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2D and 3D reconstruction and geomechanical characterization of kilometre-scale complex folded structures

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The geometrical, structural and geomechanical characterization of large-scale folded structures in sedimentary rocks is an important issue for different geological and geo-hazard applications (e.g. hydrocarbon and geothermal reservoir exploitation, natural rock slope stability, mining, and tunnelling). Fold geometry controls topography and the spatial distribution of rock types with different strength and permeability. Fold-related fracture systems condition the fracture intensity, degree of freedom, and overall strength of rock masses. Nevertheless, scale issues and limited accessibility or partial exposure of structures often hamper a complete characterization of these complex structures. During the last years, advances in remote survey techniques as terrestrial Lidar (TLS) allowed significant improvements in the geometrical and geological characterization of large or inaccessible outcrops. However, sound methods relating structures to rock mass geomechanical properties are yet to be developed. Here we present results obtained by integrating remote survey and field assessment techniques to characterize a folded sedimentary succession exposed in unreachable vertical rock walls. The study area is located in the frontal part of the Southern Alps near Bergamo, Italy. We analysed large-scale detachment folds developed in the Upper Triassic sedimentary cover in the Zu Limestone. Folds are parallel and disharmonic, with regular wavelengths and amplitudes of about 200-250 m. We used a Riegl VZ-1000 long-range laser scanner to obtain points clouds with nominal spacings between 5 cm and 20 cm from 9 scan positions characterized by range between 350 m and 1300 m. We fixed shadowing and occlusion effects related to fold structure exposure by filling point clouds with data collected by terrestrial digital photogrammetry (TDP). In addition, we carried out field surveys of fold-related brittle structures and their geomechanical attributes at key locations. We classified cloud points based on their normal vector orientations to identify and map bedding and fractures. Combined stereographic analysis of bedding orientations and use of filters allowed the quantification of fold hinge and limb geometries and their 3D reconstruction in GOCAD. Fracture patterns derived from points clouds and field data allowed identifying different geomechanical domains associated to the folded structure. Our results encourage the integrated analysis of high-resolution point clouds and detailed structural and geomechanical field data as inputs to the 3D geometrical reconstruction and modelling of folded rock masses. Validation of virtual outcrop reconstructions through a comparison with field structural measurements suggests that very precise geometrical constraints can be obtained by TLS on geological bodies with complex geometrical features. However, additional constraints on TLS survey layout design are required to optimise the reconstruction and distinction of specific structural elements associated to folding as bedding and fold-related fracture systems.