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2013-2014 PROJECTS

MAGNETIC AND GEOCHEMICAL CHARACTERIZATION OF IN SITU OBSIDIAN, NEW MEXICO*:*
Faculty: *ROB STERNBERG*, Franklin & Marshall College, *JOSHUA FEINBERG*, Univ. Minnesota, *STEVEN SHACKLEY,* Univ. California, Berkeley, *ANASTASIA STEFFEN*, Valles Caldera Trust, and Dept. of Anthropology, University of New Mexico
Students: *ALEXANDRA FREEMAN*, Colorado College, *ANDREW GREGOVICH*, Colorado College, *CAROLINE HACKETT*, Smith College, *MICHAEL HARRISON,* California State Univ.-Chico, *MICHAELA KIM*, Mt. Holyoke College, *ZACHARY OSBORNE*, St. Norbert College, *AUDRUANNA POLLEN*, Occidental College, *MARGO REGIER*, Beloit College, *KAREN ROTH*, Washington & Lee University

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JOSHUA M. FEINBERG, Institute for Rock Magnetism, University of Minnesota
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Research Advisors: James Rougvie, Beloit College and Joshua M. Feinberg, University of Minnesota

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GEOCHEMICAL VARIABILITY OF OBSIDIAN IN WESTERN NEW MEXICO WITH LABORATORY-BASED PXRF

KAREN ROTH,Washington and Lee University
Research Advisor: Jeffrey Rahl

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MAGNETIC PROPERTIES OF CERRO TOLEDO OBSIDIAN

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INTRODUCTION

In order to determine the geological origin of obsidian artifacts and the path the material has taken along the way, archaeological obsidian must be matched to its source. Trace element geochemistry determined by XRF is a common technique that has been successfully employed around the world. Magnetic properties have also been used in obsidian provenance studies with varying degrees of success (McDougall et al., 1983;Vasquez et al., 2001; Zanella et al., 2011). Recent work suggests that magnetic techniques have the potential to identify quarry-scale procurement within an obsidian flow (Frahm and Feinberg, 2013).

Intra-flow sourcing was put to the test in this study. Geological obsidian was collected from four locations within the Jemez Mountains, specifically from the Valle Toledo Member of the Cerro Toledo Formation within the Valles Caldera. The Valles Caldera National Preserve also graciously provided archaeological obsidian for analysis, in the form of finished points made from Cerro Toledo obsidian.

With previously applied geochemical techniques, including ED-XRF, NAA, and ICP-MS, the different outcroppings of Valle Toledo obsidian are indistinguishable (Glascock et al., 1999; Steffen, 2005). Since the interplay between a variety of processes can create a specific magnetic signature at a given outcrop, magnetic techniques have the potential to uniquely characterize these sites (Frahm and Feinberg, 2013). If these sites are characterized in such a way, artifacts can be sourced to a more specific location than previously documented.

Magnetic analyses also have the potential to show properties prehistoric knappers preferred in obsidian and perhaps other, as yet unrealized connections. Frahm and Feinberg (2013) previously demonstrated that knappers in Europe and the Near East selected obsidian with low concentrations of magnetic minerals and of as small a size as possible.

STUDY AREA

The Valles Caldera is located in the Jemez Mountains volcanic field in north-central New Mexico. The timing of regional volcanism spans from 25 Ma to 40 Ka. Inherently permeable crust at the western intersection between the Rio Grande Rift and the Jemez Lineament has served as a conduit for ~2,000 km^3 of eruptive material since widespread volcanism began (Rowe et al., 2007).

The youngest and best artifact quality obsidian in the area belongs to the Tewa Group (Shackley, 2005). Resurgent volcanism produced this obsidian after two large caldera-forming eruptions, the Toledo and Valles—dated at 1.61 Ma and 1.23 Ma by $^{40}Ar/^{39}Ar$ (Spell et al., 1996). During the ~0.4 Ma between the eruptions, intra-caldera volcanism produced rhyolitic domes and pyroclastic rocks that host Cerro Toledo obsidian.

The Valles Caldera and surrounding mountains have been occupied continuously for at least 10,000 years, with the best evidence for early occupation preserved in obsidian artifacts (Steffen, 2013). In the more recent past Ancestral Puebloans used the caldera for hunting, maize agriculture, collection of plants for food and medicine, and gathering of obsidian. More distant groups such as the Hopi, Navajo, Ute, and Zuni were also attracted to the caldera's bounty of resources (Steffen, 2013).

METHODS

Geological samples were collected from four different locations within the Valle Toledo Member of the Cerro Toledo Formation in the Valles Caldera (Figure 1). Of the two domes—Qct and Qcr—it was only possible to sample Qct *in situ*. The other geological samples, coming from the Capulin Quarry and Obsidian Ridge locations, were deposited in a pyroclastic flow (Heiken et al. 1986). Twenty four Cerro Toledo artifacts were provided by Ana Steffen for non-destructive analysis. These artifacts came from the Valles Land Trust's collection, which have been collected during archaeological surveys of the Valles Caldera National Preserve.

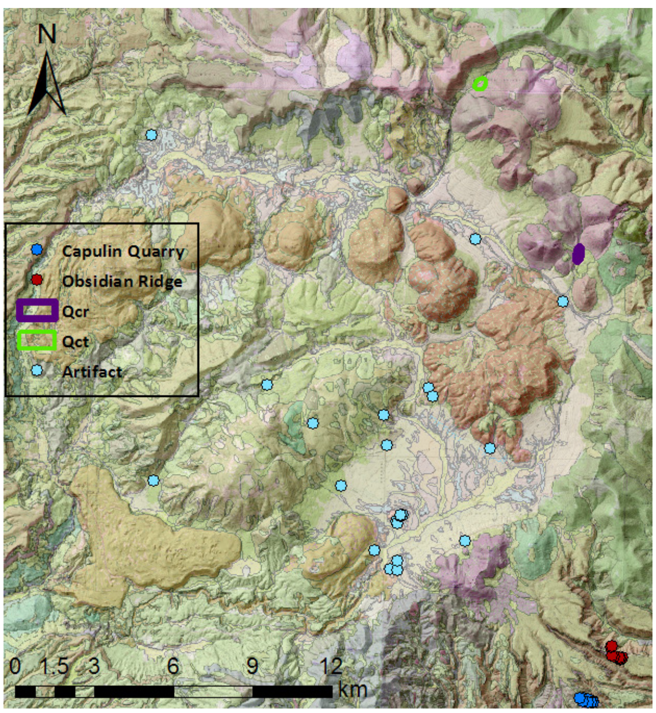

Figure 1: Map of the Valles Caldera showing locations from which artifacts and geological samples were collected.

Hysteresis loops, backfield curves, and the frequency dependence of susceptibility (X_{fd}) were collected for both artifacts and geological samples at the Institute for Rock Magnetism. For the artifacts, hysteresis parameters (M_s, saturation magnetization; M_r, saturation remanence; H_c, bulk coercivity; and H_{cr}, coercivity of remanence) were measured on a Princeton Applied Research vibrating sample magnetometer (VSM). For geological samples the more sophisticated Princeton Measurements MicroMag model 3900 microVSM was used. Susceptibility measurements were made on a MAGNON variable frequency susceptibility meter. Hysteresis parameters and susceptibility were used to determine the magnetic mineral assemblage in the samples.

RESULTS

Discrimination using hysteresis parameters

Day plots, made famous by Day et al. (1977), show the relationship between the coercivity ratio (H_{cr}/H_c) and the squareness ratio (M_r/M_s) and show the average magnetic domain state of a sample. Dunlop (2002) defined three main zones for magnetite: single domain, pseudo-single domain, and multidomain. These zonations are frequently used as proxies for the grain size of magnetic minerals in a sample, where single domain grains are finest (≤100 nm), and multidomain grains are the coarsest (≥1 μm).The majority of geological samples fall into the pseudo-single domain range (Figure 2). This matches with the observed shape of most hysteresis loops as well. Given the amount of variability observed and the pyroclastic nature of most of the deposits in this study (which consist of jumbled obsidian from multiple outcrops), it is not possible to associate any of the artifacts with a specific sample collection area. Range in the concentration-dependent parameters, M_s and M_r, is 15 to ~380 times the minimum value, which for some locations is greater than the variation noted by Sternberg et al. (2011) across the *entire Southwest*. The magnetic grain size of minerals in artifacts is similar to that of the geological samples.

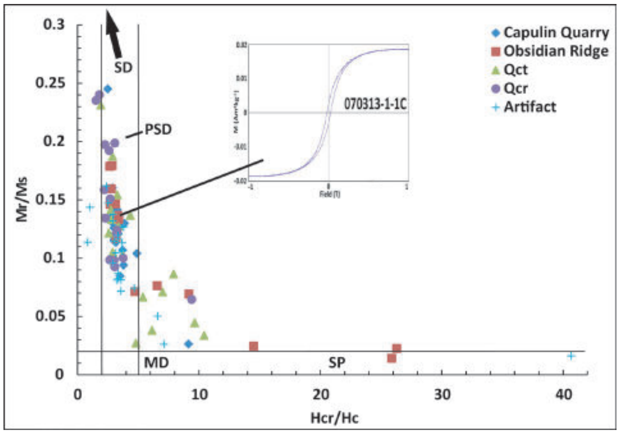

Figure 2: Day plot for all samples. Boundaries for different magnetic mineral sizes come from Dunlop (2002) and assume that magnetite is the primary carrier of magnetism. The hysteresis loop for a sample representing average values is also shown.

In the plot of M_r/M_s vs coercivity (H_c) (Figure 3) most samples plot below the magnetite line. This suggests that partially oxidized magnetite is the primary carrier of magnetism. In this plot as well, it is not possible to match artifacts to a specific collection area.

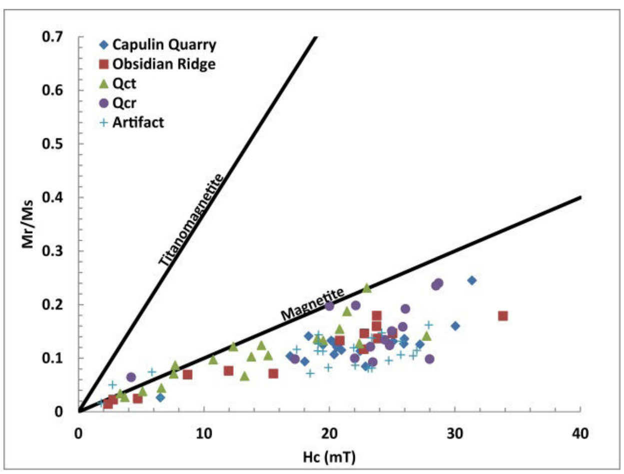

Figure 3: Mr/Ms vs Hc plot for all samples. The upper line represents the expected trend for titanomagnetite and the lower, the trend for magnetite. Established by Wang and Van der Voo (2004), these lines incorporate theory and empirical evidence.

Susceptibility

Of 135 samples measured, 38% (51 samples) were below the detection limit of the MAGNON susceptibility meter. These low measurements can be due to either low concentrations of magnetic material, or a preponderance of single domain sized grains, which by their nature have low susceptibilities. In general, we feel that most samples have low concentrations of magnetic material. However, some samples have high X_{fd} and the hysteresis loops to suggest a significant superparamagnetic component. These samples have a higher concentration of magnetic material overall. This kind of obsidian makes up a small, but intriguing portion of the Cerro Toledo artifacts.

MAGNETIC PROPERTIES OF CERRO TOLEDO ARTIFACTS

Overall artifacts show lower values for M_s and M_r, indicating a lower concentration of magnetic material compared to the geological samples (Figure 4). For the size-dependent parameters—H_c, H_{cr}, H_{cr}/H_c, and M_r/M_s—there is little noticeable difference. Hysteresis loops and discriminatory diagrams like the day plot suggest that Cerro Toledo obsidian contains a mixture of magnetic grain sizes, so it is not surprising that there is no difference in size-dependent parameters between artifacts and geological samples.

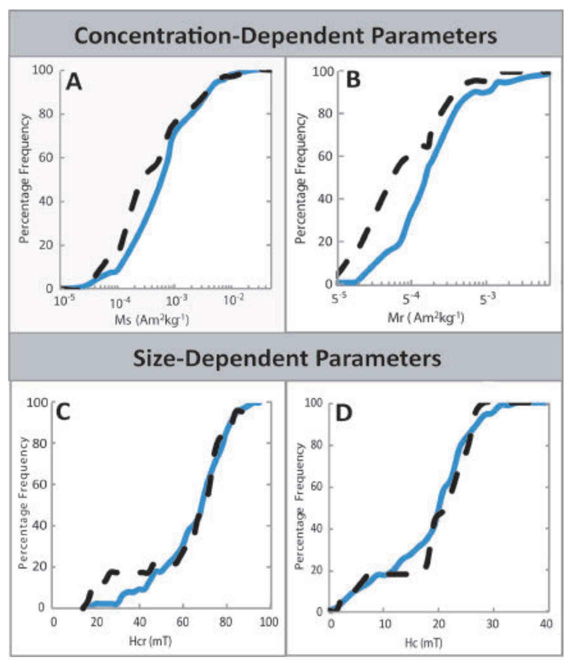

Figure 4: Cumulative distribution plots highlighting the difference between artifacts (dashed lines) and geological samples (blue lines). There is a noticeable difference for the concentration dependent parameters (M_s and M_r), but not for the size dependent parameters (H_c and H_{cr}).

Based on my experience preparing samples in the lab, it might make sense that knappers preferred obsidian with a lower concentration of magnetic material. Dark, opaque obsidian clasts—which have a higher concentration of magnetic material—typically broke into large chunks and disintegrated glass. Translucent obsidian on the other hand is more likely to flake in a predictable manner.

While very dark obsidian generally has a higher magnetic mineral concentration, this difference is often only apparent when a fresh surface is present. Knappers working in the Valles Caldera may have had a hard time differentiating between these types of obsidian before they began reducing a clast.

There is a noticeable difference in quality between artifacts made from dark obsidian and the seemingly preferred, translucent variety (Figure 5). Dark artifacts from this collection are easily picked out because of their misshapen and irregular form, making it difficult for archaeologists to identify the point type or time period during which they were made.

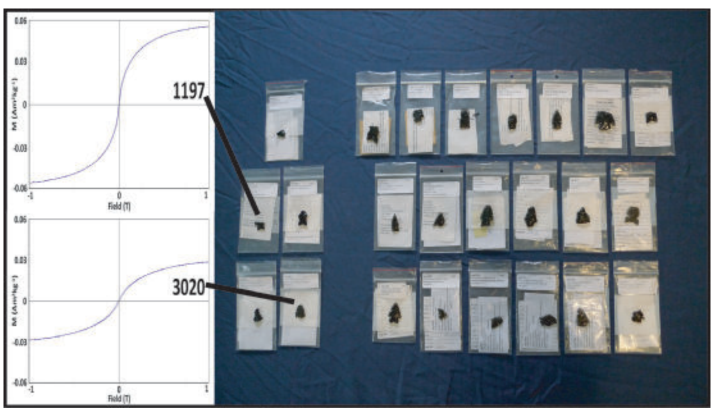

Figure 5: Cerro Toledo artifacts. Notice the difference between artifacts made from dark obsidian (on the left) and the rest.

FURTHER WORK

Future magnetic obsidian studies should recognize that prehistoric knappers selected for obsidian with certain magnetic properties. Provenance studies focusing on intra-flow sourcing may have success identifying the most utilized quarries within a flow. However, these studies will only be successful in locations where knappers selected obsidian directly from an effusive flow.

Intra-flow sourcing could open the doors to new kinds of anthropological research, particularly in areas from which large numbers of artifacts have been collected. While geochemical obsidian studies have been used to reconstruct regional trade patterns, fine-scale magnetic sourcing could provide insight to local patterns of human movement.

A large portion of the Valles Caldera National Preserve has yet to be surveyed for archaeological materials. With future discoveries and better magnetic characterization of the obsidian-bearing rhyolitic domes in the Northwest portion of the preserve, researchers may gain better insight into human movement within and around the Valles Caldera. This kind of research could be particularly interesting in the Valles Caldera, an area in which both hunting and agriculture occurred together.

Over 80 obsidian artifacts from as far as 1,520 km away have been sourced to Cerro Toledo (Steffen and LeTourneau, 2007). By analyzing these artifacts, it might be possible to see a correlation between distance travelled and magnetic mineral assemblage. Are artifacts with less magnetic material more likely to be transported far from the original source?

Because of the low concentration of magnetic material in many samples, this obsidian is not the best for magnetic analyses. Surveys of magnetic properties of obsidian across a region will help identify areas where this kind of work could be the most successful. Projects similar to Sternberg et al. (2011) provide a useful baseline in areas where obsidian magnetic data is sparse.

CONCLUSIONS

Cerro Toledo obsidian is primarily composed of partially oxidized magnetite that is pseudo single domain size. Using magnetic proxies for grain size, concentration, and mineralogy it was not possible to match artifacts to specific collection areas. Prehistoric knappers selected obsidian with lower concentrations of magnetic material. Artifacts with the highest amounts of magnetic material are misshapen and difficult to identify compared to other artifacts, possibly reflecting greater difficulty of working with this kind of obsidian.

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