Determining the relationship between rock colour and the type of physical weathering on desert pavements in arid landscapes, Ras Al Khaimah, UAE.

Swift, O.J.H.
3rd year student, Geography and Anthropology Department, Oxford Brookes University, Oxford.

Abstract

Despite opposition to the theory that diurnal heat fluxes within desert rocks cause enough internal stress to form cracks on clasts leading to the break down of the desert material, this study provides further evidence that this is a credible process in physical weathering. The investigation set out to discover if the colour of a clast determines the likelihood that a clast will experience meridional cracking, as opposed to longitudinal, surface parallel and fabric related cracks near Ras-Al-Khaimah, in the United Arab Emirates. The results did not reveal a relationship that was significant in a Chi-squared Test. The results yielded significant evidence that no specific weathering process would occur on a clast due to its colour. However, the results indicated tensile stresses in the clasts' interior, which contributes to rapid breakdown and to the formation of desert pavement. The majority of the cracks' orientations lie closer to the east-west bearing than north-south. This information suggests a new theory for meridiornal cracking although local conditions, such as the geographic location of the Musandam Mountains could explain the results in this instance. Rose diagrams present the evidence found in these proximities. This method enables easy visual analysis for both comparison with McFadden et al's (2005) data and other such sources and also for the different classes in this study.

Keywords: United Arab Emirates, physical weathering, meridional cracks, desert pavement, rose diagrams, chi-squared.

Introduction

Physical weathering is the mechanical breakdown of exposed rocks on the earth's surface to form smaller clasts which still have the same chemical makeup as the parent material (Park 2003), hence, physical weathering is only a physical change. There are three main types of physical weathering; freeze thaw, salt weathering and thermal cracking (Holden, 2005). Thermal cracking is the dominant process of desert pavement formation Ras-Al-Khaimah, United Arab Emirates. Thermal cracking is an important process and coupled with chemical weathering the material formed produces regolith, colluvium, sediment and soils. In arid and semi arid areas the breakdown of large rocks is a key role in the formation of desert pavement (McFadden *et al*., 1987). Thermal cracking is a common process in arid regions where a diurnal temperature range of around 50^{o}C produces the expansion and contraction at the centre of the rock to create a large enough stress to form the crack (Park, 2003). This study does address thermal conductivity of rocks, but there is such a variation in differing rocks that without samples being arranged into groups defined by Clauser and Huenges (1995) the task of explaining it would be made impossible. Thermal conductivity can vary by as much a single factor to three factors for any given rock type (Clauser and Huenges, 1995). This is due to changes in mineral content as well as physical and diagenetic factors (Clauser and Huenges, 1995). Although complex factors control this property, the theory behind it is still a simple process. At midday, when the tendency for the outer shell of the clast to expand is greatest relative to its cooler interior, internal tension will be at its greatest, and the vertical cracks will initiate in the interior of the clast and migrate to the surface (McFadden et al, 2005).

In a previous study by McFadden *et. al.* (2005) it was revealed that there are four main types of cracks found in this environment: longitudinal, surface parallel, fabric related and meridional. The first three of these are related to the clast shape and rock fabric, however meridional cracks are orientated roughly along a north south bearing and are believed to be a result of the solar radiation on the clast during the day; and as the sun's position changes the tensile stresses in the interior cause this phenomenon to occur (McFadden et. al. 2005). Since 1927 there has been some debate about the ability of thermal stresses to produce thermal cracks in rocks (Griggs, 1936; Ollier, 1963; Twidale, 1968) and this debate is continuing.

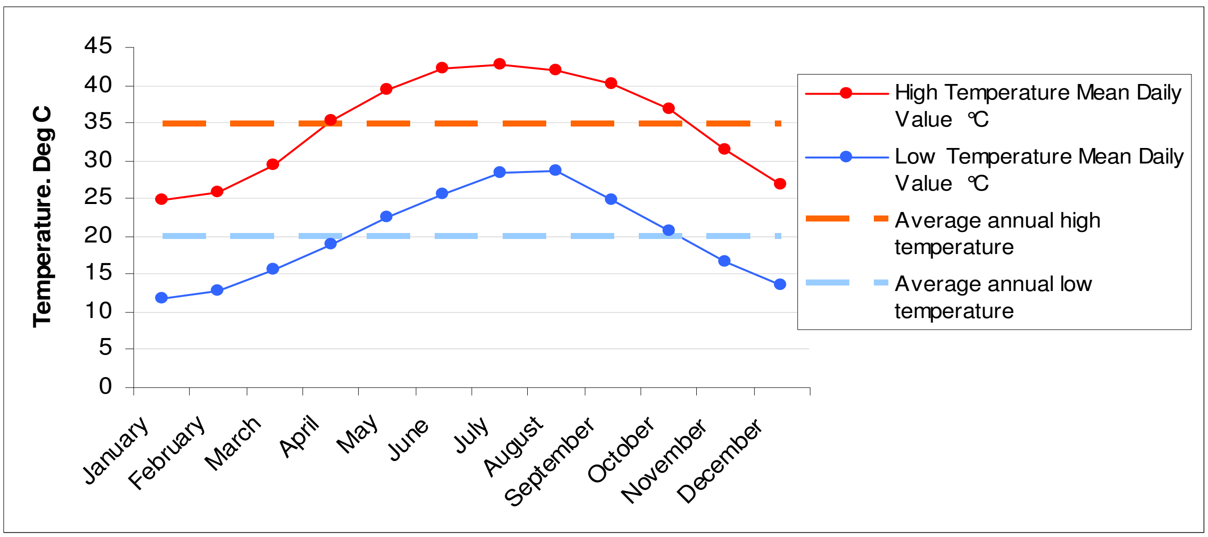
This study was carried out in the United Arab Emirates near the town of Ras al Khaimah. Figure 1 shows the average temperatures and rainfall in the town and figure 2 shows the location of all three sites used. Note that two transects were taken at Site 1 and at Sites 2 and 3 only one transect was taken. This was due to time limitations that were experienced in the field and the belief that enough data could be obtained with only the one. Table 1 provides the precise location and altitudes for all the sites.

Study area

The deposits that make the alluvial terraces and desert pavement are thought to be a product of the breakdown of alluvial deposits left during the peak of the Eemian interglacial 125,000 years BP (Al-Farraj and Harvey, 2000). The desert pavement at the three sites consists of sub-rounded clasts ranging in size from 5cm by 6cm to 100cm by 150cm with a varied geology; however, the majority of material is seen to be a light grey limestone originating from the tectonic uplift of the Musandam on the Oman UAE border. Figure 2a). The breakdown of the material on the desert floor, and consequently the formation of the desert pavement is a slow process requiring tens of thousands of years to fully develop (Pelletier *et al.,* 2007).

Three age-related groups of fans and terraces have been identified and mapped on the basis of their morphostratigraphic relationships within this wadi system. Deposition of the oldest terrace sediments and associated fans followed a long period of sustained incision after Miocene uplift of the region. (Al-Farraj and Harvey, 2000.) The oldest terrace is estimated to date from sometime prior to ca. 100 ka BP, the second terrace and the most extensive fan surface from the Late Pleistocene, and the youngest terrace and fan phase from the Latest Pleistocene or Early Holocene. (Al-Farraj and Harvey, 2000.)

The aim for this study was to compare the relationship of the orientation of the crack with the colour of the clast and determine whether there is a strong enough correlation to say that clast colour is correlated with a certain crack type. The theory behind this is that a clast with a low albedo will allow sufficient heating for a meridional crack where another more reflective clast will not be subjected to the same heat fluctuation and therefore the same stresses and will breakdown in another manner (McFadden et. al. 2005). If there is no apparent relationship between clast colour and crack orientation then the process occurs regardless of colour and the determining factor of the crack type is due to the rock fabric or size or mineralogy or another factor altogether.



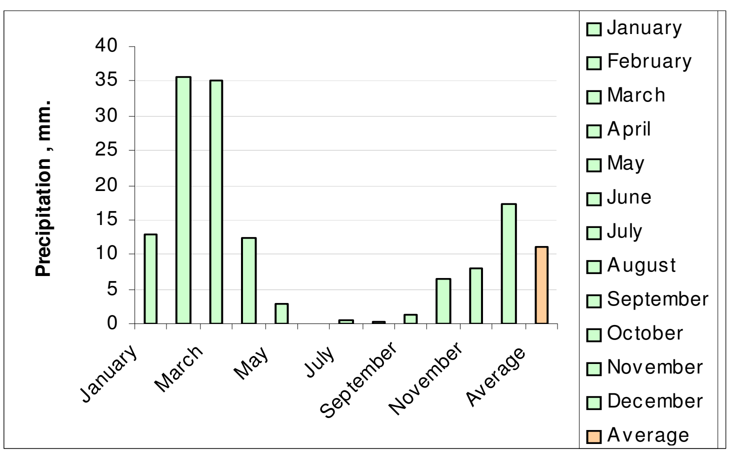


Figure1. Average annual daytime temperature in ^{o}C and precipitation measured in mm. in Ras-Al-Khaimah.
Latitude: 25 ^{o}37’N
Longitude: 055^{o}56’E
Elevation: 31m
Station: UE51184.

Source: Author, after climate-charts.com 24/10/07

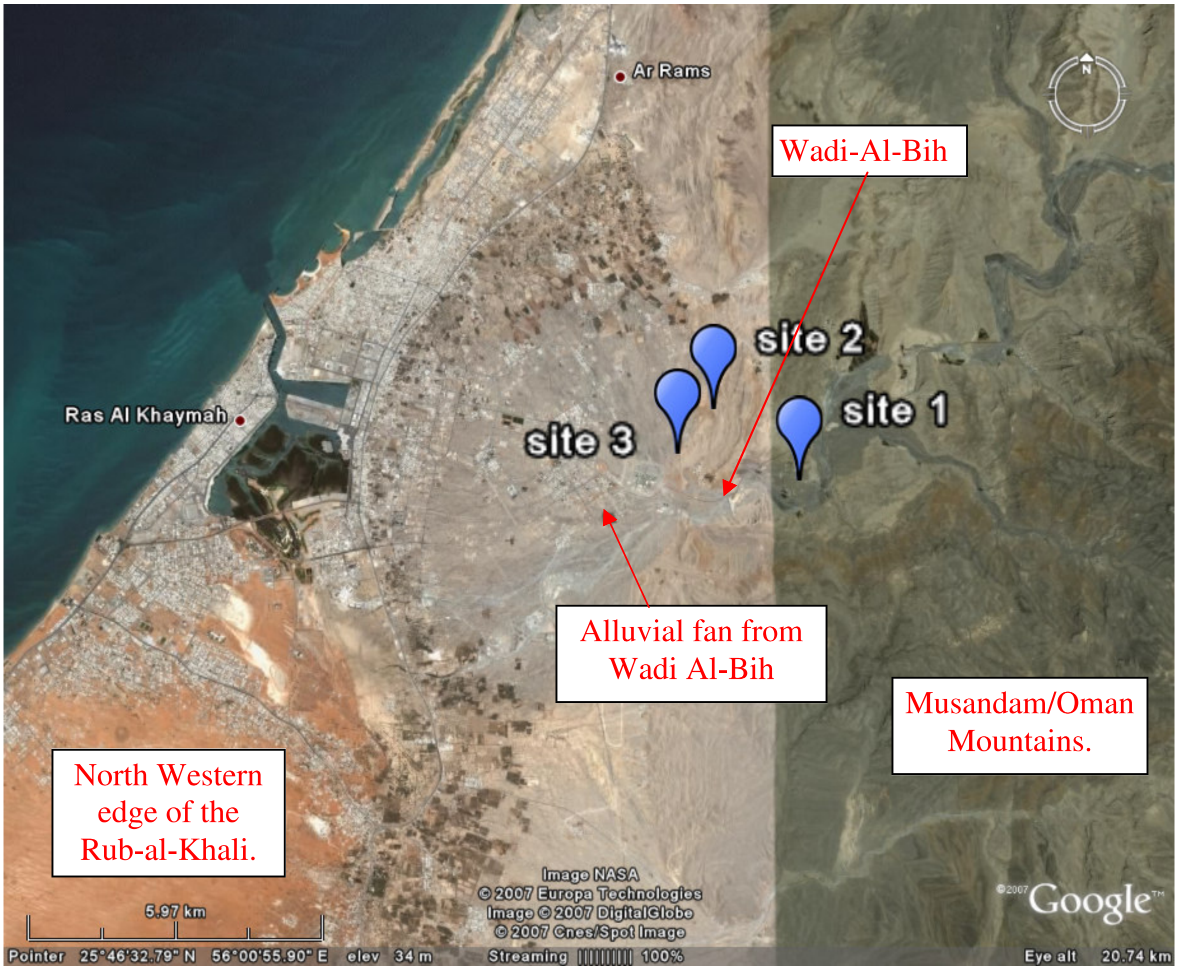


Figure 2a). Annotated satellite photographs of Ras-Al-Khamiah with the location of all three sites illustrated by blue pointers. Google Earth.

2b). The north eastern tip of the Arabian Peninsular. Google Images.

Table 1. Table of the grid references and altitudes of the study sites in the UAE.

Site	Grid reference	Altitude a. s. l.
Site 1	25^{o}46’89.9” N 056^{o} 03’86.4” E	96m
Site 2	25^{o}46’54.09” N 056^{o}01’59.84” E	57m
Site 3	25^{o}47’22.65” N 056^{o}02’26.83” E	39m

This investigation is insignificant because it is the first process of the rock cycle and the formation of desert soils. To understand the mechanisms going on behind the process will provide a better understanding of the ways in which the different geographical processes interlink with one and other.

Methods

Site selection

The sites that the data were obtained from were selected on the strength of five main criteria. It was crucial that at each location there must have been an abundance of weathered material showing cracks. It was imperative that the clasts were in constant sunlight during the day. There was a scattering of acacia trees in Wadi-Al-Bih so when locating a transect for site 1 it was made sure that none of the transect was under any of the trees’ shadows during the day. The two transects ideally needed to be on a flat ground. This was required for two reasons: the first being that being on a slope would mean that the distribution of solar radiation intensity would be affected; any slope facing the sun would be subjected to a more concentrated dose of radiation, and conversely any slope facing away from the sun would reduce its surface area facing the sun and there would be less radiation directed at a specific point.

The second reason for a flat and level sample area is that these locations tended to be further away from any large mountains which would cast shadows upon the wadi floor and the Shimal plain during the morning.

In order to obtain the orientation of the crack only clasts that were lodged firmly in the ground were measured. This gave us the clear indication that the clast has been there for a period of time and that no recent disturbance had altered its position.

There were three possible ways that a clast could have been disturbed: human activity such as vehicles, walking and industrial processes. Animals grazing and scratching on the ground were a possibility for disruption as there were many goats grazing freely in the area. This was especially a concern in Sites 2 and 3. Site 1 seemed to be exempt from this as it was more remote and the goats did not seem to graze in that area.

The final concerns were natural processes. These might include weathering and the falling of rocks from the hills above and transportation via water due to a flood in Wadi-Al-Bih.

These all being considered, the transects at Site 1 were located on the higher terraces so that they avoided any active channels. Weathering on features on rocks such as Rillen Karren (tiny channels radiating from the centre/ highest point on the clast to the desert floor) and Taffoni (small rounded hollows within in the clasts surface) both formed by salt, shown in figure 3 and also vegetation abundance gave good indications that water had not flowed over this area. For health and safety purposes the final criterion that had to be met was that all sites had safe access for vehicles.

Figure 3. Examples of salt weathering on the clasts of the desert pavement. On the left, Rillen Karren and on the right, Taffoni.

The three sites

The three sites finally select are shown in figure 2a and their grid references are given in table 1. Site 1 was located in Wadi-Al-Bih upon a braided channel system. There was evidence of chemical weathering on a selection of the clasts so this provided enough evidence that the area was old enough for sampling. The chemical weathering that was encountered was taffoni weathering and carbonation weathering; both processes requiring a long periods and substantial weathering (French and Guilielmin, 2002). There was a varying degree of roundedness to the clasts at this site and also a mixture of colour clast, however light grey prevailed. Due to this site's mixed geology and the roundedness of the clast it was determined that it was based upon a gravel deposit.

Site 2 was located on the edge of the Shimal plain next to a radar site. The clast material was weathered limestone and this was the only type of rock at the site. The clasts seem to be weathered bedrock as there was much evidence of exposed bedrock in the area. This site has been subjected to the open environment for some time as there were a number of ghost rocks and examples of bread and butter weathering; as shown in photo D. in figure 4. The site itself was on the top of a small spur with a small gully system eroding around the base and there was an extensive gravel deposit backed up behind it - assumed to have been a feature of Wadi-Al-Bih.

Site 3 was located in between Wadi-Al-Bih and Site 2, it was situated next to the road on another smaller gravel deposit not dissimilar to the one found at Site 2. This meant that there was a varying amount of rock types - however, unlike site 2 all the clast seemed to be well rounded.

Data collection

The methodology of McFadden et al (2005) was as far as possible adopted for comparability. Three locations shown in figure 2 were found and transects of 30 metres were laid out at each. Not every rock was documented and a pragmatic sampling technique was adopted. At every metre mark on the tape the nearest clast to that point with a suitable crack was recorded. The colour of each clast was noted. To simplify the data-set five categories of colour were used: black, dark grey, light grey, white and red. The clasts' length and width of material above ground, the number of cracks, the orientation of the crack and the width of the crack were recorded. Four crack-widths were recorded: incipient (<0.1mm wide); thin (0.1-1mm); moderately wide (1-3mm) and large (>3mm). The orientation was obtained by using a standard Silva Ranger type 15 compass. Each crack was treated individually regardless of whether or not there was more that one to a clast, and orientation ($\pm 5^{o}$) was measured and noted.

A total of 250 clasts and 411 cracks were measured, 48 and 52 clasts at transects one and two at site one with 60 and 78 cracks respectively, 75 clasts at site two with 153 cracks and 75 clasts at site 3 with 120 cracks. Figure 4 shows examples of the clast, transects and data sampling techniques that were encountered and used.

Results

Results were recorded and analysed by plotting the number of cracks into rose diagrams as shown in figure 5. Rose diagrams were used as they provide a clear, visual representation of the orientation of the crack patterns. This also allows an average orientation to be plotted on the diagram. This average was calculated by multiplying the number of cracks within an orientation bracket of 15^{o} by the bracket degree, (15^{o}, 30^{o} all the way to 180^{o}.) These 12 values were all added together and then divided by the total number of cracks on the clast type at that site. This value in this study was termed the average crack orientation. It will be important to note that this mean average (red line) is different to the mode (green line) in figure 5. (Modal average is the figure with the most commonly occurring value (Watts and Halliwell, 1996)).

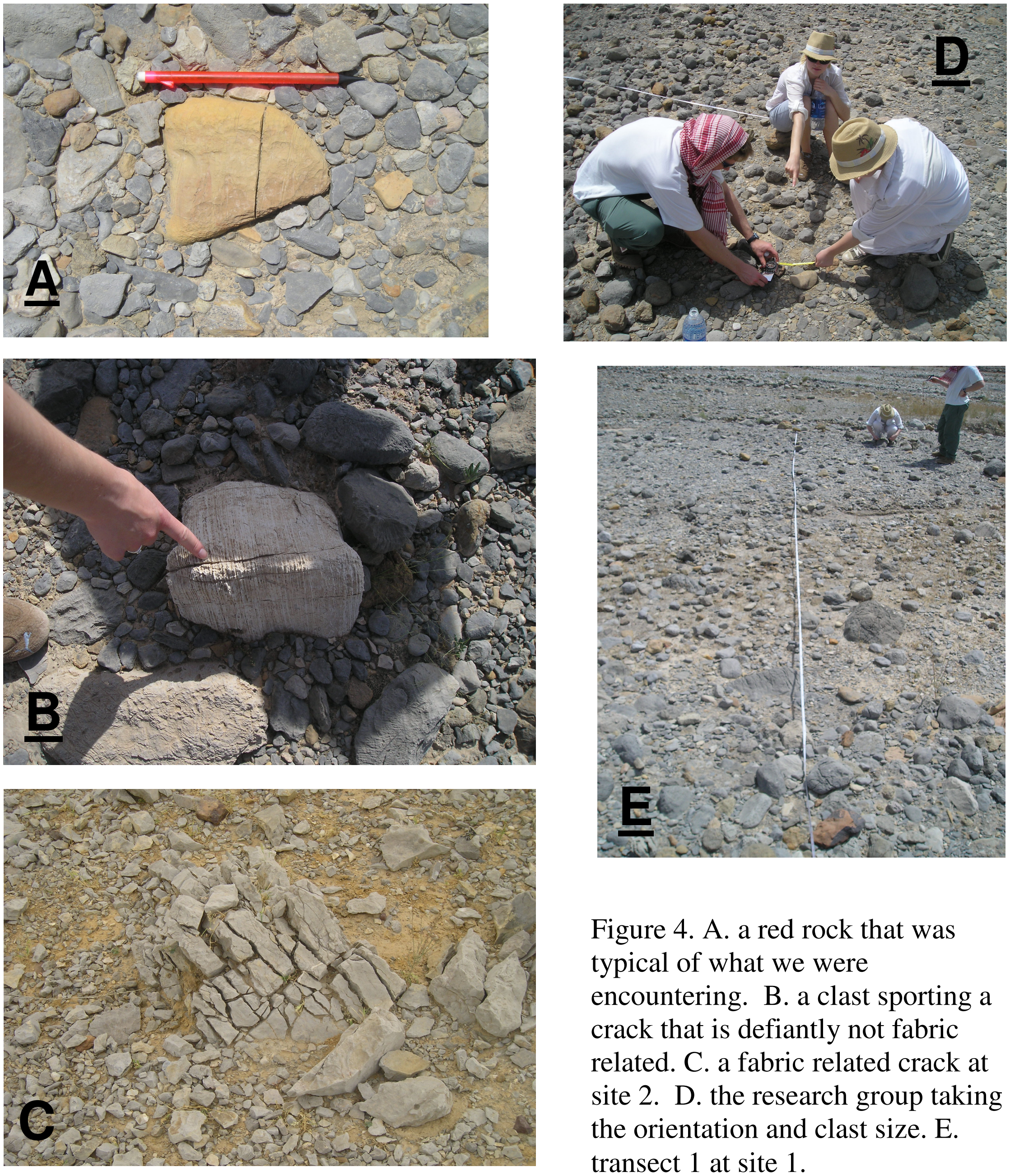


Figure 4. A. a red rock that was typical of what we were encountering. B. a clast sporting a crack that is defiantly not fabric related. C. a fabric related crack at site 2. D. the research group taking the orientation and clast size. E. transect 1 at site 1.

Figure 5 displays the orientation of the clast crack and the clast colour for all sites. All the averages fall within the range of 90^{o}-270^{o} to 120^{o}-315^{o}**.** Of all the results, all of the charts reflected this behaviour except for two examples, see figure 6. These were the dark grey clasts at Site 1 and the light grey clasts at Site 2, (the only clast type at this site.) At Site 2 the average orientation was found at 175.6^{o}**-**353.6^{o}**.** This was the kind of result that was expected to duplicate across the board in this study as that is what McFadden *et. al.* (2005) recorded.

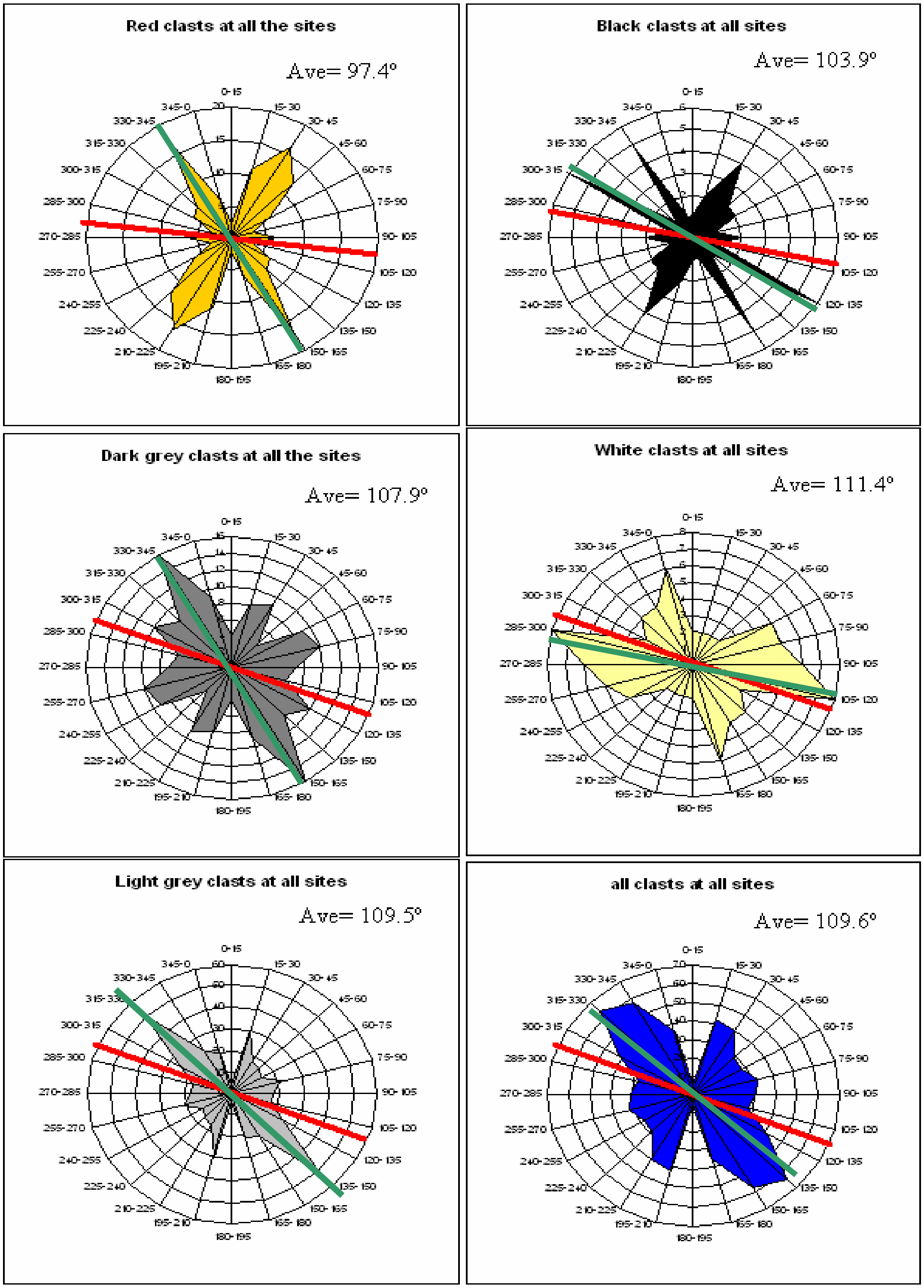


Figure 5. Radar diagrams showing the abundance of cracks in this study, the red line indicates the mean average orientation for that class and the green line shows the modal average.

These results indicate meridional cracks as McFadden *et al* (2005) defined them. The relationships between the average orientations in figure 5 are all so similar that it would be very unlikely that there was no significance.

To test the significance of the relationship between the red clasts and all the other clast a Chi-squared test was carried out. The relationship between the red clasts and the other groups was compared against McFadden et al's (2005) findings to test the hypothesis that a certain coloured clast will be more prone to a certain type of physical weathering than a clast with a higher or lower albedo. The Chi-squared test revealed that with the five degrees of freedom (being the five different clast colours) there was a 0.0005 level of significance. A value of 0.0005 is the expected value to occur by chance (Watts and Halliwell, 1996) for this particular type of test. This was calculated by comparing the results of this study with the conclusion of McFadden et al (2005).

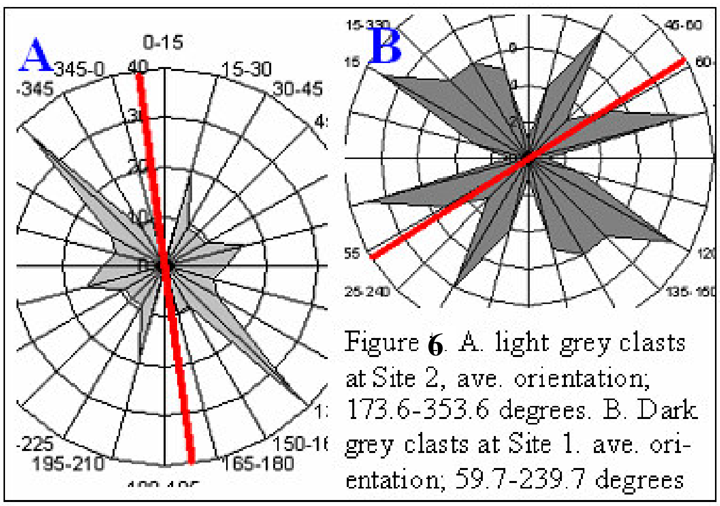


Figure 6. A. light grey clasts at Site 2, ave. orientation; 173.6-353.6 degrees. B. Dark grey clasts at Site 1. ave. orientation; 59.7-239.7 degrees

Discussion

The results in figure 6 are intriguing; this being because they would be easier to explain if they were to be the other way round. Site 2 was all weathered parent rock whereas Site 1 was predominantly gravel deposits. This would mean that if result B was found at Site 2 the varied orientation could have easily been put down to the parent bedrock and the rock fabric. This would mean that result A would have been the consequence of the clast colour allowing more rapid heating during the day time, the internal heat stresses would be acting earlier on in the day so the orientation would sway further to the east. However this is not true and there was a fair representation of dark grey clasts at onsite 1 so an argument cannot really be mounted that this is not a representative sample. By observing figure 6, B it is clear that the red line is only the average and the not the mode value. There are two modal averages for this sample and they lie at 90-270degrees and 135-315 degrees. Any area between these modes would happily lie on any other sites average orientation; it is therefore put that this individual data set could possibly be inconclusive. The fact that the area was a gravel deposit means that rock fabric could not have played a large role in the orientation as the clasts were deposited there in a random act. Figure 6 A's orientation is skewed towards the north significantly more that the rest of the results, this average is a text book example of a meridional crack however the mode average is clearly at 150-330 degrees which is more like the rest of the results that we are used to seeing in this study.

The comparison of mean and mode averages in these results is controversial. McFadden et al (2005) in their results found that 40% of the cracks in their study were orientated along the North South bearing and thus named meridional. However the mean has been calculated in this instance as there is such a strong relationship between all the clast types and there is also higher mathematical significance. The mode shall not be discounted all together in this study; this is because there are many cases where the most commonly occurring orientation is located north of the average. The red clast diagram in Figure 5 shows the average orientation dissecting the two modes of 150-345 degrees and 45-225degrees. Although the mode does lay on the bearing north west to south east the bulk of the results are orientated north east to south west. This therefore follows the characteristics of the majority of the results in other studies (McFadden et al 2005). However with the bulk of the results from this study facing another direction it is thought that these too are also meridional cracks however in these instances the rock is subjected to fast warming during the day due to its absorbent properties and some cracks follow that pattern. For this to be recognised as a accurate conclusion a further study needs to be carried out on the thermal conductivity of the rocks in question in order to see the rate at which they warm up and cool down.

With Figure 7 illustrating the average orientation for cracks in the whole study it is clear that the results taken at Ras-Al-Khaimah differ from those taken in the United States of America by McFadden et al (2005). The fact that there is a strong significance means that there must be a process happening to do with the environment and thermal stresses and not with the rock fabric must be at work. In hindsight it is a great shame that more of the rock fabric details were not collected. This would have allowed a clearer decision to be made on what the controlling factor might be in this process.

Following sunrise, when the clast is at its coolest the clast will then be heated throughout the day. The reason it is thought that these cracks face westward of north is that the temperatures in the area are still rising long after noon. This allows for further heating of the clast in to the afternoon and unlike McFadden's (2005) study where the cracks strike the north south line the cracks in this investigation swung anti clockwise. Another contributing factor to this variation is the positioning of the Musandam Mountains, this range is located directly to the east of the sites as shown in Figure 2, this obstacle would delay the time at which the sun first touches the wadi and plain floor, thus prolonging the cooling further. A further study would need to set up sun light monitors and calculate the precise time through out the year that the sun first touches the ground. From previous studies it can therefore be said that due to these local factors this pattern could be a localised phenomena. The rate and time of the heating is only half the issue in this study and one issue that seems have been over looked and not addressed is the rate of which the clast cool down during the diurnal heat flux. Wind patterns have not been looked at at all in this study however being this close to the coast it could make for an interesting study to investigate the impacts of localised winds for example katabatic winds and their effects of cooling during the evening.

The rate at which these cracks form seems to be geologically speaking relatively quick. This is thought to be the case as it was known that the site samples used in this study ranged over an unknown yet considerable period of time, however there is not variation between the relationship of crack type from transect to transect.

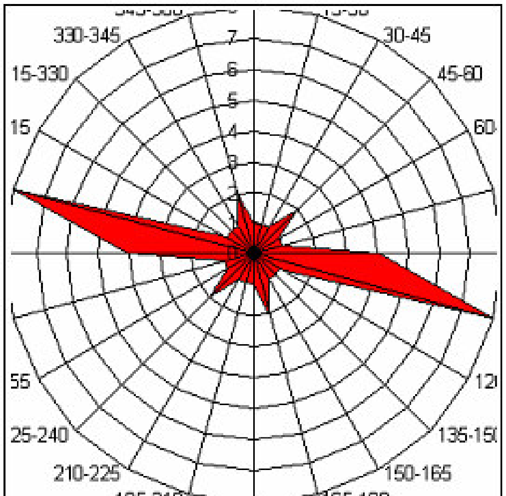


Figure 7. The average clast crack orientation for all sites in this study

Conclusion

With the absence of some local measurements such as specific sunrise and sunset times and clast fabric information the significances of the Chi-squared results suggest that colour does not determine the orientation of a crack.

Although the preferred north/south line was not replicated here the evidence does suggest that the results are due to some kind of diurnal thermal stress mechanism. From this study it has been shown that, in this area and its surrounding rock types, the clast colour does not affect the type of physical weathering. This means as there is no evidence from this study to say otherwise that the Null Hypothesis must be accepted to the effect that this event is random. Arguments placed in the discussion of this paper hint McFadden et al (2005) believe that midday is the hottest time of the day, when in fact it is later on in the afternoon. This means that meridional cracks should closely correspond to a 150° to 330° bearing. Also the variation of the crack orientation could possibly depend on the time and rate of heating as well as the time and rate of cooling of the clast over 24 hours.

The result of this study is that it is not possible to predict which weathering process is most likely to take place regardless of clast colour. Desert pavement should form at the same rate as another location on the earth so long as the climate and environmental conditions are the same.

References

- Al-Farraj, A., Harvey, A.M., (2000) Desert pavement characteristics on wadi terrace and alluvial fan surfaces: Wadi Al-Bih, U.A.E. and Oman. *Geomorphology.* V. 35 p.279-297.

- Clauser, C., Huenges, E., (1995) Thermal conductivity of rocks and minerals. *Rock physics and phase relations; a hand book of physical constraints.* P. 1.5-126.

- French, H.M., Guglielmin M. (2002) Observations on granite weathering phenomena, Mount Keinath, Northern Victoria Land, Antarctica. *Permafrost and Periglacial Processes.* V. 13 p. 231 – 236.

- Holden, J., (2005) *an Introduction to Physical Geography and the Environment*. Harlow, Pearson.

- McFadden, L.D., Wells, S.G., and Jercinovic, M.J., (1987) Influences of eolian and pedogenic processes on the evolution and origin of desert pavements: *Geology*, v. 15, p. 504–508.

- McFadden, L.D., Eppes, M.C., Gillespie, A.R., Hallet, B. (2005) Physical weathering in arid landscapes due to diurnal variation in the direction of solar heating. *Geological Society of America*. V.117, p. 161-173.

- Ollier, C.D., (1963) Insolation weathering: Examples from central Australia: *American Journal of Science*, v. 261, p. 376–418.

- Pelletier, J.D., Cline, M., DeLong, S.B., (2007) Desert pavement dynamics: numerical modelling and field-based calibration. *Earth Surface Processes and Landforms*. Published online. DOI; 10.1002/esp.1500

- Park C. (2003) *The Environment, Principles and Applications second edition*. London, Routledge.

- Twidale, C.R., (1968), *Geomorphology with special reference to Australia: Nelson*, Melbourne and Sydney, 406 p.

- Watt, S., Halliwell, L., (1996) *Essential Environmental Science Methods and Techniques.* Routledge, Abingdon.