INTERPRETATION OF GRANITE FLARE STRUCTURES IN THE CITY OF ROCKS NATIONAL RESERVE, IDAHO

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INTRODUCTION

Flare structures are concave features that form beneath the ground surface as part of a two-stage erosional process (fig. 1). The formation of such features is important when trying to understand the physical and chemical processes that take place within the vadose zone. Flare structures may also be important when trying to map past topography, as the crests of these features represent ground surface levels during formation (Twidale and Bourne 1998). Flares have been reported throughout the world, in a variety of geologic settings, but no widely published studies exist in the United States; this project represents one of the first detailed attempts, looking at flare structures occurring on granite rocks in The City of Rocks National Reserve, Cassia County, Idaho. This area lies within one of four structural domes that make up the metamorphic core complex of the Albion Range, and has an exposed core of 29 Ma Oligocene granite intruding 2.5 Ga gneiss (Armstrong 1968). The primary goal of this study is to quantify the geometry and distribution of flare structures with regard to the processes responsible for their formation. The results will then be compared to what has been observed previously in other studies.

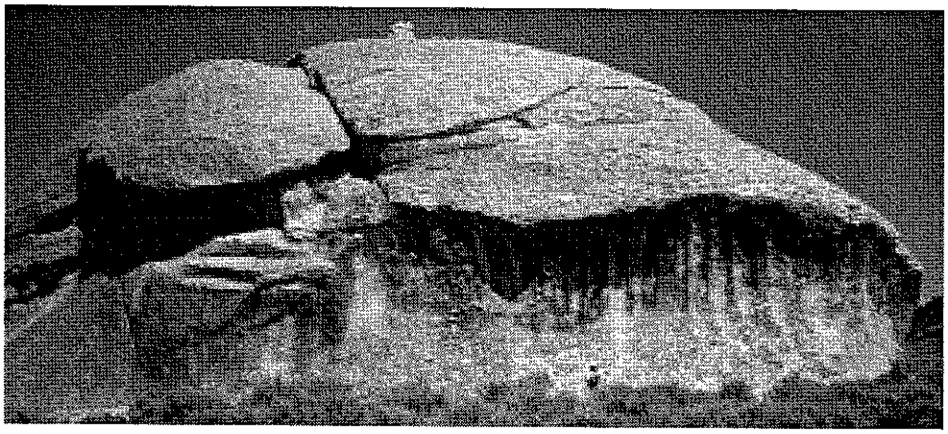

Figure 1: Kaiser's Helmet. Picture is taken from a distance of 100 feet. The concavity on the front of the rock is the flare structure. Faculty Sponsor shown at the base of the flare is for scale.

PREVIOUS STUDIES

First noted in 1941 by Hellström, the first analytical studies of flare structures were conducted by C.R. Twidale in the late 1950s and 60s. According to Twidale and Bourne (1975; 1998) flare structures occur in limestone, sandstone, dacite, rhyolite, and basalt, but are most commonly seen in granite. Each flare represents a period of subsurface weathering followed by one of erosion and exposure. The concave form of the flare is due, in part, to water table fluctuations, which lead to the most efficient weathering occurring centimeters to meters below the surface. Optimal formation conditions for flare structures would allow sufficient time for subsurface weathering to occur, followed by sufficient erosion to expose the feature; therefore, flare structures are best formed in tectonically stable areas. In tectonically active areas, such as the southwestern United States, the rates of erosion and exposure tend to be relatively rapid, resulting in small flares. This effect is sometimes negated in areas where the rock is highly susceptible to weathering, such as the rhyolitic tuff in Grant County, New Mexico (Twidale and Bourne 1975; 1998).

The most important factor in flare formation is the weathering agent itself: groundwater. The most developed flares are found in arid or semi-arid environments, where alkaline groundwaters come in contact with acidic rocks such as quartzite and granite. Proximity to paleochannels is important to flare formation for two reasons: one, availability of subsurface moisture; and two, associated erosion and exposure (Twidale and Bourne 1998).

GRANITIC WEATHERING

The principal component of flare development is subsurface weathering, which occurs as a series of chemical reactions resulting from the contact of groundwater with the host rock. The type of reaction is dependant upon the pH of the soil solution, the climate, and the mineralogy of the rock. Different minerals have varying degrees of susceptibility to weathering by groundwater, and that is what determines their leach rates. Generally, the lower the pH of a solution the higher the leach rate for a given mineral. The average pH of a typical soil solution is between 4 and 5. At room temperature and pressure and a pH less than 6, quartz has a leach rate of 0.60 – 0.06 mg/m^{2}yr. This is considerably less than the leach rates for potassium feldspar and plagioclase, which at a pH of 5 and under the same temperature and pressure have rates of 13.17 – 285.30 mg/m^{2}yr and 22.15 - 30.70 mg/m^{2}yr* respectively (Nesbitt et al. 1997).

Once a state of saturation for a given mineral is reached, that mineral stops dissolving. Quartz reaches a state of saturation when 6 mg/L SiO_2 (aq) is present in solution. Most ground and river waters are already saturated with respect to quartz, with rivers containing roughly 10 mg/L SiO_2 (aq). Therefore most natural waters will not dissolve quartz, which explains its abundance in sedimentary environments. Natural waters seldom achieve saturation with respect to plagioclase, and waters with a pH of 7 or less are generally undersaturated with respect to potassium feldspar. Groundwater studies and weathering simulations have shown that potassium feldspar generally reaches a state of saturation before plagioclase. Therefore, plagioclase is the most rapidly weathered mineral constituent of granite, followed by potassium feldspar and mafic trace minerals such as biotite and hornblende (Nesbitt et al. 1997).

DATA AQUISITION

Direct measurements of height, bench level, bench dip, aspect, lateral extent, scoop depth, and slope of the ground surface away from the feature were recorded for forty flares throughout the City of Rocks and neighboring Castle Rocks (fig. 2 and 3). The aspect was the most important measurement taken at each site. Perpendicular to the strike and at the center of each flare, it represents the side of the rock on which the feature formed. The bench corresponds to the subhorizontal plane connecting the bottom of the scoop with the unweathered bedrock below, and is defined by angles less than or equal to 45 degrees. In cases where the crest of the flare was variable, maximum and minimum values were recorded for the height. Sketches were made of each flare, and slides were taken from both 100 feet out from the center point and along one of the sides to depict the concavity. In some cases, the ground surface was eroded below the base of the bench, exposing rock below the flare structure. Where this was observed, the height of the flare off the ground was recorded. Other observations were also made at each site, such as amount of overhang, flaking of scoop surface, presence of duricrust (case hardening), and presence of scallops, jointing, and stream proximity.

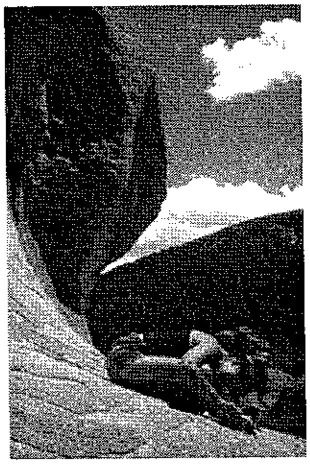

Figure 2: Measuring the dip of the bench on the Curtis Durfee flare.

DATA INTERPRETATION

The flare structures were generally well defined, with a protruding crest, prominent scoop, and subhorizontal bench (fig. 3). Fifty percent of the flare structures had western aspects, with 35 percent being between 240 and 280 (fig. 4). The northern sides the rocks hosted the least number of flares with only 7.5 percent, while the southern and eastern sides showed 17.5 percent and 25 percent respectively. The majority of the flares were also located near the floor of the valley of Circle Creek, the main stream in the City of Rocks, where the slopes of the land surface tended to be gradual.

Most of the scoops within the flares showed pronounced flaking, and brushing the surface with a hand was enough to cause shedding. Many flares also showed duricrust formation above the crest, which may support the notion that these two features are related. There were also two flares that were interrupted by joints or dikes, and a few that had ribs running vertically throughout.

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* data modified from Nesbitt et al. (1997), leach rates originally in moles/m^{2}s.

Parameter	Min (m)	Max (m)	Mean (m)
height	0.43	7.6	1.8
lateral extent	0.85	24.4	6.7
bench level *	0.05	1.8	1.65
scoop depth **	0.07	1.3	0.52

*not all flares had visible benches
** four depths could not be measured due to height
off ground

Figure 3: Profile of flare structure with associated features

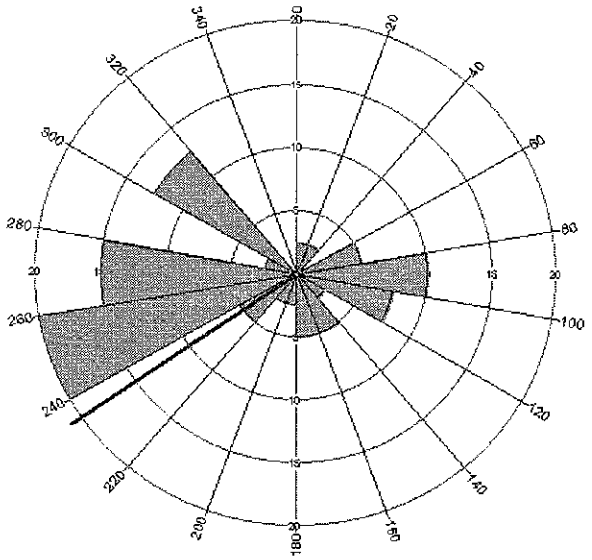

Figure 4a: Frequency distribution of aspects plotted at 20_ intervals. Line at 235 represents the mean.

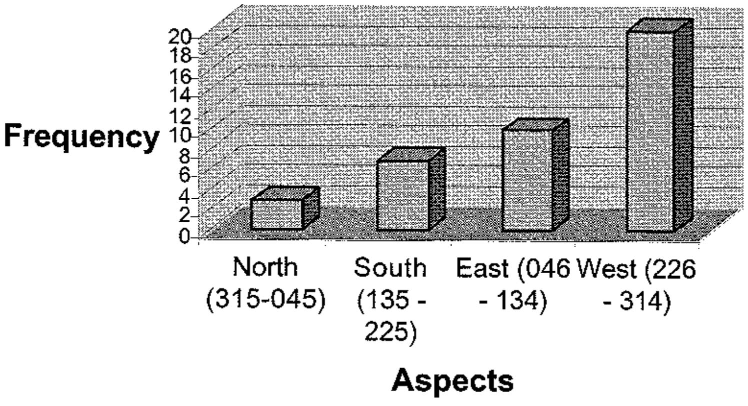

Figure 4b: Frequency chart of flare aspects.

DISCUSSION

Many small flares that were not fully exposed were observed in the City of Rocks. These flares provide support for the theory of subsurface formation, as the upper portion of the scoop is visible, but the remainder of the feature is still buried (fig. 5). Some of these forming flares, like many of the developed ones, showed flaking of the scoop surface, though it is not evident whether this came about during or after scoop formation. The crest represents the transition zone between the top of the scoop and the rest of the host rock; it also marks the ground surface level during scoop weathering and remains relatively unchanged throughout the process of formation. The bench corresponds to the transition zone between the bottom of the scoop and the fresh bedrock. The linearity of this feature represents the decrease in the rate of weathering from the vadose zone to the zone of saturation. Once the water table is reached, the relative rates of weathering would come to a standstill, as the water would already be saturated with respect to the granite minerals. Therefore, the most efficient weathering would occur within the vadose zone, resulting in the concave shape of the flare.

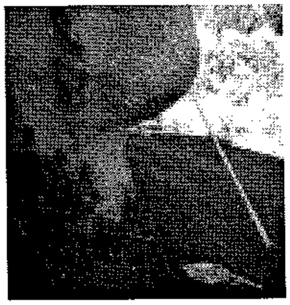
Figure 5: Forming flare.

Twidale and Bourne (1998) reported that the majority of the flare structures in their Australian study had southern aspects, corresponding to the shadier side of the rock in the southern hemisphere. They explained that the shadier side of the rock is also the cooler side, and therefore retains more soil moisture necessary for flare formation (Twidale and Bourne 1998). Therefore, it was expected that the bulk of the flares measured in the City of Rocks would have northern aspects, corresponding to the shadier side of the host rock in the northern hemisphere. This was not the case, however, as the majority of the flares had western aspects and the minority had northern ones. The western side of the host rock would generally be warmer than the eastern one, because as the sun rises in the east the west starts to warm up as well, so that by the time the sun is directly overhead, the western side of the rock has been sufficiently warmed. As the sun sets, its energy at any given point in the sky will be equal to that of when the sun rose, assuming the angle from the sun to the ground surface is the same. Therefore, the energy directed to the ground as the sun sets is hitting already warmed land in the west, whereas the energy from the sun at the same angle as it rises hits cold land in the east.

The data reported here suggest that flare formation might actually be enhanced on the sunnier, warmer side of the rock where more evaporation takes place. This evaporation would remove groundwater that was becoming, or had become, saturated with respect to some of the feldspars, and allow for fresh rainwater to take its place. On the shadier side of the host rock there is less evaporation, and therefore less room for the fresh rainwater to infiltrate. When the fresh water does infiltrate the soil it mixes with the water already there, increasing its ion concentration levels and limiting its ability to weather the host rock. The fact that more flares were found on the southern rather than the northern side of the rock provides support for this theory, as the southern side corresponds to the sunnier side of the rock in the northern hemisphere. Another possibility is that the preferential side of the host rock for flare formation depends on the surrounding environment. Factors such as ambient temperature, surrounding vegetation, topography, and soil type will affect the potential amount of weathering. To test these theories, further investigation involving ground sampling and soil analysis in the City of Rocks, as well as comparison to other areas, would need to be undertaken.

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