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Potential of Sentinel-2 data on detecting hydrothermal alteration using clustering: the case of Nisyros caldera (Greece).

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The aim of this study is to investigate the potential of detecting and mapping hydrothermal alteration from Sentinel-2 data, using an innovative clustering algorithm, as well as the interpretation of the resulting clusters using spectral indices (SIs) linked to the hydrothermal alteration within the caldera of Nisyros.

Geological setting

Nisyros is a small, almost circular, island, which constitutes the youngest volcano of the South Aegean Active Volcanic Arc (SAAVA) with a central caldera depression of 4km diameter (Fig. 1a). The volcanic edifice, entirely formed during the Late Quaternary, lies above an Alpine basement of Mesozoic limestones and is characterized by calc-alkaline series (from basaltic andesitic to rhyolitic composition) (Francalanci *et al*., 2005). In historical times, several hydrothermal eruptions took place in the south-eastern part of the caldera generating hydrothermal craters. Nowadays, various fumarolic fields are present in the hydrothermal crater area (Gorceix synthem) with the major fumarolic vents to be located in the craters of Stephanos, Polybotes (Micros Polybotes and Megalos Polybotes) and Phlegethon and the minor fumarolic vents in the Kaminakia craters area (Marini *et al.*, 2002). In these areas, steam-heated, acid sulfate hot waters are formed, due to O_2-driven oxidation of H_2S to H_2SO_4, where ascending hydrothermal gases condense, in shallow groundwaters or surface waters. These acidic solutions react with the host rocks and form advanced argillic alteration.

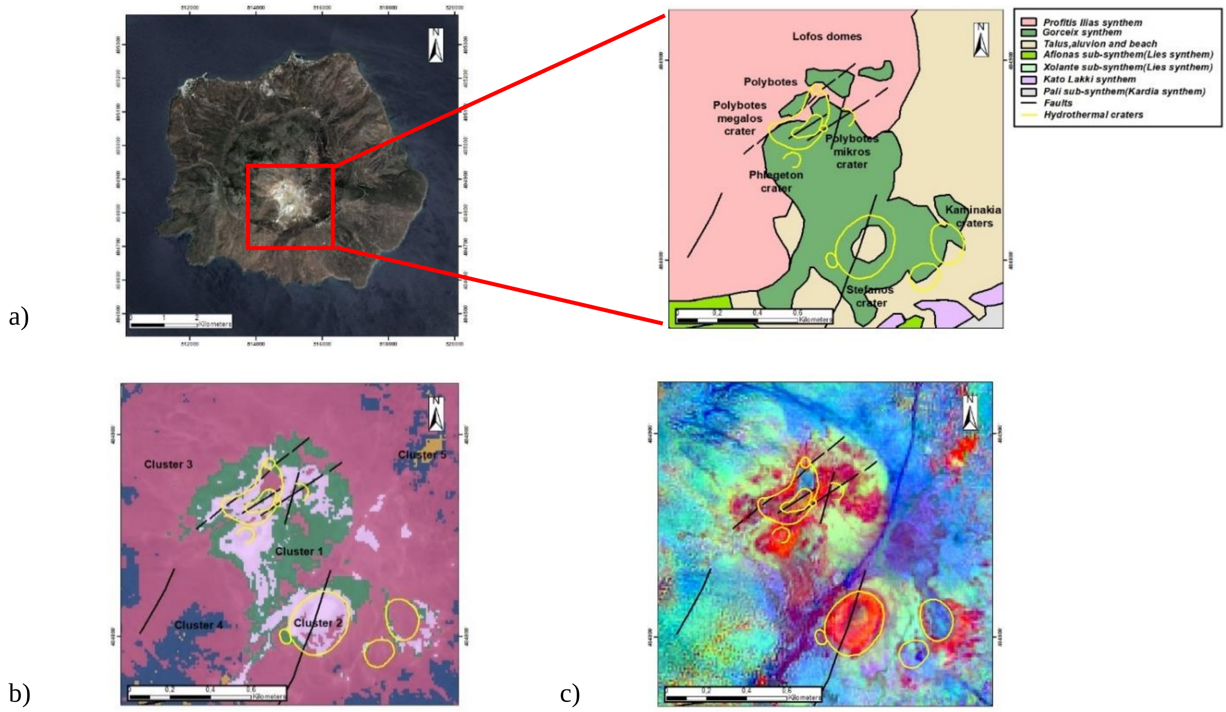

Figure 1. a) Left: Nisyros island. The red rectangle shows the location of hydrothermal alterations within the caldera. Right: Simplified geological map of Nisyros caldera (1:10.000) by Volentik *et al.*, 2005, b) Clustering map and c) Color composite map of the spectral indices around the hydrothermal field within the caldera of Nisyros (R:Hydroxyl-bearing alteration index, G: All iron oxides index, B: Ferric iron oxides index).

Materials

Recent studies have shown the capabilities of Sentinel-2 MSI data in geological and lithological mapping (Van der Meer *et al*., 2014, Ge *et al.*, 2018). For the purpose of this study, a Sentinel-2A MSI L1C image was used, acquired on 22/7/2017. The image has been atmospherically corrected with the Sen2Cor tool within ESA's SNAP software. The resulting bottom-of-the-atmosphere reflectance dataset, consisting of 12 spectral bands with 10m spatial resolution, was then subset to the caldera area.

Methodology

The adopted methodology consists of the following processing steps: a) Projection of the data on the space spanned by the first three principal components. b) Application of the Online GAPCM (O-GAPCM) clustering algorithm on the projected data. The O-GAPCM is a possibilistic clustering algorithm, which has the ability to recover the true number of clusters, while, in addition, it can identify hyperellipsoidally-shaped clusters, formed in the feature space (Xenaki *et al*., 2018). c) Comparison of the clustering results with the georeferenced simplified geological map of Nisyros (1:12.500) (Volentik *et al.*, 2005), in order to investigate whether the hydrothermal alteration area of the Gorceix synthem is identified. d) Interpretation of the clusters covering the Gorceix synthem and the surrounding area, using the hydroxyl-bearing alteration (SI-i), the all iron oxides (SI-ii) and the ferric iron oxides (SI-iii) spectral indices (Van der Werff & Van der Meer, 2016).

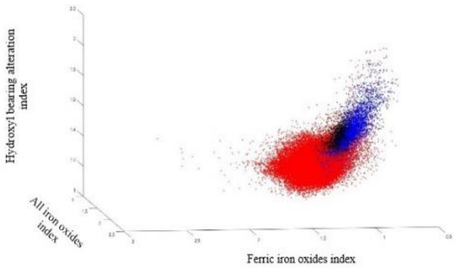

Figure 2. 3D-plot of the three clusters covering the Gorceix synthem (Cluster 1 (blue), Cluster 2 (black)) and the surrounding area (Cluster3 (red)) resulting by the O-GAPCM algorithm space spanned by the three spectral indices.

Results

The O-GAPCM algorithm has produced five clusters within the Nisyros caldera (Fig. 1b). In the sequel, we focus on the following three clusters: Clusters 1 and 2, which according to the simplified geological map exhibit significant overlap (69%) with the hydrothermal area (Gorceix synthem) (Fig. 1a) and Cluster 3, which covers the surrounding area. As shown in Figs. 1b-1c, Clusters 1 and 2 differ from Cluster 3, in terms of hydroxyl-bearing alteration (SI-i), all iron oxides (SI-ii) and ferric iron oxides (SI-iii) presence. Cluster 3 is mainly characterized by the presence of iron (both ferric and all iron oxides), which is in accordance with Seymour and Lalonde (1991). In particular, all iron oxides (west of the Gorceix synthem) are mainly detected on post-calderic dacitic lava domes (Profitis Ilias synthem) and ferric iron oxides (east of Gorceix synthem) on lacustrine intracalderic deposits (talus, aluvion and beach) (Fig. 1a). In contrast, Clusters 1 and 2 exhibit stronger hydroxyl-bearing alteration than Cluster 3 (Fig. 2). Focusing on Clusters 1 and 2, the former is characterized by a strong presence of both all iron oxides and hydroxyl-bearing alteration, while the latter is mainly characterized by strong hydroxyl-bearing alteration (Fig. 1c). Concluding, Sentinel-2 data seem to contain the necessary spectral information for the detection of hydrothermal alterations in a geothermal volcanic environment, which can be extracted using clustering methods. Current investigations include the examination of the mineralogical content of the alteration zones inside the Nisyros caldera, utilizing Sentinel-2 and/or other multispectral data.

Acknowledgements

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