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Provenance analysis of porphyritic volcanic materials in San Diego using portable X-ray Fluorescence

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ABSTRACT

Geochemical research using aphanitic volcanic rocks such as basalt and obsidian has long contributed to archeological understanding. Porphyritic materials have proven less amenable to methods of compositional analysis largely due to their complex structure. Under some circumstances, similarities in structure can mask geochemical signatures indicative of localized formations. Fine-grained volcanic materials comprise the majority of lithic assemblages in San Diego County, California, yet include a wide variety of geologic formations that each contains rocks with similar structural features and quality for producing lithic tools. This combination of diversity and overlapping structure have led to a dominant assumption that materials were either locally procured from the nearest available source of tool stone, or attributed to the Santiago Peak Volcanic formation as a known source of high-quality fine-grained volcanic materials. This study investigates the potential for using pXRF for provenance research on fine-grained volcanic materials in southern California. Results indicate that volcanic materials can be suitably discriminated using pXRF that sourcing porphyritic volcanic materials is possible and can be applied to archeological assemblages.

1. Introduction

Research into the utilization, transport, and trade of lithic artifacts has traditionally focused on exotic items, such as obsidian and cryptocrystalline silicates, which are not available within geological formations in proximity to a given archeological site. An approach focusing on exotic materials often includes an informal assumption, such that any materials similar to local geological formations must have their origins within those formations. Without verification, assumptions may serve to obscure more localized movements of peoples and lithic materials, and unintentionally bias research towards inferences of limited or localized patterns of land use in prehistory.

Analysis of obsidian and homogenous fine-grained volcanic (FGV) lithic materials using X-ray Fluorescence (XRF) has been repeatedly demonstrated as being useful for provenance research, while efforts using complex banded or porphyritic volcanic materials have been limited (Grave et al., 2012; Pollard et al., 2007; Potts and West, 2008; Shackley, 2011). San Diego presents a difficult challenge in respect to determining both material types and origins (Dietler, 2004). In San Diego County three major sources exist for locally derived volcanics with Santiago Peak Volcanics/Metavolcanics, Jacumba/Table Mountain Volcanics and the Lusardi Formation. Porphyritic materials from these formations generally have a fine-grained groundmass suitable for flaking, but vary in grain size, consistency, and phenocrysts of variable size and spacing within the matrix. The spacing of non-conformities and phenocrysts is frequently larger than the analytical volume (surface area and penetration depth) for XRF. While not the preferred homogeneous matrix, there appears to be suitable groundmass accessible for geochemical analysis.

The presence of multiple related volcanic formations of varying consistency and quality for producing functional lithic tools makes identifying patterns of lithic procurement and possible movements difficult. Generic categories of "volcanic" or made attempts at attributing sources, such as Santiago Peak, based solely on visual cues are pervasive in the San Diego region (Dietler, 2004). This may well be effective, but concerted efforts at demonstrating the effectiveness of these visual classifications have been lacking. There is also the problem of variation in the colors and characteristic grain structure within known geological formations in the region. Depending on the individuals' familiarity with San Diego area geology, the effective classification of materials will be limited. The basic question is whether or not another means of differentiating between different lithic material sources with similar visual and physical properties?

In the current study the overall goal was to examine the geochemical relationships and affinities between some of the more commonly occurring types of volcanic materials and to test the potential relationships between a lithic material typology based upon visual attributes as well as chemical affinities. Portable XRF (pXRF) has been effectively demonstrated on a variety of archeological materials and is growing in use on

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archeological materials through a combination of portability, speed, and ease of use (Potts and West, 2008; Shugar and Mass, 2012). In order to assess the feasibility of using pXRF to differentiate between known geologic formations and potential for provenance analysis using FGV materials, samples of reference materials ($n = 239$) and archeological debitage ($n = 59$) were collected from throughout San Diego County (Table 1). The focus was on the Santiago Peak and Table Mountain Formations as they both contain fine-grained materials suitable for flaked stone production, have similar physical properties, and range in colors from green to black.

Promising results from the preliminary test of feasibility demonstrated that geochemical differentiation exists between Santiago Peak and Jacumba Volcanics, led to a full case-study of provenance analysis of archeological lithics in southern California. Analysis of archeological samples identified the surprising movement of FGV materials from the Otay Mesa area eastward into desert areas around Jacumba.

2. Relevant geological formations

The most commonly used lithic materials in archeological collection in San Diego County, through all periods of prehistory, has been volcanics. There are however several different volcanic formations, including both primary tabular deposits and secondary cobble deposits producing materials that include andesite, basalt, dacite, "felsite," rhyolite, and metavolcanics (McFarland, 2000). Materials reported as felsite are often misidentified examples of Bedford canyon metasedimentary, Piedra de Lumbra (PDL) Chert, Lusardi Formation metavolcanics, or metamorphosed tuff found in various deposits.

2.1. Santiago Peak Volcanics

The dominant primary geologic unit in San Diego County is the Santiago Peak Volcanic formation (Fig. 1) that also contributes greatly to secondary cobble deposits throughout the county. The Santiago Peak Volcanics comprise an elongated belt of mildly metamorphosed volcanic, volcaniclastic, and sedimentary rocks that crop out from the southern edge of the Los Angeles basin southward into Mexico (Hanna, 1926; Kennedy and Peterson, 1975). The volcanic rocks range in composition from basalt to rhyolite but are predominantly dacite and andesite. The succession is typified by a wide variety of breccia, agglomerate, volcanic conglomerate, and fine-grained tuff and tuff breccia. They were originally named "Black Mountain Volcanics" for exposures in the northeast part of the area, but were re-named Santiago Peak Volcanics as the name "Black Mountain" was pre-empted (Hanna, 1926; Kennedy and Peterson, 1975; Larsen, 1948).

Table 1
Geologic formations and archeological sites sampled in this study.

Site	No. of samples
Reference samples	
Border Fields	20
Dictionary Hill	15
Lake Hodges	27
Lusardi Formation	16
Jacumba Road Grade	24
Otay Mesa 1	10
Otay Mesa 2	18
San Marcos Creek	25
Vista	17
CA-SDI-6776	10
CA-SDI-7030	18
CA-SDI-7060	18
CA-SDI-7074	11
CA-SDI-19303	10
Unknown archeological artifacts	
CA-IMP-103	12
CA-IMP-3784	6
CA-SDI-4788	4
CA-SDI-19018	1
CA-SDI-19281	20
CA-SDI-19293	1
CA-SDI-19304	4
CA-SDI-19364	4
CA-SDI-19851	5
CA-SDI-19853	2

The Santiago Peak Volcanics are hard and extremely resistant to weathering and erosion, occur along the Peninsular Range and foothills from the Santa Ana range in Baja California to Orange County, but is most common in the vicinity of Otay Mountain (see Dietler, 2004 Fig. 2) and form elevated peaks immediately east of the area at Black Mountain (Kennedy and Peterson, 1975; McFarland, 2000). This material varies widely in color, from light gray-green (sometimes incorrectly identified as felsite) to black, with most of the volcanic rocks exhibiting dark greenish gray where fresh and grayish red to dark reddish brown when weathered. Age estimates have varied from the Late Triassic, to the Mid-Cretaceous, but have been revised to the latest (Portlandian) Jurassic (Dietler, 2004; Fife et al., 1967; Kennedy and Peterson, 1975; Milow and Ennis, 1961).

2.2. Jacumba Volcanics

The "Jacumba Volcanics" or "Table Mountain Gravels" refers to a complex series of basaltic volcanic flows and dikes, cinder cones, ash deposits, volcanic debris flows, volcanic plugs, and breccias, forming thick (up to 500 feet thick) "piles" or mesa-like lava flows (May, 1976; Minch and Abbott, 1973). The mesa-like surfaces of Table Mountain represent erosional remnants of once-extensive lava flows, while the Mountain itself is sedimentary. Round Mountain, near Jacumba, is a remnant basaltic plug of an extinct volcano. Jacumba Volcanics are exposed and accessible around the margins of Jacumba Valley and to the northeast in proximity to Table Mountain (Laylander and Christenson, 1994; May, 1976). The formation was deposited during the early Miocene approximately 18 Ma ago (Brooks and Roberts, 1954; Strand, 1962; Todd, 2004).

The Jacumba Volcanics overly the Table Mountain Formation and are often associated in exposures with the yellowish and reddish brown, medium to coarse-grained sandstones (Minch and Abbott, 1973). The Table Mountain Formation is the remnant of an extensive fluvial deposit and contains clasts of local granite, intrusive gabbro and mixed granitic–metamorphic rocks often used in thermal features such as hearths and roasting pits (Brooks and Roberts, 1954; May, 1976; Strand, 1962). Lithics used for the production of chipped tools include fine-grained basalts of black and gray, porphyritic andesites, as well as low-grade green metavolcanics and metasedimentary rocks. These latter greenish rocks are similar in appearance to and often confused with Santiago Peak Volcanics, but are generally of lower quality and rarely exist in clasts larger than 30 cm, though this original size does little to help archeologists examining finished tools or debitage (May, 1976; Minch and Abbott, 1973).

2.3. Lusardi Formation

The Lusardi Formation has presented an interesting challenge to archeologists in San Diego County. The formation itself comprises an alluvial fan deposit of reddish brown cobble and boulder conglomerate with muddy sandstone interlayers, with outcrops in east Carlsbad, Rancho Santa Fe, east Poway (Poway Grade), northeast of San Vicente Reservoir and Alpine, dating to approximately 90–75 Ma ago (Abbott, 1999; Nordstrom, 1970). The largest and most abundant clasts include coarse-grained diorite, quartz diorite, and medium-grained granodiorite, as well as a variety of very fine-grained, greenish-gray, and dark-gray metamorphosed tuff (Kennedy and Peterson, 1975). Some of these clasts exhibited finely crenulated flow-banding, while others are very fine-grained black hornfels and volcanic rocks. The combination of sedimentary, metamorphosed, and volcanic materials intermingled