

# PROCEEDINGS OF THE TWENTY-SEVENTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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Mt. Holyoke College, South Hadley, MA

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Research Advisor: Dr. Scott Bogue

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BASED PXRF**

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## EFFECTS OF WILDFIRE ON FLOAT OBSIDIAN CLASTS FROM THE VALLES CALDERA, NEW MEXICO

AUDRIANNA POLLEN, Occidental College  
Research Advisor: Dr. Scott Bogue

### INTRODUCTION

This study looked at the magnetic properties of float obsidian clasts from the Valles Caldera National Preserve in northern New Mexico to determine if surficial indicators of heating due to wildfire, such as fire fracturing, also indicate the magnetic properties of the sample have been altered. Average wildfires reach temperatures upwards of 800° C and in extreme conditions can exceed 1200° C (“Fire Smart” 2005). Studies have shown that exposure to high temperatures causes obsidian to fracture and/or develop other surficial indicators of heating (Steffen 2005). Previous studies have attempted to source obsidian artifacts using their magnetic properties. The ability to visually distinguish samples that have been altered due to wildfires would allow researchers to easily eliminate samples that will produce inaccurate results, thus improving on the quality of the data and enhancing the sourcing process.

Wildfires can affect the archaeological artifacts present in the area. Rhyolite outcrops within the Valles Caldera were common quarries of excellent quality obsidian that was used by ancient peoples to make spear points, arrowheads, cutting tools, and religious objects (Gardner et al 2007). Sourcing this obsidian is of interest to archaeologists studying the anthropological history of the region. By determining the source of the obsidian that was used to create the artifact and the location the artifact was found, archaeologists can trace ancient peoples trade routes (Freund 2012).

Sourcing obsidian is widely done using geochemical processes, most commonly X-ray fluorescence (XRF)

or neutron activation analysis (NAA). Utilizing both the geochemical signature and the magnetic properties of the obsidian artifact may more reliably interpret the source of the obsidian outcrop. However, exposure to high temperatures can affect the magnetic record in rocks. If obsidian experiences a change in magnetic remanence due to heating, artifacts found in regions with prolific wildfires cannot be reliably sourced using magnetic data.

### PREVIOUS WORK

Early magnetic remanence studies attempted to replicate the way geochemical analysis was used to source samples using their magnetic rather than geochemical properties. The results produced by magnetic analysis vary in success. A study looking at obsidian artifacts and outcrop sources in Patagonia showed positive determination of source provenance utilizing the magnetic susceptibility, and initial and isothermal remanence of the obsidian artifacts (Vasquez et. al. 2001). Conversely, a study in Argentina did not determine artifact sources; the data had a large distribution of values and many samples’ magnetic properties overlapped with several source outcrops (Vasquez et. al. 2001). Magnetic analysis initially appealed to researchers because it was cheaper, faster, and generally nondestructive to the appearance of the artifact. However, the invention of portable XRF analyzers which also provide cheap, quick, nondestructive analysis negated those possible benefits of using magnetic properties (Frahm and Feinberg 2013).

A study published in 2013 by Frahm and Feinberg argued that magnetic analyses could effectively be

used to differentiate quarries within a single outcrop. After emplacement, obsidian can be exposed and relocated due to erosion or faulting as well as human transport; an obsidian artifact found on the ground can be far from the originally emplaced outcrop. If an artifact is exposed to extreme heat in a wildfire which changes its magnetic properties, but the source is far away and not burned over, the outcrop and the artifact will exhibit different magnetic signatures. If heating due to wildfires is shown to change not only the magnetic remanence in the rock, but also the visual appearance, fire fractured samples can be quickly and easily eliminated from quarry source studies, increasing the ability to accurately interpret the results.

## OBSIDIAN CLASSIFICATION

There have been very few studies describing and classifying the effects of fire on obsidian (Steffen 2005). This study focused on samples that exhibited fire fracturing and compared them with samples that showed no visual indicators of fire. Fire fractured pieces of obsidian can be difficult to distinguish from intentionally worked cores and flakes at first glance. Fortunately, with more detailed analysis, there are several pronounced differences between fractures occurring from heating versus knapping. When obsidian is heated from an external source, such as wildfire, the outer region of the rock will experience thermal expansion before the core of the rock. The core of the rock is then compressed by the exterior of the rock, causing the rock to fracture from the interior (Steffen 2005). Fire fractured obsidian clasts can most easily be distinguished from artifacts because fire fracturing does not create the distinct positive core and negative flake shapes inherent in intentional lithic reduction (Steffen 2005).

## GEOLOGIC SETTING

Valles Caldera is a resurgent caldera within the Jemez lineament, which runs across northern New Mexico. The Valles Caldera erupted and collapsed at  $\sim 1.25$  Ma on top of an established larger caldera called the Toledo Caldera. The earlier Toledo Caldera eruptive activity formed the Cerro Toledo rhyolite at  $\sim 1.47$  Ma (Gardner et. al., 2007). Two thirds of the samples used in this study were from outcrops of the Cerro

Toledo rhyolite. After the regional tumescence and ring fractures that initiated formation of the Valles Caldera, the floor of the caldera began to rise (Goff 2009). This resurgence lasted only  $\sim 30$  thousand years, but emplaced a thick layer of volcanic tuff known as the Bandelier tuff (Gardner et. al., 2010). After the resurgent uplift, six highly silicic rhyolite domes formed to the north of the caldera. The first, Cerro del Medio, formed at  $\sim 1.23$  Ma, and the final third of my samples was collected from this Valles rhyolite (Goff 2009). The large amount of volcanic activity in this region produced a significant amount of obsidian that was widely utilized by ancient peoples (Goff 2009).

## METHODS

Approximately 300 samples of obsidian were collected in total at three sites within the Valles Caldera National Preserve. At each site, samples were collected from four to five locations  $\sim 10$  m apart. Both fire fractured and unfractured float obsidian samples were collected from the ground surface at each location. Out of the initial 300 samples, fourteen sample pairs, consisting of a fractured sample and an unfractured sample from the same collection location within in a single outcrop, were selected for the magnetic measurements. First, the natural remanent magnetization (NRM) of each pair of samples was measured using a cryogenic magnetometer. Samples were then heated in zero field in  $50^{\circ}$ - $20^{\circ}$  C increments up to  $580^{\circ}$  C and the remanent magnetization was measured after each heating.

Additional measurements of the samples were conducted on 1-3 mm thick ends of a subset of the original sample cores. This subset of samples was subjected to stepwise alternating field (AF) demagnetization of the NRM to 90 mT, stepwise AF demagnetization (to 90 mT) of an anhysteretic remanent magnetization (ARM) imparted by an 81 mT AF and 1 mT bias field, and stepwise AF demagnetization (to 90 mT) of isothermal remanent magnetization (IRM) imparted by 81 mT direct field.

## RESULTS

The results from the thermal demagnetization measurements did not indicate a significant difference between the magnetic remanence of the fire fractured



and the unfractured samples as seen in Figures 1 and 2. The majority of both the fire fractured and unfractured samples lost the bulk of their magnetization within a narrow blocking temperature range. These samples retained the majority of their magnetic moment until heated to  $\sim 500^{\circ}\text{C}$ ; each additional increment of heating caused the samples to lose a large portion of their magnetic remanence, and by  $580^{\circ}\text{C}$  the samples were completely demagnetized (See Figure 1 and 2). This was expected as the Curie temperature for obsidian is  $\sim 600^{\circ}\text{C}$ . In addition, 11 of 14 fractured samples exhibited univectorial demagnetization trends; therefore, less than a quarter of the fractured samples showed two directional components when demagnetized. Only 7 out of 14 unfractured samples showed univectorial demagnetization trends while the other 7 exhibited two directional components of remanent magnetization.

While 11 sample pairs did not exhibit the expected thermal demagnetization results, measurements of 3 of the sample pairs did indicate there was a significant difference between the magnetic record of the fractured sample and the unfractured sample. Figures 3 and 4 show a sample pair that exhibited noticeably different results when thermally demagnetized. The unfractured sample 222 shown in Figure 3 shows a more distributed blocking temperature range where each increment of heating partially erased the imprinted magnetic record until it completely disappeared at  $580^{\circ}\text{C}$ . The fractured sample 222 shown in Figure 4 has a narrow blocking temperature range and lost the majority of its magnetic remanence between  $\sim 500^{\circ}\text{C}$  and  $580^{\circ}\text{C}$ .

While thermal demagnetization measurements did not prove conclusive, the alternating field magnetic measurements shown in Figure 5 showed slight indications there may be a difference in the magnetic remanence of the fire fractured samples compared to the unfractured samples. Both types of samples described in the graph in Figure 5 have nearly identical ARM and IRM curves, but their NRM demagnetization curves show two different trends. The NRM curve of the fractured sample aligned with the IRM demagnetization trend while the NRM curve of the unfractured sample more closely represented the ARM demagnetization trend.

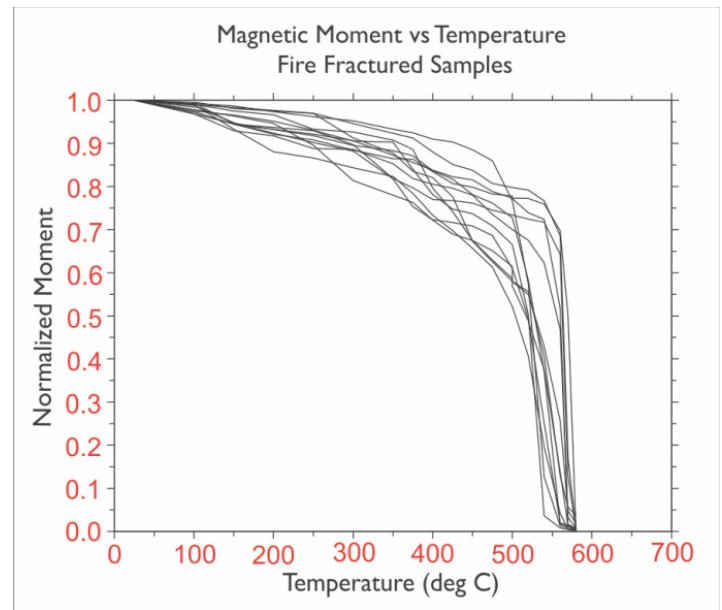


Figure 1. The above graph shows the magnetic remanence of the fractured samples at increasing temperatures determined from thermal demagnetization measurements. All results divided by the original NRM to emphasize the shapes of the curves.

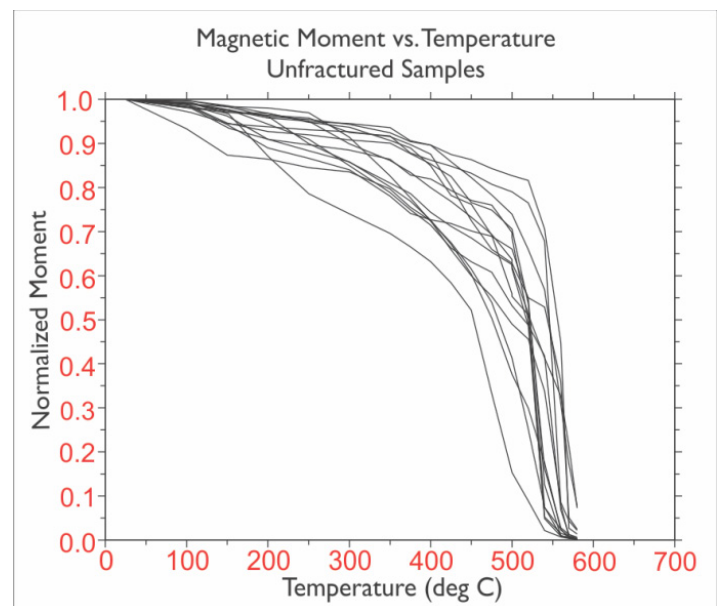


Figure 2. The above graph shows the magnetic remanence of the unfractured samples at increasing temperatures determined from thermal demagnetization measurements. All results divided by the original NRM to emphasize the shapes of the curves.



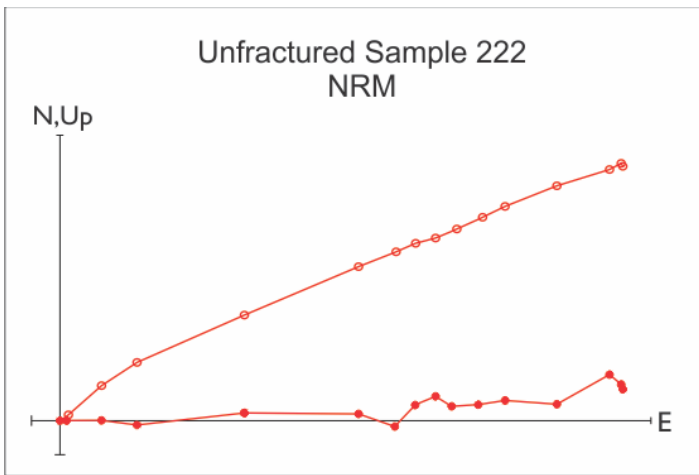


Figure 3. Thermal demagnetization measurements of an unfractured sample

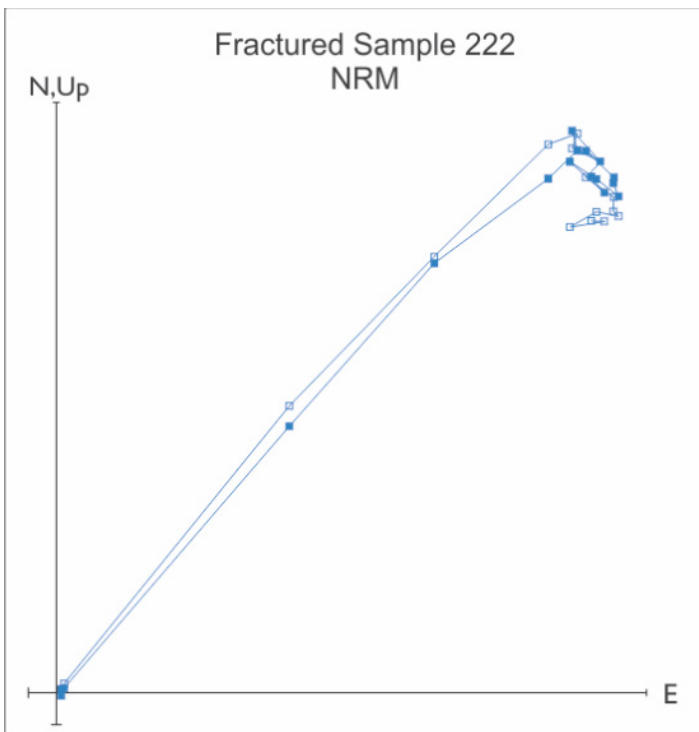


Figure 4. Thermal demagnetization measurements of a fire fractured sample

## INTERPRETATIONS

The thermal demagnetization measurements of the fractured and unfractured samples do not show significant variation; therefore, it is inconclusive whether heating due to wildfire produces a predictable effect on the magnetic record in the rocks (Figure 1 and Figure 2). While these graphs do not demonstrate

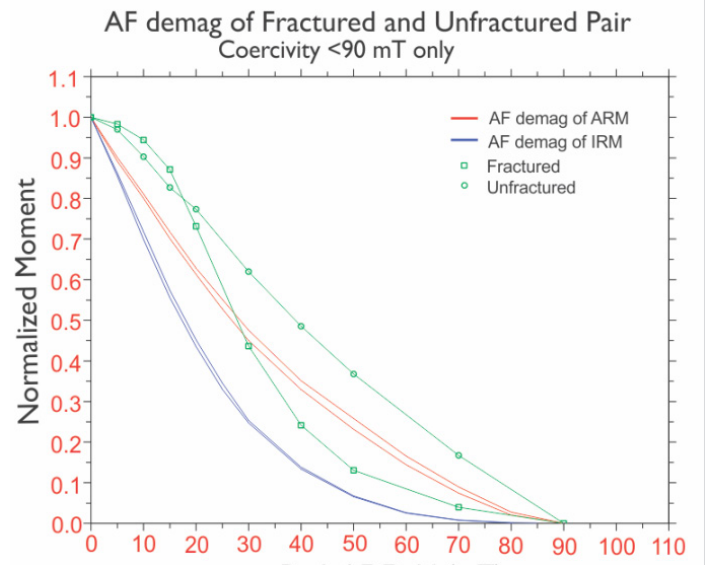


Figure 5. Shows a sample pair with distinctly different natural remanent magnetization

the expected results, they clearly show that nearly all the samples abruptly lost their magnetic moment between  $\sim 500^{\circ}\text{C}$  and  $580^{\circ}\text{C}$ . These findings may indicate there is no significant difference produced by heating the two sample types. A more likely explanation is that many of the unfractured samples also underwent heating due to wildfire, but did not fire fracture due to various reasons, such as their composition or the presence of zeolites in the sample. There is no evidence of a two component magnetization trend from reheating in the fire fractured samples as the majority exhibited univectorial demagnetization trends. This may be due to reheating at temperatures above  $580^{\circ}\text{C}$  which completely reprinted the magnetic remanence in the rock causing it to have a univectorial demagnetization trend.

Figure 5 shows a sample pair with distinct differences in the NRM stepwise AF demagnetization trends between the two types of samples. The NRM demagnetization shown by the fractured sample more closely aligns with the IRM trend as if it had been struck by lightning so that part of its remanence is an IRM. A lightning strike is similar to the large artificial magnetic field produced in IRM AF demagnetization. A firm conclusion is not possible without oriented samples. The NRM trend shown by the unfractured

sample closely resembles the curve produced by ARM AF demagnetization. This indicates the unfractured sample retained the magnetic imprint imposed by the orientation of the Earth's magnetic field when it originally cooled.

This distinctive narrow blocking temperature range shown by most of the samples indicates wildfires would not noticeably alter the magnetic remanence in the sample unless they burned the rocks at temperatures between 500° C and 580° C. If a wildfire heated the samples to less than 500° C the samples would retain their original magnetic remanence and not be partially or wholly remagnetized to the orientation of the Earth's field at the time of the wildfire. A fire that burned hotter than 580° C would completely overprint the original magnetic remanence in the sample leaving no measureable indication that the current magnetism in the sample is the result of wildfire exposure or due to its original cooling. Samples would need to be heated to temperatures between 500° C and 580° C to retain a portion of their original magnetization as well as a component of new magnetism imprinted when the sample was heated by a wildfire.

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