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Application of airborne LiDAR to the detailed geological mapping of mineralised terrain: the Troodos ophiolite, Cyprus

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The identification of mineral prospects is highly dependent upon the acquisition and synthesis of a wide variety of geological information, e.g., lithological, structural, geophysical and geochemical data. Conventionally, the majority of this information is acquired through field-based surveys. However, the quality of data collected in this manner is often affected by subjectivity and lack of detail due to coarse sampling over vast areas or inaccessible terrain. Both multi- and hyperspectral satellite remote sensing and the interpretation of aerial photography are typically used to help try and overcome some of the limitations associated with field-based surveys. However, the use of these approaches for the extraction of exploration data can be hindered by spatial and spectral limitations and by dense forest cover.

A relatively new active remote sensing technology—known as airborne Light Detection And Ranging (LiDAR)—offers the possibility of acquiring accurate and high-resolution (ca. 1–4 m) topographic data through dense forest cover. The ability of LiDAR systems to detect multiple returns from the emission of a single laser pulse can be utilised to generate a high-resolution digital elevation model (DEM) of the ground beneath the forest canopy. Airborne LiDAR is an important tool for geoscience research, with a wide spectrum of applications including the mapping of landslides and faults to help inform hazard assessment studies. A LiDAR system can also provide an insight into the spectral and textural properties of surface materials using intensity data—a ratio of the reflected laser energy to the emitted laser energy. Where rocks outcrop, these properties are linked to the surface mineralogy and weathering at the LiDAR footprint scale. The ability to acquire two high-resolution datasets simultaneously from a single survey makes airborne LiDAR an attractive tool for the extraction of detailed geological information in terrain with either sparse or dense forest cover.

To examine the efficacy of LiDAR in mineral exploration, an airborne survey was flown over approximately 375 km^2 of the Troodos ophiolite, Cyprus—a region noted for its volcanogenic massive sulphide (VMS)-style mineralisation. Although most commonly found at the Lower Pillow Lava–Upper Pillow Lava interface, sulphide mineralisation occurs throughout the pillow lava sequence. Therefore, accurate identification of geological contacts is a key parameter for VMS exploration in the Troodos complex. However, the existing geological maps, produced using a combination of conventional field mapping and aerial photograph interpretation, have significant differences and do not adequately represent the geological complexity in high detail.

In this study, we present a semi-automated algorithm for the detailed lithological mapping of a 16 km^2 study area using high-resolution (4 m) airborne LiDAR topographic data in which non-ground features such as trees and buildings have been removed (i.e., bare-earth). Differences in the geomorphological characteristics of each major lithological unit result in each unit having a distinctive topographic signature in the bare-earth LiDAR DEM. Thematic maps (slope, curvature and surface roughness) are derived from the LiDAR DEM in order to quantify the topographic signatures associated with each lithological unit. With the thematic maps as the input layers, Kohonen's Self-Organising Map is used as a supervised artificial neural network to assign each pixel to a lithology to produce a geological map. The algorithm successfully identifies the major lithological units—Basal Group ($>$ 50 % dykes and $<$ 50 % pillow lavas), pillow lavas, alluvium and Lefkara Formation (chalks and marls)—in excellent detail and highlights geological features to a 20 m resolution. Although the ability to distinguish between lithologies in some areas is affected by anthropogenic activity (e.g., farming), the resultant lithological map easily

surpasses the quality and detail of the existing geological maps for the area. As well as providing a qualitative description of lithology, this method also provides a quantitative perspective of the terrain.

The results of this study demonstrate the significant potential of airborne LiDAR elevation data to: (i) quickly furnish high-resolution lithological discrimination and detailed geological maps over large areas of either forested or non-forested terrain and (ii) provide valuable baseline information and follow-up targets for ground-based mineral exploration campaigns.