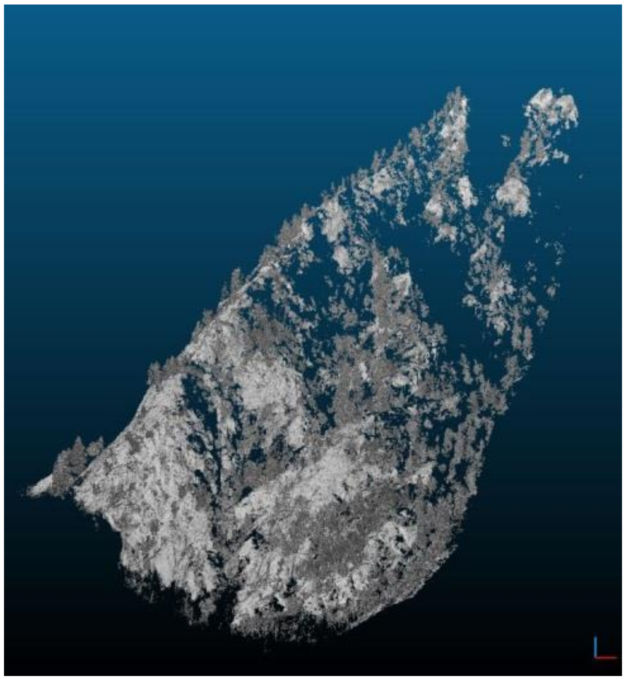
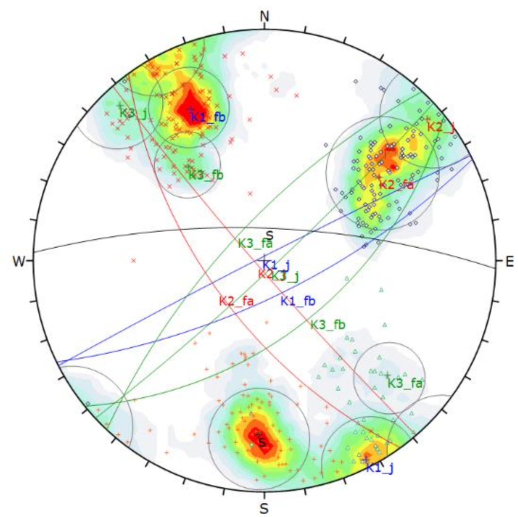
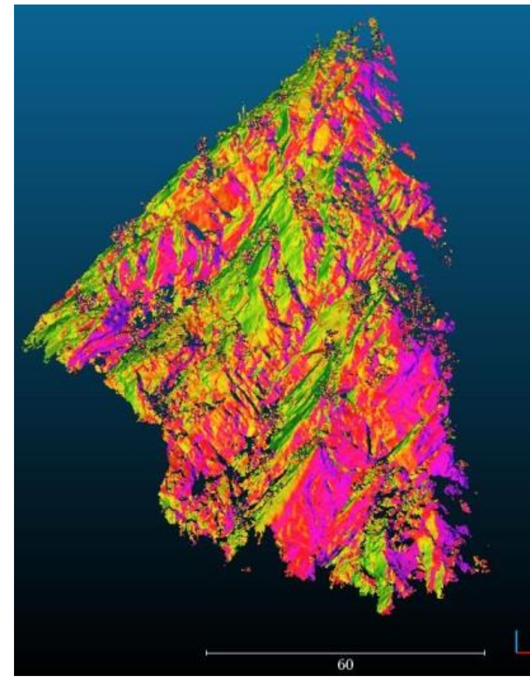
Quantitative characterization of fracture networks on Digital Outcrop Models obtained from avionic and terrestrial laser scanner





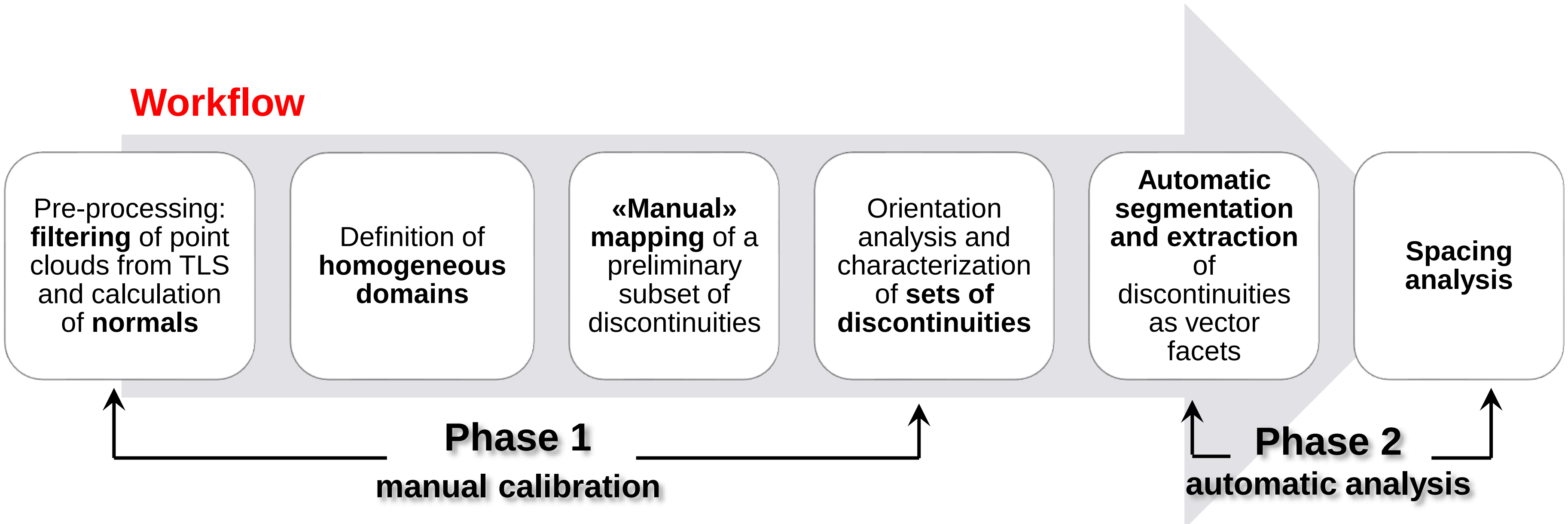


Gloria Arienti[(1)], Matteo Pozzi[(1)], Anna Losa[(1)], Federico Agliardi[(1)], Bruno Monopoli[(2)], Andrea Bistacchi[(1)], Davide Bertolo[(3)]

[(1)]Università degli Studi di Milano-Bicocca, Dipartimento di Scienze dell'Ambiente e della Terra, Milano, Italy
[(2)]LTS – Land technology & Services SrL, Treviso, Italy
[(3)]Regione Autonoma Valle d'Aosta, Dipartimento programmazione, risorse idriche e territorio

Structural analysis on point clouds

Workflow



Goals of the analysis:

- Extraction of quantitative **structural data** from point clouds.
- Characterization of **discontinuity sets**, **elemental blocks** and **kinematic analysis**.

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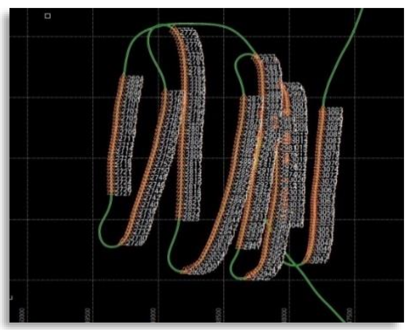
Data collection with avionic Lidar and TLS

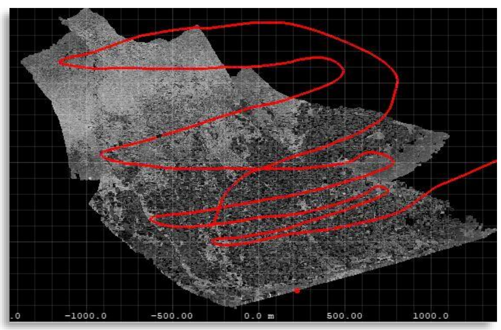
Data integration from:

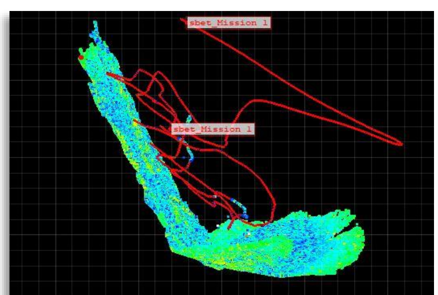
Avionic Lidar survey

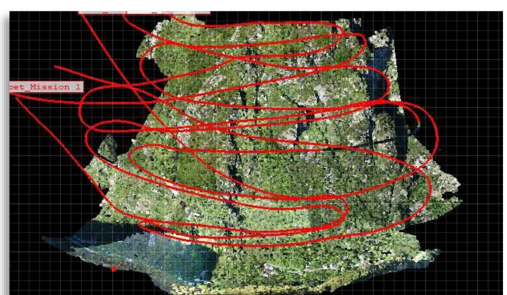
Complete area coverage, Lidar and photographic survey.

Flight plan with gradual lowering of altitude in terrain-follow mode, to obtain homogeneous resolution.







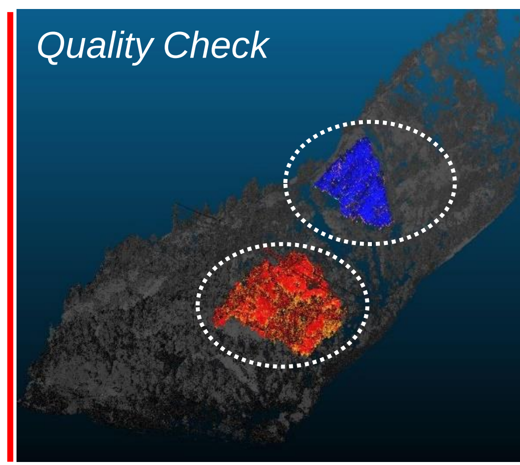


TLS survey

Reserved for **sub-areas** for increased-resolution analysis.

TLS survey conducted with **short baselines**.

Such sub-areas have good **exposure** and are representative of the local geology.



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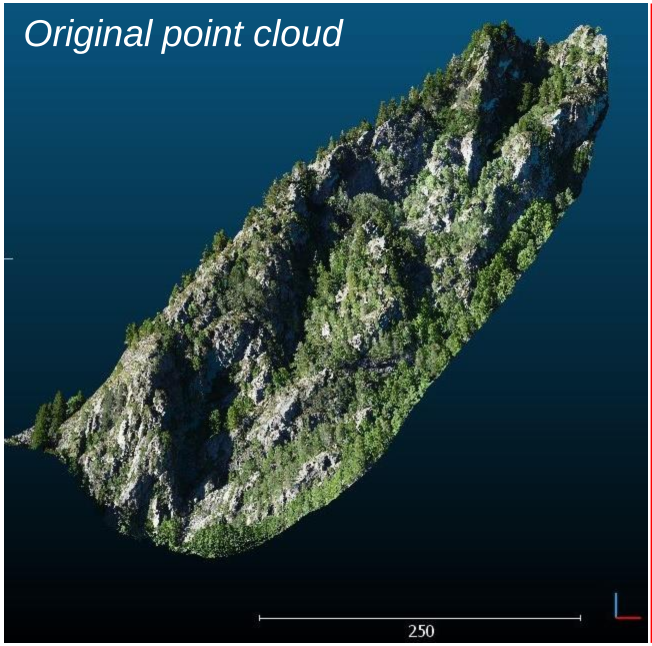
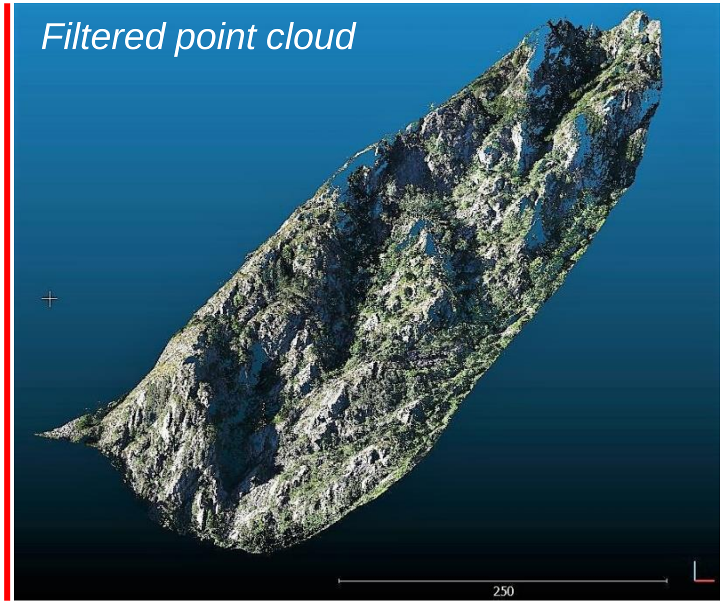
Pre-processing of point clouds (Phase 1)

- **RGB**: useful to identify sectors.
- «Full waveform» survey: **classified points**.
- **Removal of vegetation**: first arrival and connected components segmentation.
- Elimination of noise near edges: filtering by **Roughness**.

Filtering, preliminary to structural mapping, performed in **CloudCompare** (www.danielgm.net/cc/).





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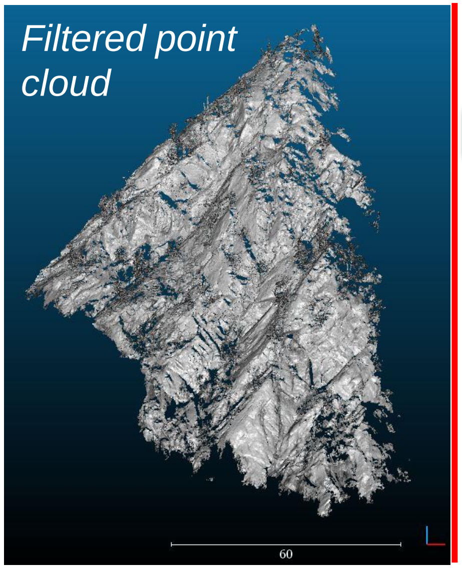
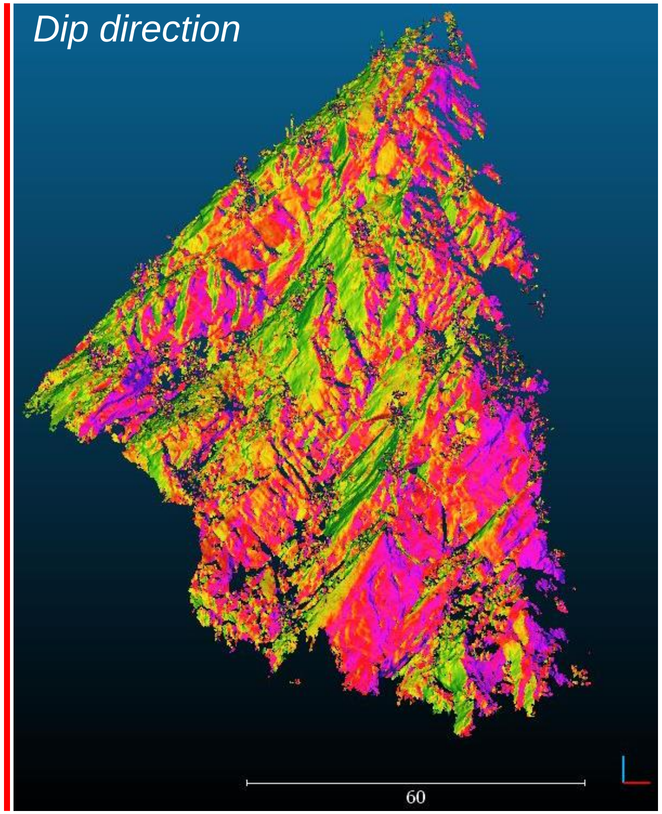
Calculation of normal (Phase 1)

Assumption: if a small patch of the outcrop («facet») represents the morphologic evidence of a **fracture** (discontinuity), then the attitude of the **discontinuity** can be measured from the facet.

Resulting attributes
(for each point)

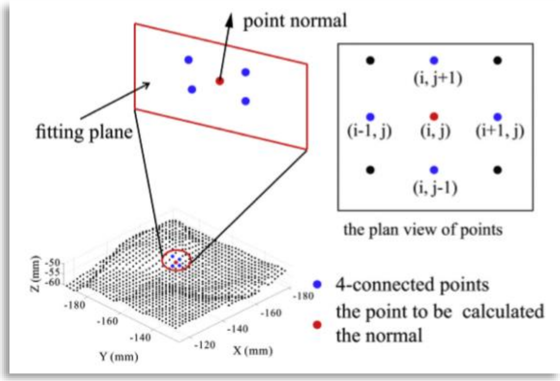
- Normal unit vector
- Dip Azimuth/Dip





E.g.: 1,365,000 points
Mean areal density: about 150 pts/m^2
Appropriate resolution for the identification of fracture surfaces of sub-metrical size.

Definition of point normal
(Ge et al., 2018)



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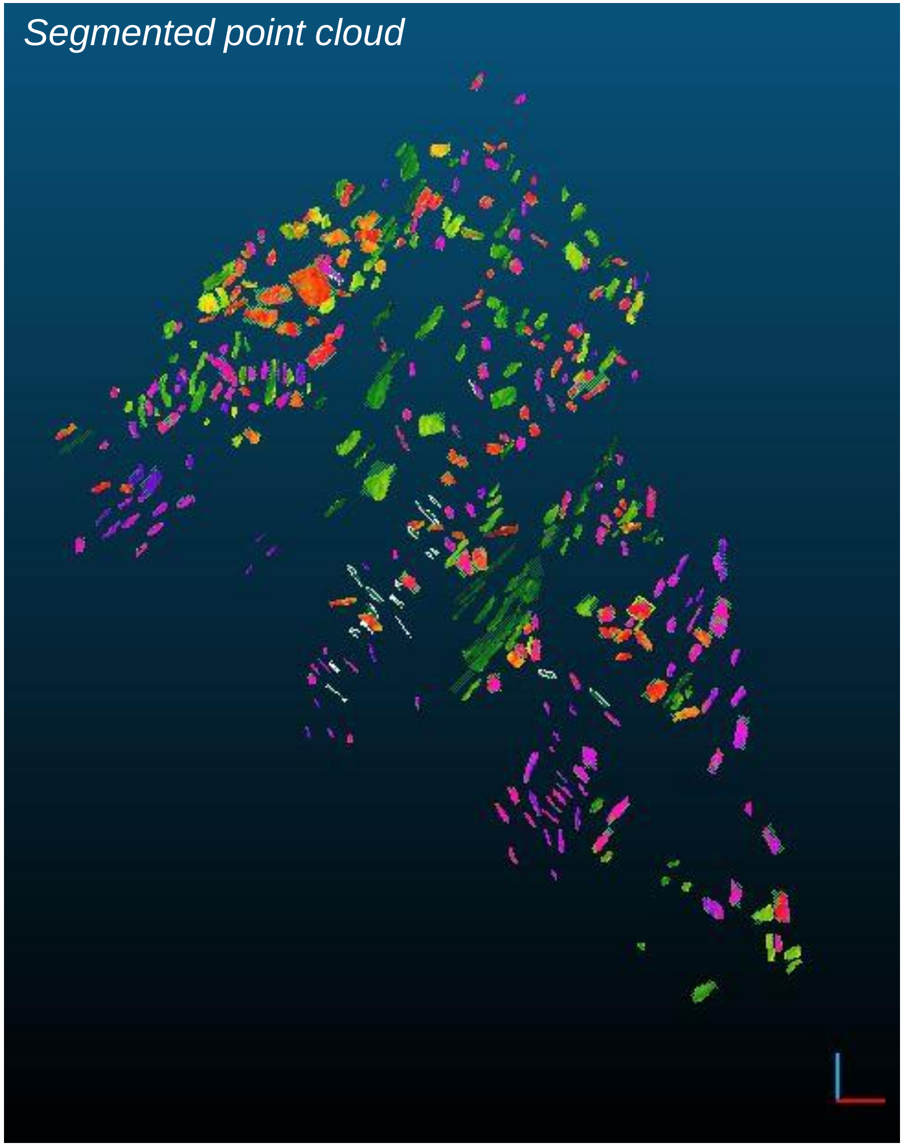
Manual mapping of facets (Phase 1)



Identification of **planes**

↓

Segmentation of patches of points

↓

For each patch

- **Best-fit plane** → local attitude
- Preliminary attribution to a **fracture set**

⚠ **Limits of the mapping** ⚠

- **Scale** → small planes that are not seen due to the resolution of the pointcloud
- **Orientation/occlusion** problems
- This all gets worse with **distance**

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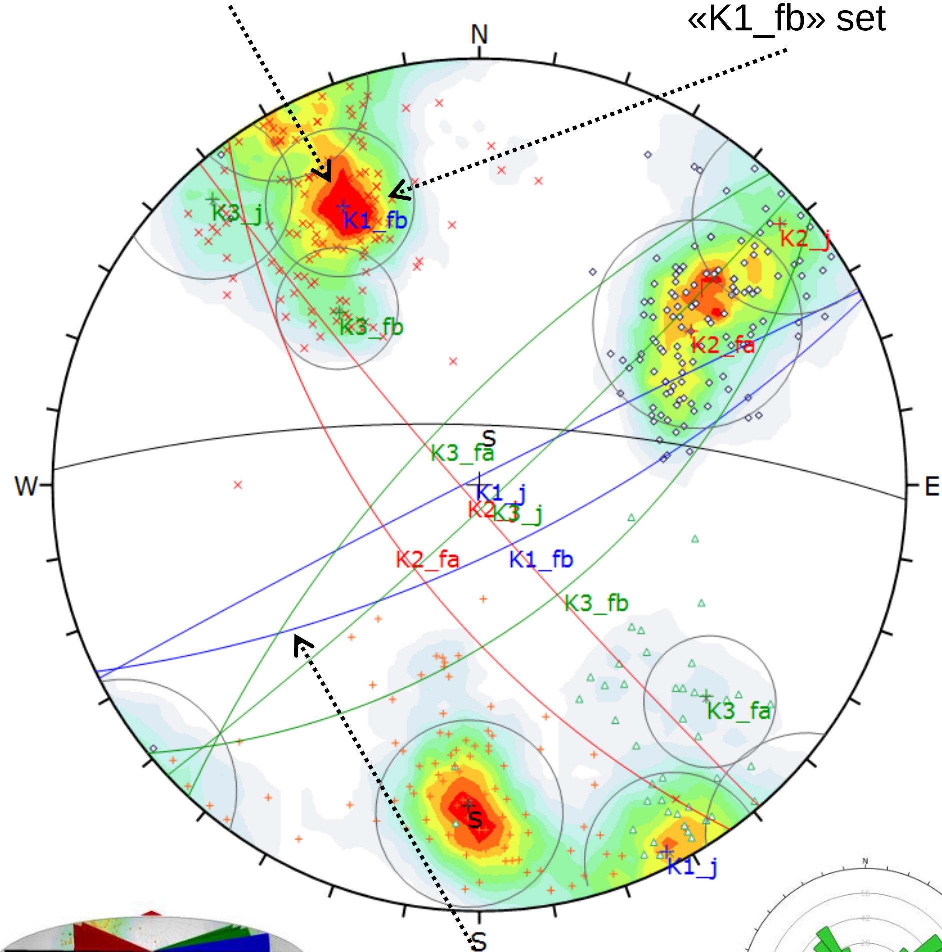
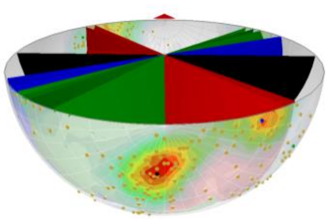
Characterization of sets of discontinuity (Phase 1)

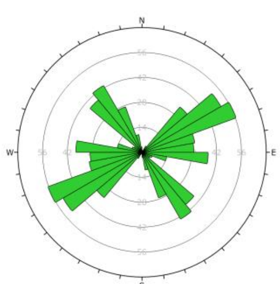
Mean pole, «K1_fb» set

Variability cone, «K1_fb» set



Mean great circle, «K1_fb» set





Orientation analysis and definition of fracture sets

Plotting poles and contours

↓

Selecting **clusters** from contours and **structural and kinematic constraints** (using prior knowledge about the tectonic evolution of the studied area)

↓

Fisher distribution:

Mean orientation, as for the plane and for the normal

Dispersion (variability cone)

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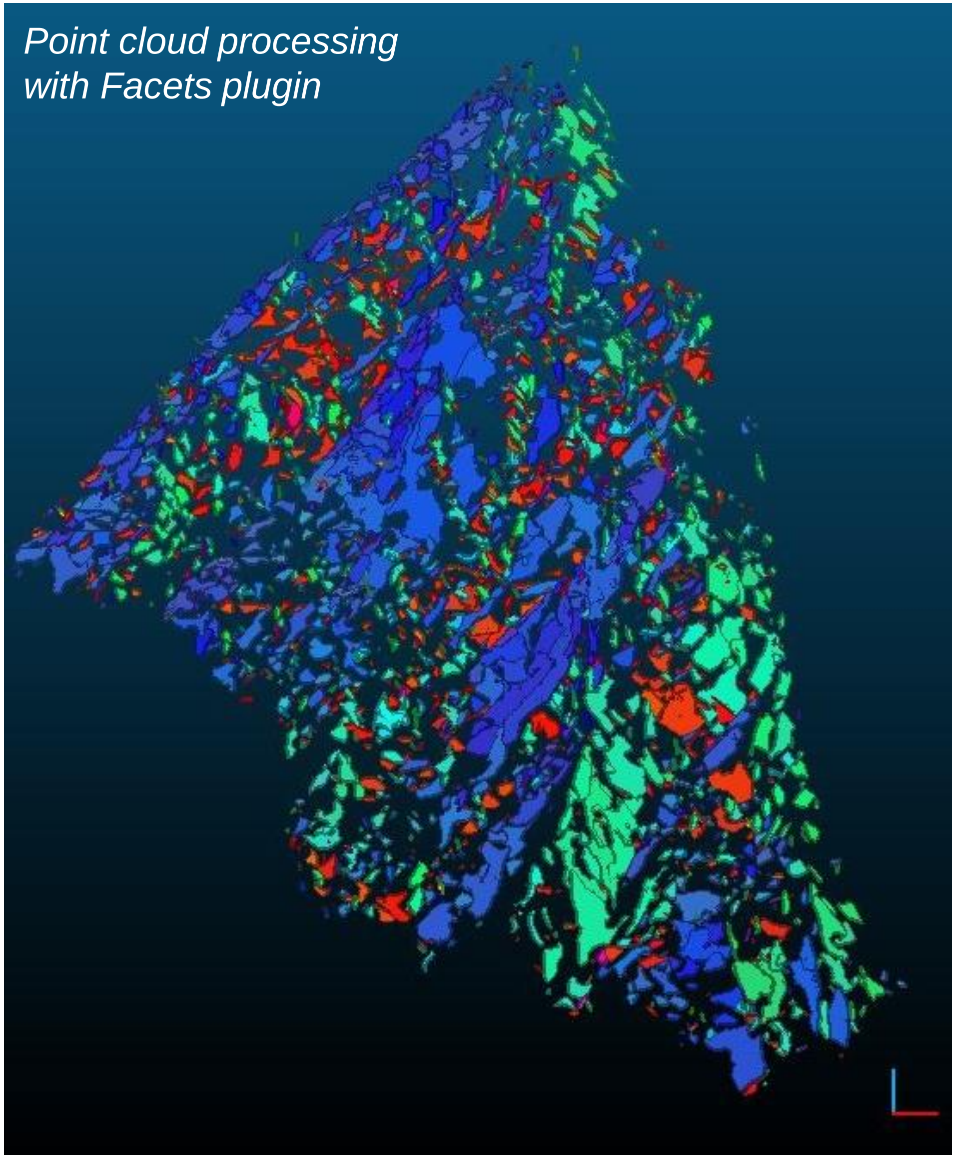
Semi-automatic segmentation of discontinuities (Phase 2)



Facets

Plugin in Cloud Compare (*Thomas Dewez, BRGM).*

Automatic→ it identifies and aggregates co-planar points into clusters

Applied for **every set** to the patches of the manual segmentation

Extraction of **vector objects** (planes attributed to different sets)

Facets plugin parameters:
Octree level= 8 (grid step= 0.506)
Max distance @99% = 0.2
Min points per facet= 10
Max edge length= 1.32

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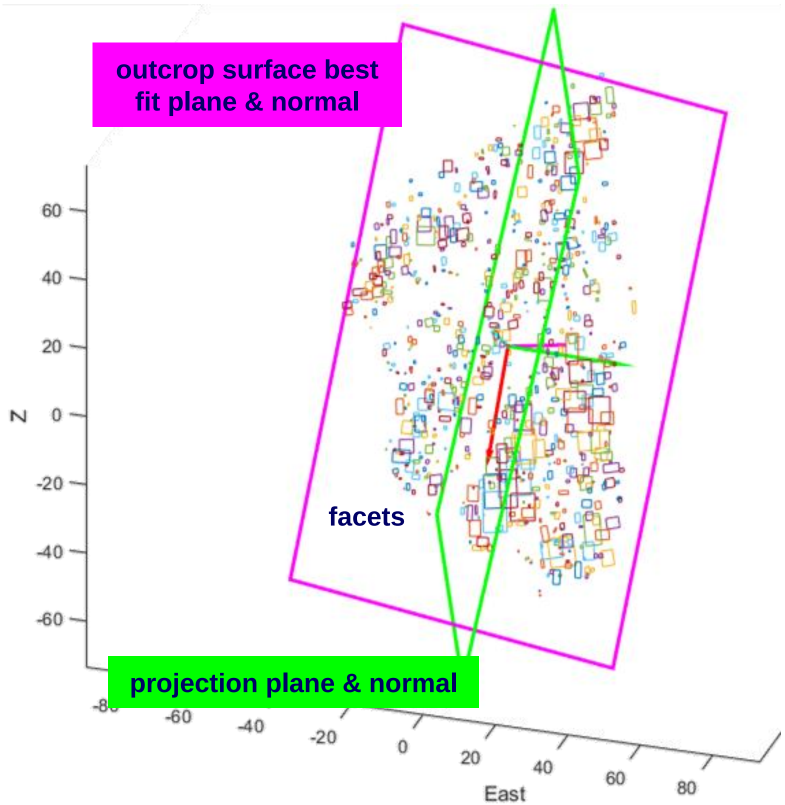
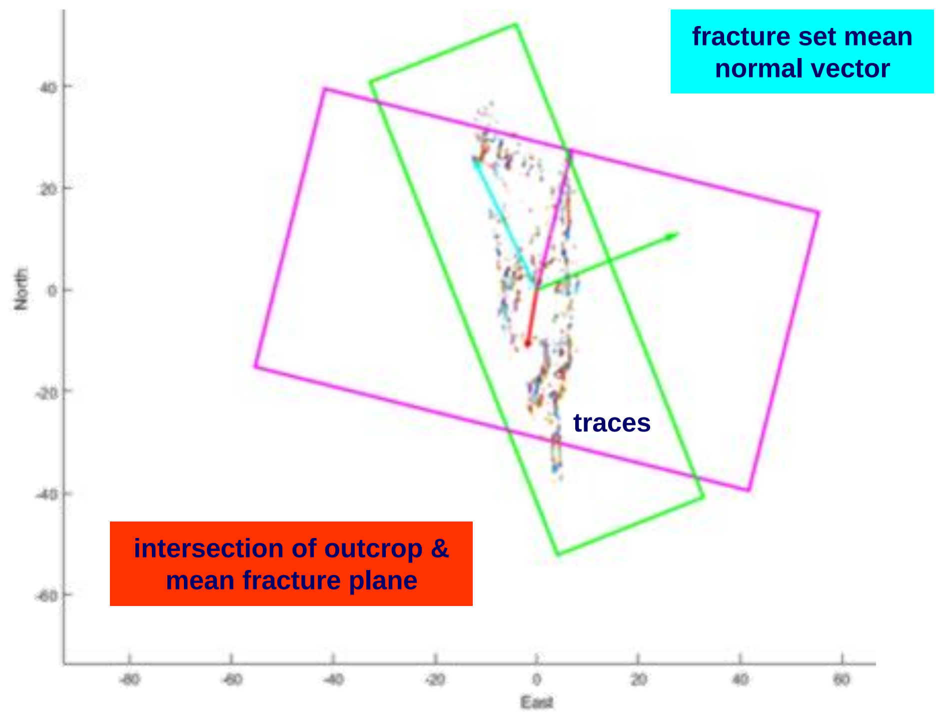
Spacing analysis (Phase 2)

Matlab original *tool*, interfaced with Facets from **Cloud Compare** → for **each set**: **virtual scanlines** and sampling of **discontinuity normal spacing**.



Projection plane is defined as the plane (i) containing the fracture set mean normal and (ii) as close as possible to the outcrop surface best-fit plane



→ *Projection of facets as fracture traces onto the projection plane*

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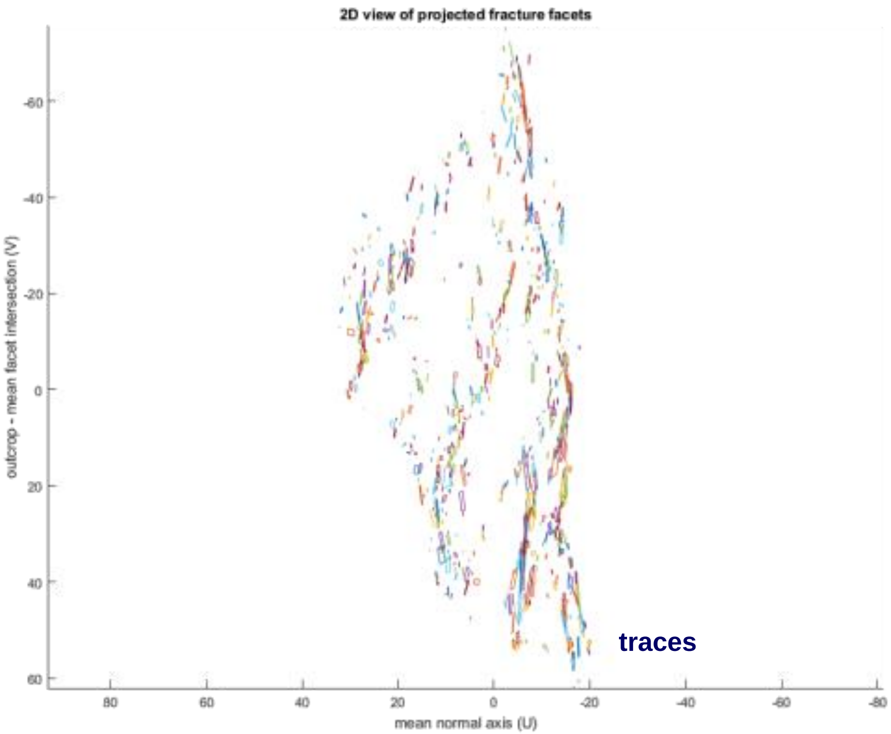
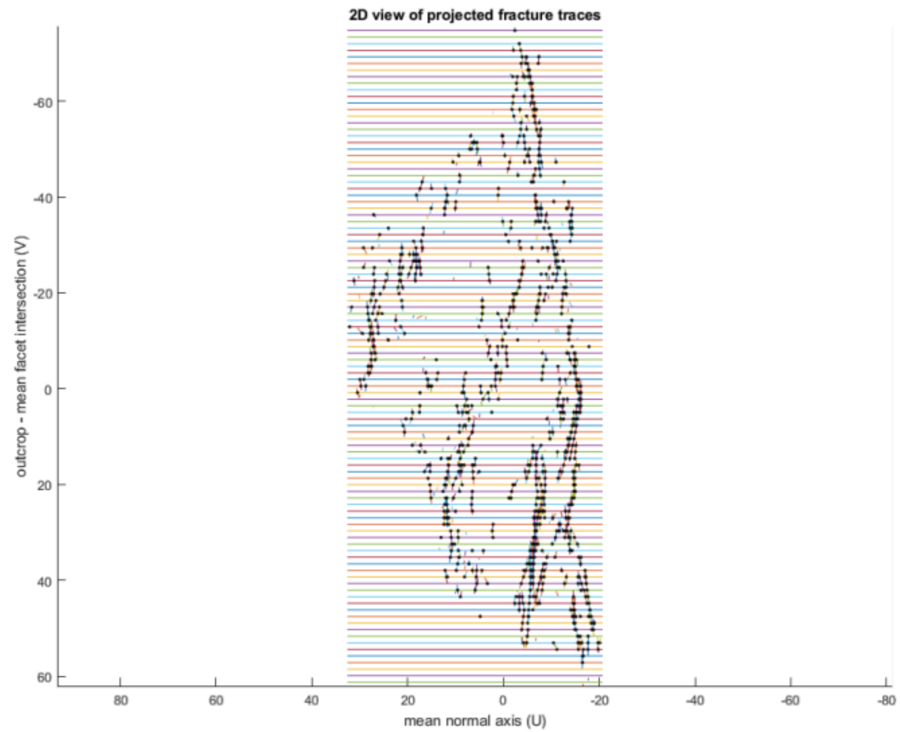
Spacing analysis (Phase 2)

Matlab original *tool*, interfaced with Facets from **Cloud Compare** → for **each set**: **virtual scanlines** and sampling of **discontinuity normal spacing**.



→ *2D map of fracture traces, seen on the projection plane (containing fracture set mean normal)*

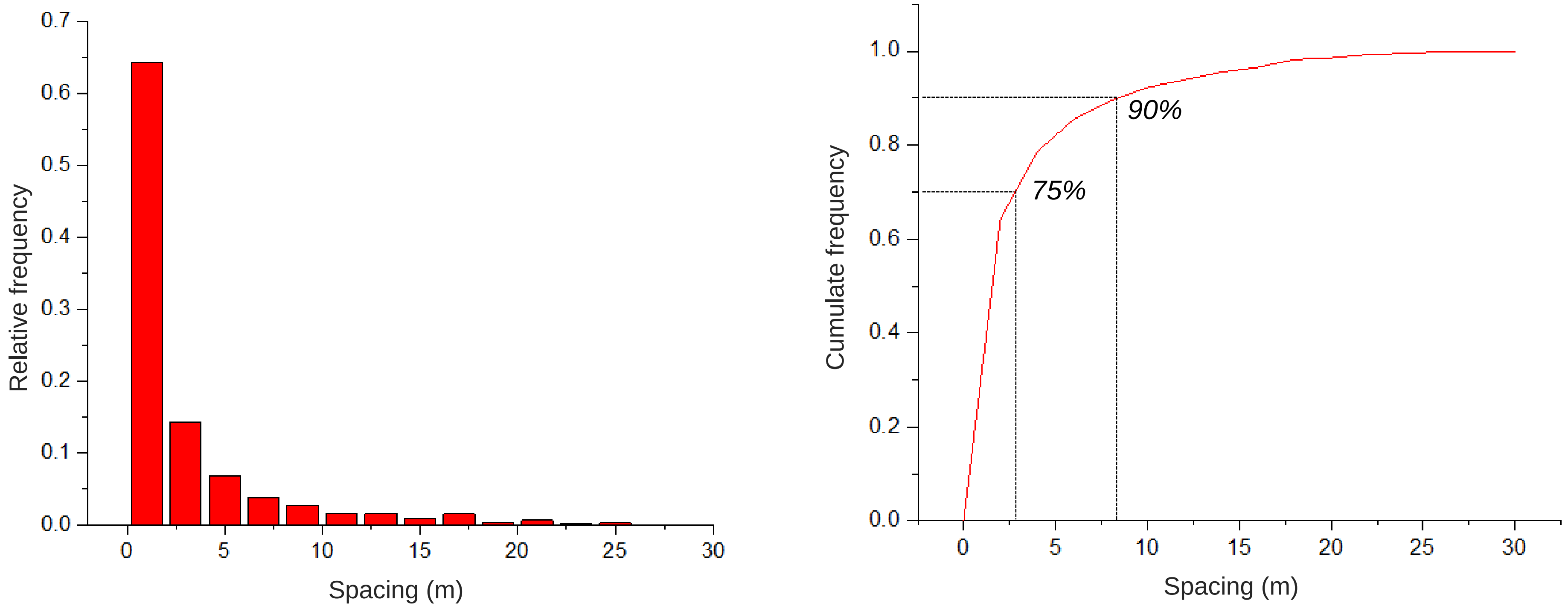


→ *measurement of spacing along 100 synthetic scanlines in the projection plane*

Spacing analysis (Phase 2)

For each set: **frequency analysis** of the discontinuity spacing dataset.

E.g. percentiles: useful for the empirical distribution of **elemental volumes**.



Limits of the analysis:

→ **Scale:** possibility to detect small values of spacing @ given resolution of the point cloud.

→ Systematic errors (***size*** and ***orientation bias***).

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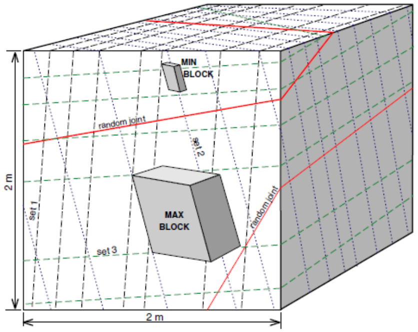
Spacing analysis

Jv – Volumetric Joint Count (Palmstrom, 1985)

$$J_v = \frac{1}{s_1} + \frac{1}{s_2} + \frac{1}{s_3} + \ldots + \frac{1}{s_n}$$

$s_i =$ mean spacing of the i-th discontinuity set.



Block Volume

Vb (Palmstrom, 2001)

$$\mathbf{Vb} = \frac{\mathbf{S1} \times \mathbf{S2} \times \mathbf{S3}}{\sin\gamma\mathbf{1} \times \sin\gamma\mathbf{2} \times \sin\gamma 3}$$

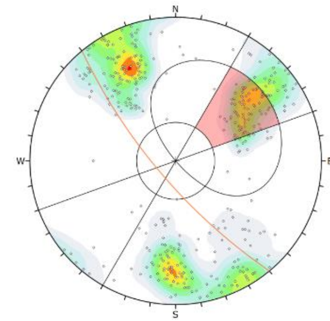
$\boldsymbol{\gamma 1}, \boldsymbol{\gamma 2}, \boldsymbol{\gamma 3}$: angles between discontinuity sets

➡ Empirical correlation Jv-Vb: $\boldsymbol{Vb = \beta \times Jv^{-3}}$

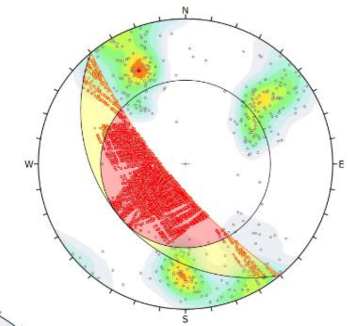
Kinematics analysis, stereographic

Mechanisms of elementary instability, controlled by discontinuities

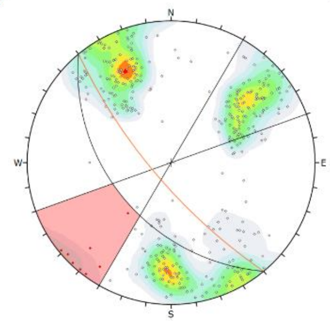
➡ «kinematic susceptibility»



Planar sliding



Wedge sliding



Flexural overturn

We will be happy to **answer any question!**

Gloria Arienti	g.arienti5@campus.unimib.it
Matteo Pozzi	m.pozzi53@campus.unimib.it
Anna Losa	a.losa3@campus.unimib.it
Federico Agliardi	federico.agliardi@unimib.it
Bruno Monopoli	bruno.monopoli@ltsht.com
Andrea Bistacchi	andrea.bistacchi@unimib.it
Davide Bertolo	d.bertolo@regione.vda.it

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References

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Ge, Y., Tang, H., Xia, D., Wang, L., Zhao, B., Teaway, J.W., Chen, H., Zhou, T., 2018. Automated measurements of discontinuity geometric properties from a 3D-point cloud based on a modified region growing algorithm. Engineering Geology 242, 44–54. DOI: 10.1016/j.enggeo.2018.05.007

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