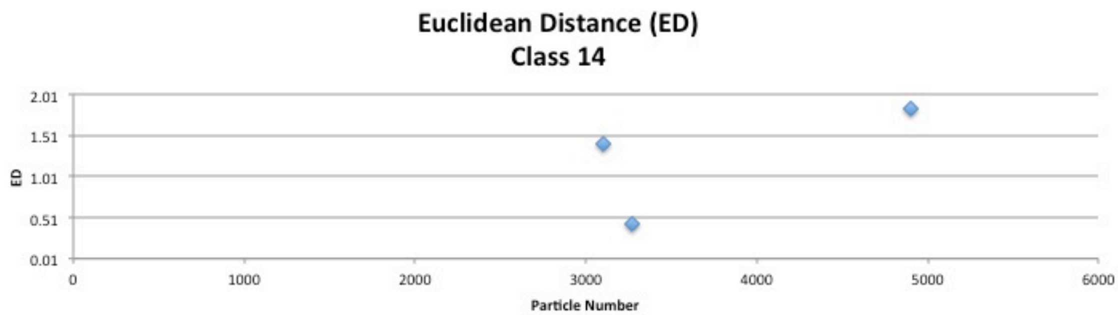

Figure 5-684: Euclidean Distance Class 14

Class 15 of Chad Arid 42 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Chad Arid 42 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 52 particles in this class (Figure 5-685).

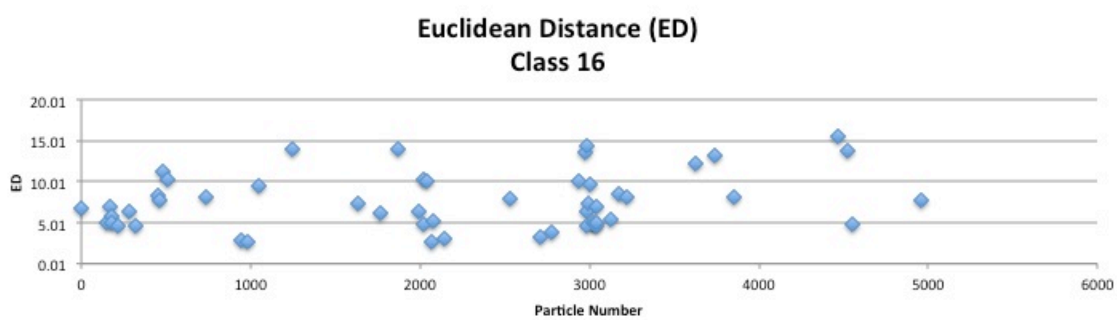

Figure 5-685: Euclidean Distance Class 16

Class 17 of Chad Arid 42 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 40 particles in this class (Figure 5-686).

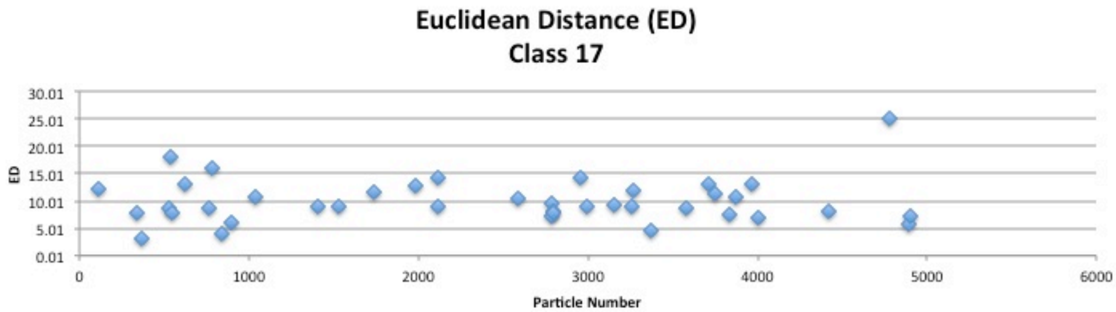

Figure 5-686: Euclidean Distance Class 17

Class 18 of Chad Arid 42 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 162 particles in this class (Figure 5-687).

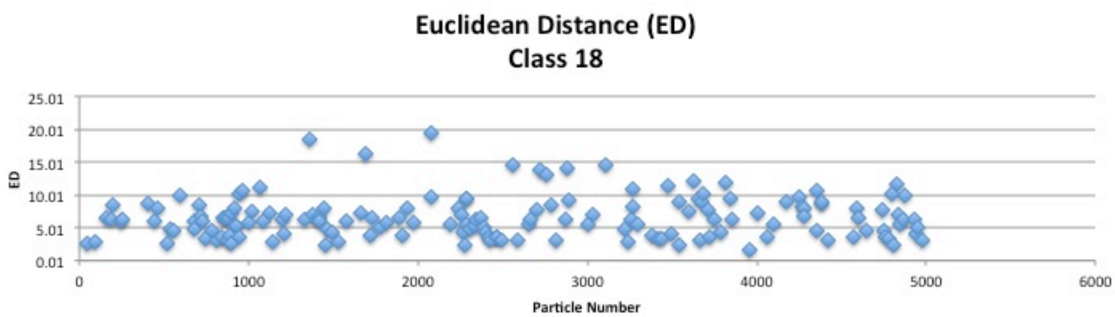

Figure 5-687: Euclidean Distance Class 18

Class 19 of Chad Arid 42 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are 7 particles in this class (Figure 5-688).

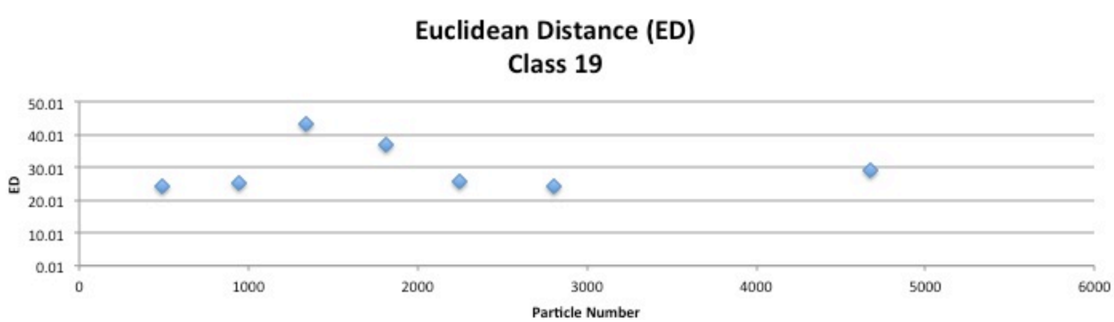

Figure 5-688: Euclidean Distance Class 19

Class 20 of Chad Arid 42 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 349 particles in this class (Figure 5-689).

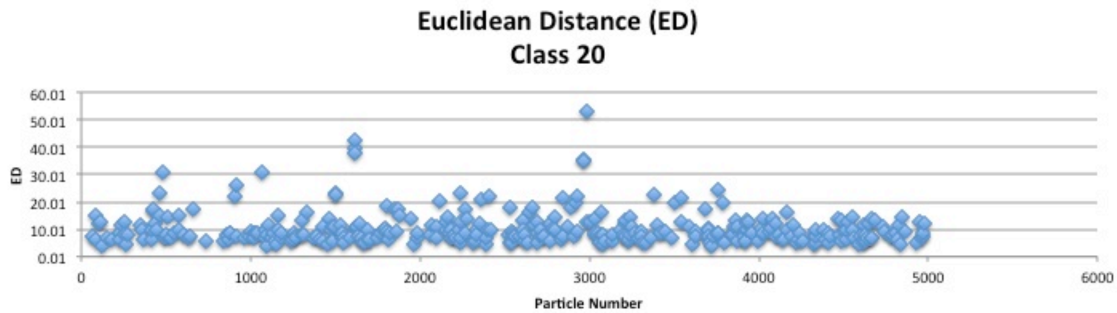

Figure 5-689: Euclidean Distance Class 20

Class 21 of Chad Arid 42 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 152 particles in this class (Figure 5-690).

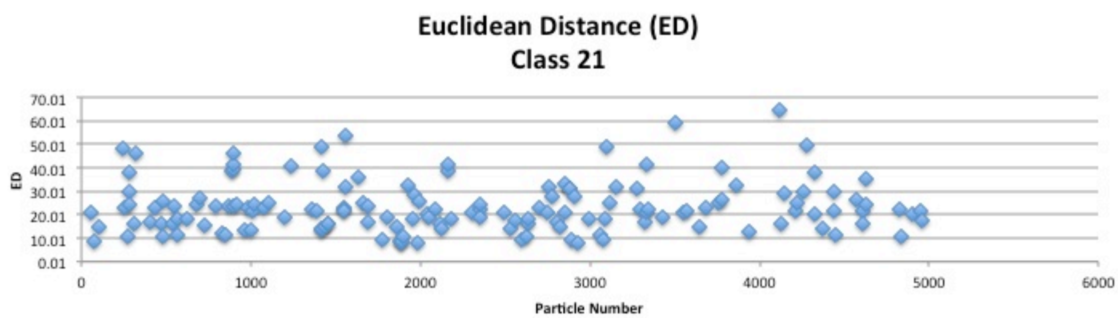

Figure 5-690: Euclidean Distance Class 21

Class 22 of Chad Arid 42 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 1008 particles in this class (Figure 5-691).

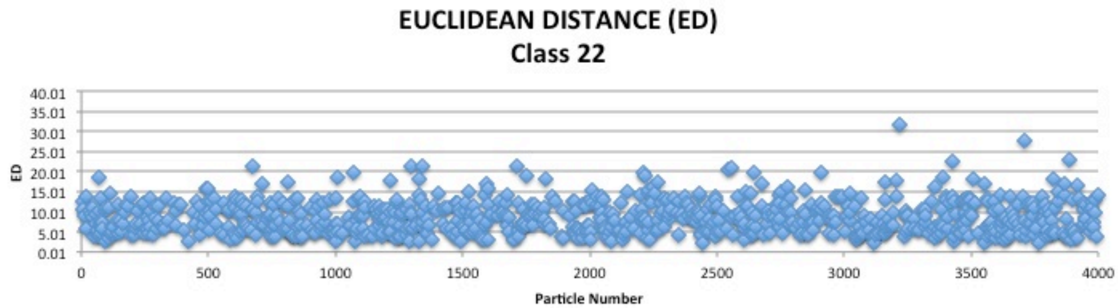

Figure 5-691: Euclidean Distance Class 22

Class 23 of Chad Arid 42 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 31 particles in this class (Figure 5-692).

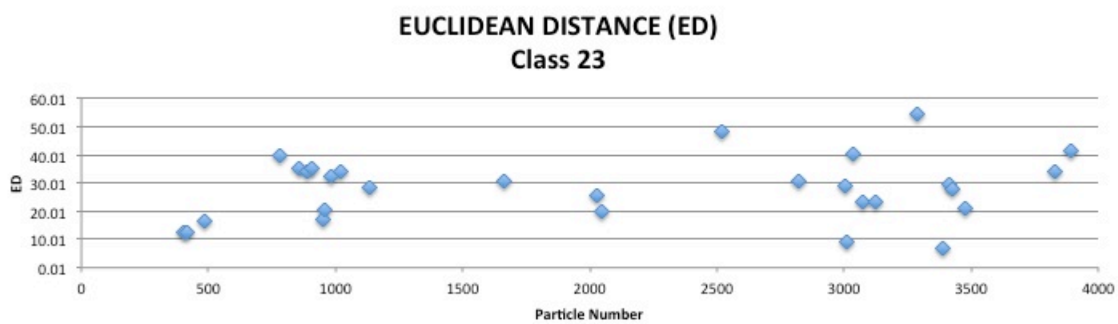

Figure 5-692: Euclidean Distance Class 23

Class 24 of Chad Arid 42 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 19 particles in this class (Figure 5-693).

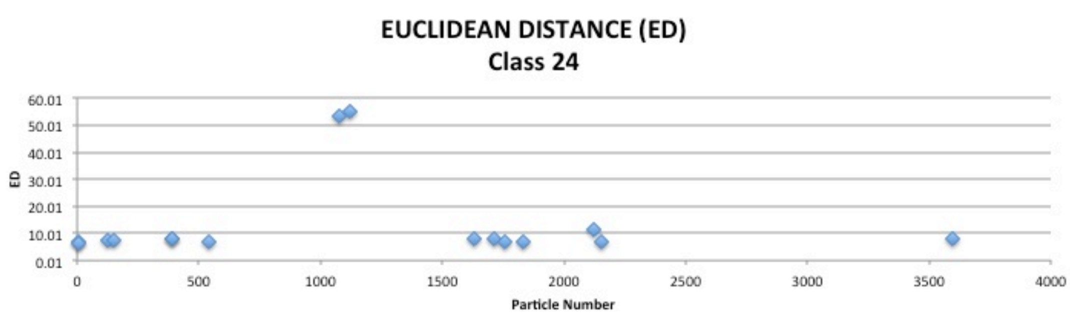

Figure 5-693: Euclidean Distance Class 24

Class 25 of Chad Arid 42 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 75 particles in this class (Figure 5-694).

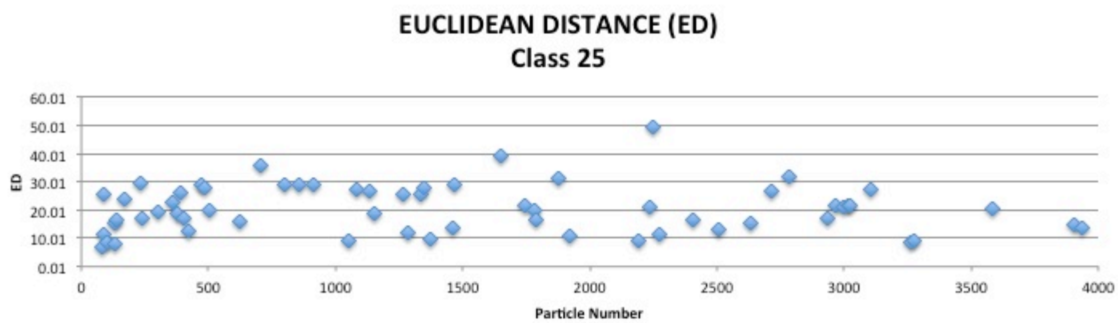

Figure 5-694: Euclidean Distance Class 25

Class 26 of Chad Arid 42 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 1868 particles in this class (Figure 5-695).

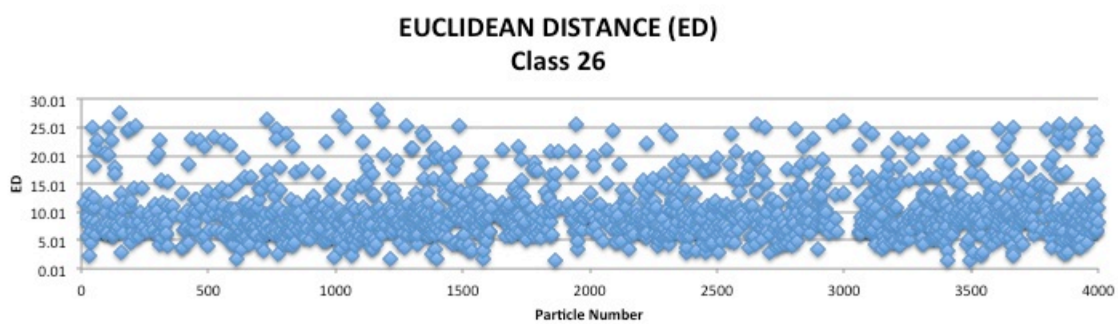

Figure 5-695: Euclidean Distance Class 26

Class 27 of Chad Arid 42 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 448 particles in this class (Figure 5-696).

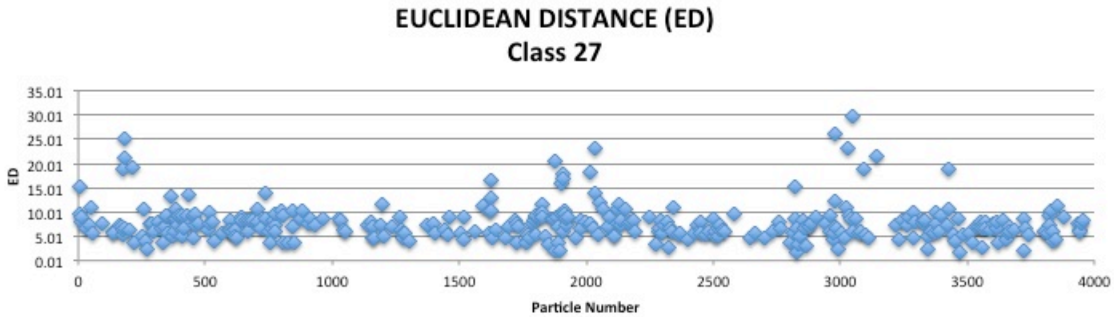

Figure 5-696: Euclidean Distance Class 27

Class 28 of Chad Arid 42 is composed of Aluminum less than 1%. There are a total of 41 particles in this class (Figure 5-697).

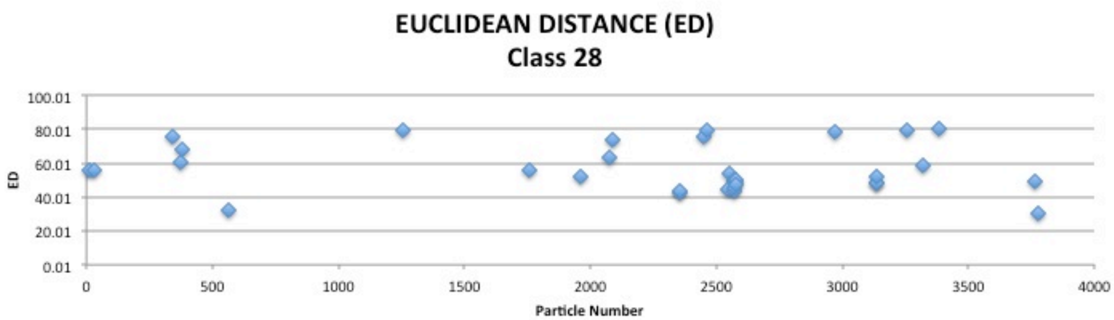

Figure 5-697: Euclidean Distance Class 28

Chad Arid 45

Chad Arid 45 has been separated into 29 elemental classes (Figure 5-698). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-60).

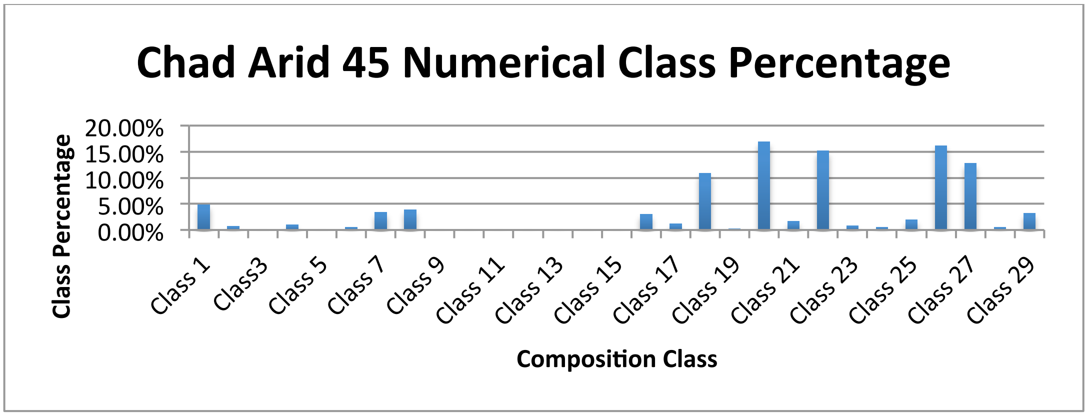

Figure 5-698: Numerical percentage per class.

Table 5-60: Numerical percentage and number of particles per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
161	23	3	35	1	18	113	130
4.82%	0.69%	0.09%	1.05%	0.03%	0.54%	3.38%	3.89%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
2	1	1	2	5	1	0	102
0.06%	0.03%	0.03%	0.06%	0.15%	0.03%	0.00%	3.05%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
40	364	8	566	55	507	28	19
1.20%	10.89%	0.24%	16.93%	1.65%	15.17%	0.84%	0.57%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
66	541	427	17	107	3343		
1.97%	16.18%	12.77%	0.51%	3.20%	100.00%		

Table 5-60 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 20, 22, and 26. Class 20 is composed of Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 22 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. This represents 48.28% of the entire sample and contains 1614 particles. Class 29 represents the "unclassified" particles and contains only 3.20% of the entire sample.

The volumetric percentage of Chad Arid 45 represents the volume of particles that are represented in each respective elemental class (Figure 5-699). Table 5-61 shows the breakdown of each class volumetric percentage and, as with the numerical percentage, shows the majority of the particles are contained in classes 20, 26, and 27. Class 20 is composed of Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 83.84% of the entire sample and contains an average volume of 453251.69 μm^3. Class 29 represents the "unclassified" volume of particles and contains 0.20% of the entire sample.

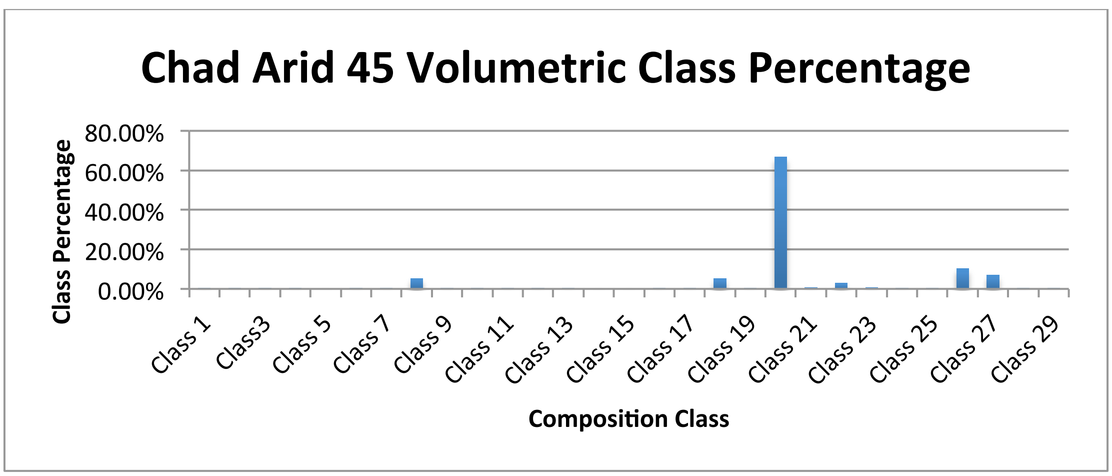

Figure 5-699: Volumetric percentage per class.

Table 5-61: Volumetric percentage and volume of each class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
2999.48	195.89	67.43	156.51	0.00	6.35	729.20	28750.02
0.55%	0.04%	0.01%	0.03%	0.00%	0.00%	0.13%	5.32%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
30.54	81.61	4.45	239.35	36.05	0.15	0.00	161.07
0.01%	0.02%	0.00%	0.04%	0.01%	0.00%	0.00%	0.03%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
286.79	28071.03	53.05	360579.76	3025.31	15354.07	3738.05	70.15
0.05%	5.19%	0.01%	66.69%	0.56%	2.84%	0.69%	0.01%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
187.24	55174.06	37497.87	2069.70	1088.53	540653.71		
0.03%	10.21%	6.94%	0.38%	0.20%	100.00%		

Analysis of class 29 showed a minimal amount of particles. The highest elements contained within Chad Arid 45 unclassified are Fe, Si, Al, and only compose a volume of 0.20% of the entire sample particles. The unclassified elements are evenly spread between the elements Iron, Silica and Aluminum, with most of the particles being high in Iron and lower in Silica and Aluminum (Figure 5-700 and Figure 5-701).

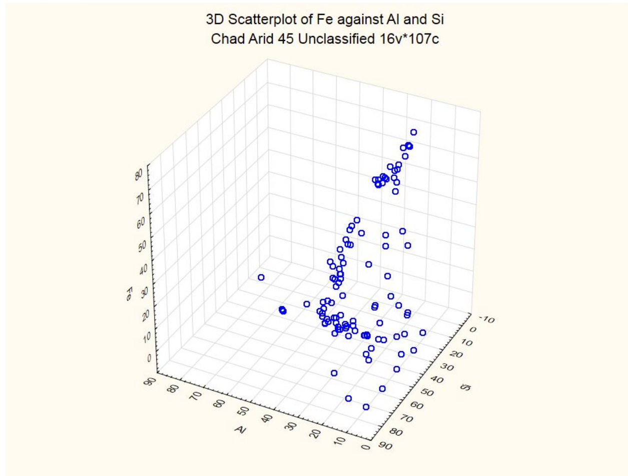

Figure 5-700: Scatterplot of Chad Arid 45 elements Al, Si and Fe. The unclassified particles contain 0.20% volume of the particles in the sample.

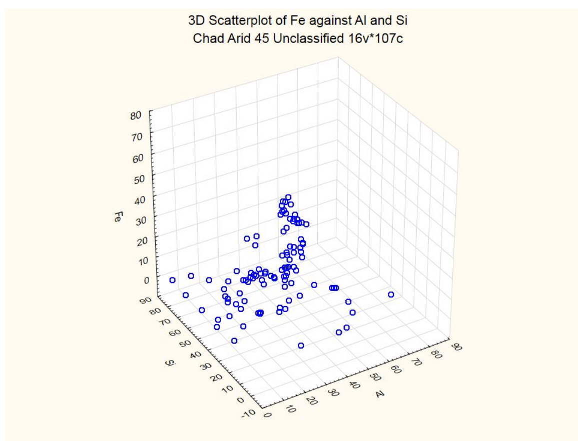

Figure 5-701: Chad Arid 45 alternate 3D scatterplot view.

Euclidean Distance

The Euclidean Distance for Class 1 of Chad Arid 45 is composed of greater than 99% Silica. There are a total of 161 particles in this class (Figure 5-702).

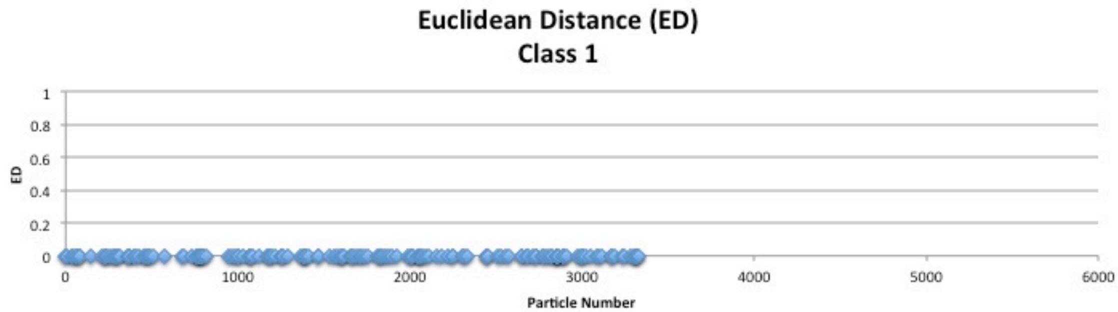

Figure 5-702: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 23 particles in this class (Figure 5-703).

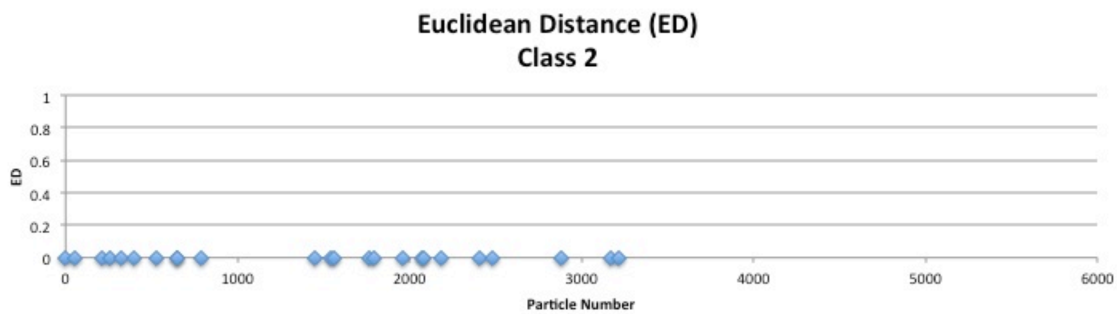

Figure 5-703: Euclidean Distance Class 2

Class 3 of Chad Arid 45 is composed of greater than 99% Calcium. There are a total of 3 particles in this class (Figure 5-704).

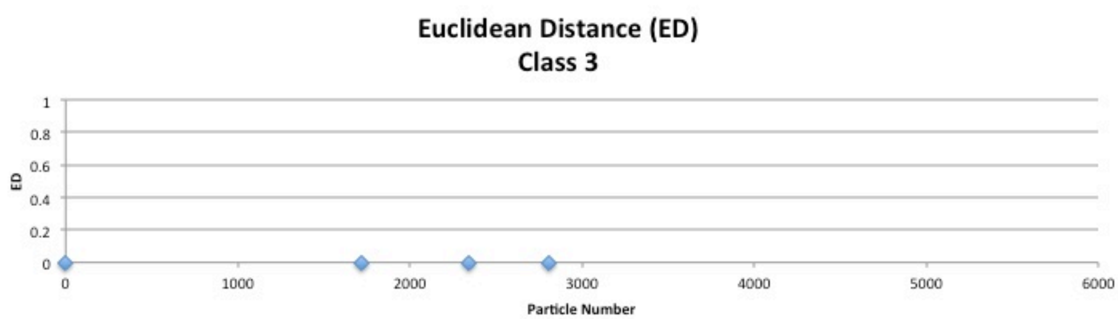

Figure 5-704: Euclidean Distance Class 3

Class 4 of Chad Arid 45 is composed of Titanium greater than 55% and Lead less than

5%. There are 35 particles in this class (Figure 5-705).

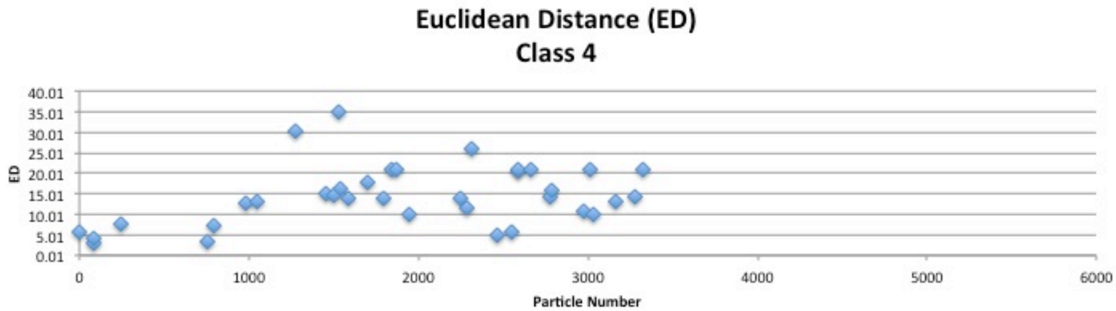

Figure 5-705: Euclidean Distance Class 4

Class 5 of Chad Arid 45 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There is particle in this class (Figure 5-706).

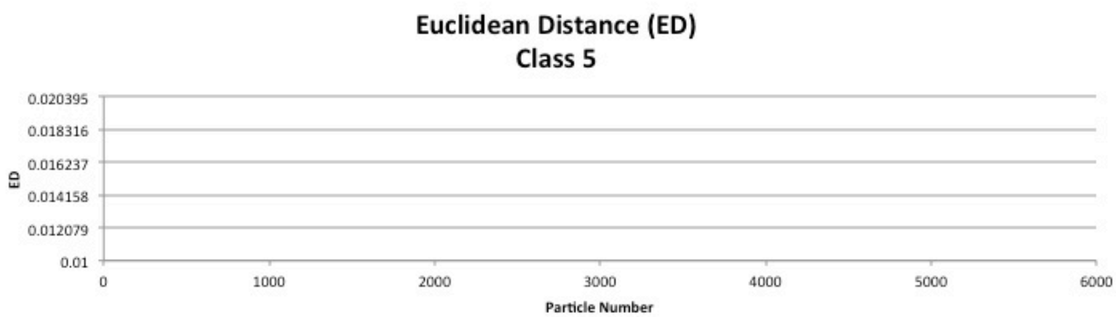

Figure 5-706: Euclidean Distance Class 5

Class 6 of Chad Arid 45 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 18 particles in this class (Figure 5-707).

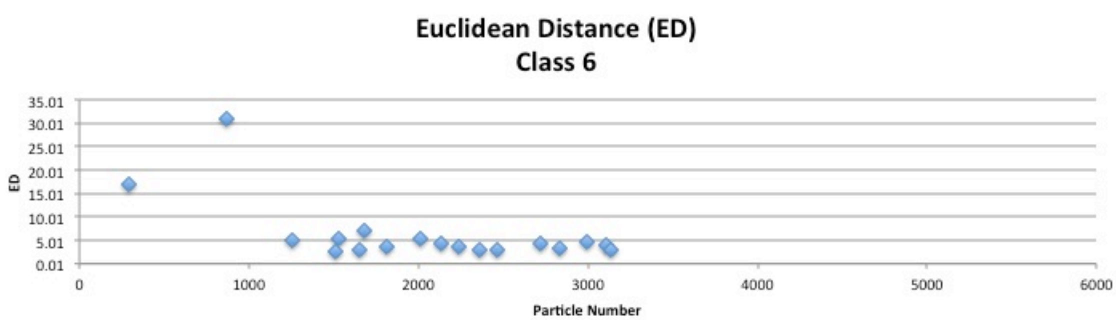

Figure 5-707: Euclidean Distance Class 6

Class 7 of Chad Arid 45 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 113 particles in this class (Figure 5-708).

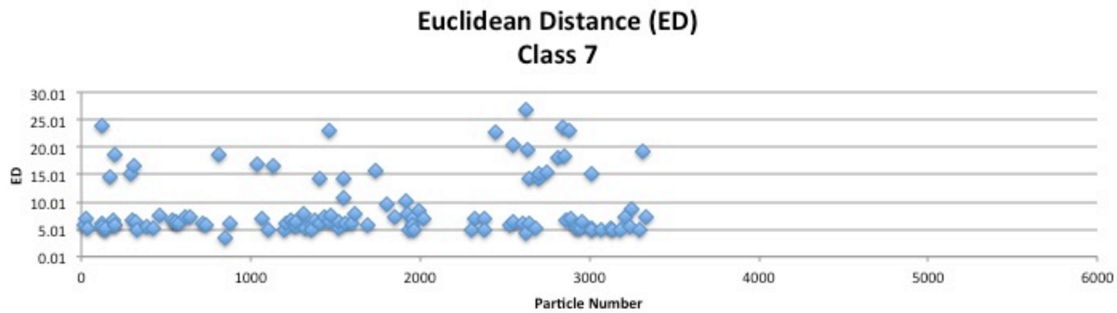

Figure 5-708: Euclidean Distance Class 7

Class 8 of Chad Arid 45 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 130 particles in this class (Figure 5-709).

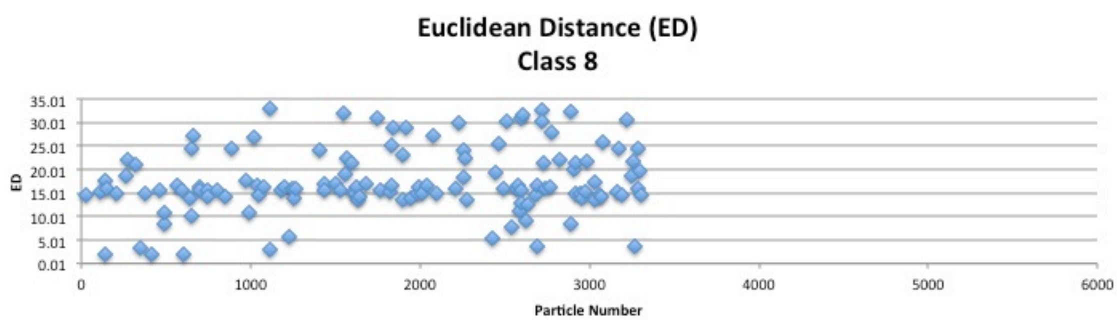

Figure 5-709: Euclidean Distance Class 8

Class 9 of Chad Arid 45 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 2 particles in this class (Figure 5-710).

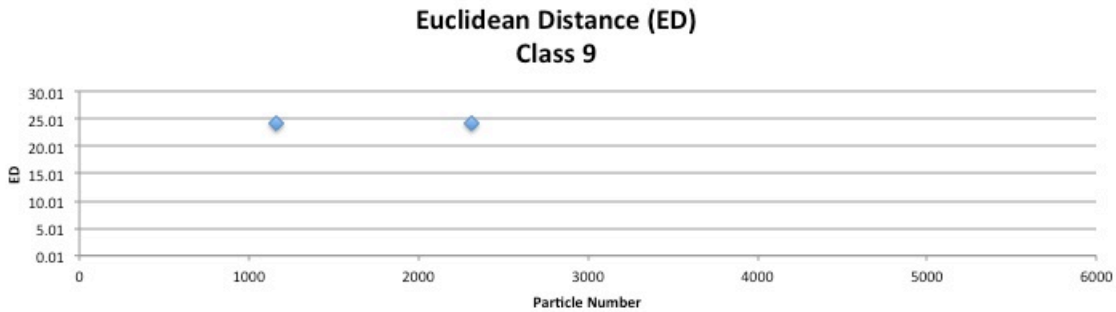

Figure 5-710: Euclidean Distance Class 9

Class 10 of Chad Arid 45 is composed of Calcium greater than 80% and Lead less than 5%. There is 1 particle in this class (Figure 5-711).

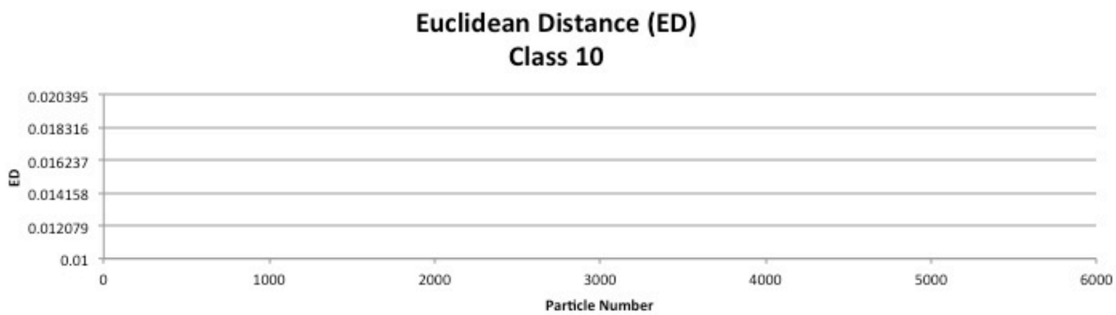

Figure 5-711: Euclidean Distance Class 10

Class 11 of Chad Arid 45 is composed of the total Calcium and Manganese greater than 90%. There is 1 particle in this class (Figure 5-712).

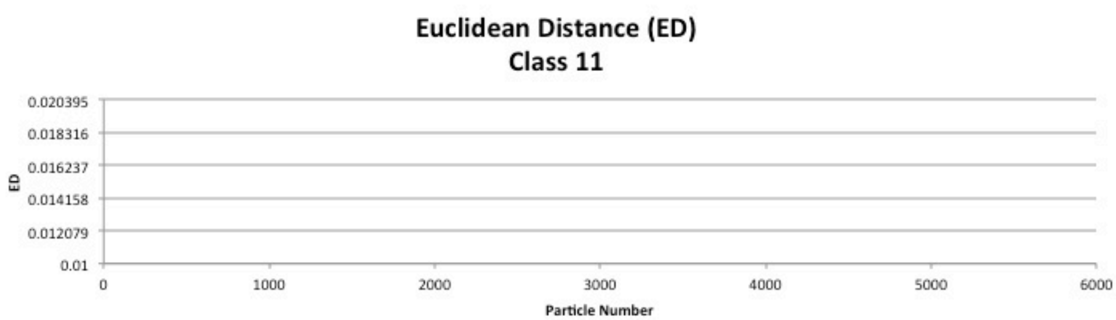

Figure 5-712: Euclidean Distance Class 11

Class 12 of Chad Arid 45 is composed of the total Calcium and Phosphorus greater

than 90%. There are 2 particles in this class (Figure 5-713).

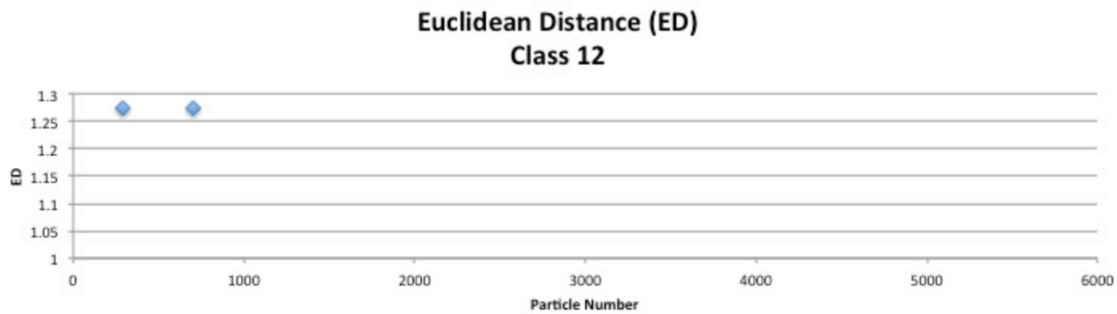

Figure 5-713: Euclidean Distance Class 12

Class 13 of Chad Arid 45 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 5 particles in this class (Figure 5-714).

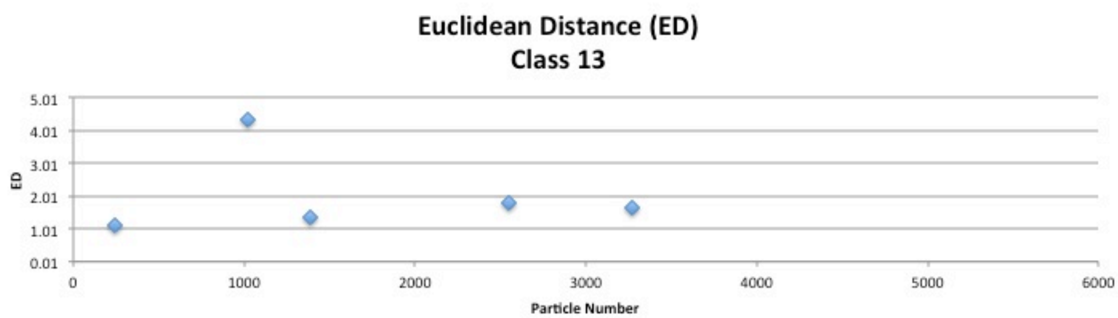

Figure 5-714: Euclidean Distance Class 13

Class 14 of Chad Arid 45 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There is 1 particle in this class (Figure 5-715).

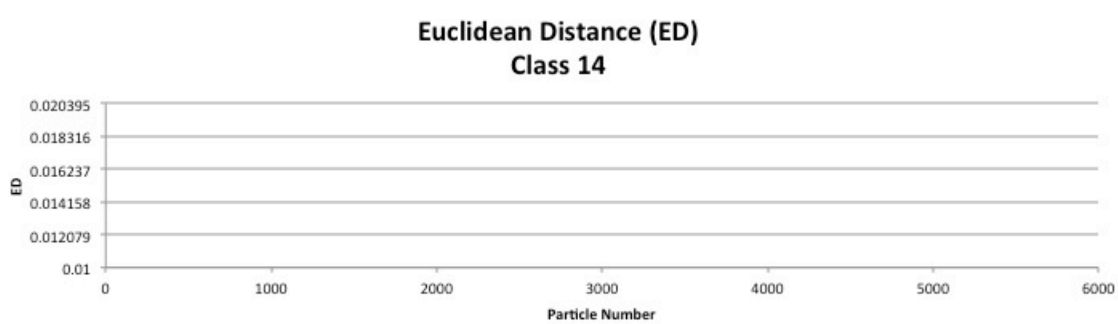

Figure 5-715: Euclidean Distance Class 14

Class 15 of Chad Arid 45 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Chad Arid 45 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 102 particles in this class (Figure 5-716).

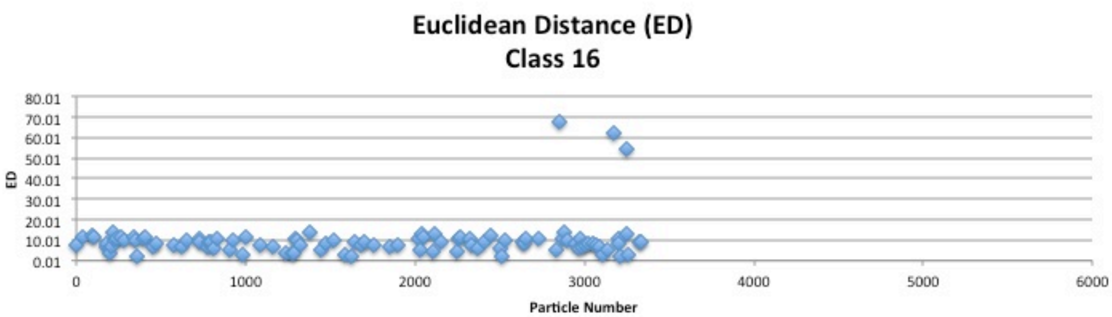

Figure 5-716: Euclidean Distance Class 16

Class 17 of Chad Arid 45 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 40 particles in this class (Figure 5-717).

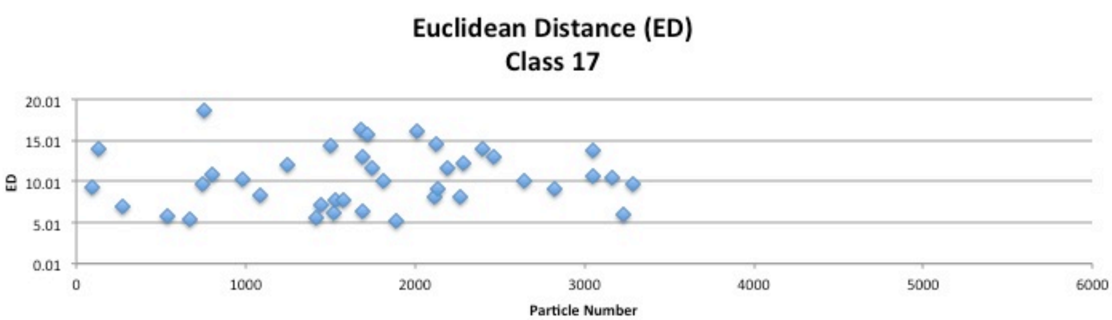

Figure 5-717: Euclidean Distance Class 17

Class 18 of Chad Arid 45 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 364 particles in this class (Figure 5-718).

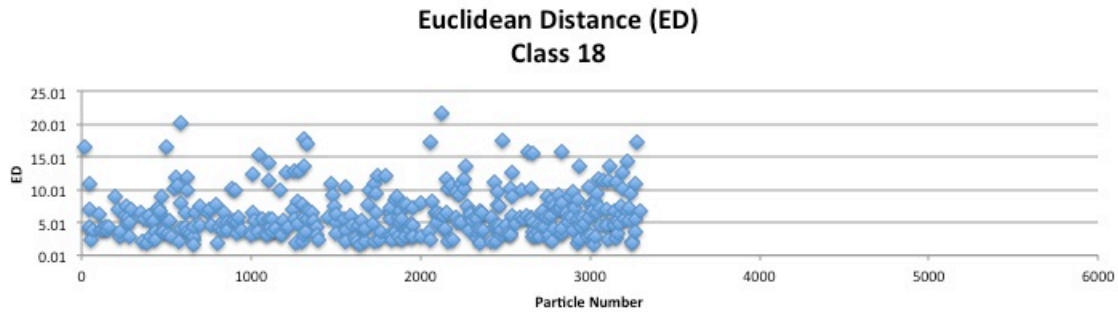

Figure 5-718: Euclidean Distance Class 18

Class 19 of Chad Arid 45 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are 8 particles in this class (Figure 5-719).

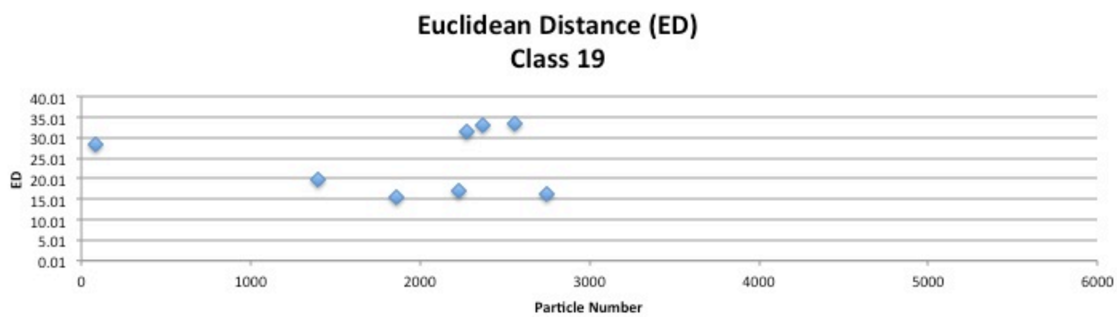

Figure 5-719: Euclidean Distance Class 19

Class 20 of Chad Arid 45 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 566 particles in this class (Figure 5-720).

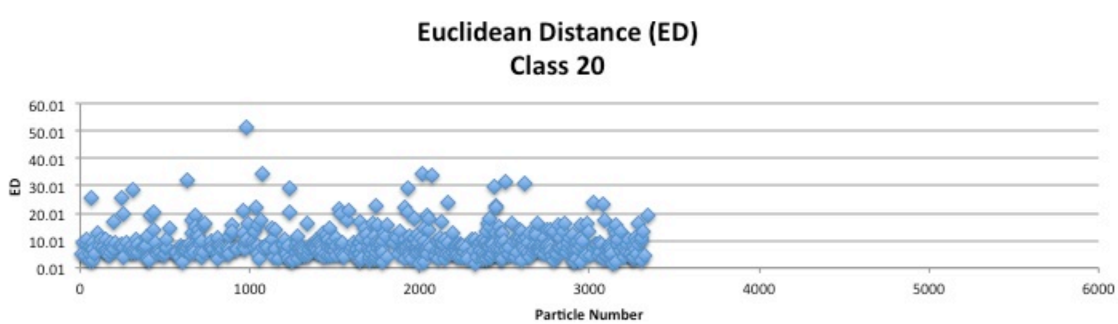

Figure 5-720: Euclidean Distance Class 20

Class 21 of Chad Arid 45 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 55 particles in this class (Figure 5-721).

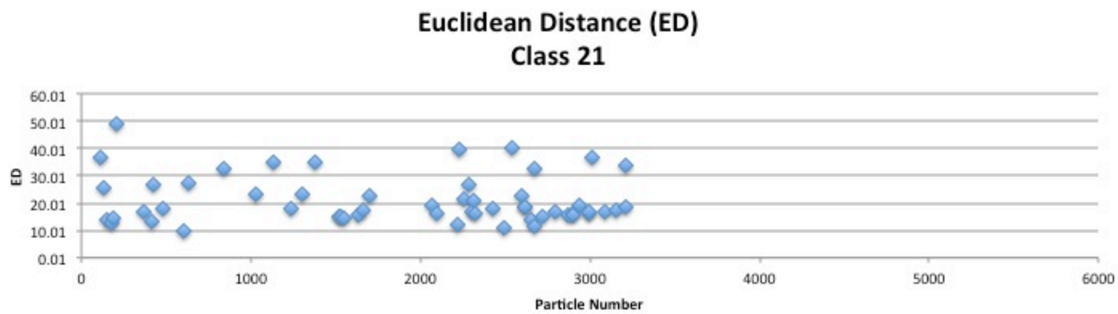

Figure 5-721: Euclidean Distance Class 21

Class 22 of Chad Arid 45 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 507 particles in this class (Figure 5-722).

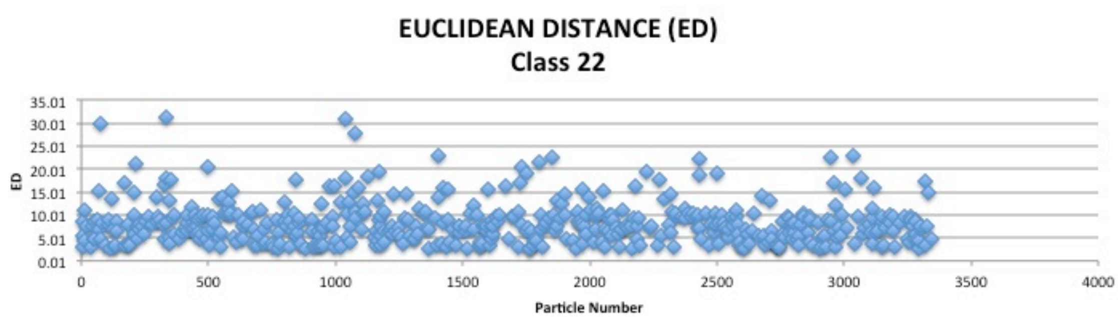

Figure 5-722: Euclidean Distance Class 22

Class 23 of Chad Arid 45 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 28 particles in this class (Figure 5-723).

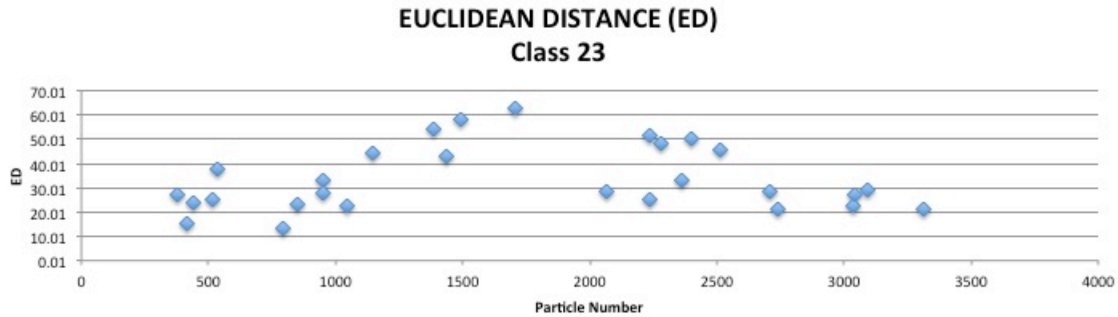

Figure 5-723: Euclidean Distance Class 23

Class 24 of Chad Arid 45 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 19 particles in this class (Figure 5-724).

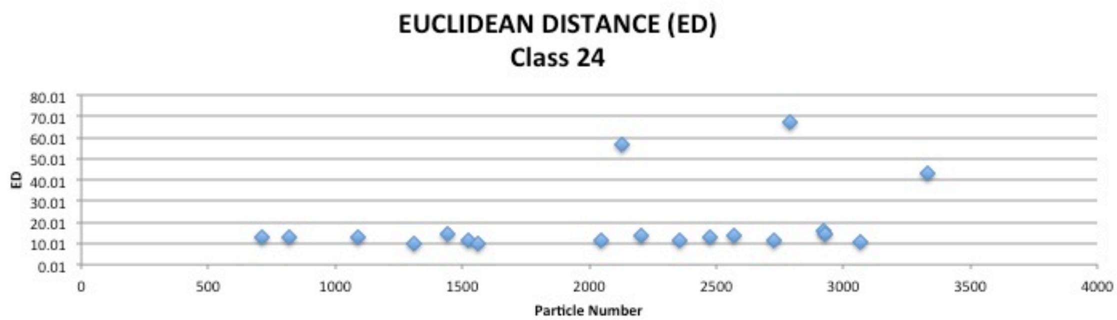

Figure 5-724: Euclidean Distance Class 24

Class 25 of Chad Arid 45 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 66 particles in this class (Figure 5-725).

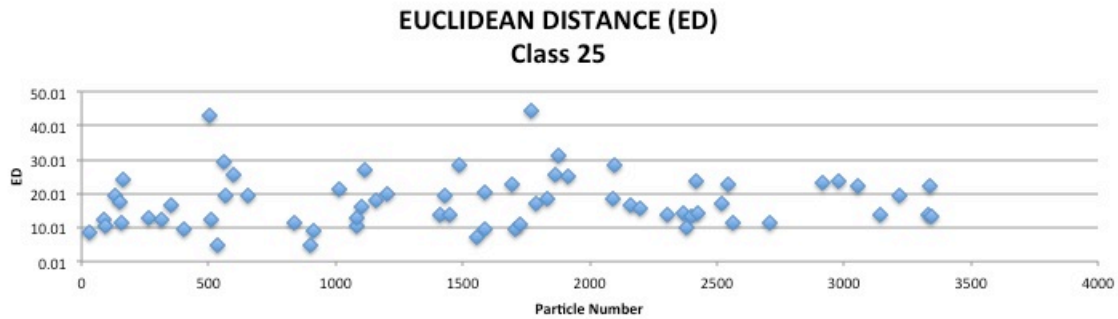

Figure 5-725: Euclidean Distance Class 25

Class 26 of Chad Arid 45 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 541 particles in this class (Figure 5-726).

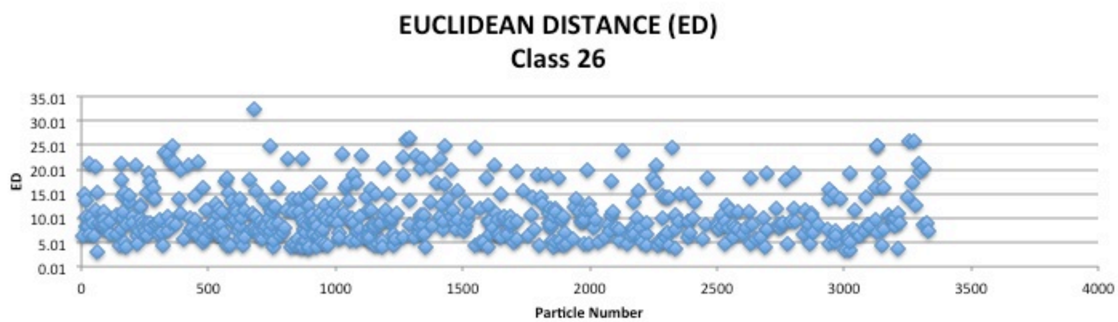

Figure 5-726: Euclidean Distance Class 26

Class 27 of Chad Arid 45 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 427 particles in this class (Figure 5-727).

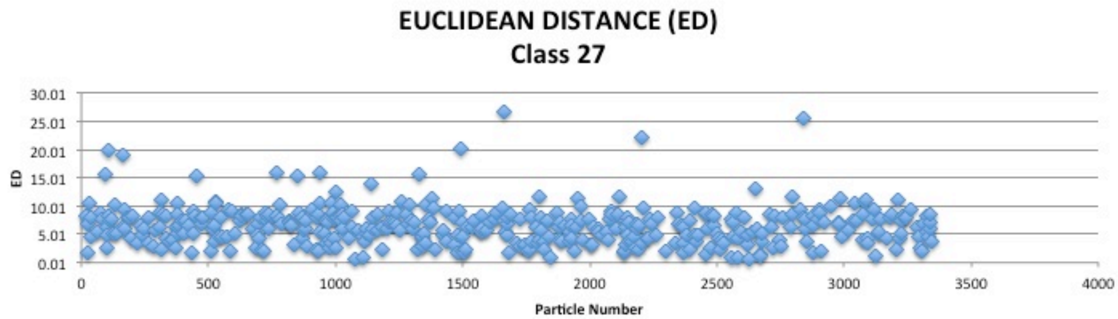

Figure 5-727: Euclidean Distance Class 27

Class 28 of Chad Arid 45 is composed of Aluminum less than 1%. There are a total of 17 particles in this class (Figure 5-728).

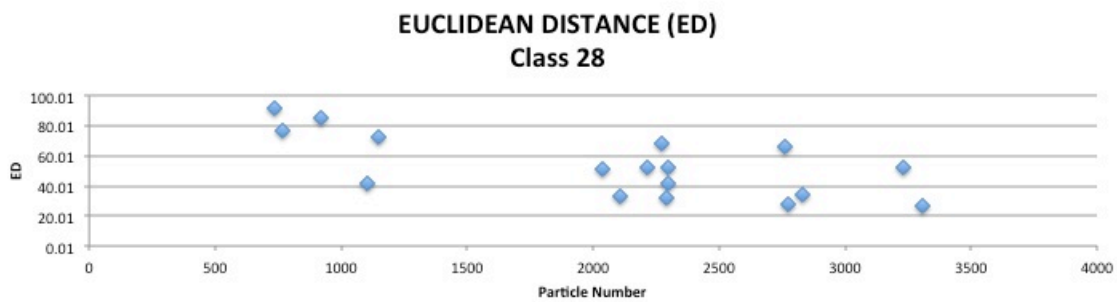

Figure 5-728: Euclidean Distance Class 28

Chad Arid 47

Chad Arid 47 has been separated into 29 elemental classes (Figure 5-729). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-62).

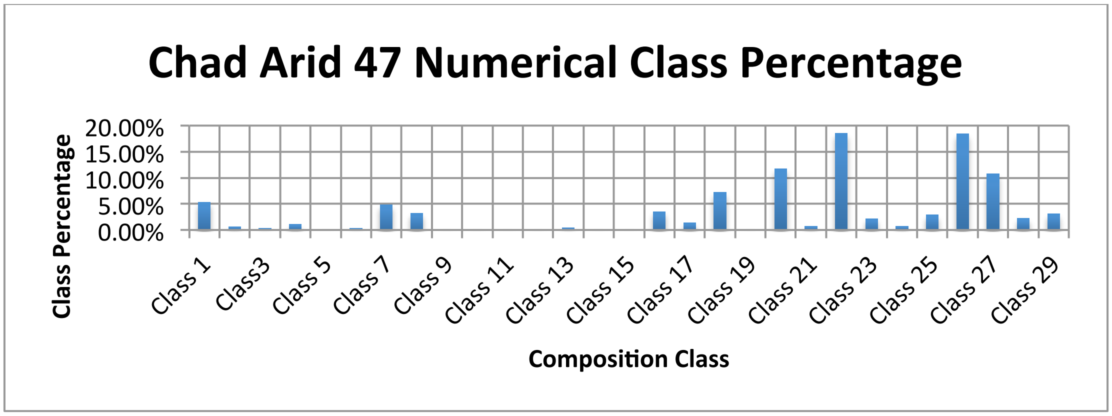

Figure 5-729: Numerical percentage per class.

Table 5-62: Numerical percentage and number of particles per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
112	13	7	23	0	7	101	68
5.35%	0.62%	0.33%	1.10%	0.00%	0.33%	4.82%	3.25%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
1	1	0	1	9	2	0	74
0.05%	0.05%	0.00%	0.05%	0.43%	0.10%	0.00%	3.53%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
28	151	1	245	15	389	46	15
1.34%	7.21%	0.05%	11.70%	0.72%	18.58%	2.20%	0.72%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
61	386	226	47	65	2094		
2.91%	18.43%	10.79%	2.24%	3.10%	100.00%		

Table 5-62 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 20, 22, and 26. Class 20 is composed of Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 22 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. This represents 48.71% of the entire sample and contains and 1020 particles. Class 29 represents the “unclassified” particles and contains only 3.10% of the entire sample.

The volumetric percentage of Chad Arid 47 represents the volume of particles that are represented in each respective elemental class (Figure 5-730). Table 5-62 shows the breakdown of each class volumetric percentage and, as with the numerical percentage, shows the majority of the particles are contained in classes 22, 26, and 27. Class 22 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 76.57% of the entire sample and contains an average volume of 67843.45 μm^3. Class 29 represents the “unclassified” volume of particles and contains 1.75% of the entire sample.

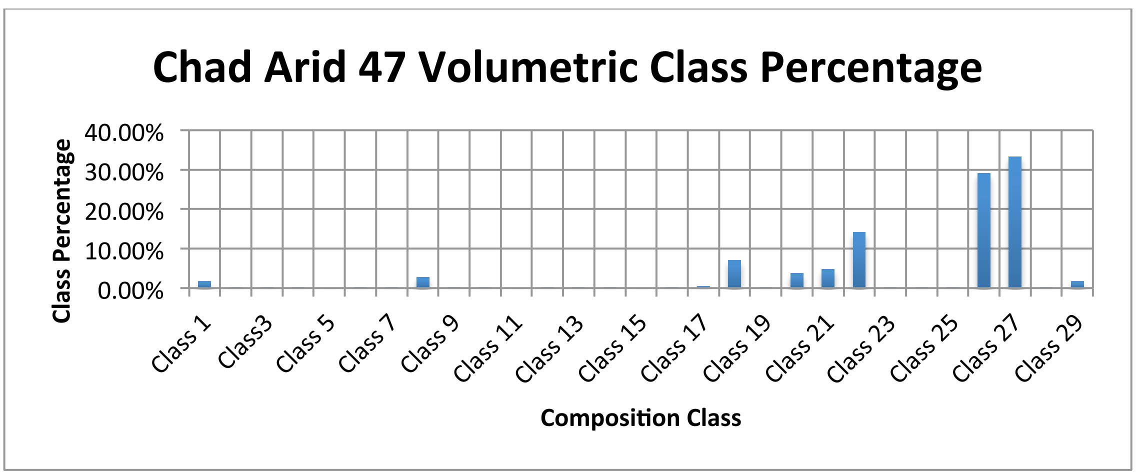

Figure 5-730: Volumetric percentage per class.

Table 5-63: Volumetric percentage and volume of each class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
1554.66	97.71	203.23	15.44	0.00	3.56	221.11	2380.75
1.75%	0.11%	0.23%	0.02%	0.00%	0.00%	0.25%	2.69%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
0.33	0.17	0.00	3.28	40.66	4.13	0.00	63.06
0.00%	0.00%	0.00%	0.00%	0.05%	0.00%	0.00%	0.07%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
448.45	6203.97	2.05	3282.54	4241.24	12543.58	128.83	11.14
0.51%	7.00%	0.00%	3.71%	4.79%	14.16%	0.15%	0.01%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
174.18	25784.89	29514.98	122.35	1550.39	88596.67		
0.20%	29.10%	33.31%	0.14%	1.75%	100.00%		

Analysis of class 29 showed a minimal amount of particles. The highest elements contained within Chad Arid 47 unclassified are Fe, Si, Al, and only compose a volume of 1.75% of the entire sample particles. The unclassified elements are evenly spread between the elements Iron, Silica and Aluminum, with most of the particles being high in Iron and lower in Silica and Aluminum (Figure 5-731 and Figure 5-732).

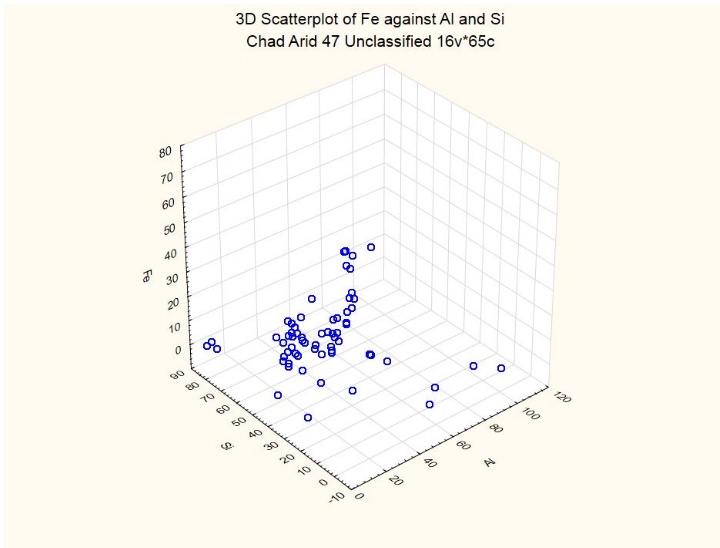

Figure 5-731: Scatterplot of Chad Arid 47 elements Al, Si and Fe. The unclassified particles contain 1.75% volume of the particles in the sample.

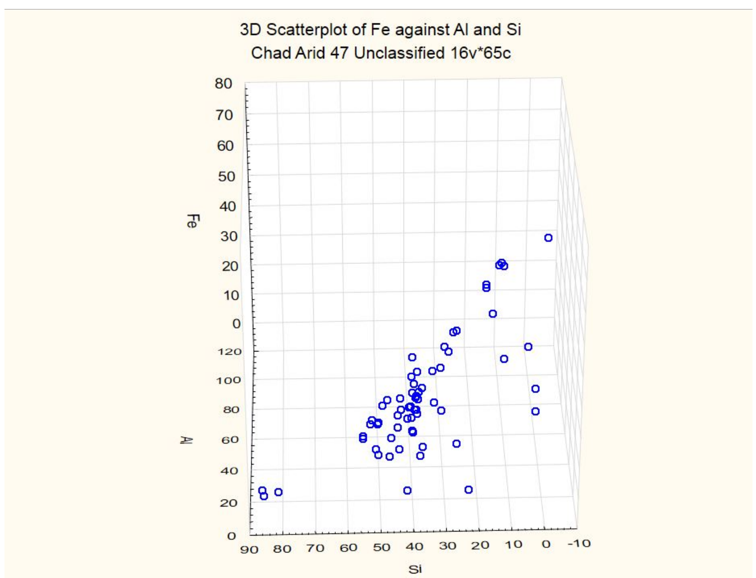

Figure 5-732: Chad Arid 47 alternate 3D scatterplot view.

Euclidean Distance

The Euclidean Distance for Class 1 of Chad Arid 47 is composed of greater than 99% Silica. There are a total of 112 particles in this class (Figure 5-733).

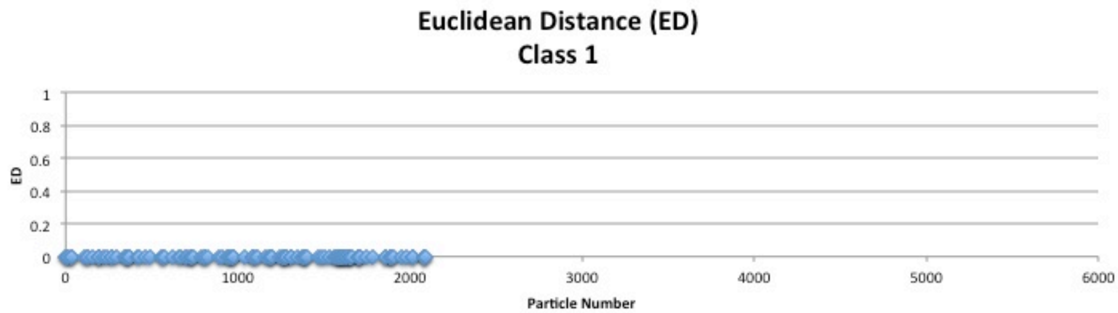

Figure 5-733: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 13 particles in this class (Figure 5-734).

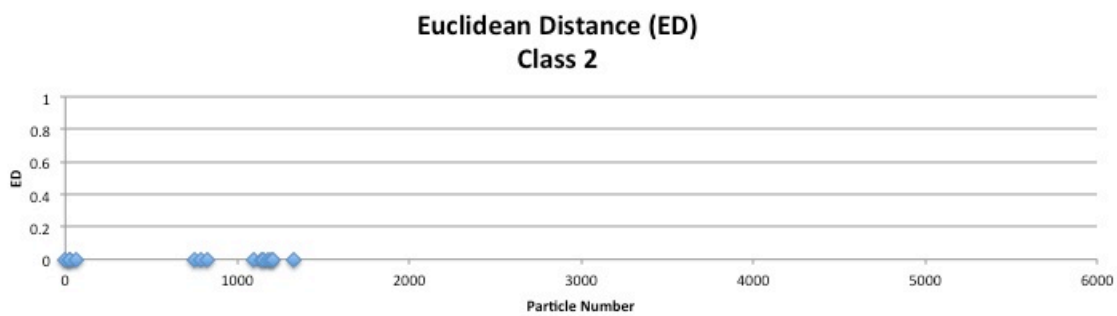

Figure 5-734: Euclidean Distance Class 2

Class 3 of Chad Arid 47 is composed of greater than 99% Calcium. There are a total of 7 particles in this class (Figure 5-735).

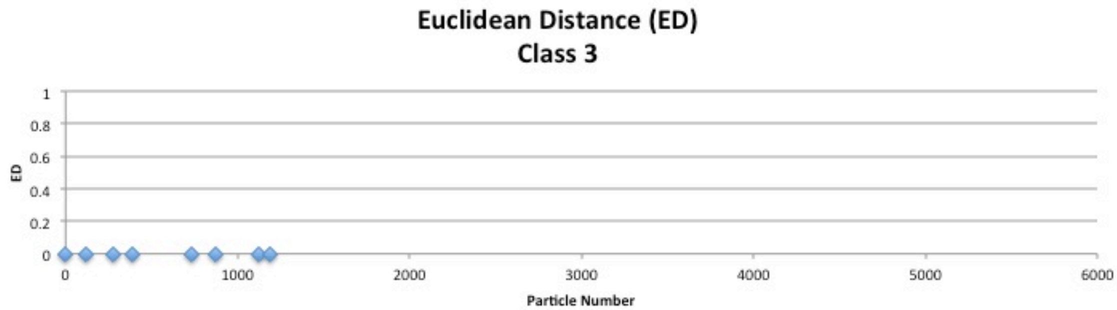

Figure 5-735: Euclidean Distance Class 3

Class 4 of Chad Arid 47 is composed of Titanium greater than 55% and Lead less than 5%. There are 23 particles in this class (Figure 5-736).

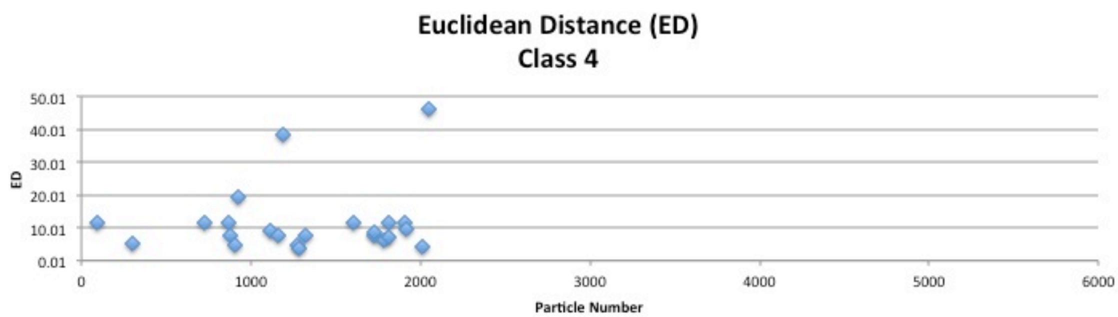

Figure 5-736: Euclidean Distance Class 4

Class 5 of Chad Arid 47 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Chad Arid 47 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 7 particles in this class (Figure 5-737).

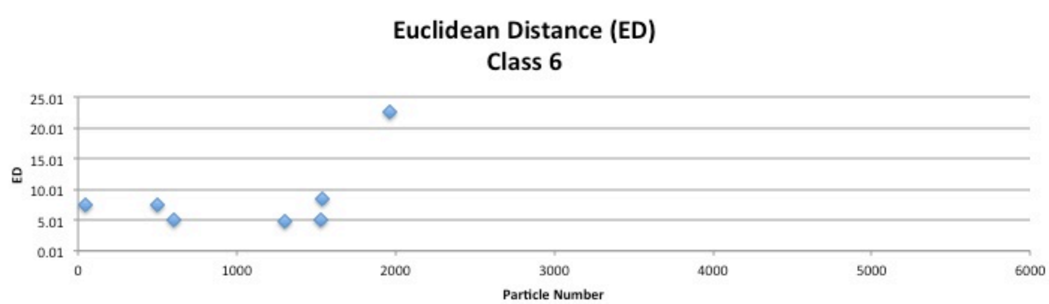

Figure 5-737: Euclidean Distance Class 6

Class 7 of Chad Arid 47 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 101 particles in this class (Figure 5-738).

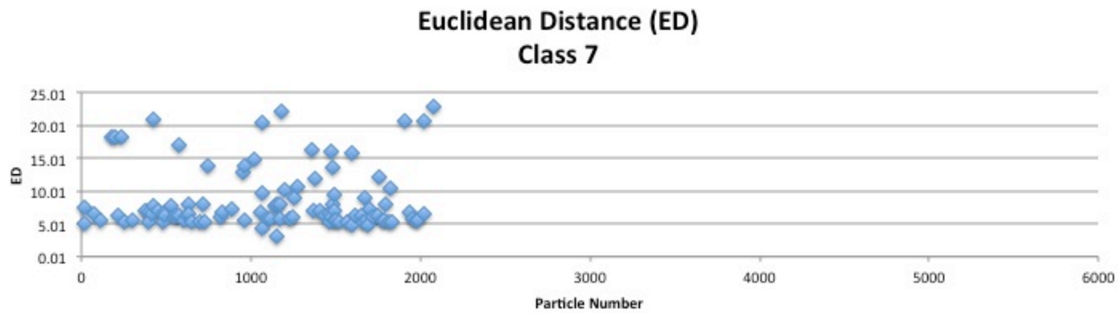

Figure 5-738: Euclidean Distance Class 7

Class 8 of Chad Arid 47 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 68 particles in this class (Figure 5-739).

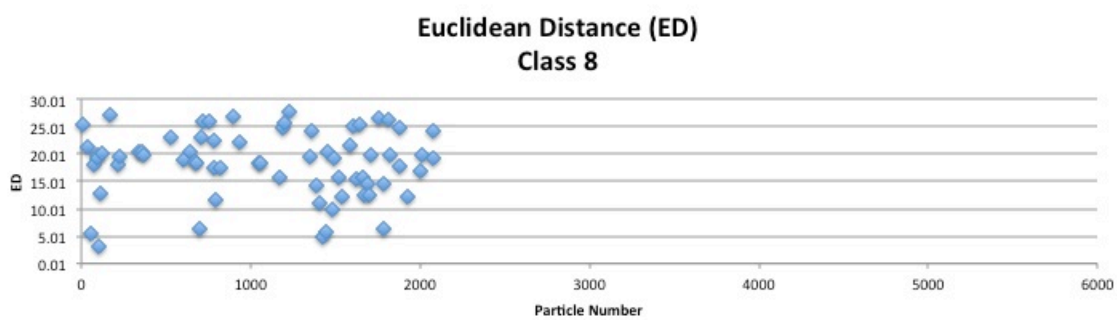

Figure 5-739: Euclidean Distance Class 8

Class 9 of Chad Arid 47 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There is 1 particle in this class (Figure 5-740).

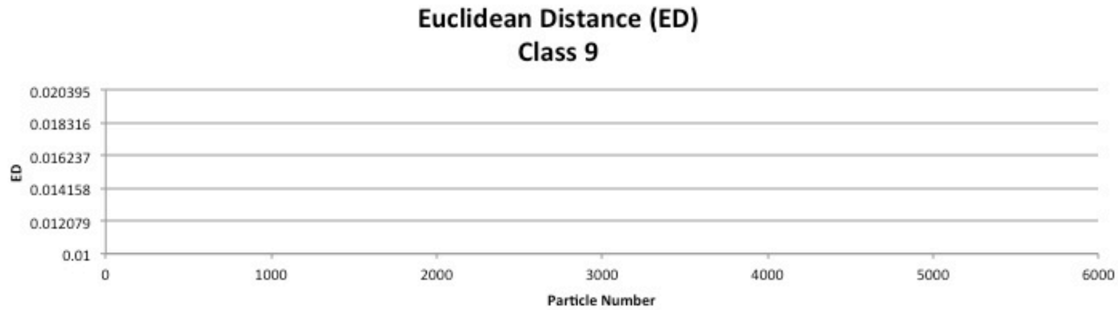

Figure 5-740: Euclidean Distance Class 9

Class 10 of Chad Arid 47 is composed of Calcium greater than 80% and Lead less than 5%. There is 1 particle in this class (Figure 5-741).

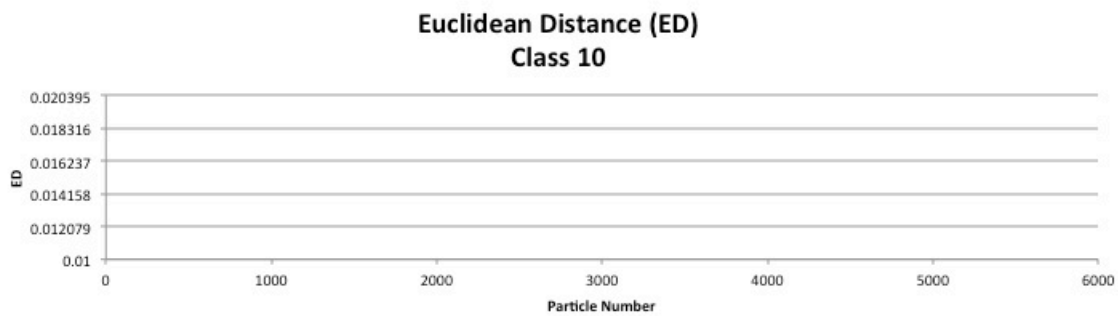

Figure 5-741: Euclidean Distance Class 10

Class 11 of Chad Arid 47 is composed of the total Calcium and Manganese greater than 90%. There are no particles in this class.

Class 12 of Chad Arid 47 is composed of the total Calcium and Phosphorus greater than 90%. There is 1 particle in this class (Figure 5-742).

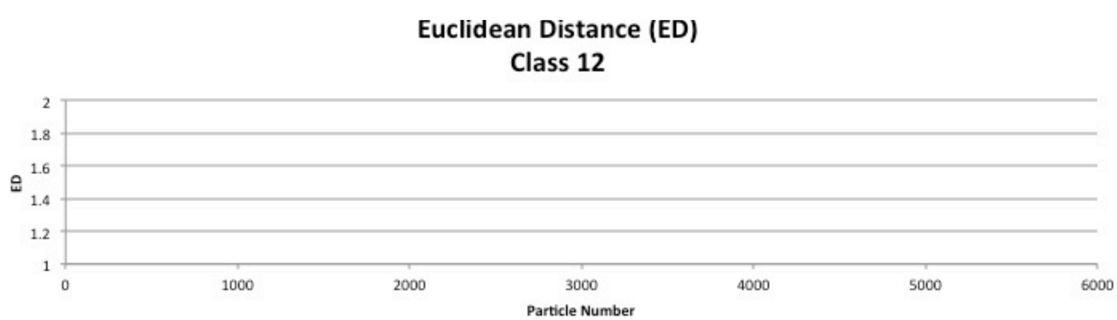

Figure 5-742: Euclidean Distance Class 12

Class 13 of Chad Arid 47 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 9 particles in this class (Figure 5-743).

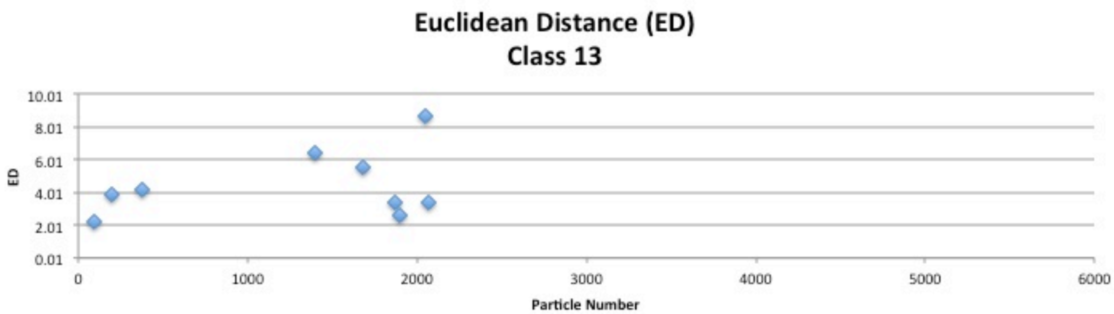

Figure 5-743: Euclidean Distance Class 13

Class 14 of Chad Arid 47 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are 2 particles in this class (Figure 5-744).

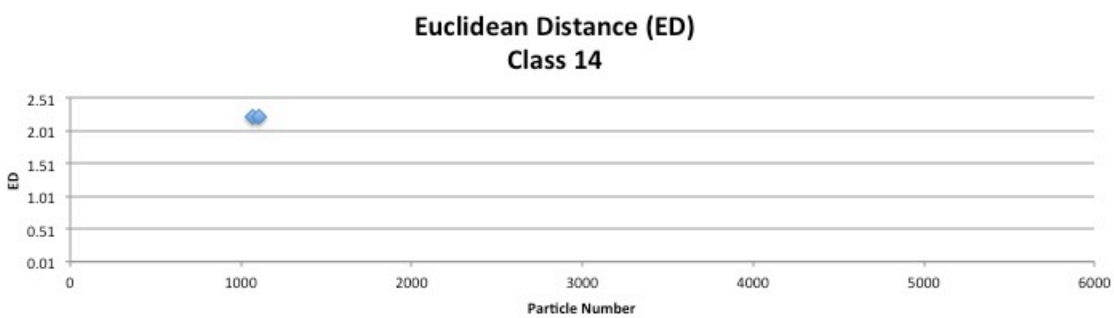

Figure 5-744: Euclidean Distance Class 14

Class 15 of Chad Arid 47 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Chad Arid 47 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 74 particles in this class (Figure 5-745).

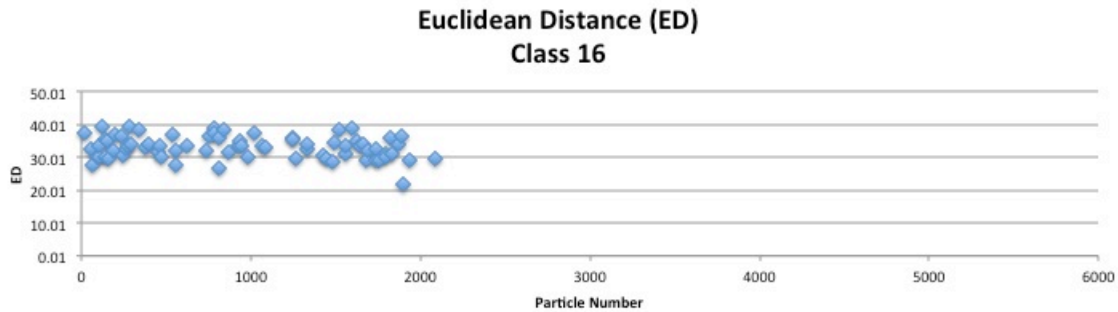

Figure 5-745: Euclidean Distance Class 16

Class 17 of Chad Arid 47 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 28 particles in this class (Figure 5-746).

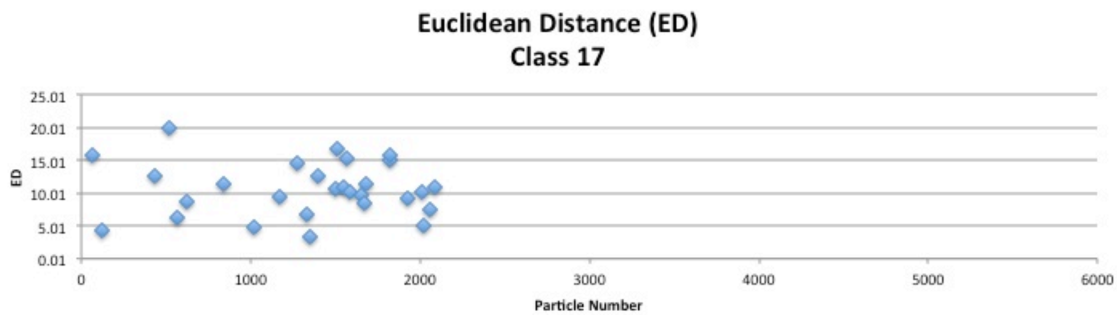

Figure 5-746: Euclidean Distance Class 17

Class 18 of Chad Arid 47 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 151 particles in this class (Figure 5-747).

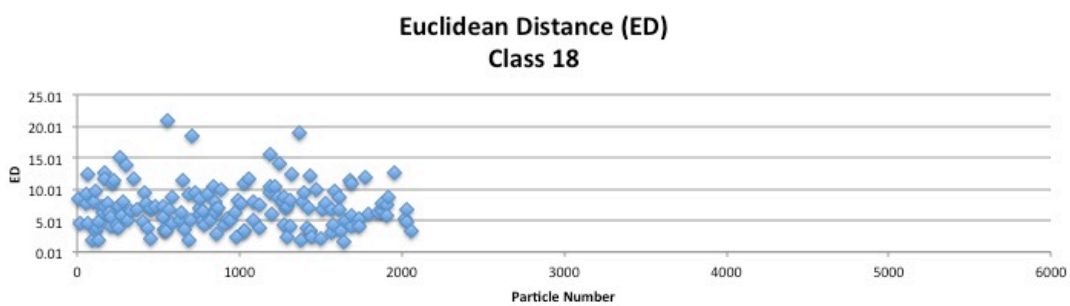

Figure 5-747: Euclidean Distance Class 18

Class 19 of Chad Arid 47 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There is 1 particle in this class (Figure 5-748).

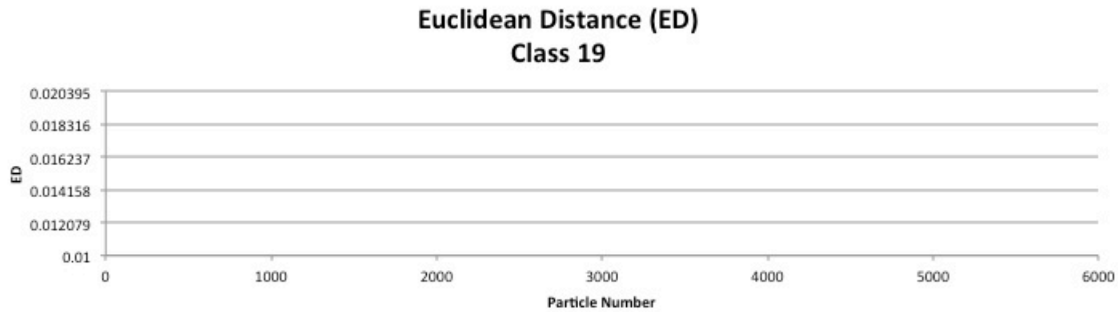

Figure 5-748: Euclidean Distance Class 19

Class 20 of Chad Arid 47 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 245 particles in this class (Figure 5-749).

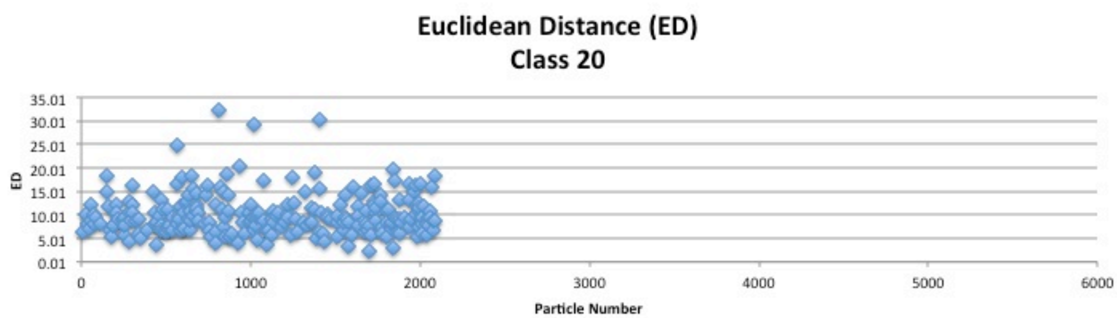

Figure 5-749: Euclidean Distance Class 20

Class 21 of Chad Arid 47 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 15 particles in this class (Figure 5-750).

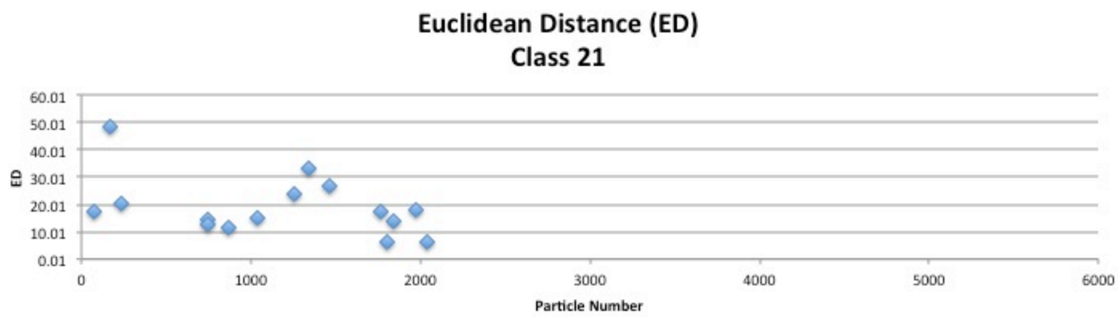

Figure 5-750: Euclidean Distance Class 21

Class 22 of Chad Arid 47 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 389 particles in this class (Figure 5-751).

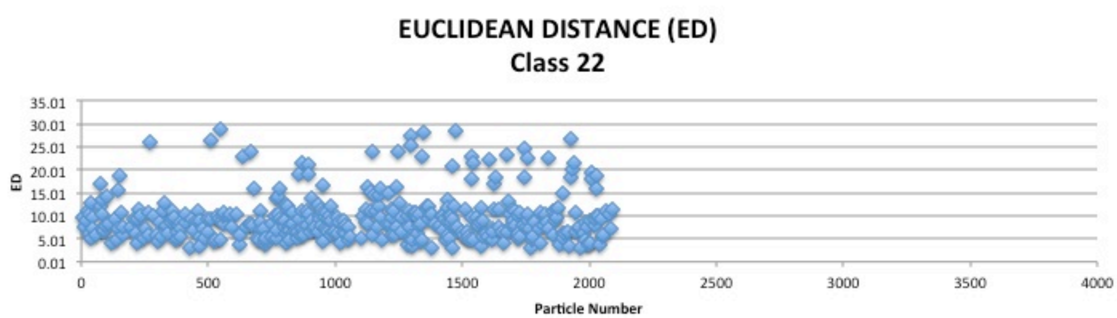

Figure 5-751: Euclidean Distance Class 22

Class 23 of Chad Arid 47 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 46 particles in this class (Figure 5-752).

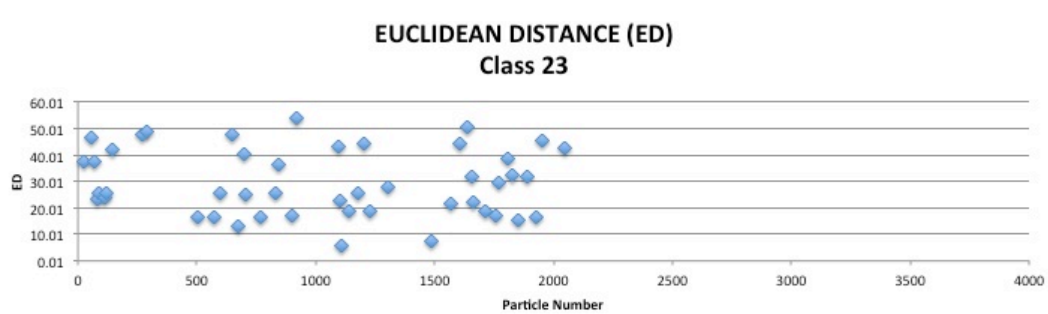

Figure 5-752: Euclidean Distance Class 23

Class 24 of Chad Arid 47 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 15 particles in this class (Figure 5-753).

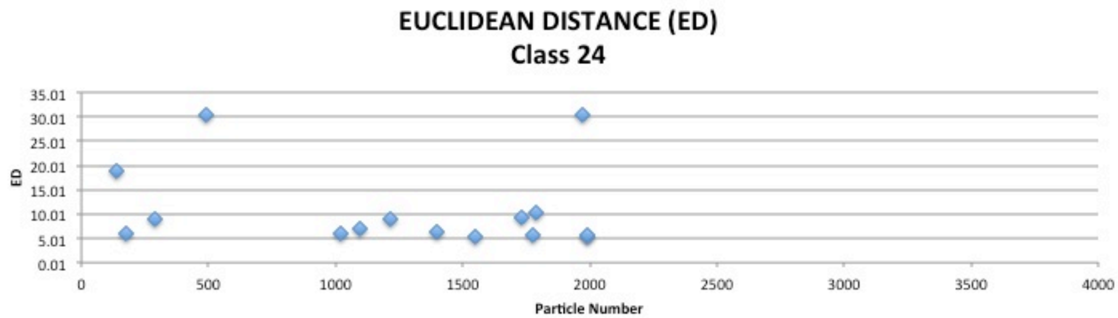

Figure 5-753: Euclidean Distance Class 24

Class 25 of Chad Arid 47 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 61 particles in this class (Figure 5-754).

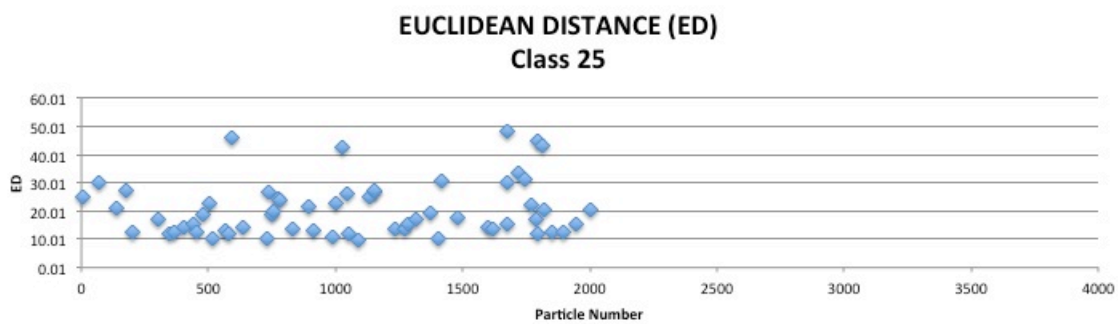

Figure 5-754: Euclidean Distance Class 25

Class 26 of Chad Arid 47 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 386 particles in this class (Figure 5-755).

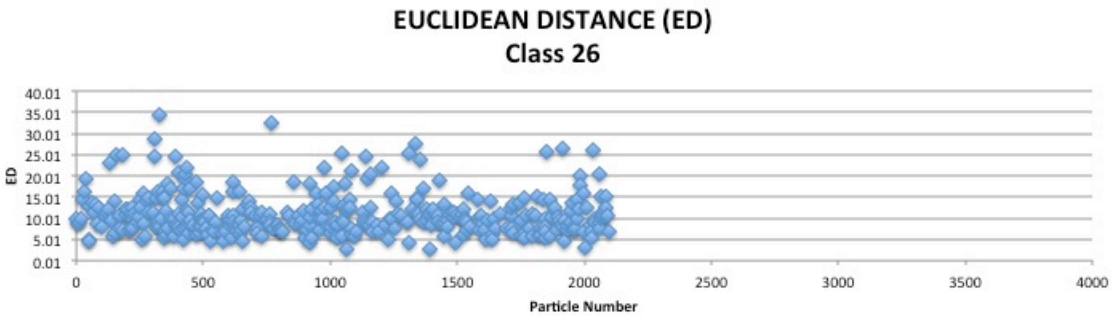

Figure 5-755: Euclidean Distance Class 26

Class 27 of Chad Arid 47 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 226 particles in this class (Figure 5-756).

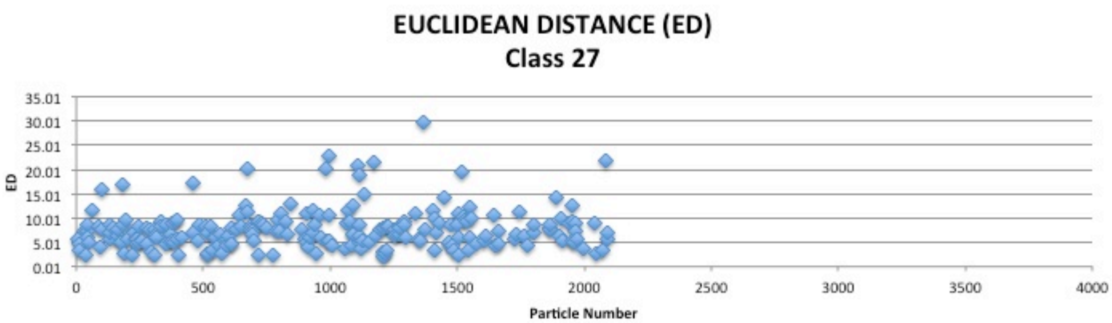

Figure 5-756: Euclidean Distance Class 27

Class 28 of Chad Arid 47 is composed of Aluminum less than 1%. There are a total of 47 particles in this class (Figure 5-757).

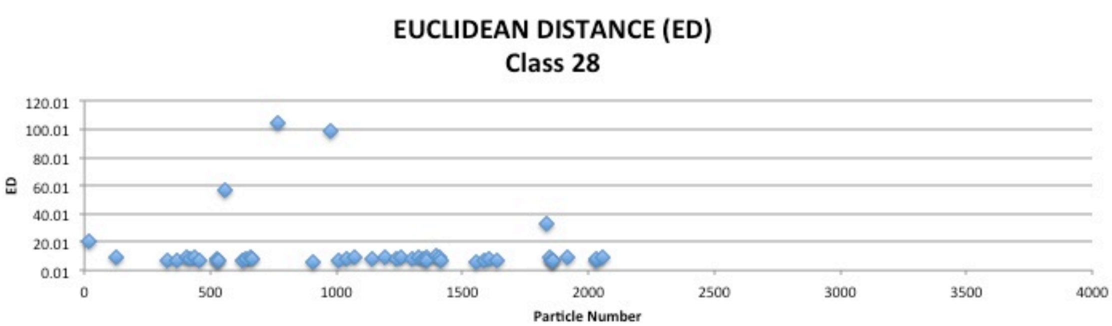

Figure 5-757: Euclidean Distance Class 28

Chad Arid 48

Chad Arid 48 has been separated into 29 elemental classes (Figure 5-758). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-64).

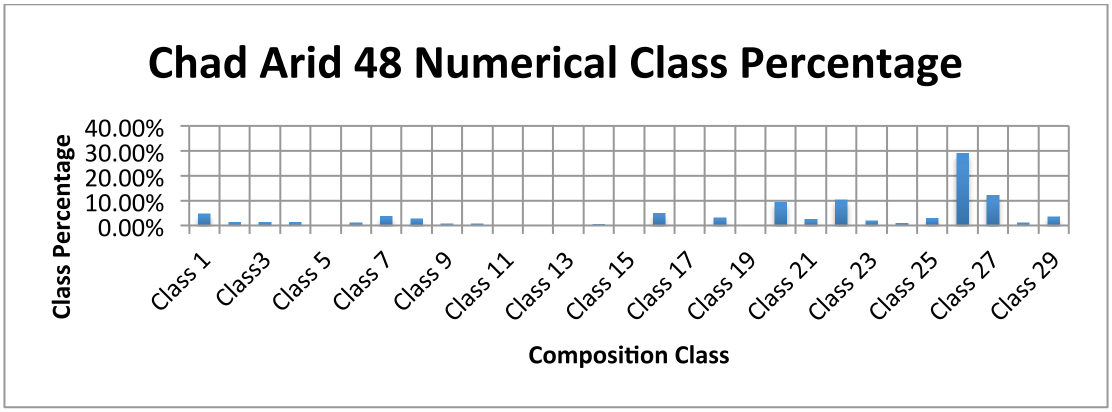

Figure 5-758: Numerical percentage per class.

Table 5-64: Numerical percentage and number of particles per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
154	41	42	40	0	35	120	89
4.68%	1.25%	1.28%	1.22%	0.00%	1.06%	3.65%	2.70%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
22	20	2	2	3	14	0	164
0.67%	0.61%	0.06%	0.06%	0.09%	0.43%	0.00%	4.98%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
12	105	3	308	83	341	64	30
0.36%	3.19%	0.09%	9.36%	2.52%	10.36%	1.94%	0.91%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
96	956	398	34	113	3291		
2.92%	29.05%	12.09%	1.03%	3.43%	100.00%		

Table 5-64 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 22, 26, and 27. Class 22 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. This represents 51.50% of the entire sample and contains 1695 particles. Class 29 represents the "unclassified" particles and contains only 3.43% of the entire sample.

The volumetric percentage of Chad Arid 48 represents the volume of particles that are represented in each respective elemental class (Figure 5-759). Table 5-65 shows the breakdown of each class volumetric percentage and, as with the numerical percentage, shows the majority of the particles are contained in classes 14, 21, and 26. Class 14 is composed of greater than 40% Magnesium, greater than 25% Silica, and less than 1% Aluminum. Class 21 has Calcium between 4% and 80%, less than 1% Potassium, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. This represents 63.12% of the entire sample and contains an average volume of 55616.67 μm^3. Class 29 represents the "unclassified" volume of particles and contains 3.07% of the entire sample.

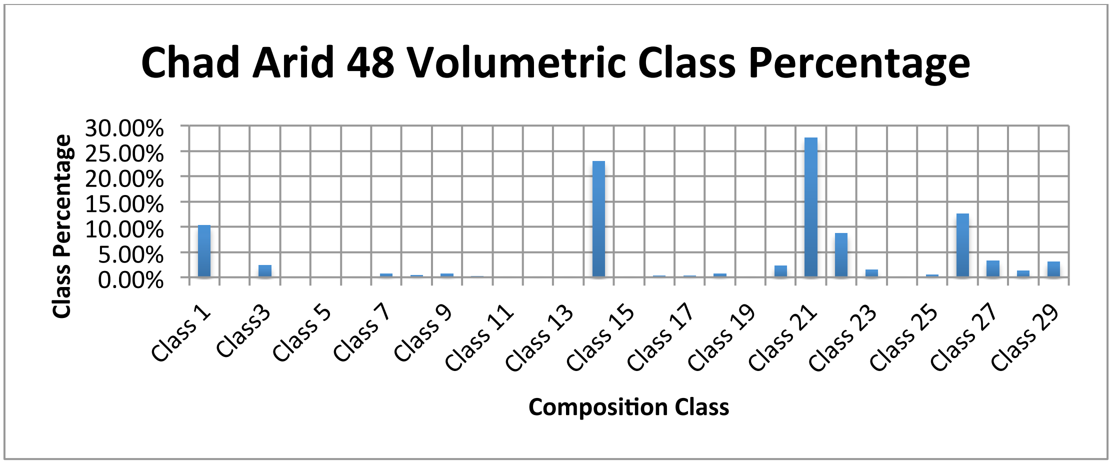

Figure 5-759: Volumetric percentage per class.

Table 5-65: Volumetric percentage and volume of each class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
9042.92	57.50	2063.02	20.39	0.00	27.26	631.25	388.97
10.26%	0.07%	2.34%	0.02%	0.00%	0.03%	0.72%	0.44%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
578.31	200.74	17.79	0.02	1.14	20193.67	0.00	228.19
0.66%	0.23%	0.02%	0.00%	0.00%	22.92%	0.00%	0.26%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
268.16	657.35	3.79	1995.16	24321.25	7709.89	1348.21	115.20
0.30%	0.75%	0.00%	2.26%	27.60%	8.75%	1.53%	0.13%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
432.80	11101.75	2908.49	1099.69	2701.63	88114.54		
0.49%	12.60%	3.30%	1.25%	3.07%	100.00%		

Analysis of class 29 showed a minimal amount of particles. The highest elements contained within Chad Arid 48 unclassified are Fe, Si, Al, and only compose a volume of 3.07% of the entire sample particles. The unclassified elements are evenly spread between the elements

Iron, Silica and Aluminum, with most of the particles being high in Iron and lower in Silica and Aluminum (Figure 5-760 and Figure 5-761).

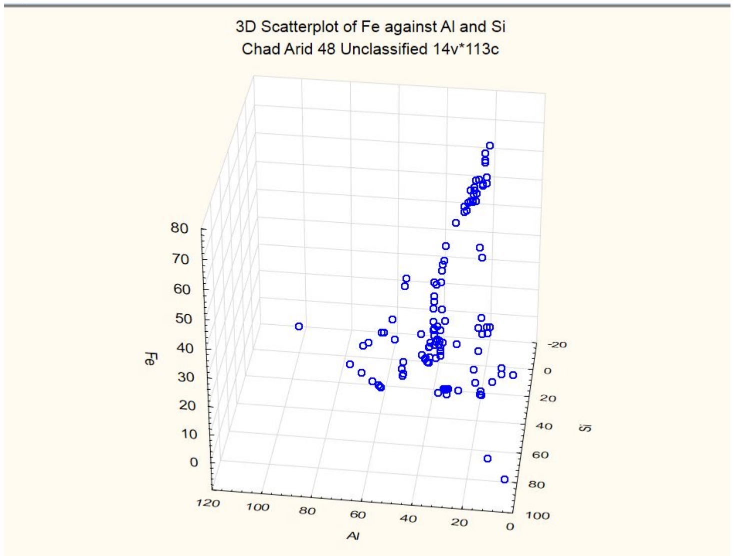

Figure 5-760: Scatterplot of Chad Arid 48 elements Al, Si and Fe. The unclassified particles contain 3.07% volume of the particles in the sample.

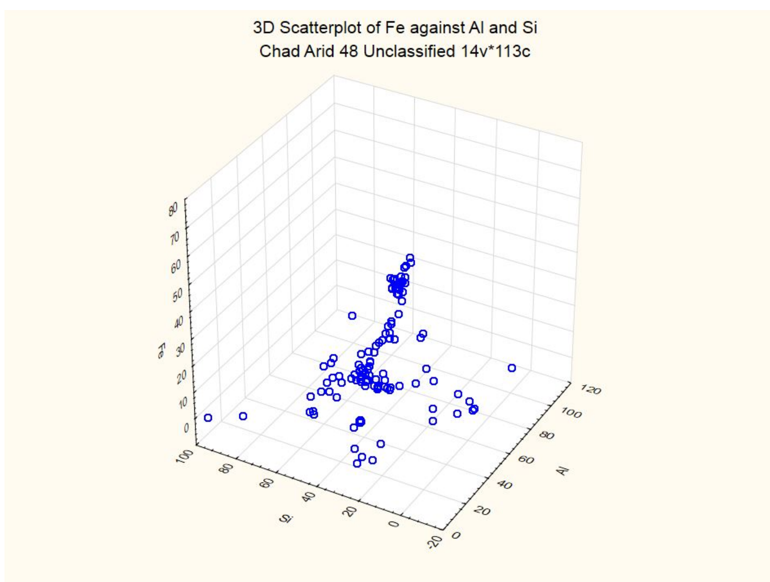

Figure 5-761: Chad Arid 48 alternate 3D scatterplot view.

Euclidean Distance

The Euclidean Distance for Class 1 of Chad Arid 48 is composed of greater than 99%

Silica. There are a total of 154 particles in this class (Figure 5-762).

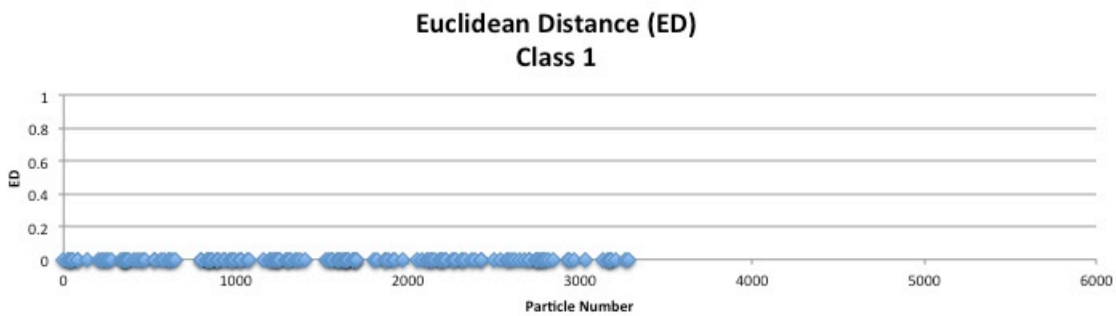

Figure 5-762: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 41 particles in this class (Figure 5-763).

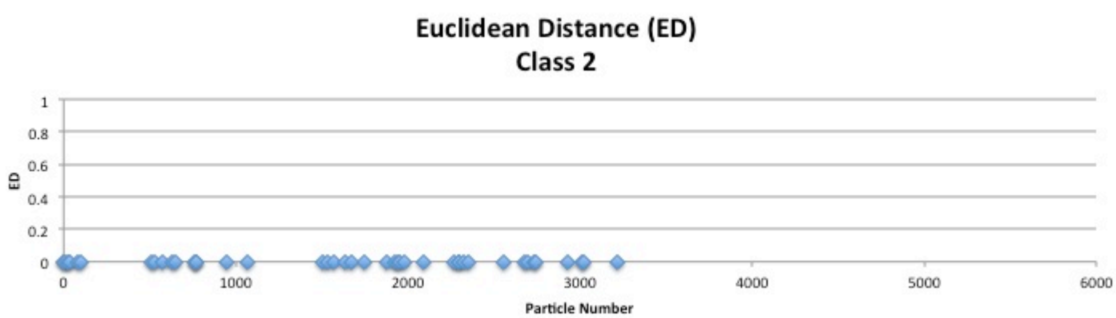

Figure 5-763: Euclidean Distance Class 2

Class 3 of Chad Arid 48 is composed of greater than 99% Calcium. There are a total of 42 particles in this class (Figure 5-764).

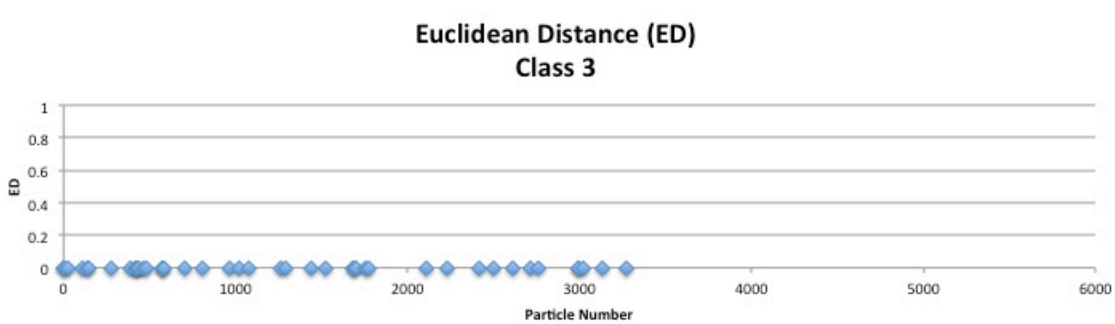

Figure 5-764: Euclidean Distance Class 3

Class 4 of Chad Arid 48 is composed of Titanium greater than 55% and Lead less than 5%. There are 40 particles in this class (Figure 5-765).

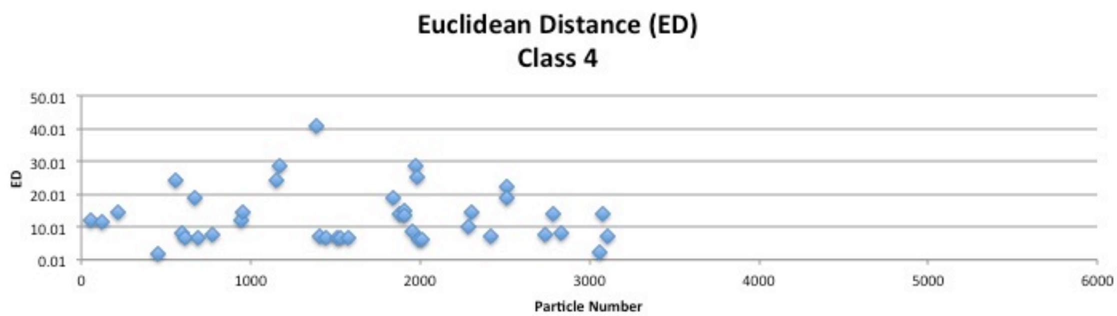

Figure 5-765: Euclidean Distance Class 4

Class 5 of Chad Arid 48 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Chad Arid 48 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 35 particles in this class (Figure 5-766).

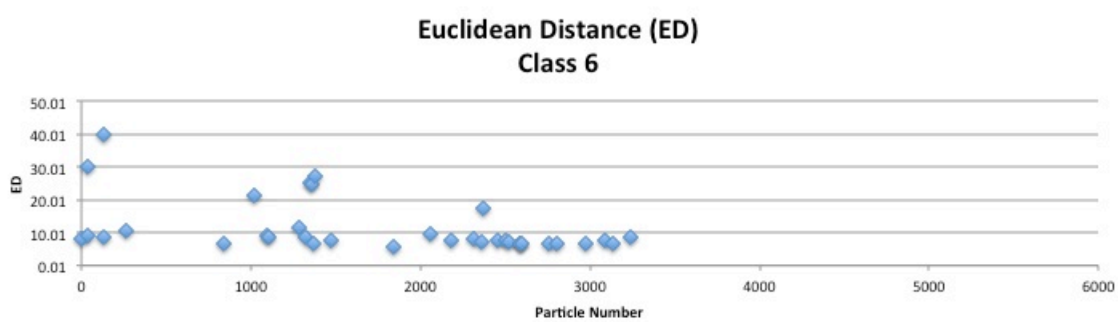

Figure 5-766: Euclidean Distance Class 6

Class 7 of Chad Arid 48 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 120 particles in this class (Figure 5-767).

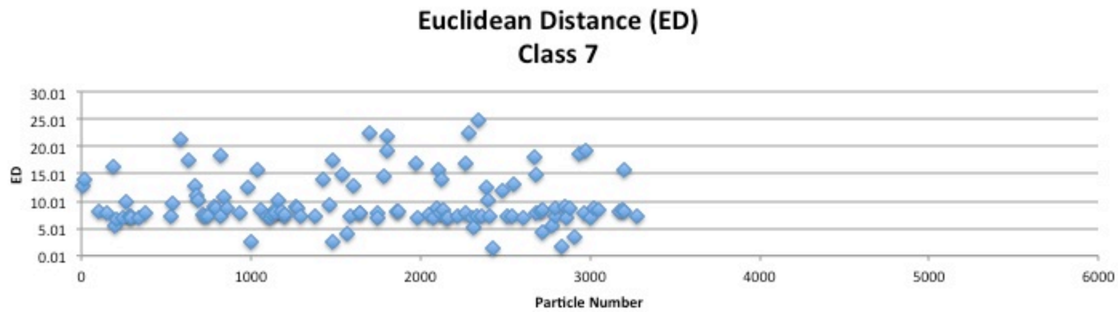

Figure 5-767: Euclidean Distance Class 7

Class 8 of Chad Arid 48 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 89 particles in this class (Figure 5-768).

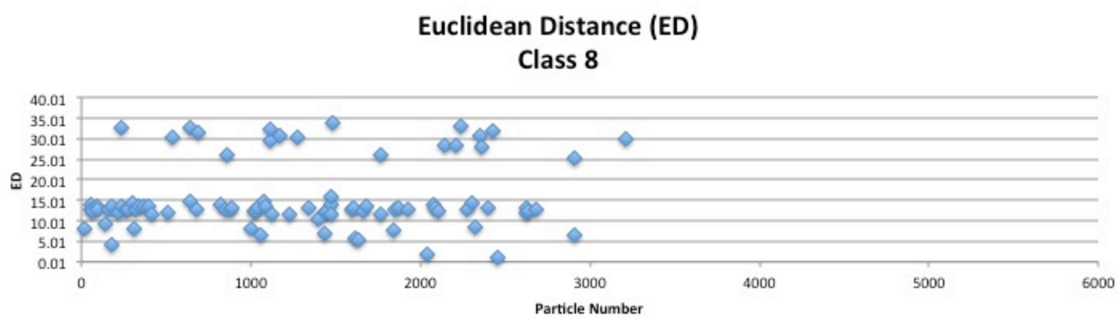

Figure 5-768: Euclidean Distance Class 8

Class 9 of Chad Arid 48 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 22 particles in this class (Figure 5-769).

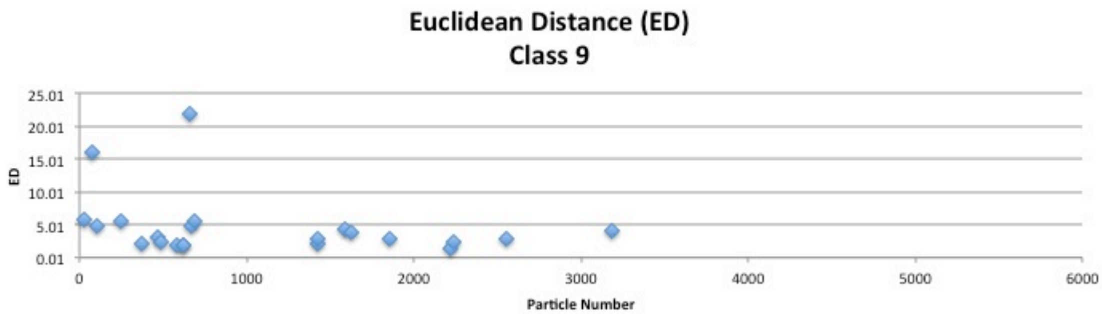

Figure 5-769: Euclidean Distance Class 9

Class 10 of Chad Arid 48 is composed of Calcium greater than 80% and Lead less than 5%. There are 20 particles in this class (Figure 5-770).

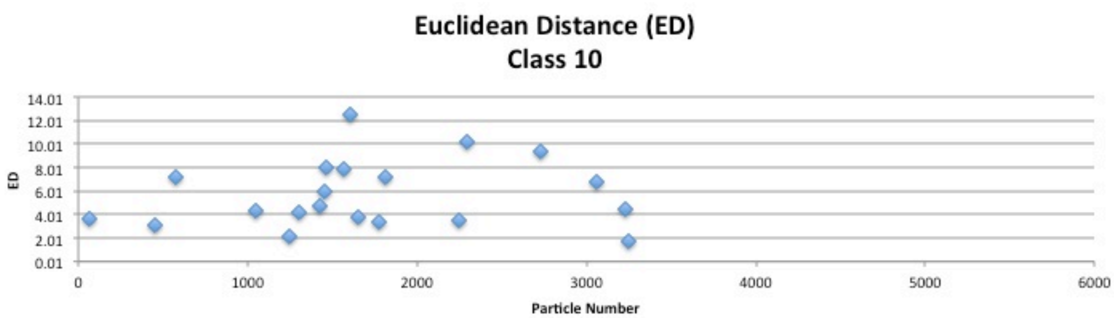

Figure 5-770: Euclidean Distance Class 10

Class 11 of Chad Arid 48 is composed of the total Calcium and Manganese greater than 90%. There are 2 particles in this class (Figure 5-771).

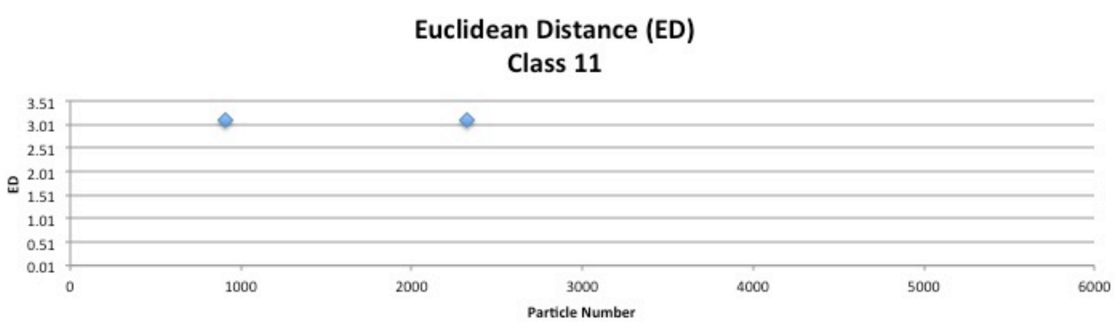

Figure 5-771: Euclidean Distance Class 11

Class 12 of Chad Arid 48 is composed of the total Calcium and Phosphorus greater than 90%. There are 2 particles in this class (Figure 5-772).

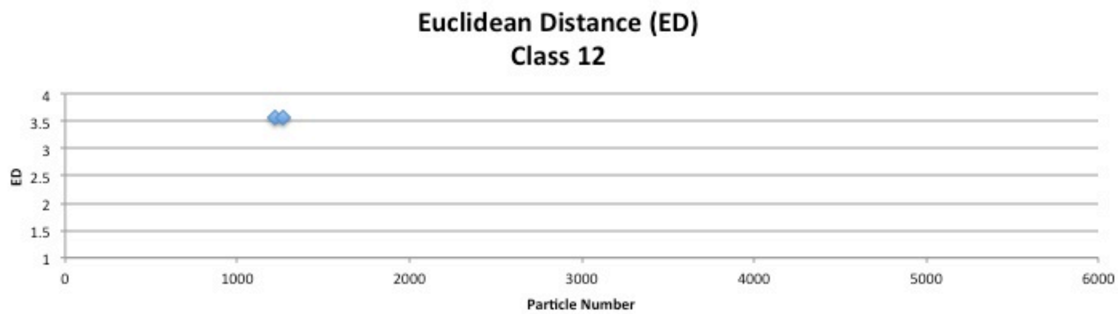

Figure 5-772: Euclidean Distance Class 12

Class 13 of Chad Arid 48 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 3 particles in this class (Figure 5-773).

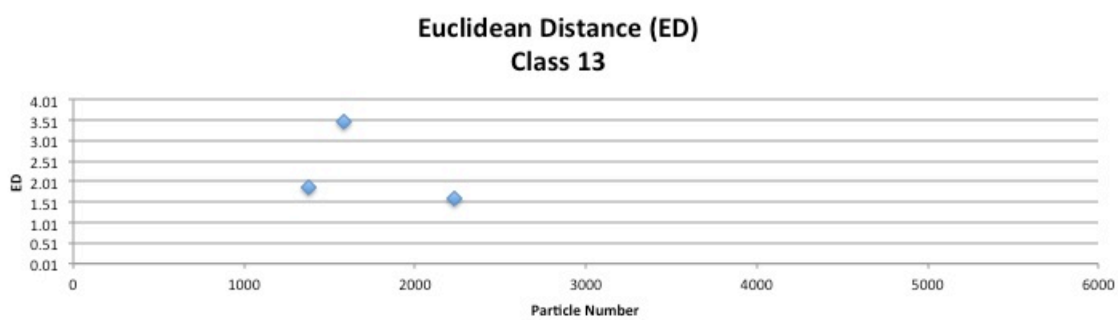

Figure 5-773: Euclidean Distance Class 13

Class 14 of Chad Arid 48 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are 14 particles in this class (Figure 5-774).

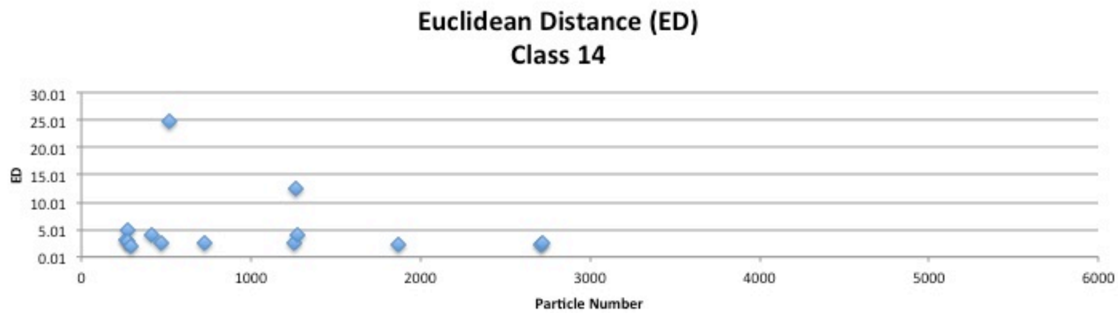

Figure 5-774: Euclidean Distance Class 14

Class 15 of Chad Arid 48 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Chad Arid 48 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 164 particles in this class (Figure 5-775).

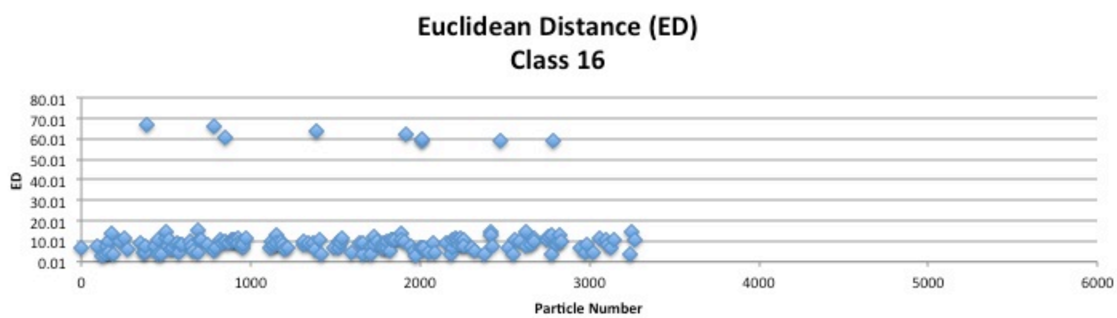

Figure 5-775: Euclidean Distance Class 16

Class 17 of Chad Arid 48 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 12 particles in this class (Figure 5-776).

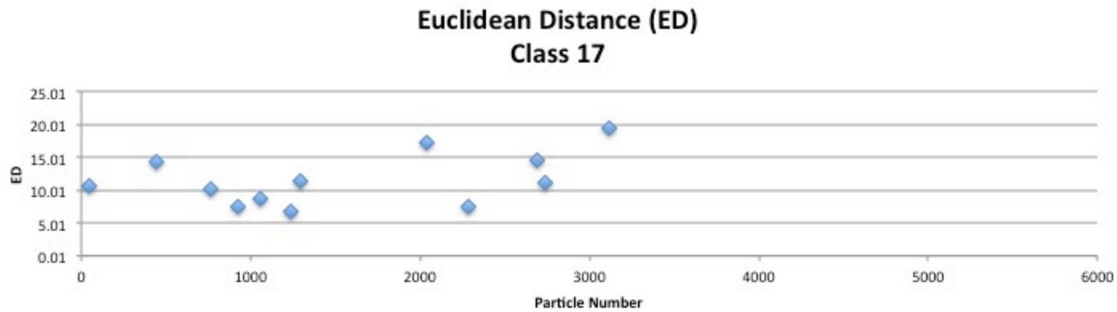

Figure 5-776: Euclidean Distance Class 17

Class 18 of Chad Arid 48 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 105 particles in this class (Figure 5-777).

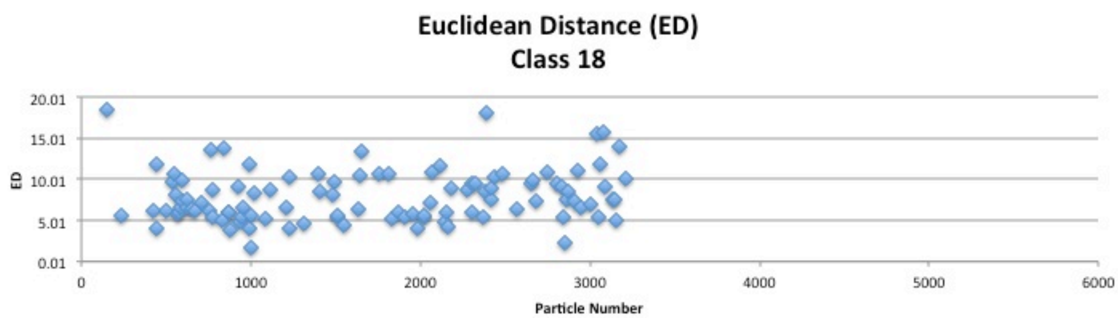

Figure 5-777: Euclidean Distance Class 18

Class 19 of Chad Arid 48 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are 3 particles in this class (Figure 5-778).

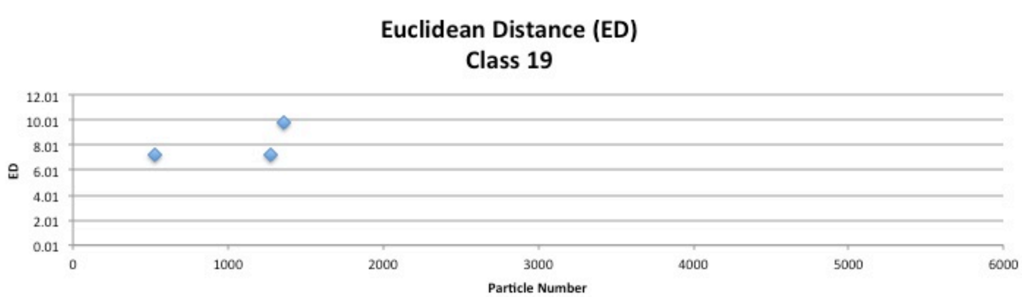

Figure 5-778: Euclidean Distance Class 19

Class 20 of Chad Arid 48 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 308 particles in this class (Figure 5-779).

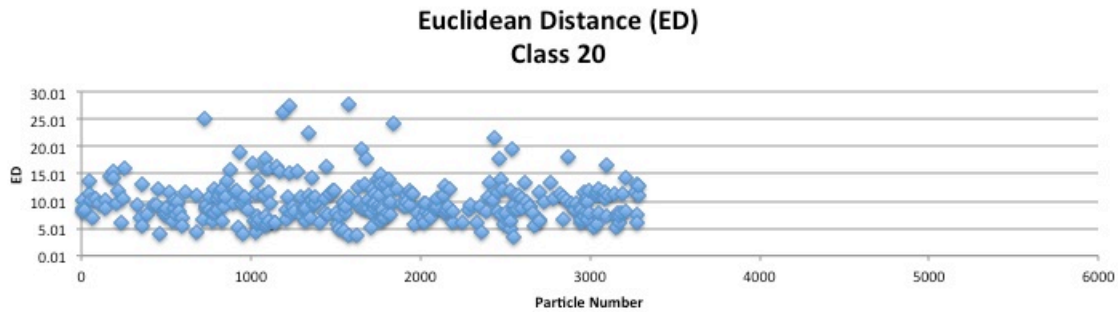

Figure 5-779: Euclidean Distance Class 20

Class 21 of Chad Arid 48 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 83 particles in this class (Figure 5-780).

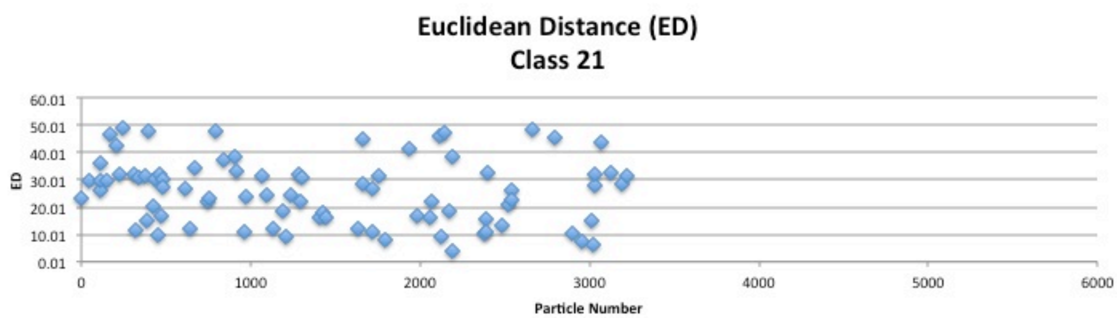

Figure 5-780: Euclidean Distance Class 21

Class 22 of Chad Arid 48 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 341 particles in this class (Figure 5-781).

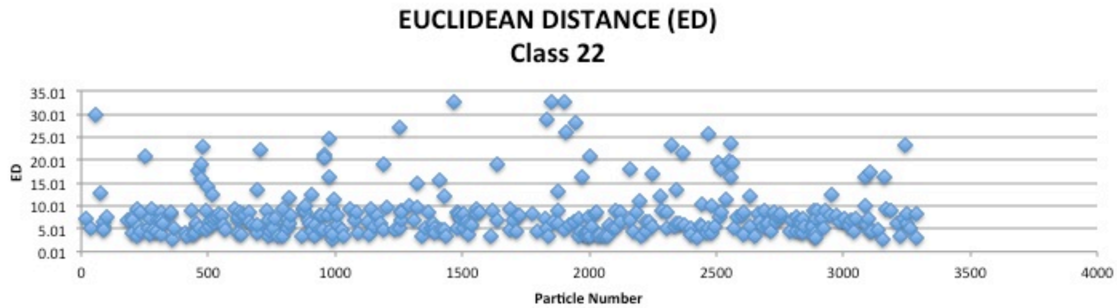

Figure 5-781: Euclidean Distance Class 22

Class 23 of Chad Arid 48 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 64 particles in this class (Figure 5-782).

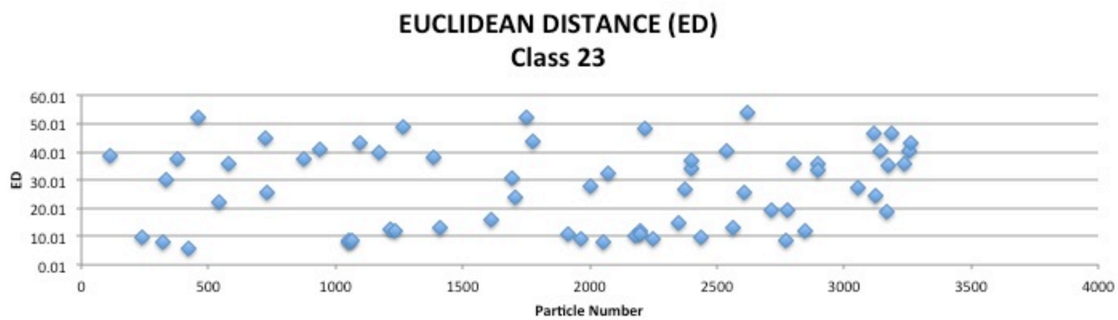

Figure 5-782: Euclidean Distance Class 23

Class 24 of Chad Arid 48 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 30 particles in this class (Figure 5-783).

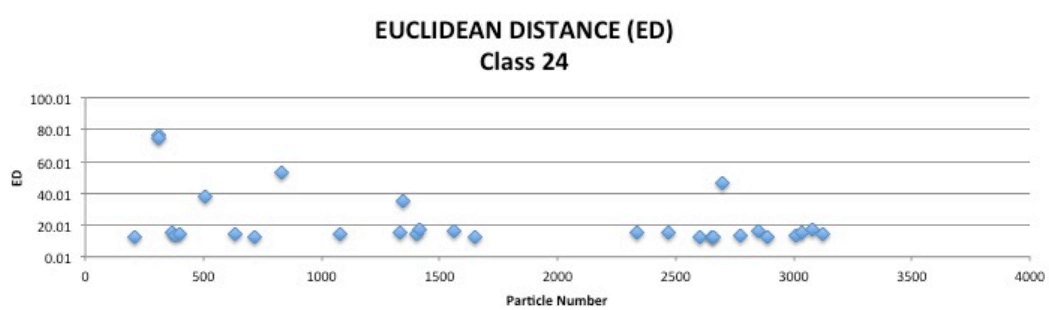

Figure 5-783: Euclidean Distance Class 24

Class 25 of Chad Arid 48 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 96 particles in this class (Figure 5-784).

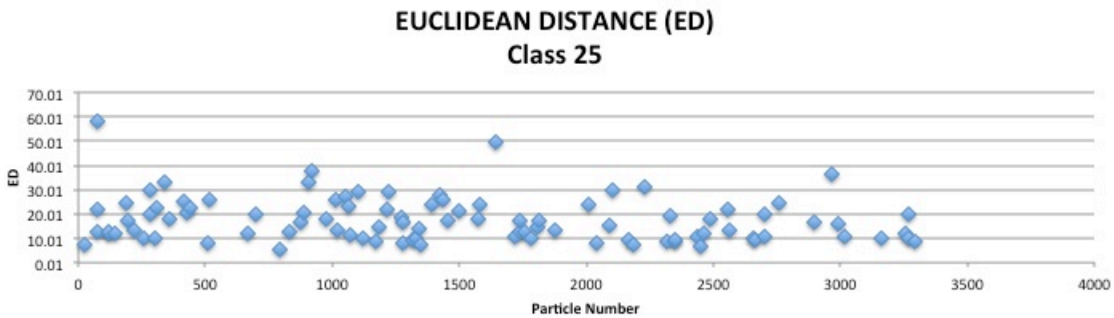

Figure 5-784: Euclidean Distance Class 25

Class 26 of Chad Arid 48 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 956 particles in this class (Figure 5-785).

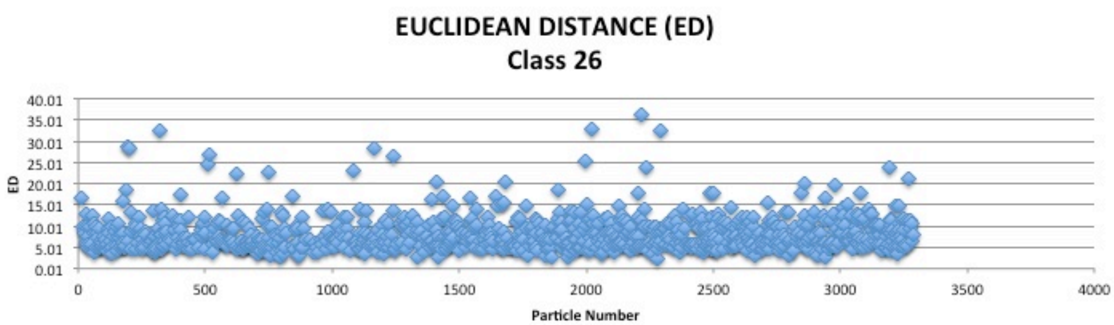

Figure 5-785: Euclidean Distance Class 26

Class 27 of Chad Arid 48 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 398 particles in this class (Figure 5-786).

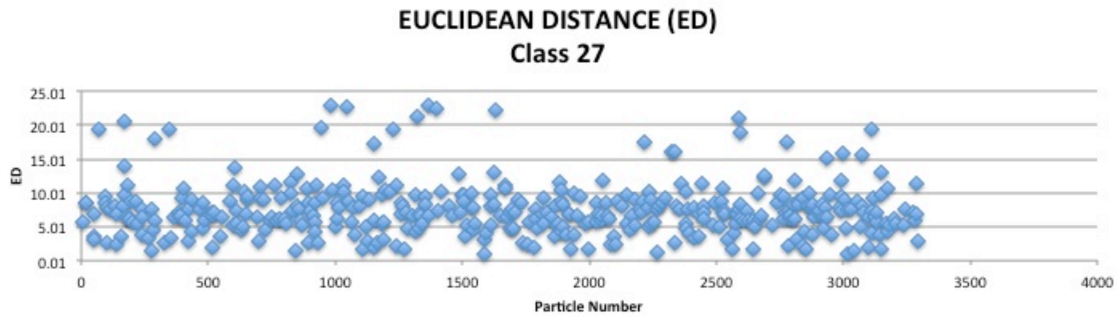

Figure 5-786: Euclidean Distance Class 27

Class 28 of Chad Arid 48 is composed of Aluminum less than 1%. There are a total of 34 particles in this class (Figure 5-787).

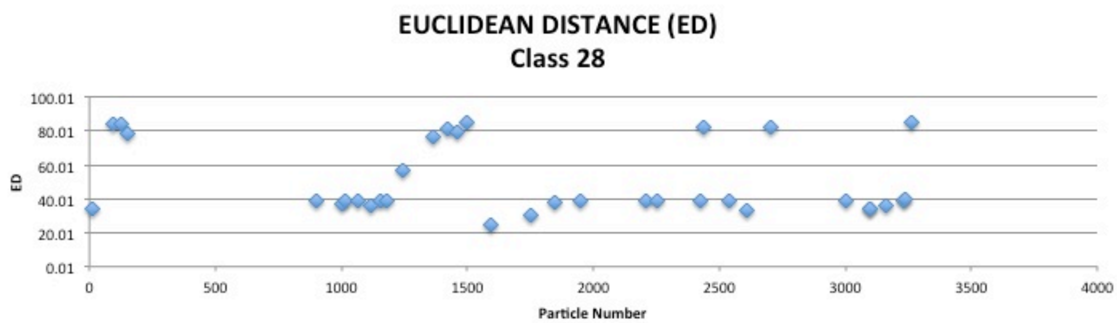

Figure 5-787: Euclidean Distance Class 28

Chad Arid 50

Chad Arid 50 has been separated into 29 elemental classes (Figure 5-788). The numerical percentage shows the number of particles in each class, and what percentage those particles represent to the entire class (Table 5-66).

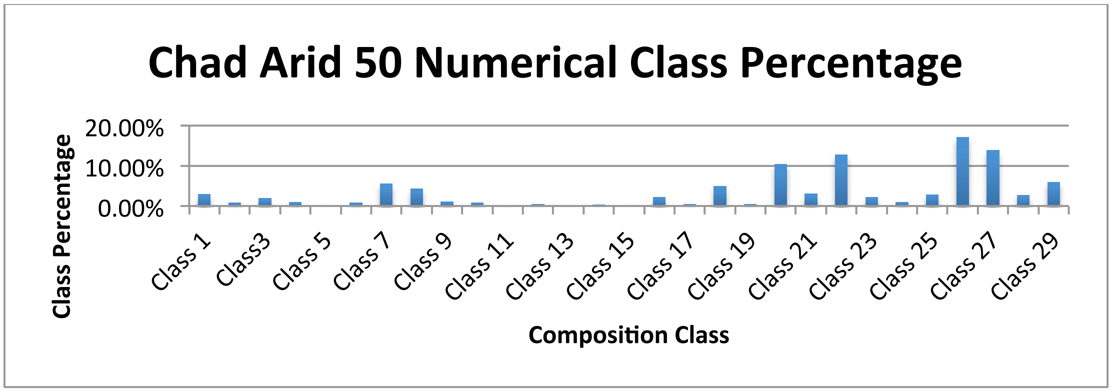

Figure 5-788: Numerical percentage per class.

Table 5-66: Numerical percentage and number of particles per class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
94	27	61	29	0	26	173	136
2.98%	0.86%	1.93%	0.92%	0.00%	0.82%	5.48%	4.31%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
35	24	7	13	4	9	0	70
1.11%	0.76%	0.22%	0.41%	0.13%	0.29%	0.00%	2.22%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
14	153	15	328	96	403	70	31
0.44%	4.85%	0.48%	10.40%	3.04%	12.77%	2.22%	0.98%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
90	538	436	85	188	3155		
2.85%	17.05%	13.82%	2.69%	5.96%	100.00%		

Table 5-66 shows the breakdown of each class numerical percentage and shows the majority of the particles are contained in classes 22, 26, and 27. Class 22 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. Class 27 has Potassium and Calcium less than 1%, Aluminum between 40%

and 60%, and Silica between 20% and 60%. This represents 43.64% of the entire sample and contains 1377 particles. Class 29 represents the “unclassified” particles and contains only 5.96% of the entire sample.

The volumetric percentage of Chad Arid 50 represents the volume of particles that are represented in each respective elemental class (Figure 5-789). Table 5-67 shows the breakdown of each class volumetric percentage and, as with the numerical percentage, shows the majority of the particles are contained in classes 20, 22, and 26. Class 20 is composed of Potassium between 4% and 30%, Aluminum between 20% and 50%, and Silica between 20% and 50%. Class 22 has Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. Class 26 has Potassium and Calcium less than 1%, Aluminum between 18% and 40% and Silica between 40% and 60%. This represents 49.21% of the entire sample and contains an average volume of 266975.27 μm^3. Class 29 represents the “unclassified” volume of particles and contains 10.80% of the entire sample.

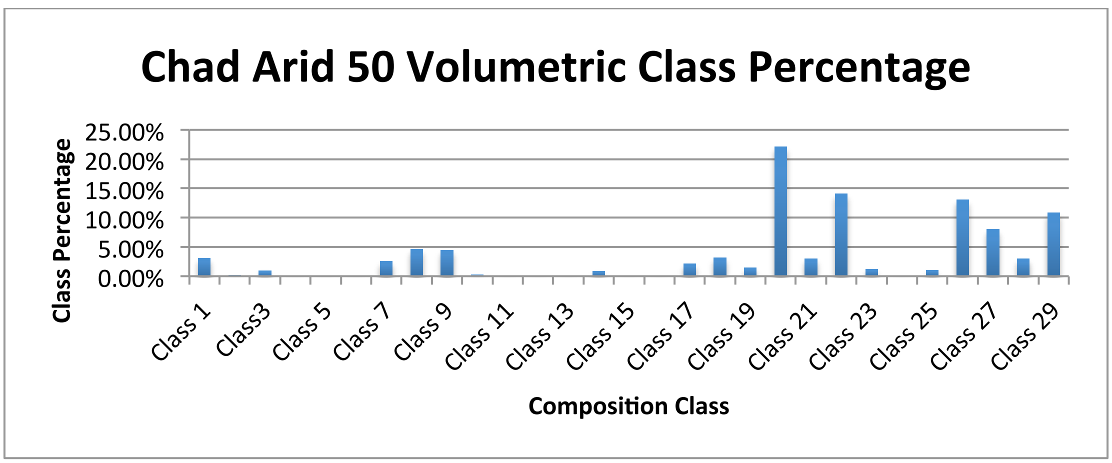

Figure 5-789: Volumetric percentage per class.

Table 5-67: Volumetric percentage and volume of each class.

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
16770.58	651.09	4832.62	153.11	0.00	293.48	13661.09	25131.82
3.09%	0.12%	0.89%	0.03%	0.00%	0.05%	2.52%	4.63%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
24247.26	1310.84	419.97	33.71	17.83	4722.14	0.00	157.72
4.47%	0.24%	0.08%	0.01%	0.00%	0.87%	0.00%	0.03%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
11605.60	17226.02	7756.01	119951.24	16383.40	76190.31	6367.64	397.37
2.14%	3.18%	1.43%	22.11%	3.02%	14.04%	1.17%	0.07%
Class 25	Class 26	Class 27	Class 28	Class 29	Total		
5545.35	70833.72	43298.40	15965.55	58596.42	542520.30		
1.02%	13.06%	7.98%	2.94%	10.80%	100.00%		

Analysis of class 29 showed a minimal amount of particles. The highest elements contained within Chad Arid 50 unclassified are Fe, Si, Al, and only compose a volume of 10.80% of the entire sample particles. The unclassified elements are evenly spread between the elements Iron, Silica and Aluminum, with most of the particles being high in Iron and lower in Silica and Aluminum (Figure 5-790 and Figure 5-791).

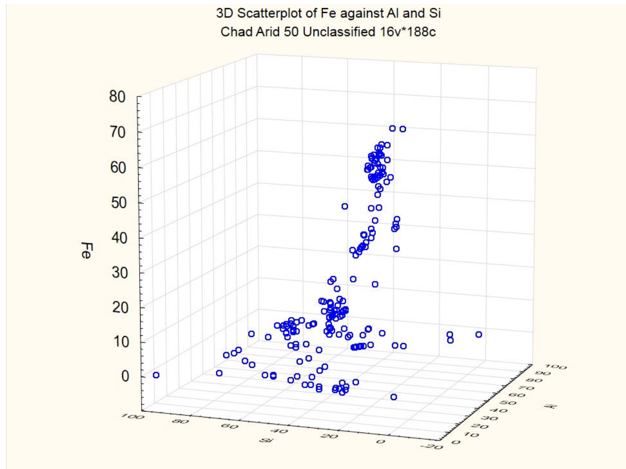

Figure 5-790: Scatterplot of Chad Arid 50 elements Al, Si and Fe. The unclassified particles contain 10.80% volume of the particles in the sample.

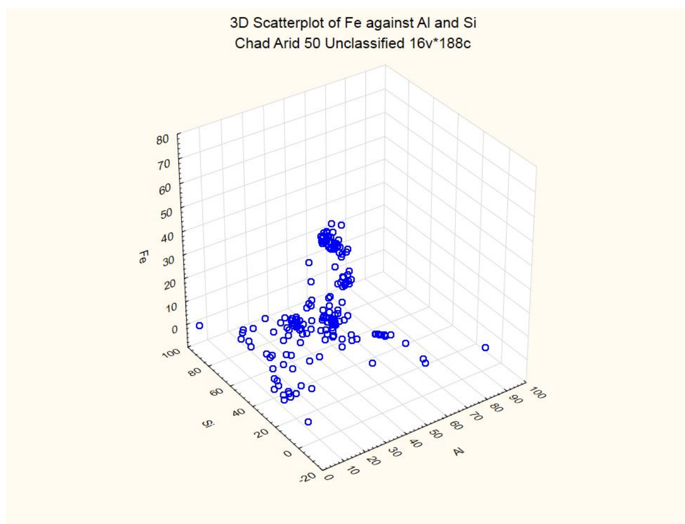

Figure 5-791: Chad Arid 50 alternate 3D scatterplot view.

Euclidean Distance

The Euclidean Distance for Class 1 of Chad Arid 50 is composed of greater than 99% Silica. There are a total of 94 particles in this class (Figure 5-792).

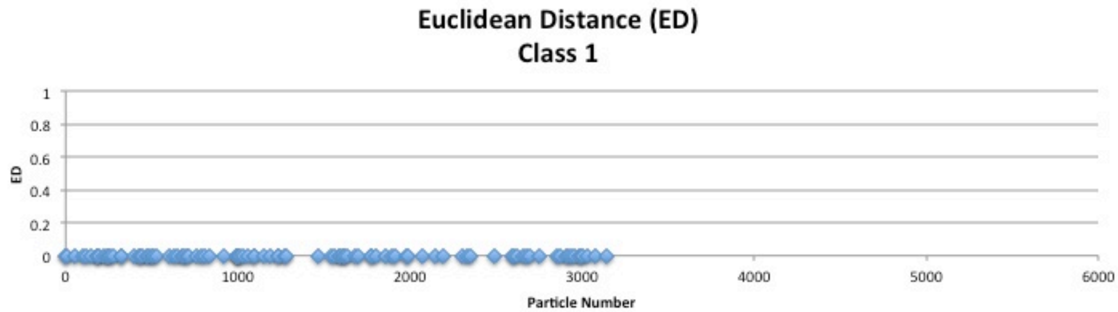

Figure 5-792: Euclidean Distance Class 1

Class 2 is composed of greater than 99% Iron. There are a total of 27 particles in this class (Figure 5-793).

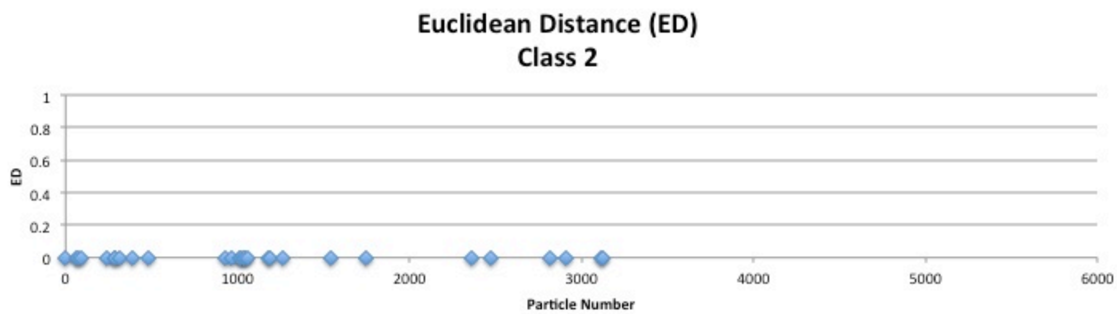

Figure 5-793: Euclidean Distance Class 2

Class 3 of Chad Arid 50 is composed of greater than 99% Calcium. There are a total of 61 particles in this class (Figure 5-794).

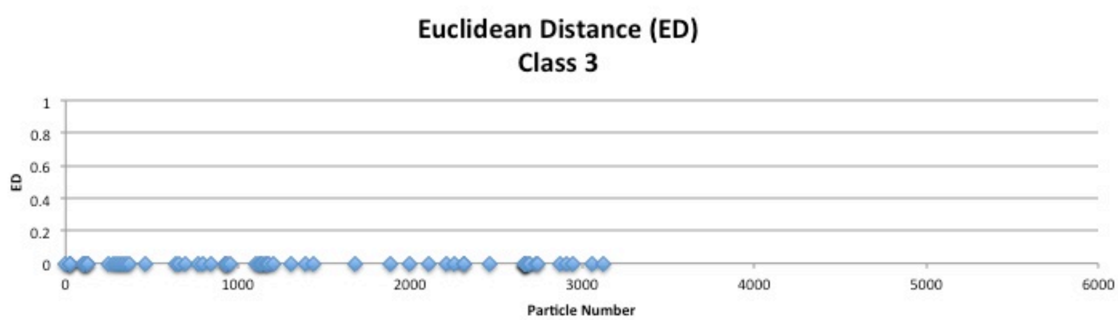

Figure 5-794: Euclidean Distance Class 3

Class 4 of Chad Arid 50 is composed of Titanium greater than 55% and Lead less than 5%. There are 29 particles in this class (Figure 5-795).

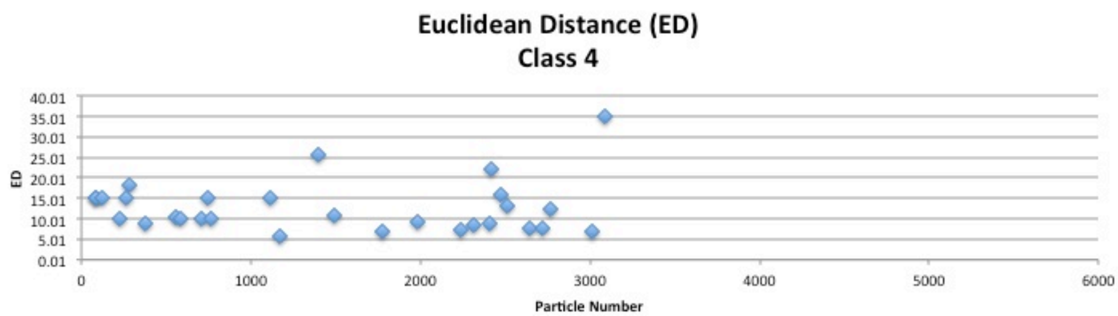

Figure 5-795: Euclidean Distance Class 4

Class 5 of Chad Arid 50 is composed of Iron and Sulfur totaling greater than 95% with Sulfur being greater than 5%. There are no particles in this class.

Class 6 of Chad Arid 50 is composed of Iron greater than 65% and Aluminum less than 1%. There are a total of 26 particles in this class (Figure 5-796).

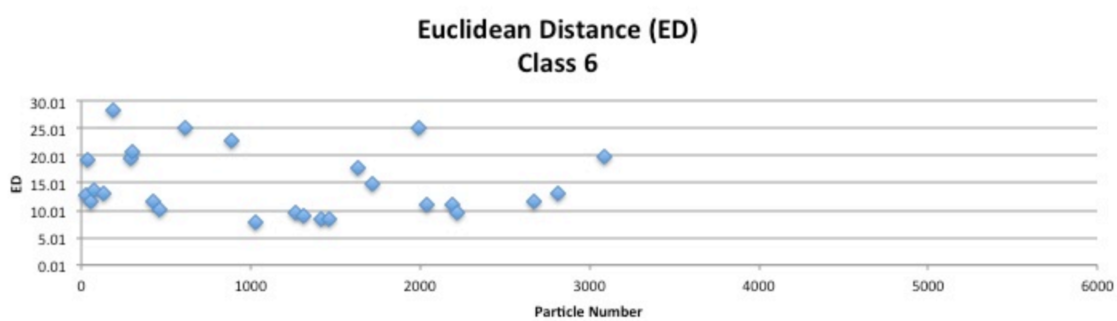

Figure 5-796: Euclidean Distance Class 6

Class 7 of Chad Arid 50 is composed of Iron less than 1%, Silica between 30% and 50%, and Aluminum between 35% and 60%. There are a total of 173 particles in this class (Figure 5-797).

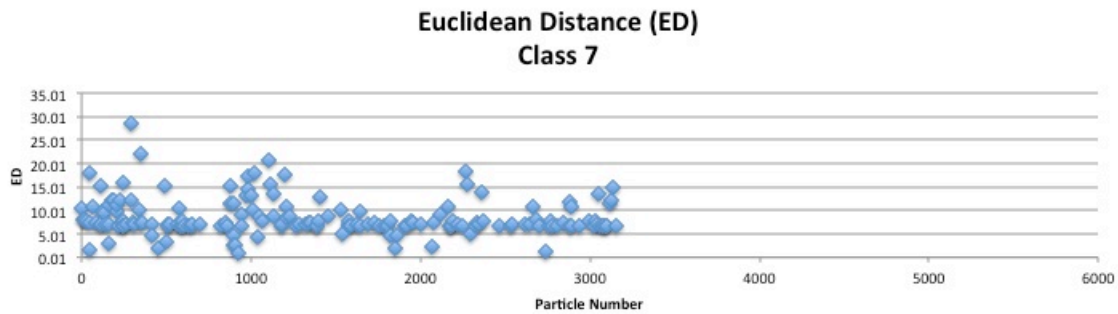

Figure 5-797: Euclidean Distance Class 7

Class 8 of Chad Arid 50 is composed of Iron less than 1%, Silica between 40% and 60%, and Aluminum between 20% and 35%. There are a total of 136 particles in this class (Figure 5-798).

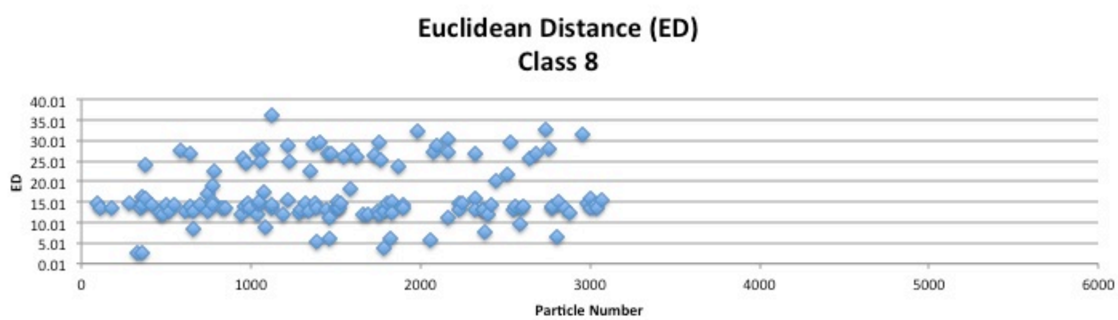

Figure 5-798: Euclidean Distance Class 8

Class 9 of Chad Arid 50 is composed of Iron less than 1%, Silica between 4% and 20%, Aluminum between 4% and 20%, Lead less than 5%, Nickel less than 4%, and Magnesium less than 4%. There are 35 particles in this class (Figure 5-799).

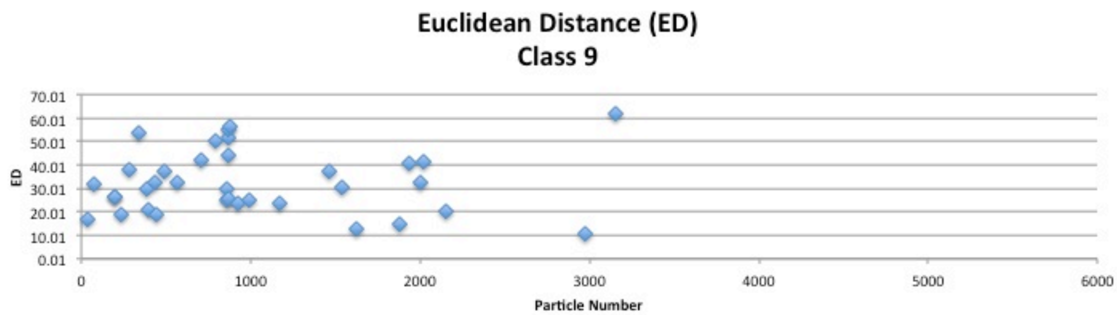

Figure 5-799: Euclidean Distance Class 9

Class 10 of Chad Arid 50 is composed of Calcium greater than 80% and Lead less than 5%. There are 24 particles in this class (Figure 5-800).

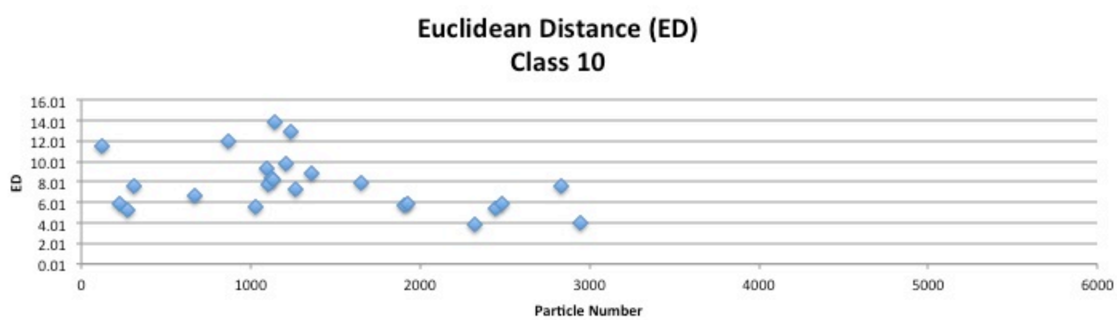

Figure 5-800: Euclidean Distance Class 10

Class 11 of Chad Arid 50 is composed of the total Calcium and Manganese greater than 90%. There are 7 particles in this class (Figure 5-801).

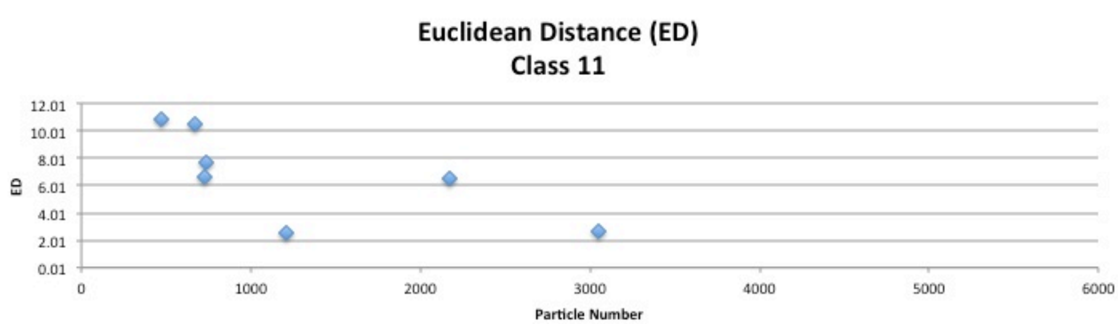

Figure 5-801: Euclidean Distance Class 11

Class 12 of Chad Arid 50 is composed of the total Calcium and Phosphorus greater than 90%. There are 13 particles in this class (Figure 5-802).

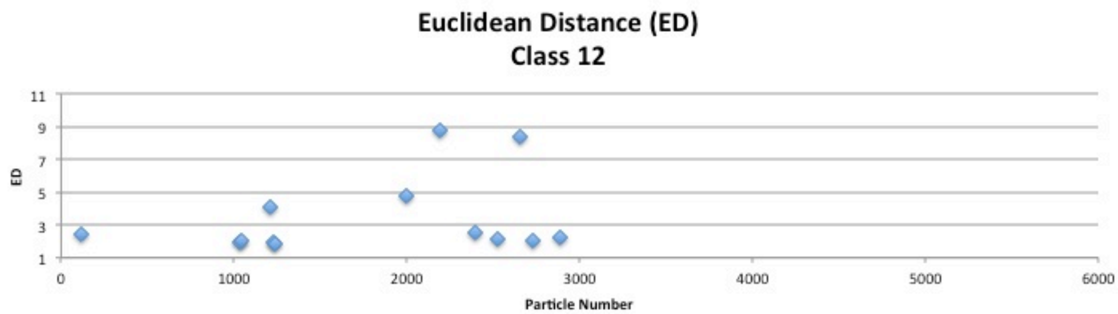

Figure 5-802: Euclidean Distance Class 12

Class 13 of Chad Arid 50 is composed of Aluminum less than 1%, Iron greater than 4%, and Silica greater than 80%. There are 4 particles in this class (Figure 5-803).

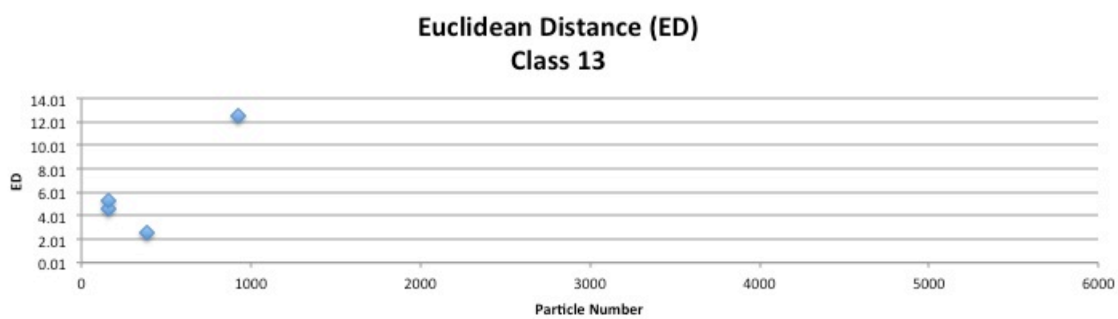

Figure 5-803: Euclidean Distance Class 13

Class 14 of Chad Arid 50 is composed of Magnesium greater than 40%, Silica greater than 25% and Aluminum less than 1%. There are 9 particles in this class (Figure 5-804).

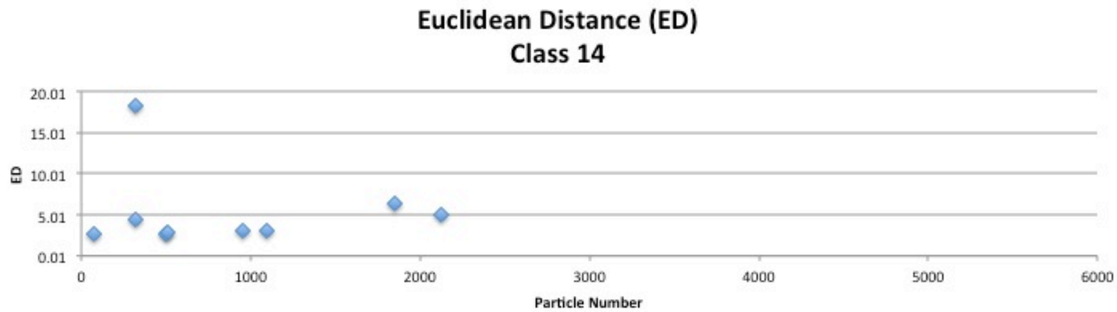

Figure 5-804: Euclidean Distance Class 14

Class 15 of Chad Arid 50 is composed of Aluminum less than 1%, Iron greater than 64%, and Lead less than 5%. There are no particles in this class

Class 16 of Chad Arid 50 is composed of Iron greater than 40% and the total Iron and Calcium greater than 75%. There are 70 particles in this class (Figure 5-805).

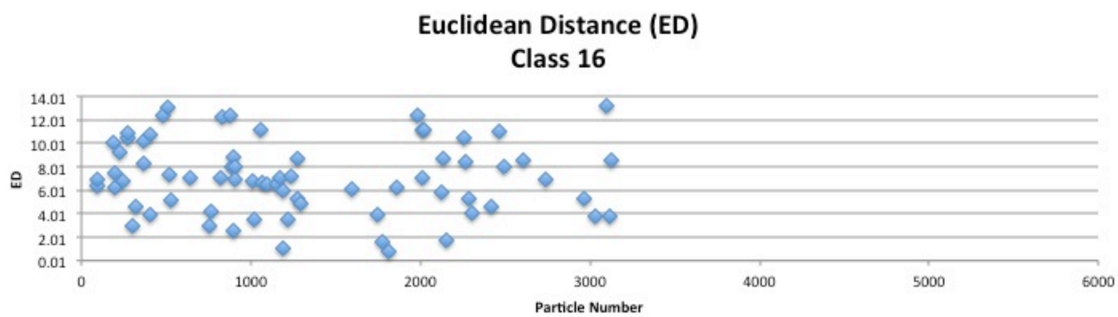

Figure 5-805: Euclidean Distance Class 16

Class 17 of Chad Arid 50 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 55% and 90%, and Aluminum between 10% and 30%. There are a total of 14 particles in this class (Figure 5-806).

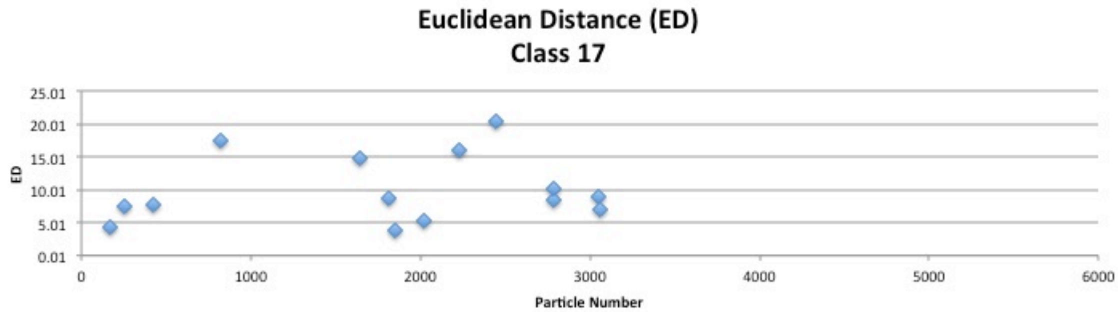

Figure 5-806: Euclidean Distance Class 17

Class 18 of Chad Arid 50 is composed of Potassium between 4% and 30%, Calcium less than 1%, Silica between 40% and 55%, and Aluminum between 20% and 30%. There are a total of 153 particles in this class (Figure 5-807).

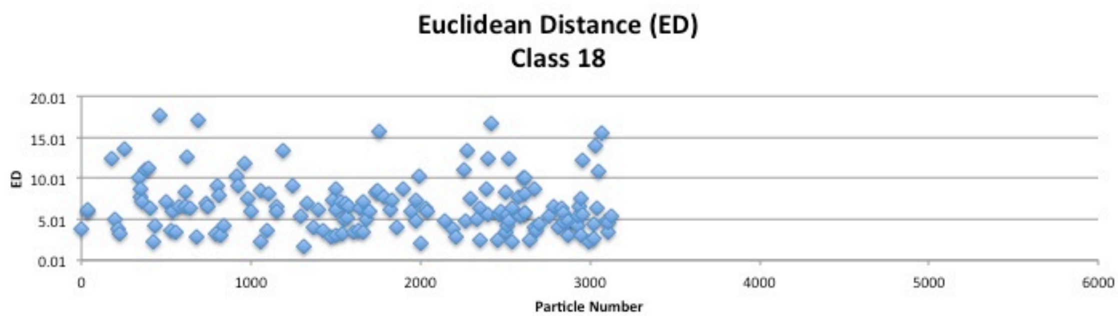

Figure 5-807: Euclidean Distance Class 18

Class 19 of Chad Arid 50 is composed of Potassium between 4% and 30%, Aluminum between 4% and 20%, and Silica between 4% and 30%. There are 15 particles in this class (Figure 5-808).

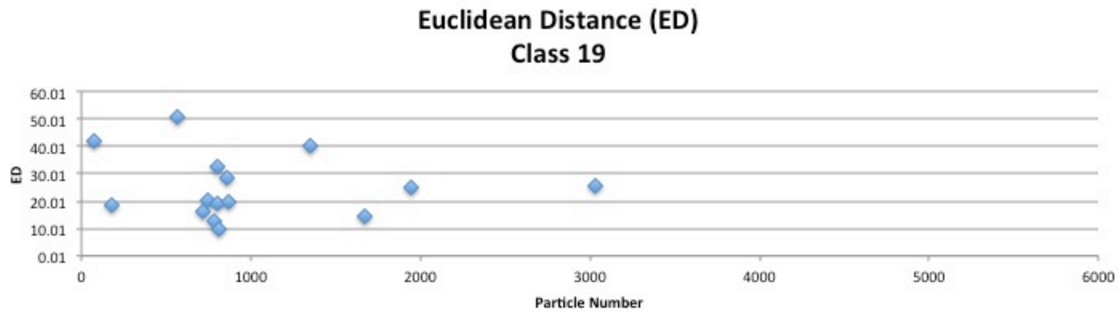

Figure 5-808: Euclidean Distance Class 19

Class 20 of Chad Arid 50 is composed of Potassium between 4% and 30%, and Aluminum between 20% and 50%, Silica between 20% and 50%. There are a total of 328 particles in this class (Figure 5-809).

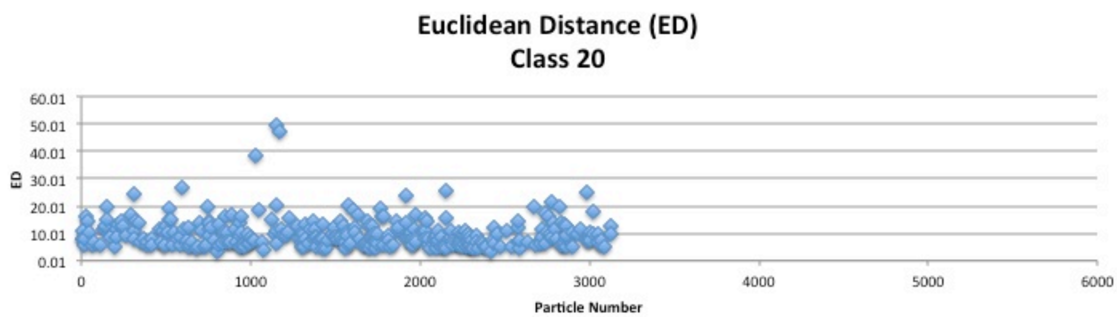

Figure 5-809: Euclidean Distance Class 20

Class 21 of Chad Arid 50 is composed of Calcium between 4% and 80%, Aluminum between 4% and 35%, Silica between 4% and 50%, and Iron between 4% and 50%. There are a total of 96 particles in this class (Figure 5-810).

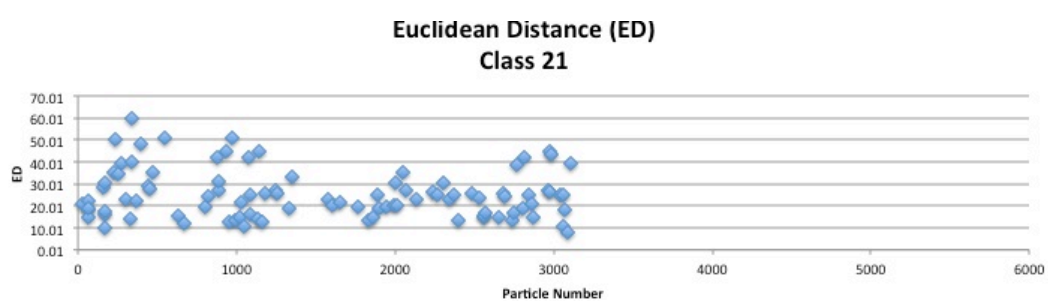

Figure 5-810: Euclidean Distance Class 21

Class 22 of Chad Arid 50 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica greater than 60%. There are a total of 403 particles in this class (Figure 5-811).

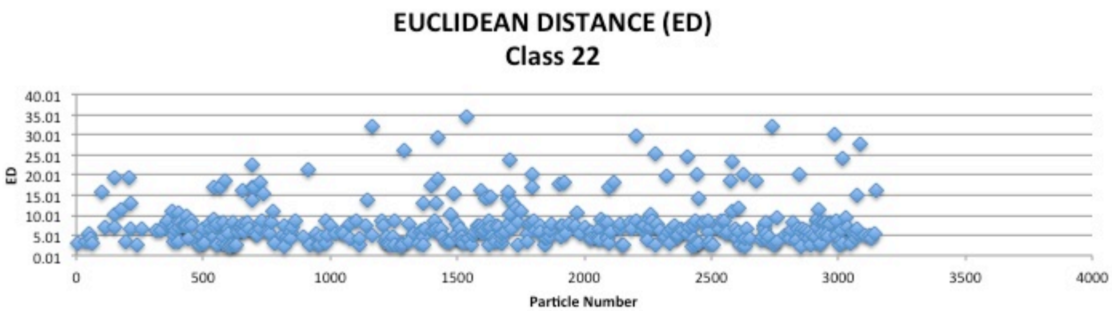

Figure 5-811: Euclidean Distance Class 22

Class 23 of Chad Arid 50 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 15% and 66%. There are a total of 70 particles in this class (Figure 5-812).

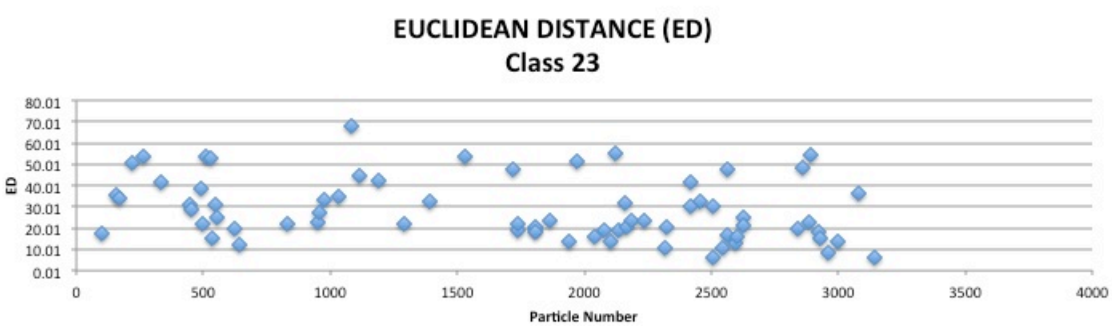

Figure 5-812: Euclidean Distance Class 23

Class 24 of Chad Arid 50 is composed of Potassium and Calcium less than 1%, Aluminum between 4% and 20%, and Silica between 4% and 18%. There are a total of 31 particles in this class (Figure 5-813).

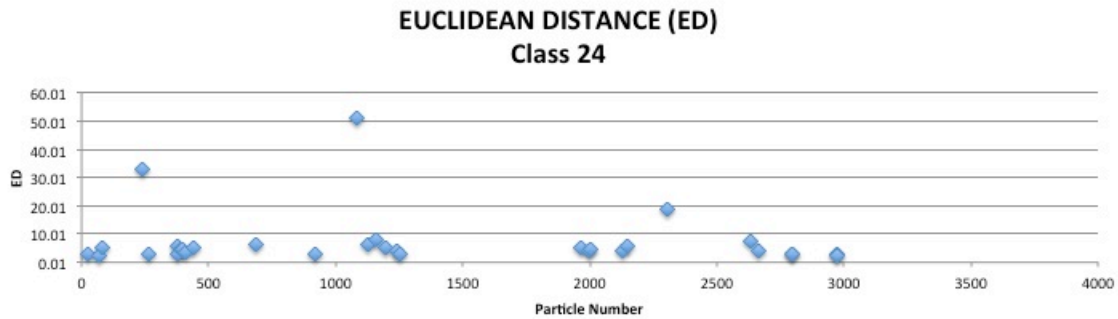

Figure 5-813: Euclidean Distance Class 24

Class 25 of Chad Arid 50 is composed of Potassium and Calcium less than 1%, Aluminum between 20% and 35%, and Silica between 18% and 40%. There are a total of 90 particles in this class (Figure 5-814).

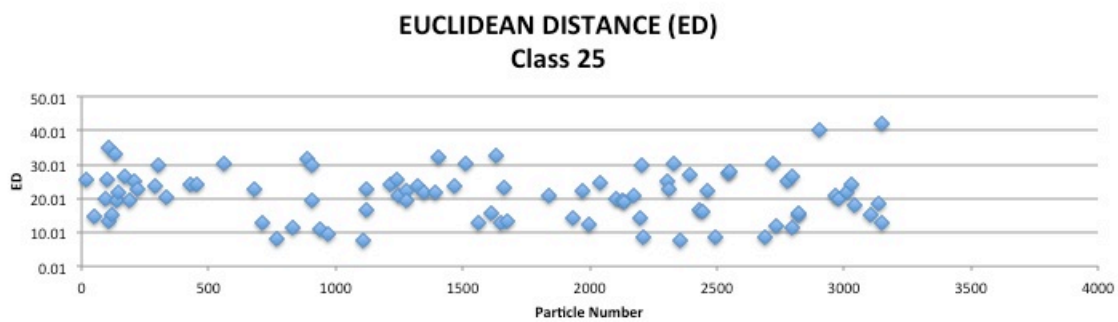

Figure 5-814: Euclidean Distance Class 25

Class 26 of Chad Arid 50 is composed of Potassium and Calcium less than 1%, Aluminum between 18% and 40%, and Silica between 40% and 60%. There are a total of 538 particles in this class (Figure 5-815).

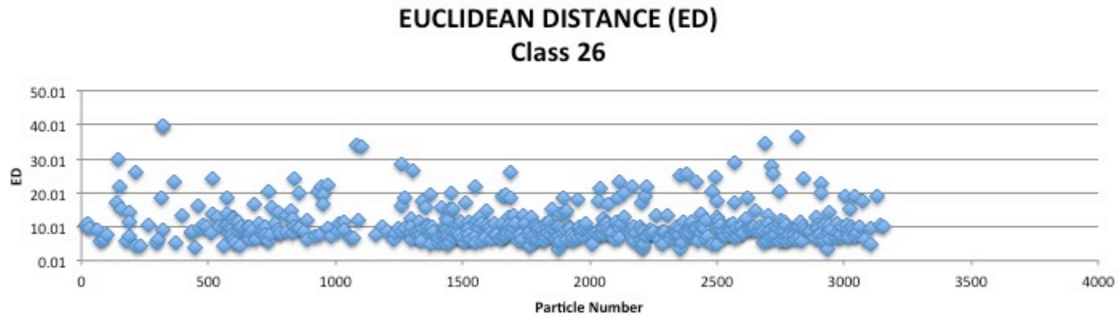

Figure 5-815: Euclidean Distance Class 26

Class 27 of Chad Arid 50 is composed of Potassium and Calcium less than 1%, Aluminum between 40% and 60%, and Silica between 20% and 60%. There are a total of 436 particles in this class (Figure 5-816).

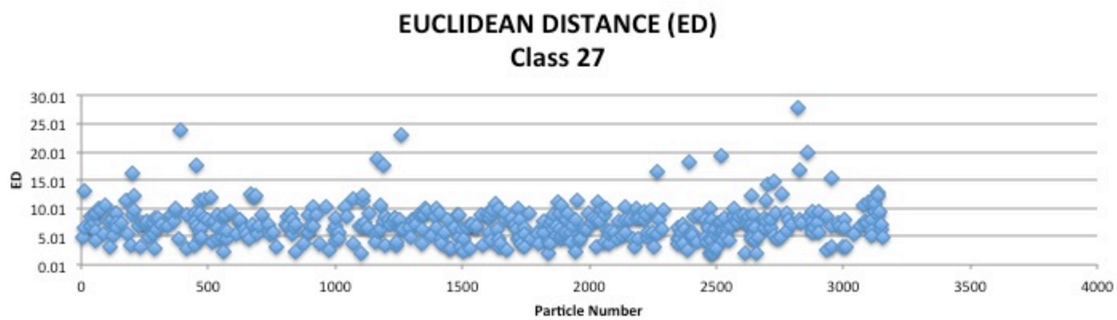

Figure 5-816: Euclidean Distance Class 27

Class 28 of Chad Arid 50 is composed of Aluminum less than 1%. There are a total of 85 particles in this class (Figure 5-817).

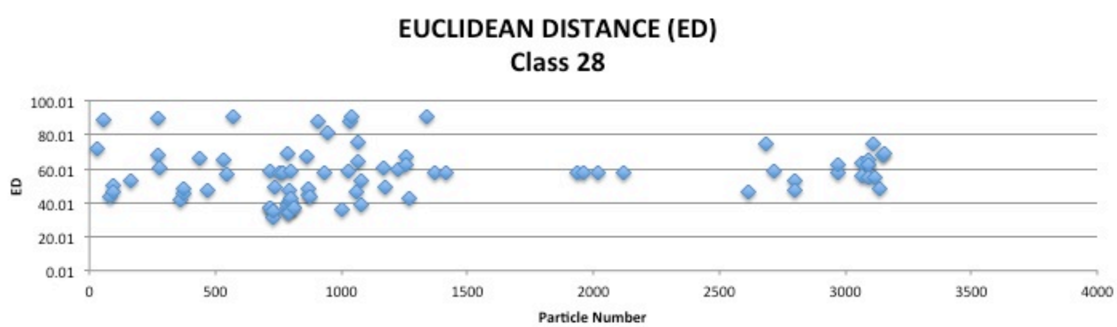

Figure 5-817: Euclidean Distance Class 28

Chad Arid Summary

The average number of particles in each class for all of the Chad Arid samples gives a total class average of 3476.50 particles, which constitutes 100% of the sample (Table 5-68). Class 26 has the highest average number of particles with 23.03% or 800.50 particles (Figure 5-818). The most abundant elements within this class are Silica (40%<Si<60%) and Aluminum (18%<Al<40%), with less than 1% Calcium and Potassium. Class 22 comes in as the second largest average particle class with 16.46% and 572.17 particles (Figure 5-819). The elements with the largest abundance are Silica (Si>60%) and Aluminum (4%<Al<20%), with Potassium and Calcium being less than 1%. Class 20 is the third largest average particle class, with 10.71% and 372.50 particles (Figure 5-820). The elements with the largest abundance are Silica (20%<Si<50%) and Aluminum (20%<Al<50%), with between 4% and 30% Calcium. These particles could by a variety of silicate minerals, or more likely clays, with the quartz being the least likely to transform. The most likely minerals these particles could be are Kyanite, Sillimanite or Andalusite. It is also worth mentioning classes 20 and 18 as they are K-bearing classes that are most likely K-Feldspars.

Table 5-68: Class Average-Numerical Percentage

Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
194.83	25.00	30.83	34.67	0.17	20.00	119.50	170.50
5.60%	0.72%	0.89%	1.00%	0.00%	0.58%	3.44%	4.90%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
23.17	17.17	2.67	9.17	4.17	5.00	0.33	80.00
0.67%	0.49%	0.08%	0.26%	0.12%	0.14%	0.01%	2.30%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
33.17	177.00	7.00	372.50	86.50	572.17	48.00	20.50
0.95%	5.09%	0.20%	10.71%	2.49%	16.46%	1.38%	0.59%
Class 25	Class 26	Class 27	Class 28	Class 29		Total	
73.83	800.50	370.50	56.17	121.50		3476.50	
2.12%	23.03%	10.66%	1.62%	3.49%		100.00%	

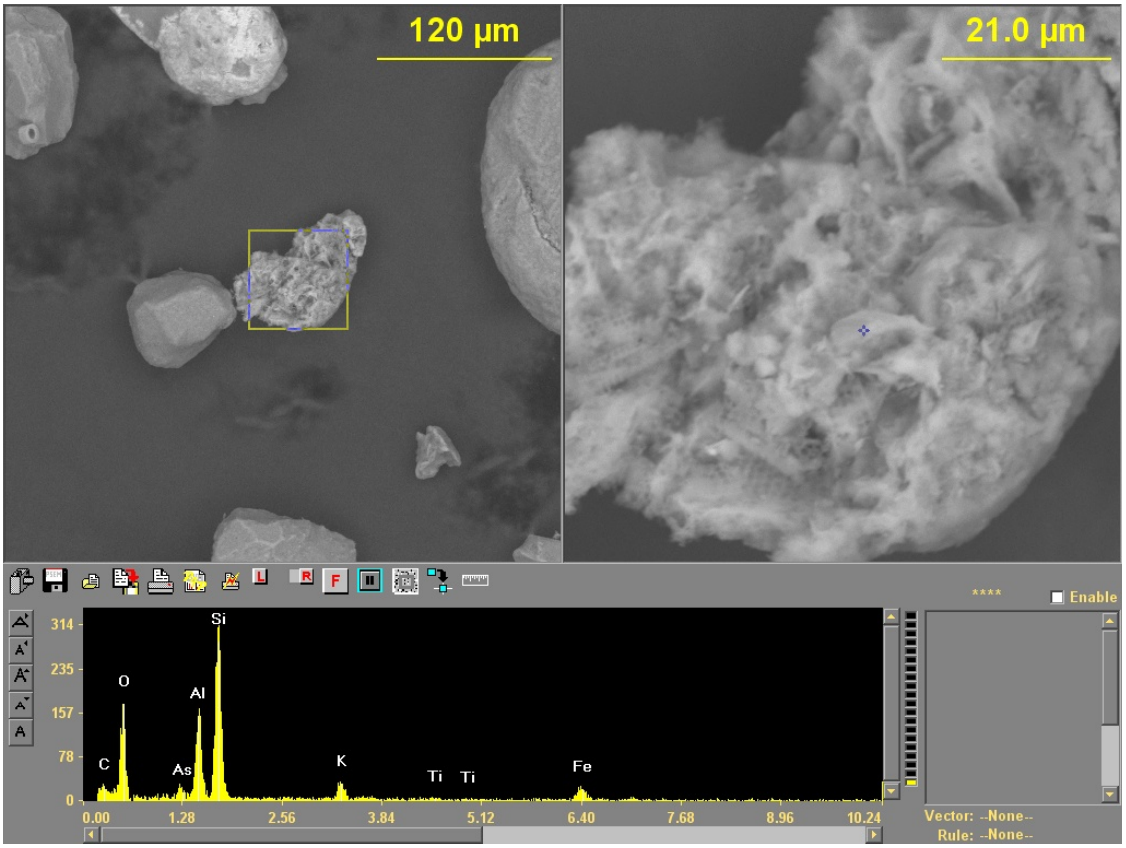

Figure 5-818: Class 26 showing Al and Si.

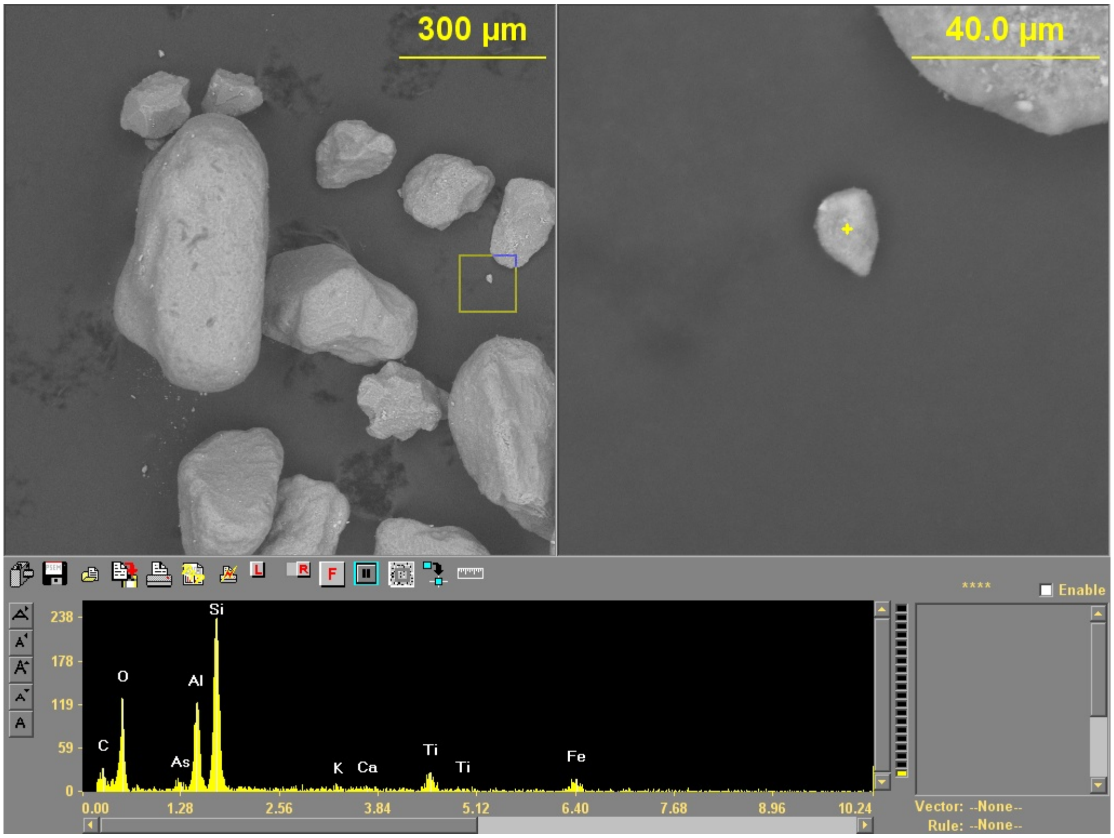

Figure 5-819: Class 22 showing Si, Al.

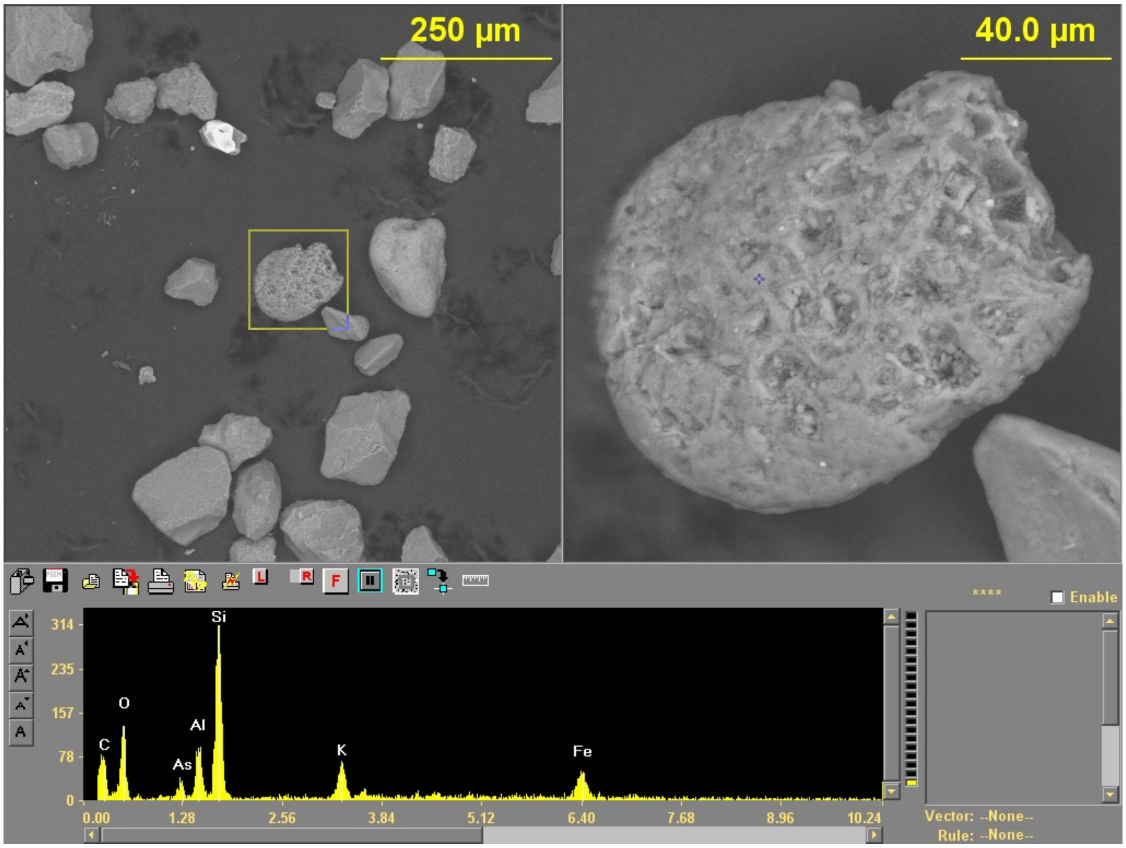

Figure 5-820: Class 20 Showing K, Al, Si.

The average volume of particles in each class for all of the Chad Arid samples gives a total class volume average of 400982.37 µm^3, which constitutes 100% of the sample (Table 5-69). Class 20 has the highest volume of particles with 24.68% or a volume of 98944.38 µm^3. The elements with the largest abundance are Silica (20%<Si<50%) and Aluminum (20%<Al<50%), with between 4% and 30% Potassium. Class 26 comes in as the second largest average volume class with 15.66% and 62795.54 µm^3 average volume. The most abundant elements within this class are Silica (40%<Si<60%) and Aluminum (18%<Al<40%), with less than 1% Calcium and Potassium. Class 22 is the third largest average volume class with 15.46% and a volume of 61977.06 µm^3. The elements with the largest abundance are Silica (Si>60%) and Aluminum (4%<Al<20%), with Potassium and Calcium being less than 1%.

Table 5-69: Class Average-Volumetric Percentage

Class 1	Class 2	Class3	Class 4	Class 5	Class 6	Class 7	Class 8
14626.05	177.25	1555.49	710.25	0.00	69.90	3204.40	25541.60
3.65%	0.04%	0.39%	0.18%	0.00%	0.02%	0.80%	6.37%
Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15	Class 16
4883.52	2691.39	204.34	63.46	16.43	4265.82	2.54	236.18
1.22%	0.67%	0.05%	0.02%	0.00%	1.06%	0.00%	0.06%
Class 17	Class 18	Class 19	Class 20	Class 21	Class 22	Class 23	Class 24
14192.24	11505.17	1434.30	98944.38	12627.32	61977.06	2164.22	109.92
3.54%	2.87%	0.36%	24.68%	3.15%	15.46%	0.54%	0.03%
Class 25	Class 26	Class 27	Class 28	Class 29		Total	
1957.12	62795.54	24795.50	36988.11	13242.87		400982.37	
0.49%	15.66%	6.18%	9.22%	3.30%		100.00%	

Comparing the average numerical percentages, Class 26, 22, and 20, and volumetric average percentages, Class 20, 26, and 22, the three highest classes represent 50.20% of the numerical value and 55.80% for the volumetric value for all the Burkina Laterite samples. The difference in the percentage between number of particles and volume of particle of the three highest classes is 5.60%. The difference in the particle number and volume is exacerbated by the large difference in the moderate-rich Potassium class (class 20). Class 20 is characterized by moderate Silica and Aluminum, with the Potassium being between 4% and 30%. By looking at the other high-class values, the Silica and Aluminum content are determined to be the most abundant element in the Chad Arid samples, but unlike the Burkina and Bodele samples, Potassium plays an important role in the chemical composition of the Chad Arid Samples.

The Euclidean distance for the all the Chad Arid samples gives us an idea of the distribution of the particles and distance from the centroid of the cluster. While the Euclidean distance values themselves are arbitrary, the pattern of distribution is important for identification of sample types. Each sample class will have a unique distribution of particles around the centroid of the cluster, which can be a valuable tool for identification of samples. This unique distributive pattern, along with the Potassium mineral content, is a useful tool for identifying samples within the Chad Arid Region of Africa.

Along with chemistry and Euclidean distance, the average particle size of each elemental class was identified (Table 5-70). The particles were separated into 4 size classes, with size 1 having particles with a diameter between 0-2.49μm, class 2 having a diameter between 2.5-4.9μm, class three having a diameter between 5-10μm, and class 4 having a diameter greater than 10μm. Size class 1 includes 73.43% of all Chad Arid particles, size class 2 includes 18.47%, size class 3 contains 5.83%, and class 4 includes 2.27%. This analysis showed an abundance of small particle sizes (Class 1) with no correlation between chemistry of the particles and size of the particles.

Table 5-70: Chad Arid Particle Size Classes by Elemental Class.

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
Size Class 1	74.36%	0.00%	61.82%	91.15%	16.67%	93.97%	77.53%
Size Class 2	17.02%	100.00%	32.30%	7.17%	0.00%	4.75%	18.20%
Size Class 3	5.78%	0.00%	3.90%	0.99%	0.00%	1.28%	3.67%
Size Class 4	2.84%	0.00%	1.99%	0.69%	0.00%	0.00%	0.61%
	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	Class 14
Size Class 1	77.97%	67.11%	65.23%	58.81%	73.25%	73.98%	65.87%
Size Class 2	13.78%	24.21%	13.37%	15.48%	18.41%	9.35%	7.28%
Size Class 3	4.67%	5.66%	19.95%	5.71%	8.33%	0.00%	18.39%
Size Class 4	3.58%	3.02%	1.45%	3.33%	0.00%	0.00%	8.47%
	Class 15	Class 16	Class 17	Class 18	Class 19	Class 20	Class 21
Size Class 1	8.33%	92.03%	64.71%	79.12%	76.47%	75.48%	60.37%
Size Class 2	8.33%	7.00%	18.57%	14.45%	9.07%	17.24%	24.75%
Size Class 3	0.00%	0.96%	12.16%	5.00%	6.83%	4.89%	10.58%
Size Class 4	0.00%	0.00%	4.56%	1.43%	7.64%	2.39%	4.30%
	Class 22	Class 23	Class 24	Class 25	Class 26	Class 27	Class 28
Size Class 1	76.89%	80.73%	93.32%	81.69%	69.33%	73.66%	79.42%
Size Class 2	16.25%	11.43%	4.73%	14.77%	21.68%	18.55%	11.98%
Size Class 3	5.17%	5.63%	1.95%	2.95%	6.85%	6.30%	3.96%
Size Class 4	1.69%	2.20%	0.00%	0.59%	2.15%	1.48%	4.64%

Total Class %

Class 1	Class 2	Class 3	Class 4
73.43%	18.47%	5.83%	2.27%

Chapter 6

Conclusion

The objective of this research was to characterize and quantify the chemical composition and volume of African dusts that originate in the Sahel and Saharan regions of Africa. Data has been collected and analyzed on 29 samples from the Sahel and Saharan region of Africa. These samples were logged as:

1. Bodele 79
2. Bodele 80
3. Bodele 82
4. Bodele 83
5. Bodele 84
6. Bodele 85
7. Bodele 86
8. Burkina Laterite 53
9. Burkina Laterite 54
10. Burkina Laterite 56
11. Burkina Laterite 57
12. Burkina Laterite 58
13. Burkina Laterite 60
14. Burkina Laterite 61
15. Burkina Laterite 62
16. Burkina Laterite 63
17. Burkina Soil 70
18. Burkina Soil 71
19. Burkina Soil 72
20. Burkina Soil 73

21. Burkina Soil 76
22. Burkina Soil 77
23. Burkina Soil 78
24. Chad Arid 40
25. Chad Arid 42
26. Chad Arid 45
27. Chad Arid 47
28. Chad Arid 48
29. Chad Arid 50

The Bodele samples derive from the Bodele Depression in North Africa, which in the past was an inland fresh body of water. The distinguishing characteristics of the Bodele samples are their extremely high Silica content, most of which is composed of Siliceous Diatoms.

The Burkina Soils and Laterites originate from the same region in Burkina Faso, Africa. Both groups are primarily composed of Silica and Iron with varying amounts of Aluminum. While similarities exist among both the Laterites and the Soils, particularly the Silica and Aluminum content, the Iron composition differs greatly between the two samples. The difference in Iron content is enough to conclude that some mixing is occurring though Aeolian processes but each set of samples, Laterites and Soils, are distinguishable from one another. Along with the Iron content, the extra elemental class composed of the previously unclassified particles, including Iron, Silica, and Aluminum, allows for a unique distribution of particles. Most of the unclassified elements are contained within the two distinct clusters between 25% and 40% Iron and 45% and 65% Iron, with 25% to 40% Silica and Aluminum.

The Chad Arid Samples derive from the Chad region of Africa and primarily consist of Silica and Aluminum, with varying amounts of Potassium. The addition of the Potassium to the samples creates a distinguishing characteristic from the other sample sets, as it pertains to chemistry. The distribution around the centroid of Euclidean distance particle cluster for class 8 also distinguishes this sample set between the other three.

Overall, the analyses of the all the samples, Bodele, Burkina Soil, Burkina Laterite, and Chad Arid, show large amounts of Si, Fe, and Al-rich minerals that demonstrate a close correlation in relative elemental amounts. This is to be expected from clay minerals of the pyroxene group. The Fe and Si-rich minerals trend towards an inverse relationship, which is also consistent with iron oxides of the spinel group that generally consist of magnetite. Other elemental constituents within the samples include varying amounts of Potassium. A run of the Burkina Soils and Laterites, show a basic similarity in chemical composition (Si, Al, Fe) with varying smaller amounts of Ca, Ti, P and trace amounts of Na, S, and K, leading to the hypothesis that the soils and Laterites are mixing through Pedogenic processes, but are still distinguishable from one another. We can see similar Aeolian processes contributing to the mineral content of other surface dusts, but the differences in the elemental percentages, along with the trace elements leads to the conclusion that African Dusts from the Sahel and Saharan regions of North Africa can be chemically and physically differentiated. This research can be used in the future as the source material has been analyzed and the relative proportions of particles that fall into each class can be used to create a source signature matrix. This could be used to apportion the percentage of particles from each source and create a particle class balance model approach to analyzing samples collected from the Caribbean and Atlantic Ocean.

Future Directions

Quantifying the contributions of material at a receptor site from potential sources is an exercise in apportionment by mathematical receptor modeling. One can use CCSEM data rather than species concentration data from source and receptor samples and employ the same type of apportionment model. The particle class balance (PCB) model was proposed by Johnson and McIntyre (1982) in order to evaluate the source contributions at a receptor site based on individual particle information. An advantage of the PCB approach is the fine scale sample component resolution (accomplished by the definition of multiple homogenous particle groups in a sample) that avoids the problem of co-linearity. The starting point in the application of the PCB approach is to determine particle mass. This requires particle volume extrapolations and expert judgment of the molecular form of occurrence of the element in a particle. In the case of the latter, Fe particles from a laterite source will likely be in the form Fe_2O_3 (goethite) rather than Fe_3O_4 (magnetite). The calculated particle masses in a given particle class at the receptor is assumed to be the sum of the contributions of the source to those classes. This can be represented by:

$$X_{ij} = \sum_{k=1}^{p} c_{ik} f_{kj} \qquad i = 1, \text{m classes} \qquad j=1, \text{n samples}$$

where:

x_{ij} is the mass of particles of *i*th class for the *j*th sample,

c_{ik} is the mass fraction of *i*th class from the *k*th source,

f_{kj} is the mass contribution of *k*th source for the *j*th sample.

PCB holds the promise of greater source resolution. While receptor samples were not available for this study. It is not unreasonable, given the number source samples analyzed here, to propose that a future study where ambient samples have been collected (for, instance following long range transport of dust across the Atlantic, or to Northern Europe), that the PCB approach to source-receptor modeling could be profitably used to identify which areas of North Africa are significantly contributing to aerosols that have undergone long range transport after originating in North Africa.

References

Avila, A., Queralt-Mitjans, I., Alarcon, M. 1997. Mineralogical Composition of African Dust Delivered by Red Rains Over the Northeastern Spain, *J. Geophys. Res,* 102, 21 977–21 996.

Bartholet, J. 2012. Swept From Africa to the Amazon, *Scientific American*, 45-49.

Bennet, C.M., McKendry, I.G., Kelly, S., Denike, K., Koch, T. 2006. Impact of the 1998 Gobi Dust Event on Hospital Admission in the Lower Fraser Valley, British Columbia, *Sci. Tot. Environ.* 366, 918-925.

Blanco, A., De Tomasi, F., Fillippo, E., Manno, D., Perrone, M.R., Serra, A., Tafuro, A.M., Tepore, A. 2003. Characterization of African Dust Over Southern Italy, *Atmos. Chem. Phys. Discuss*, 3, pp. 1-38.

Coz, A., Andrés, A., Soriano, S., Viguri, J. R., Ruiz, M. C., Irabien, J. A. 2009. Influence of Commercial and Residual Sorbents and Silicates as Additives on the Stabilisation/Solidification of Organic and Inorganic Industrial Waste, *Journal of Hazardous Materials*, 164, 755–761.

Cos, E., Moreno, T., Artinano, B. 2011. Variations on the Mineralogical Particle Properties of Atmospheric Saharan Dust from Different Source Regions. *Revista de la Sociedad Espanola de Mineralogia*, Macla 15, pp. 69-70.

"Dust to Gust". EurekAlert!. AAAS. 28 December 2006. Retrieved 17 August 2014.

Falkovich, A.H., Schkolnik, G., Ganor, E., Rudich, Y., 2004. Adsorption of Organic Compounds Pertinent to Urban Environments onto Mineral Dust Particles. *J. Geophys. Res*. 109, D02208. doi:10.1029/2003JD003919.

Formenti, P., Shutz, Y., Desboeufs, K., Ebert, M., Kandler, K., Petzold, A., Scheuvens, D., Weinbruch, S., Zhang, D. 2011. Recent Progress in Understanding Physical and Chemical Properties of African and Asian Mineral Dust. Atmos. Chem. Phys., 11, 8231-8256, doi: 10.5194/acp-11-8231-2011.

Goudie, A.S., Middleton, N.J., 2001. Saharan Dust Storms: Nature and Consequences, *Earth-Sci. Rev*., 179-204.

Hopke, P. (2003) Recent developments in receptor modeling. J. Chemometrics, 17:255-265

Intergovernmental Panel on Climate Change (IPCC). 2007. Available from: <http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf>.

Johnson, D. L., and McIntyre, B. L. (1982). In *Receptor Models Applied to Contemporary Pollution Problems,*SP-48. Air Pollution Control Association, Pittsburgh,PA.

Kim, D., and Hopke P. (1988) Source Apportionment of the El Paso Aerosol by Particle Class Balance Analysis, Aerosol Science and Technology, 9:3, 221-235.

Krech, S., McNeill, J.R., Merchant, C., Jump Up. Encyclopedia of World Environmental History. Routledgw. Pp. 748-749. ISBN 0-415-93734-5

Lyons, R., Oldfield, F., Williams, E. 2010. Mineral Magnetic Properties of Surface Soils/Sands Across Four North African Transects and Links to Climatic Gradients, Geochemistry, Geophysics, Geosystems, vol 11, issue 8, doi: 10.1029/2010GC003183.

Mahowald, N.M., Baker, A.R., Bergametti, G., Brooks, N., Duce, R.A., Jickells, T.D., Kubilay, N., Prospero, J.M., Tegen, I. 2005. Atmospheric Global Dust Cycle and Iron Inputs to the Ocean, *Global Biogeochem. Cy.*, 19, GB4025, doi: 10.1029/2004GB002402.

Mamane, Y., Ganor, E., Donagi, A.E., 1980. Aerosol Composition of Urban and Desert Origin in the Eastern Mediterranean I: Individual Particle Analysis. *Water Air Soil Pollut.* 14, 29–43.

Mather, R.L., Reynolds, S.E., Wolff, G.A., Williams, R.G., Torre-Valdes, S., Woodward, E.M.S., Landolfi, A., Pan, X., Sanders, R., Achterberg, E.P. 2008. Phosphorus Cycling in the North and South Atlantic Ocean Subtropical Gyres, *Nature Geoscience*, 1, 439-443.

Mormon, S., Plumlee, G. 2013. The Role of Airborne Mineral Dusts in Human Disease, *Aeolian Research 9*, 203-212.

Plumlee, G.S., Morman, S.A., Ziegler, T.L. 2006. The Medical Geochemistry of Dusts, Soils, and Other Earth Materials: Invited. In: Lollar, G.S. (Ed.), Treatise on Geochemistry, vol. 9, Elsevier, pp. 1-61.

Prospero, J.M., Glaccum, R.A., Nees, R.T. 1981. Atmospheric Transport of Soil Dust from Africa to South America, *Nature*, 289, 570-572.

Prospero, J.M., 1999. Long-Range Transport of Mineral Dust in the Global Atmosphere: Impact of African Dust on the Environment of the Southeastern United States, *Proc. Natl. Acad. Sci.* USA, 96, 3396-3403.

Shultz, H., Brand, P., Heyder, J. 2000. Particle Deposition in the Respiratory tract. In: Gehr, Peter, Heyder, Joachim (Eds.), Particle-Lung Interactions. Lung Biology in Health and Disease, vol. 143. Marcel Dekker, Inc., New York, pp. 229-277.

Sullivan, R.C., Guazzotti, S.A., Sodeman, D.A., Tang, Y., Carmichael, G.R., Prather, K.A., 2007. Mineral Dust is a Sink for Chlorine in the Marine Boundary Layer. *Atmos. Environ.* 41, 7166–7179.

United States Environmental Protection Agency (USEPA). 2012a. Particulate Matter. Available from: <http://www.epa.gov/airquality/particlepollution/>.

World Health Organization (WHO). 2012a. Available from: http://www.who.int/mediacentre/factssheet/fs313/en/.

Biographical Information

Robert received his undergraduate in Geophysics, and a minor in mathematics and focused his research on the correlation between seismic and acoustic sensors at Southern Methodist University. During his tenure at University College London, where he received his Masters in Geophysical Hazards, he was able to research and show that small changes in atmospheric conditions can lead to large increases in runoff of surface and near-surface water flows.

Robert's current research at the University of Texas at Arlington focuses on source characterization (chemistry and size) of African dusts, the role they play in extreme weather, the oceans and atmosphere, and the amounts that are transported across the Atlantic Ocean. African Dusts are sampled and run through SEM, XRF, and XRD analysis with the purpose of determining mineral and elemental compositions. Along with composition, sediment sizes are analyzed and compared to chemistry in order to determine the ability to transport short and long distances. Recent studies have shown a sharp increase in African dusts, specifically from the Sahel region of Africa. This increase is caused by an increase in the Atlantic Ocean temperatures and has a major impact on global climate and extreme weather.

Robert's current research interests include floods and flood forecasting, droughts and their global impacts (specifically Sahel and Saharan region of Africa), slope instability caused by extreme weather events and increased oceanic sedimentation, prediction methods for extreme weather events, and hazard mitigation. His current and previous research experience includes flood forecasting and modeling, short-term (extreme) and long-term climate change, their impacts on existing climates and people (hazard mitigation and Vulnerability and Capacity Analysis), and monitoring and tracking severe storm cells.