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# Characterization of Texture and Composition for Rapaki Paleo-Boulders and Relative Influence in Determining Surface Roughness

**Abstract:** This study uses clast counts and rock sample analyses of five boulders in Rapaki to provide insight towards classifying the modern and paleo-boulders' texture and composition with already known cosmogenic helium dates. All of the boulders are fine grained volcanic breccia with uniformly high vesicularity in the clasts. They have porphyritic texture and a fine grained mineral rich matrix containing plagioclase and augite phenocrysts. Pixel counts of photos taken of paleo-boulder sections where clast counts were performed yields an average composition of ~74.86% clast and ~25.14% host matrix materials. The sole modern boulder segment counted has a clast to matrix ratio of ~1.94:1 while a paleo-boulder segment counted on the same boulder, via a paleo-modern contact, has a substantially larger clast to matrix ratio of ~4.66:1. Modern boulders contain ~2.4 times more matrix than the paleo-boulders and as a result are more fine-grained and appear more coherent. Paleo-boulders have a higher clast to matrix ratio than the modern boulders and more apparent surface roughness. This results from texture acting as the primary control on surface roughness because it influences the removal of matrix material from the surface over time. Modern and paleo-boulders share the same intrinsic composition while their textures differ in extrinsic appearance due to the amount of matrix erosion they have experienced as a function of their age.

## Intro:

Studying Rapaki modern and paleo-boulders' texture and composition is relevant for understanding the geologic transformation that a boulder goes through with time in an earthquake prone environment. Discerning how modern vary from paleo-boulders is necessary for recognizing what geologic alterations the modern boulders will experience as a result of weathering over time. Although texture and composition are key geologic aspects that geologists often use to first describe rocks, no previous studies specifically on the texture or composition of the boulders in Rapaki have ever been done. This dearth of crucial knowledge has left a wide gap for many geologists who are interested in understanding the fundamental geology of the boulders in the Rapaki region.

Specific geology of the Rapaki site is not well known as it has only become an area of geologic interest since the most recent CES (Canterbury Earthquake Sequence), when boulders fell and damaged nearby infrastructure. However, Rapaki is a part of the larger Banks Peninsula volcanic group which has been studied extensively. It is known from R. J. Sewell's (1988) study on Banks Peninsula stratigraphy that the rocks present at Rapaki are Late Miocene alkali to transitional volcanic rocks which erupted from the Lyttelton composite volcano between 9.7 and 11 Ma, based on K-Ar ages. Rocks in the greater Lyttelton area were from a 350 $km^3$ eruption of mildly alkali to transitional hawaiite to trachyte lavas of the Lyttelton Volcanic Group, but the boulders we see at Rapaki are comprised of vesicular basalt and volcanic breccia that is less coherent (Sewell, 1988). Price and Taylor's (1980) study on the geochemistry of Banks Peninsula shows that the boulders at Rapaki have high $SiO_2$ content, olivine that becomes progressively more iron-rich, smooth alkali feldspars, and augite as the predominant pyroxene present. They also determined that the basalt present at Rapaki is nearly all transitional alkalic on both chemical and normative mineralogical classification schemes (Price, Taylor, 1980). These works only brush the surface of explaining the geologic story behind the Rapaki boulders' texture and composition as they lack explicit detail on Rapaki. My research advisor Josh Borella provided cosmogenic helium dates previously done on selected surfaces of the Rapaki boulders (*Figure 1*). The probable age of boulder emplacement and the boulders' relation to Banks Peninsula volcanism were groundwork for this study. However, these helium ages are not entirely reliable as they were not taken on the specific boulder surfaces sampled.

Geologists are interested in the Rapaki boulders since they constantly pose a significant rockfall geohazard to nearby residents and their infrastructure whenever local earthquakes occur (Avery, 2012). Classifying the texture and composition of the Rapaki boulders is important because knowing what kind of rock the boulders are helps determine how future, modern, and paleo-boulders will change in size, shape, and surface roughness over time in response to erosive processes (*Figure 2*). The geodynamics of the boulders can greatly change with these kinds of physical changes that boulders undergo during aging. Properly recognizing these changes is required to effectively determine the extent of the geohazard that the Rapaki boulders pose and what, if any kind of mitigation is needed. This study provides new information on the Rapaki boulders' clast to matrix ratio and how that ratio evolves overtime with respect to age. If surface roughness increases with boulder age and is generated by the removal of matrix, then paleo-boulders should have more surface roughness than modern ones because they will have a higher clast-matrix ratio. Detailed descriptions of the Rapaki boulders' texture and composition are also provided.

**Setting:**

The town of Rapaki lies in the South Island of New Zealand in the Port Hills region next to Lyttelton. Boulders found at Rapaki originate from the Lyttelton composite volcano's eruptions and are part of Banks Peninsula, the largest accumulation of Miocene volcanic rocks in the Canterbury Province (Sewell, 1988). The geologic setting of the Rapaki site is driven by Banks Peninsula volcanism. This volcanic promontory has developed on continental crust at the western end of the Chatham Rise, has an area of 1200km$^2$, and connects to the mainland by alluvial gravels of the Canterbury Plains (Sewell, 1988). Climate at Rapaki is temperate with moderate rainfall. During pre-European contact the hills at Rapaki were covered with thick forest, which has now been removed to make way for farm land and consequently now further exposes the boulders to the effects of weathering. The site directly experiences the undergoing active tectonics of the region, as boulders break off from source areas at the top of hills and tumble down during localized earthquakes, which occur frequently in the Canterbury region.

**Data Methods:**

**Clast Counts:**

Seven clast counts were done on five different boulders, with four of the boulders being paleo and one containing a modern-paleo contact**.** The boulder containing the modern-paleo contact had a clast count done on its modern and paleo section so that both sections' clast-matrix ratios could be compared. Clasts counts were done on 1m$^2$ sections on the best exposed and most easily accessible surfaces of the boulders. Boulders that were completely covered by lichen or did not have known cosmogenic helium dates were not selected for clast counting. "Clasts" were considered to be any part of the boulder that was not matrix that had an area of at least 1 cm$^2$. Clasts that were right on the border of the 1m$^2$ sections were accounted for if a majority of the area was within the square. Chalk was used to draw 1m$^2$ grids that were measured out on the boulder surfaces. Clasts were marked with chalk as their lengths and widths were recorded in a field notebook and transposed into Microsoft Excel**.**

Photos were then taken of each of the square meter section where clast counts were performed and then used in Microsoft Paint, where clasts and matrixes were color coordinated separately to obtain the clast to matrix ratio of each section from pixel counts of the colored features (*Figure 3*). Pixel counts were done via a basic C++ program command. In Microsoft Excel clast-matrix ratios of all of the boulder surfaces were calculated. Calculations for the minimum value, first quartile, median, second quartile, maximum value, average, and standard deviation of the clast and matrix percentages of the paleo-boulders were also done. Data from the clast counts is represented as tables, box and whisker plots, and histograms. Error could have easily occurred at multiple steps throughout these processes. Clasts could easily have been missed and not accounted for when doing the physical clast count and when selecting clasts out of the photos for the pixel count.

**Rock Sample Analysis:**

Rock samples were taken from each section where clast counts were performed after the clast counts and photos of each section were acquired. Fist size samples of matrix and clast that best represented the texture and composition of the boulder being sampled were selected. Rock samples were then cut into thin section sized samples and dried in an oven to make the phenocrysts and vesicularity clearly visible. Textural and compositional descriptions of each boulder were made based off interpretative analysis of each rock sample. Samples were placed under a normal flatbed scanner to clearly see a detailed image of the rock comparable to the quality of a thin section. Grain size and mineral percentage comparator cards were used to provide basic textural and compositional information of the matrixes and clasts. Background knowledge of Lyttelton volcanism suggests that lithics, augite, and plagioclase comprise the boulders, so compositional percentages were assigned for these three components of the rock.

**Results:**

Calculations done in Microsoft Excel with the results from the pixel count data are represented in Tables 1 and 2. This same data is also depicted as a box and whisker plot for the clast-matrix ratios of the paleo-boulders (*Figure 4*). Histograms of RAP #02, RAP #03 Section 1, RAP #03 Section 2, RAP #05, RAP #12, RAP #25 Paleo, and RAP #25 Modern are illustrated in Figures 5-11 respectively. A histogram reflecting the data from all of the paleo-boulders can also be seen (*Figure 12*). All of the histograms were created with bins that increase increments of five until all of the clast area sizes were accounted for. The frequency shows the number of clasts that have an area that lies within the range of a bin. For example, if 5 bins have a frequency of 100, then 100 clasts of all the clasts counted on the boulder surfaces have an area that lies between $0cm^2$ and $5cm^2$. Percent composition of the boulders was estimated using a mineral percentage comparator card while looking at the cut rock samples under the flatbed scanner (**Table 3**).

**Interpretation:**

Basic textural and compositional descriptions and analyses can be drawn from the observations and estimated calculations of the boulder hand samples. First and foremost, there was no apparent significant difference between the compositions of the modern boulder with that of the paleo-boulders. As seen in Table 3, the percent composition for the modern boulder follows the same general trend as the percent composition of the paleo-boulders. Both types of boulders fall in a percent composition range of 15-20% plagioclase, 2-5% augite, and 75-83% volcanic lithics. This is a desirable result, as we would not expect the composition of the boulders to change with age. Minerals appear as phenocrysts of 1-4mm in both modern and paleo-boulders, with larger phenocrysts present in modern boulders. Volcanic lithics are fine grained and derive from a lava source that has high magnesium and iron content. Rapaki boulders are massive and rubbly volcanic breccias that sharply grade out into more coherent basalts at some areas. Boulders appear in a variety of sizes, from ~0.3-5.0m + in diameter as boulders can be up to the size of multiple minivans. Modern boulders at the research site tend to be substantially smaller (*Figure 2*).

All of the boulders are fine grained volcanic breccia with porphyritic texture and are light gray to muddy brown in color. Rocks are uniformly vesicular, with 1-3mm vesicles present over ~40-50% of the surface of any given clast. Minimal to no vesicularity is present in matrix. On average clasts make up ~74.86% of each paleo-boulder (**Table 2**) and most frequently have a surface area $\leq 20cm^2$. Clasts are subrounded and predominantly oblong in shape. Modern boulders tend to have less apparent surface roughness and vesicularity than paleo-boulders since they are less clast dominated. Host matrix in both boulder types is finer than clasts and light to muddy brown in color. Matrix is a low silica glass (40-50%) that is iron and magnesium based due to its mafic origins. Some matrix material is red from the oxidation of iron. The main textural difference in between modern and paleo-boulders is in surface roughness, which appears to change with clast-matrix ratios over time.

Many interesting attributes arise from the clast count data. Table 1 provides the best comparison between modern and paleo-boulders with the results of RAP #25's modern and paleo sections. As mentioned previously RAP#25 has both modern and paleo sections because the boulder has a modern-paleo contact. Table 1 shows that the RAP #25 paleo section has a clast to matrix ratio ~4.66 of while the RAP#25 modern section has a clast to matrix ratio of ~1.94. This means that the paleo section reveals ~2.4 times more clasts than the modern section. It should be noted that RAP#25 Paleo had the highest clast to matrix ratio even though it is part of the same boulder as RAP#25 Modern, with the lowest clast to matrix ratio. Excluding data from RAP #02, all of the boulders have an increase in clast-matrix ratio with more age. This is a strong indication that the amount of apparent surface roughness is primarily dependent on age. Both the paleo and modern boulder sections counted from RAP #25 have been exposed to the same external geologic factors since its current emplacement. The only difference between these sections is age and consequently the amount of weathering. This would indicate that the amount of surface roughness is time-dependent, at least for RAP#25.

Older boulders experience more weathering, which results in the erosion of matrix, the increase of clast-matrix ratios, and more surface roughness. However, comparing all of the clast-matrix ratios from Table 1 does not suggest a direct correlation between age and matrix erosion, since the clast-matrix ratios do not successively increase with increases in the probable ages of emplacement. Figure 12 shows a significant drop off in clast frequency for clasts $\geq 20\text{cm}^2$, with a few larger clasts having an area up to $805\text{cm}^2$ acting as outliers. Although large clasts contribute greatly to our clast to matrix ratio calculations, they are not representative of the typical clasts seen. Most clasts are within an area from $5\text{-}10\text{cm}^2$. Table 2 and its visual representation in Figure 4 show that on average paleo-boulders are ~74.86% clast and ~25.14% matrix, compared with ~65.98% clast and ~34.02% matrix in our modern boulder. This ~8.88% difference in matrix material between paleo and modern suggests that the process of a modern boulder losing matrix material is slow but substantial.

From a broad context it is evident that surface roughness relates to clast-matrix ratio, but the nature of this relationship and its relation to other textural and compositional features of the Rapaki boulders is unclear. None of the data reflects any direct correlation between age and surface roughness, so it is not known how exactly how surface roughness changes with time. It is presumed that the erosion of matrix further exposes the surface area of the oblong clasts, resulting in more roughness. However, surface roughness is actually an ambiguous determiner for age because with time clasts can be rounded through weathering and lose surface roughness. I will argue that because the matrix is composed of a silica glass finer than the clasts, that it is much easier and faster to erode with its increased surface area. The weathering of matrix exposes more of a boulder's surfaces, causing more physical weathering with increased clast variability. The weathering of matrix exposes more of a boulder's surfaces, causing more physical weathering with increased clast variability. Therefore, the overall surface roughness that we see is more dependent on matrix removal rather than clast rounding. Older boulders appear to have more surface roughness than modern ones because the erosion of matrix exceeds the shrinking of clasts, resulting in a higher clast-matrix ratio. It is also possible that the difference in surface roughness between modern and paleo-boulders is due to boulders originating from different lava horizons or eruptions. As phenocrysts grow in shallow intrusives or volcanic flows prior to eruption they are surrounded by a fine grained to glassy matrix. The fact that the modern boulders had more phenocrysts potentially suggests that they may derive from a different lava source than the paleo-boulders. However, since there are multiple lava flows visible at the top of the Rapaki hillside, it is also likely that the paleo-boulders derive from different lava flow sources as well and may have started with similar sized phenocrysts during their initial emplacement that were then removed during erosion. Crystal size is not a good indicator for surface roughness and identifying boulder ages because the lava sources of the boulders as and the effects of weathering on the phenocrysts are unknown.

Texture is one of the most useful geologic features for discerning differences between modern and paleo boulders at Rapaki. Clast-matrix ratio differences between modern and paleo-boulders reflect matrix removal through time and the resulting generation of surface roughness. Our study indicates that texture is the primary control on surface roughness. However, time is required to allow the influence of texture to manifest at the surface. Both modern and paleo-boulders have a porphyritic texture, suggesting that the rates of generating surface roughness on the textures of all boulders' surfaces should be the same through time if no other external factors intervene with the boulders. Rates of generating surface roughness change with time and correspond with the rates of matrix weathering. Clast-matrix ratios in Figure 4 best reflect a boulder’s texture and its resulting surface roughness. Developing a correlation between texture, surface roughness, and age is constrained by the fact that only a few of the analyzed surfaces have exposure ages.

**Conclusion:**

Textural and compositional analysis of the Rapaki boulders clarifies how the interconnectivity in the relationship between texture, surface roughness, and age functions. Rapaki boulders are predominantly volcanic breccia that is fine grained and clast dominated with porphyritic texture, uniform vesicularity, plagioclase and augite phenocrysts, and a finer glassy host matrix deriving from a mafic source. Excluding external factors, the surface roughness of all the boulders should initially be similar because all of the boulders have an analogous porphyritic texture. Texture is the primary control on surface roughness because it influences the removal of matrix material from the surface over time. However, composition is still a significant aspect of the Rapaki boulders because it helps explain the formation of the boulders, telling the overarching geologic story that they reflect. Further research needs to be done performing more clast counts on modern boulders, quantifying the actual surface roughness of each boulder, and obtaining accurate boulder ages. As the first case study on this topic, this research generates just as many questions as it does answers.

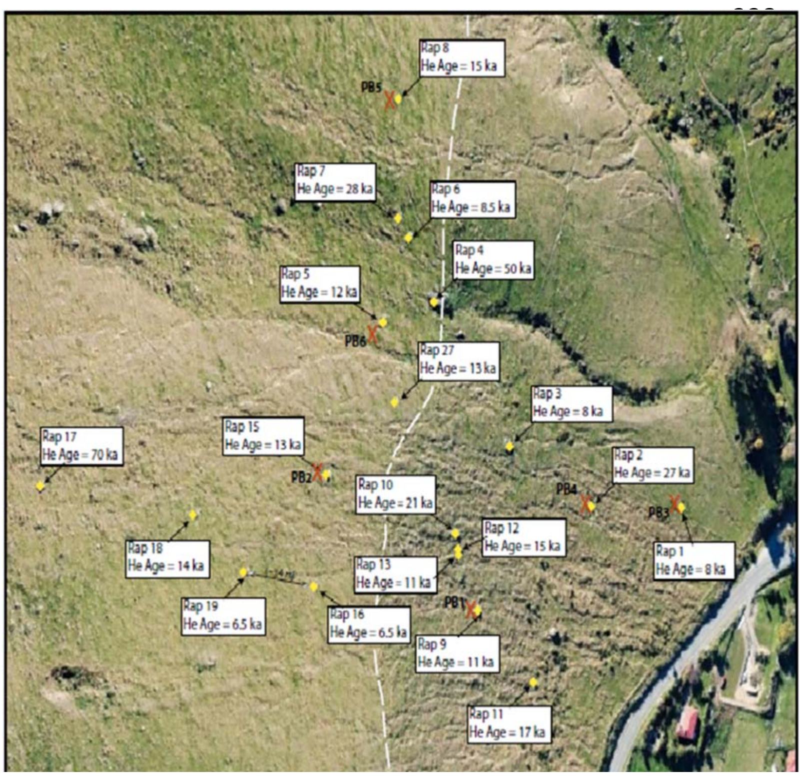


**Figure 1: Location, helium age, and number classification scheme for each helium dated boulder along the hillside of the study site at Rapaki.*

**Figure 2: Comparison of modern boulder (forefront) with a paleo-boulder (rear). Notice how the paleo-boulder has more exposed clasts.*

**Figure 3: Photo taken of RAP #03 Section 2 prior to clast count (left) compared with same photo after 1m$^2$ grid is drawn in and clasts have been colored black in Microsoft Paint for pixel counting.*

| Boulder # | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **RAP #02** | **RAP #03 Section 1** | **RAP #03 Section 2** | **RAP # 05** | **RAP #12** | **RAP #25 Paleo** | **RAP # 25 Modern** |
| **Number of Matrix Pixels** | 617979 | 388467 | 1194274 | 794737 | 445185 | 407182 | 622487 |
| **Number of Clast Pixels** | 1390121 | 997669 | 2781360 | 2424415 | 1821587 | 1895526 | 1207022 |
| **% Matrix Pixels** | 30.77 | 28.03 | 30.04 | 24.69 | 19.64 | 17.68 | 34.02 |
| **% Clast Pixels** | 69.23 | 71.97 | 69.96 | 75.31 | 80.36 | 82.32 | 65.98 |
| **Ratio of Clast to Matrix** | 2.25 | 2.57 | 2.33 | 3.05 | 4.09 | 4.66 | 1.94 |

**TABLE 1:** *The number of matrix and pixel clasts of each boulder as counted by C++ is shown, as well as the percentage of matrix and clasts that the number of pixels equates to. Ratios of clast to matrix were also calculated.*

| **Paleo Boulders** | **Minimum Value** | **Quartile 1** | **Median** | **Quartile 3** | **Maximum Value** | **Average** | **Standard Deviation** |
|---|---|---|---|---|---|---|---|
| **Clast (%)** | 69.226 | 70.464 | 73.644 | 79.098 | 82.317 | 74.858 | 5.480 |
| **Matrix (%)** | 17.683 | 20.902 | 26.356 | 29.536 | 30.774 | 25.142 | 5.480 |

**TABLE 2:** *Depicted data of all the paleo-boulders that corresponds with Figure 4.*

| | Boulder # | | | | | | |
|---|---|---|---|---|---|---|---|
| | RAP #02 | RAP #03 Section 1 | RAP #03 Section 2 | RAP # 05 | RAP #12 | RAP #25 Paleo | RAP # 25 Modern |
| **% Plagioclase** | 15 | 20 | 20 | 20 | 15 | 20 | 20 |
| **% Augite** | 2 | 2 | 3 | 3 | 5 | 2 | 5 |
| **% Remainder Volcanic Lithics** | 83 | 78 | 77 | 77 | 80 | 79 | 75 |
| **Probable Age of Emplacement** | 27 ka | 8 ka | 8 ka | 12 ka | 15 ka | 21 ka | 0 ka |

**TABLE 3:** *Table illustrates percentage of plagioclase, augite, and volcanic lithics of each boulder as well as their ages for reference (Figure 1).*

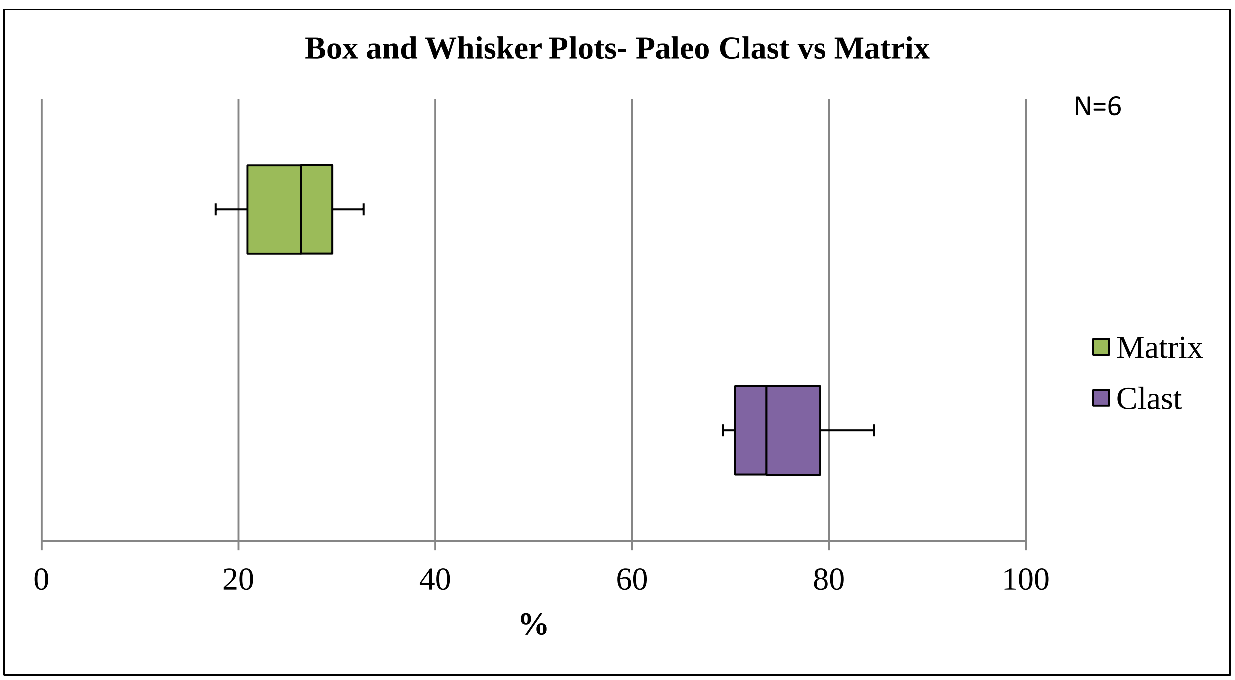


**Figure 4: Box and whisker plots depicting the minimum values, first quartiles, medians, third quartiles, maximum values, and averages for clasts and matrixes from all 6 paleo-boulder clast counts. Data is drawn from the pixel count results illustrated in Table 2. Paleo-boulders are on average ~74.86% clast and ~25.14% matrix material. Medians were calculated to be ~73.64% and ~26.36% for clast and matrix respectively.*

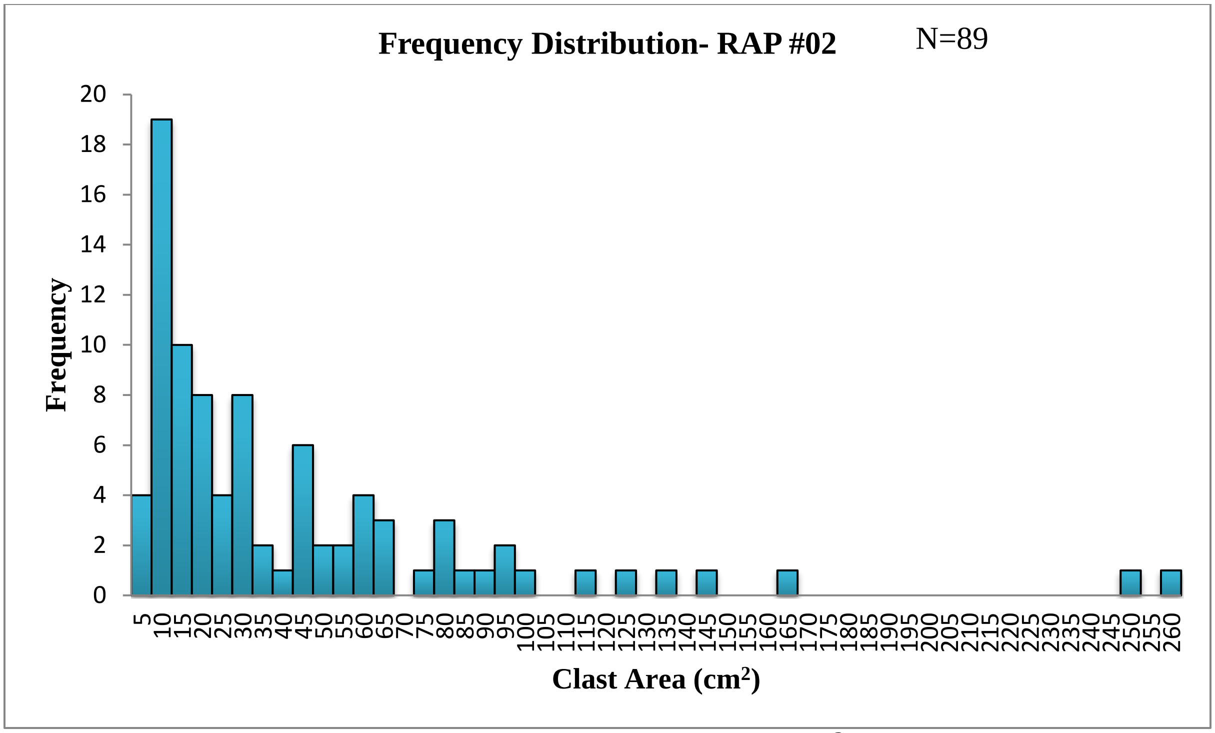


**Figure 5:** **Figure 5: Histogram showing frequency of ranges (bins) in cm$^2$ that clast areas occupy for RAP #02.*

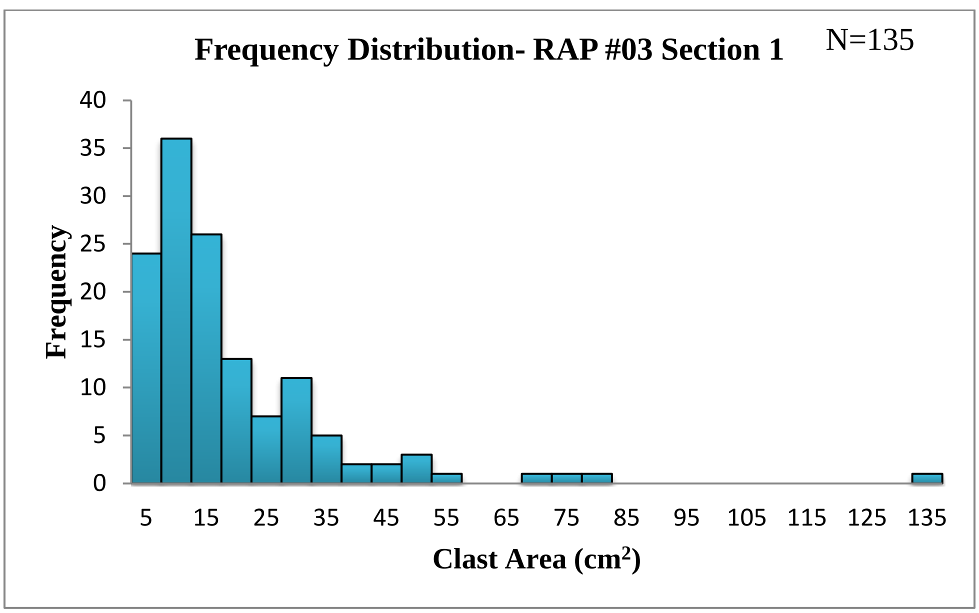


**Figure 6: Histogram showing frequency of ranges (bins) in cm$^2$ that clast areas occupy for RAP #03 Section 1.*

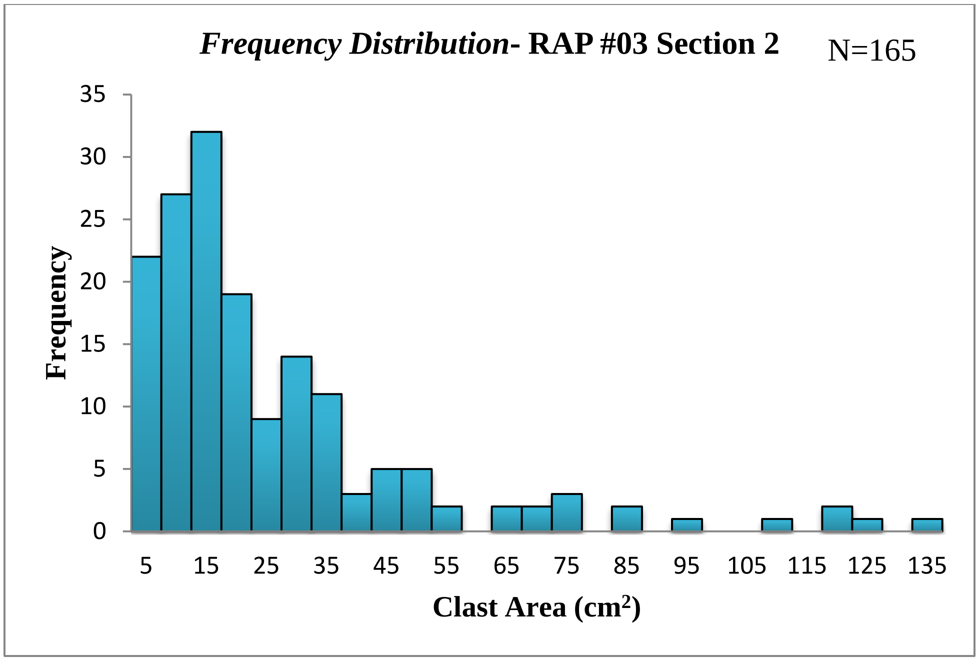


**Figure 7: Histogram showing frequency of ranges (bins) in cm² that clast areas occupy for RAP #03 Section 2.*

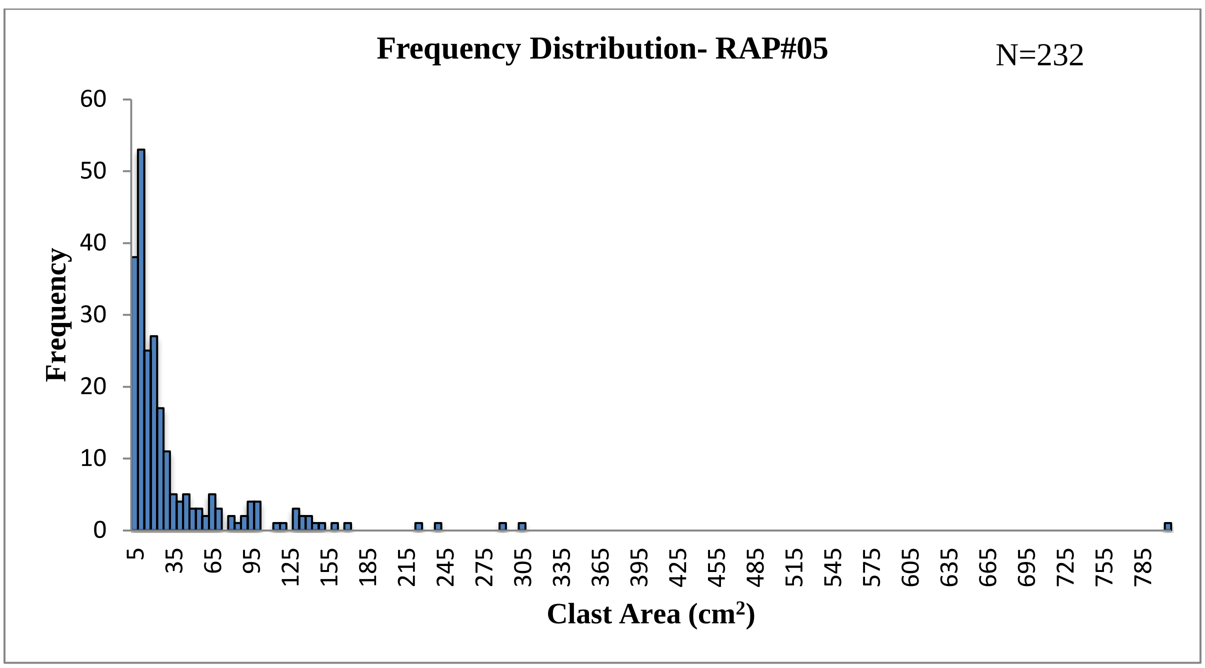


**Figure 8: Histogram showing frequency of ranges (bins) in cm² that clast areas occupy for RAP #02.*

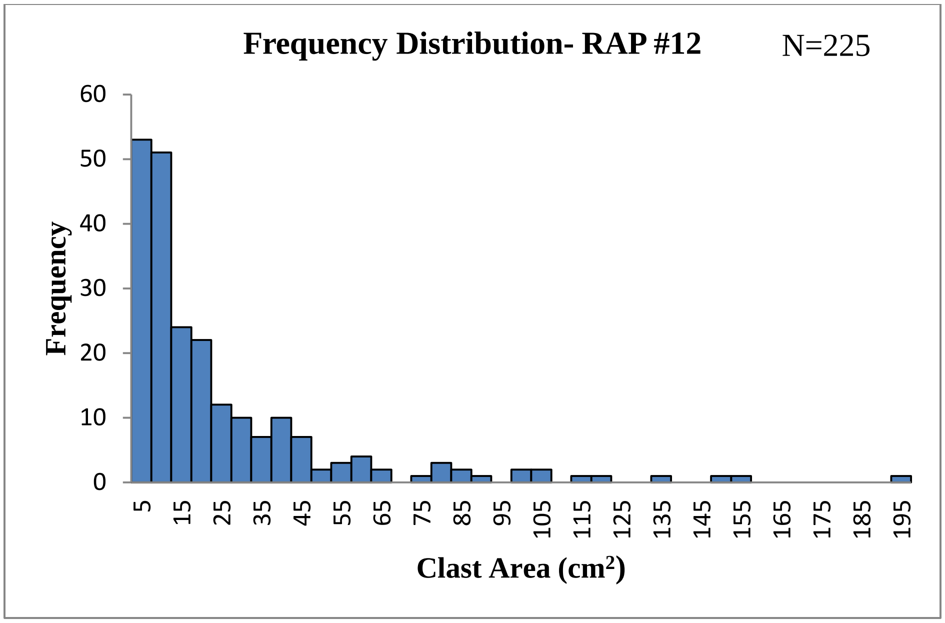


**Figure 9:* *Histogram showing frequency of ranges (bins) in cm² that clast areas occupy for RAP #12.*

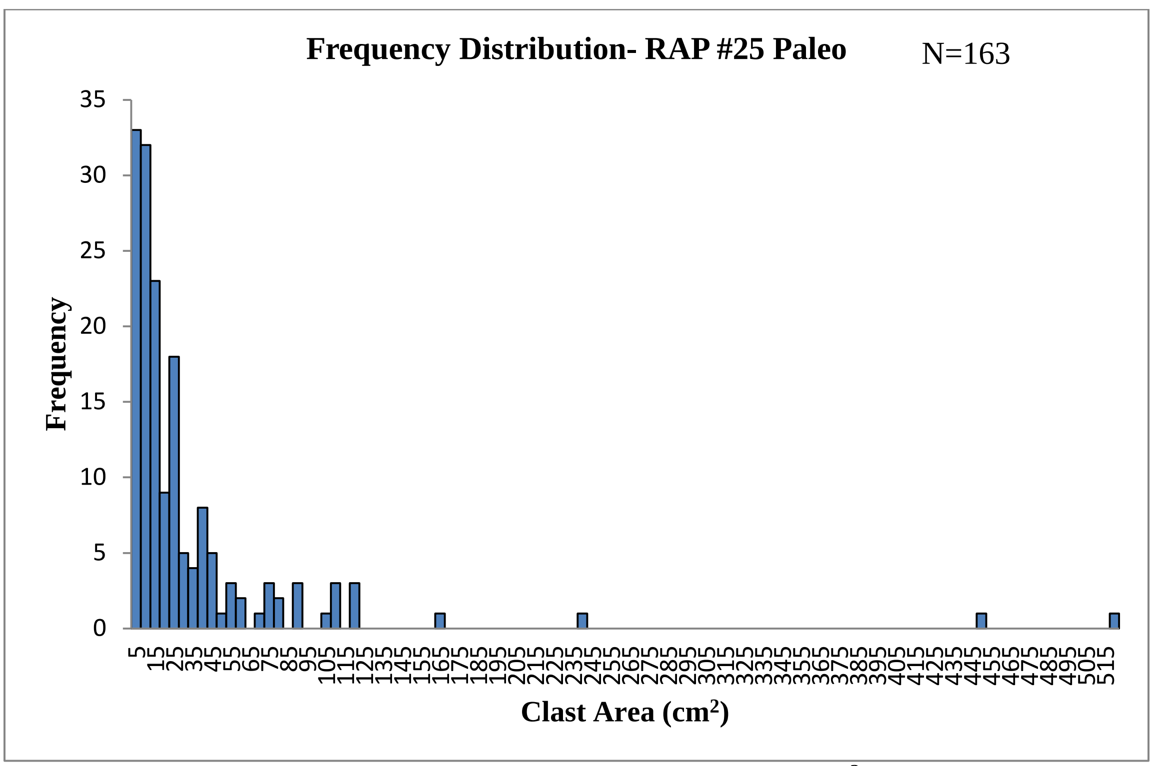


**Figure 10:* *Histogram showing frequency of ranges (bins) in cm² that clast areas occupy for RAP #25 Paleo.*

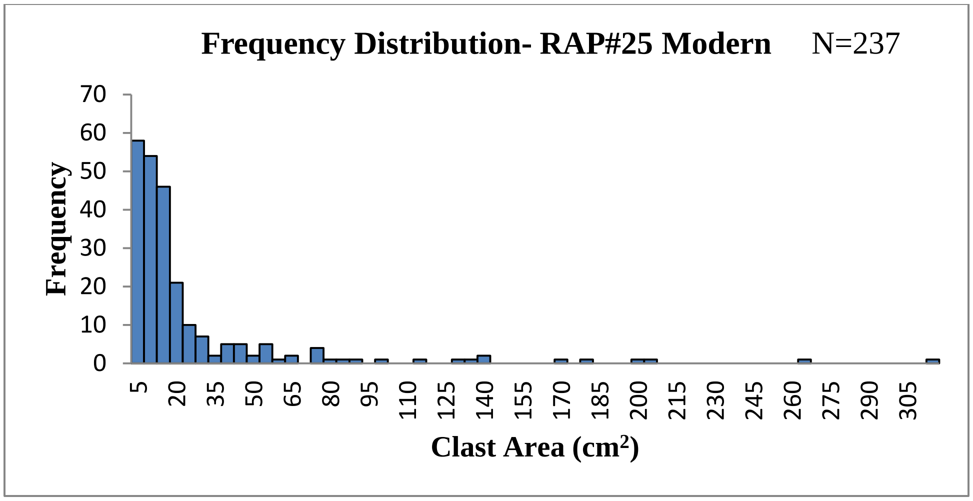


**Figure 11: Histogram showing frequency of ranges (bins) in $cm^2$ that clast areas occupy for RAP #25 Modern.*

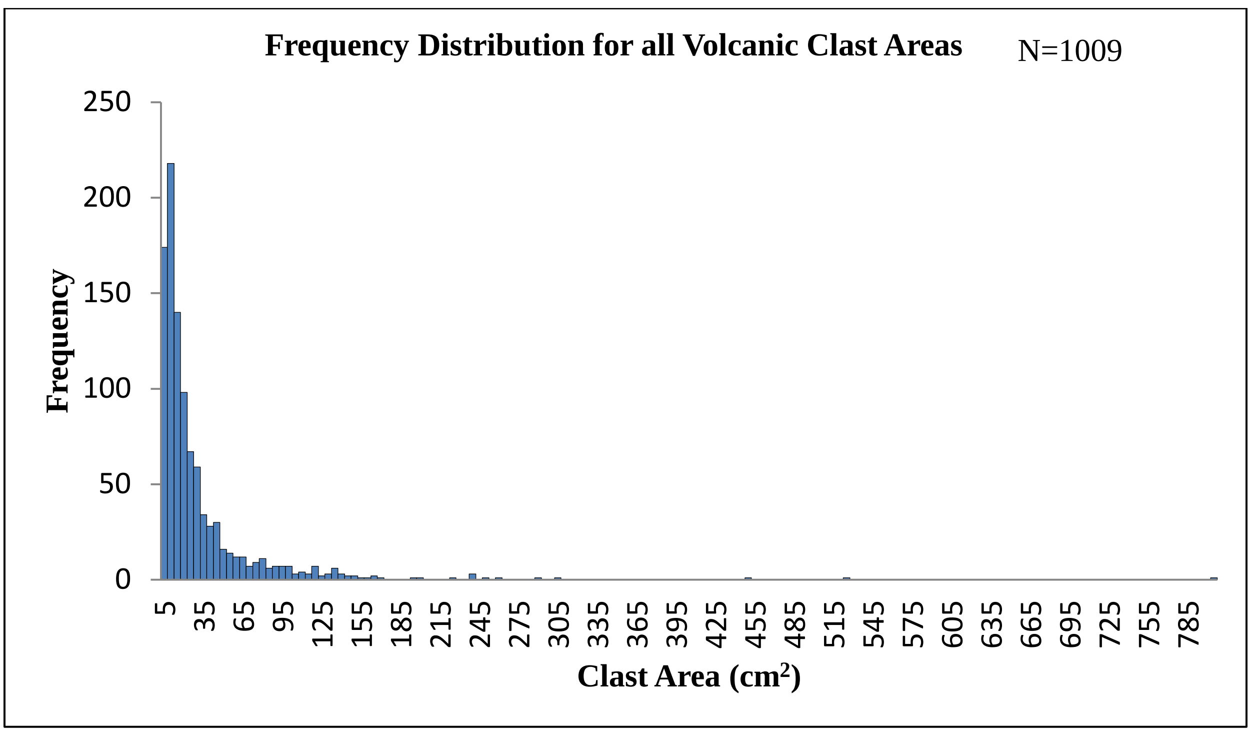


**Figure 12: Histogram made from all 1009 clasts measured by hand of all of the paleo-boulders. Data shows that a majority of clasts in paleo-boulders are $\leq 20cm^2$, with most clasts (218) being between 5-10$cm^2$. Very large clasts ≥ 100cm occur less frequently and are not representative of the general clast size found in the paleo-boulders even though they have a significant impact on clast-matrix ratios due to their size.*

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