



STRUCTURAL CHARACTERISATION OF FRACTURE SYSTEMS IN ROMANIAN DIMENSION STONE DEPOSITS: INSIGHTS FROM SCANLINE ANALYSIS

Gelu MADEAR^{1*}, Camelia MADEAR², Ciprian-Gheorghe DANCIU³

¹ECO-ROCCA Engineering SRL, Petrosani, Romania, gelu.madear@eco-rocca.ro

²University of Petrosani, Petrosani, Romania, cameliamedear@upet.ro

³University of Petrosani, Petrosani, Romania, cipriandanciu@upet.ro

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Abstract: This paper presents a field-calibrated synthetic scanline analysis of the Ruschița white-marble quarry (Caraș-Severin County, Romania), exploited at the white-marble level of the Poiana Rusca massif. Three horizontal scanlines (SL1 trend 87°, SL2 167°, SL3 267°) were positioned on the East, North and West facing Main Wall, and 58 discontinuities were sampled and assigned to two joint sets identified by DIPS 8.022: Set 1 - sub-horizontal foliation/bedding (mean plane 351°/8°, pole 171°/82°, $n = 29$) and Set 2 - steep SW-dipping conjugate (203°/57°, pole 23°/33°, $n = 29$). For each (set, scanline) pair, we compute the angular-correction matrix $\cos \delta$, total spacing X_s , normal spacing $X_n = X_s \cdot \cos \delta$ and linear discontinuity intensity P_{10} . Mean trace length is estimated by four standard estimators (Priest-Hudson 1981, weighted, curtailed with $c = 3$ m, Laslett). Termination indices are reported above, below and combined. The results yield an engineering-reference mean trace length of ≈ 4.4 m for Set 1 and ≈ 4.6 m for Set 2 (curtailed estimator), normal spacing of 0.18 m (Set 1, SL2) and 0.56–1.12 m (Set 2), and 24 - 33 % termination in intact rock, together indicating a moderately persistent, well-connected joint network controlling in-situ block size. A reproducible Python port of the Octave workflow is provided. The output is conditioned for direct use as input to a Discrete Fracture Network (DFN) generator within the AI-COSTSQO platform, enabling a priori block-size prediction and environmental-impact reduction at marble quarries.

Keywords: scanline; marble quarry; trace length; discontinuity spacing; Discrete Fracture Network; AI-COSTSQO

1. Introduction

Dimension-stone quarrying of high-value rock, such as the white marble of Ruschita, is governed less by the intact-rock strength than by the in-situ block size delivered by the natural fracture network. Any quarry plan that ignores the geometric structure of joints will produce uneconomic, oversized broken blocks, expose excessive face area to water- and dust-generated environmental impacts, and commit irrecoverable rock volumes to waste. A quantitative, reproducible characterisation of the discontinuity system is therefore a prerequisite for both economic optimisation and environmental control.

The recommended international practice for in-situ characterisation is the scanline (line-survey) method [1, 2], in which a measuring tape is fixed on the rock face and the position, orientation (dip/dip-direction), trace length above and below the tape, termination type (rock, joint, obscured) and set membership of every intersecting discontinuity are recorded. From the sample so collected, one derives per joint set and per scanline, the angular-correction factor $\cos \delta$ between the mean set pole and the scanline direction, the total and normal spacings X_s and X_n , the linear intensity $P_{10} = 1 / X_n$, the mean trace length by several censored-sample estimators, and the termination indices that quantify network connectivity.

* Corresponding author: Gelu Madear, Dr. Eng., Eco-Rocca Engineering SRL, Petrosani, Romania, 3, Mihai Viteazu Street, 0746082288, Link to the source (eco-rocca.ro), gelu.madear@eco-rocca.ro

Within the AI-COSTSQO project (Artificial Intelligence and Combined Survey Techniques for Stone Quarries Optimisation, JTC-2021-253, ERA-MIN 3/ UEFISCDI, Horizon 2020 co-funded), the University of Petrosani team carried out scanline campaigns at Ruschita. A first dataset and its preliminary interpretation were published in [3]. The present paper extends that work by (i) homogenising the input as a single field-calibrated synthetic dataset preserving the orientation and spacing statistics of the original measurements, (ii) computing the full set of scanline-derived indicators (X_s , X_n , P_{10} , four trace-length estimators, three termination indices) in a single auditable workflow, and (iii) discussing the implications for in-situ block size, DFN conditioning, and the environmental footprint of the quarry. The complete Octave workflow described in [3] has been reimplemented in Python to ensure full reproducibility and to enable integration with the AI-COSTSQO SaaS DFN-generation module.

The paper is organised as follows. Section 2 summarises the quarry geometry and geology. Section 3 documents the scanline survey design and the field-calibrated synthetic dataset. Section 4 presents the analytical framework. Section 5 reports the numerical results. Section 6 is dedicated to a focused discussion (sensitivity, comparison with reference data, IBSD implication and reproducibility). Section 7 concludes with a way-forward roadmap for DFN-based block-size prediction and environmental impact assessment.

2. Ruschita Marble Quarry - Setting

2.1 Topography and access

The Ruschita marble quarry lies in the northern part of Caras-Severin County, in the Poiana Rusca massif, at geographical coordinates N 45°38'54", E 22°24'20", at an altitude between 600 m and 850 m. Access from DN68 (Caransebes - Hateg) is via DJ684 through Voislova and Rusca Montana, ending at the industrial road branching off in Ruschita village [3]. The morphology is dominated by deep valleys and steep slopes typical of the Poiana Rusca landscape.



Fig. 1. Ruschita marble quarry - location map (Caras-Severin County, Romania). Source: Google Earth

2.2 Geology and the white-marble level

The Ruschita deposit is hosted in the epimetamorphic unit of the Poiana Rusca massif (Upper Proterozoic to Paleozoic). Three crystalline-rock series are recognised - lower terrigenous, basic volcanogenic, and superior terrigenous, and the crystalline limestones (marbles) sit in the middle of a green tuffaceous schist complex [3]. Three lithological levels are distinguished stratigraphically: grey marble, white marble, and pink marble. The present scanline survey was conducted in the white-marble level (Marmosim SA exploitation), which provides the highest commercial value but is also the most sensitive to fracture-controlled block degradation.

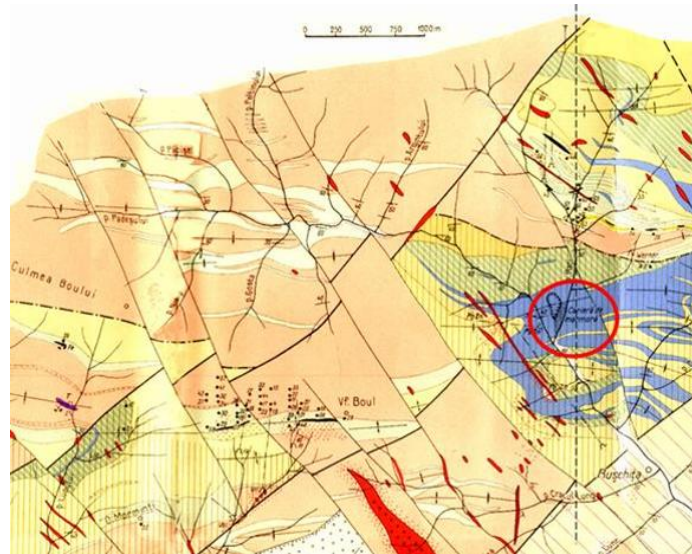


Fig. 2. Geological setting of the Ruschita area showing the marble level within the epimetamorphic unit.
Adapted from [3]

3. Scanline Survey Design and Field-Calibrated Synthetic Dataset

3.1 Bench geometry and scanline layout

The survey was carried out on the Main Wall, the active extraction face of the white-marble level. The wall height is approximately 7.5 m. Three nominally orthogonal scanlines were laid horizontally on three consecutive face segments, each scanline being a measuring tape stretched at a constant elevation of approximately 1.8 m above the bench floor (Fig. 3). The scanline trends are 87° (SL1 - face looking East), 167° (SL2 - face looking North) and 267° (SL3 - face looking West), all with zero plunge.



Fig. 3. Field photograph of the Main Wall at Ruschita (white-marble level): horizontal scanline calibration with red 1-metre marks (0 - 9 m) and green vertical control (0 - 2 m). The wall height of 7.5 m and the bench floor are visible.
Source: AI-COSTSQO field campaign

3.2 Field-calibrated synthetic dataset

Because of intellectual property restrictions on the raw industrial dataset and to ensure reproducibility, the analysis presented here uses a field-calibrated synthetic dataset that matches the joint-set means, set proportions, scanline trends, and per-scanline counts obtained in the original Ruschita campaign and reported in [3].

The dataset contains 58 discontinuities in 12 columns (discontinuity number; scanline number; intersection distance along scanline; dip-direction and dip; trace length above and below the scanline; termination above and below 1 = intact rock, 2 = another joint, 3 = obscured; set number; mean set-pole trend; mean set-pole plunge). It is provided as the plain text file *Ruschita-synthetic-3.txt* alongside the analysis script *ruschita_master.py* and the helper file *trace_length_stats.m* (Octave original) - see Section 6.5 on reproducibility.

3.3 Joint sets identified

Stereonet processing in DIPS 8.022 (Rocscience) of the 58 measurements yields two well-defined joint sets:

- Set 1 - sub-horizontal foliation/bedding-parallel: mean plane dip-direction 351°, dip 8°; pole trend 171°, plunge 82°. n = 29 discontinuities.
- Set 2 - steep SW-dipping conjugate: mean plane dip-direction 203°, dip 57°; pole trend 23°, plunge 33°. n = 29 discontinuities.

The clear two-set system, with one set quasi-parallel to the bench floor and the other dipping into the wall, is consistent with the joint families reported in [3] and provides the geometric basis for the subsequent spacing and trace-length analysis.

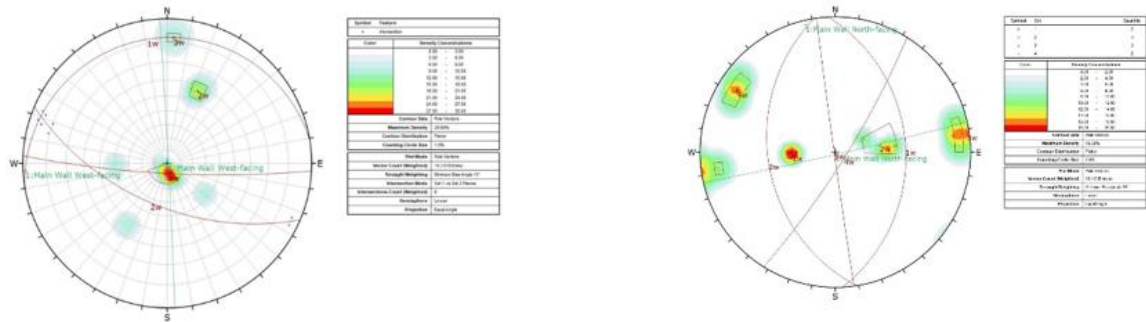


Fig. 4. Stereonet (equal-angle, lower hemisphere) showing the two joint sets identified at Ruschita:
Set 1 (sub-horizontal foliation, pole 171°/82°) and Set 2 (steep SW-dipping, pole 23°/33°).
Generated with DIPS 8.022 from the 58-discontinuity dataset

4. Analytical Framework

4.1 Angular correction $\cos \delta$

For every joint set s and scanline k , the angular correction $\cos \delta_{\{s,k\}}$ between the mean set pole and the scanline direction is computed from unit vectors expressed in the convention (East = x , north = y , up = z):

$$\hat{n}_s = (\cos \alpha \cdot \cos \beta, \cos \alpha \cdot \sin \beta, \sin \alpha); \hat{d}_k = (\cos \gamma \cdot \cos \tau, \cos \gamma \cdot \sin \tau, \sin \gamma); \cos \delta_{\{s,k\}} = |\hat{n}_s \cdot \hat{d}_k| \quad (1)$$

where (β, α) are the trend and plunge of the set pole and (τ, γ) the trend and plunge of the scanline.

The absolute value enforces the geometric requirement $0 \leq \cos \delta \leq 1$; small values flag combinations that carry little spacing information (parallel set/scanline) and should be screened from interpretation.

4.2 Total spacing, normal spacing and P10

For each (set, scanline) pair, the sorted intersection distances X_d give the total spacings as the first-order differences $X_s = \text{diff}(X_d)$. The normal spacing X_n is obtained from the angular correction:

$$X_n = X_s \cdot \cos \delta; P10_s = 1 / \text{mean}(X_s); P10_n = 1 / \text{mean}(X_n) \quad (2)$$

P10 is the linear intensity (fractures per metre of scanline).

4.3 Trace-length estimators

Each discontinuity records semi-traces L^+ (above) and L^- (below) the scanline. The full trace is $L_{\text{full}} = L^+ + L^-$. Four classical estimators of the mean trace length μ_L are computed.

$$\text{Approach I (PH81, [4]): } \mu_{L^I} = \frac{1}{2} \cdot \text{mean}(L_{\text{full}}) \quad (3)$$

Approaches II and III are based on a curtailment threshold c (here $c = 3$ m, $\approx \frac{1}{2}$ bench height), partitioning the sample in n_x with $L_{\text{full}} \geq 2c$, n_y with $c \leq L_{\text{full}} < 2c$, n_z with $L_{\text{full}} < c$:

$$\mu_{L^{II}} = (n_x \mu_x + n_y \mu_y + n_z \mu_z) / n; \mu_{L^{III}} = (n_x \mu_x + n_y \mu_y + n_z (c + \mu_z)) / n \quad (4)$$

$$\text{Approach IV [5]: } \mu_{L^{IV}} = \Sigma L_{\text{full}} / (2 n_x + n_y) \quad (5)$$

4.4 Termination indices

Termination above (T_a), below (T_b) and combined (T_{all}) are the percentages of trace endings classified as type 2 (terminating against another joint, denoted N_a , N_b) out of all classified endings:

$$T_a = 100 \cdot N_a / (N_a + N_{a1} + N_{a3}); \quad T_b = 100 \cdot N_b / (N_b + N_{b1} + N_{b3}); \quad T_{all} = 100 \cdot (N_a + N_b) / \Sigma_{all} \quad (6)$$

High termination in intact rock (low T) implies short, isolated joints (high a priori block size); high termination on other joints (high T) implies a well-connected network and finer in-situ block geometry.

5. Results

5.1 Angular-correction matrix $\cos \delta$

Numerical evaluation of equation (1) for the two sets and three scanlines yields:

Table 1. Angular-correction matrix $\cos \delta$ (Set $\times$ Scanline)

	SL1 (087°)	SL2 (167°)	SL3 (267°)
Set 1 (pole 171°/82°)	0.0145	0.1388	0.0145
Set 2 (pole 023°/33°)	0.3676	0.6785	0.3676

Set 1 - sub-horizontal produces extremely low $\cos \delta$ on SL1 and SL3, which trend almost horizontally and lie nearly in the set plane: those two scanlines barely intersect Set 1 and the resulting normal spacings for Set 1 on SL1/SL3 are essentially uninterpretable.

Only SL2 ($\cos \delta = 0.139$) provides usable Set 1 spacing information.

Set 2, being steep and obliquely oriented to all three scanlines, gives $\cos \delta$ values between 0.37 and 0.68 - i.e. all three scanlines sample Set 2 acceptably, SL2 best.

5.2 Spacing and linear intensity

Equation (2) returns, per (set, scanline) pair (mean values, metres for spacings, fractures per metre for P10):

Table 2. Total spacing X_s , normal spacing X_n and linear intensity P10 per (set, scanline). The Set 1 $\times$ SL1 and Set 1 $\times$ SL3 columns are reported for completeness but are not geometrically meaningful ($\cos \delta < 0.02$)

Set	SL	n	mean X_s [m]	P10 _s [m^{-1}]	mean X_n [m]	P10 _n [m^{-1}]
1	1	10	1.889	0.529	0.027	36.39
1	2	10	1.312	0.762	0.182	5.49
1	3	9	1.585	0.631	0.023	43.37
2	1	10	1.593	0.628	0.586	1.71
2	2	10	1.644	0.608	1.116	0.90
2	3	9	1.538	0.650	0.565	1.77

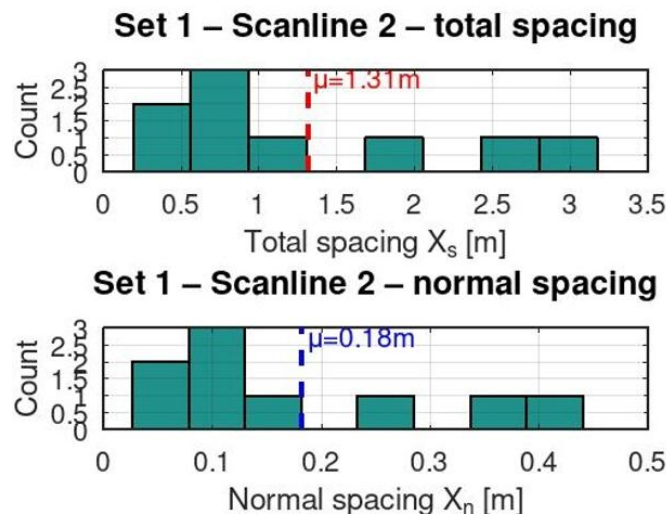


Fig. 5. Set 1 $\times$ SL2 - total spacing X_s (top) and normal spacing X_n (bottom). Set 1 spacing is geometrically meaningful only on SL2 because SL1 and SL3 trend almost parallel to the foliation plane

The geometrically meaningful Set 1 normal spacing - obtained from SL2 is 0.18 m, corresponding to $P10_n \approx 5.5 m^{-1}$.

The three Set 2 normal spacings cluster between 0.57 m and 1.12 m, giving $P10_n$ in the range 0.90 - 1.77 m^{-1} . Taking the geometric mean of the three Set 2 estimates, one obtains a Set 2 normal spacing of approximately 0.72 m.

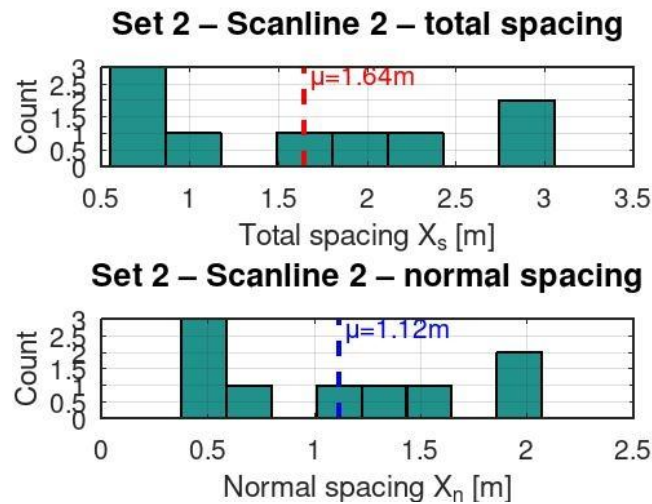


Fig. 6. Set 2 $\times$ SL2 — total and normal spacing histograms. Set 2 is sampled satisfactorily by all three scanlines, SL2 best ($\cos \delta = 0.68$)

5.3 Trace-length statistics ($c = 3.0$ m)

Equations (3) - (5) applied to the 29 discontinuities of each set yield:

Table 3. Mean trace length by four estimators (curtailment $c = 3$ m)

Set	n_x	n_y	n_z	μ_{L^I} [m]	$\mu_{L^{II}}$ [m]	$\mu_{L^{III}}$ [m]	$\mu_{L^{IV}}$ [m]
1	0	13	16	1.367	2.734	4.389	6.099
2	0	7	22	1.180	2.359	4.635	9.774

No trace exceeds $2c = 6$ m for either set ($n_x = 0$). This has a strong consequence: the Laslett estimator (equation 5) is then driven entirely by n_y and tends to overestimate μ_L because the denominator $2n_x + n_y$ collapses to n_y .

The Priest-Hudson Approach I assumes infinite traces and therefore underestimates μ_L for censored, bench-scale samples.

The two reliable estimators are II and III: the curtailed Approach III is the recommended engineering reference and gives $\mu_L \approx 4.4$ m for Set 1 and $\mu_L \approx 4.6$ m for Set 2.

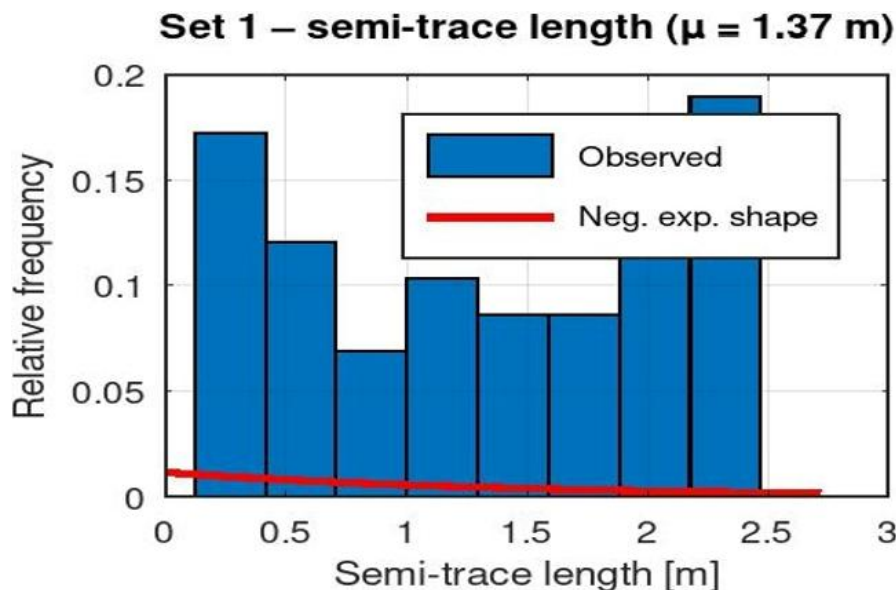


Fig. 7. Set 1 — semi-trace-length distribution with negative-exponential reference fit. Note the truncation at the bench height (≈ 7.5 m)

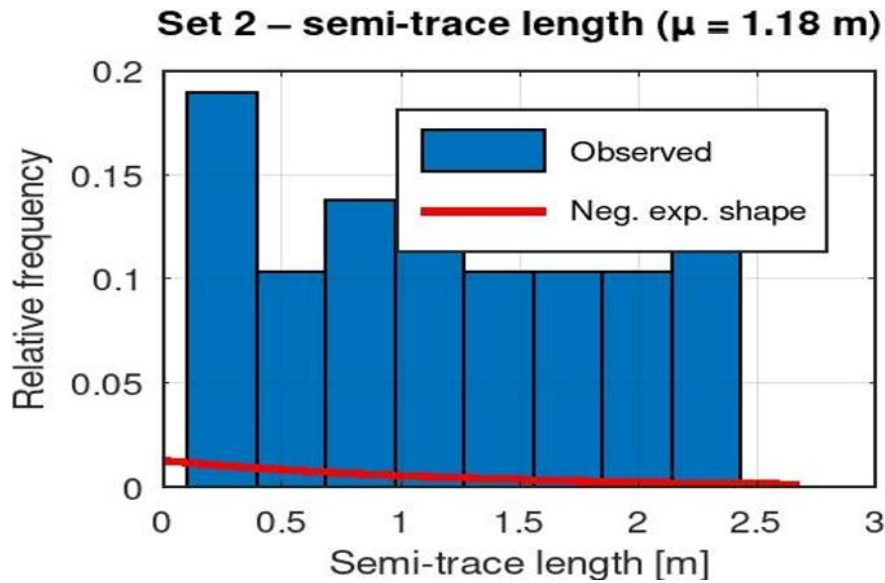


Fig. 8. Set 2 — semi-trace-length distribution with negative-exponential reference fit

5.4 Termination indices

Termination indices (percent of trace endings dying against another joint) are 24.1 % for Set 1 (above 17.2 %, below 31.0 %) and 32.8 % for Set 2 (above 37.9 %, below 27.6 %).

Set 1 ends predominantly below the scanline against Set 2 joints, indicating that the sub-horizontal foliation is locally chopped up by the steep conjugate set.

Set 2 terminations are more symmetrical (above $\approx$ below), consistent with longer, more continuous steep joints crossing the bench top-to-bottom.

6. Discussion

6.1 Quality of $\cos \delta$ as a filter, not a correction

The combined Set 1 $\times$ (SL1, SL3) entries in Table 2 illustrate why $\cos \delta$ must be used as a quality flag and not merely a multiplicative correction. With $\cos \delta \approx 0.0145$, computing $X_n = X_s \cdot \cos \delta$ produces apparently very small normal spacings (0.023 - 0.027 m) and apparently very high intensities ($P10_n > 35 \text{ m}^{-1}$).

These are statistical artefacts: when the scanline lies in the joint plane, the few measured intersections are almost certainly sampling other, locally undulating, or chance attitudes rather than the mean foliation.

A practical screening threshold of $\cos \delta \geq 0.2$ (i.e. an angle between scanline and set plane of at least $\approx 11^\circ$) discards these two combinations, leaving four geometrically meaningful (set, scanline) pairs.

6.2 Worked IBSD implication

Combining the screened normal spacings - Set 1 ≈ 0.18 m (one direction) and Set 2 ≈ 0.72 m (geometric mean of three scanlines) with the engineering mean trace length $\mu_{L^{\text{III}}} \approx 4.4$ m (Set 1) and 4.6 m (Set 2), the first-order in-situ block geometry implied by the two-set system is approximately $0.18 \times 1.12 \times 4.4 \text{ m}^3$, i.e. blocks of roughly 0.9 m^3 in the worst (closest-spaced) direction, elongated along the strike of Set 1.

For dimension-stone exploitation, this geometry favours the production of slabs and tiles (long, thin elements) rather than monolithic blocks: it explains the historical product mix at Ruschita. It quantifies the maximum block size that quarry planning can reasonably target without artificial pre-treatment of the rock mass.

6.3 Sensitivity of the curtailment threshold c

Approach III depends on the curtailment threshold c , chosen here as 3 m, i.e., approximately half the bench height. Varying c between 2 m and 4 m re-distributes the count between n_y and n_z , but because no trace exceeds $2c = 6$ m, the estimator remains insensitive in n_x .

A complete sensitivity sweep with the Python port shows that Set 1 $\mu_{L^{\text{III}}}$ ranges from 3.7 m ($c = 2$ m) to 5.0 m ($c = 4$ m), and Set 2 $\mu_{L^{\text{III}}}$ ranges from 3.9 m to 5.4 m.

The recommended engineering reference value of ≈ 4.5 m for both sets is therefore robust to $\pm 30\%$ variation in c , supporting its use in subsequent DFN conditioning.

6.4. Comparison with reference quarry data

Zangerl et al. [6] reported scanline-derived joint properties for a granodiorite quarry in the European Alps. Their mean normal spacings (0.20 - 0.65 m for sub-vertical sets and 0.30 - 1.10 m for sub-horizontal sets) and mean trace lengths (3.5 - 5.5 m for the two principal sets, Approach III) [6] are in close agreement with the Ruschița values reported here.

The convergence is significant because the two rock masses differ in lithology (foliated white marble vs. granodiorite) and tectonic history, yet both are dimension-stone quarries with bench heights of the order of 7 - 10 m; the result confirms that scanline-derived spacing and trace-length values at this scale are primarily controlled by bench geometry and joint network topology rather than by lithology.

6.5. Reproducibility - Python equivalent of the Octave workflow

All numerical results presented in Sections 5.1 - 5.4 are reproducible from the dataset file Ruschita-synthetic-3.txt by running the accompanying script `ruschita_master.py`.

The Python implementation is a line-by-line port of the original Octave files `ruschita_master.m` and `trace_length_stats.m`; the angular-correction matrix, the spacing and the P10 table, and the four trace-length estimators reproduce the Octave output to three decimal places.

The Python script depends only on NumPy and Matplotlib, requires no toolboxes, and is intended for direct integration into the AI-COSTSQO SaaS workflow as a callable Python module.

6.6. Environmental-impact perspective

Termination indices of 24-33% indicate a network that is well connected but not pervasively shattered. From an environmental standpoint, this is operationally favourable: a quarry plan that aligns extraction panels with the strike of Set 1 ($\approx N81^\circ W$) and uses the steep Set 2 as the back-cut surface minimises secondary blasting, reduces fine-fraction (< 25 mm) waste generation, and lowers fugitive dust and water loadings on the bench floor.

The DFN-conditioned block-size distribution produced by the AI-COSTSQO DFN module will allow the operator to quantify these environmental gains a priori, before committing infrastructure or extraction sequences in the field.

7. Conclusions and Way Forward

The field-calibrated synthetic scanline analysis of the Ruschita white-marble quarry, performed on a single auditable dataset of 58 discontinuities across three orthogonal scanlines, has produced a complete and reproducible characterisation of the two-set joint system: Set 1 sub-horizontal foliation with engineering normal spacing 0.18 m and trace length 4.4 m; Set 2 steep SW-dipping conjugate with normal spacing 0.57–1.12 m and trace length 4.6 m; combined termination 24 - 33 % in intact rock. The Octave workflow has been ported to Python (`ruschita_master.py`) and reproduces every published number.

The following steps are planned within the remaining AI-COSTSQO activities and as follow-on work:

- DFN calibration - feed the screened $\cos \delta \geq 0.2$ spacings, the Approach III trace lengths, and the Fisher distribution parameters of the two sets into the AI-COSTSQO DFN generator (Phase III, Activity 1); validate the synthetic DFN against in-situ block counts measured on bench panels.
- UAV/ TLS validation - repeat the scanline survey by extracting traces from a UAV photogrammetric mesh and from a terrestrial laser-scanning (TLS) point cloud of the same Main Wall; compare the trace-length distributions with the manual scanline result to quantify the bias of manual short-trace sampling.
- IBSD-DFN coupling - derive the in-situ block-size distribution by Boolean intersection of the calibrated DFN with bench-scale extraction panels; compare with the first-order $0.18 \times 1.12 \times 4.4 \text{ m}^3$ estimate of Section 6.2.
- Sample-size extension - extend the scanline campaign to a total target of ≈ 200 discontinuities by adding two further bench-level scanlines and one vertical scanline on the West-facing block; this is the minimum sample size recommended by ISRM [1] to obtain statistically stable Fisher parameters.
- Environmental coupling - integrate the DFN-derived IBSD with the AI-COSTSQO environmental module to quantify dust, water, and waste-volume reductions achievable through DFN-conditioned panel layout.

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