



In situ shallow subsurface reflectance spectroscopy of archaeological soils and features: a case-study of two Native American settlement sites in Kansas



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ABSTRACT

The results of *in situ* shallow subsurface reflectance spectroscopy surveys at two late 18th – 19th century Native American sites in Kansas contribute to a growing literature on the chemical characterization of anthropogenic features at archaeological sites. Near infrared and visible diffuse reflectance spectroscopy of known sub-soil features (hearths, storage pits, earthlodge walls, living surfaces, and defensive palisades) yielded characteristic signatures distinguishable from background spectra of adjacent locations. The spectra, obtained by insertion of a reflectance probe into the ground to depths up to 1 m at a series of locations, are further correlated with: electrical resistivity and magnetic gradiometry surveys; electrical conductivity and insertion force (soil compaction) contour plots; organic carbon, phosphorus, magnesium, and calcium spectra from analysis of core samples; and archaeological features recorded via excavation. The close spatial correlation of the spectroscopic data with known archaeological features supplements traditional topographic, surface, and subsurface geophysical survey methods by providing chemical information about ancient features and activity areas. The *in situ* recording of data has significant advantages over laboratory-based analyses.

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1. Introduction

1.1. Objectives

This paper presents the results of an emerging technology for archaeological prospection that records shallow subsurface optical spectra of soils and anthropogenic features using a mobile instrument with probes connected by fiber optics to visible and near-infrared spectrometers. Subsurface survey at two field sites in Kansas produced spectral signatures of interest recorded as a function of depth and at defined spatial intervals across several archaeological features, allowing the mapping of features and their chemical characterization without excavation. The results of this study complement archaeological field techniques already

employed at the Kansas sites and demonstrate the potential for shallow subsurface spectrographic survey to provide a chemical characterization of *in situ* archaeological deposits over a broad spectral wavelength range for a number of archaeological contexts. The two test sites in Kansas are both historic period Native American sites with a number of typical settlement features: hearths, storage pits, earthlodge walls, living surfaces, and defensive palisades and had already been the subject of considerable archaeological investigation. The detailed existing archaeologically documented features at these sites allowed for the correlation of the reflectance spectra and other measured properties taken in the field with unambiguous targets of archaeological interest.

1.2. Geochemical prospection in archaeology

Chemical analyses of soils derived from archaeological contexts and features have been in general use for over half a century. Early

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applications in archaeology involved testing phosphorus and nitrogen concentrations to find distribution patterns indicative of past human activities such as trash disposal, the penning of animals, and soil fertilization. Such studies required archaeological excavation to expose primary contexts and the use of either field soil kits for limited *in situ* testing, or the transportation of core or hand-collected samples to laboratories for detailed analysis (Eidt, 1973; Hassan, 1981; Pollard et al., 2007). While the chemical testing of residues from artifacts and features is well-established in archaeological laboratory settings, *in situ* chemical testing of soils and features remains methodologically underdeveloped. Recent work by Dalan et al. (2011) has examined spectral data related to features recovered via geophysical survey, although our approach described below differs significantly from theirs, which reduces the spectra to intensity ratios of visible light components.

1.3. Soil spectroscopy in geological and archaeological studies

Soil can be defined as a natural, three dimensional body formed at the earth's surface (Schaeztl and Anderson, 2005). Soil properties vary considerably over short distances both vertically (soil horizons) and horizontally, responding to variations in climate, biota, relief, parent material, and time (Jenny, 1941). Anthropogenic soils form an important component of the archaeological record and represent a specific target of our inquiry. Spectroscopic techniques have been applied to the analysis of soil properties outside of archaeology beginning at least in the 1980s, but their use, especially involving diffuse reflectance of the visible and near infrared (hereafter NIR) portion of the spectrum, has only recently increased (Stenberg et al., 2010; Reeves, 2010; Bellon-Maurel and McBratney, 2011; Stenberg, 2010). Advantages of spectroscopic techniques over traditional chemical or physical analyses include minimal sample preparation (Guerrero et al., 2007; Viscarra Rossel et al., 2011), speed of analysis, and minimally invasive use of samples (Stenberg et al., 2010).

Most commonly, spectroscopic studies of non-archaeological soil targets have involved some form of reflectance spectroscopy performed in different parts of the spectrum. Most soil studies have measured reflectance in the visible (400–700 nm) and NIR (700–2500 nm) wavelengths, though some have chosen to employ the mid infrared (hereafter MIR) (2500–25,000 nm) (Reeves, 2010). Problems with overlapping absorption of soil constituents in the visible and NIR are often addressed through calibration using a variety of multivariate statistics or chemometric analyses (Stenberg et al., 2010; Ben-Dor et al., 2008a; Vasques, et al., 2008; Viscarra Rossel and Behrens, 2010; Mouazen et al., 2010; Fidencio et al., 2002). While laboratory-based MIR spectroscopy can have some interpretive advantages over visible and NIR spectroscopy of soil targets, e.g., many materials have their fundamental vibrations in the MIR wavelengths, including mineral components like quartz that has a strong MIR signal, but none in the NIR (Reeves, 2010; Janik et al., 1998) there are a number of difficulties in field use of MIR. The present study is limited to work in the visible and NIR spectra.

In the visible portions of soil spectra, absorption features are primarily associated with iron-bearing minerals (Stenberg et al., 2010), including second-derivative peaks at around 420 and 535 nm (Sellitto et al., 2009). An iron (Fe) absorption band around 900 nm has also been shown to be useful in modeling Fe content of soils (Richter et al., 2009). Hydroxyl groups in water and other compounds have narrow, well-defined absorption bands near 1400 and 1900 nm (Viscarra Rossel et al., 2011). Organic matter has a broad absorption throughout the visible and NIR wavelengths; thus, soils with high organic matter content tend to have lower overall reflectance (Stenberg et al., 2010; Viscarra Rossel et al., 2011,

Bartholomeus et al., 2008). Other soil constituents with identifiable absorption features in the visible and NIR wavelengths include carbonates (Stenberg et al., 2010) and clay minerals (Stenberg et al., 2010; Viscarra Rossel et al., 2011; Leone et al., 2011; Kariuki et al., 2004). Stenberg et al. (2010) caution that the position of these absorption bands can vary with composition.

Laboratory-based studies using visible and NIR spectroscopy have been shown to be useful for estimating a wide variety of soil constituents. Soil organic matter content has been commonly investigated (Stenberg et al., 2010; Jarmer et al., 2008; Dalal and Henry, 1986; Konen et al., 2003). Researchers have also had some success in characterizing various structural components of the organic fraction using visible and NIR spectroscopy (Terhoeven-Urselmans et al., 2006). Other studies have used visible and NIR spectroscopy to simultaneously estimate a number of different major and minor chemical constituents, including total carbon (C), total nitrogen (N), calcium carbonate, calcium (Ca), potassium (K), magnesium (Mg), Fe, and copper (Cu) (Viscarra Rossel et al., 2011; Terhoeven-Urselmans et al., 2006; Middleton et al., 2011; Cozzolino and Moron, 2003; Chang et al., 2001; Ben-Dor and Banin, 1995), carbonate content (Summers et al., 2011), moisture content (Ben-Dor et al., 2008a; Lobell and Asner, 2002; Liu et al., 2003), and soil texture (Stenberg et al., 2010; Summers et al., 2011). It is important to note that much of the work referenced above speaks to the compounds and elements *per se*. As outlined below, our primary interest is in the difference spectrum – that is, the difference between the archaeological feature and adjacent or “background” soil. A sufficient signal-to-noise ratio and adequate contrast relative to the background will be required to identify and map chemical targets of archaeological interest.

Less commonly, reflectance spectroscopy has been used to investigate soil properties for agricultural or other industrial purposes. For example, a portable visible spectrophotometer has been used on the face of a soil pit (Barrett, 2002). Other studies have performed measurements in the field directly on soil cores (Wills et al., 2007; Kusumo et al., 2011; Waiser et al., 2007). Most of these have found prediction levels comparable to those in laboratory-based studies. Other existing commercial instruments have been designed to be dragged behind a tractor over, or just below, the soil surface in order to produce a map of the variation in soil properties over the space of an agricultural field (Huang et al., 2007; Christy, 2008; Barnes et al., 2003; Mouazen et al., 2005; Mouazen et al., 2007). These instruments have typically been used to estimate soil organic matter content, although there has also been some success with mapping soil total C, moisture levels, pH, and P (Mouazen et al., 2007). Also included in this category is a multisensor instrument with a shank capable of sensing visible and NIR reflectance, electrical conductivity, and soil temperature at the soil surface (Knadel et al., 2011). Two prototype instruments mounted on a probe capable of insertion downward into the soil have been reported (Ben-Dor et al., 2008b; Chang, et al., 2011).

2. Native American Archaeology

2.1. Kansas Monument Site (14RP1)

Lying atop a bluff overlooking the Republican River valley, the Kansas Monument site represents the remains of a mudlodge village of the Kitkahahki band of the Pawnee Nation. Documentary evidence attributes the site occupation to ca. 1770–1802, or possibly 1809 (Roper, 2009). The full extent of the site is not securely known but is estimated at 3.0 ha; modern land-use has truncated portions of the site. The northern portion of the Kansas Monument village is preserved as a state historic site with a

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