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2013-2014 PROJECTS

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Students: *LUCY ANDREWS*, Macalester College, *AMY DELBECQ*, Beloit College, *SAMANTHA DOW*, Univ. Connecticut, *CATHERINE DUNN*, Oberlin College, *WESLEY JOHNSON*, Univ. Massachusetts, *RACHEL JOHNSON,* Carleton College, *SCOTT KUGEL*, The College of Wooster, *AIDA OROZCO*, Amherst College, *JULIA SEIDENSTEIN,* Lafayette College

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Short Contributions— Obsidian Provenance, New Mexico Project

MAGNETIC AND GEOCHEMICAL CHARACTERIZATION OF GEOREFERENCED OBSIDIAN SAMPLES FROM FOUR SOURCE AREAS IN NEW MEXICO
Faculty: ROB STERNBERG, Franklin & Marshall College
M. STEVEN SHACKLEY, Geoarchaeological XRF Laboratory, Albuquerque, NM,
JOSHUA M. FEINBERG, Institute for Rock Magnetism, University of Minnesota
ANASTASIA STEFFEN, Valles Caldera Trust, and Dept. of Anthropology, University of New Mexico

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ALEXANDRA FREEMAN, The Colorado College
Research Advisor: Christian M. Schrader, The Colorado College

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ANDREW GREGOVICH, Colorado College
Research Advisors: Christian M. Schroder, Colorado College and Joshua M. Feinberg, University of Minnesota

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CAROLINE HACKETT, Smith College
Research Advisor: Mark Brandriss

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MARGO REGIER, Beloit College
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 AND GEOCHEMICAL CHARACTERIZATION OF GEOREFERENCED OBSIDIAN SAMPLES FROM FOUR SOURCE AREAS IN NEW MEXICO

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INTRODUCTION

There are a number of geologic sources of archaeological obsidian in the Greater Southwest (Figure 1) and the goal of this Keck project was to further characterize the magnetism and geochemistry of a small but important subset in order to explore intra-flow variability. In the summer of 2013, we sampled four obsidian source areas in New Mexico: Mule Creek, Mt. Taylor, Obsidian Ridge, and Cerro del Medio (we have sometimes lumped the last two together as "Jemez/Valles Caldera"). In each area, we collected samples from multiple localities. One of these localities in the Mule Creek area, here called west Antelope Creek (sometimes called Danny Welch), had not previously been known. Over 3,000 unoriented samples, the majority of which were georeferenced, were collected from all localities. Some samples were pried in situ from perlitic matrices; the majority were marekanites. Some field measurements of magnetic susceptibility were made, but samples were primarily brought back for laboratory analyses of geochemical, paleomagnetic, and rock magnetic properties. We also attempted to provenance archaeological artifacts from two archaeological sites. The pilot studies in obsidian magnetism pursued in this project are an important contribution towards increasing the global utility of obsidian studies.

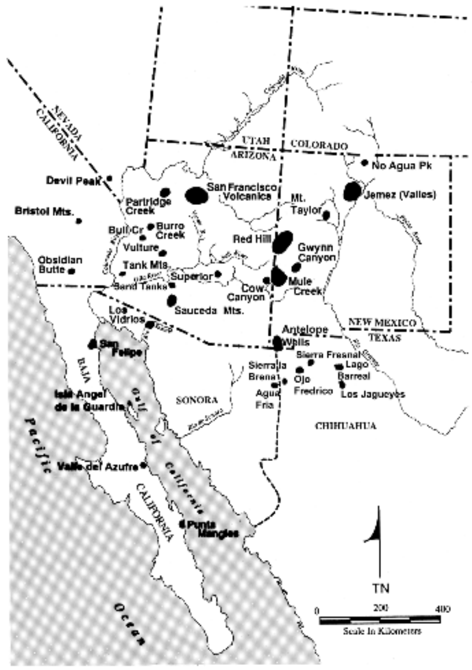

Figure 1. Map of obsidian source areas in the American-Mexican Southwest (Shackley, 2005). The source areas studied in this project were Mule Creek, Mt. Taylor, and Jemez (Valles).

PROVENANCE HYPOTHESIS

The idea of provenance in archaeology allows the tracing back of raw materials to a geologic source. Wilson and Pollard (2001) summarize the components of the "provenance hypothesis":

1. Some property of the geologic raw material is maintained as the material is transformed into the finished object, or artifact;

2. Potential sources of the raw material have characteristic "fingerprints," i.e., they can be discriminated from each other by suitable measurements, because inter-source variability of the property considered is greater than intra-source variability;

3. Raw materials are not mixed (or the result of doing so can be estimated);

4. Post-depositional processes do not obscure the fingerprint.

In addition, these authors stress the importance of being able to use the information acquired to help interpret human behavior, such as the patterns of procurement of the raw material. Lithics such as obsidians are particularly suitable for provenance studies in that, unlike ceramics or metals, there is essentially no chance for different raw material to be mixed in producing the final object. Sometimes groups can be discriminated via simple bivariate plots, although multivariate statistics are often employed.

OBSIDIAN GEOCHEMISTRY STUDIES IN THE SOUTHWEST

The availability of obsidian for production of artifacts and now provenance studies in the Southwest is due to silicic volcanism peculiar to this part of the North American plate (Goff 2009). Studies by Boyer and Robinson (1956) in northwestern New Mexico, including Valles Caldera, and by Jack (1971) and Schreiber and Breed (1971) in the San Francisco Volcanic Field represent the earliest attempts to chemically characterize Southwestern obsidians for archaeological problems. By the late 1980s, archaeological obsidian studies in the North American Southwest had come of age (Hughes, 1988; Shackley, 1988; Stevenson et al., 1990), although only five or six sources of archaeological obsidian had been chemically fingerprinted. Now, over 55 sources and source groups in the region have been mapped and chemically characterized (Shackley, 2005; see Figure 1). This database has allowed for more nuanced studies of Southwestern prehistory, including inferences of exchange, social identity, migration, and long-term social change (Arakawa et al., 2011; Duff et al., 2012; Mills et al., 2013). Archaeological obsidian provenance studies are now part of normal science in Southwestern archaeological research.

At the Valles Caldera National Preserve (VCNP) in particular, obsidian studies are a central research component of the cultural resources management program. Geochemical analyses have been used to produce systematic elemental characterizations for, thus far, two of the Jemez Mountains obsidian-bearing source deposits, the Cerro Toledo and the Valles Rhyolites. The focus is on evaluating potential intra-source variation rather than inter-source distinctions, providing not only a more detailed consideration of geographical distributions of obsidian composition but also a more nuanced treatment of the role of glass composition for obsidian hydration dating. VCNP research projects are exploring, among other questions, how Jemez Mountains obsidian artifacts were used in prehistory across North America (Steffen and LeTourneau, 2007).

MAGNETIC STUDIES OF OBSIDIANS

Past research on the magnetic properties of obsidian has varied in focus and scale. Although obsidian typically exhibits many of the rock magnetic properties that would be considered ideal for a traditional paleomagnetic study (e.g., high coercivities and remanence ratios), such studies are few and far between because obsidian blocks are rarely found in the same position that they were in during cooling. Thus, a paleomagnetic direction cannot be recovered from the obsidian's magnetization, although there have been several recent studies that have used obsidian as a recorder of the paleointensity of the geomagnetic field (e.g., Ferk et al., 2011).

Rock magnetic studies of obsidian are more common and are typically conducted within an archaeological context, where researchers try to discern populations of obsidian that originated from different flows. McDougall et al. (1983) demonstrated that individual obsidian sources created discrete distributions of magnetic parameters on simple bivariate plots, and suggested that such patterns could potentially be used to determine the provenance of unknown samples. Geochemical provenancing of obsidian has since matured considerably, and field-based portable

X-ray Fluorescence (pXRF) instruments allow rapid characterization of an obsidian artifact's geologic source. Thus, to continue to be useful, the magnetic analysis of obsidian must provide some additional information about an artifact's origin that geochemical characterization cannot.

Recent work by Frahm and Feinberg (2013a, 2013b, 2013c) has demonstrated several ways in which magnetic information can continue to be useful to obsidian sourcing studies. First, there are some instances where two separate obsidian flows may have virtually identical geochemistry, and a different kind of characterization is needed to differentiate whether an artifact originated from one or the other flow. Second, an analysis of obsidian artifacts from Tell Mozan, Syria, revealed that ancient knappers were carefully selecting obsidian with low concentrations of very fine-grained crystallites. When compared to an assortment of obsidian samples collected from the same eruptive centers, the archaeological obsidian had notably lower magnetic susceptibilities and saturation magnetizations, and significantly higher coercivities and remanence ratios (see also Gregovich, this volume). Third, the magnetic properties within an individual obsidian flow vary in such a way that they can potentially be used to source obsidian objects to discrete quarry sites within the flow. In this way, the rock magnetics studies in this Keck project aim to test or further expand upon the models set out in Frahm and Feinberg (2013a). The existing obsidian geochemistry framework in the American Southwest established through decades of research provides an ideal backdrop for such rock magnetic research.

PROJECT OVERVIEWS

As summarized in Table 1, over 3000 samples were collected. Other than the samples at west Antelope Creek, which were only georeferenced into two groups on different terraces, most samples were either individually georeferenced, or georeferenced along with a group of nearby samples.

Students on the project (Figure 2) selected research problems based on their interests, the expertise of the advisers at their home institutions, availability of instrumentation, the research goals of the overall project, and logistics of sharing samples. Table 2 classifies the projects by general type of analysis and by location. For each of the three source areas, there was one paleomagnetic project, one rock magnetic project, and one geochemistry project.

Table 1. Number of samples for each of the nine localities, for the different sampling areas. For this table, Jemez and Valles have been listed as one source area. Most samples were georeferenced individually or in small groups, except for west Antelope Creek, where one generalized GPS reading was taken for each of two sub-locales. The west Antelope Creek locality (1) has been called Danny Welch in some of our notes, after the person who located this new locality in the summer, 2013. St. Peter's Dome and Obsidian Ridge (2) both sample the Cerro Toledo Rhyolite. Sampling of the Valles Rhyolite at the Cerro del Medio (3) took place at both the Qvdm4 and Qvdmw units (per Gardner et al. 2007).

Number of samples	Mule Creek	Mt. Taylor	Jemez/Valles
N. Sawmill Creek	232		
Antelope Creek	648		
west Antelope Creek[1]	143		
Grants Ridge		459	
Horace Mesa		575	
La Jara Mesa		69	
St. Peter's Dome[2]			487
Obsidian Ridge[2]			143
Cerro del Medio[3]			626
Subtotals	1023	1103	1256
Total			3382

Figure 2. Student (and faculty) participants, at Valle Grande, Valles Caldera National Preserve. Standing, left to right: Rob Sternberg (faculty), Michaela Kim, Karen Roth, Andrew Gregovich, Ryan Samuels (teaching assistant), Michael Harrison, Margo Regier, Christian Schrader (visiting faculty), and Audrianna Pollen. Kneeling, left to right: Caroline Hackett, Zach Osborne, and Alexandra Freeman. Steven Shackley, Josh Feinberg, and Ana Steffen are not pictured.

Table 2. Student projects by source area, and whether the project was geochemical (GC), paleomagnetic (PM), or rock magnetic (RM). Karen Roth did geochemistry on samples from two areas. Alexandra Freeman worked on artifacts from the Piedras Marcadas archaeological site in Albuquerque, which mostly sourced to Jemez/Valles courses, but in one case sourced to Mt. Taylor.

	Mule Creek	Mt. Taylor	Jemez/Valles
Caroline Hackett	GC		
Michael Harrison	PM		
Margo Regier	RM		
Karen Roth	GC	GC	
Michaela Kim		PM	
Zach Osborne		RM	
Alexandra Freeman		GC (+artifacts)	GC (+artifacts)
Audrianna Pollen			PM
Andrew Gregovich			RM(+artifacts)

Michael Harrison and Michaela Kim measured basic paleomagnetic properties of magnetic susceptibility, strength of the natural remanent magnetization, and alternating field demagnetization from Mule Creek and Mt. Taylor, respectively. Median destructive fields were inferred from the demagnetizations. Previous work by Sternberg et al. (2010) suggested that susceptibility, NRM, and MDF had some ability to discriminate sources. Audrianna Pollen used thermal demagnetization on samples from Jemez/Valles to see if re-heatings and remagnetizations related to the forest fires that have occurred in this region (Steffen, 2002) could be inferred. Sternberg et al. (2013) made additional paleomagnetic measurements on samples from Mule Creek.

Andrew Gregovich, Zach Osborne, and Margo Regier visited the Institute for Rock Magnetism at the University of Minnesota for their projects, to measure rock magnetic properties such as hysteresis loops on more specialized equipment not always available at other paleomagnetic laboratories. This is an extension of initial rock magnetic work on Southwestern obsidians by Sternberg et al. (2011).

Alexandra Freeman, Caroline Hackett, and Karen Roth carried out geochemical studies. Alexandra worked on artifacts from Piedras Marcadas, a pueblo besieged by Coronado during his 1540-1542 expedition that we visited during our field season, to provenance obsidians to their geologic sources. Caroline used high-precision WXRF analyses to compare against non-destructive EDXRF analysis done on samples from the same locations. Karen worked on portable-XRF in a laboratory setting, to test the merits this would have as a field technique relative to benchtop XRF.

FUTURE SYNTHESIS

The student projects focused on specific source areas, using geochemistry, paleomagnetism, or rock magnetism. Once their projects are complete, our goals include: comparing any complementary geochemical methods from the student projects and previous work; taking a closer look at the geospatial variability or lack thereof of the various properties across the various localities; comparing the ability of geochemical and magnetic properties to distinguish among localities; considering whether magnetics is useful for distinguishing quarries within localities; applying multivariate analysis within localities. We also made some in situ measurements of magnetic susceptibility in outcrop while in the field; those results have not been included in these student projects, so we will re-analyze and include those with results from the samples brought back to the labs. Students at F&M have also been measuring some basic paleomagnetic properties of obsidian artifacts from the Dinwiddie archaeological site (Archaeology Southwest, 2014) in southwestern New Mexico, and we will examine how successfully they can be provenanced against the source localities studied.

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REFERENCES

Arakawa, F., Ortman, S.G., Shackley, M.S., and Duff, A.I., 2011, Obsidian evidence of interaction and migration from the Mesa Verde region, southwest Colorado: American Antiquity, v. 76, p. 773-795.

Archaeology Southwest, 2014, Investigations at the Dinwiddie site: http://www.archaeologysouthwest.org/what-we-do/investigations/salado/field-school/dinwiddie/ (accessed March 2014).

Boyer, W.W., and P. Robinson, 1956, Obsidian artifacts of northwestern New Mexico and their correlation with source material: El Palacio v. 63, n. 11-12, p. 333-345.

Crumpler, L.S., 1982, Volcanism in the Mount Taylor region: New Mexico Geological Society Guidebook, 33rd Field Conference, Albuquerque Country II, p. 291-298.

Duff, A.I., Moss, J.M., Windes, T.C., Kantner, J., and Shackley, M.S., 2012, Patterning in procurement of obsidian in Chaco Canyon and in Chaco-era communities in New Mexico as revealed by x-ray fluorescence: Journal of Archaeological Science, v. 39, p. 2995-3007.

Ferk, A., Leonhardt, R., Hess, K.-U., and Dingwell, D. B., 2011, Paleointensities on 8 ka obsidian from Mayor Island, New Zealand: Solid Earth, v. 2, p. 259-270

Frahm, E., and Feinberg, J.M. 2013a, From flow to quarry: Magnetic properties of obsidian and the changing scales of archaeological sourcing: Journal of Archaeological Science, v. 40, no. 10, p. 3706-3721.

Frahm, E., and Feinberg, J.M., 2013b. Empires and resources: Central Anatolian obsidian at Urkesh (Tell Mozan, Syria) during the Akkadian Period: Journal of Archaeological Science, v. 40, p. 1122-1135.

Frahm, E., and Feinberg, J.M., 2013c. Environment and collapse: Eastern Anatolian obsidians at Urkesh (Tell Mozan, Syria) and the third-millennium Mesopotamian urban crisis: Journal of Archaeological Science, v. 40, p. 1866-1878

Gardner, J.N., Sandoval, M.M., Goff, F., Phillips, E., Dickens, A., 2007, Geology of the Cerro del Medio moat rhyolite center, Valles Caldera, New Mexico. Geology of the Jemez Mountains Region II, 58th Field Conference, New Mexico Geological Society Guidebook, p. 367-372.

Goff, F., 2009, Valles Caldera: A geologic history: Albuquerque: University of New Mexico Press, 128 p.

Hughes, R.E., 1988, Archaeological significance of geochemical contrasts among Southwestern New Mexico obsidians: The Texas Journal of Science, v. 40, n. 3, p. 297-307.

Jack, R.N., 1971, The source of obsidian artifacts in Northern Arizona: Plateau, v. 43, p.103-114.

McDougall, J.M., Tarling, D.H., and Warren, S.E., 1983, The magnetic sourcing of obsidian samples from Mediterranean and Near Eastern Sources. Journal of Archaeological Science, v. 10, p. 441-452.

Mills, B.J., Clark, J.J., Peeples, M.A., Haas, Jr., W.R., Roberts, Jr, J.M., Hill, J.B., Huntley, D.L., Borck, L., Breiger, R.L., Clauset A., and Shackley, M.S., 2013, Transformation of social networks in the Late Pre-Hispanic US Southwest: PNAS, v. 110, p. 5785-5790.

Ratte, J.C., 2004, A guide to the Mule Creek volcanic vent, the rhyolite of Potholes Country, and obsidian ledges, Gila National Forest, southwestern New Mexico: New Mexico Geology, v. 26, n. 4, p. 111-122.

Schreiber, J.P. and Breed, W.J., 1971, Obsidian localities in the San Francisco Volcanic Field, Arizona: Plateau, v. 43, p. 115-119.

Shackley, M.S., 1998, Geochemical differentiation and prehistoric procurement of obsidian in the Mount Taylor volcanic field, northwest New Mexico: Journal of Archaeological Science, v. 25, p. 1073-1082.

Shackley, M.S., 2005, Obsidian: geology and archaeology in the North American Southwest:

Tucson, University of Arizona Press, 264 p.
Shackley, M.S., 2013, Grants Ridge and Horace/La Jara Mesa Mount Taylor volcanic field northwestern New Mexico: http://www.swxrflab.net/grants.htm (accessed March 2014).
Steffen, A., 2002, The Dome Fire Pilot Project: Extreme obsidian fire effects in the Jemez Mountains. In Loyd, J.M., Origer, T.M., and Fredrickson, D.A. (eds.), The Effects of Fire/Heat on Obsidian: United State Department of Interior, Bureau of Land Management, Cultural Resources Publication, p. 159-201.
Steffen, Anastasia, and Philippe D. LeTourneau, 2007, Sources in the middle: The Jemez Mountains Obsidian Database Project: Society for American Archaeology, 71st Annual Meeting, Austin, TX, 25-29 April.
Sternberg, R., Gilder, S., Renne, P., Shackley, M.S., 2010, Magnetic properties of obsidians from the Southwestern U.S.:American Geophysical Union Fall Meeting, San Francisco, 13-17 December.
Sternberg, R., Jackson, M.J., Shackley, M.S., 2011. Hysteresis, thermomagnetic, and low-temperature magnetic properties of Southwestern U.S. obsidians: American Geophysical Union Fall Meeting, San Francisco, 5-9 December.
Sternberg, R.S., Samuels, R., Feinberg, J.M., Shackley, M.S., 2014, Magnetic properties of a new obsidian source, west Antelope Creek, Grant County, New Mexico:American Geophysical Union Fall Meeting, San Francisco, 9-13 December.
Stevenson, C.M., and M. Klimkiewicz, 1990, X-Ray fluorescence analysis of obsidian sources in Arizona and New Mexico: Kiva, v. 55, p. 235-243.
Wilson, I., and Pollard, A.M., 2001, The provenance hypothesis, in Brothwell, D.R., and Pollard, A.M., eds., Handbook of archaeological sciences: New York, John Wiley, p. 507–517.