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Spectral properties of volcanic materials from hyperspectral field and satellite data compared with LiDAR data at Mt. Etna

Claudia Spinetti [a,*], Francesco Mazzarini [b], Ruggero Casacchia [c], Laura Colini [a], Marco Neri [d], Boris Behncke [d], Rosamaria Salvatori [e], Maria Fabrizia Buongiorno [a], Maria Teresa Pareschi [b]

[a] Istituto Nazionale di Geofisica e Vulcanologia, Sezione CNT, Via di Vigna Murata 605, Roma, Italy
[b] Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa, Italy
[c] CNR, Dipartimento Terra e Ambiente, Roma, Italy
[d] Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania, Italy
[e] CNR, Istituto Inquinamento Atmosferico, Monterotondo Stazione, Roma, Italy

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ABSTRACT

Spectral properties of volcanic materials in the optical region (350–2500 nm) of the electromagnetic spectrum are analyzed. The goal is to characterize air-fall deposits, recent lava flows, and old lava flows based on their spectral reflectance properties and on the textural characteristics (grain size) of pyroclastic deposits at an active basaltic volcano. Data were acquired during a spectroradiometric field survey at Mt. Etna (Italy) in summer 2003 and combined with hyperspectral satellite (Hyperion) and airborne LiDAR (Light Detection and Ranging) data. In addition, air-fall deposits produced by the highly explosive 2002–2003 eruption have been sampled and spectrally characterized at different distances from the new vents. The spectral analysis shows that air-fall deposits are characterized by low reflectance values besides variations in grain size. This distinguishes them from other surface materials. Old lava flows show highest reflectance values due to weathering and vegetation cover. The spectral data set derived from the field survey has been compared to corrected satellite hyperspectral data in order to investigate the Hyperion capabilities to differentiate the surface cover using the reflectance properties. This has allowed us to identify the 2002–2003 air-fall deposits in a thematic image just few months after their emplacement. Moreover, the observed differences in the field spectra of volcanic surfaces have been compared with differences in the signal intensity detected by airborne LiDAR survey showing the possibility to include information on the texture of volcanic surfaces at Mt. Etna. The approach presented here may be particularly useful for remote and inaccessible volcanic areas and also represents a potentially powerful tool for the exploration of extraterrestrial volcanic surfaces.

1. Introduction

Remote sensing data acquired between ultraviolet and microwave wavelength range has proved useful in studying the surface changes of active volcanoes due to emplacement of erupted products (e.g. Mouginis-Mark and Domergue-Schmidt, 2000). In particular, the use of thermal infrared spectral region is very useful during eruptions in studying lava flows and volcanic ashes (e.g. Prata, 1989; Wen and Rose, 1994; Harris et al., 1997; Lombardo and Buongiorno, 2006). The visible and near infrared region of the electromagnetic spectrum are suitable to analyze alteration of volcanic deposits by multispectral and hyperspectral airborne or spaceborne data, as well as field and laboratory spectral data (e.g. Mazzarini et al., 2001; Byrnes et al., 2004; Hellman and Ramsey, 2004; Pieri and Abrams, 2004; Sgavetti et al., 2006; Byrnes et al., 2007). Indeed, spectral field data have been used to support analyses of satellite and airborne data (e.g. Goetz, 1992; Barry et al., 2002). Furthermore, the knowledge of spectral response of volcanic surfaces is helpful in the study of tropospheric volcanic plumes (Spinetti et al., 2003). Although most of the spectral features of silicate are in the thermal infrared region, the use of thermal sensors is limited by their low spatial resolution, whereas they are very effective for high temperature surfaces.

Reflectance spectroscopy is the technique used to analyze spectral data in the visible and short wave infrared region to identify different materials on the basis of their reflectance characteristics. This technique is based on the concept that all surface materials can be characterized by a unique spectral signature, i.e. the absolute reflectance as a function of solar radiation wavelength (reflectance curve), acquired under specific environmental

* Corresponding author. Tel.: +39 06 51860393; fax: +39 06 5041181.
E-mail address: spinetti@ingv.it (C. Spinetti).

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conditions. The unique signature is referred to a specific target structure. In the application of hyperspectral technique on active basaltic volcanoes, it is preferable to construct a specific data set where investigation of field reflectance can be supported by ancillary information concerning the structure of the surveyed targets and the local climatic conditions.

Usually, in the visible and near infrared spectral range mafic rocks are characterized by very low reflectance due to the presence of large amounts of dark mafic minerals (Carmichael, 1982). However, some lava flows can have a similar chemical/mineralogical composition but dissimilar spectral behavior due to the different grain size, surface texture and presence of weathering. The main components of igneous rocks do not display any peculiar spectral features in the visible and near infrared spectral range. In the case of basalts, the only spectral feature commonly found is an absorption peak, due to iron, located around 1000 nm (Carmichael, 1982; Clark and Roush, 1984). However, in the case of hydrothermal alteration, hydroxyl bearing minerals show distinctive absorption features in the 2000–2500 nm spectral region (Hellman and Ramsey, 2004). Until photons impact materials, they are scattered one or more times, some are absorbed and others are scattered (Clark, 1999). However, surface reflectance is a much more complex phenomenon and the photons optical path is a random walk (Hapke, 1993). In the case of a bright grain such as quartz grain at visible wavelengths, most of the photons are scattered and the random walk process can continue for hundreds of impacts. In case of dark grains such as magnetite, all the photons are absorbed in few impacts. The amount of scattered and absorbed light by a grain strongly depends on its size (Hapke, 1993). In the visible and near infrared wavelength region where multiple scattering dominates, lower grain size is proportional to higher reflectance for material with small absorption coefficients.

To investigate the capability of reflectance spectroscopy in discriminating low albedo volcanic surfaces such as those measured at active basaltic volcanoes, we have analyzed three different data sets: field spectral data, medium resolution hyperspectral (Hyperion) and high resolution monochromatic (LiDAR) data.

For this purpose, Mt. Etna (Italy) has been selected as case study site as spectral field survey data and airborne LiDAR and satellite Hyperion data are available. The Hyperion data were acquired in the same period of the field survey (summer 2003) just after the 2002–2003 eruption, whereas LiDAR was acquired in late summer 2004, during a period of very low activity.

In volcanically active areas such as Etna, surfaces are subjected to rapid changes due to the emplacement of new lava flows and pyroclastic deposits (scoriae, lapilli and ash; hereafter referred to as tephra; Behncke et al., 2004, 2006), that generate new surfaces and degrade old ones (Thouret, 1999). Many studies (e.g. Stretch and Viles, 2002 and references there) demonstrate that lava flows are affected by weathering and vegetation growing, especially lichens, more rapidly than other surface areas. This implies that in few years the recent lava flows will start to be weathered and vegetated so that they can be considered as old lava flows. Thus the emplacement of new products transforms the surfaces covering all old lava flows with new younger flows and/or tephra fields.

In summer 2003 Etna was in a quiescent period, after an important eruption that lasted from October 2002 to January 2003. That eruption was characterized by the formation of new cones close to the summit area, and by lava flow emission from fissures on the northeast and south flanks associated with voluminous pyroclastic emission and deposition during explosive phases (Acocella and Neri, 2003; Behncke and Neri, 2003; Andronico et al., 2005; Neri et al., 2004, 2005; Walter et al., 2005; Allard et al., 2006).

This work is aimed at (a) spectrally characterizing old and recent lava flows and tephra, (b) correlating reflectance changes to textural structural features of the measured surfaces (i.e. grain size for tephra), (c) using collected reference spectra for selected ground reference points in order to inspect the hyperspectral satellite and LiDAR airborne sensor capability in identifying different materials in basaltic volcanoes.

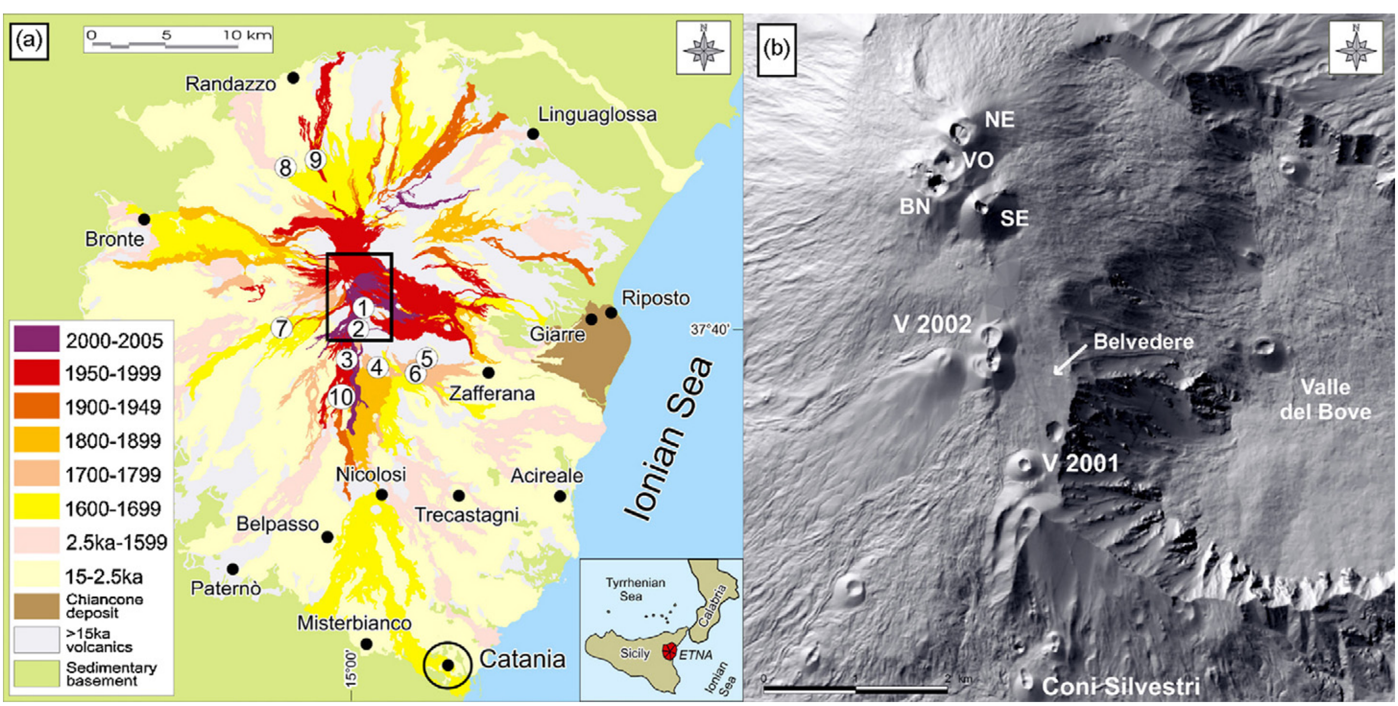

Fig. 1. (a) Mt. Etna location map showing lava flows of various ages and distribution of volcanic and pre-Etnean sediments as well as the ground survey of the measurement sites (see Table 1 for site descriptions). (b) Mt. Etna summit area showing the central craters Bocca Nuova (BN), La Voragine (VO), Northeast (NE), Southeast (SE) and the Belvedere area; the pyroclastic cones formed during 2001 (V 2001) and 2002–2003 (V 2002) eruptions are located in this area.