Geostatistical study of the linear Fracture Frequency (FF) in two Chilean copper deposits

Serge Antoine Séguret, MINES ParisTech, Fontainebleau, France
Cristian Guajardo, Codelco, Chuquicamata, Chile
Ramon Freire, Codelco, Casa Matriz, Chile
Geostatistics ?

Continuous (grade)

Categorical (geol. Unit)

Geostatistics

Spatial statistics

Modeling spatial uncertainty
Continuous (grade)

Categorical (geol. Unit)

Geostat. ESTIMATION

Geostat. SIMULATION

1 simu.

(100 → 10000)
Fracture Frequency

$L_{NC}$ : total length of Non Cruhed part of the sample

$L_c$ : total length of Cruhed part of the sample

$L_{NC} + L_c = 1.5m$

$N_{fract} : number of fractures (corrected or not) along $L_{NC}$

$$FF(x) = \frac{N_{fract}(x)}{L_{NC}(x)}$$
Observation of a natural phenomenon

From 490.50 To 492.00
Crushed length: 11 centimeters
Nº Fracturas: 1

From 684.0 To 685.5
Crushed length: 74 centimeters
Number of fractures: 16
• 13,000 samples
• 1,5 m length
• Underground mine, Codelco
• 1000x2300x1000 m³
Understanding this link

\[ N_{\text{fract}} \quad \text{(Fractures number)} \]

\[ \rho = 0.75 \]

\[ L_c \quad \text{(Crush length)} \]
Directional Classes

\[ N_{tot}(x) = \sum_{\theta=1}^{n_\theta} N(\theta, x) \]
Terzagui Correction

\[ FF = \frac{\sum n(\theta)}{L} \]

\[ FF_{corrected} = \frac{\sum \frac{n(\theta)}{\sin(\theta)}}{L} \]  

(Terzaghi, 1965)
Directional Concentration

\[ N_{tot}(x) = \sum_{\theta=1}^{n_\theta} N(\theta, x) \]

\[ \sigma^2_\theta(x) = \text{Var}_\theta[N(\theta, x)] = E_\theta[(N(\theta, x) - N_{\theta,mean}(x))^2] \]

\[ N_{\theta,mean}(x) \approx \frac{N_{tot}(x)}{n_{\theta}} \]

\[ \sigma^2_\theta(x) \approx \frac{1}{n_{\theta}} \sum_{\theta=1}^{n_\theta} (N(\theta, x) - N_{\theta,mean}(x))^2 \]
Directional Concentration

\[ 0 \leq \sigma_\theta^2(x) \leq \sigma_{\theta,\text{max}}^2(x) = N_{\theta,\text{mean}}(x)^2(n_\theta - 1) \]

\[ \sigma_\theta^2(x) = 0 \quad \text{full directional isotropy, all the fractures are equally distributed over the directions} \]

\[ \sigma_\theta^2(x) = \sigma_{\theta,\text{max}}^2 \quad \text{full directional anisotropy, all the fractures lie along one direction} \]

\[ R_{\theta}^2(x) = \frac{\sigma_\theta^2(x)}{\sigma_{\theta,\text{max}}^2(x)} = \frac{1}{n_\theta(n_\theta - 1)} \sum_{\theta=1}^{n_\theta} \left( \frac{N(\theta, x)}{N_{\theta,\text{mean}}(x)} - 1 \right)^2 \]
Directional Concentration

Shear Zone
West Fault

$R_0^2(x)$

Full directional anisotropy

Full directional isotropy
$N_{\text{fract}}$ (Fractures number)

$\rho = 0.75$

$L_c$ (Crush length)
Directional Concentration Classes

(a) $R^2(x) \in [0, 0.25]$
- $N_{\text{tot}}(x)$ vs $L_C(x)$
- $\rho = 0.864$

(b) $R^2(x) \in [0.25, 0.5]$
- $N_{\text{tot}}(x)$ vs $L_C(x)$
- $\rho = 0.487$

(c) $R^2(x) \in [0.5, 0.75]$
- $N_{\text{tot}}(x)$ vs $L_C(x)$
- $\rho = 0.336$

(d) $R^2(x) \in [0.75, 1]$
- $N_{\text{tot}}(x)$ vs $L_C(x)$
- $\rho = 0.319$
Another deposit
Another deposit
Deposit 1

\[ \rho_{N,Lc}(x) = 0.28 + 0.72e^{-\frac{R^2(x)}{0.33}} \]

Deposit 2

\[ \rho_{N,Lc}(x) = 0.9 - 0.77R^2(x) \]
Residual model

\[ N_{tot}(x) = \frac{\sigma_{N_{\text{tot}}}}{\sigma_{L_c}} \left( \rho_{N,L_c}(x) \right) \left( L_C(x) + \sqrt{1 - \rho_{N,L_c}(x)^2} \cdot RSD(x) \right) + C(\rho_{N,L_c}(x)) \]

\[ \forall x, \ N_{tot}(x) = N_{\text{corr}}(x) + N_{\text{ind}}(x) \]
Independent fractures
Deposit 1

<table>
<thead>
<tr>
<th>Shear Zone</th>
<th>West Fault</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Independent fracture number</th>
</tr>
</thead>
<tbody>
<tr>
<td>More fractured</td>
</tr>
<tr>
<td>Less fractured</td>
</tr>
</tbody>
</table>

Y=3500m

[Color-coded map with zones A and B]
Independent fractures
Deposit 2
Conclusion

• Crushing, a useful regionalized variable

• Directional concentration, mutual organization of the fractures

→ Spatial correlation between fracturing and crushing

• Useful in case of rock submitted to alteration
Fracturing, Crushing and Directional Concentration

Serge Antoine Séguret, MINES ParisTech, Fontainebleau, France