FAULT DATA ASSOCIATION WITH GRAPH IN MINING CONTEXT

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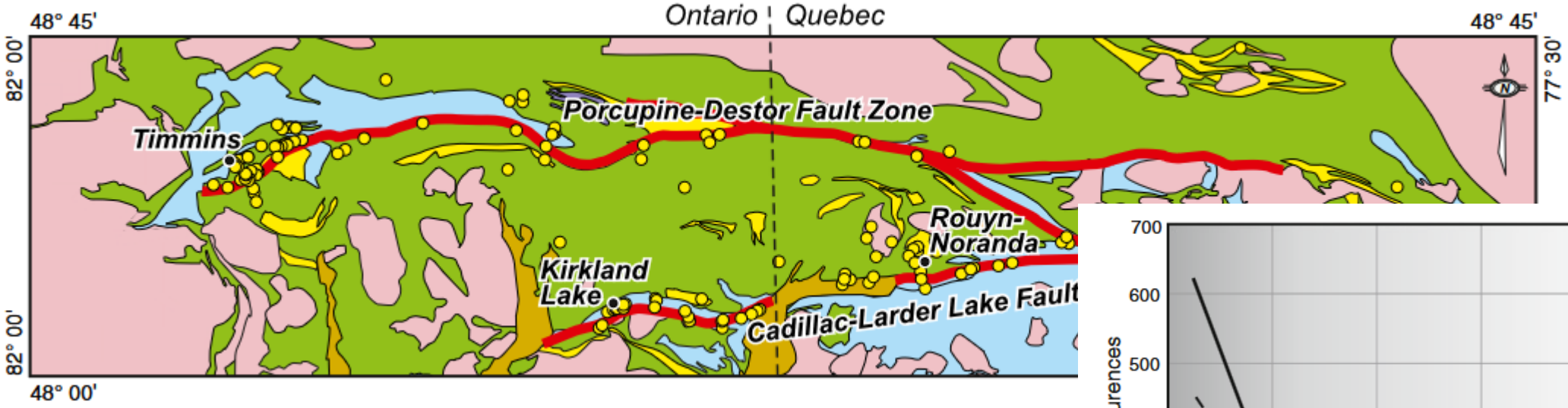
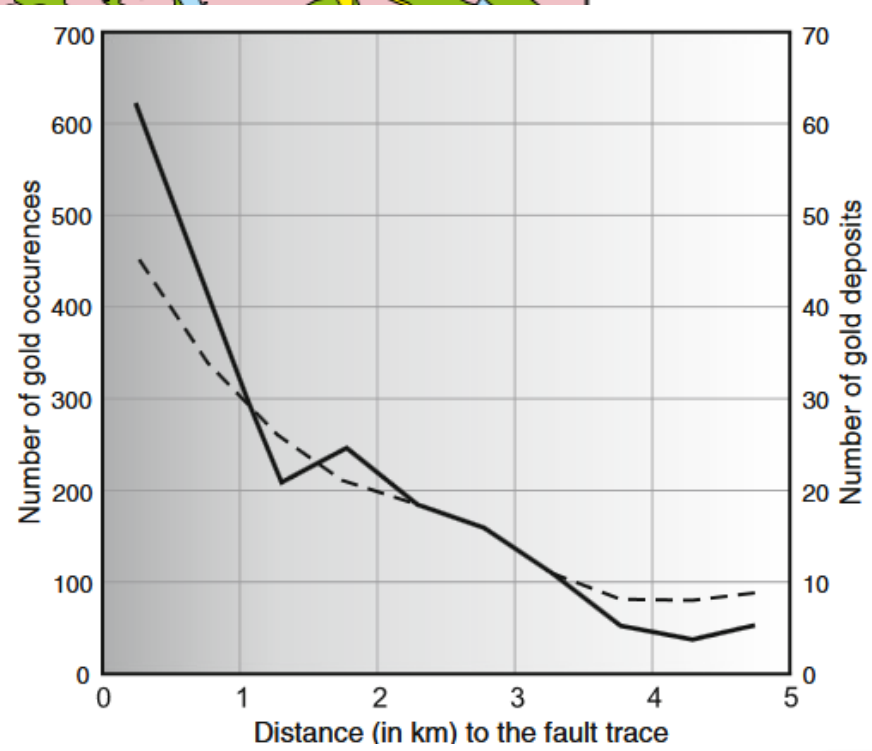
Fault = mineralization ?

[Rabeau et al., 2013, Minerallium Deposita]

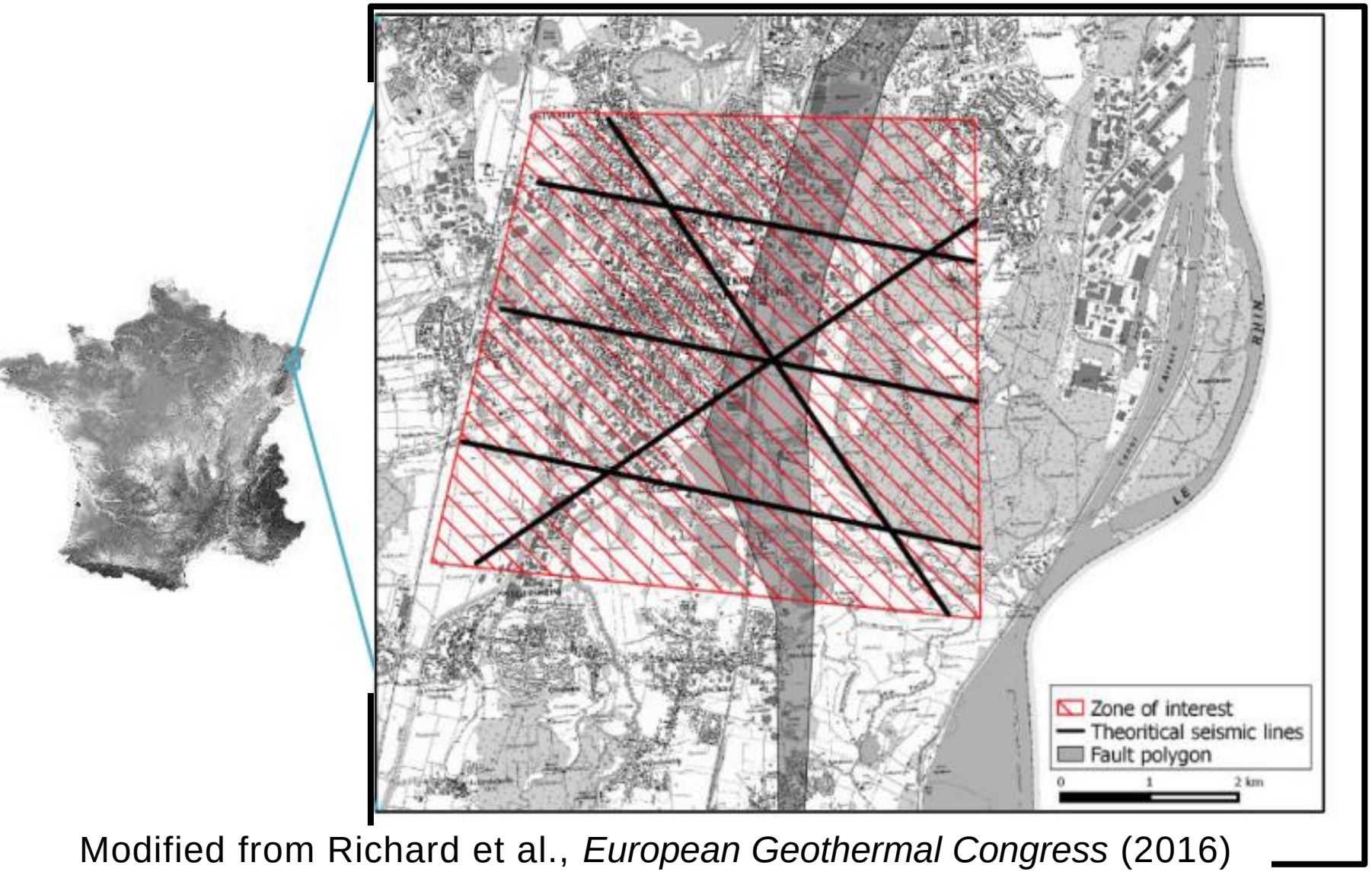




Gold mineralization

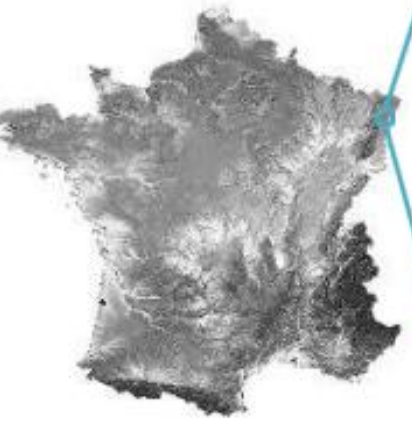
Mostly present along fault

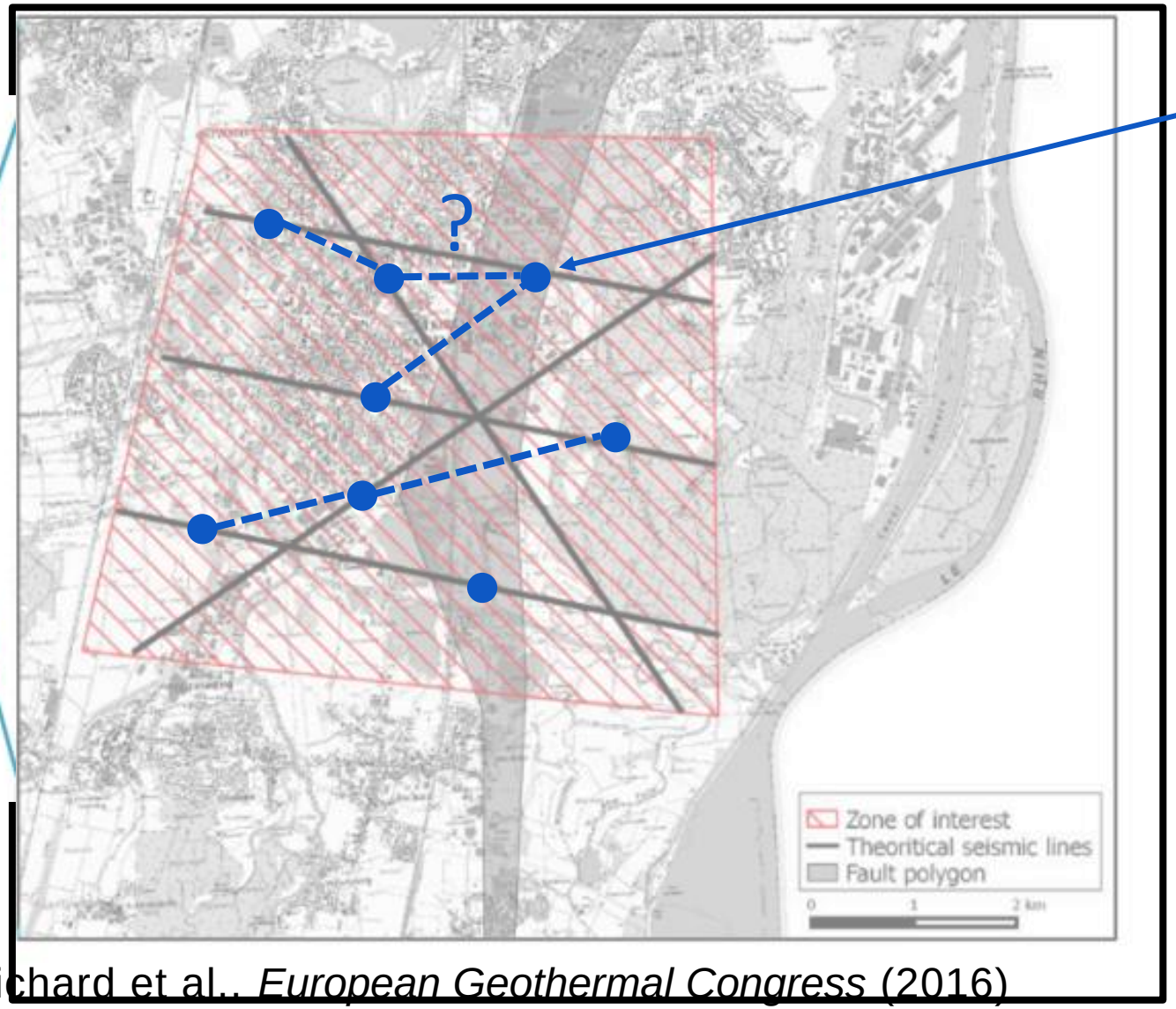
Where are the faults ?

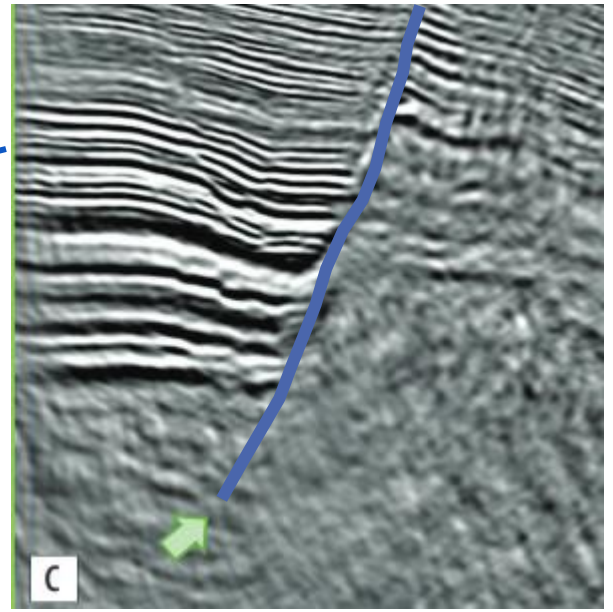


Modified from Richard et al., *European Geothermal Congress* (2016)

Where are the faults ?



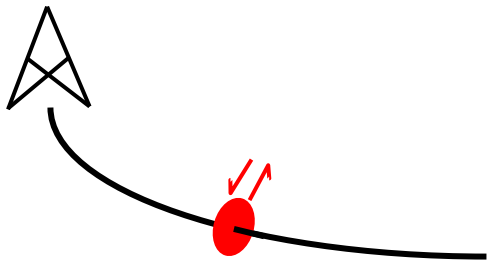


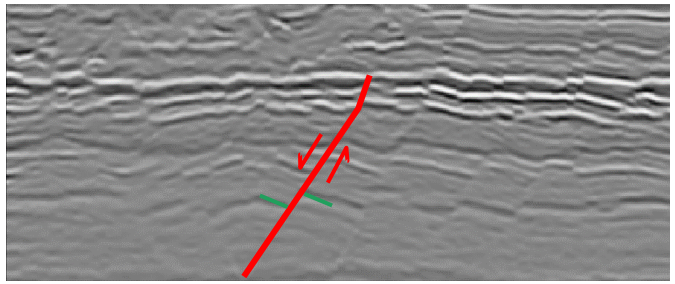


[Salaun et al., 2020, *The Leading Edge*]

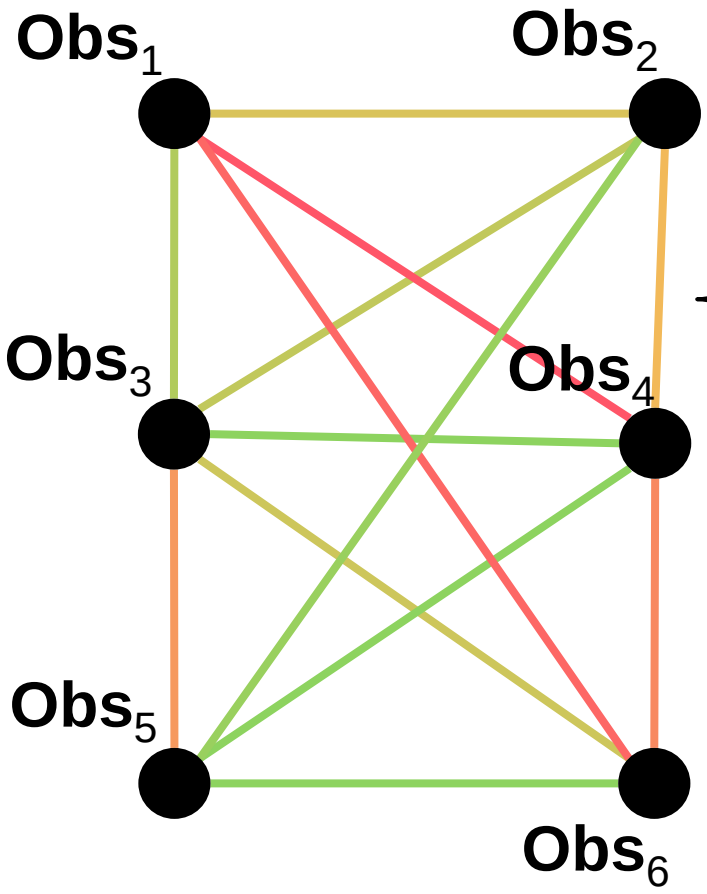
Modified from Richard et al., *European Geothermal Congress* (2016)

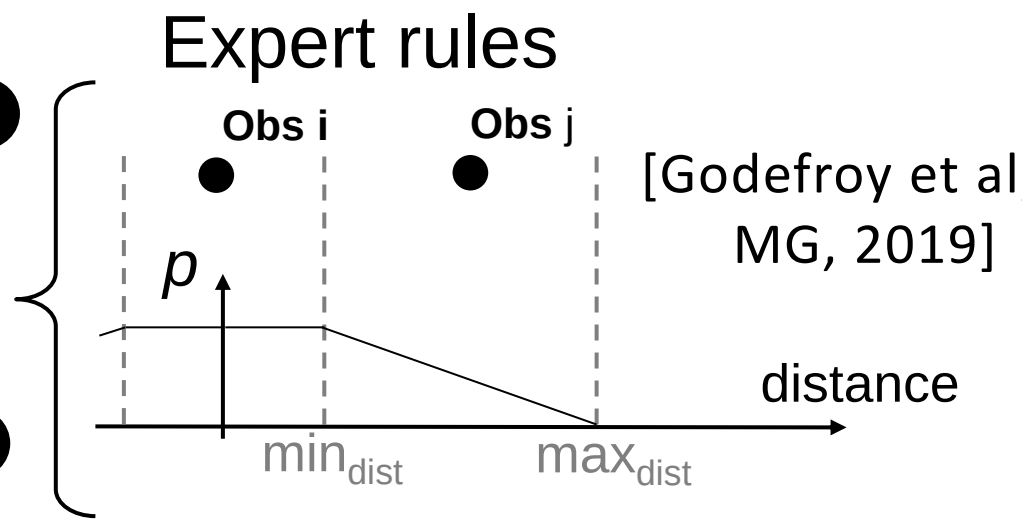
Fault association using graph theory [Godefroy et al., MG, 2019]

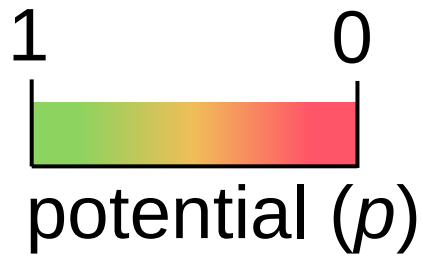




Courtesy of Equinor

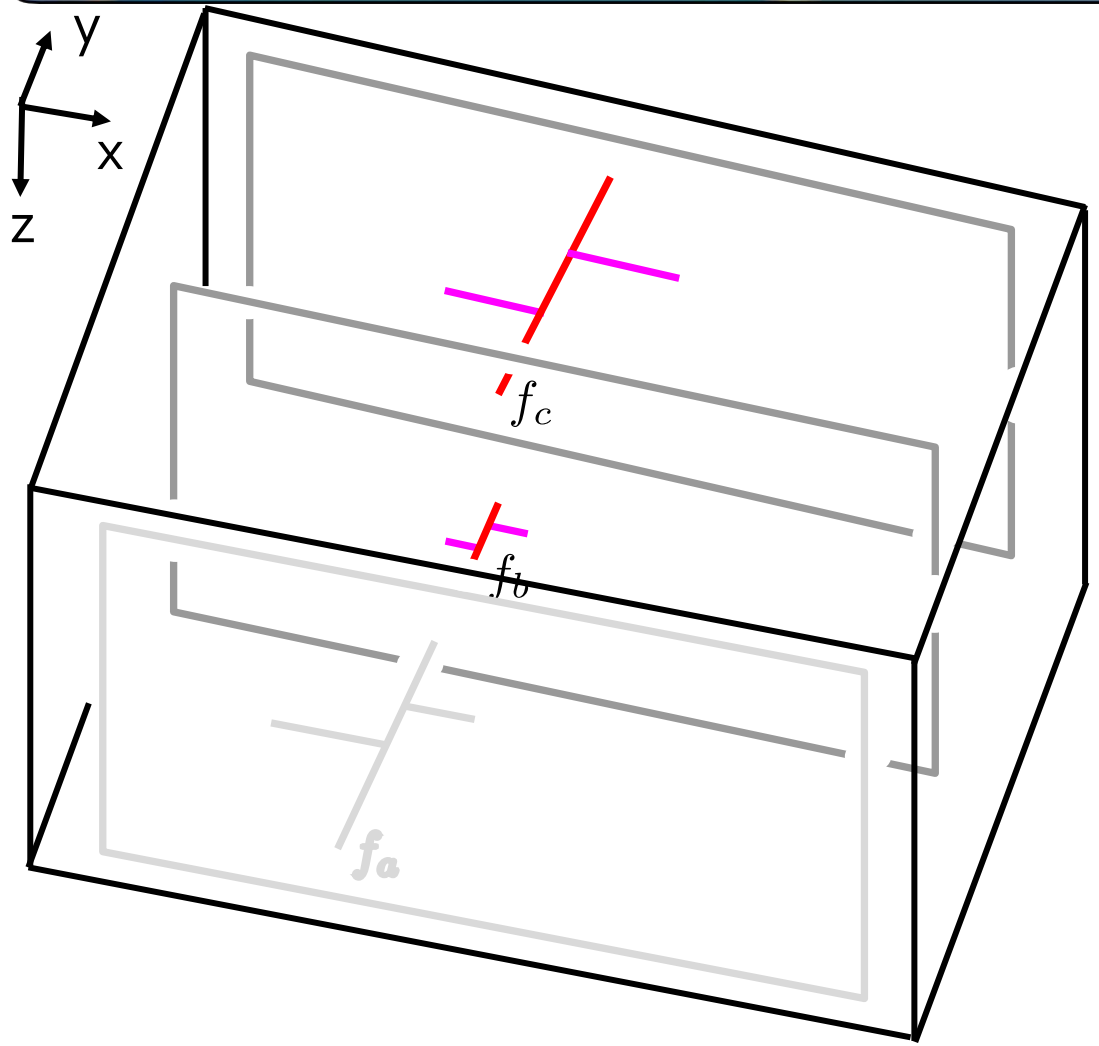


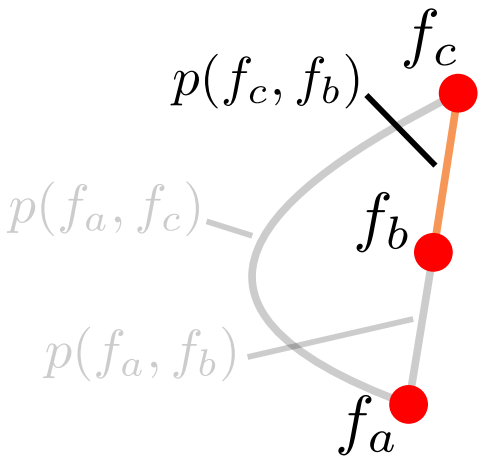


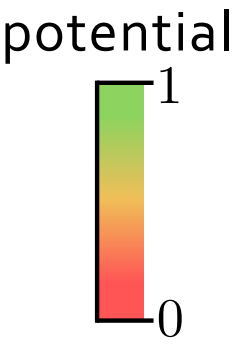


- Expert rules defined only for fault traces from 2D seismic images
- Expert rules limited to pair association

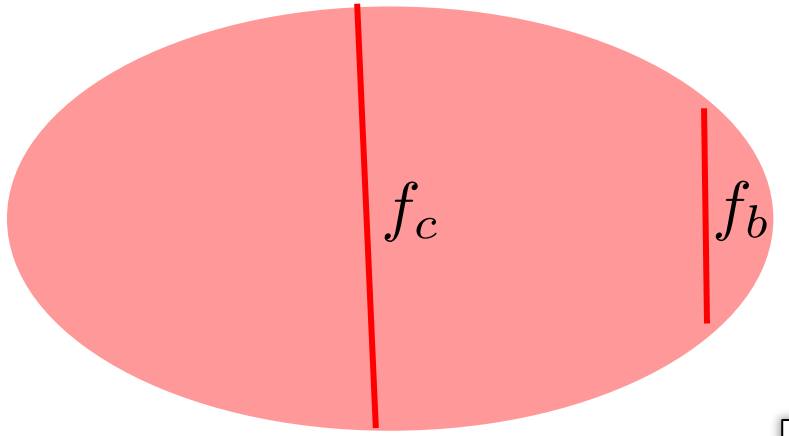
Multi-point information



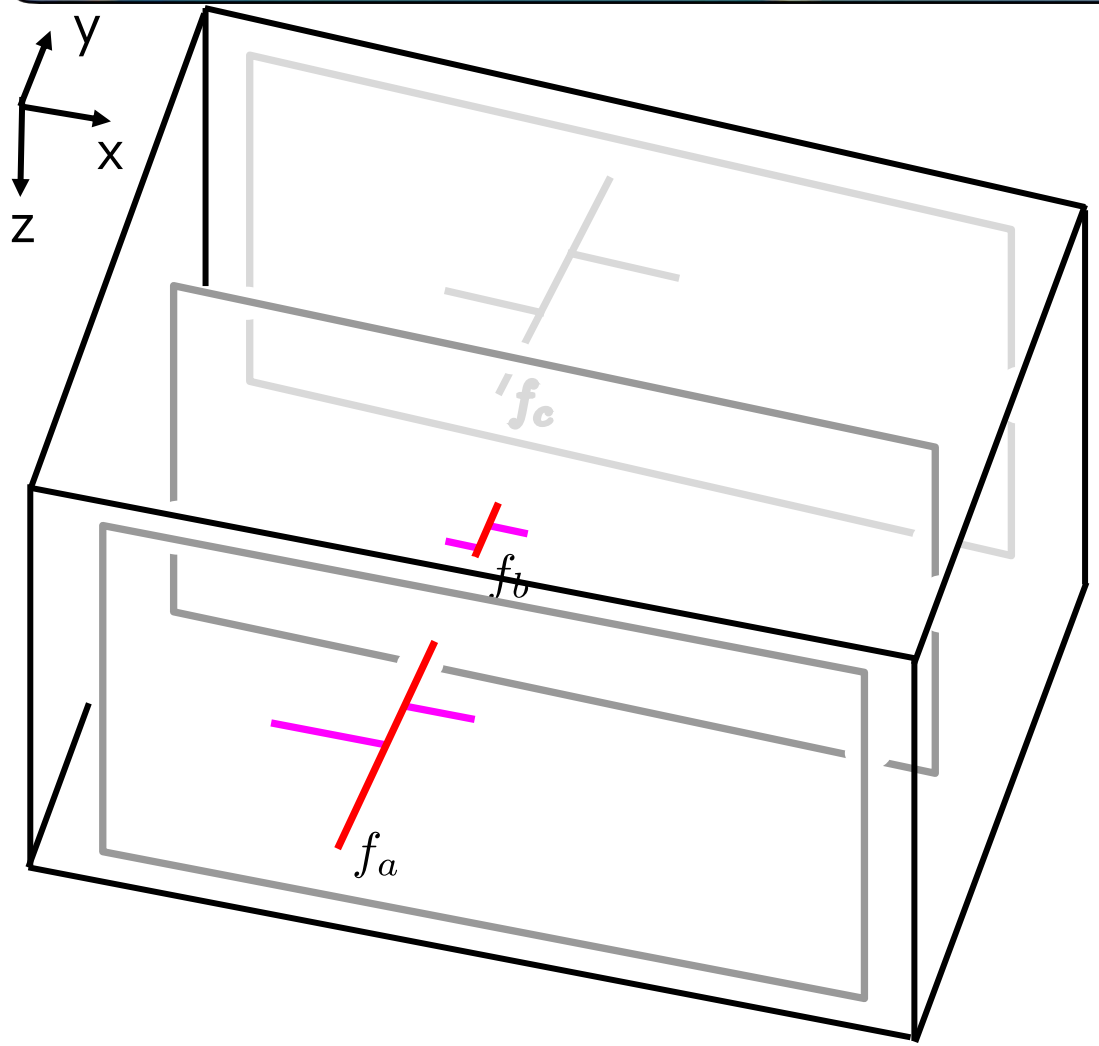


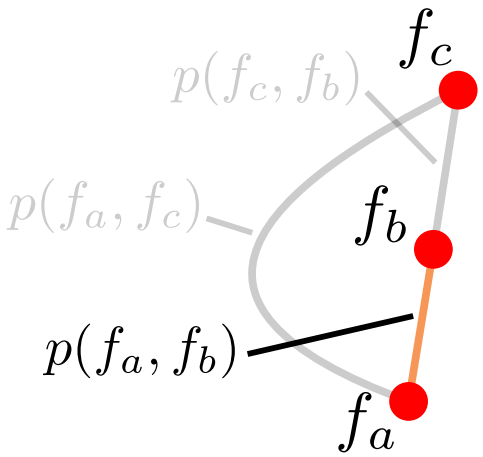


Theoretical Elliptical shape of a fault
[Walsh et Watterson, JSG, 1989]



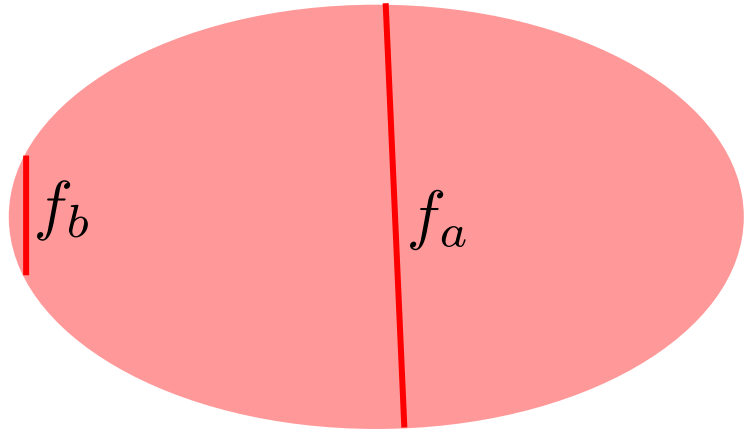
Multi-point information



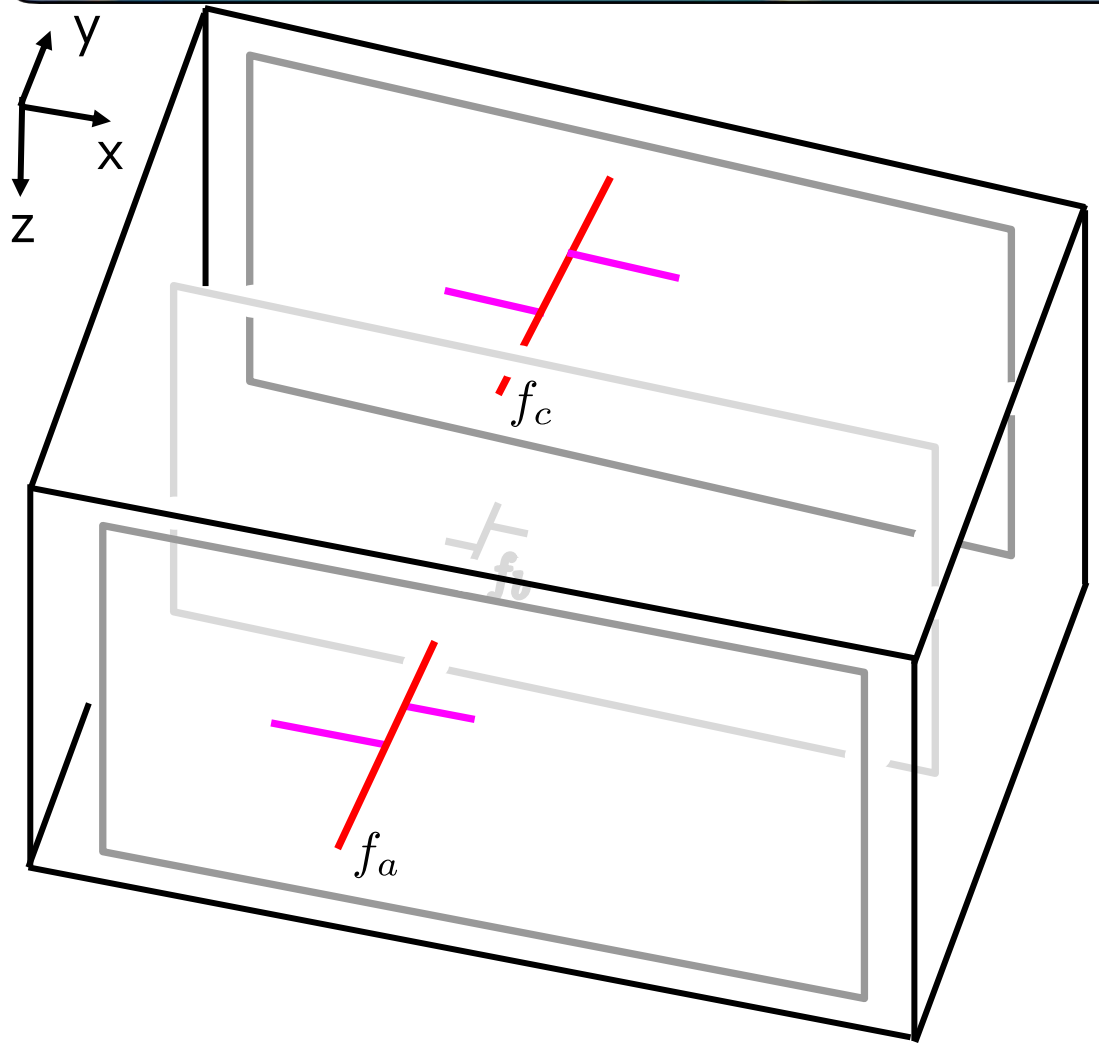


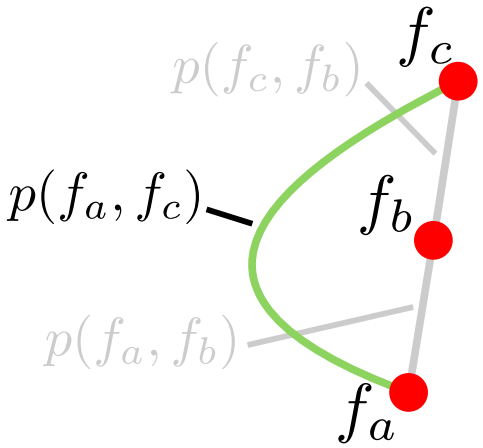
potential

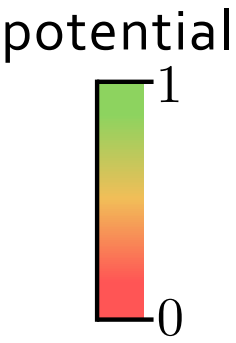
Theoretical Elliptical shape of a fault
[Walsh et Watterson, JSG, 1989]



Multi-point information







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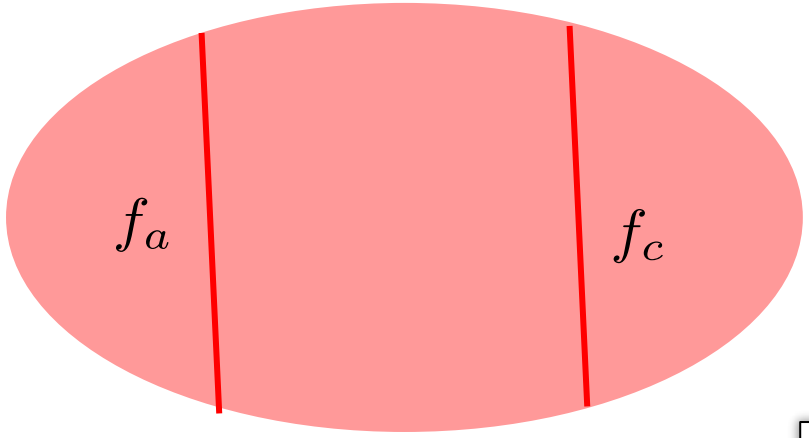
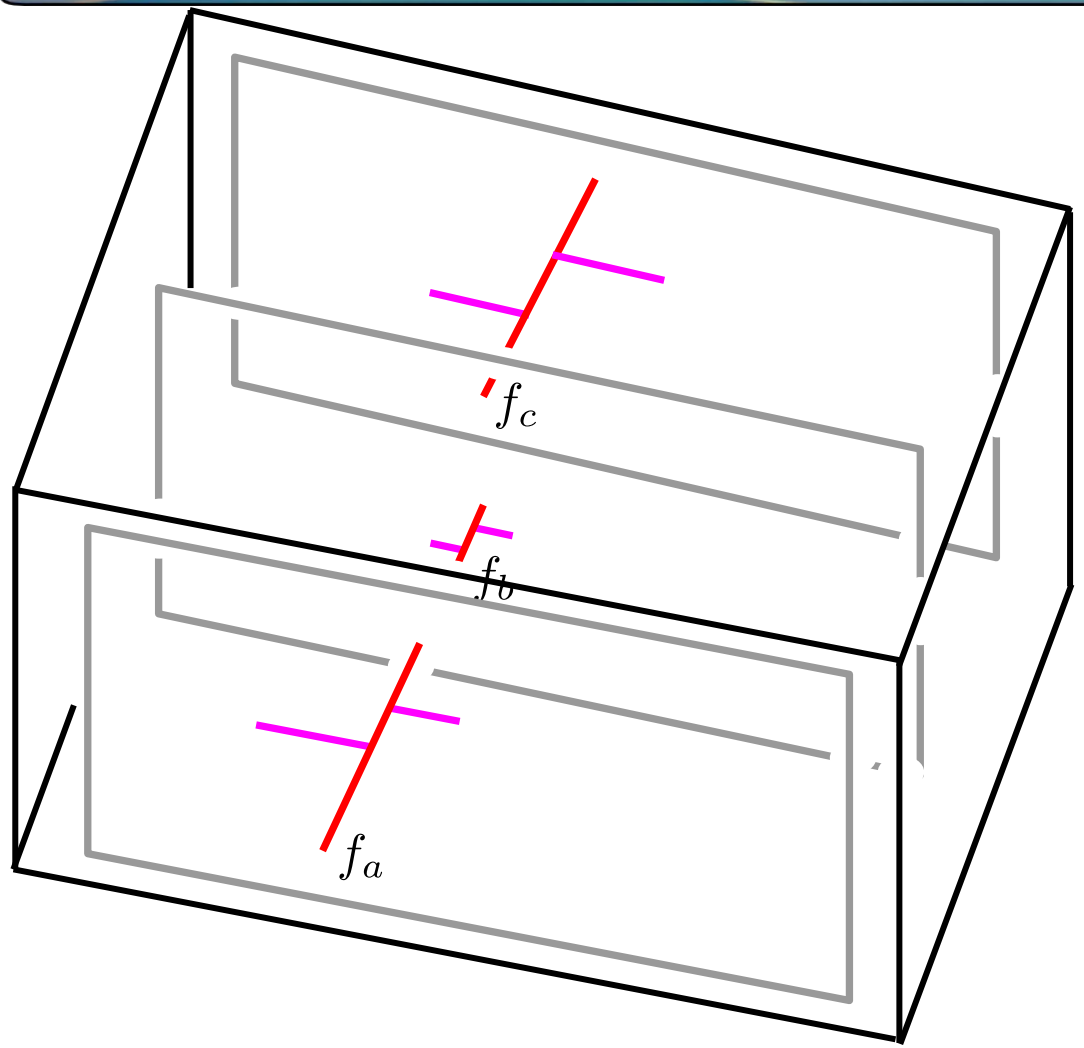
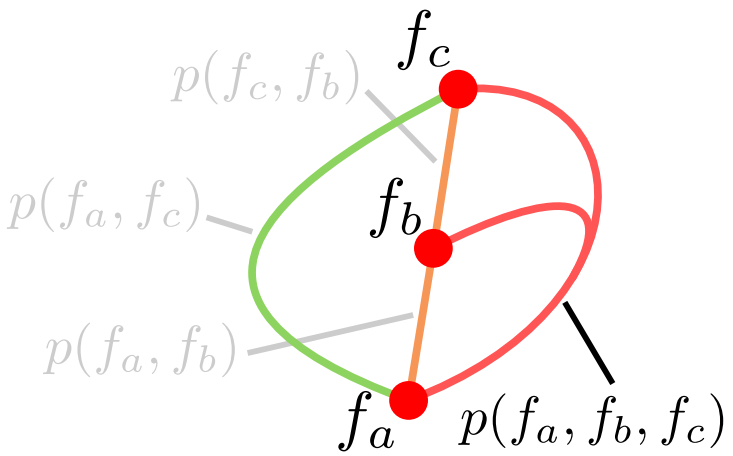
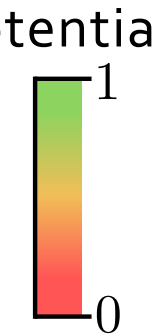


Multi-point information







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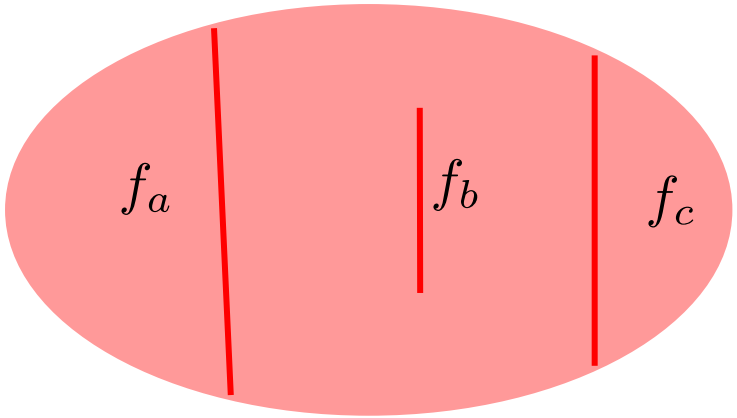


Mean of pair potential
[Godefroy et al., JGR, 2021]

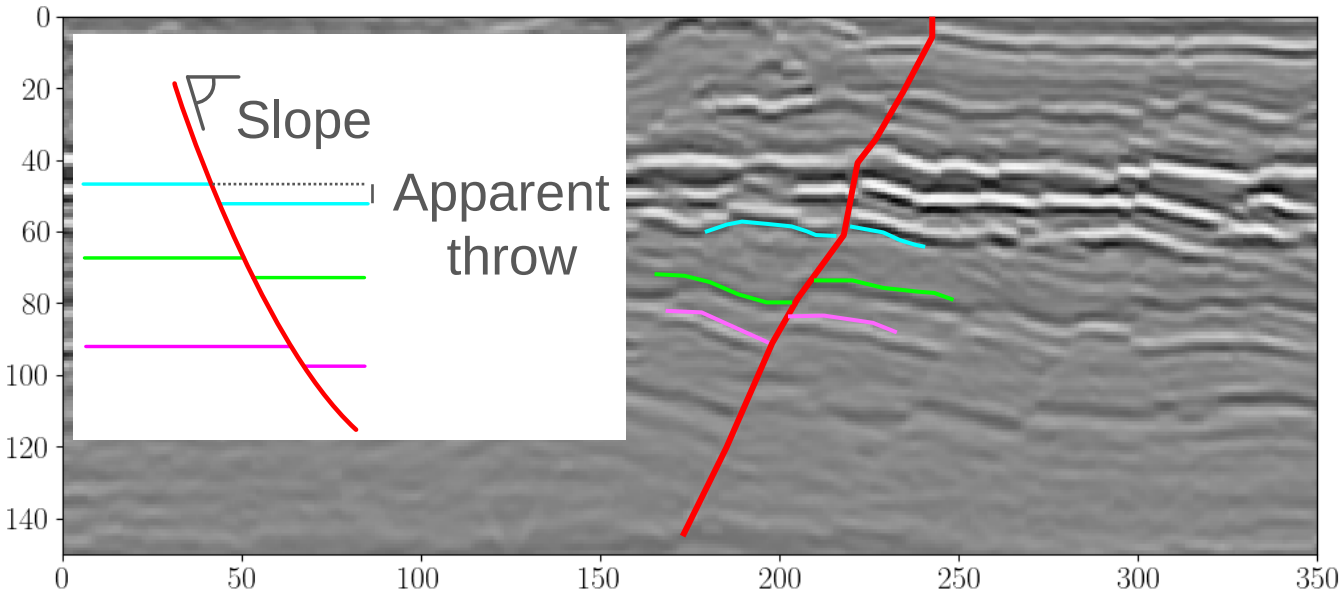
How to adapt the graph formalism to mining context ?

New expert rules for borehole imaging interpretation

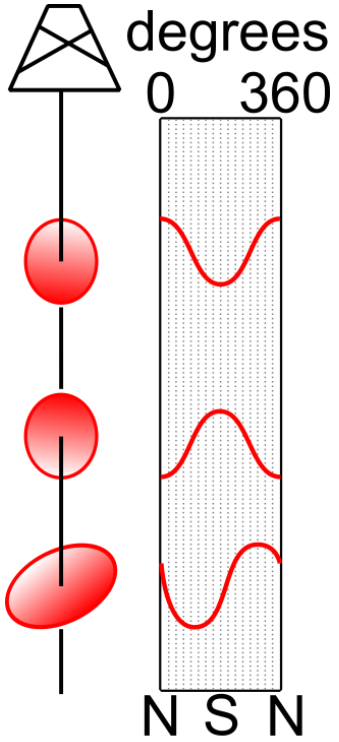
How to take into account multiple-point information during the association ?

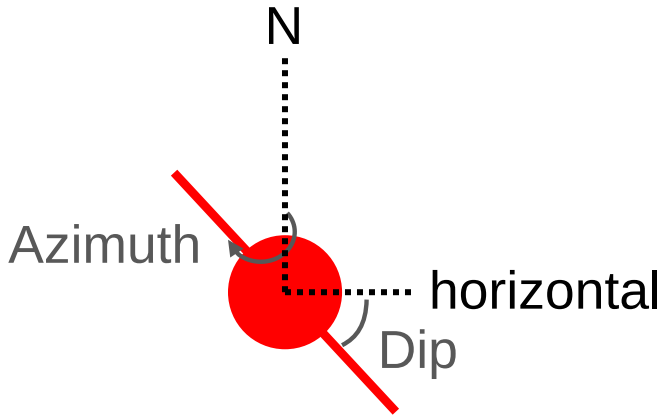
Multiple-point potential using Balanced Random Forest

Fault observation on seismic and on borehole images



Courtesy of Equinor

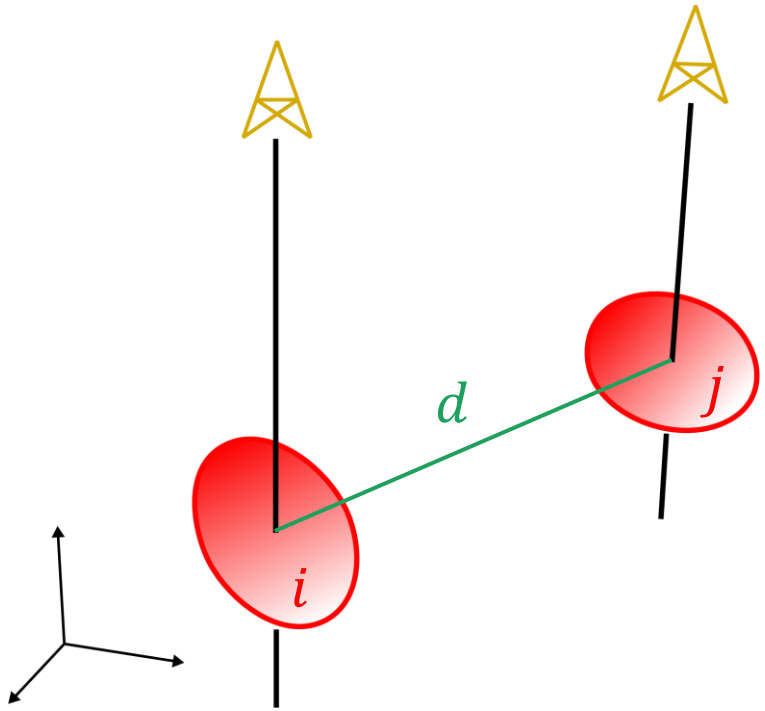


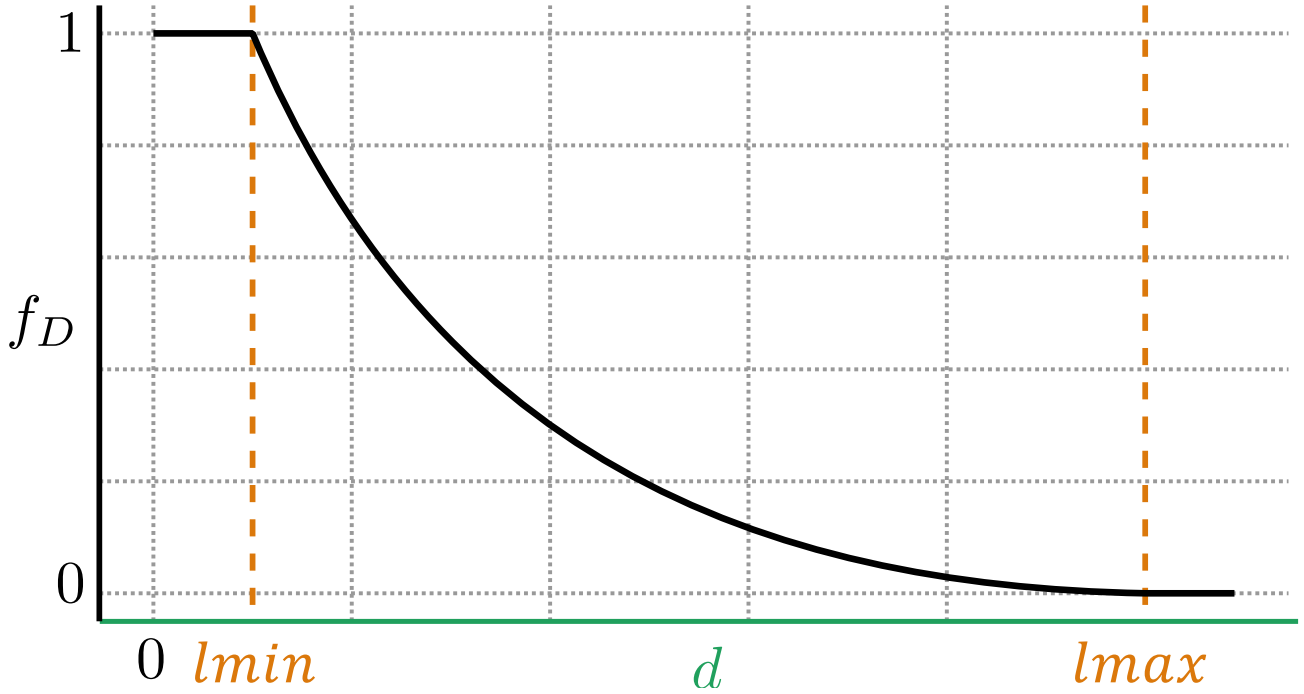


- Position
- Length
- Slope
- Throw

- Position
- Dip
- Azimuth
- Aperture

The distance rule



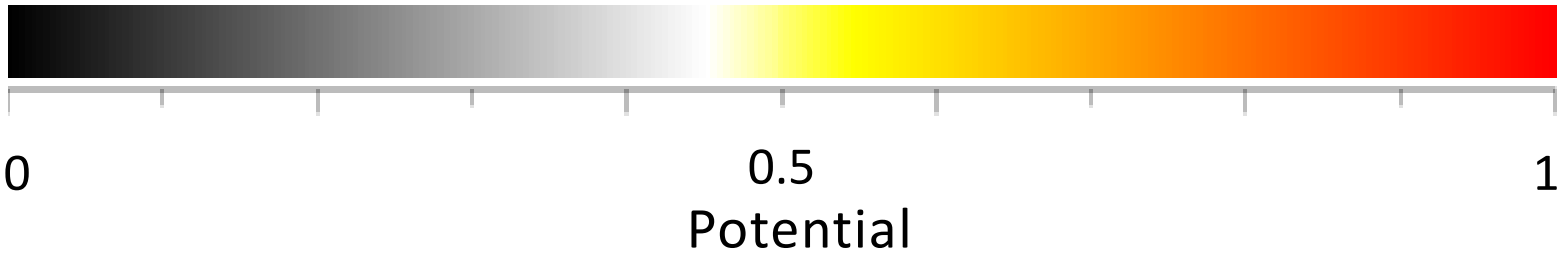


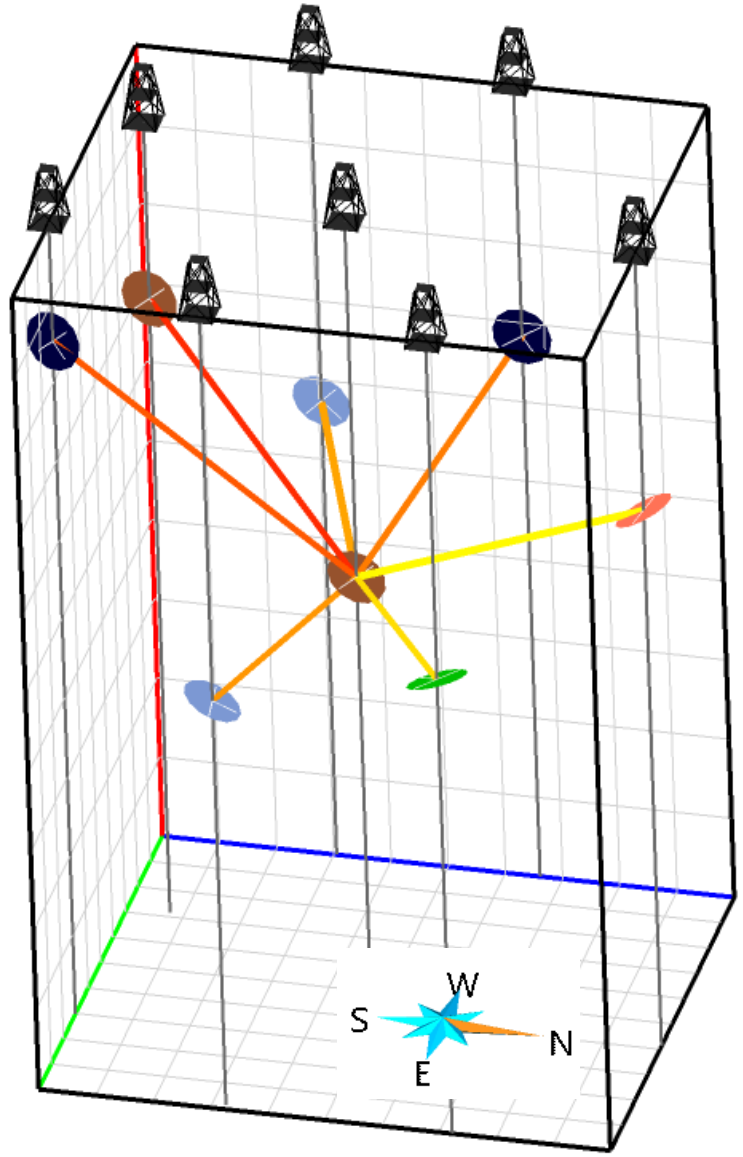
The plane rule

Application on synthetic marker:

Colors of marker corresponding to true association

- Best potential between the true association
- Worst potential between the opposite orientation





How to adapt the graph formalism to mining context ?

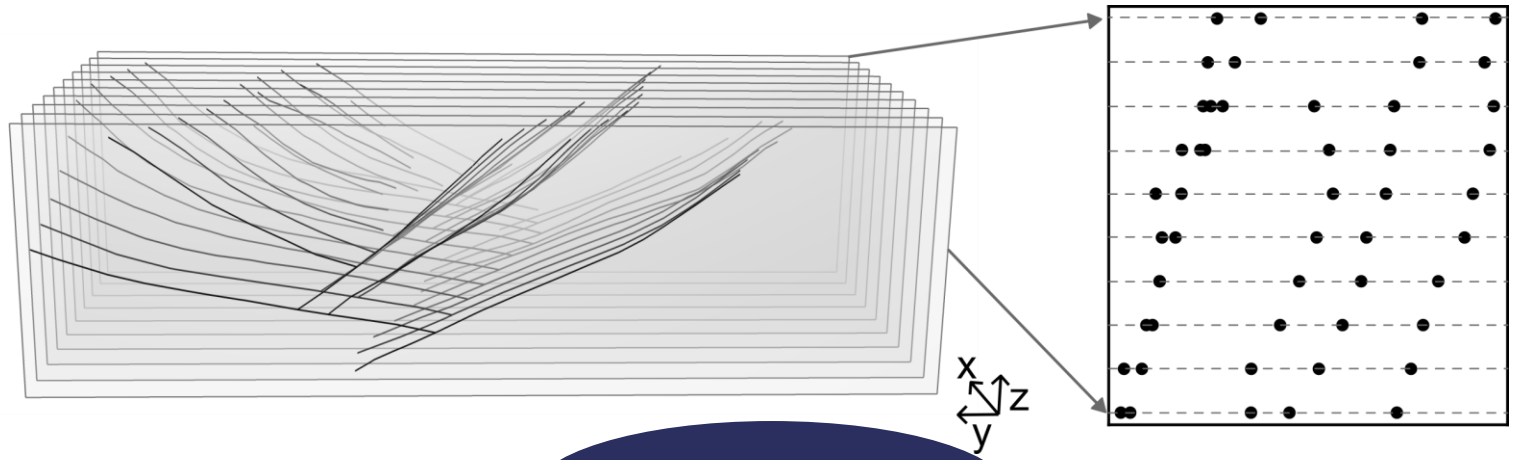
→ New expert rules for borehole imaging interpretation

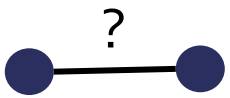
How to take into account multiple-point information during the association ?

→ Multiple-point potential using Balanced Random Forest

Multiple point association using Balanced Random Forest

Modified from [Fratani et al., in review, 2025]

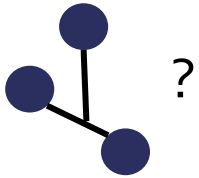


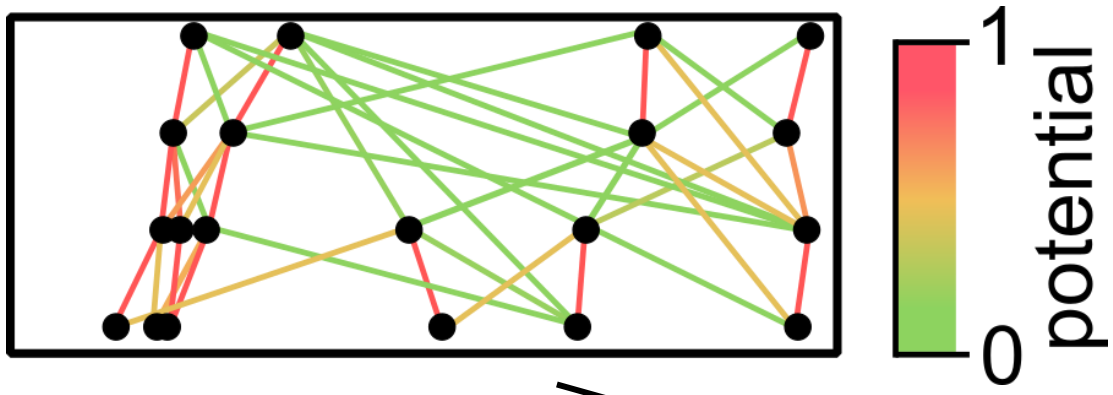


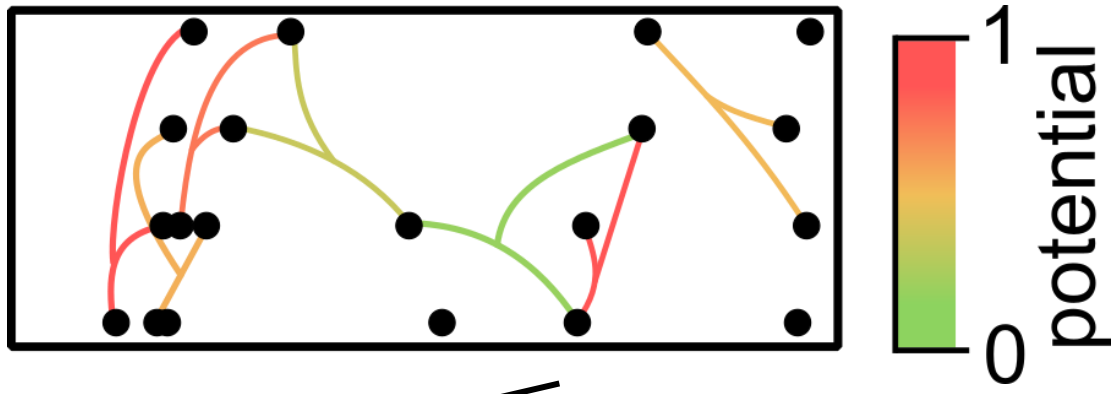
Pair potential

Trained RF

Triplet potential



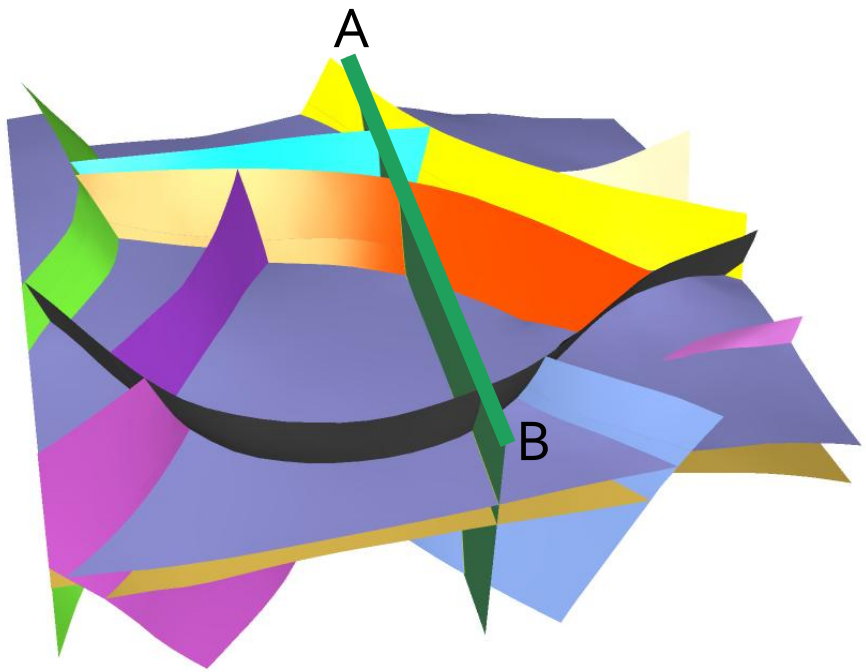




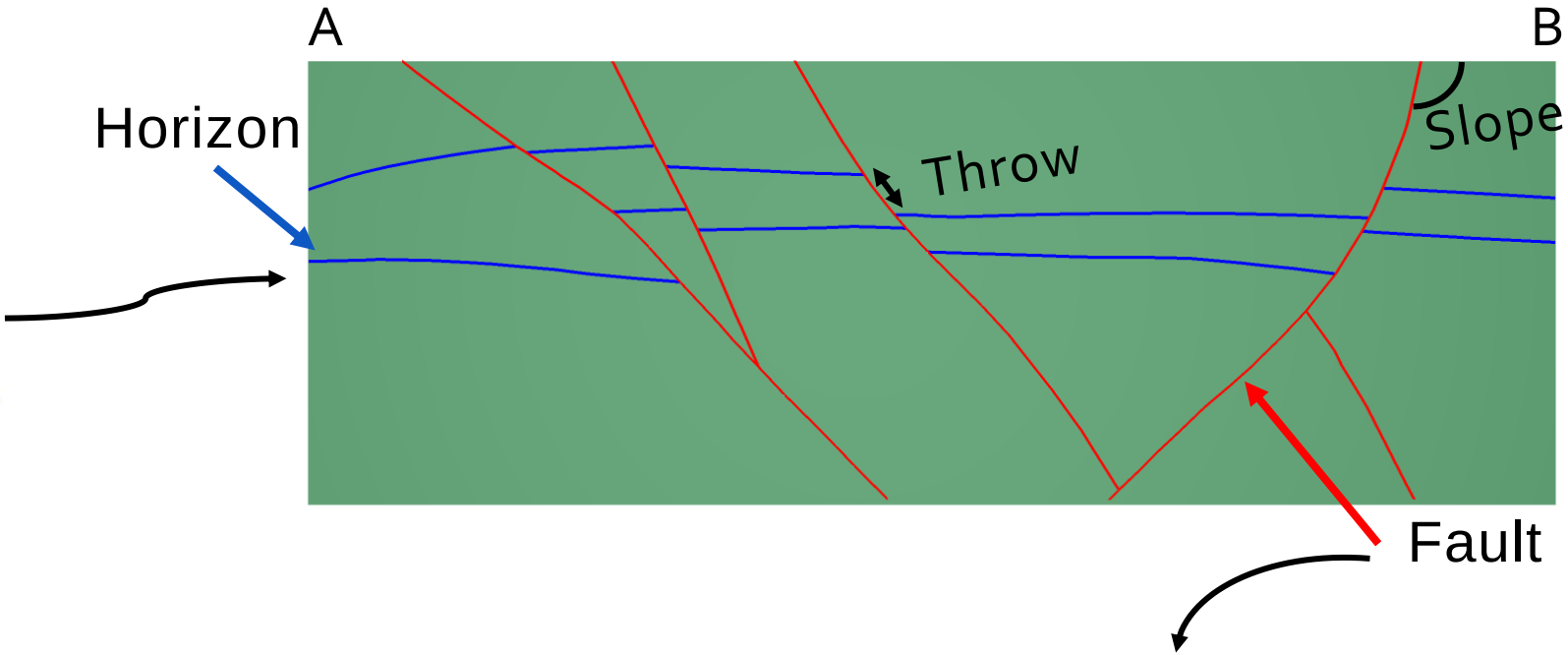
one graph

projected on a graph

Generating training database ➔ Synthetic fault traces



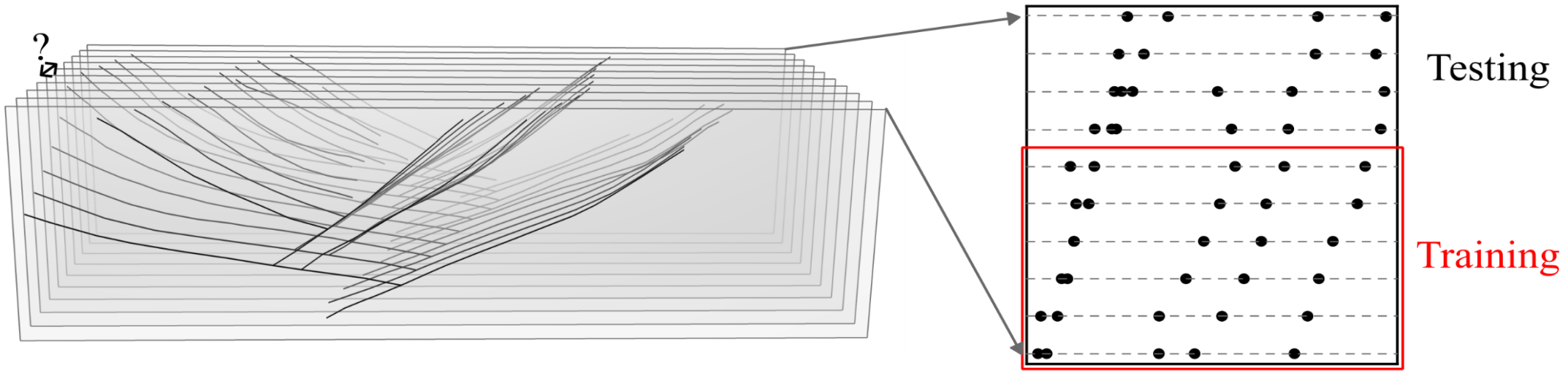
3D model courtesy of TotalEnergies



Modified from [Fratani et al., in review, 2025]

id	Centroid x	Centroid y	Centroid z	length	Slope	Max throw	Num section
1001	403788	90745,61	-3376,92	7710,20	179	0,0	0
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
1002	404553	91160,33	-2785,94	9685,60	172	59,3	17

Generating training database

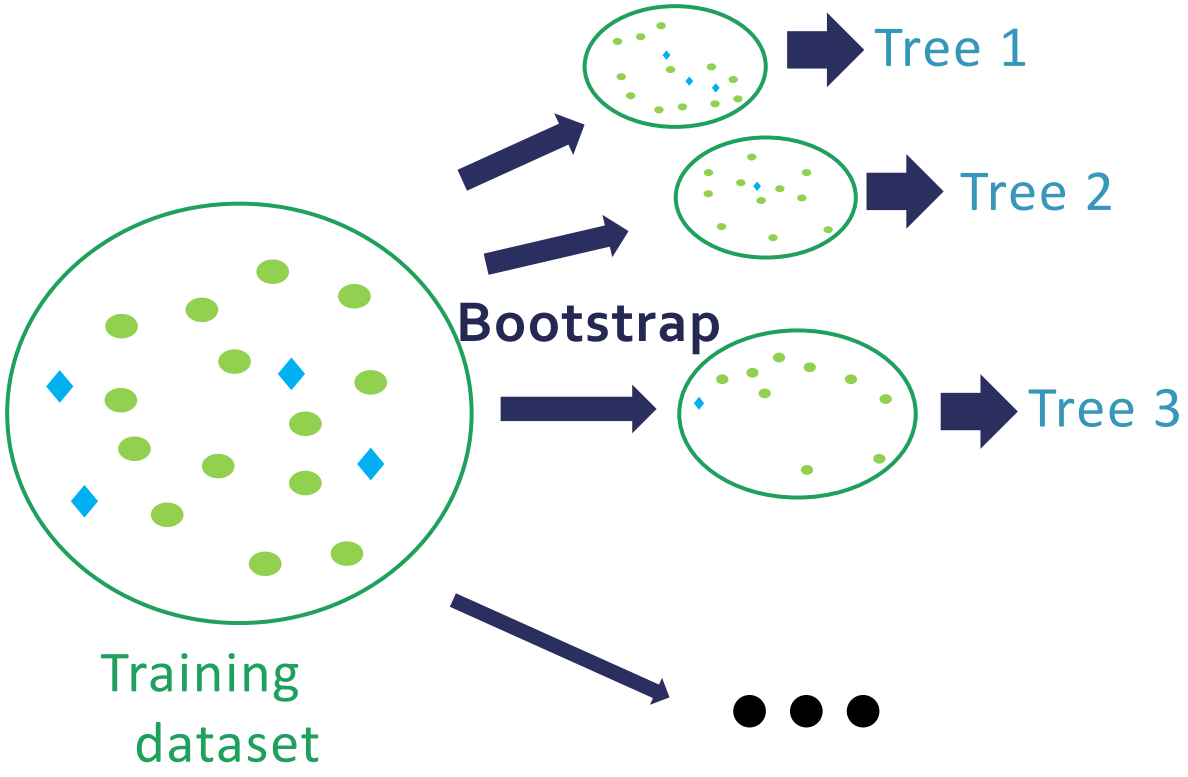


Create pair & triplet features and class:

- Points belong to the same fault ➔ associated
- Else ➔ disjoint

➡ Imbalanced dataset

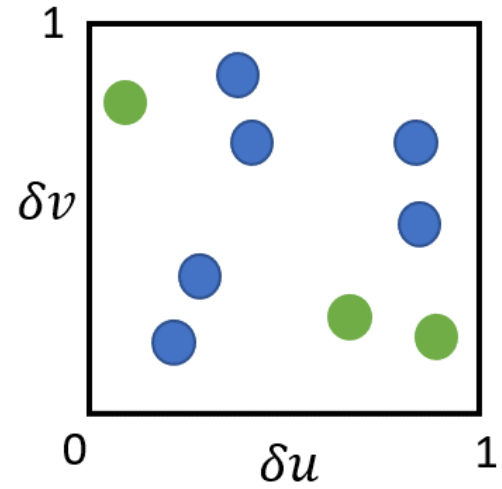
Random Forest



Balanced Random Forest

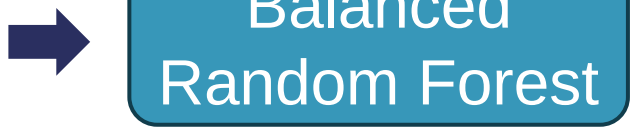
Decision tree

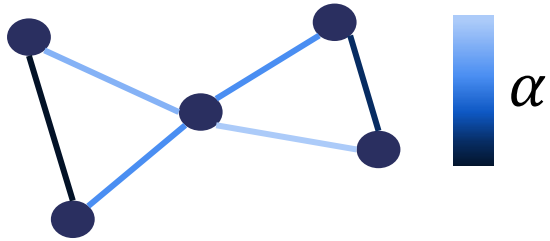
Associated Disjoint



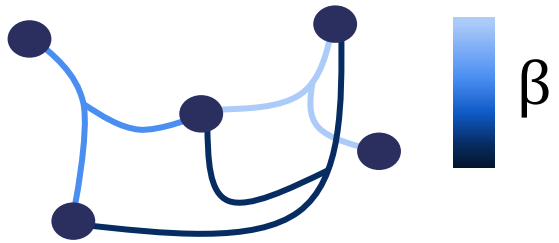
Methodology with Random Forest

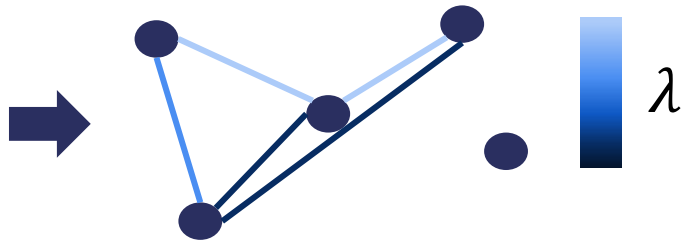
dx
dy
dz
dlen
dslope
dthrow





Brier Score

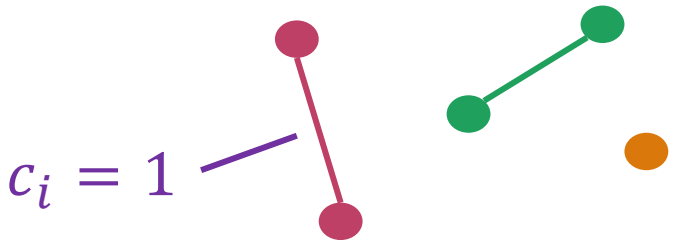




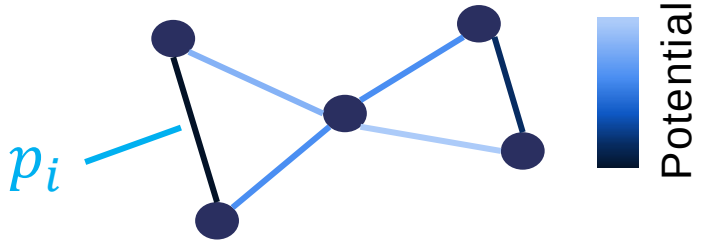
weigthed average of the triplet containing the edge

Metrics

Test



True graph



Predicted potential

Brier Score

$$BS = \frac{1}{N}\sum_{i=1}^{N}(p_i - c_i)^2$$

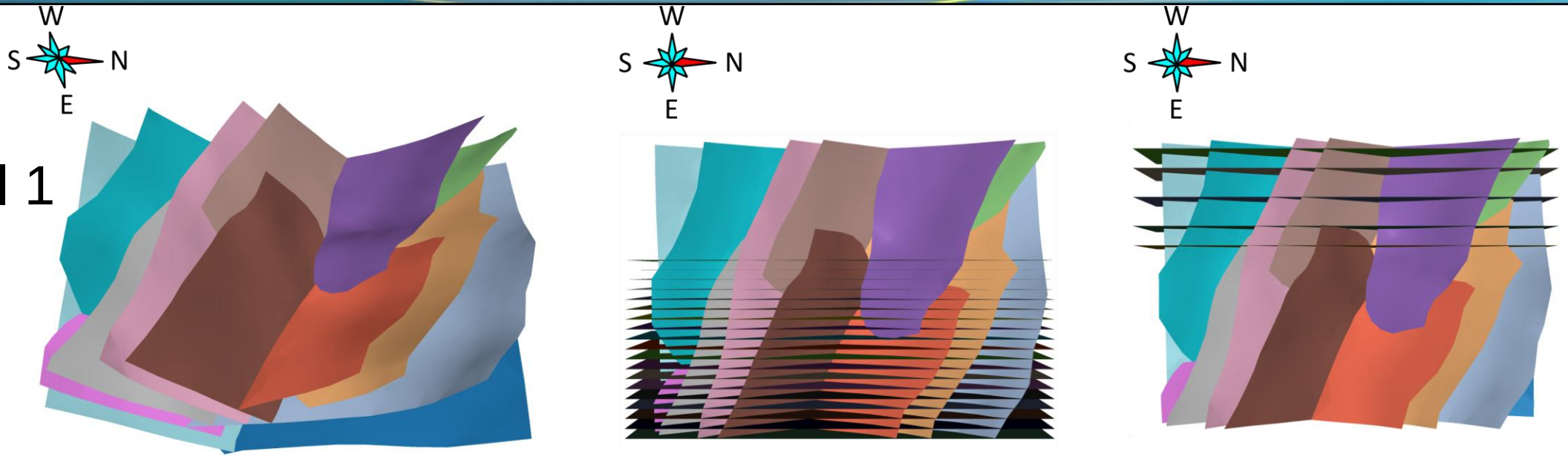
p_i: probability of associating

c_i: true value (associated or disjoint)

Results

[Fratani et al., in review, 2025]

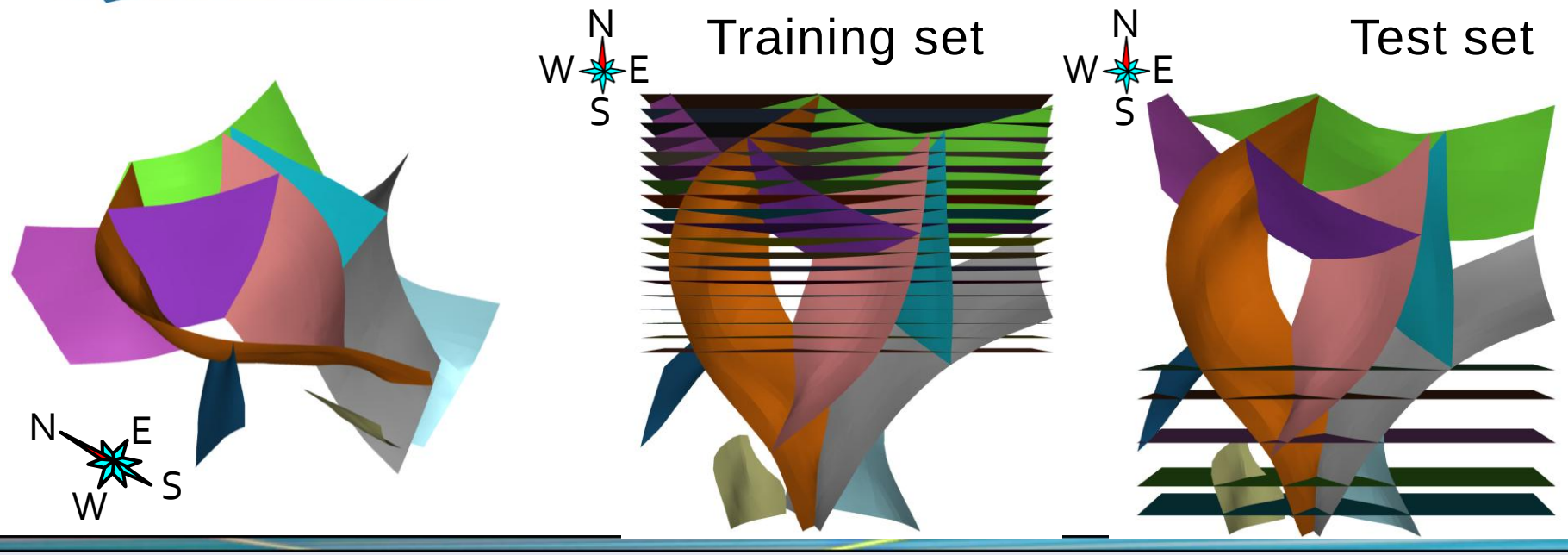
Model 1



Training set

Test set

Model 2



Triplet potential association

Comparison of the potentials of triplets with the mean of pairs potentials

Model	Random Forest	Mean of pair potential
Model 1	0.003	0.033
Model 2	0.070	0.131

Connection of pair and triplet potentials

Model	Pair potential	Triplet potential	Mean	Product	Weighted mean
Model 1	0.020	0.018	0.017	0.016	0.018
Model 2	0.188	0.154	0.159	0.133	0.138

[Fratani et al., in review, 2025]

Conclusions

Expert Rules

- 2 expert rules for borehole interpretation
- Needs to join the potential from several rules
- Limited to pair potential

➢ Rule taking into account of the aperture knowledge

Balanced Random Forest

- Take into account multi-point information
- Good results on two realistic dataset
- Limited for case with analog data

➢ Foundation ML model trained with a high number of data

➢ Efficient stochastic sampling algorithm to finally generate 3D models

Thank you !

RING Consortium

Managed by A.S.G.A.

aspentech BHP brgm

CCR Eliis ifp Energies nouvelles orano

OXY slb TotalEnergies

+ 88 Universities and surveys for support

www.ring-team.org

- AspenTech for software and API
- TotalEnergies for 3D model
- BHP for the support of the master project
- All my team for discussion

References

- Fratani, A., Stoica, R.S., Caumon, G., Giraud, J., 2025. Multiple point fault observation association using random forest from analog structural models. In review.
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