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Integration of intensity textures and local geometry descriptors from Terrestrial Laser Scanning to map chert in outcrops

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ABSTRACT

The potential of Terrestrial Laser Scanner imaging (TLS) as a tool to map chert, an amorphous variety of silica diffused in sedimentary rocks, is here discussed together with an original method for its automatic detection. Reflectance measurements in the VIS-NIR band (400–2500 nm) show that chert displays low reflectance in the IR wavelengths that are operated by several commercial TLS. To develop and test a recognition method an outcrop of limestone with chert nodules was scanned with an IR (1541 nm) TLS. The intensity information, after proper distance correction, was coupled with geometric and intensity descriptors for training Support Vector Machines (SVM) to separate vegetation from rock and limestone from chert. Results, cross inspected in the field and with reference pictures, demonstrate that TLS data can be efficiently exploited to map chert when the monochromatic information of the intensity is integrated with feature descriptors and SVM classifiers.

1. Introduction

Chert is a widespread sedimentary rock made of cryptocrystalline varieties of silica. Its origin is mainly biogenic, deriving from the settling of siliceous skeletal parts of microorganisms through the water column on the seafloor and its subsequent transformation into a stable form during early sediment burial. Chert usually occurs in the form of nodules of various size and shape, or in layers (Fig. 1), embedded and often scattered within carbonate rocks. Silica occurs in chert in various mineralogical forms, including chalcedony, microcrystalline quartz, amorphous silica (opal-A), disordered cristobalite and tridymite (opal-CT) (Boggs, 2009; DeMaster, 2004). Chert constitutes a research topic for geologists, because its presence, absence and abundance can be related to sedimentary processes, past climatic changes and may help reconstructing the events in the environmental evolution of Earth (e.g., Ikeda et al., 2010; Batenburg et al., 2012).

Chert is commonly embedded in limestone. Limestone rocks are routinely used as component for concrete aggregates and the presence of chert can affect concrete quality and durability because of Alkali-Silica Reactions (ASR) (Bektas et al., 2008) or thermo-mechanical weathering (Xing et al., 2011) that may occur after concrete hardening. The amount of chert must then be monitored. This can be done directly on the aggregates (for example via image analysis, see Castro and Wigum (2012) or via petrographic methods, see Sims and Nixon (2003) but also a pre-evaluation on the quarry wall could provide useful information on the expected properties of the final product. The evaluation of chert abundance in outcrops can be, however, difficult and time consuming because chert is often scattered and can be very similar to the host-rock in color. In this paper we illustrate a method aimed at quickly quantify and accurately map chert directly on the outcrop using terrestrial laser scanning (TLS).

The application of remote sensing techniques to discriminate various types of rocks in outcrops has been explored in several works in the last few years. Satisfactory results have been achieved using passive hyperspectral imaging sensors coupled, when necessary, with terrestrial laser scanning or photogrammetry to provide

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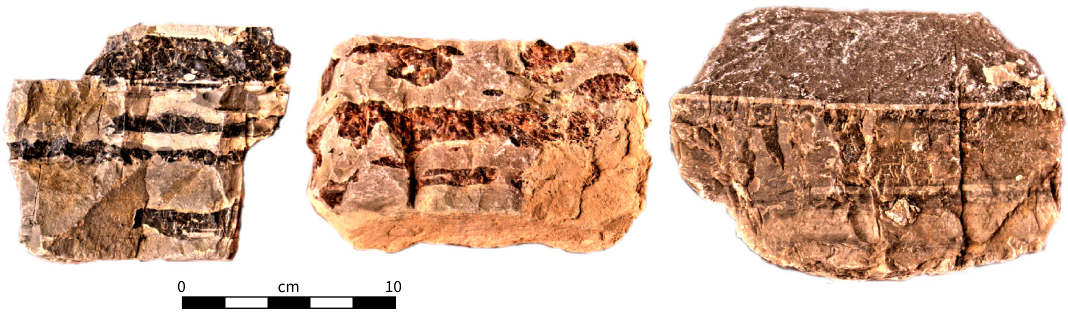

Fig. 1. Hand-sized chert samples and host rocks. Chert aspect varies from highly scattered (center) to a more hybrid banded and scattered geometry (left) to single, wide bands. Colors vary from black to yellow and brown, sometimes it is hardly distinguishable from its host rock due to similarity of colors (right). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the 3D framework for the hyperspectral information (Kurz et al., 2012, 2013; Murphy and Monteiro, 2013). Hyperspectral imaging operates in the short wave infrared (SWIR) range (1000–2000 nm), with ~5 nm typical frequency resolution, and therefore provides good results because the main spectral features of geological materials fall in this range. Nevertheless, the currently achievable spatial resolution is not better that some cm for a 50 m acquisition distance, limitations related to the use of passive sensors exist (e.g., necessity of radiometric calibration and dependence on conditions of illumination) and accurate registration on 3D models is necessary to facilitate quantification of material distribution and spatial relationships. This imaging technique is expected to gain increasing importance in the future because of technological and methodological developments.

TLS is an active sensor that produces an accurate, high-resolution 3D representation of an object in the form of a point cloud. Besides spatial information, each point carries an intensity value of the backscattered laser signal, that is function of the reflectance properties of the target. When chert is scanned with a TLS operating in the IR band, it displays low intensity values with respect to its host rock (typically limestone). In this paper we demonstrate that this feature, in association with the geometrical information carried by TLS data, can be exploited in order to map chert. Several papers investigated the potential of TLS for discrimination of rocks (Bellian et al., 2005; Pesci and Teza, 2008; Burton et al., 2011; Hodgetts, 2013). Franceschi et al. (2009, 2011) discuss the potential use of intensity as a proxy of rock properties. Outside the fields of geology the study of TLS intensity has been undertaken to detect damaged areas on historical buildings (Armesto-González et al., 2010), to quantify moisture content in aeolian sand deposits (Nield et al., 2011) and to identify biological crusts on structures (González-Jorge et al., 2012). The fact that commercial TLS usually work with a single-wavelength laser results in a minimal spectral information carried by the intensity signal, Hartzell et al. (2014) recently proposed to combine multiple TLS working at different wavelengths in the intent of overcoming this limitation.

Also the problem of segmenting point clouds on the base of geometric properties was faced by many authors, especially for airborne laser scanning data (Maas and Vosselman, 1999; Verma et al., 2006) and for mobile applications (Yang et al., 2013; Pu et al., 2011), for automating vehicle navigation (Lalonde et al., 2006) and for forestry applications (e.g., Koch et al., 2009; Ferraz et al., 2012; Brandtberg, 2007). Hybrid methods using geometry and colors or intensities were demonstrated to be useful in various scenarios improving the effectiveness of the classification algorithm (Höfle et al., 2009; Schoenberg et al., 2010). Although highly automated methods (both supervised and unsupervised) have reached high levels of complexity and effectiveness, they are still sparsely used to solve automated data collection tasks in geology (Brodu and Lague, 2012; Abellán et al., 2014; Ferrero et al., 2009; García-Sellés et al., 2011) where point clouds are often used for visual inspection and interpretation, due to the difficulty in extracting meaningful and coherent information from that huge amount of data.

In this work we show that the spatial characteristic of a point cloud (e.g., local geometric arrangement of points) as well as the spatial distribution of the intensity values can be used to enhance the potential of TLS as a tool for the discrimination of rocks. The proposed TLS-based approach contributes to the emerging studies on the application of active sensors as remote sensing tools through supervised classification, using both geometry and intensity descriptors in a combined way. It might as well have important practical implications, ranging from stratigraphy and cyclostratigraphy to rock quality evaluation.

2. Methods

2.1. Spectral and mineralogical characterization of chert

To assess the spectral behavior of chert a set of 6 chert samples together with their corresponding host rocks (limestone) were analyzed with a spectrophotometer. All samples are made of micro-crystalline quartz, by far the most common variety of chert. Reflectance spectra were investigated in the 400–2500 nm wavelength range with a spectral sampling step of 1 nm using a Cary5000 spectrophotometer. The device is manufactured by Varian and performs reflectance measurements from 200 to 2500 nm via a deuterium/halogen double light source, using an internal integrating sphere for diffuse reflectance measurements.

The samples for reflectance spectra measurement were prepared as ~2×4 cm slabs, cut with water-cooled circular saw, with no further preparations. The slabs were kept for several days at environmental humidity conditions before measurements.

2.2. TLS acquisitions

As target for testing the method an outcrop cut in cherty limestone (Fig. 2) was selected in Central Italy, nearby Gubbio.[2] The scanned rocks (Maiolica Formation) are white micritic limestone in which chert is commonly found as centimeter to decimeter-sized nodules or layers of variable continuity. Chert color varies a lot (from white to black, red, yellow, etc.) and often resembles that of the host limestone. This in many cases makes chert indistinguishable, in the visible band of the electromagnetic spectrum, from the rocks in which it is contained (see Fig. 3)

The outcrop was scanned with an Optech ILRIS-3D TLS whose laser unit emits in the infrared band at 1541 nm wavelength

[2] 43.360457N, 12.579775E.