Analysis of Dune Morphology and Wind Regime in Mesquite Dunes, Death Valley, California

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1 Introduction

Climatic changes played a major role in the formation of the Mesquite Dunes. The late Quaternary time saw numerous arid and humid cycles occurring in the North American Arid zone [1], largely caused by climatic changes associated with the presence of ice sheets and the resulting changes in atmospheric circulation patterns [2]. The presence of alpine glaciers in the Sierra Nevada Mountains resulted in a high pressure cell, which caused the Owens river to become augmented with discharge from these alpine glaciers [3]. It then overflowed into a succession of closed basins. This created Lake Manly, which inundated Death Valley during the late Pleistocene [4]. Analysis of shore terraces performed by Eliot Blackwelder indicate that Lake Manly rose to about 94m above sea level [5], which coupled with atmospheric conditions was conducive for increased humidity [6]. These changes gave rise to a steep atmospheric pressure gradient between glaciated areas and warmer areas, which increased aeolian activity and led to the construction of many sand dunes including the Mesquite dunes [7].

While there is much literature available detailing the origins of the Mesquite dunes, little has been published about the conditions that make the dune field look the way it does today. Our research addresses the impact of recent aeolian activity on the Mesquite dunes, and aims to determine whether the morphology of the dunes, and the trends in the sand grains found across the dune field, reflect the recent regional wind regime.

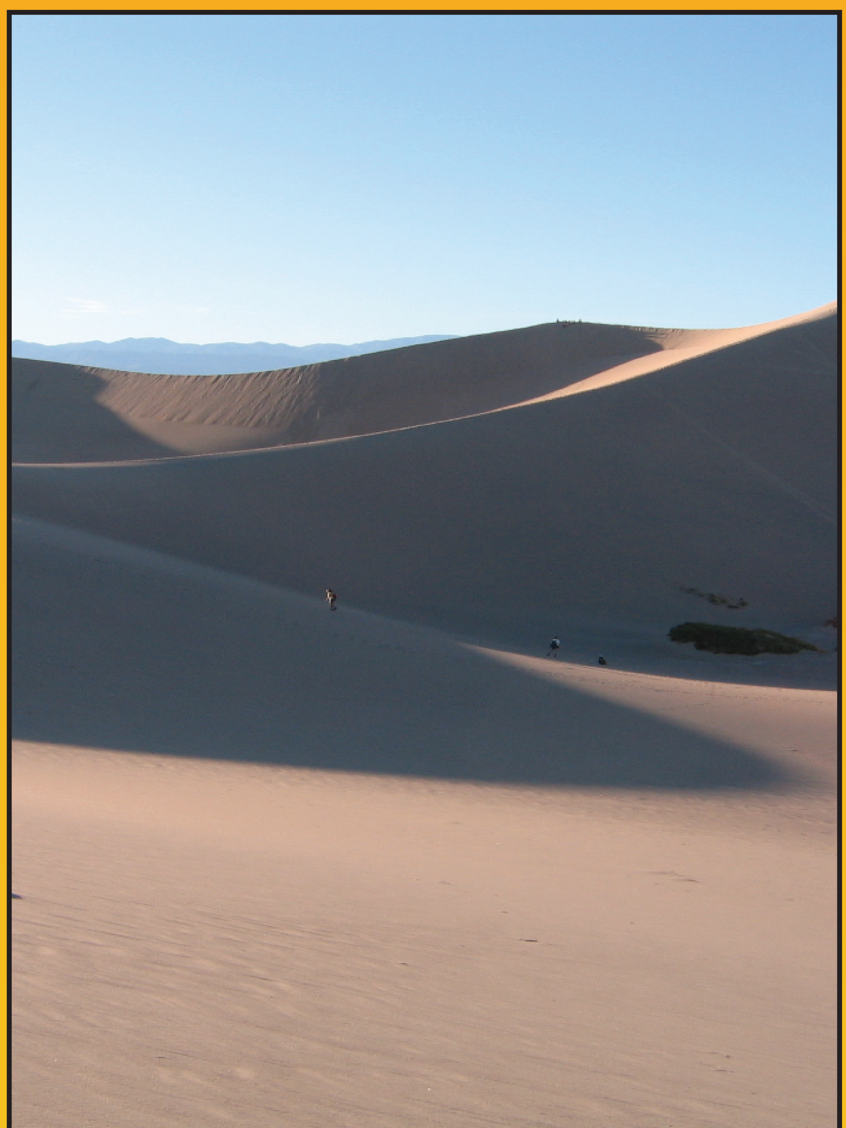

Figure 1: Photograph showing overview of Mesquite Dunes.

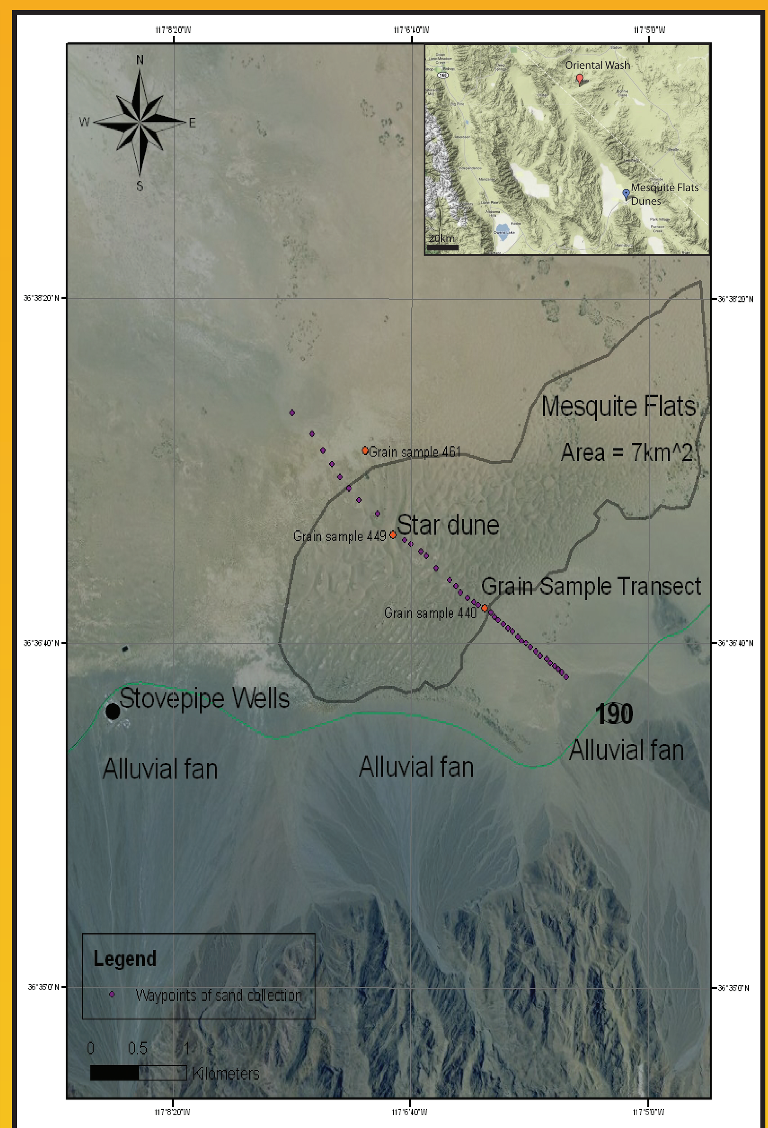

Figure 2:
Diagram showing the dune field in which our data was collected. Area of the dune field = 7km2. The purple dots show the GPS waypoints at which sand samples were collected (refer to Methods and Results). The orange dots show the GPS waypoints that Figure 7, 8, and 9 refer to.

2 Questions

Do the dune field pattern and the grain sizes of the sand along the transect reflect the regional wind regime? To what extent are morphological parameters such as dune height and dip direction affected by wind regime? Where does the sediment that makes up the Mesquite Dunes come from? Has the regional wind regime varied over the last decade, and if so, in what way? Does the collected data reflect a clear relationship between wind direction and dip direction, grain size, and dune height? What does this relationship tell us about the formation of the dunes?

3 Hypothesis

We think that the dip directions of the dunes and the grain sizes of the sand along the transect reflect the recent regional wind regime. We believe that the data we collect will not show a strong correlation between wind direction and dip direction, because the nearest weather station with available data is located about 77 km from the dune field, and the wind regime may be influenced by the northeast-trending mountains surrounding the weather station. We also believe there is a correlation between wind regime and dune size.

Acknowledgements

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Bibliography
[1] Tchakerian & Lancaster, 2002
[2] Tchakerian & Lancaster, 2002
[3] Tchakerian & Lancaster, 2002
[4] Tchakerian & Lancaster, 2002
[5] Blackwelder, 1933
[6] Tchakerian & Lancaster, 2002
[7] Tchakerian, 1994
[8] http://www.met.utah.edu/cgi-bin/droman/mesomap.cgi.
[9] Sharp & Glazner, 1997

4 Methods

Dip Directions

Five teams were each assigned a specific "square" in the dune field, with the squares covering a SE-NW transect. Within their squares, each team walked along the crest lines of the dunes, measuring dip directions orthogonal to the dune crests with compasses. Dip direction measurements were taken for each process observed on the dune: SWR, CGF, CWR, LWR, and FWR. GPS waypoints were recorded for each measurement. Rose diagrams were plotted for each "square" using MATLAB scripts and compared to wind data from the Oriental Wash weather station to determine the relationship.

Wind Directions

Thirteen years of wind data were taken from the Oriental Wash weather station [8]. This weather station is located on the border between California and Nevada, and wind data is taken at a time resolution of 1 hour. A year of wind data (Dec 2008-Nov 2009) was also collected from the Beatty weather station, which records data at a time resolution of 10 minutes, to determine the wind direction in the region around the Mesquite dunes.

Grain Analysis

A separate team walked along an SE-NW transect across the dune field, stopping slightly past the highest star dune. Sand samples were collected every ~50m in a plastic bag and labeled. GPS waypoints were recorded at each collection point. The sand samples were later put through a camsizer to measure grain size. Histograms were drawn to determine how sand size varies across the transect, which would then help us conclude which direction the dominant winds come from. A stereo-microscope was used to identify, photograph and describe grain samples from each sampling location, to determine whether all the sand across the transect comes from the same source(s).

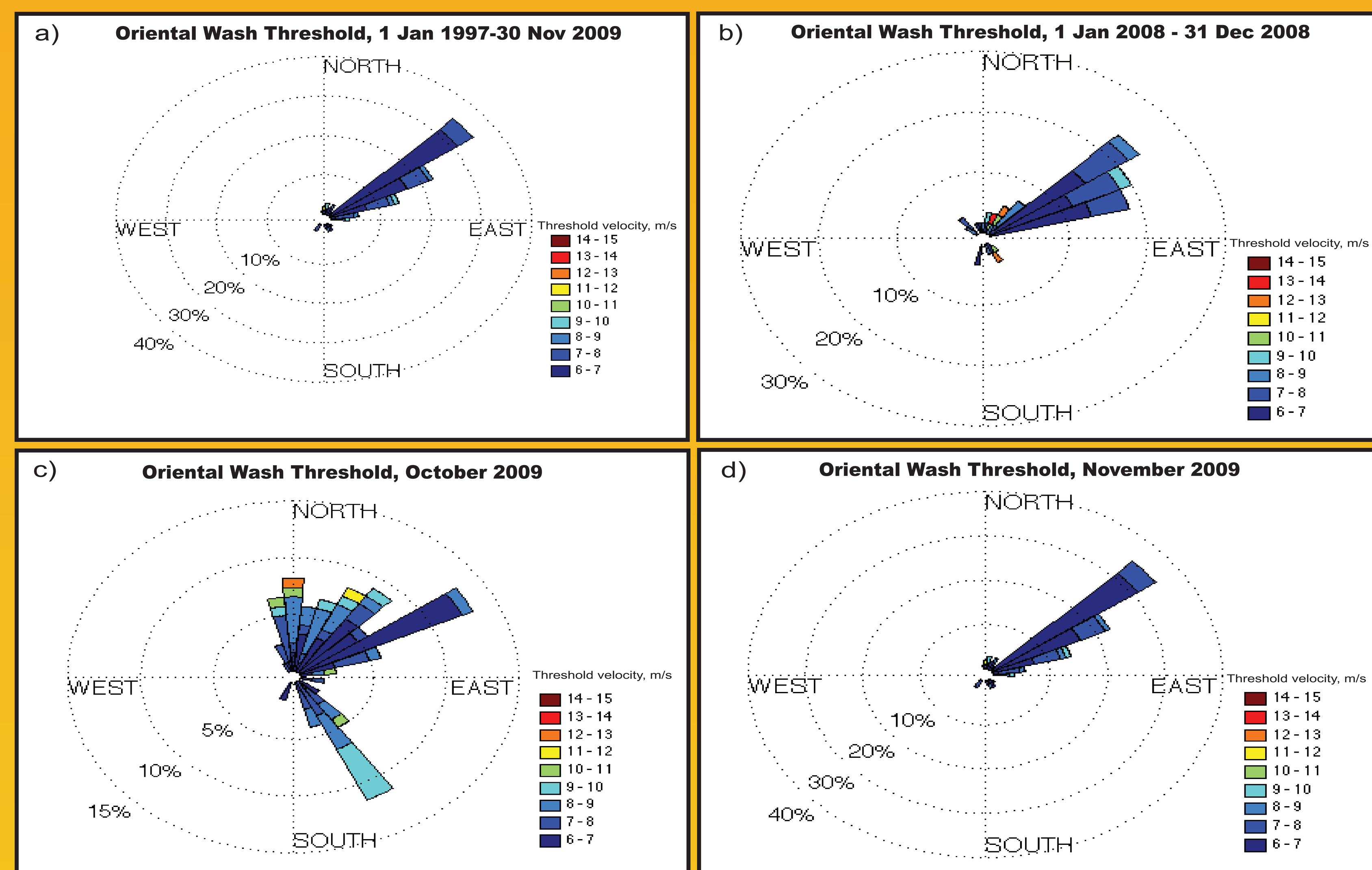

Figure 3: Rose diagrams showing wind directions and speeds for a) years 1997-2009, b) year 2008, c) October 2009, and d) November 2009. Winds are predominantly blowing from the northeast. Only winds above the threshold frequency are taken into account.

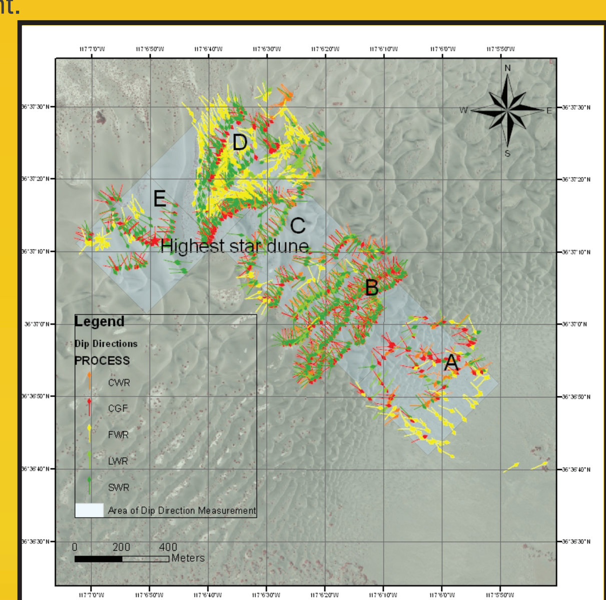

Figure 4: Map showing dip directions taken in squares 1-5, represented by arrows. Note that dip directions are predominantly oriented towards the southeast.

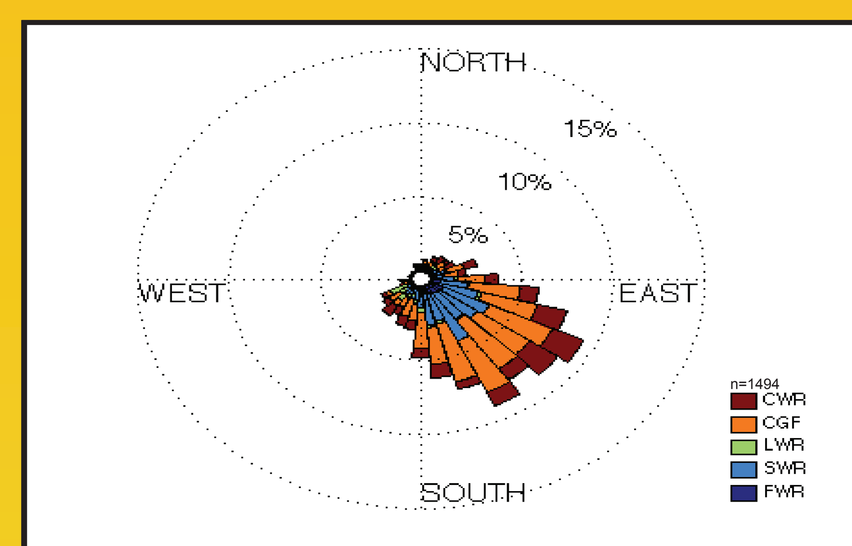

Figure 5: Rose diagram showing cumulative dip directions for squares 1-5. Wind ripples are predominantly oriented towards the southeast. Note that this does not correlate well with the wind data. However, it matches claims from other sources such as Sharp and Glazer, who suggest that winds blowing from the northwest or southeast

5 Useful Definitions

Stoss Wind Ripple (SWR): Orientation of wind ripples on stoss side of the dune
Lee Wind Ripple (LWR): Orientation of wind ripples on lee side of the dune (if they exist)
Crest Grain Flow (CGF): Orientation of crest if the lee side has grain flow
Crest Wind Ripple (CWR): Orientation of crest if the lee side has wind ripples
Flat Wind Ripple (FWR): Orientation of ripples in the flat areas in between the dunes
Threshold Wind Speed: Minimum wind velocity needed to transport sand grains

6 Results

Dip directions

The rose diagrams show a definite trend in the dip directions of dunes towards the southeast. This does not show a significant correlation with the historical wind data. However, this matches claims about wind direction from other sources such as Sharp and Glazner, who suggest that winds blowing from the northwest or southeast predominate [9].

Wind directions

The rose diagrams show that winds from the northeast predominate. This does not show a significant correlation with the collected dip direction data. This could be because the nearest weather station with available data is located about 30km from the dune field, and the northeast-trending mountains around the weather station may influence the wind regime of the surrounding area.

Grain analysis

The sands in the Mesquite dunes have the same mineral content across the transect. Grain size increases from the southeast to the northwest, and is highest at the tallest star dune.

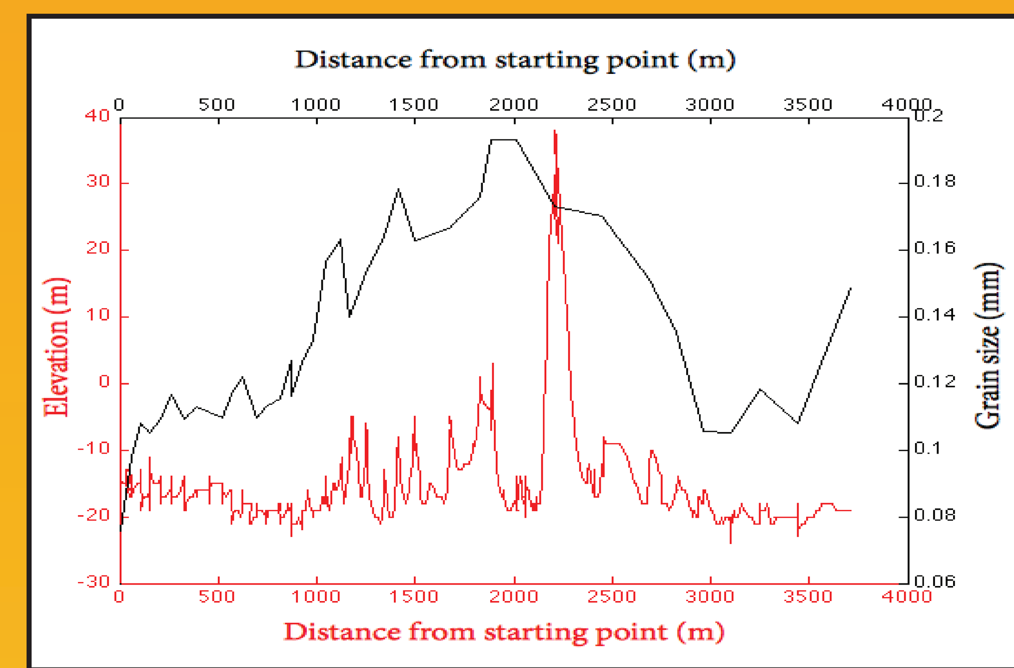

Figure 6: Graph showing relationship between dune height and grain size along the transect. There appears to be a correlation between dune height and grain size. Note that grain size increases significantly at the highest dunes.

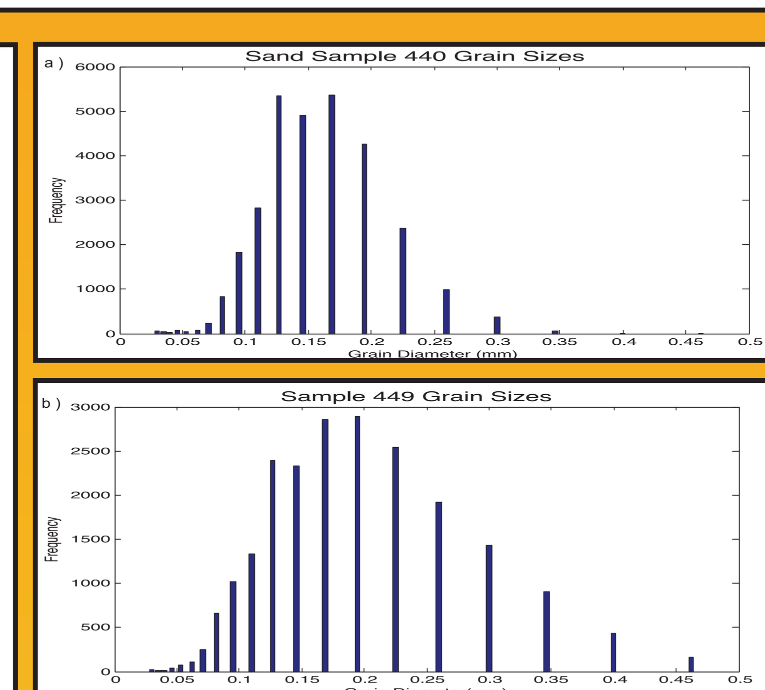

Figure 7:
Histograms showing measured grain sizes at a) the beginning of the transect (southeast of the dune field) and b) the highest star dune (refer to Figure 2). Grain sizes at the beginning of the transect (a) are the smallest, with a high frequency of grains of 0.125-0.175mm diameter, while grain sizes at the highest star dune (b) are the largest, with a high frequency of grains of about 0.2mm diameter. This shows a possible correlation between grain size and elevation.

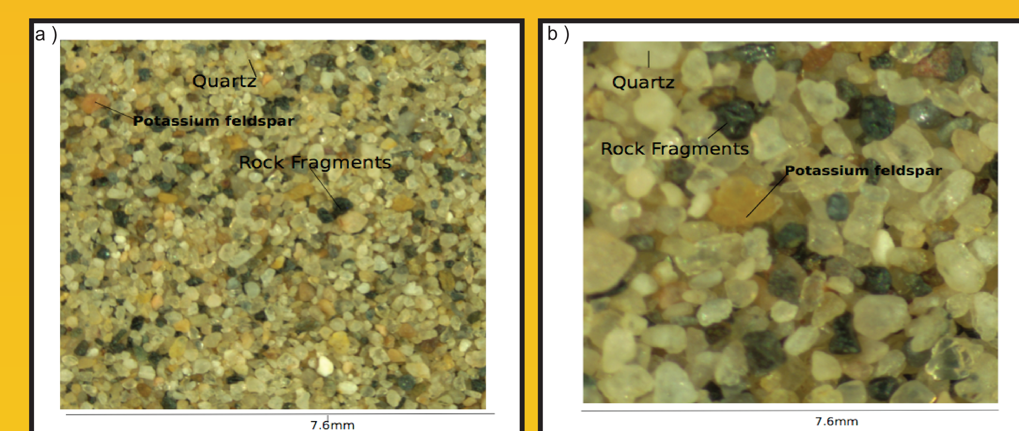

Figure 8:
Stereo-microscope images at 2x zoom of a) sand sample 440 (taken at the beginning of the transect) and b) sand sample 449 (taken at the highest star dune) - refer to Figure 2. Note the difference in grain size between the two samples. Sand sample 449 has noticeably larger grains than sand sample 440, which shows a possible correlation between grain size and elevation. Mineral content in both grain samples, and in grain samples across the transect, is the same – quartz, potassium feldspar, and rock fragments. This shows that the sands across the dune field are likely to have come from the same source(s).

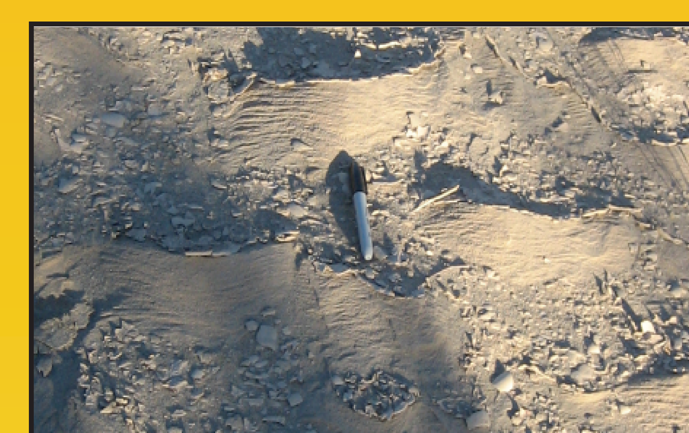

Figure 9: Photograph showing cemented dune cross- stratification (taken at grain sample 461 waypoint shown in Figure 2), or preserved dunes that are not affected by recent wind events. The lee sides are oriented towards the southeast, which shows that a southeast trending wind dominated at the time of their formation and cementation. Pen (for scale) is orientated in the same direction as the cemented dunes. This shows us that the observed trends in dip direction (towards the southeast) and the wind regime predicted to form the current dunes as a results of these trends existed before the last large wind event at this particular area of the dune field.

7 Discussion

The dip direction data demonstrates that the dominant winds of the last large transport event in this area were southeast-bound. However, wind data from the closest weather station (Oriental Wash) as shown by the wind-rose diagrams in Figure 3 suggest a southwest-bound wind is dominant. This difference can be attributed to differences in the surrounding topographies of the weather station and the dune field. The weather station has a northeast-trending mountain range on either side, which may cause the wind in this area to be funneled in the southwest direction. This explains the disparity between dip-directions in the dune field and wind-rose diagrams from Oriental Wash. Additionally, the mountain ranges surrounding the dune field are oriented in a manner that, if the mountain topography does influence the regional winds, explains the southeastern trend in dip-direction shown in Figure 5 and in the overall dune field morphology. The decrease in grain size from the northwest to the southeast corners of the dune field also suggests that the most prominent winds come from the Northwest. This matches the dip direction data. Because the tallest star dune has a greater height (~40m) relative to the other dunes and is at the northwest corner of the dune field, there appears to be a correlation between dune height and the size of the grains that make up the dunes. This is demonstrated in figures 6, 7 and 8, which show that the larger grains correspond to the highest dunes. In future studies, sediment samples should be gathered from the surrounding alluvial fans and compared to the sand samples in order to determine the origin(s) of the sand in the field. This information would be valuable in validating whether the wind regime is indeed the primary cause of spatial grain sorting which may affect the variation in dune height or if differences in proximity to the main source of the sand also play a role. Additionally, if a weather station were placed in closer proximity to the field and in the same valley, the wind data gathered could be compared to that of the Oriental Wash station to either validate or prove false the hypothesis that surrounding topography causes differences in the wind regimes of the dune field and the Oriental Wash station. All these data will be useful in furthering our understanding of the creation and evolution of the Mesquite dunes.