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High Spatial Resolution Mapping of Dykes Using Unmanned Aerial Vehicle (UAV) Photogrammetry: New Insights On Emplacement Processes

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Remote sensing has played a pivotal role in our understanding of the geometry of dykes and dyke swarms on Earth, Venus and Mars (West and Ernst, 1991; Mege and Masson, 1995; Ernst et al., 2005). Since the 1970's traditional aerial photography has been supplemented by satellite-based passive (e.g., Landsat, SPOT, WorldView) and active (e.g., synthetic aperture radar - SAR) imaging systems, with spatial resolutions varying from ~30 m to ~0.3 m. Similar systems have been deployed on a range of planetary remote sensing missions. Since the 1980's advances in instrumentation, survey design and digital data processing have steadily improved the quality and resolution of aeromagnetic survey data for mapping of dykes and dyke swarms at spatial resolutions ranging from a few hundred meters to tens of meters.

Despite these advances, very high-resolution (i.e., cm accuracy) remote sensing imagery of dykes is limited to low altitude aerial photography surveys. This in turn creates a critical gap in the observation scale of dyke studies from < 1 mm at the outcrop and thin section scale to the 10's of cm to 100's of meters scale provided by conventional remote sensing and geophysics. Fortunately, the emerging capability of unmanned aerial vehicle (UAV) photogrammetry fills this gap. Here we describe a photogrammetric workflow applied to detailed structural studies of dykes exposed on coastal outcrops in SE and SW Australia (Bemis et al. 2014; Vollgger & Cruden, 2016). We have surveyed these locations using a variety of downward looking digital cameras mounted on multi-rotor UAVs (quadcopters and hexacopters). The survey design (flight height and speed, flight line spacing, camera focal length, shutter interval, image overlap, etc.) is optimised to minimise motion blur and to maximise the spatial resolution of the resulting photogrammetric models and ortho-images (Vollgger & Cruden, 2016). The use of ground control points using RTK-GPS allows us to produce geo-referenced 3D point clouds from hundreds to thousands of digital images, which in turn results in ortho-images covering <1,000 – >15,000 m^2 at spatial resolutions < 10 mm per pixel, and cm-scale location accuracy. The 3D point cloud can be used to extract 3D structural data (e.g., strike and dip of fractures) while the ortho-image provides a high-resolution base map for structural analysis.

We are using UAV photogrammetry as one component of field and theoretical research on dyke interaction with host rock structures, dyke-sill-dyke transitions, and how magma transport networks are built and self-organise. The broader context of this work is to understand how magma flow is channelized in such networks and how sulphide liquids become trapped in channels to form magmatic sulphide deposits. The high spatial, textural and colour fidelity of 3D point clouds and ortho-images derived from UAV photogrammetry allow us to measure geometrical attributes of dykes and dyke networks. These include the spacing of jogs in relation to dyke width, angles between main dyke trends and structures that deviate into steps, and how often steps occur in relation to host-rock fracture frequency and orientation. We can also document locations within networks where conduit widening occurs and relate this to host rock structure. These measurements will enable us to define the geometrical scaling relationships necessary to provide constraints for theoretical and laboratory modelling on the influence of pre-existing structures on stair-stepping magma network development. The results will underpin and refine 3D models of (unexposed) mineralisation associated with jogs in stair-stepping networks (e.g., plunging dyke-sill-dyke intersections at Voisey's Bay, and the funnel-shaped Jinchuan and Eagle intrusions; Saumur et al., 2015; Barnes et al., 2016). Our ultimate objective is to define a set of rules to better predict the subsurface

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Fig. 1. UAV ortho-image of Cretaceous dykes on a wavecut platform at Bingie Bingie point, New South Wales, Australia. North is to the left and the image is ~25 m across. Three vertical dykes are visible – two brown weathering dacitic dykes at top and bottom and a dark grey dolerite dyke in between. All dykes show complex “stair-stepping” and “handshake” structures. The two lower dykes share a common step geometry at the bottom right.

location of steps and jogs within a magma system based on structural inputs such as the orientation and spacing of planar host-rock structures (bedding, lithological contacts, joints, faults) and the width and orientation of dykes and sills.

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