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Probabilistic constraints on structural lineament best fit plane precision obtained through numerical analysis

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A R T I C L E I N F O

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A B S T R A C T

Understanding the orientation distribution of structural discontinuities using the limited information afforded by their trace in outcrop has considerable application, with such analysis often providing the basis for geological modelling. However, eigen analysis of 3D structural lineaments mapped at decimetre to regional scales indicates that discontinuity best fit plane estimates from such datasets tend to be unreliable. Here, the relationship between digitised lineament vertex geometry (coplanarity/collinearity) and the reliability of their estimated best fitting plane is investigated using Monte Carlo experiments. Lineaments are modelled as the intersection curve between two orthonormally oriented fractional Brownian surfaces representing the outcrop and discontinuity plane. Commensurate to increasing lineament vertex collinearity (K), systematic decay in estimated pole vector precision is observed from these experiments. Pole vector distributions are circumferentially constrained around the axis of rotation set by the end nodes of the synthetic lineaments, reducing the rotational degrees of freedom of the vertex set from three to one. Vectors on the unit circle formed perpendicular to this arbitrary axis of rotation conform to von Mises (circular normal) distributions tending towards uniform at extreme values of K. This latter observation suggests that whilst intrinsically unreliable, confidence limits can be placed upon orientation estimates from 3D structural lineaments digitised from remotely sensed data. A probabilistic framework is introduced which draws upon the statistical constraints obtained from our experiments to provide robust best fit plane estimates from digitised 3D structural lineaments.

1. Introduction

Whether micro-cracks or continental scale tectonic dislocations, the surficial expression of structural discontinuities is typically a lineament or trace signifying the curve of intersection between a discontinuity plane and an outcrop surface. It is widely recognized that the underlying structures which lineaments represent (i.e. faults, fractures and veins) exert fundamental controls over fluid flow, geomechanical behaviour and seismic wave propagation within the subsurface (Barton, 1976; Brown, 1987; Schoenberg and Sayers, 1995). Consequently, understanding the geometry and distribution of structural discontinuities using the limited information afforded by their trace has considerable application, with such analysis often providing the basis for structural and geophysical models (Koike et al., 1998; Moreau et al., 1987; Rhén et al., 2007). Indeed, for many settings where geophysical imaging of the rock volume proves untenable (i.e. planetary surfaces, continental interiors, localized rock exposures), lineaments and traces provide the solitary control over subsurface structural architecture.

Conventionally, bi-dimensional approaches using photogeologic interpretation have been used to infer the geometry of parent structures from trace and lineament data (e.g. Wang and Howarth, 1990). Advances in trace extraction procedures, however, now enable three dimensional representations of structural lineaments to be delineated from digital elevation models and orthophotos (e.g. Banerjee and Mitra, 2004; Vasuki et al., 2014), as well as mesh based surface reconstructions (e.g. Umili et al., 2013). The principle advantage of obtaining higher dimensional representations of lineaments is that they allow best fit plane estimates to be made for their corresponding discontinuities. These orientation estimates yield deterministic constraints upon structural architecture and enable the assessment of spatially dependent discontinuity network properties, such as volumetric intensity and connectivity, which are known to govern key rock mass physical properties (i.e. strength, elastic modulus and permeability: Gudmundsson, 2011;

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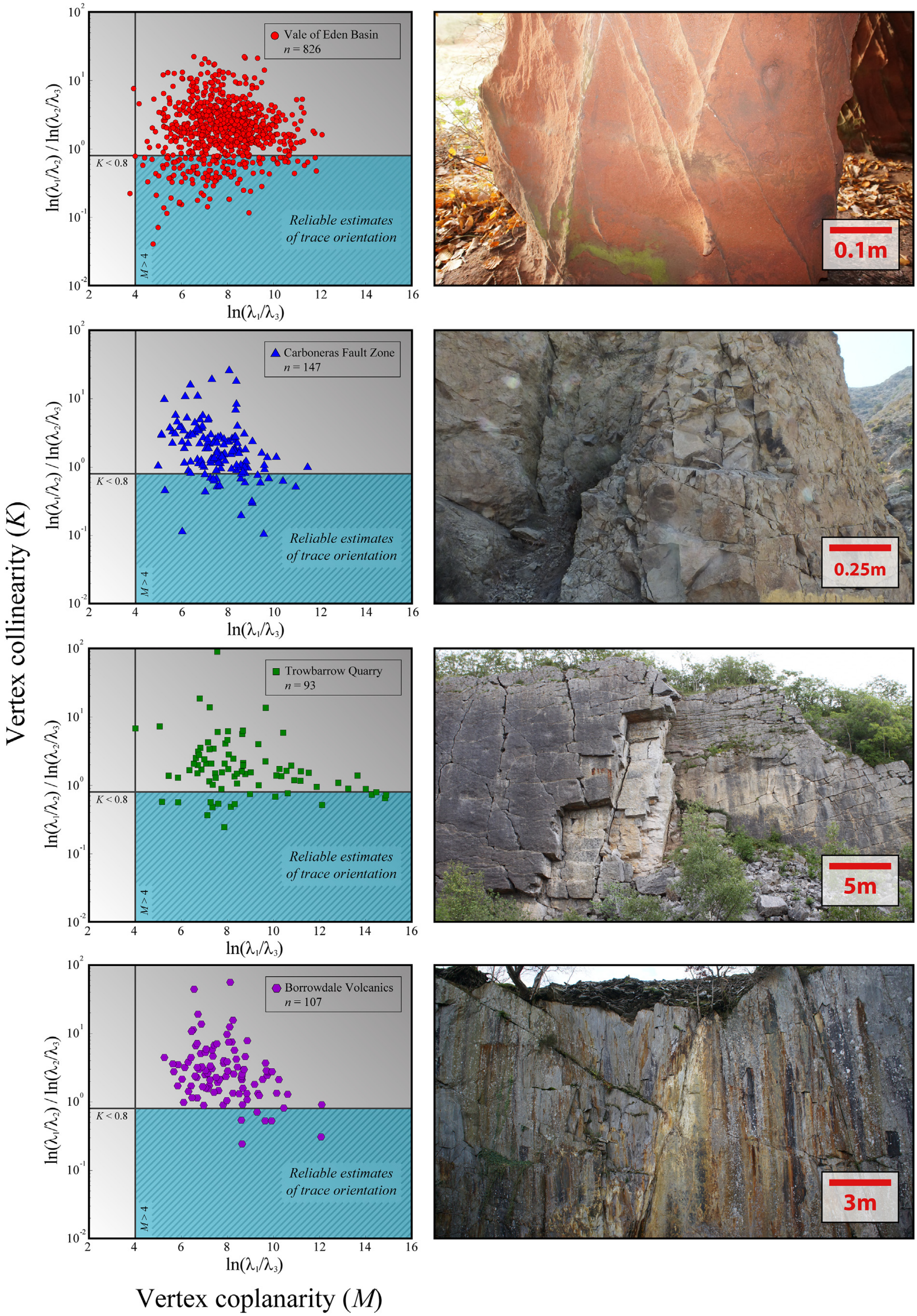
Vale of Eden Basin
n = 826
Carboneras Fault Zone
n = 147
Trowbarrow Quarry
n = 93
Borrowdale Volcanics
n = 107
K < 0.8
M > 4
Reliable estimates of trace orientation
ln(λ1/λ2) / ln(λ2/λ3)
ln(λ1/λ3)
Vertex collinearity (K)
Vertex coplanarity (M)
0.1m
0.25m
5m
3m