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Spectral analysis of lava flows: Temporal and physicochemical effects

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Summary. — In a volcanic context, the spectral response of lava flows depends on several endogenous and exogenous factors, like chemical composition, passing of years and weathering. A deeper knowledge about lava properties can be inferred by investigating their spectral response in satellite images. Here, we compare the spectral response of lava in time, physical, and chemical characteristics, inspecting visible to infrared high spatial resolution ESA Sentinel-2 satellite images of different volcanoes. Our results show increasing and decreasing patterns of the lava spectral response as a function of time and physicochemical composition.

1. – Introduction

The spectral response [1] is the absolute reflectance or radiance as a function of solar radiation wavelength, acquired under specific environmental conditions. In volcanic areas, a deeper knowledge about properties of a lava flow can be inferred by investigating this spectral measure. Moreover, the growing number of satellite images available allows exploring the spectral characteristics of lava flows from space [2]. This measure is affected by several factors, exogenous, mostly associated to the passing of years, like weathering, and endogenous, like chemical composition and physical characteristics. In particular, old basaltic lava flows have a higher value of reflectance compared to the younger ones. Changes are mostly due to weathering and revegetation, to physical properties, *e.g.*, lava texture and viscosity, and to chemical composition, *i.e.*, content of silica (ultrabasic, *e.g.*, foiditic case, basic, *e.g.*, basaltic case, intermediate, *e.g.*, andesitic case, and acid, *e.g.*, rhyolitic case) [3-6].

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Here, we investigate a variety of lava spectral responses from different volcanoes worldwide, conducting a temporal-, physical-, and chemical-based analysis. We exploit the theoretical basis of physical-mathematical models for the surfaces spectral response and satellite images, to search for specific patterns linked to factors affecting the spectrum.

2. – Methodology

Several volcanoes are selected, *i.e.*, Mt. Etna, in Sicily (Italy), Cumbre Vieja, in La Palma (Canary Islands, Spain), Geldingadalir, in Reykjanes Peninsula (Iceland), Volcán de Colima, between Colima and Jalisco (Mexico), and Puyehue-Cordón Caulle volcano (Chile), to compare the spectral response of different kinds of lava. The data used come from the Sentinel-2 satellites (S2) from the European Space Agency (ESA) Copernicus mission, a couple of identical satellites launched in 2015 and 2017 (S2A, S2B) [7]. We analyze the S2-MSI Top of Atmosphere (TOA) reflectance data. All the spectral responses are collected via Google Earth Engine (GEE) [8].

We capture the spectral response of the points for the S2-MSI TOA reflectance bands between the visible and the infrared, *i.e.*, blue, green, red bands (spatial resolution 10 m), red-edge bands (spat. res. 20 m), and near infrared band (spat. res. 10 m). For each volcano investigated, we consider two samples with a neighborhood of radius 20 m, *i.e.*, the area covered by recent lava flows ("lava"), and the surrounding older volcanic rocks ("background"), as control area, and we monitor the evolution of the spectral response for each sample. Firstly, we conduct a temporal analysis focusing on lava spectral changes in time (years), investigating the basaltic lava flow erupted at Mt. Etna on 27 October 2002 from a lateral fissure. Secondly, we conduct a physical analysis comparing the eruptions occurred in 2021 at volcanoes with similar chemical composition (ultrabasic-basic) and different physical properties, *i.e.*, Etna on 23 October 2021, Cumbre Vieja on 19 September 2021, and Geldingadalir on 19 March 2021. Finally, we analyze the spectral response in time of lava flows with different chemical composition, *i.e.*, basic, intermediate, and acid one, with samples from basaltic 27 October 2002 Etna eruption, andesitic 22 February 2002 Colima eruption and rhyolitic 04 June 2011 Cordón Caulle eruption [9-17].

3. – Results

Temporal changes of the spectral response of the basic lava flow emplaced at Mt. Etna in 2002 are shown in fig. 1(a), (a′). In this case, it is possible to see that the spectral response of Etnean basaltic lava increases significantly with the passing of time (years) and a similar trend is not present in the background. Moving to the intermediate and acid case, we found that the lava spectral response has an opposite trend, decreasing with the passing of time. This degrowth trend is observable in 2002 andesitic Colima (fig. 1(b), (b′)) and 2011 rhyolitic Cordón Caulle (fig. 1(c), (c′)) lavas (not for background). In addition, a physical analysis was conducted to investigate the changes of the spectral response of recent lavas erupted in 2021 from ultrabasic-basic volcanoes (*i.e.*, Mt. Etna, Cumbre Vieja and Geldingadalir), placed in different locations and with different physical features (*e.g.*, mean thickness: Etna ∼2 m (INGV weekly bulletins at `www.ct.ingv.it`), Cumbre Vieja ∼12 m [14], Geldingadalir ∼30 m [15]). For the lava case (fig. 2(a)), the reflectance curves are confined to a far narrower range than the background one (fig. 2(a′)) (max variation 330 and 1130, respectively).

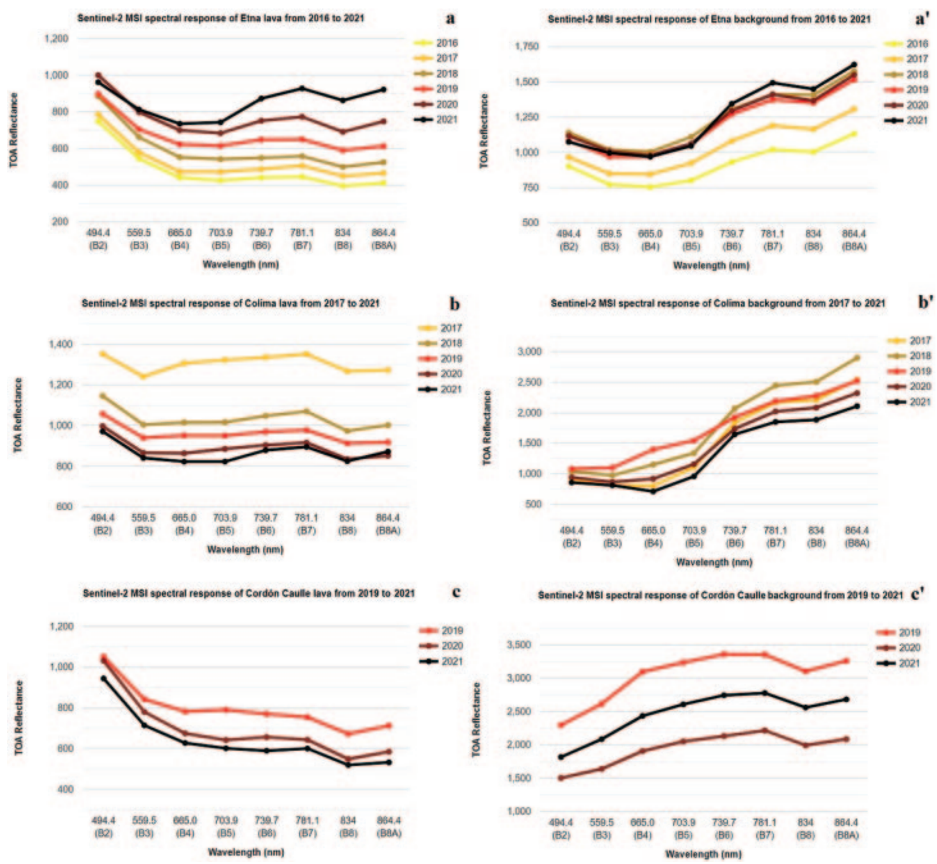

Fig. 1. – Spectral response of the lava (left) and background (right) points referred to the satellite images, from the older lava (in lower color gradation) to the younger one (in higher color gradation). (a), (a′): Basic 2002 Etna, from 2016 to 2021. (b), (b′): Intermediate 2002 Colima, from 2017 to 2021. (c), (c′): Acid 2011 Cordón Caulle, from 2019 to 2021. All the data are obtained via GEE, reflectance scaled by 10000.

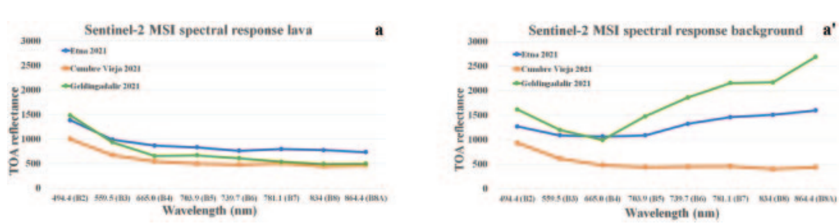

Fig. 2. – Spectral response of Etna, Cumbre Vieja and Geldingadalir lava (a) and background (a′) (lava narrower range). All the data are obtained via GEE, reflectance scaled by 10000.

4. – Discussion and conclusions

The basaltic Etna case (fig. 1(a), (a′)) highlights a growth spectral response trend with the passing of time, and a random trend for the background control point (to confirm that the trend depends only on lava properties). Comparing this result with [3], here "young" lava shows the same growing trend in time, with a peak in $\sim$780 nm. The differences at lower wavelengths with respect to [3] depend on the different type of sensor adopted thereby, namely the active higher spatial resolution LiDAR sensor. Going toward a more acidic composition, we found an opposite pattern for the spectral response (fig. 1(b), (b′), (c), (c′)), with a decreasing lava trend in time. When we consider lava flows with similar silica content and amount of time from the emplacement, neglecting temporal and chemical dependences and focusing on the different physical properties, the lava trend presents reduced variability (fig. 2(a)), due to similar chemical composition (ultrabasic to basic one), respect to the background points (fig. 2(a′)). In particular, results show that the variability of lava from different geographic areas is negligible, whereas the higher variability of the surrounding volcanic rocks (background) is due to the different geographic location and consequentely characteristic climate of each site. For each case study, uncertainty in the measured satellite reflectance due to the instruments used could affect data (use of radius 20 m for the samples).

In summary, we have characterized changes occurring in the lava spectral response trends with the passing of time and with different physical and chemical characteristics, in the visible-infrared portion of the spectrum. Our results were obtained using solely satellite observations and exploiting the theoretical physical-mathematical and chemical models that describe the spectral responses of the surfaces, and these show specific temporal and physicochemical effects.

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