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Reconstructions of local resource procurement networks at Cerro Baúl, Peru using multispectral ASTER satellite imagery and geospatial modeling

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ABSTRACT

Multispectral remote sensing is increasingly common in archaeology, but is largely oriented towards site-detection applications. A high-resolution approach using ASTER data to map environmental and geological resources in the vicinity of Cerro Baúl is outlined here. Spectral mapping evaluates several band ratio and relative band depth image transforms that target diagnostic reflectance/absorption features of earth materials. Available geological resources had a high degree of spatial heterogeneity, which conditioned household strategies for obtaining raw materials. However, some variability cannot be explained by the geological environment alone. Using Minimum Convex Polygons and Kernel Density home-territory estimates, I outline the spatial organization of resource networks that differed from household to household. Differences in household resource networks suggest that socio-economic factors conditioned the use of materials, including locally-available ones. These results demonstrate the utility of multispectral remote sensing to construct palaeoecological models on a scale congruent with archaeological questions.

1. Introduction

Satellite remote sensing is an increasingly significant archaeological research method. Early interest in remote sensing focused on utilizing spectral data, particularly from the Landsat family of sensors, to characterize environmental resources in areas of archaeological interest (e.g., Cox, 1992; Custer et al., 1986; Pope and Dahlin, 1989). While this continues to be an application, much use of multispectral information in archaeology has shifted its focus predominantly towards detecting archaeological sites. Such "site detection" approaches represent the majority of more recent archaeological remote sensing programs (see, e.g., Comer and Harrower (2013); Lasaponara and Masini (2012a); Rowlands and Sarris (2007)).

Despite initial enthusiasm about the potential of multispectral remote sensing, the focus on site detection has had a number of implications: some of these effects are positive (such as the improvements in detection methods) while others have distracted from the wider application of remote sensing to archaeological problems. The effective spatial resolution of early remote sensing platforms superseded the nominal on-the-ground footprints of many individual archaeological features, making it difficult to resolve sites. This led to some initial frustration with multispectral data. As higher spatial resolution imagery became available, remote sensing archaeology naturally gravitated towards these data. The radiometric resolution of earlier high spatial resolution platforms—their capability to resolve different bandwidths of light as discrete channels—was reduced compared with lower spatial resolution, higher radiometric resolution platforms, however. The amount of electromagnetic radiation a sensor can resolve is a limiting factor. Spectral resolution is defined as the number, position, and spectral widths of each band in an imaging sensor, while spatial resolution is the effective ground area imaged by one pixel. Tradeoffs between spatial and spectral resolution arise from problems of resolving limited electromagnetic radiation in higher wavelengths over a decreased Instantaneous Field of View (IFOV). As the IFOV decreases (increasing spatial resolution), the amount of detectable electromagnetic reflectance decreases, requiring sensors with narrower IFOV to be sensitive to a broader reflectance bandwidth (reducing radiometric resolution). High spatial resolution sensors (sub-meter to meters) operate in the panchromatic and visible–near infrared spectra, with low spectral resolution ($\leq$5 bands). Conversely, higher spectral resolution satellite platforms offer significantly more spectral data at longer wavelengths ($\geq$5 bands and bands beyond the NIR range), but at the cost of lower spatial resolution (15–90 m).

The interest in very high-spatial resolution sensors for site detection applications has meant that the dimension of spectral resolution is relatively underutilized in archaeological remote sensing. With a few recent exceptions (e.g., Menze and Ur, 2012; Lasaponara and Masini, 2012b; Altaweel, 2005), analysis of archaeological effects on spectral reflectance (of earth materials, vegetation, and the features themselves)

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beyond the visible wavelengths is underdeveloped. An important area of application that wants development is the use of spectral data to generate robust environmental datasets, particularly high-resolution geological and soil mapping, that advance archaeological analyses (Deroin et al., 2011; Siart et al., 2008, 2009). While environmental mapping was one of the earliest applications of archaeological remote sensing, the focus on site detection has shifted attention away from this area. Using spectral data to delimit environmental variables is the strong suite of remote sensing. It should be more common in archaeological programs as a complement to robust palaeo-ecological analyses.

The objectives of this paper are threefold: First, it describes the use of remotely-sensed multispectral ASTER imagery to map highly-variable, localized resources around the site of Cerro Baúl (Peru) with spatial precision. I evaluate a number of image processing logical operators (band ratios and relative band depth transforms) for enhancing the detection of geological materials in the vicinity of Cerro Baúl. Such high resolution mapping helps reconstruct socially-embedded resource procurement networks on a local level. Second, using geospatial Utility Distribution modeling, I link the availability of geological resources with their utilization across several archaeological households. Resource strategies can be reconstructed on a scale that would be impractical otherwise, and substantive differences in local resources strategies can be recognized among the households. Finally, by developing this approach, this work aims to draw attention to the importance of spectral information in archaeological applications. While multispectral data are increasingly utilized, the spectral dimension of these data generally has been poorly understood and too often underutilized. Archaeological remote sensing lags behind other applications of multispectral and active sensor datasets, and more development of spectral analysis in archaeological remote sensing is needed.

2. The study location

2.1. Archaeological setting

Cerro Baúl (17.116° S, 70.85° W) is a tableland formation in the Moquegua Valley, southern Peru, which was occupied during the Middle Horizon period (ca. AD 500–1100) (Fig. 1). Moquegua is the only region known where substantial populations of Wari colonists, from the Ayacucho region of Peru, and Tiwanaku colonists, from highland Bolivia, are known to have simultaneously resided. The region consequently is a key locus for interpreting the interactions between these two groups. Archaeological occupations at Cerro Baúl are linked to culturally- and ethnically Wari, Tiwanaku, and (subsequently) Tumilaca groups (Williams, 2001). The summit and slopes of Cerro Baúl were occupied by a Wari imperial enclave (Fig. 2). Individual households that have been excavated show marked indicators of a society that was highly socially-stratified, including differences in socio-economic status, access to foodstuffs and material commodities through long-distance trade (Williams, 2001; Moseley et al., 2005; Burger et al., 2000). Stratification, ethnic differentiation, and other socially-negotiated categories intersected to create a complex community at Cerro Baúl. Pluralistic relationships were variably characterized through competition, dominance, negotiation, or ritual performance, and changed dynamically during the course of the site's occupation (Williams, 2001; Sims, 2006; Nash and Williams, 2004).

Social variability was reinforced—perhaps even manipulated—by differential exploitation of resources. Strategies for obtaining raw materials reflect socially mediated territories and interpersonal networks. Material exploitation across the site is highly uneven. Differential access to materials applied to locally-available resources, as well as to long-distance, exotic materials (Vining, 2005; Sharratt et al., 2009). A sample of 12 households at Cerro Baúl, distributed across the summit and slopes of the site, utilized approximately 24 locally-available (i.e., within the Moquegua Valley) lithic raw material types. Shannon–Weaver diversity measures of richness (H) and evenness (J) (Popper, 1988) show a significantly greater use of material varieties by certain households (Vining, 2005: table 5.2). Residences towards the center of the community utilized a greater variety of raw materials, but also show lower evenness. Differences in diversity metrics suggest that the utilization of materials was highly preferential and conditioned by each housholds' capacity to access them. This likely can be attributed to the effects of multiple procurement strategies, such as both direct and indirect mechanisms that incorporated materials from different origins into the household assemblage. These same residences, based on independent criteria, are considered to have been socio-economic elites within the Cerro Baúl community. In contrast, households towards the edges of the Cerro Baúl community enjoyed less diverse, more even suites of material, likely indicating that they were procured locally and with only a single strategy. Richness and evenness indices combined suggest a

Fig. 1. The tableland formation of Cerro Baúl (center), with Cerro Mejía (left foreground). Note the resistant cap of the Upper Tertiary Moquegua Formation that differs from poorly consolidated material underneath.