Structural Geology and Ore Deposits

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Numerous UZ students and staff

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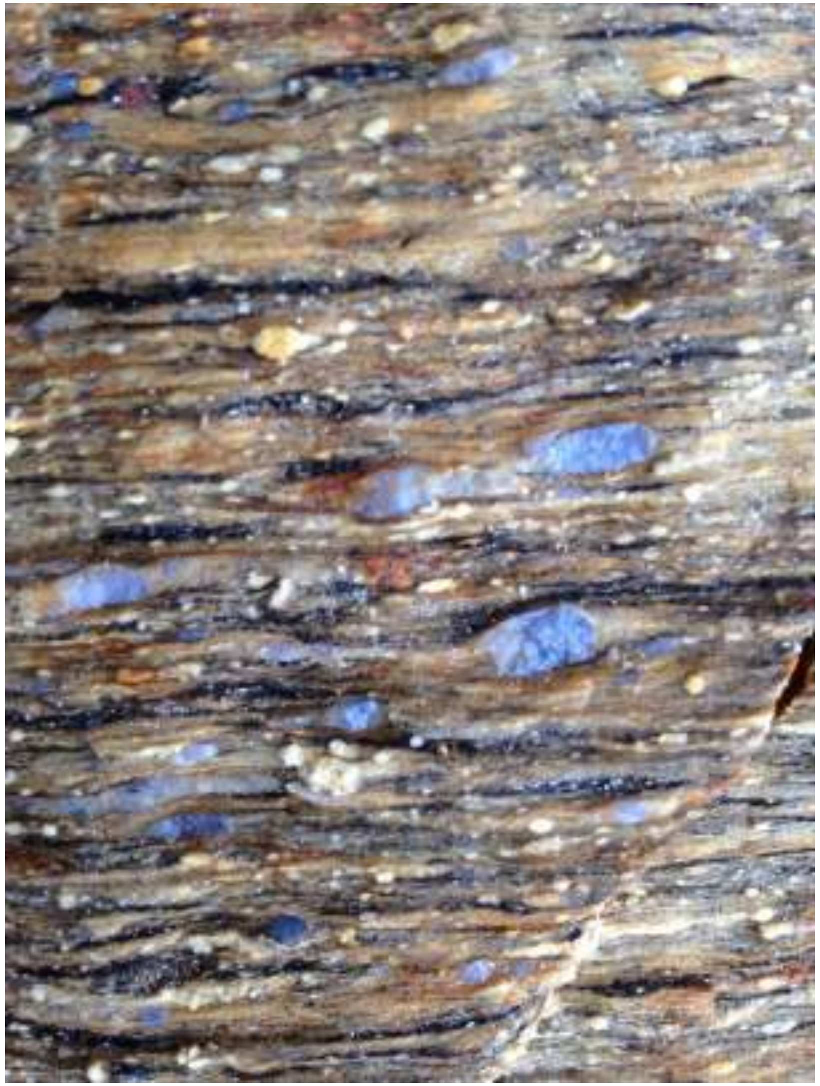
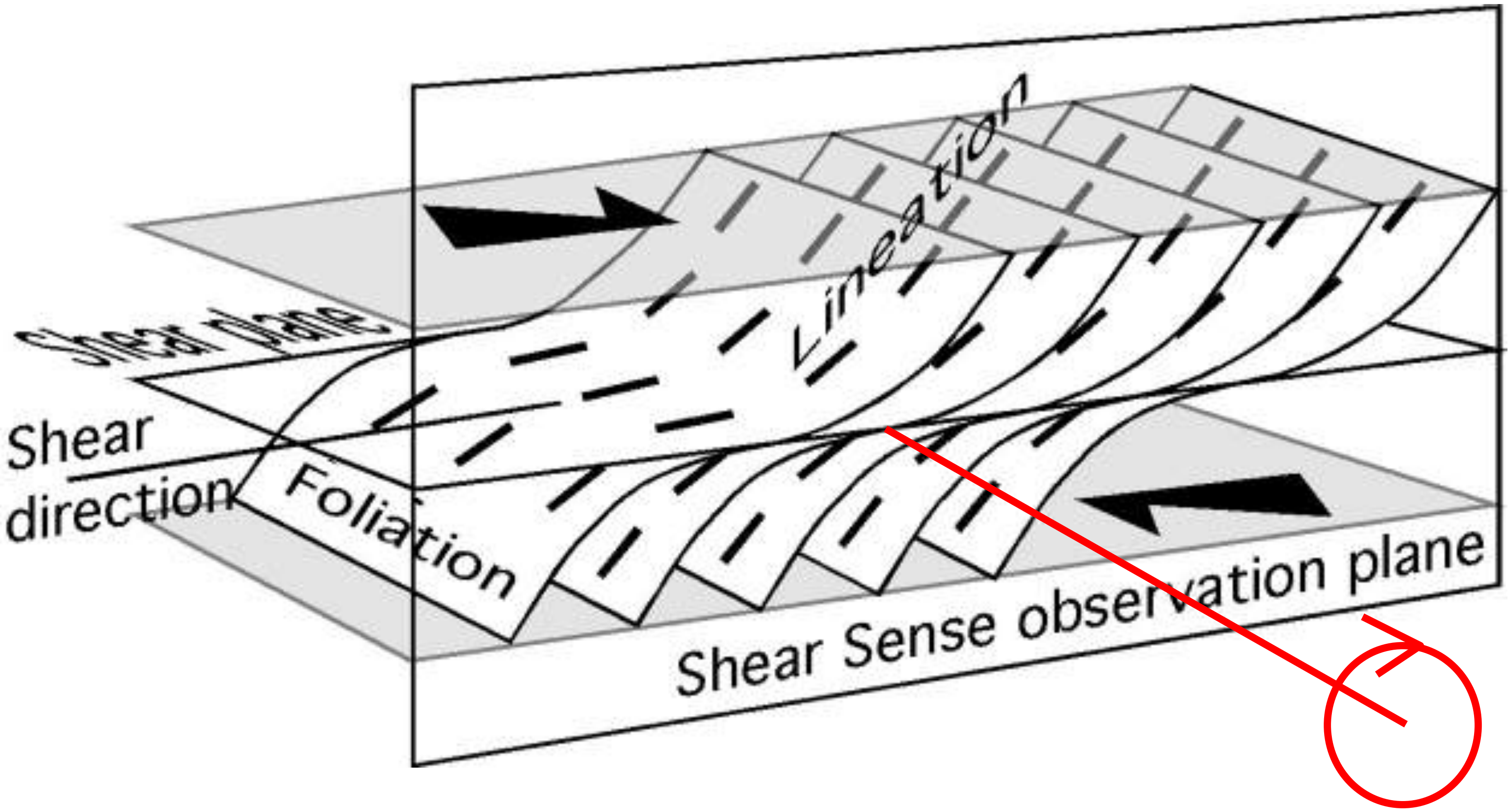
- New Approaches to Shear Zones
- Not all shear zones are simple: Pure and Simple shear
- A practical guide to modern shear zone analysis
- Case Studies



Kinematics Simple Shear Zones



Plane of Maximum Asymmetry

Vorticity Vector

The three critical elements of any shear zone:

- The shear plane S (planar)
- The shear direction L (linear)
- The vorticity vector VV (linear)

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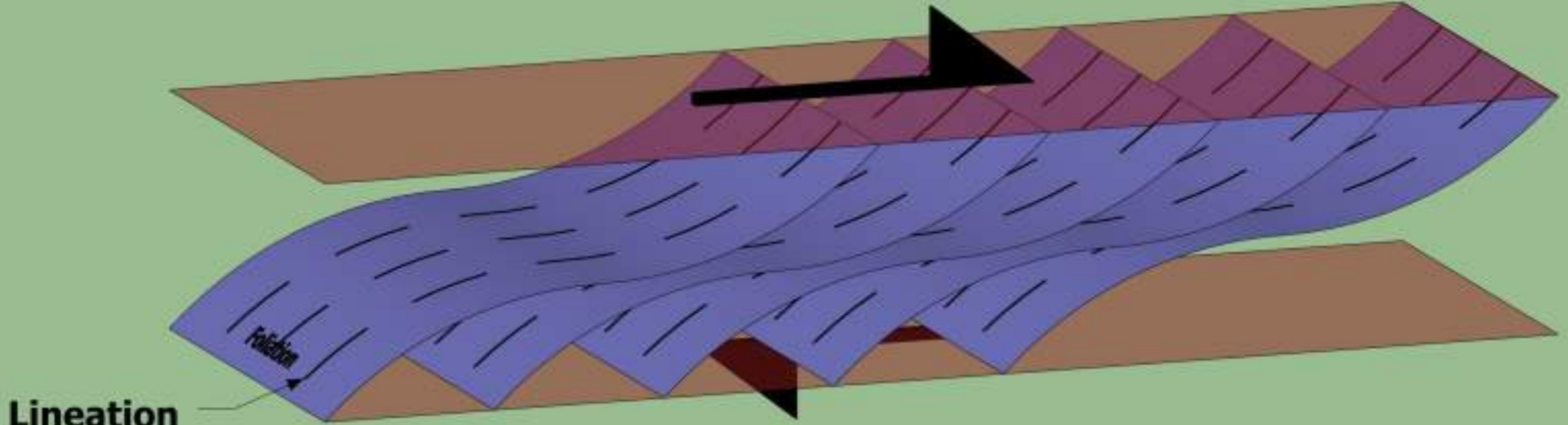
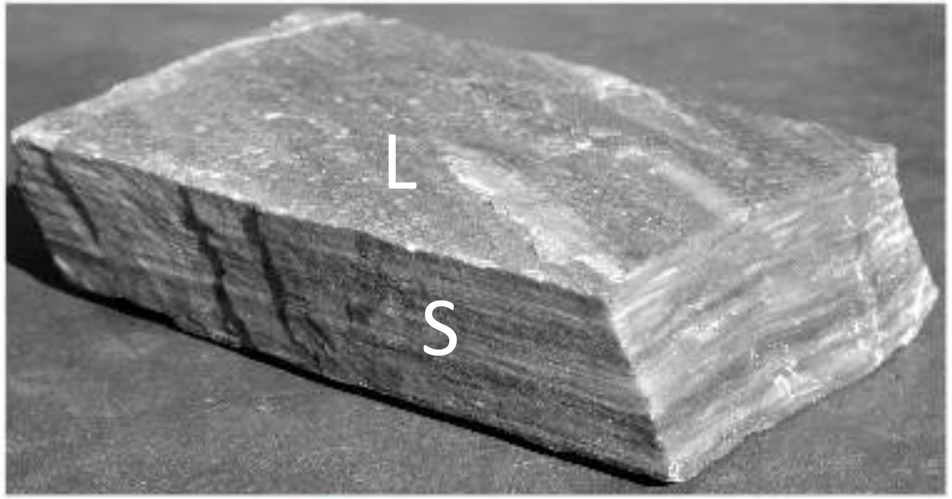
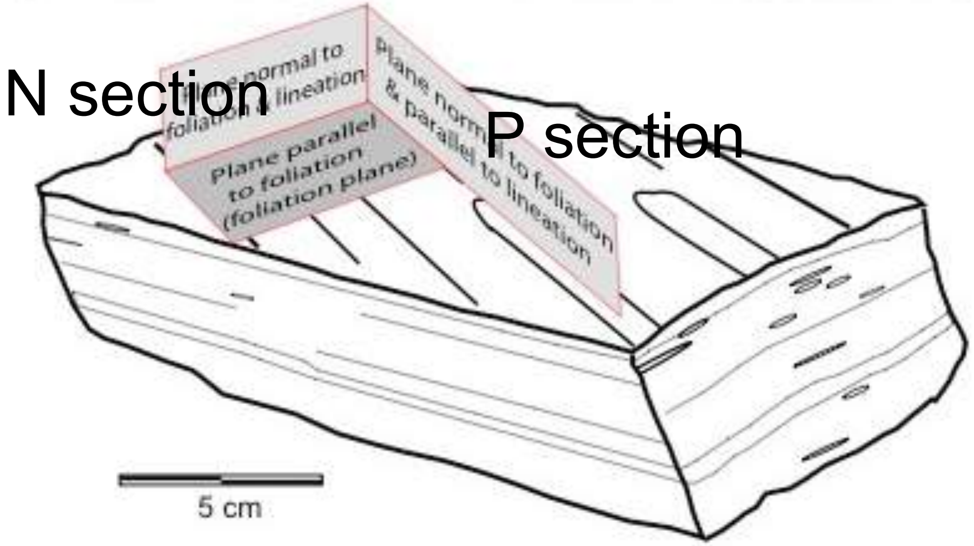

Foliation
Lineation

How do we find the three critical elements?



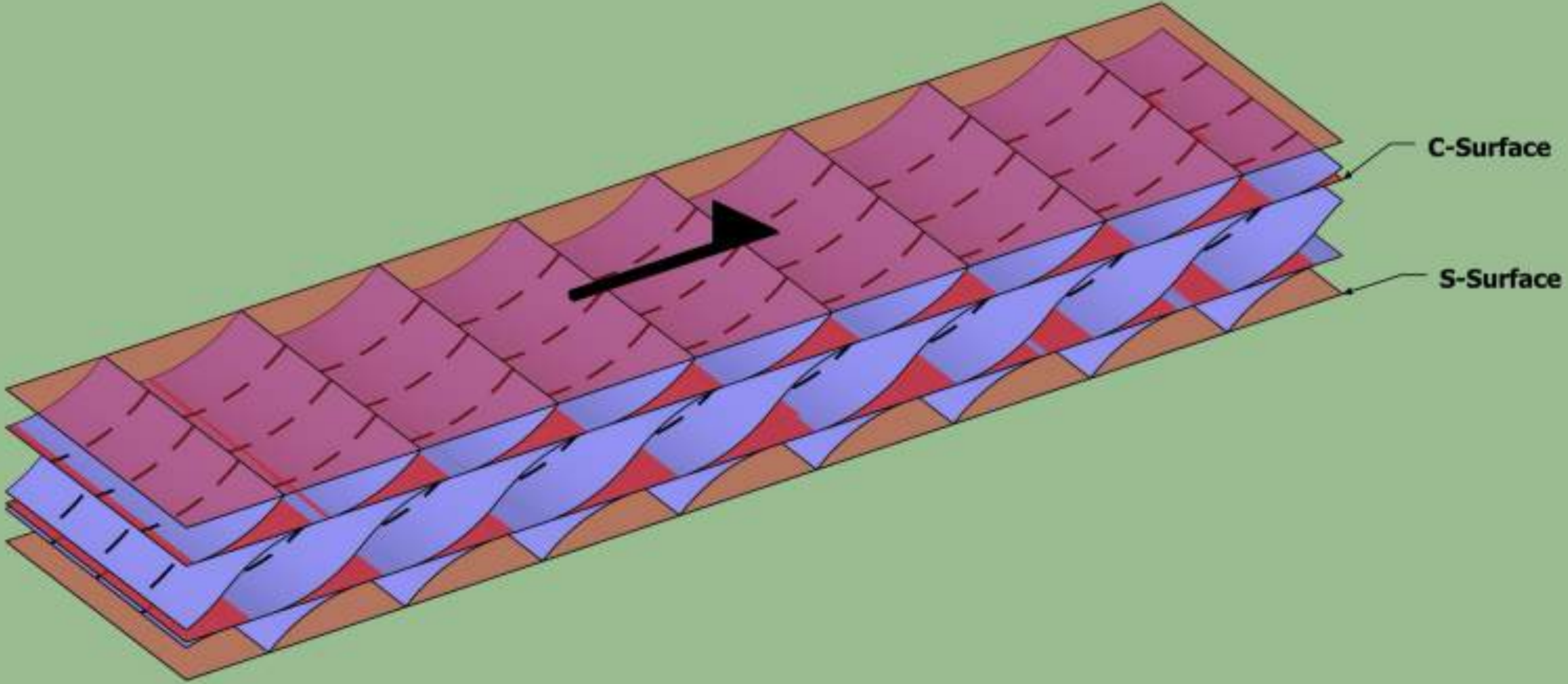


Shear sense must be determined in the shear sense observation plane, perpendicular to VV.

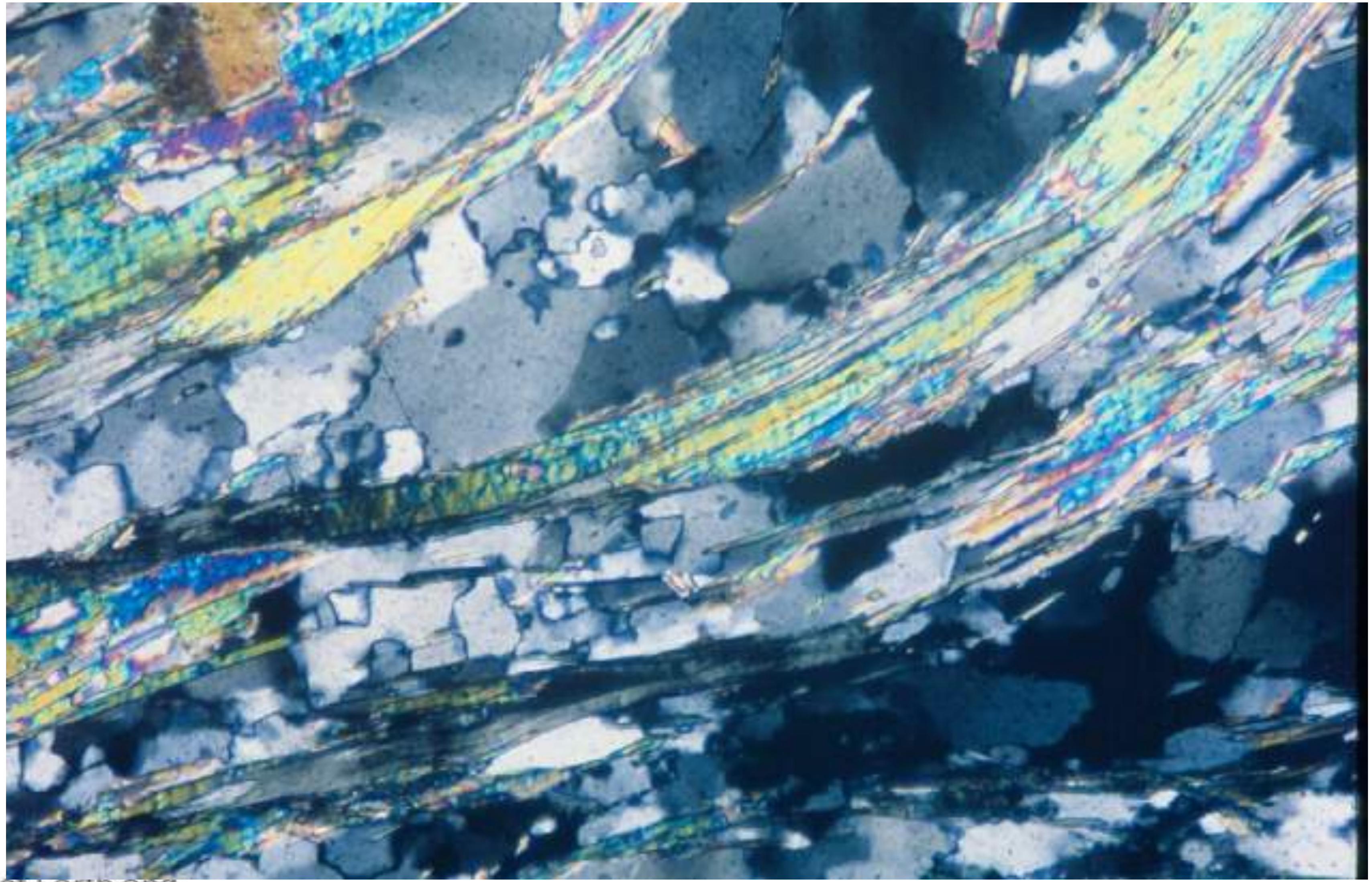
VV is perpendicular to the plane of maximum asymmetry

VV may be perpendicular or parallel to the lineation

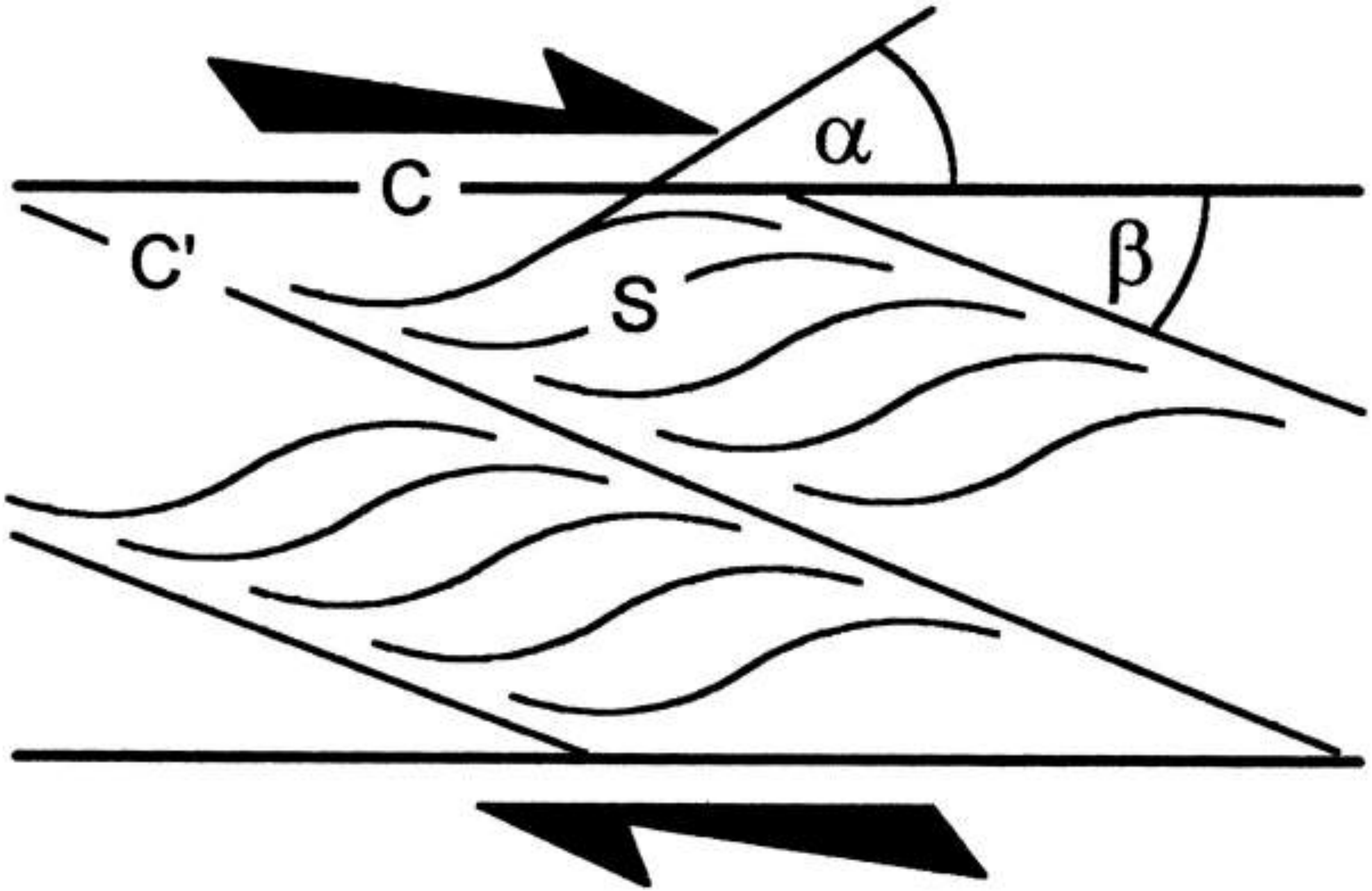
SC Fabrics



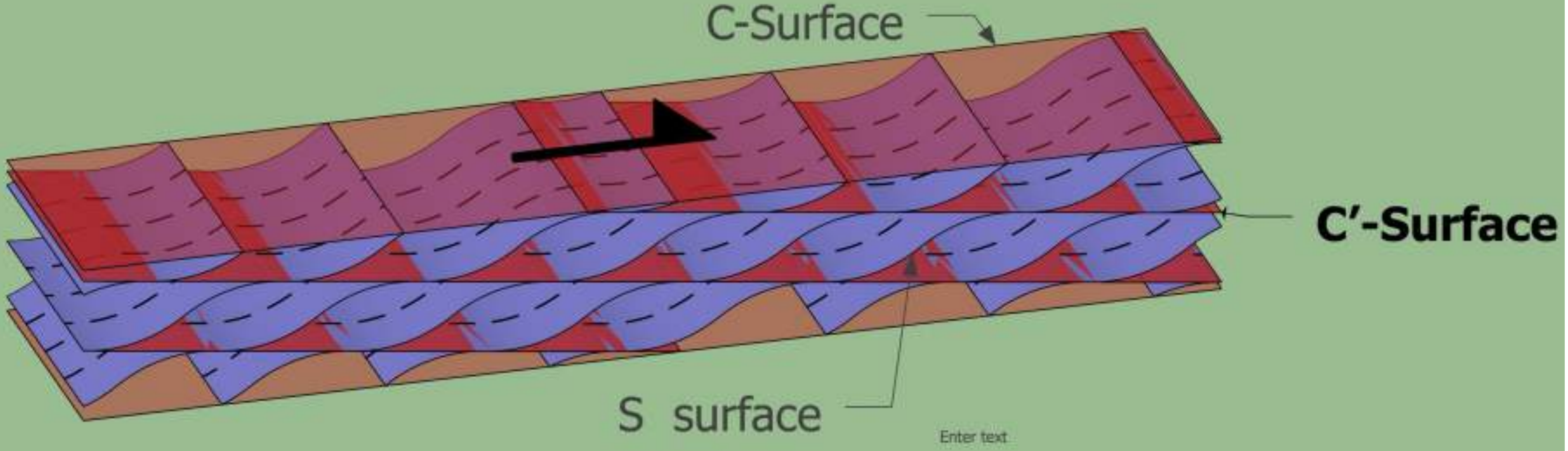
Curved foliation



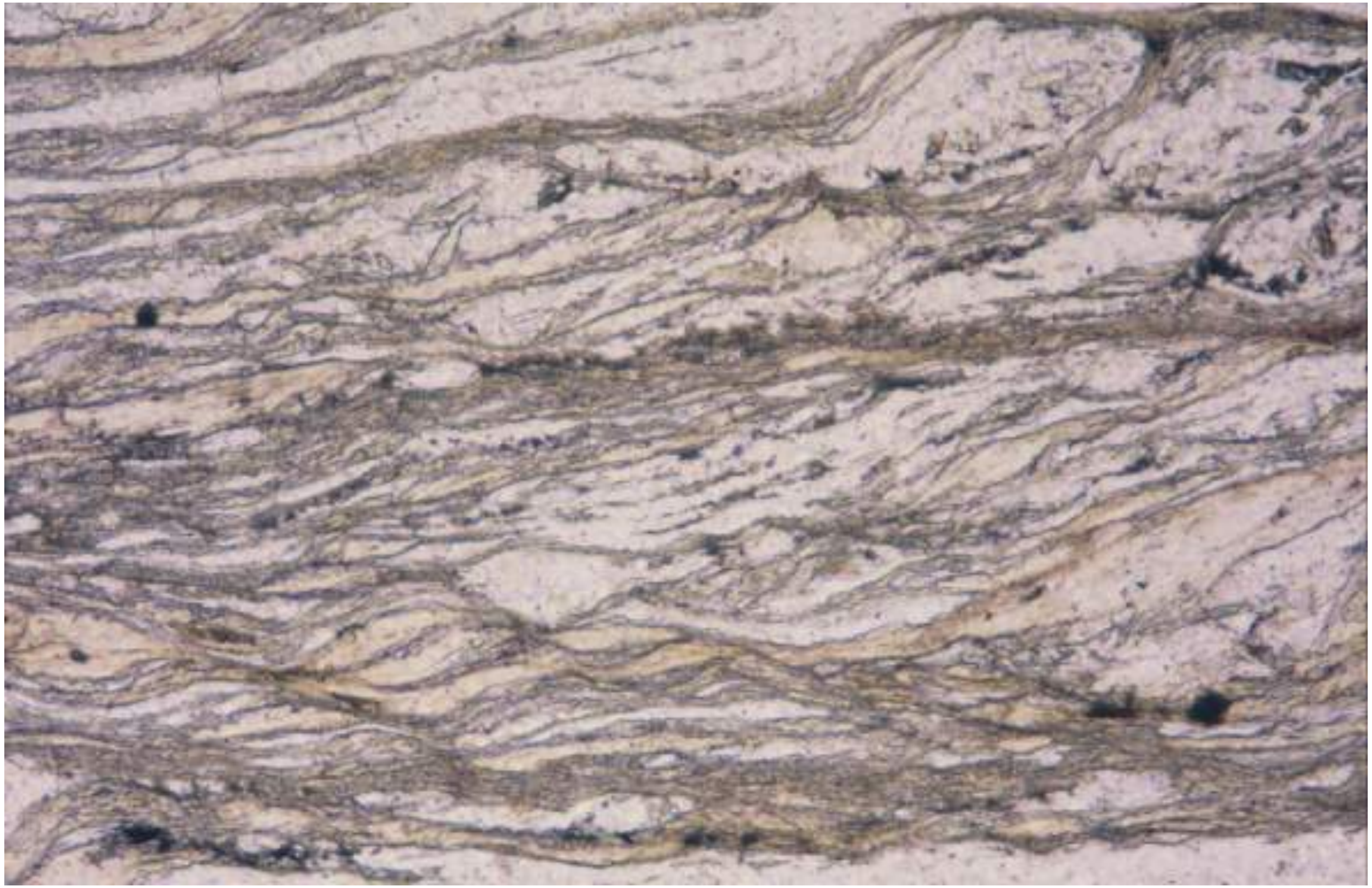
SC and SC' Fabrics



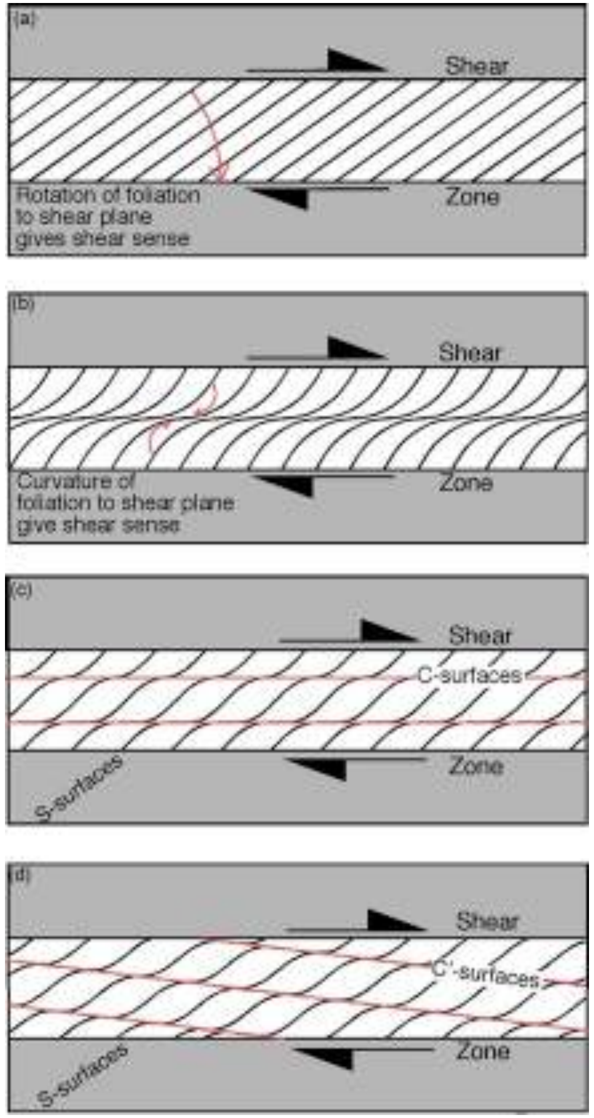
SCC’ Fabrics



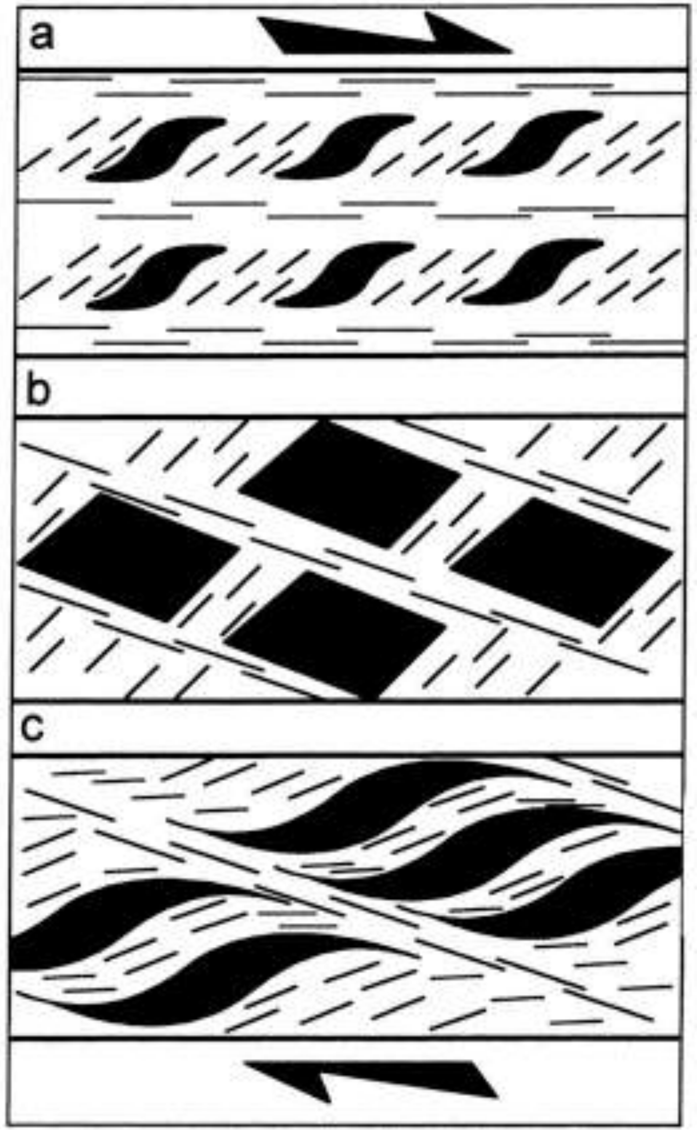
SC and SC’ Fabrics



SC and SC' Fabrics



Variety in SC fabrics



Blenkinsop, T., Treloar, P., 1995. Geometry , classification and kinematics of S-C and S-C ' fabrics in the Mushandike area , Zimbabwe. J. Struct. Geol. 17, 397–408.

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S-C’ Structure, Asturias, North Spain

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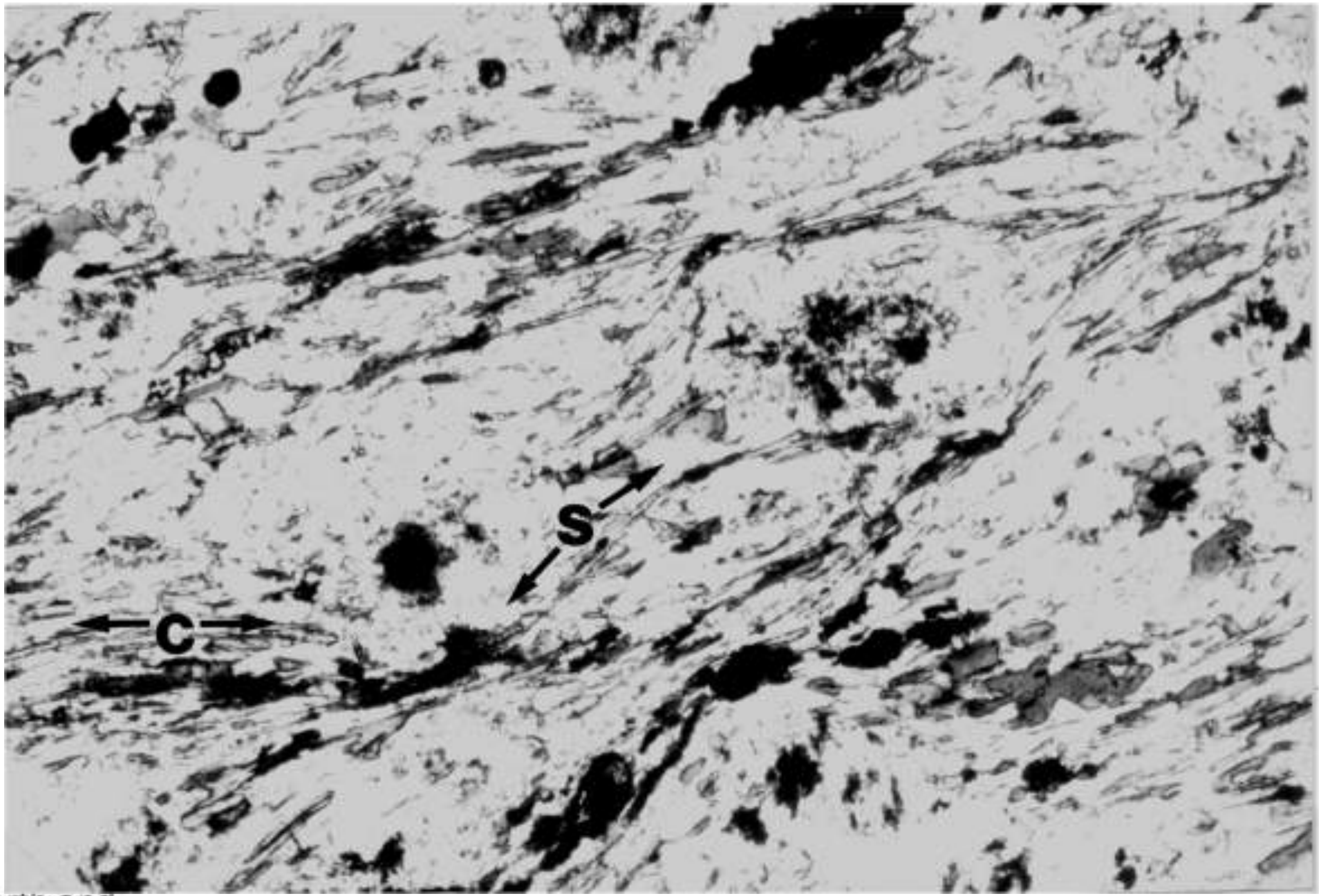
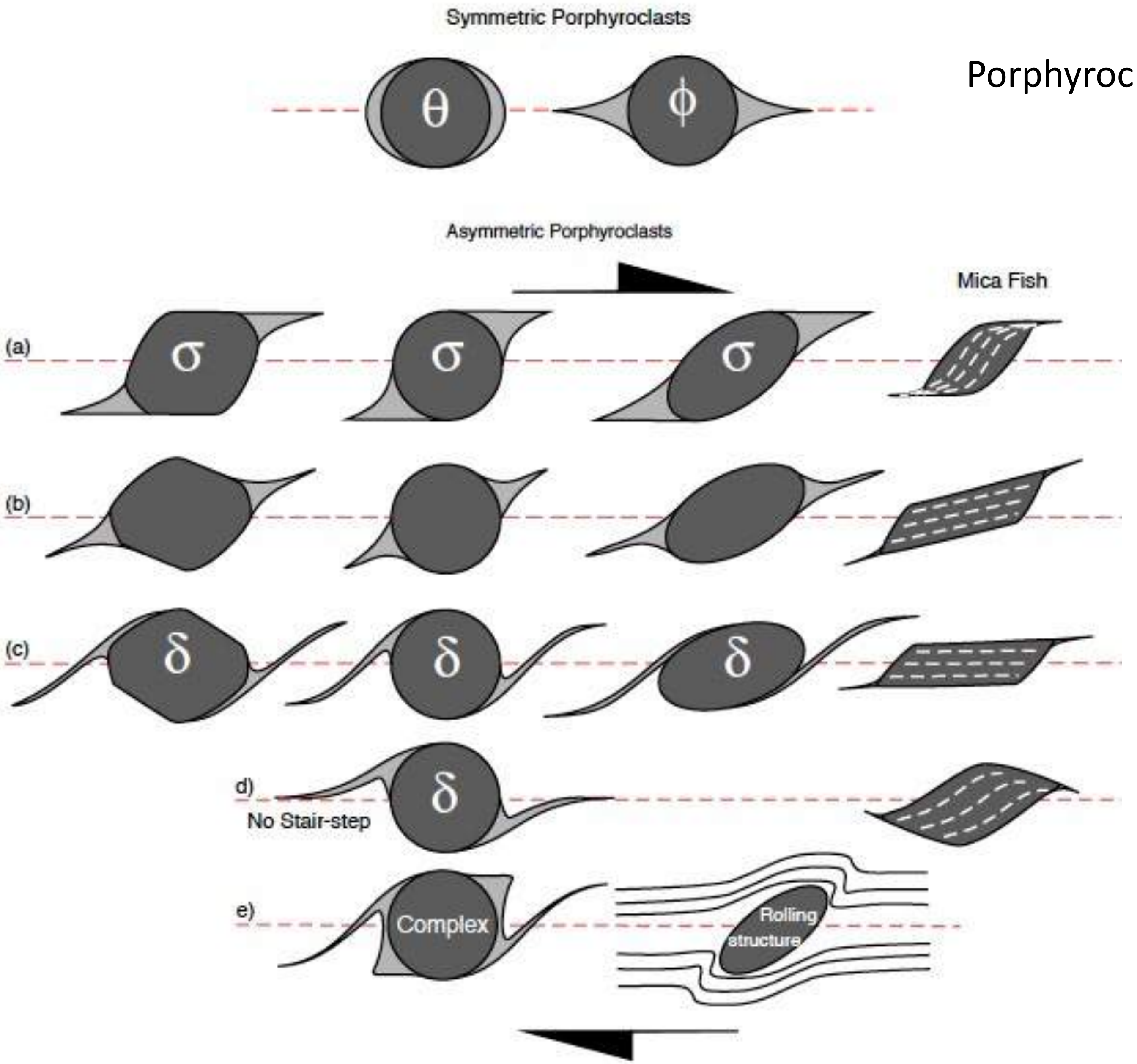
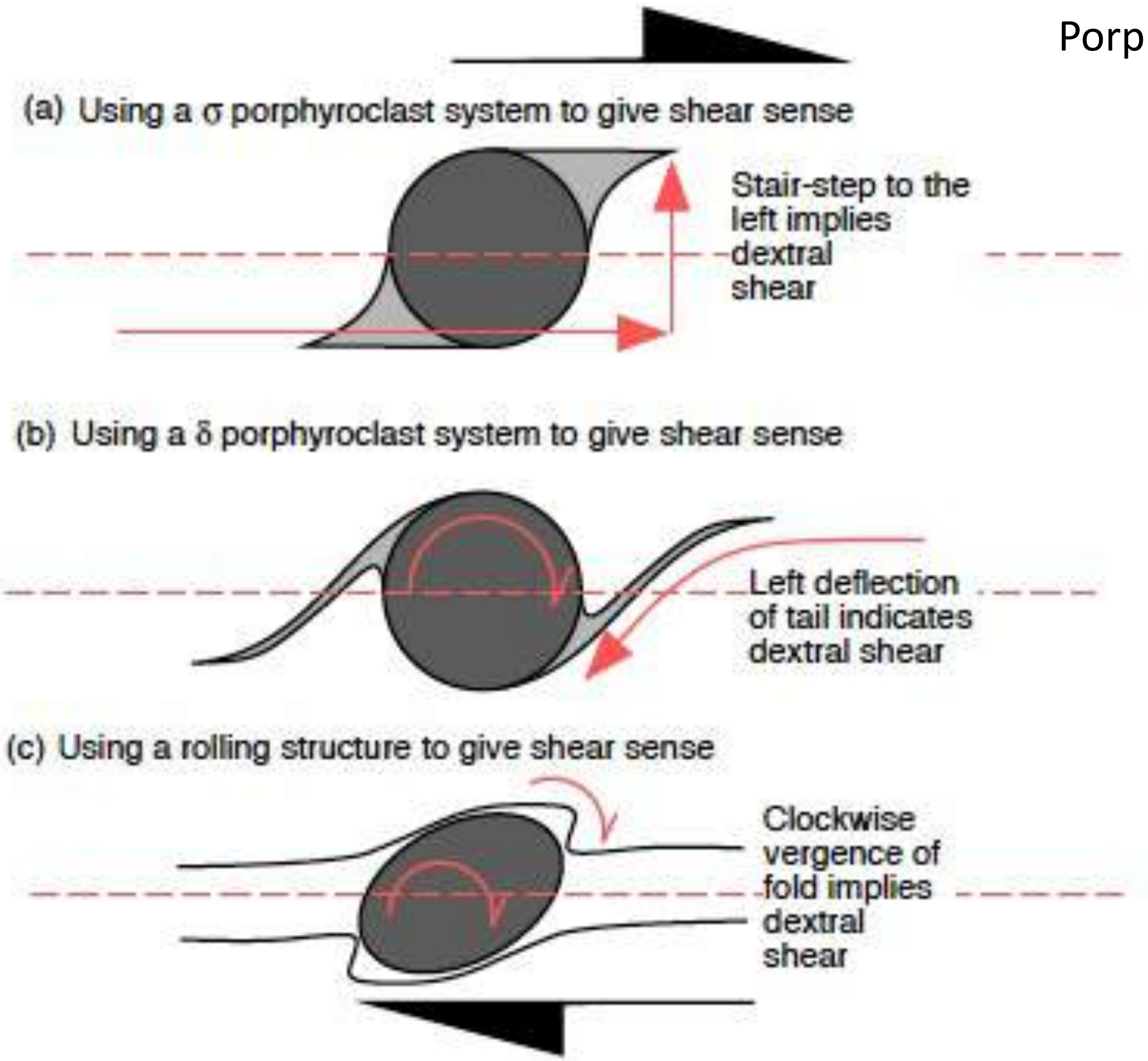
Auriferous pyrite defining SC fabrics, Freda Rebecca Mine, Zimbabwe



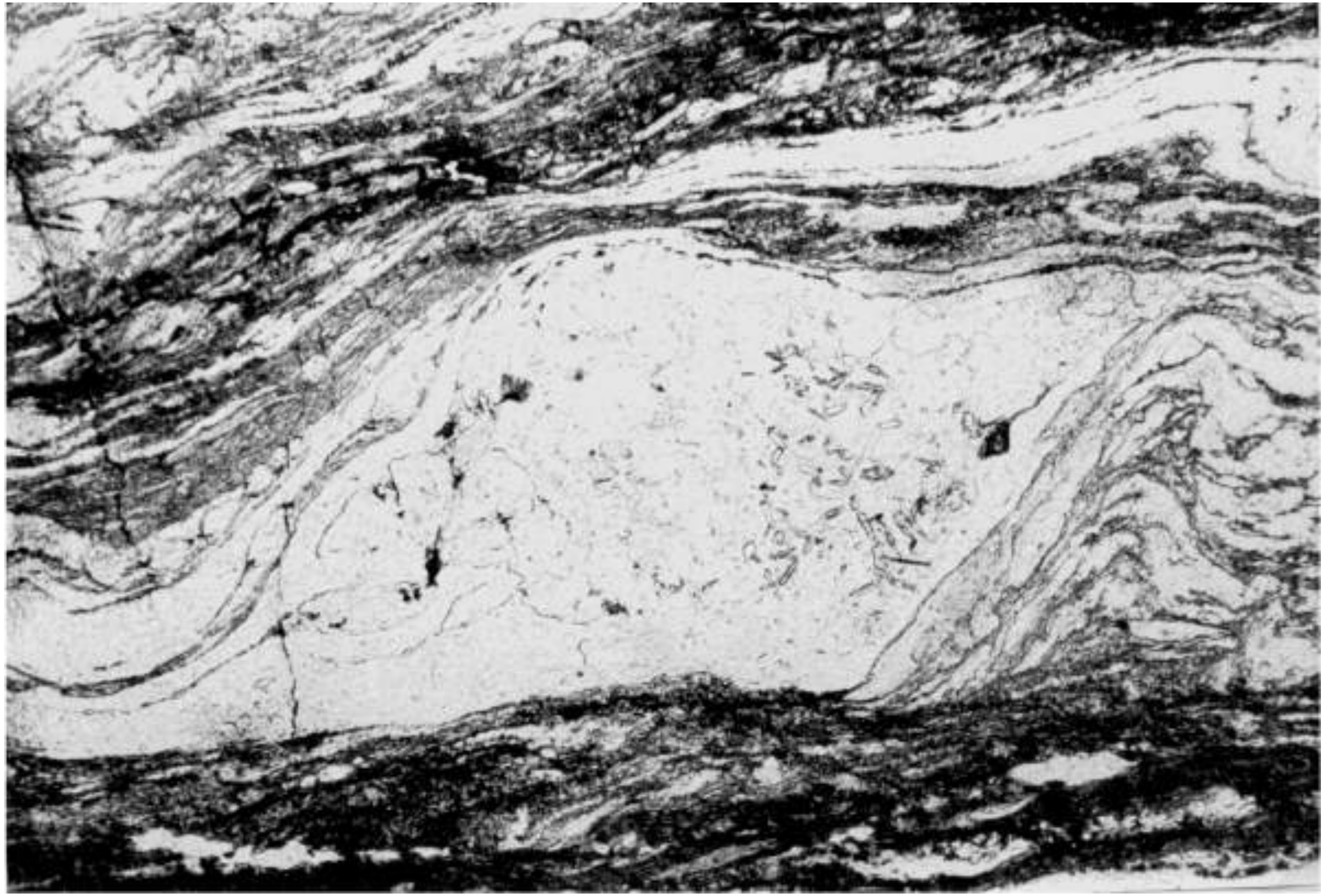
Porphyroclast systems



Porphyroclast systems



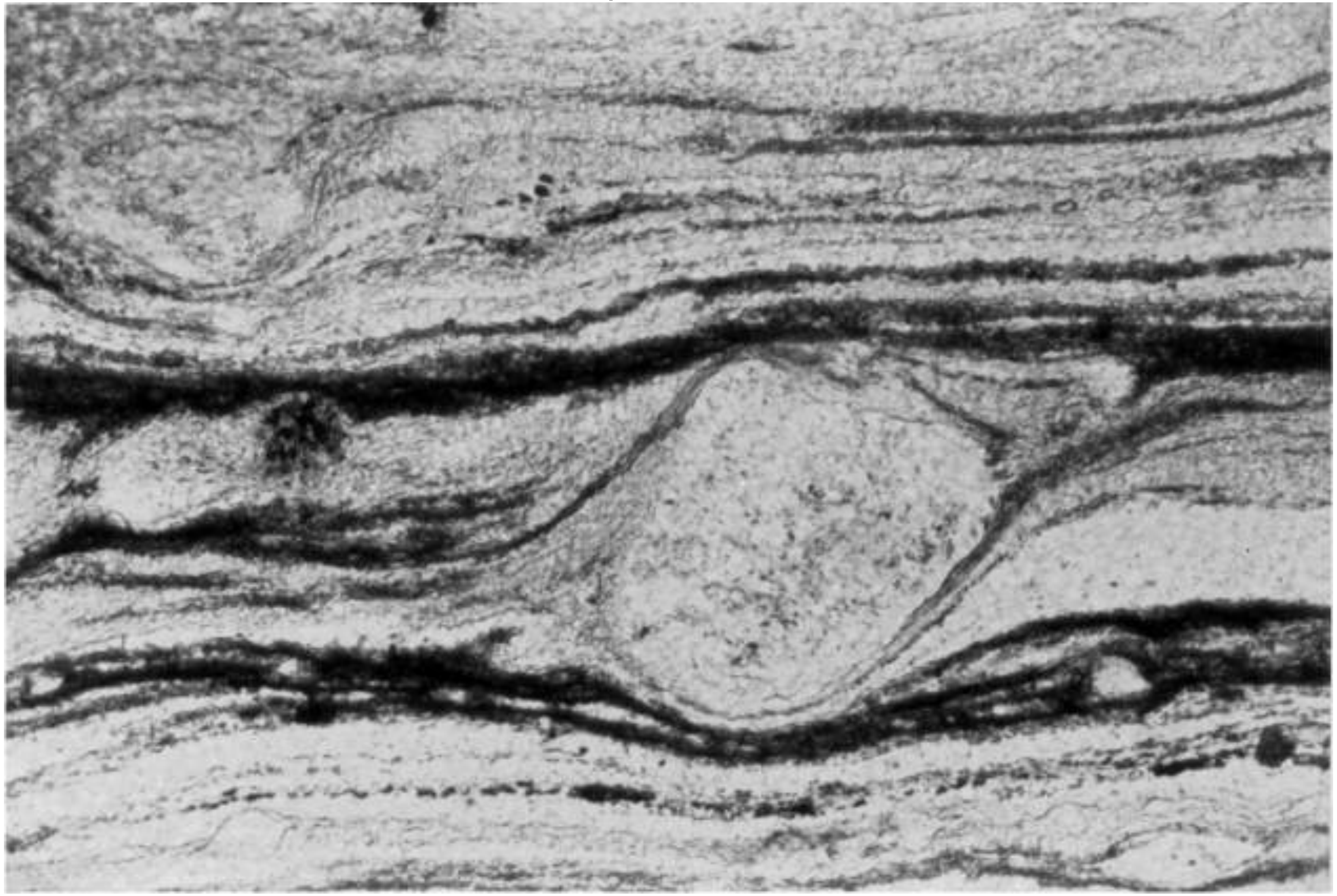
σ porphyroclast



Blenkinsop, T.G. 2000. Deformation microstructures and mechanisms in minerals and rocks Dordrecht ; London : Kluwer Academic 2000

Garnet porphyroclast, Northern Marginal Zone, Limpopo belt, Zimbabwe

Complex porphyroclast



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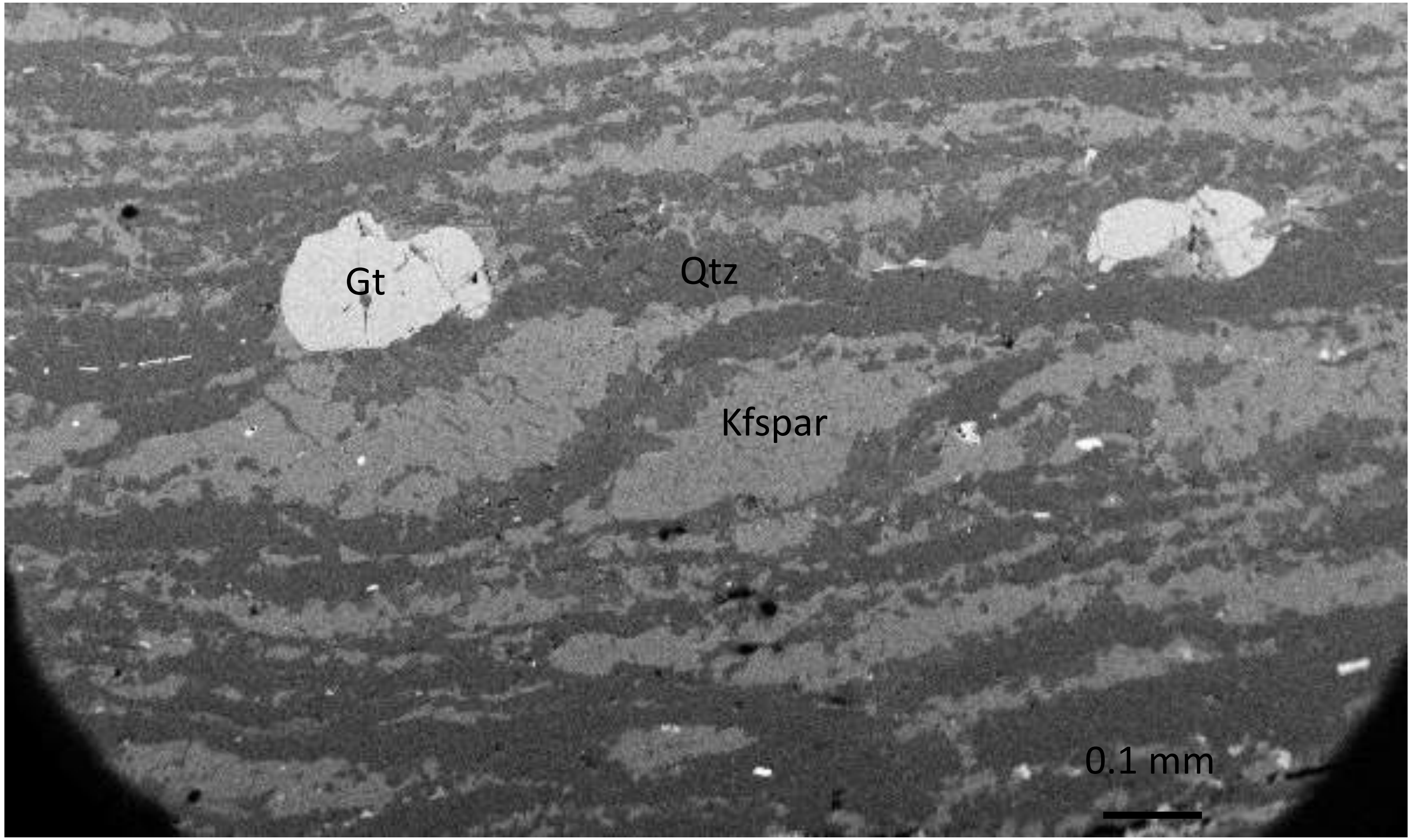
Porphyroclasts in the Mtilikwe shear zone, near Renco Mine, Zimbabwe



Blenkinsop, T.G., Kisters, a. F.M., 2005. Steep extrusion of late Archaean granulites in the Northern Marginal Zone, Zimbabwe: evidence for secular change in orogenic style. Geol. Soc. London, Spec. Publ. 243, 193–204.

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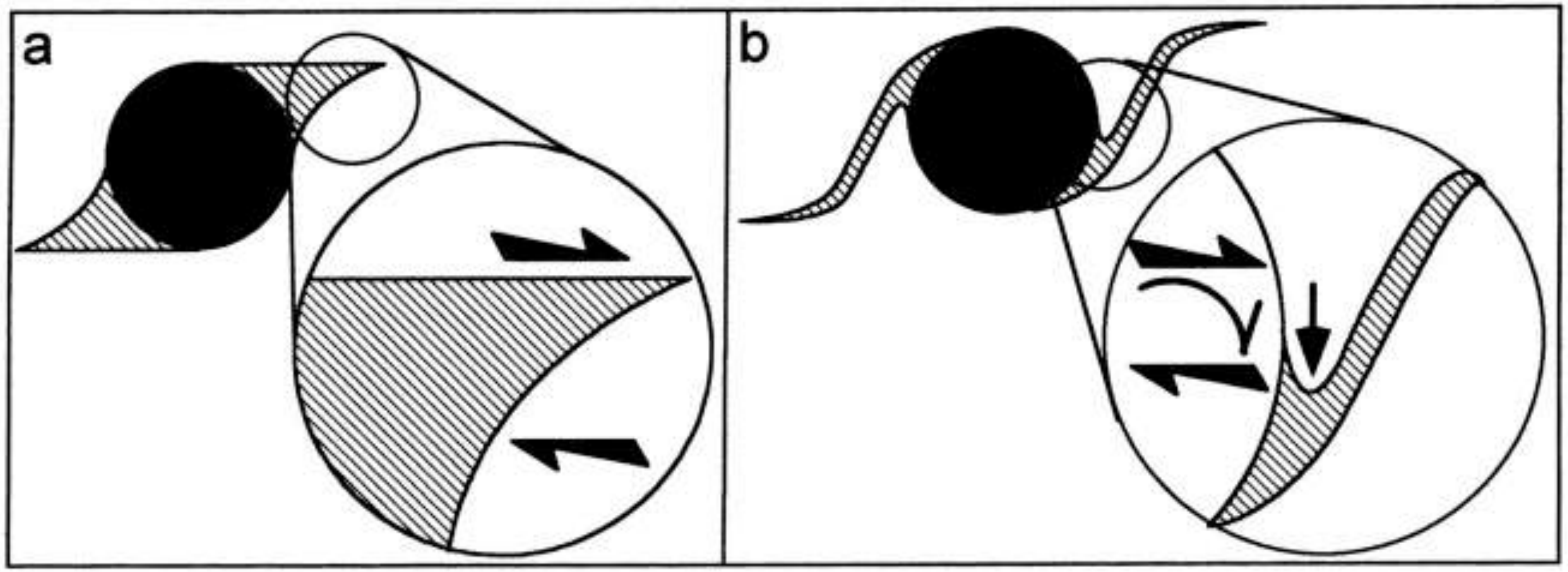
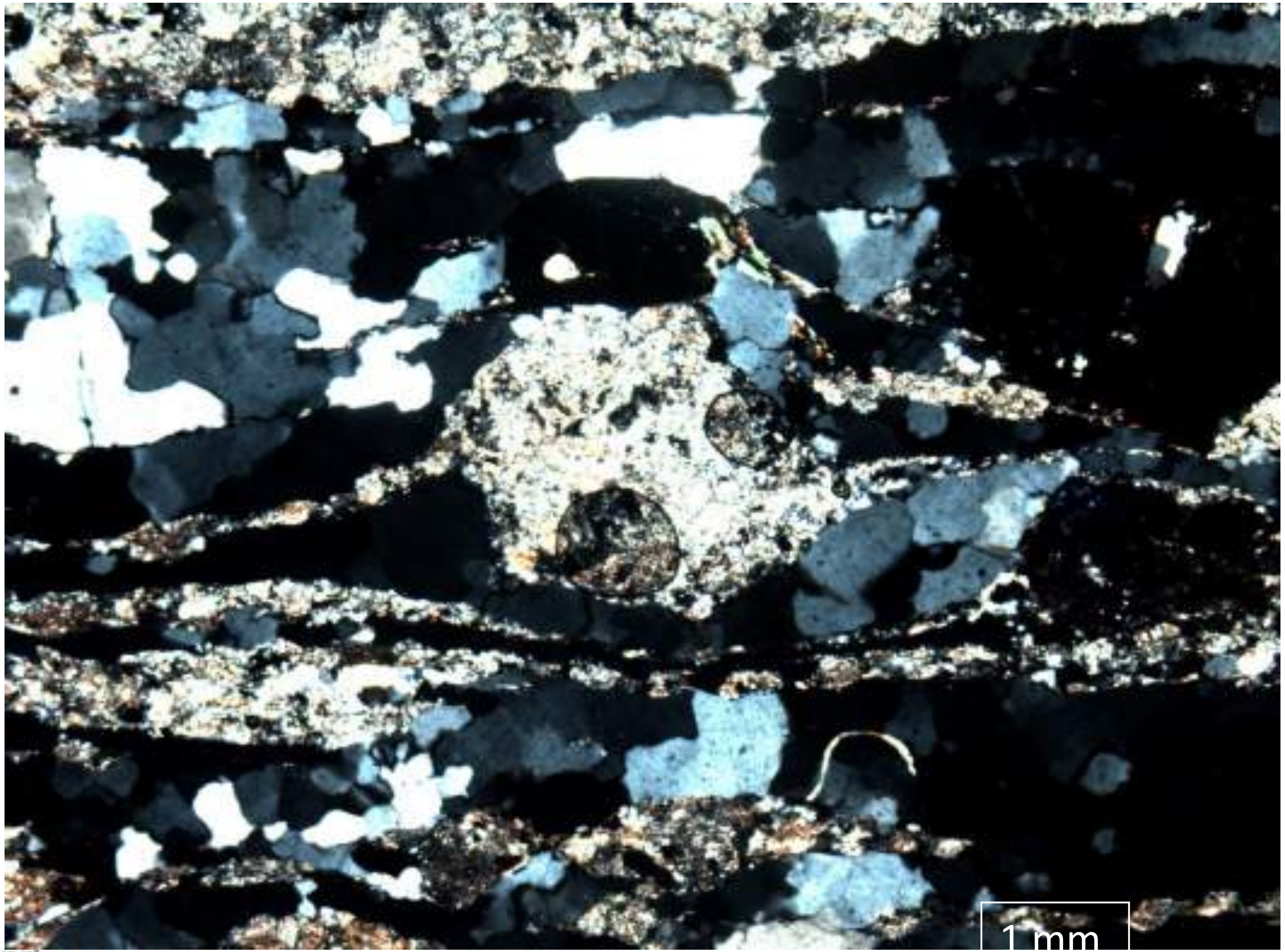
Cannington AgPbZn Mine, Queensland

Porphyroclast tails as kinematic indicators



Blenkinsop, T.G. 2000. Deformation microstructures and mechanisms in minerals and rocks Dordrecht ; London : Kluwer Academic 2000

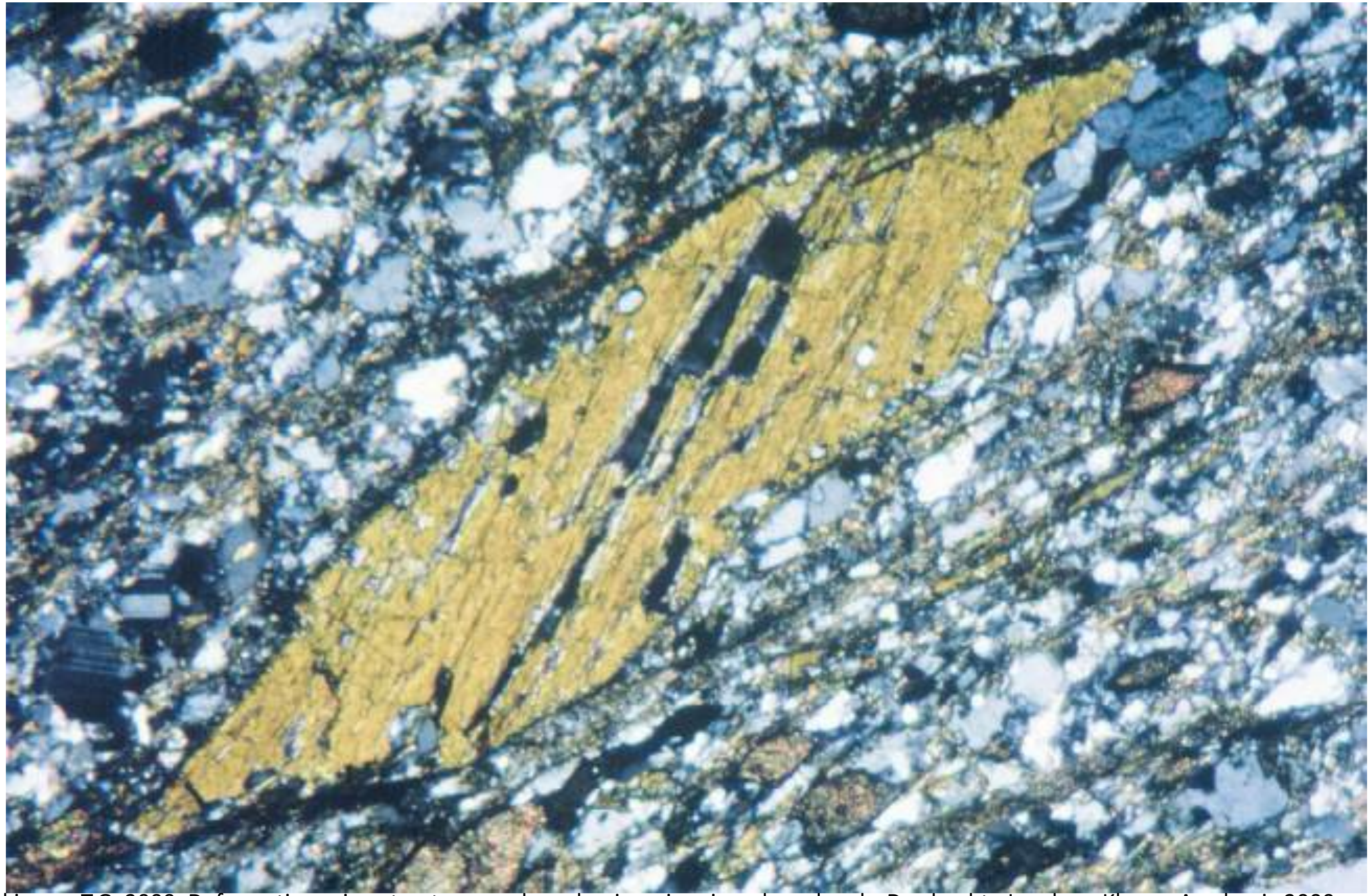
Feldspar porphyroclast, Northern Marginal Zone, Zimbabwe



Pegmatite porphyroclast, Mitilikwe shear zone, near Renco mine, Zimbabwe

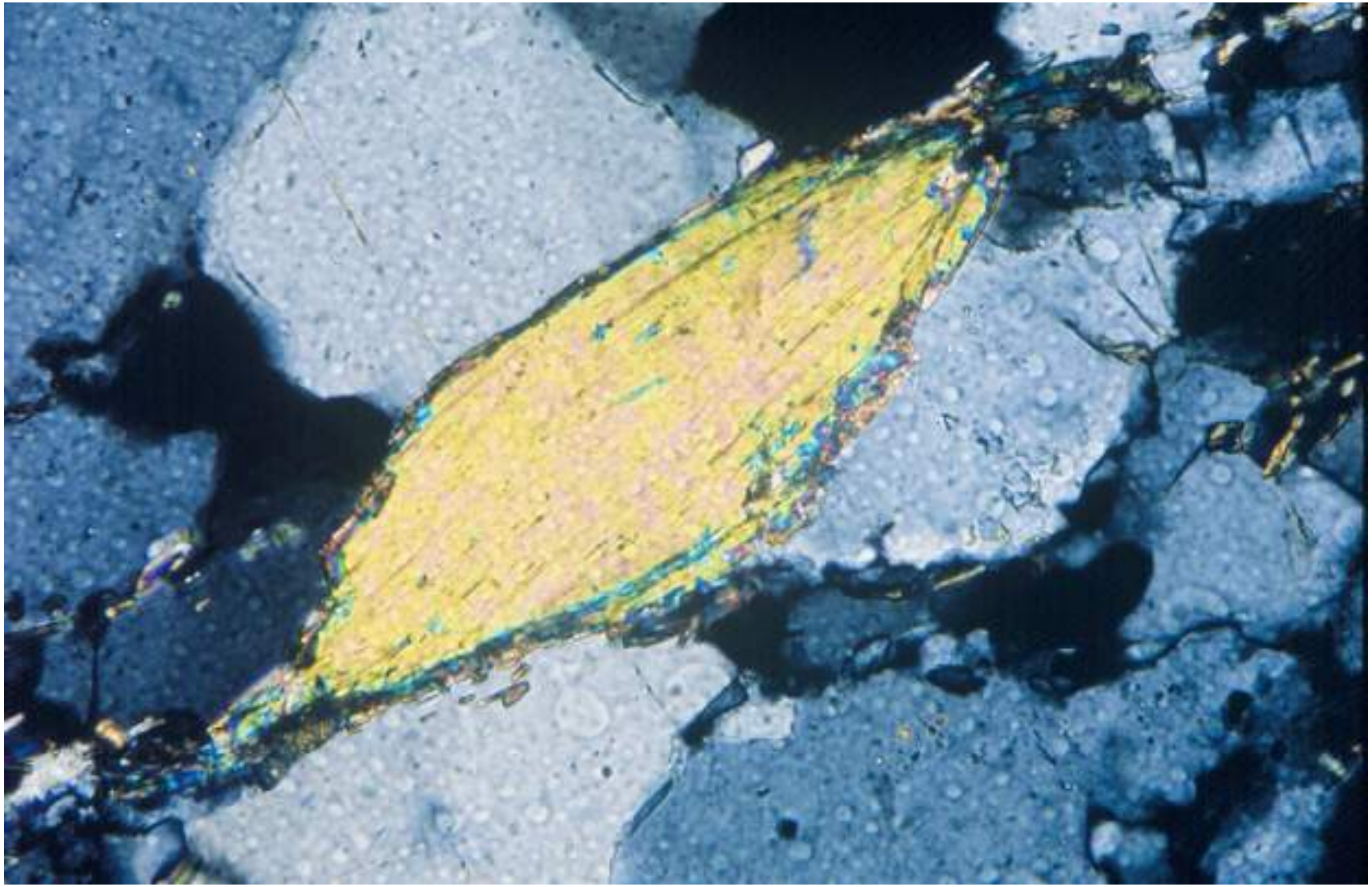
Blenkinsop, T.G. 2000. Deformation microstructures and mechanisms in minerals and rocks Dordrecht ; London : Kluwer Academic 2000

Hornblende fish



Blenkinsop, T.G. 2000. Deformation microstructures and mechanisms in minerals and rocks Dordrecht ; London : Kluwer Academic 2000

Biotite fish



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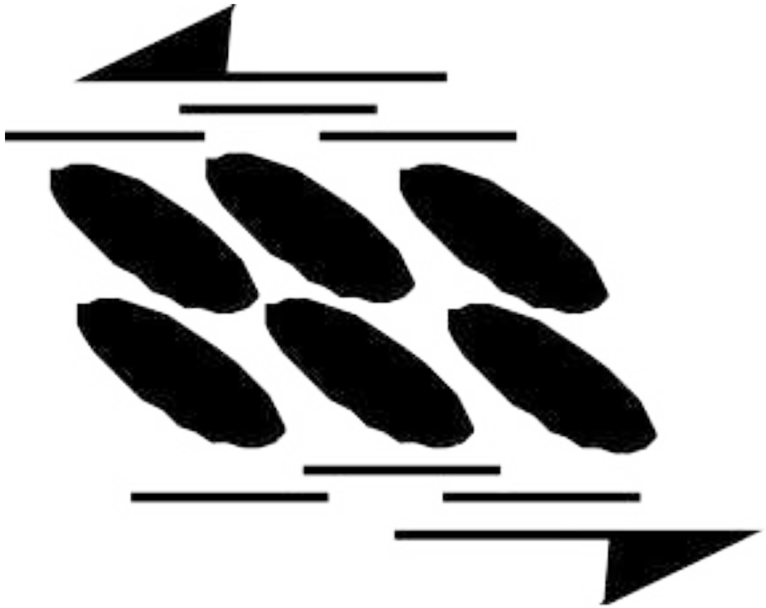
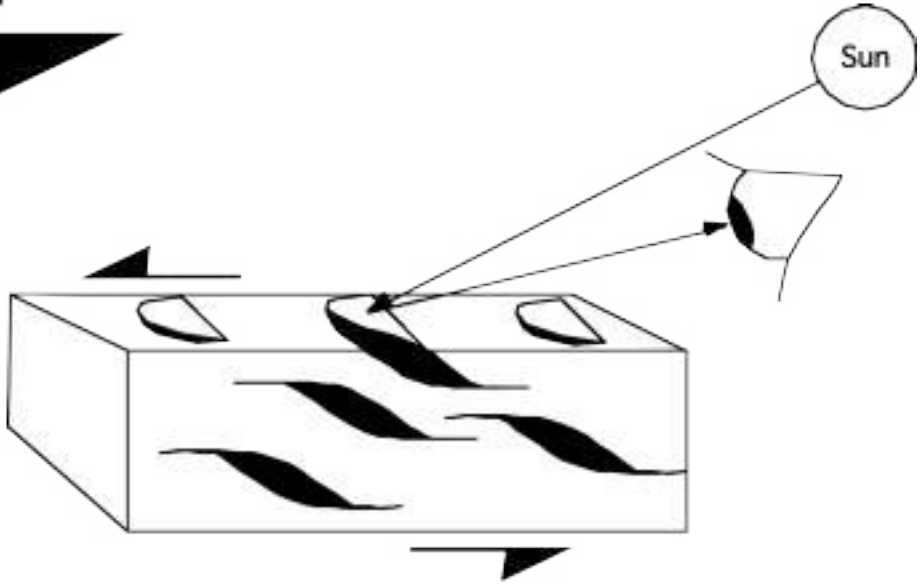
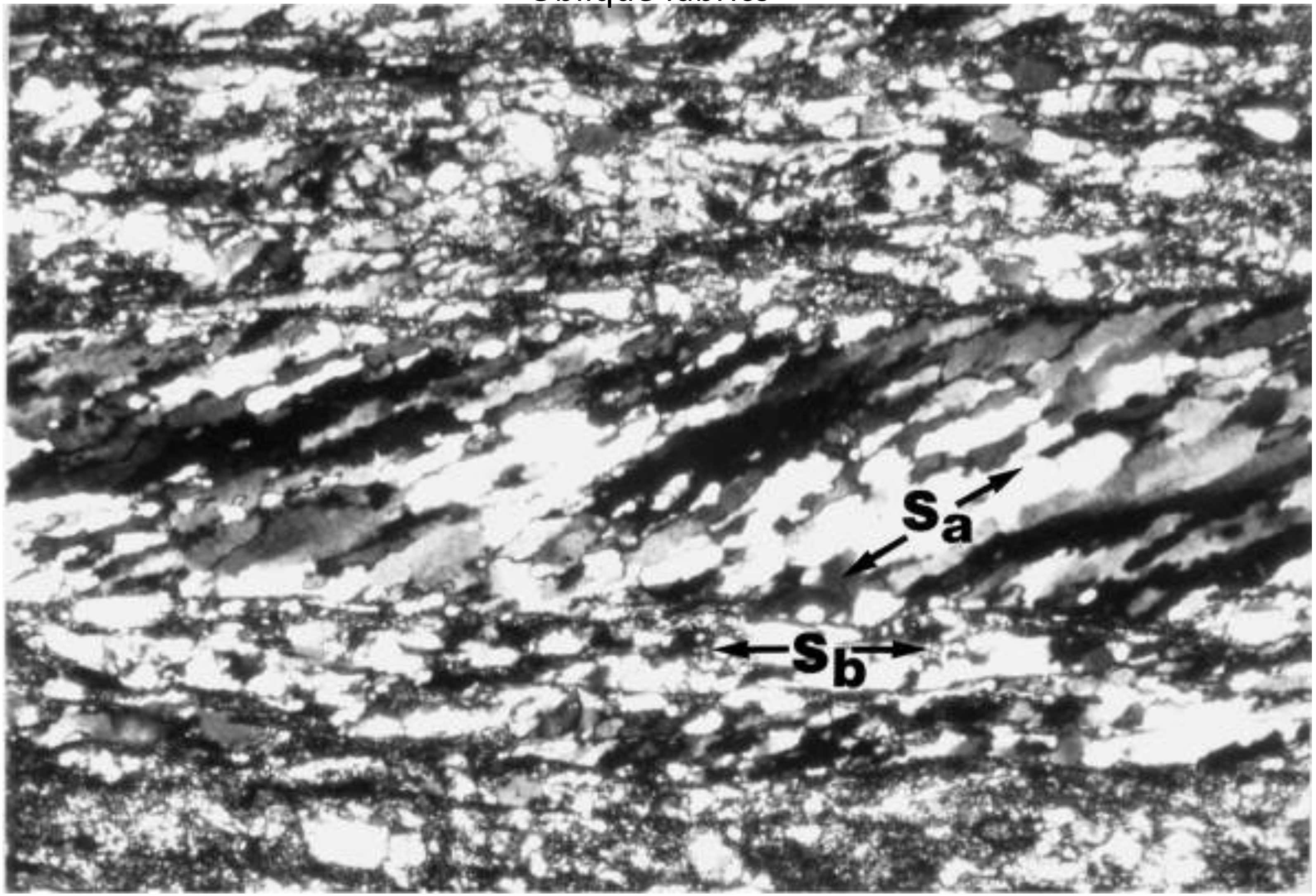


Fish flash



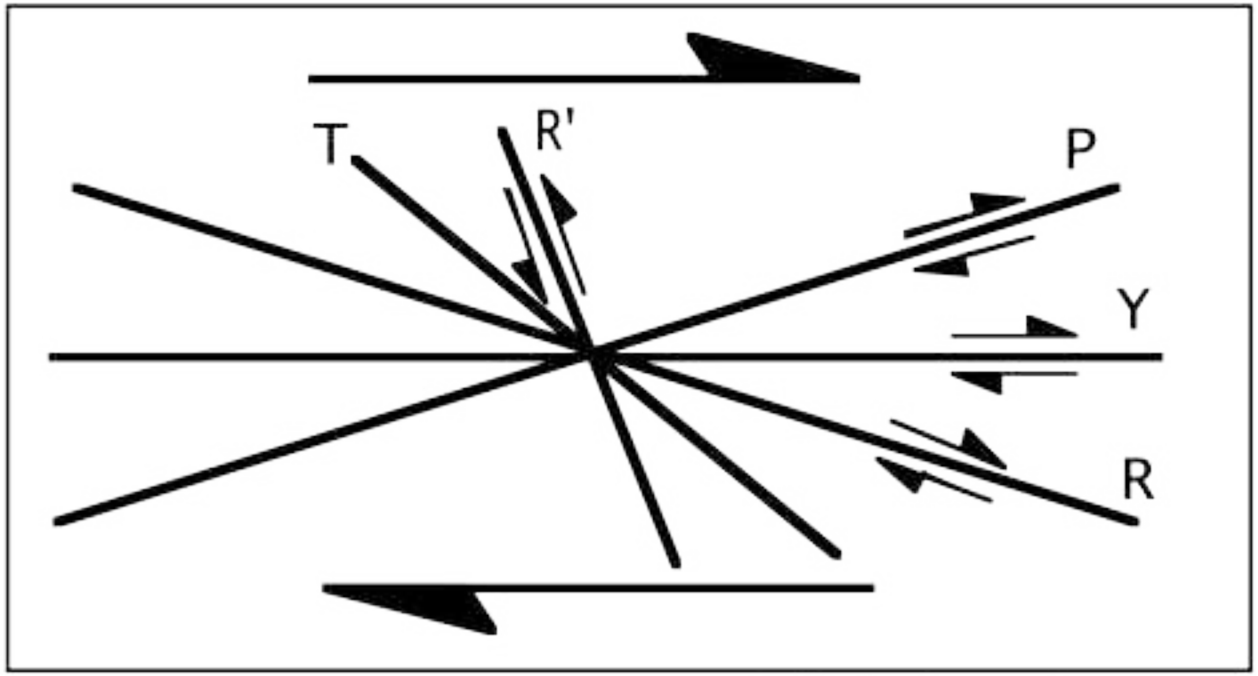
Blenkinsop, T.G. 2000. Deformation microstructures and mechanisms in minerals and rocks Dordrecht ; London : Kluwer Academic 2000

Oblique fabrics



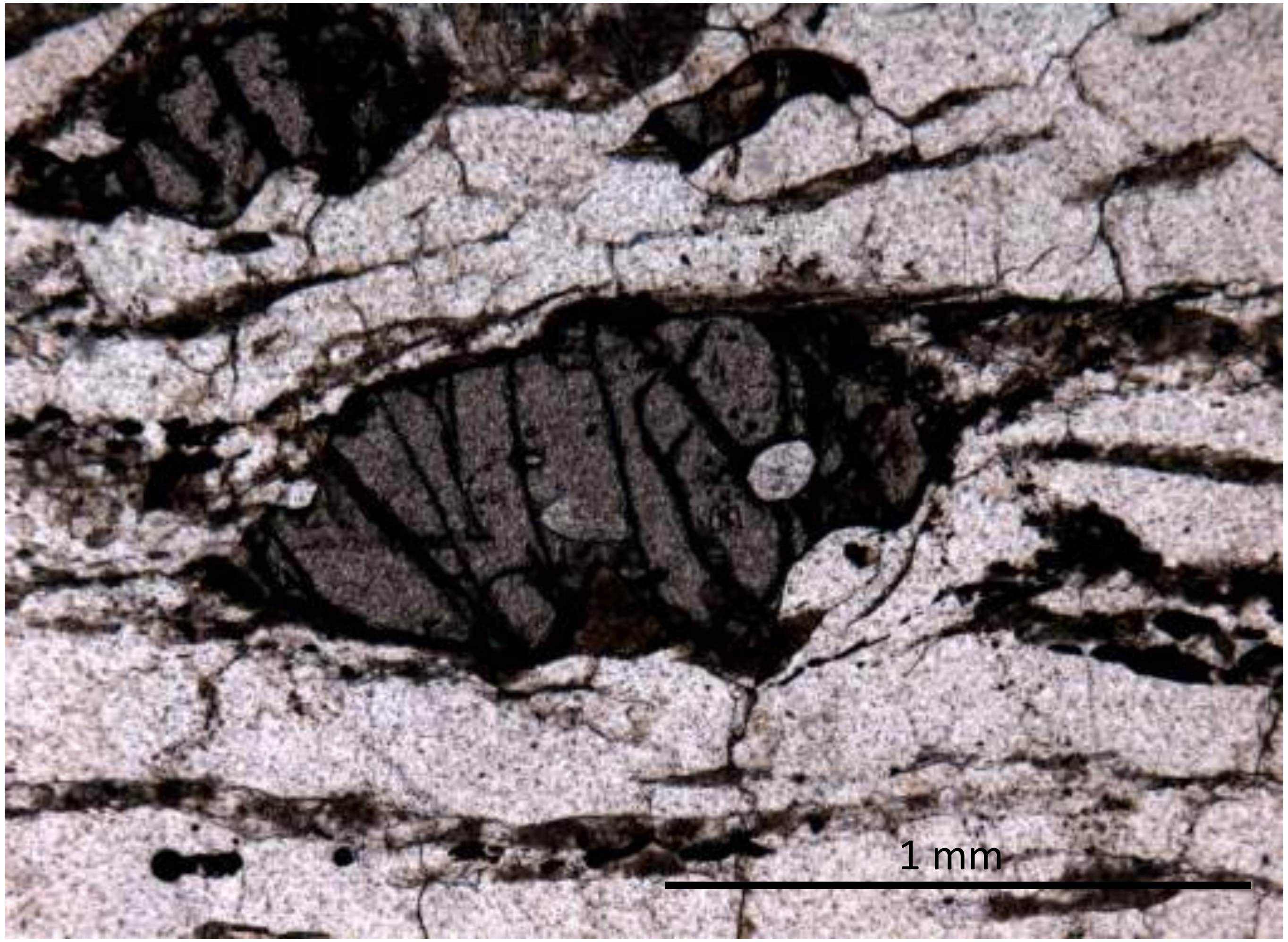
Blenkinsop, T.G. 2000. Deformation microstructures and mechanisms in minerals and rocks Dordrecht ; London : Kluwer Academic 2000

Discontinuities in Fault Zones



	Initial orientation	Sense
P shears/P foliation	low	synthetic
Riedel shears/Synthetic shears	low	synthetic
Conjugate Riedel shears/Antithetic	high	antithetic
T or extension fractures	45°	antithetic
Y shears/principle deformation zones	0°	synthetic

Extension fractures in garnet



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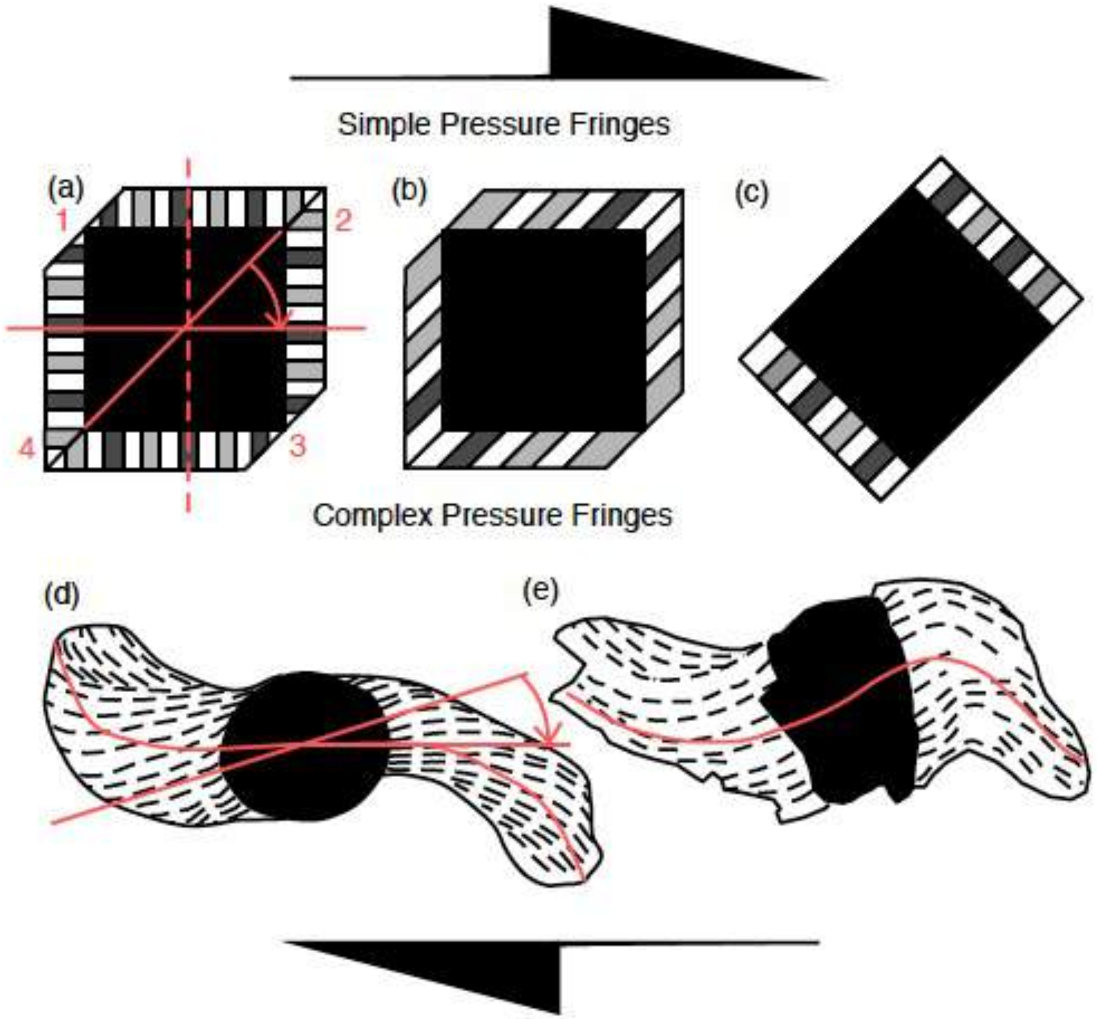
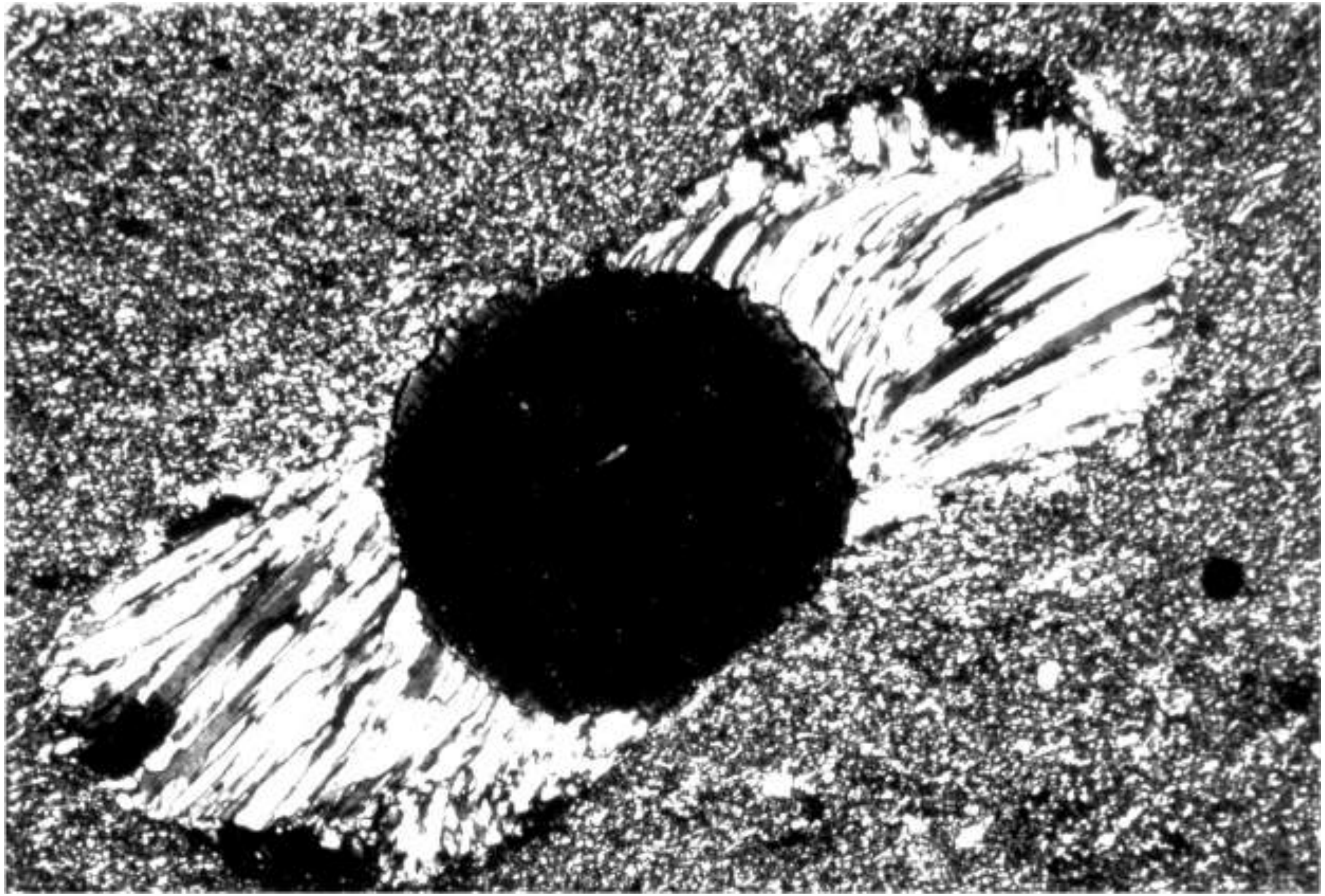

Simple Pressure Fringes
(a)
1
2
3
4
(b)
(c)
Complex Pressure Fringes
(d)
(e)

Pressure Fringes



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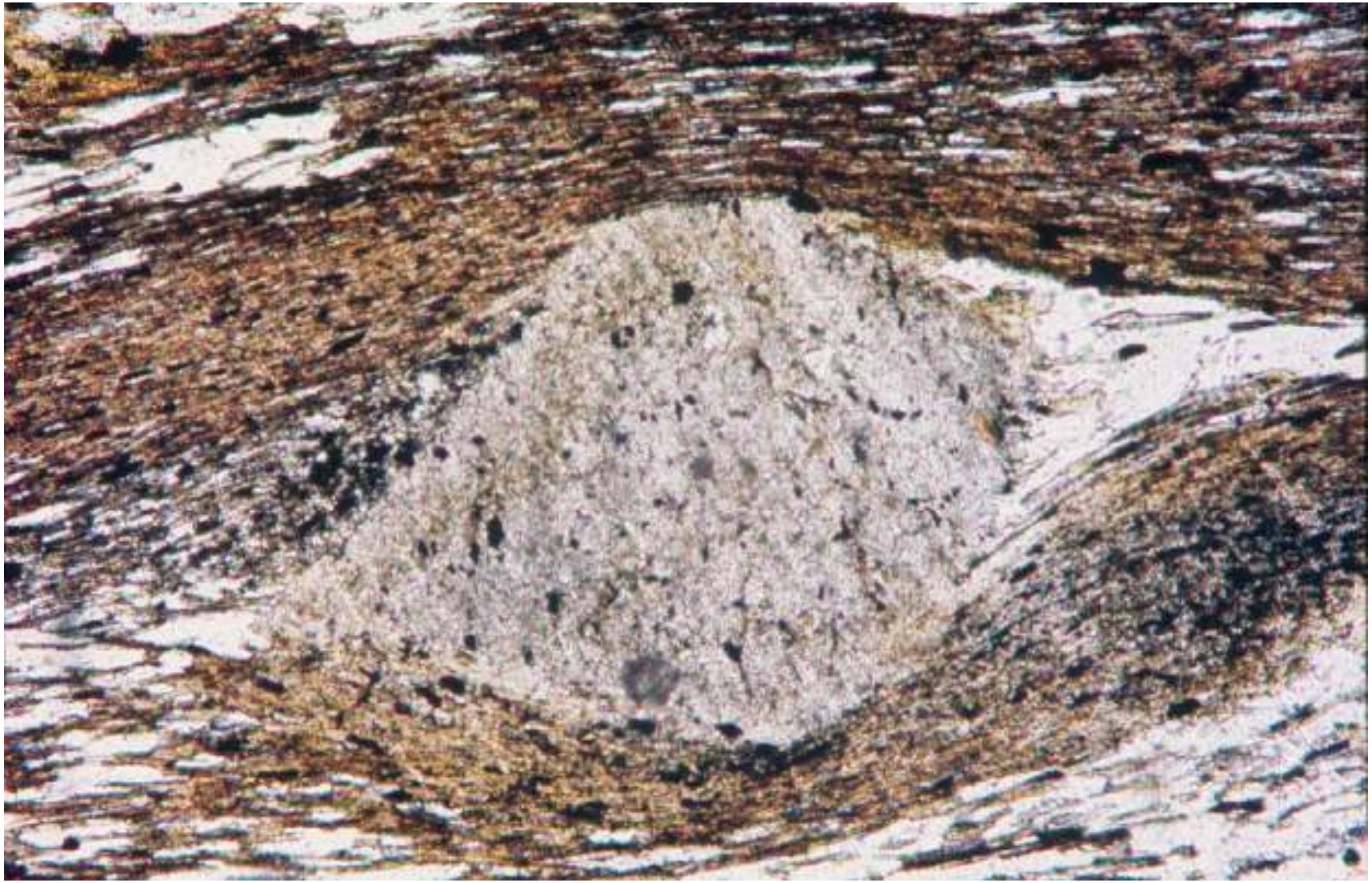
Pressure Fringes



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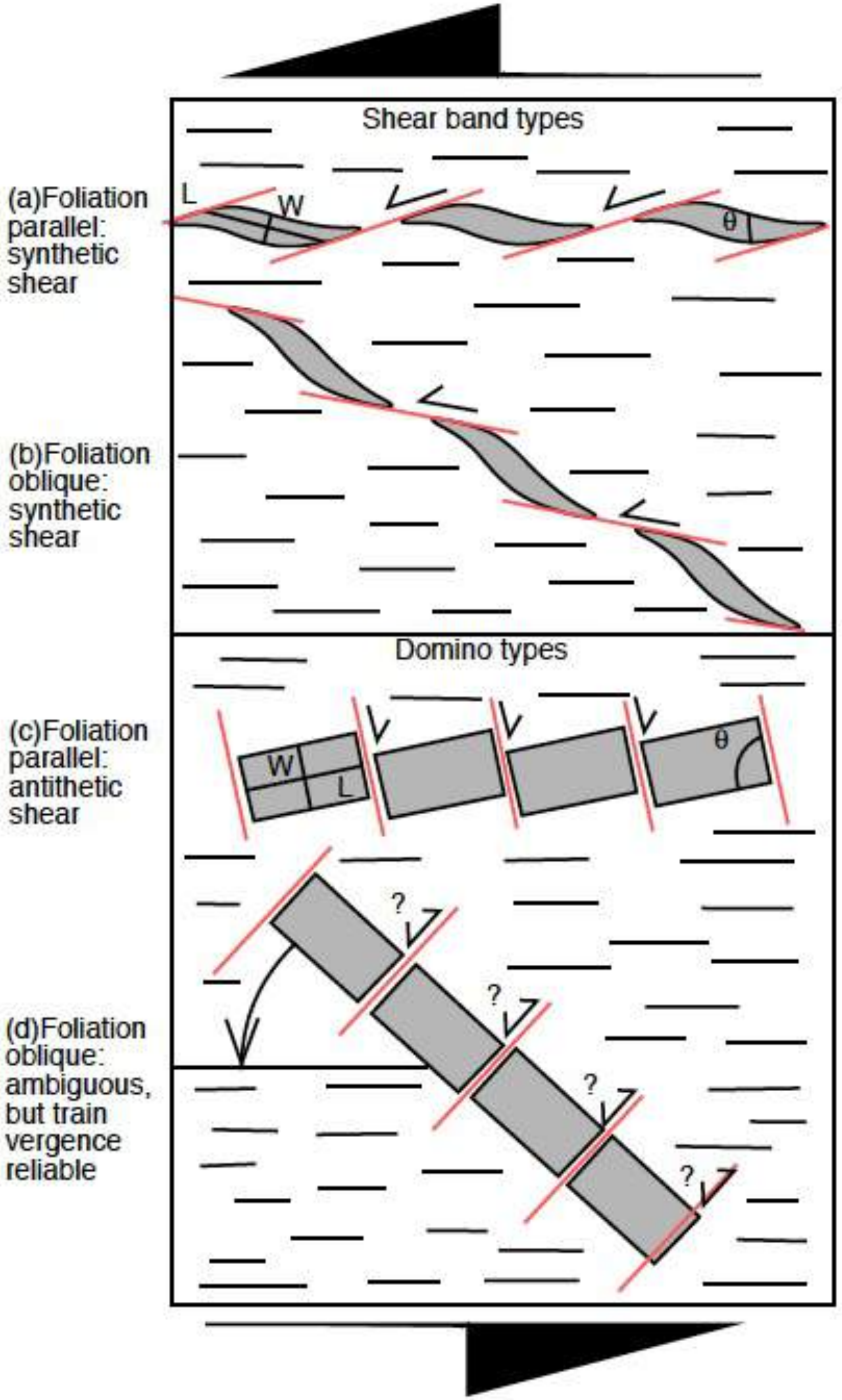
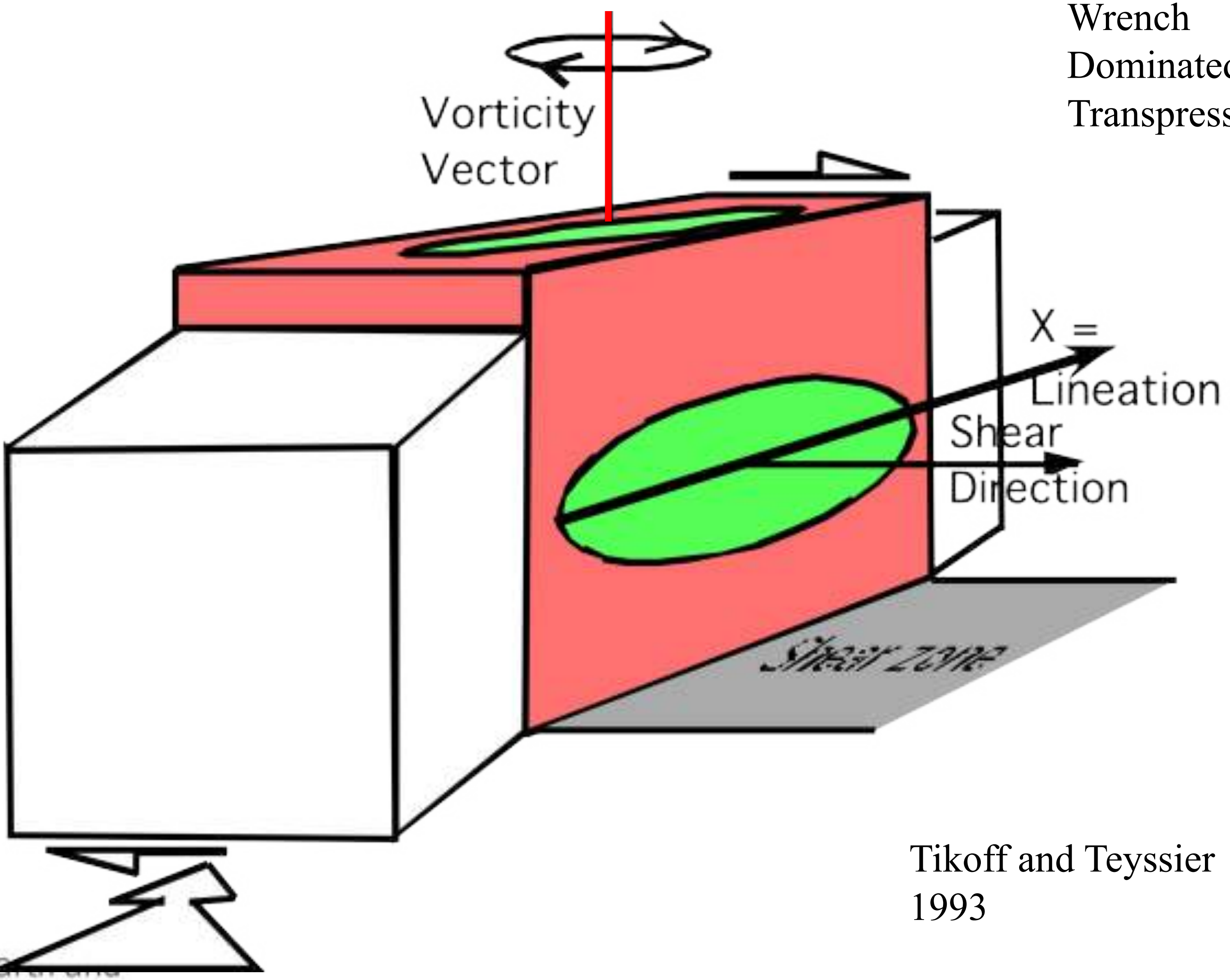
Asymmetric Boudins



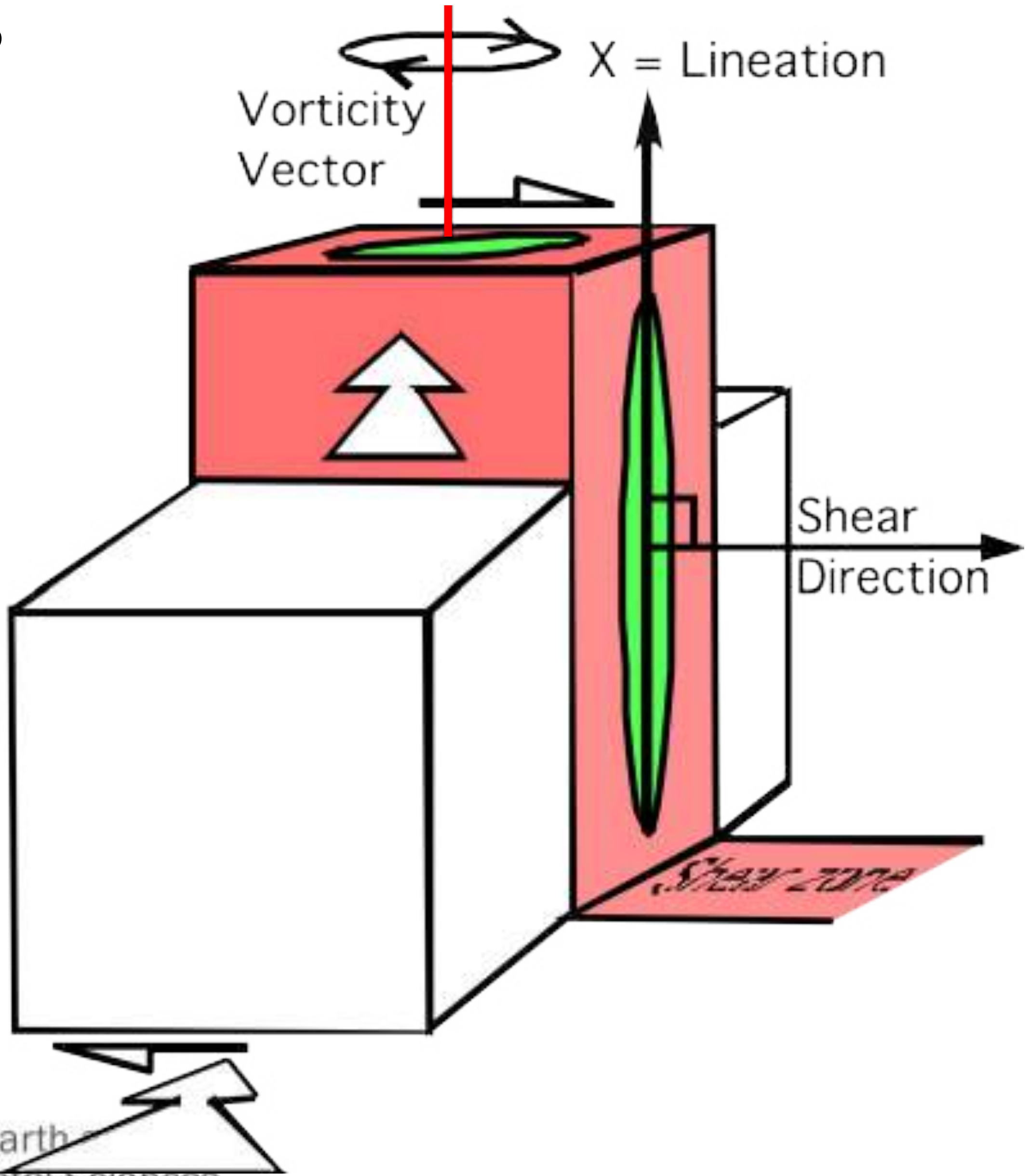
Kinematics

Wrench
Dominated
Transpression



Tikoff and Teyssier
1993

Kinematics



Pure Shear
Dominated
Transpression

Tikoff and Teyssier
1993

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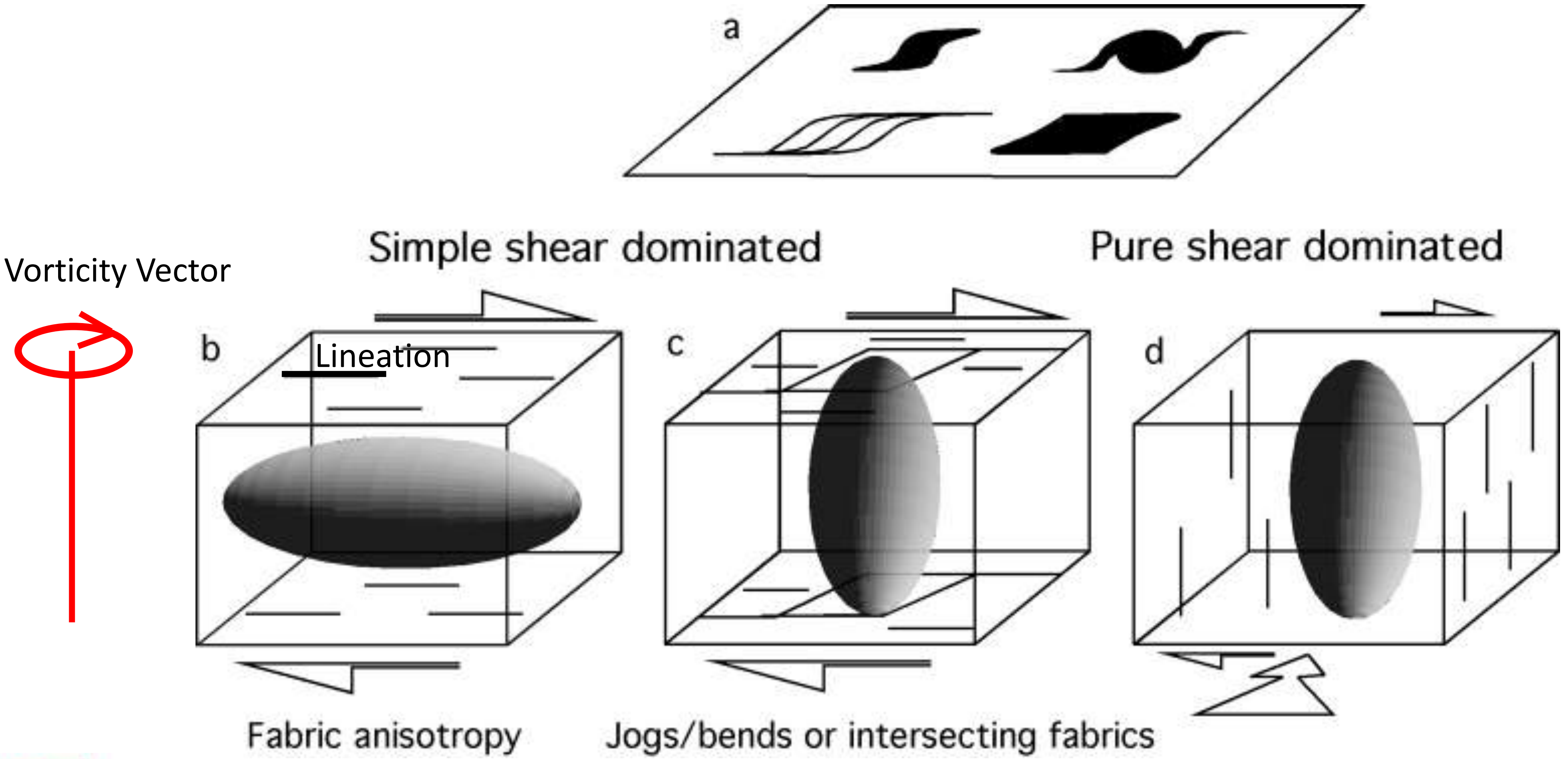
Kinematics   Shear Zones and Ore Body Orientations



Orientation of Ore Bodies

Simple Shear dominant,
Fabric control ⇨ **Ore bodies $\parallel$ to L, $\perp$ V**

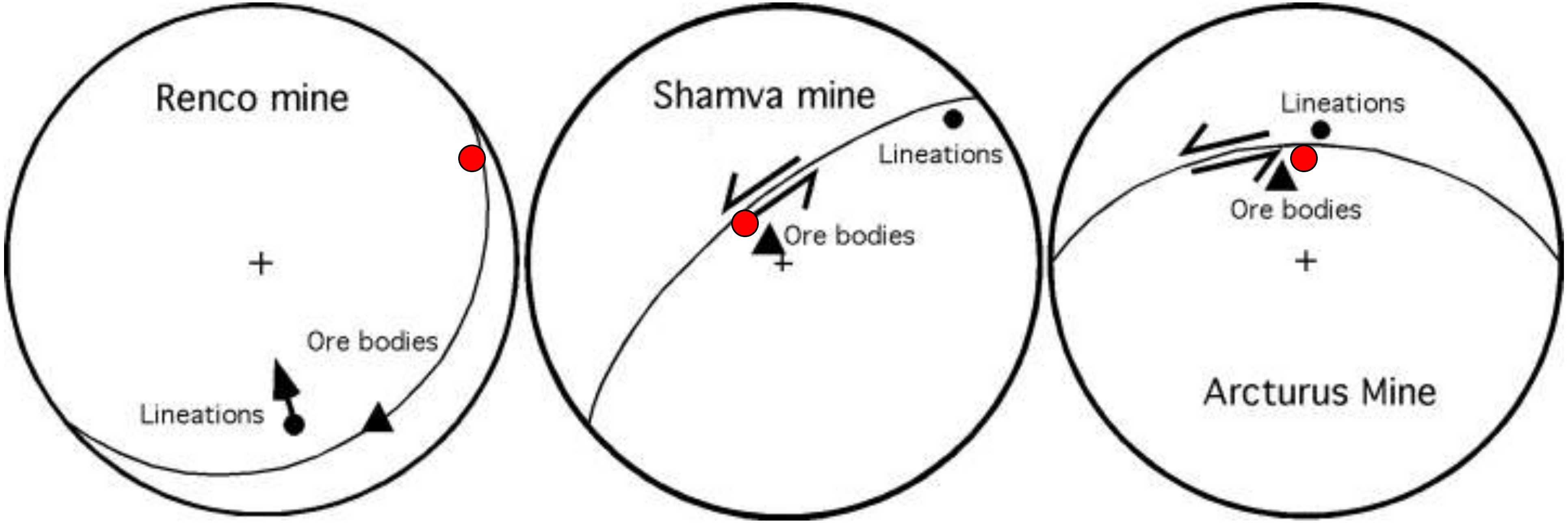
Simple Shear dominant,
Shear zone geometry control,
(bends, jogs intersecting fabrics) ⇨ **Ore bodies $\perp$ to L, $\parallel$ to V**

Pure shear dominant ⇨ **Ore bodies $\parallel$ to L, $\parallel$ to V**

Kinematics Shear Zones and Ore Body Orientations

Simple Shear Dominated

Pure Shear Dominated



Fabric control

Ore bodies: **|| to L, ⊥ V** **⊥ to L, || to V** **|| to L, || to V**

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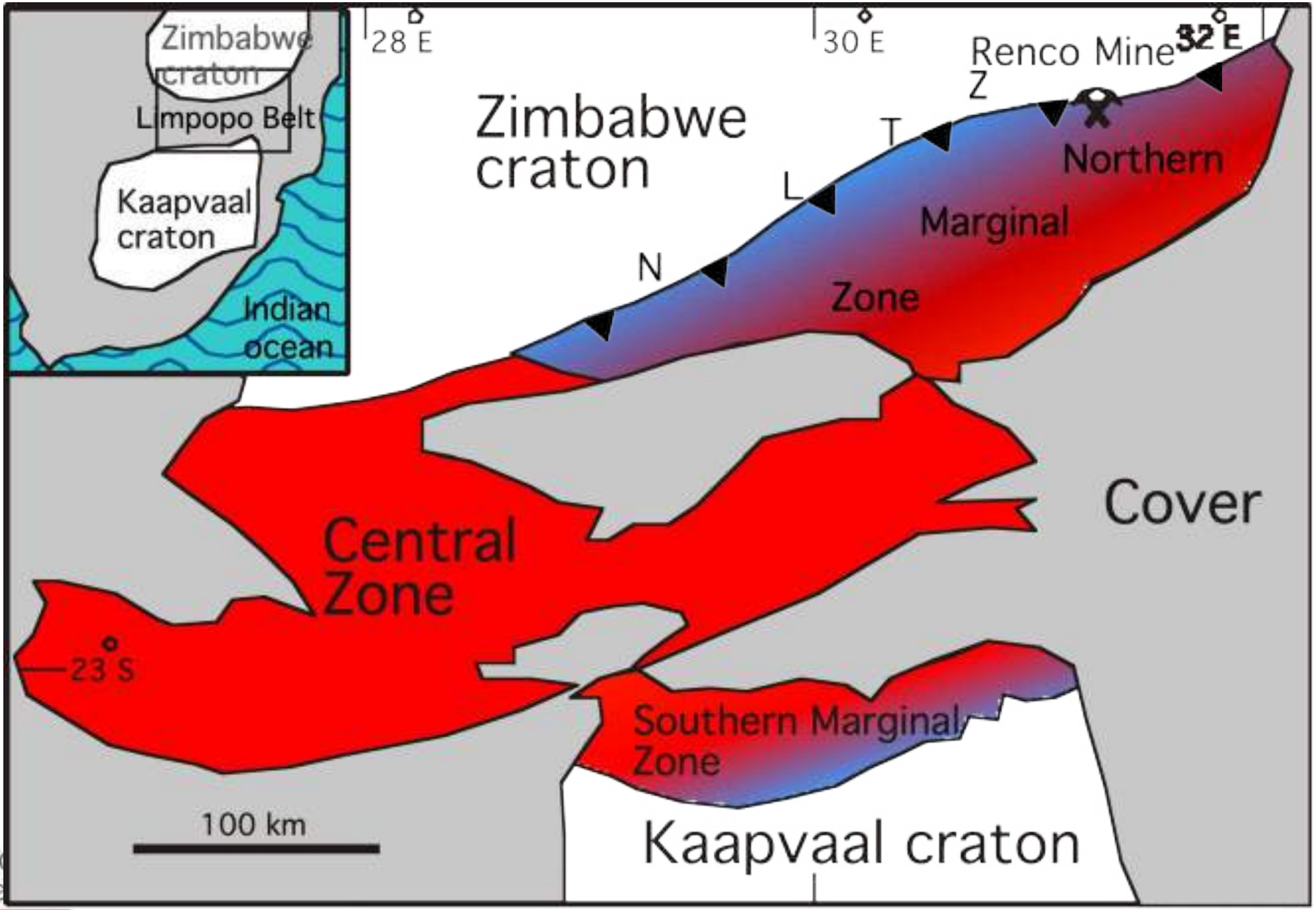
Kinematics

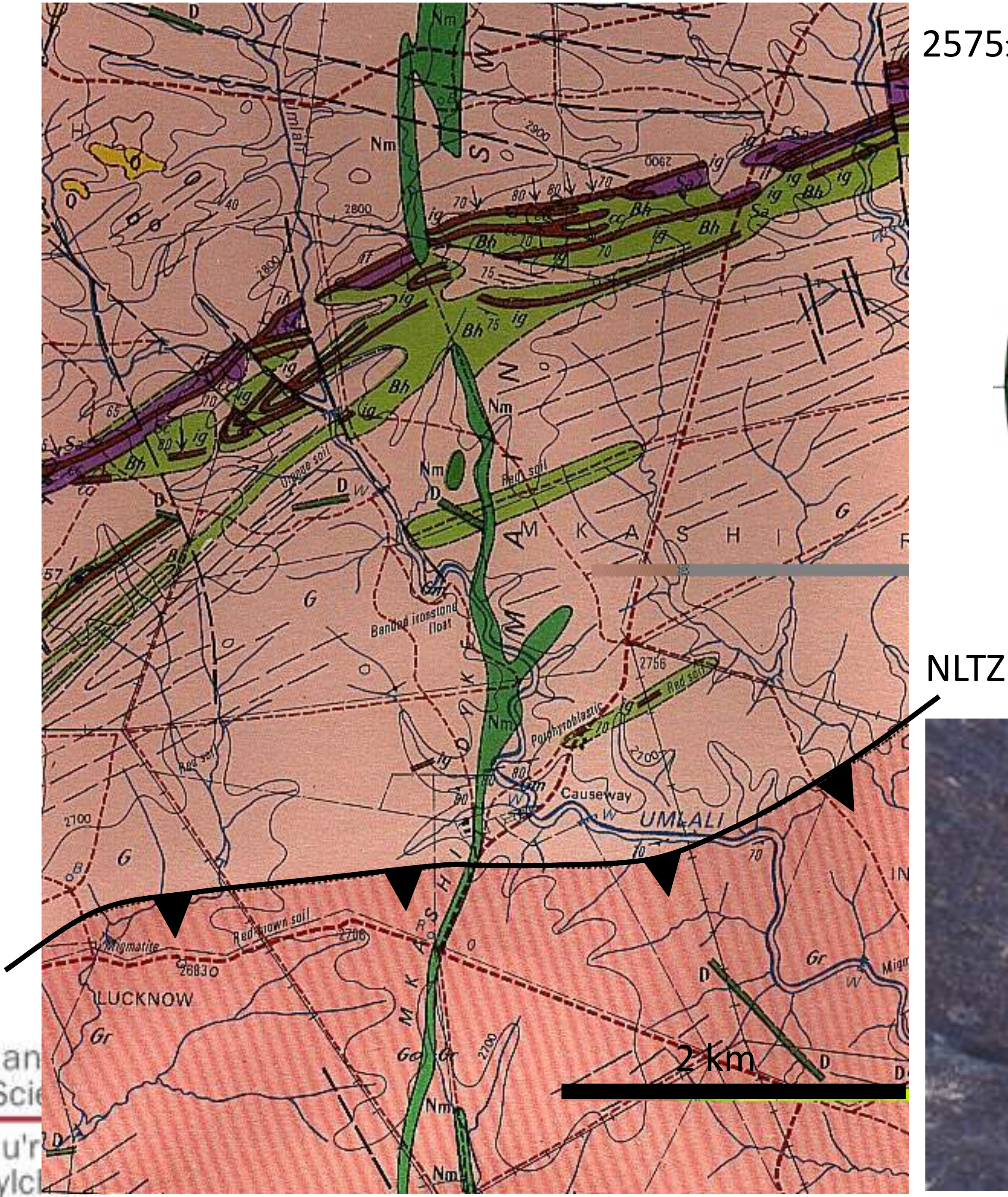


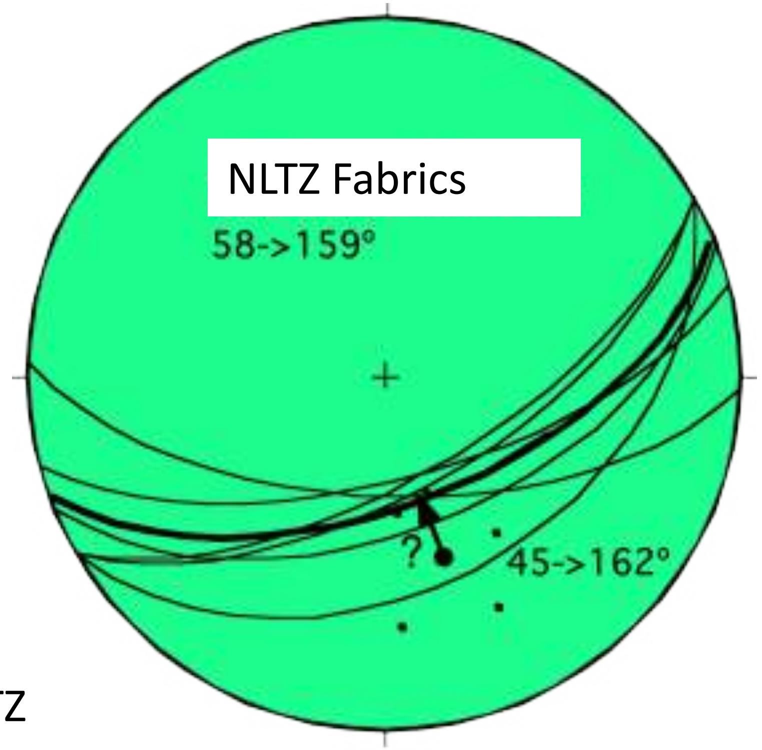
Zimbabwe craton
Limpopo Belt
Kaapvaal craton
Indian ocean
28 E
30 E
32 E
Renco Mine
Z
T
L
N
Zimbabwe craton
Northern
Marginal
Zone
Cover
Central Zone
23 S
Southern Marginal Zone
100 km
Kaapvaal craton

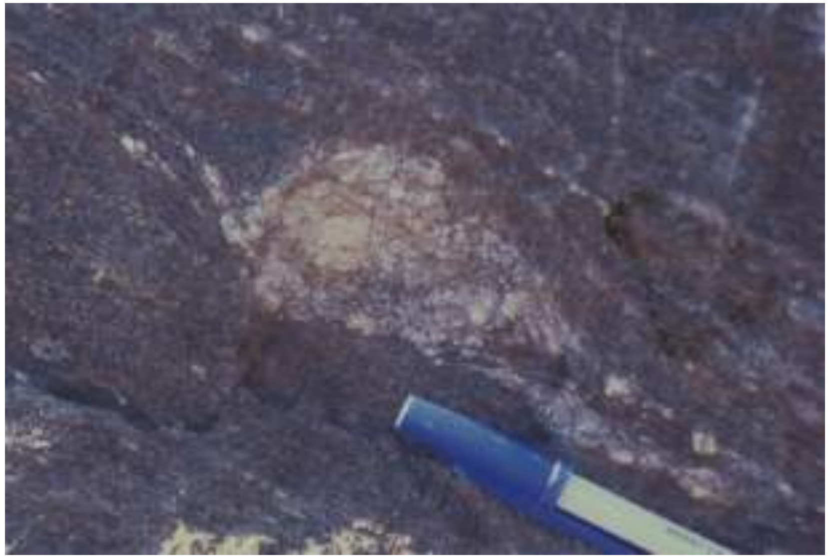
Kinematics

Kinematics

2575±0.7 Ma







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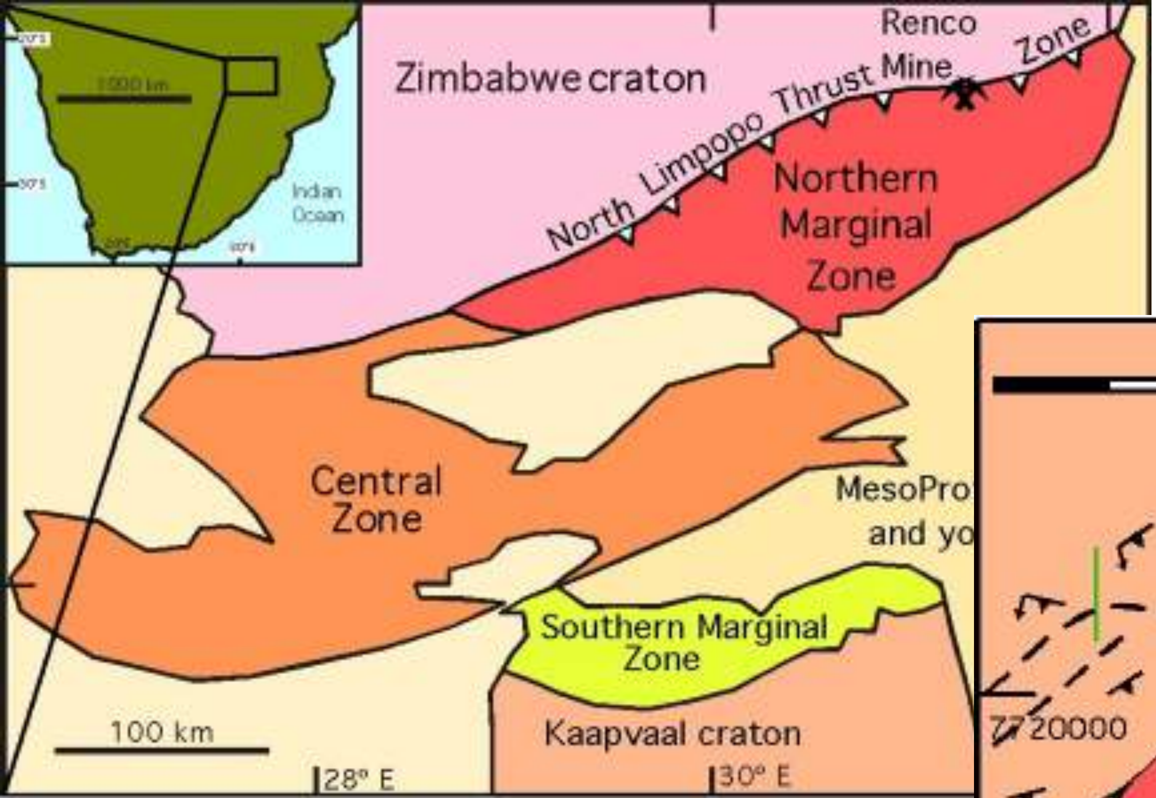
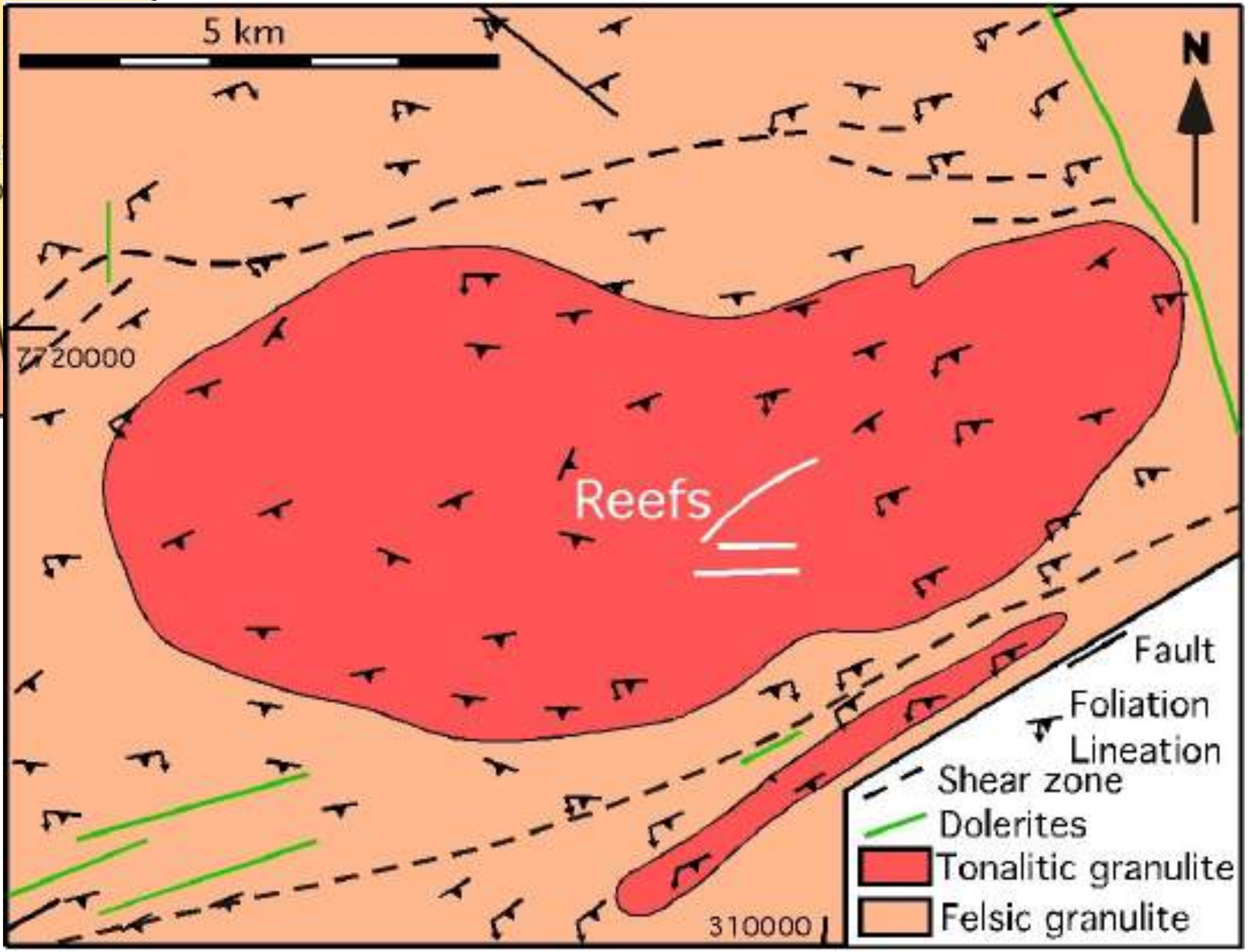
Renco Gold Mine
Northern Marginal Zone
Zimbabwe





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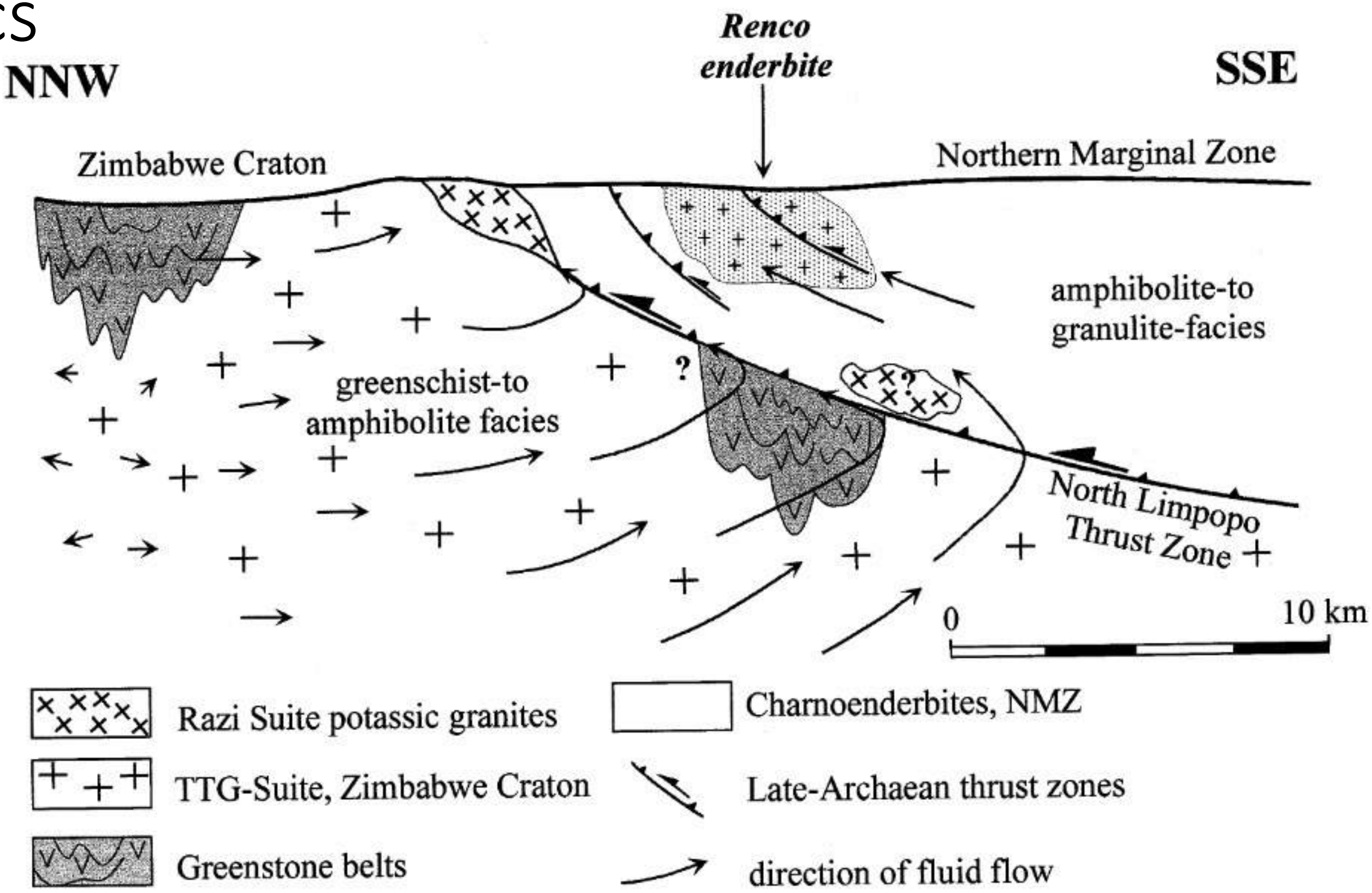
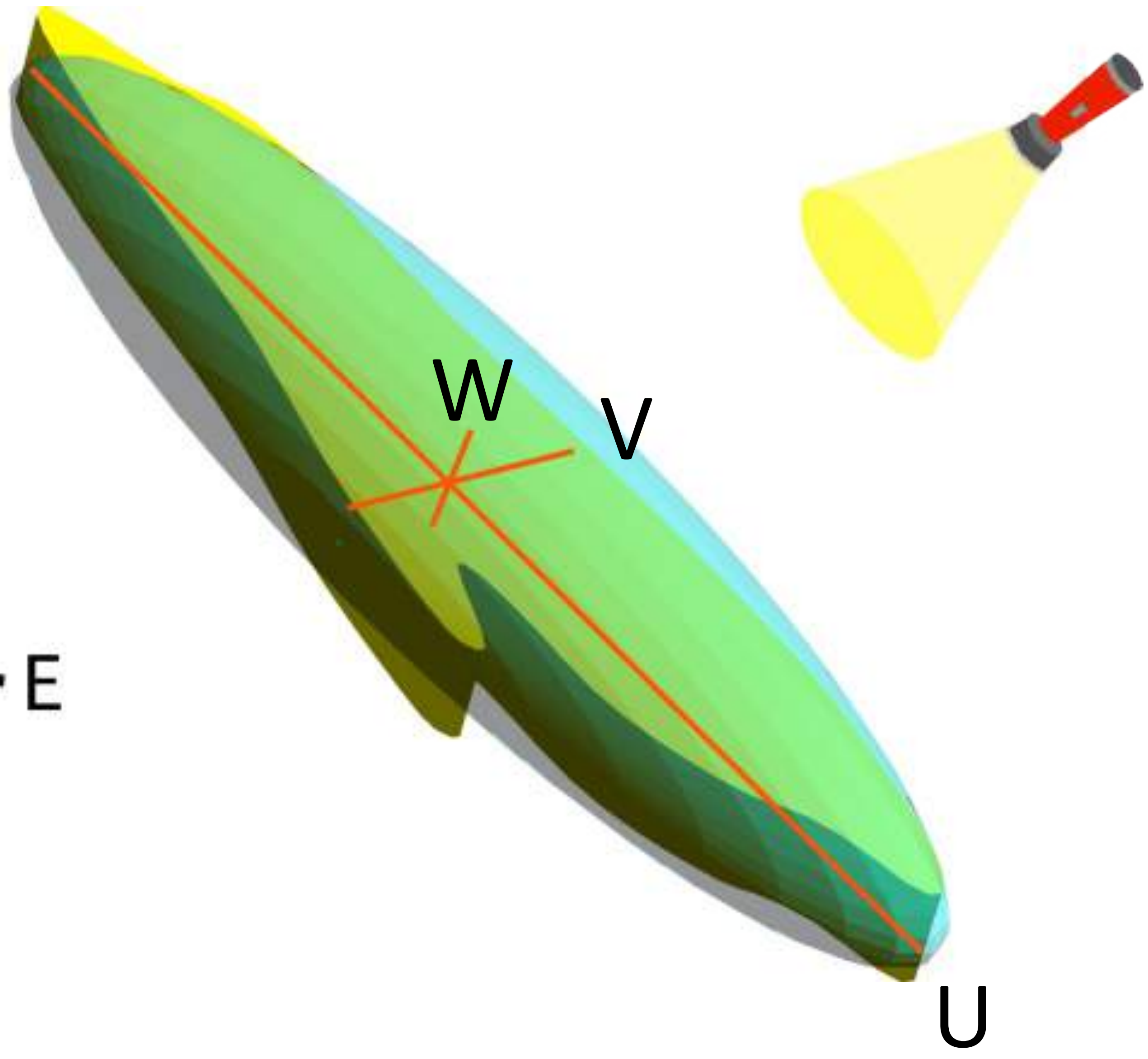
Kinematics



Kolb et al. 2000

Kinematics



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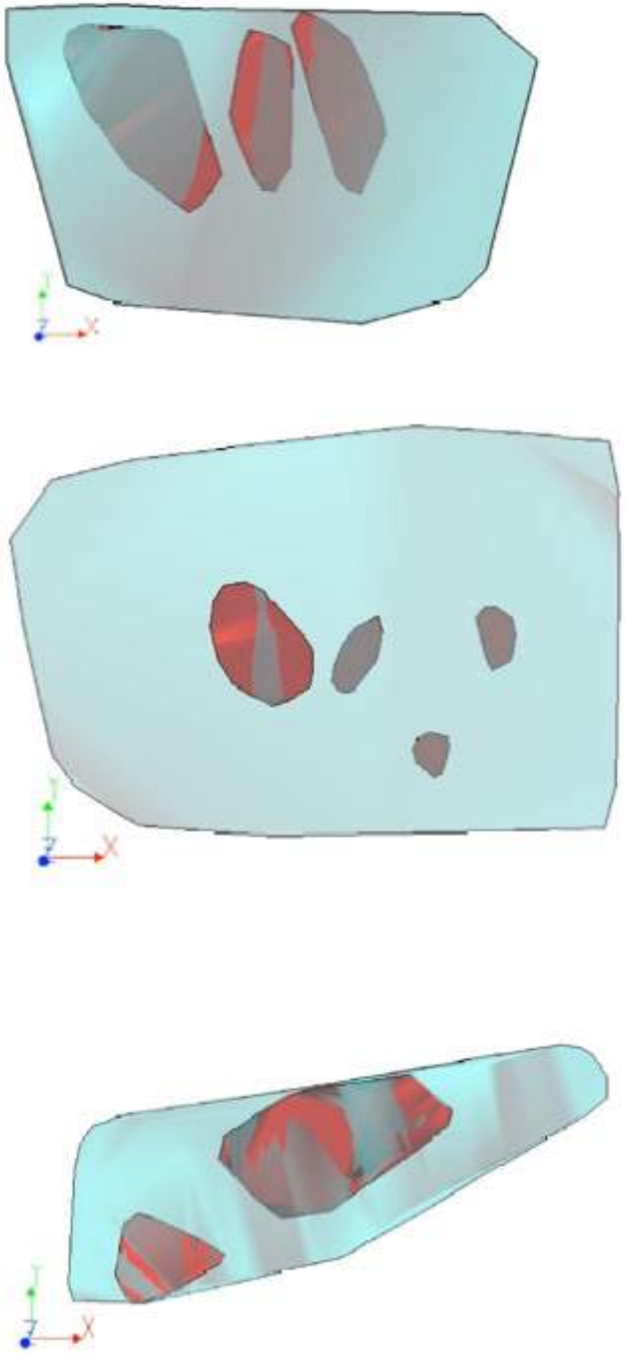
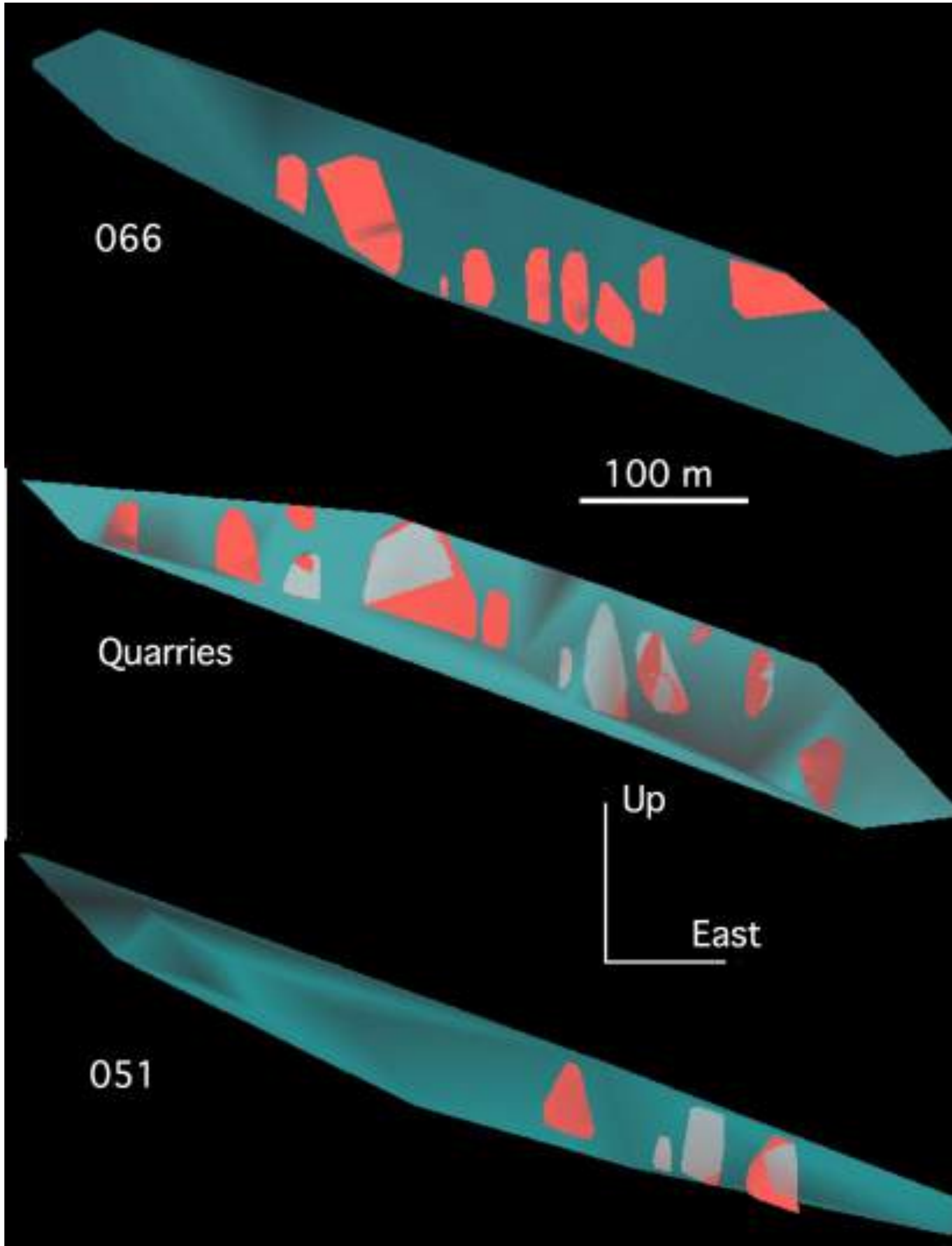
Blenkinsop 2004

Kinematics

Shallow
Ore bodies



Steep
Ore bodies



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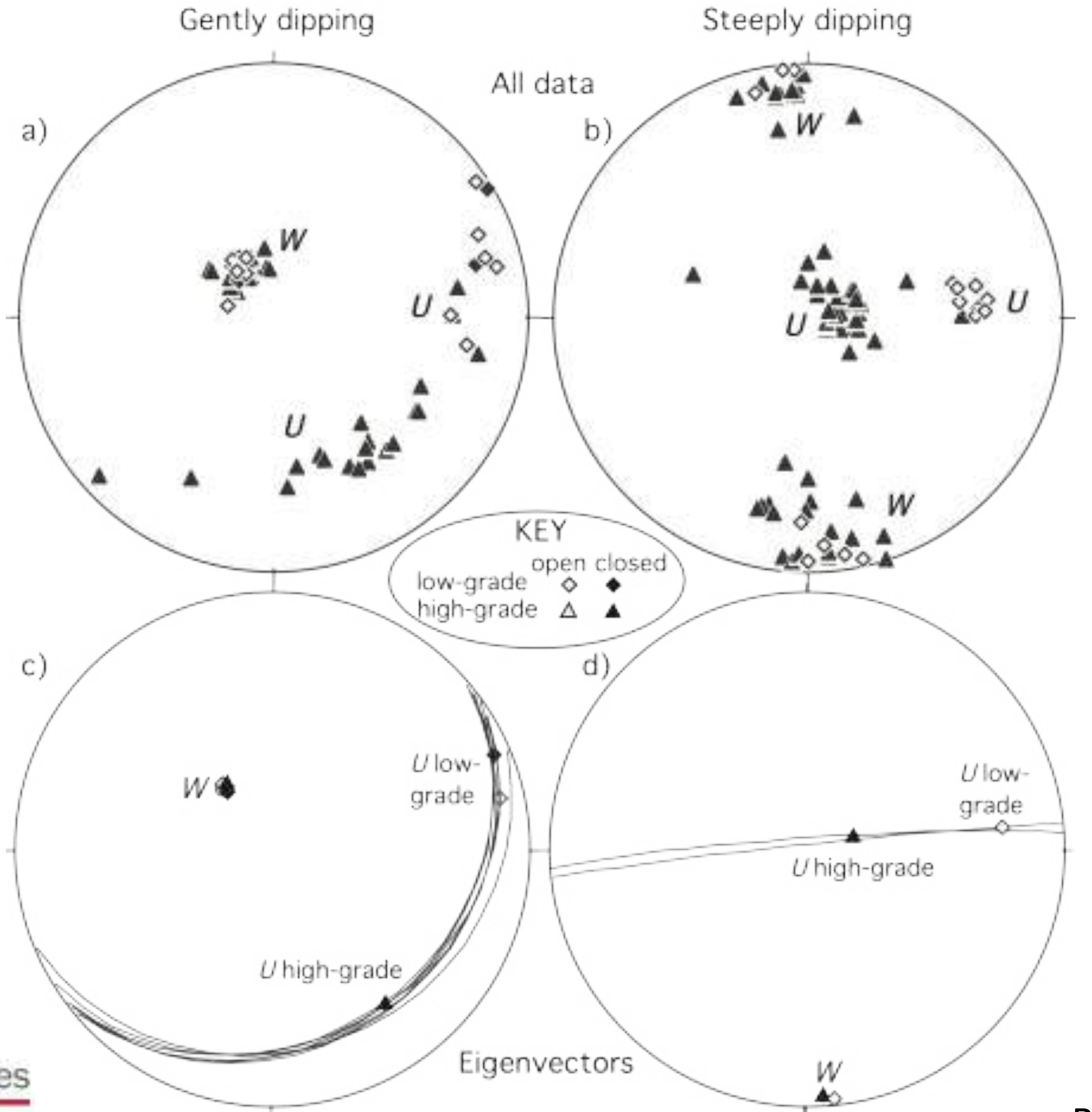
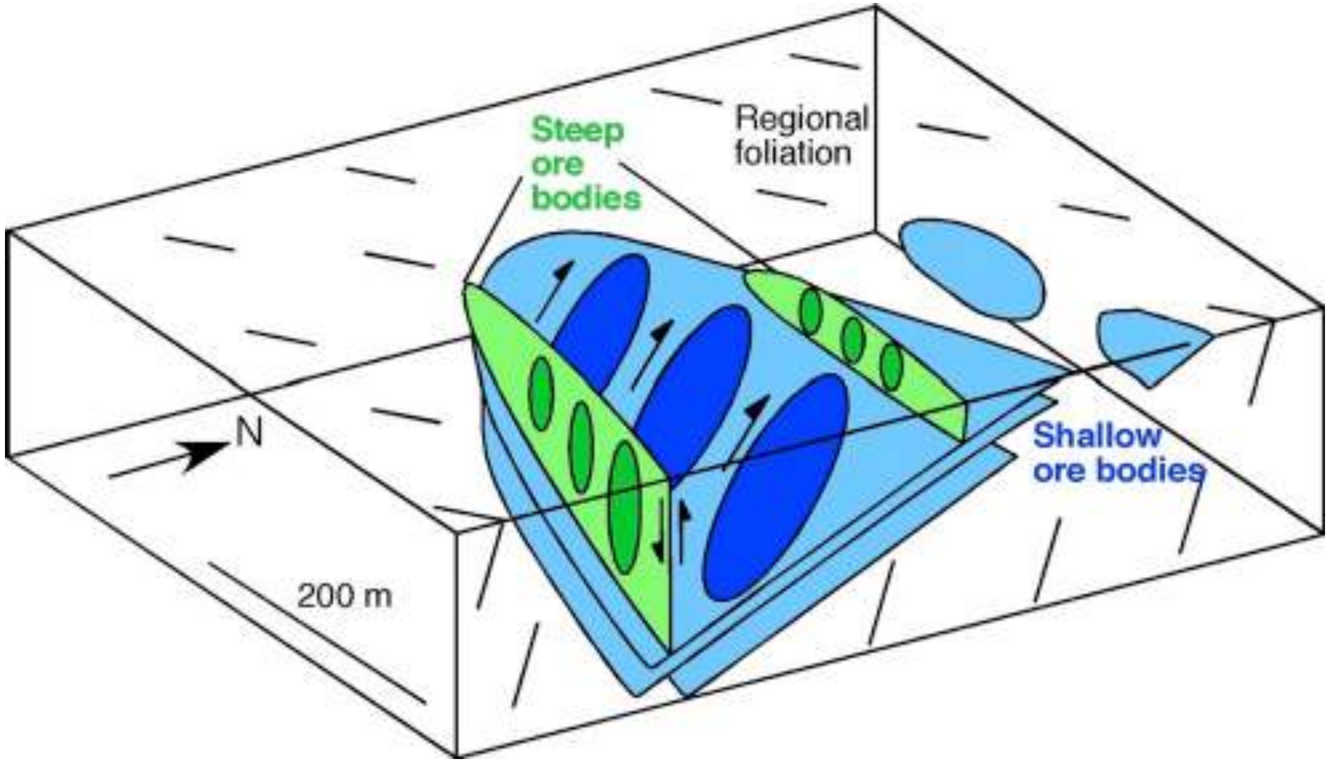
Kinematics

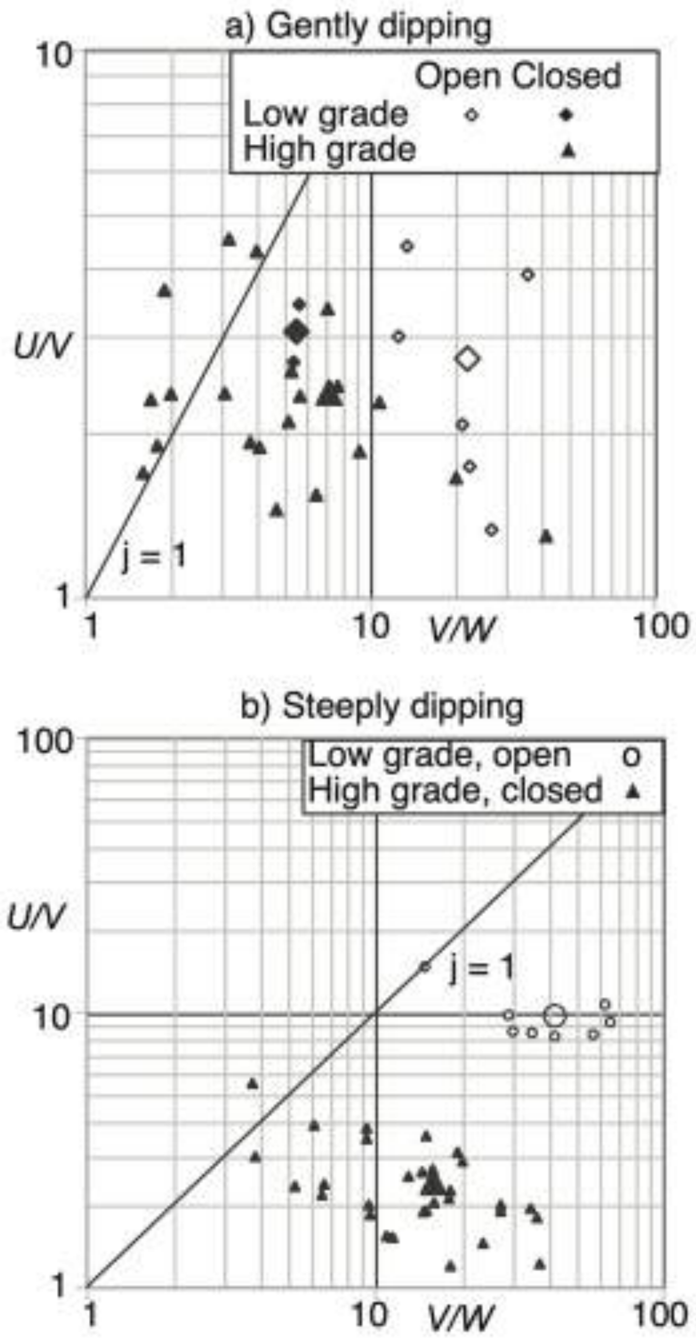


Blenkinsop and Kadzviti 2006

Kinematics

"Flinn" Plots for ore bodies at Renco





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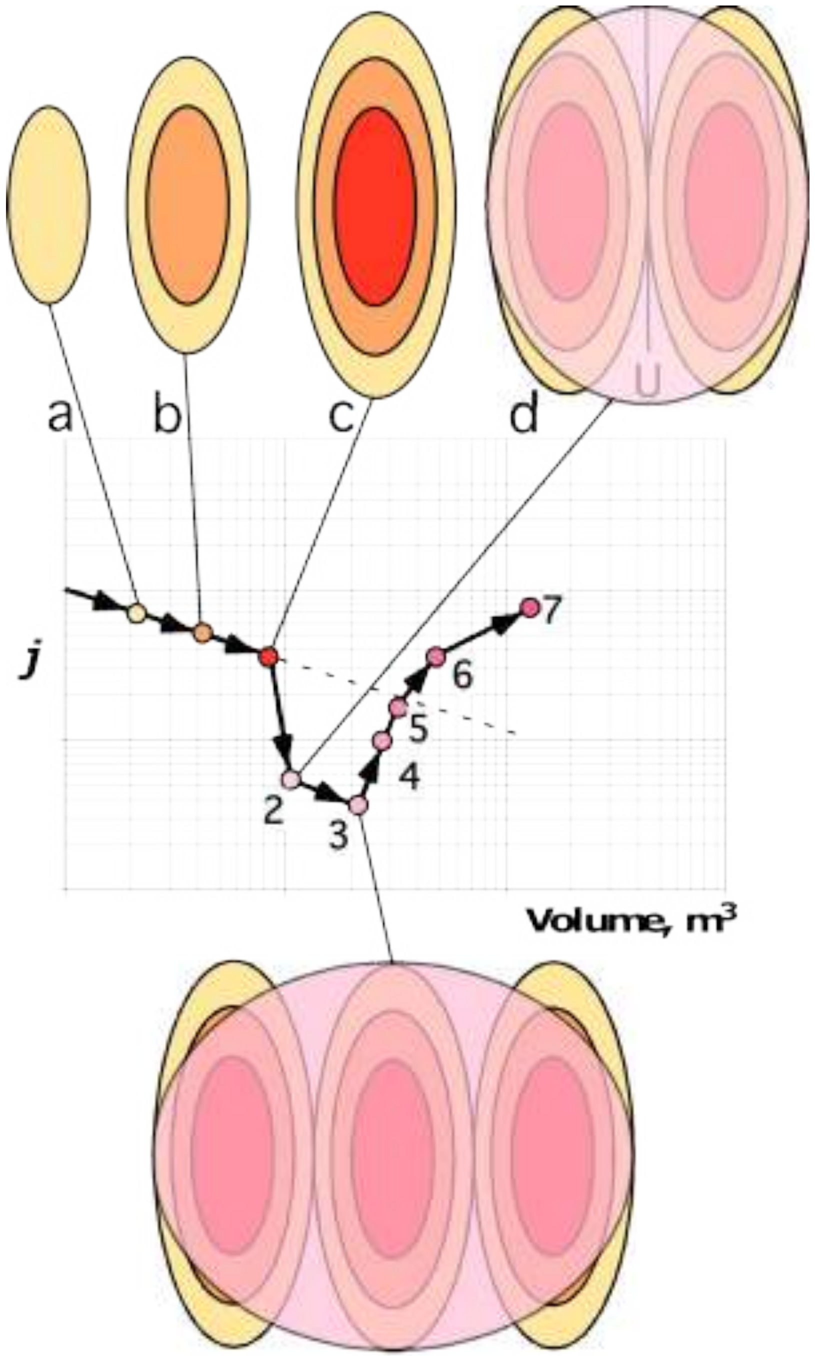
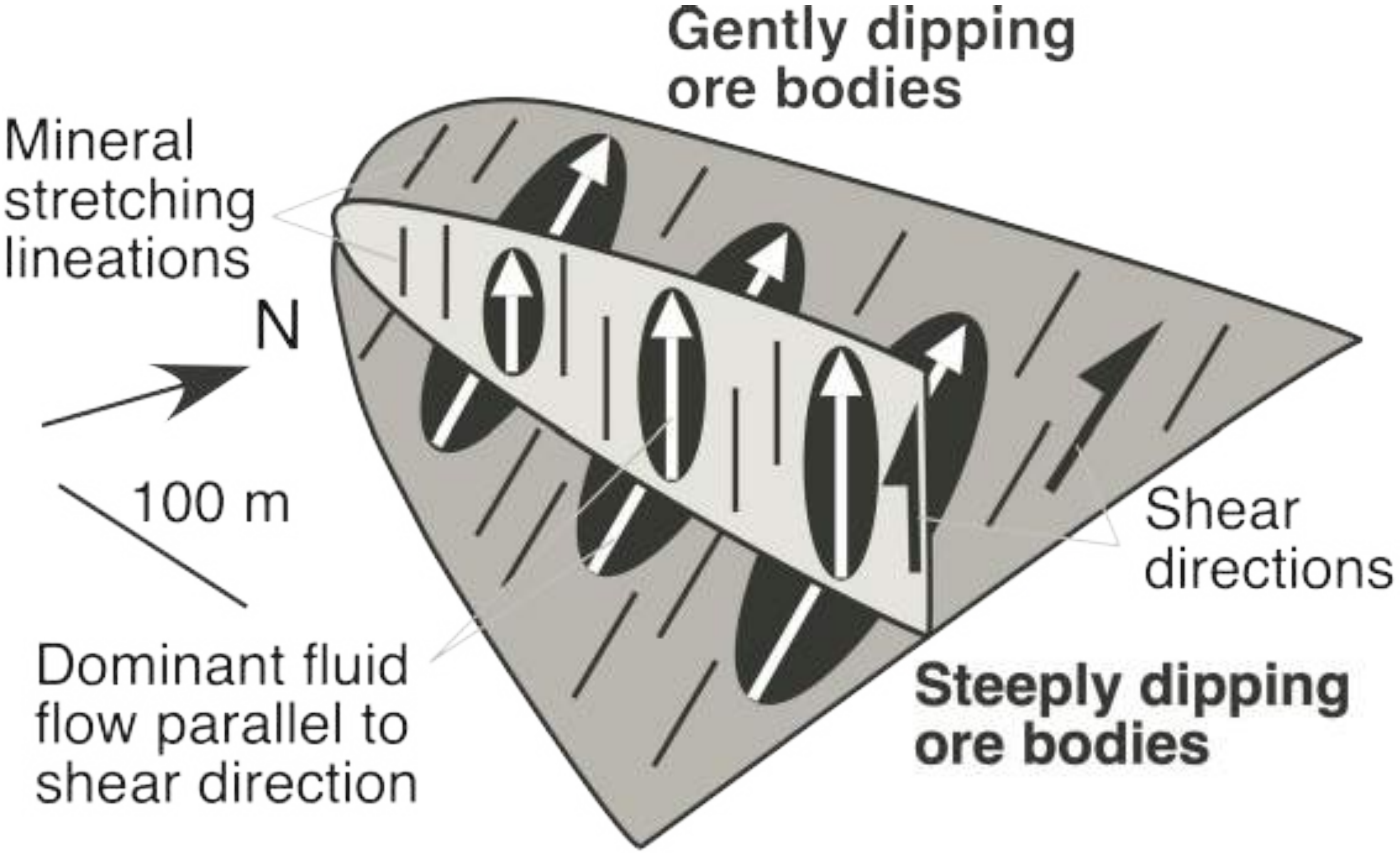
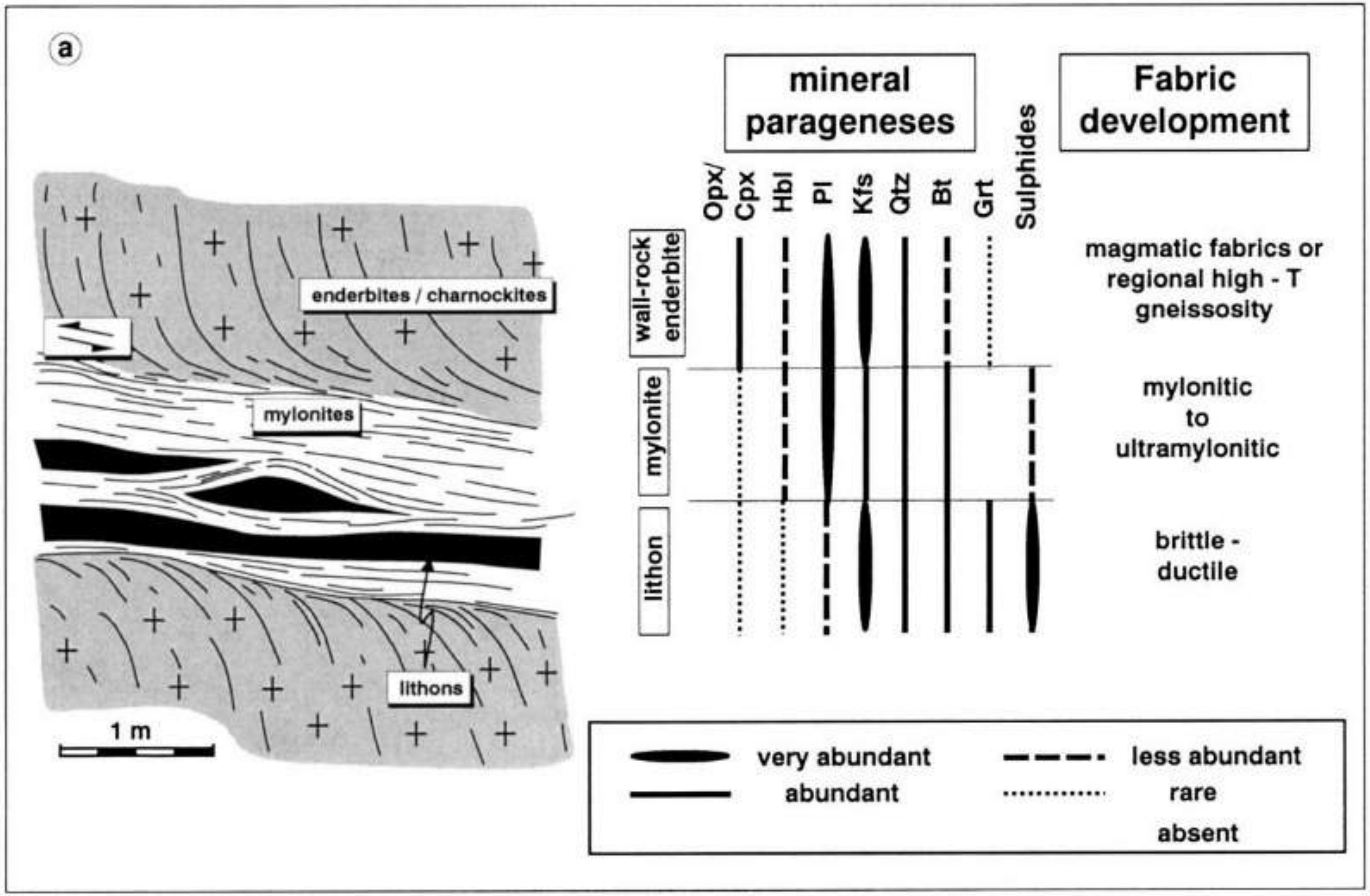
Kinematics

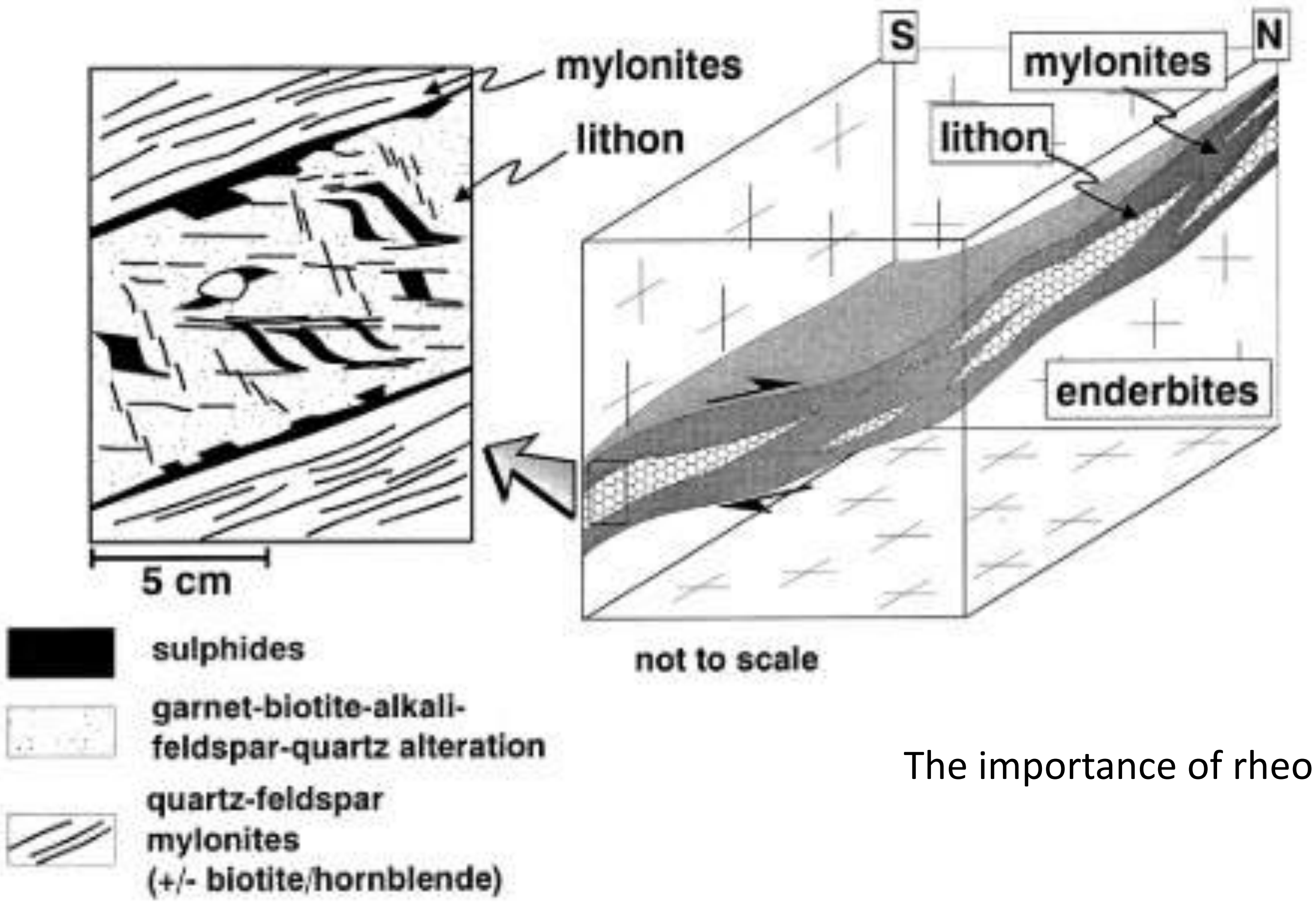


Kinematics Renco mine





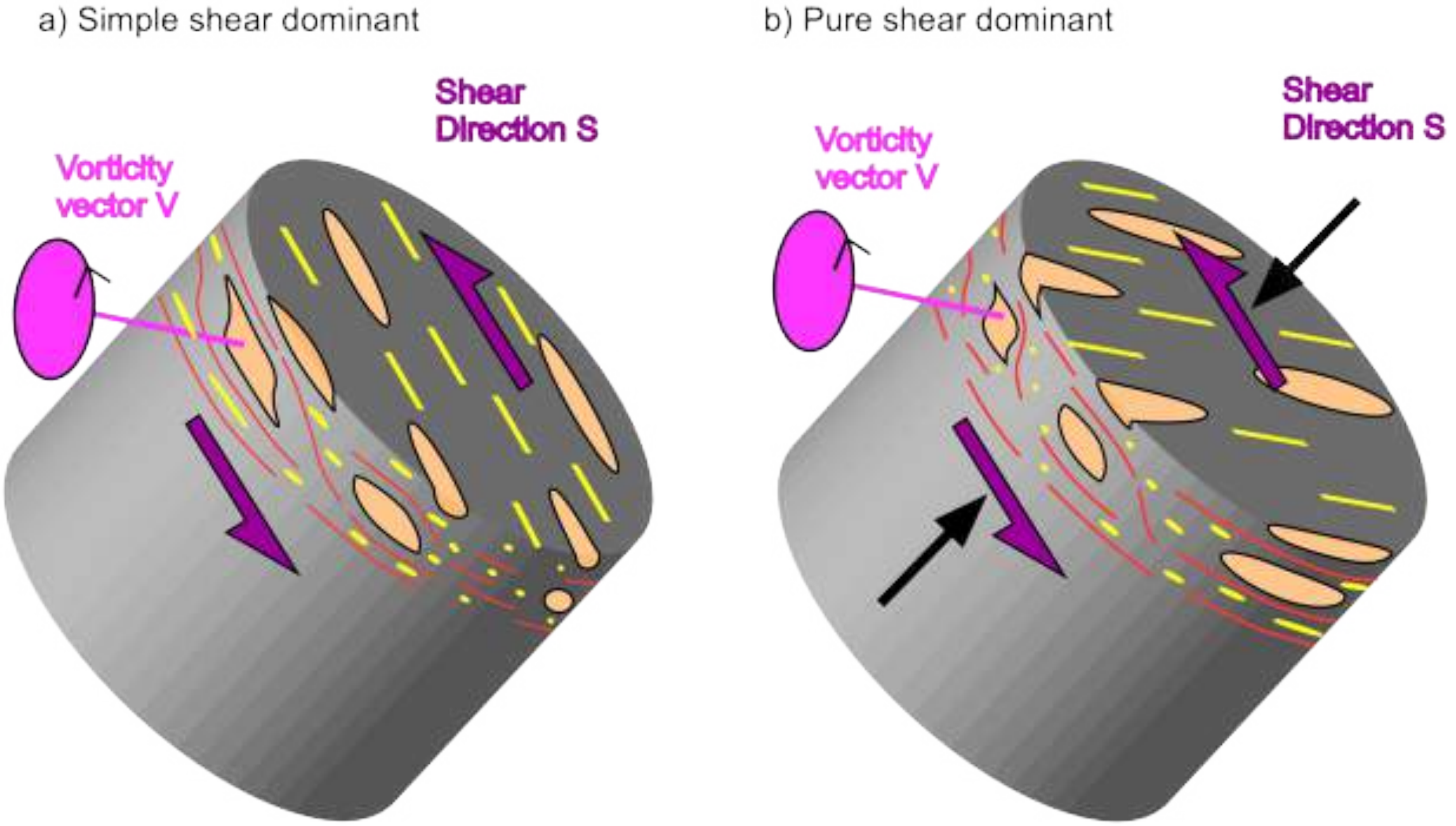
Kisters et al. 2000



The importance of rheology

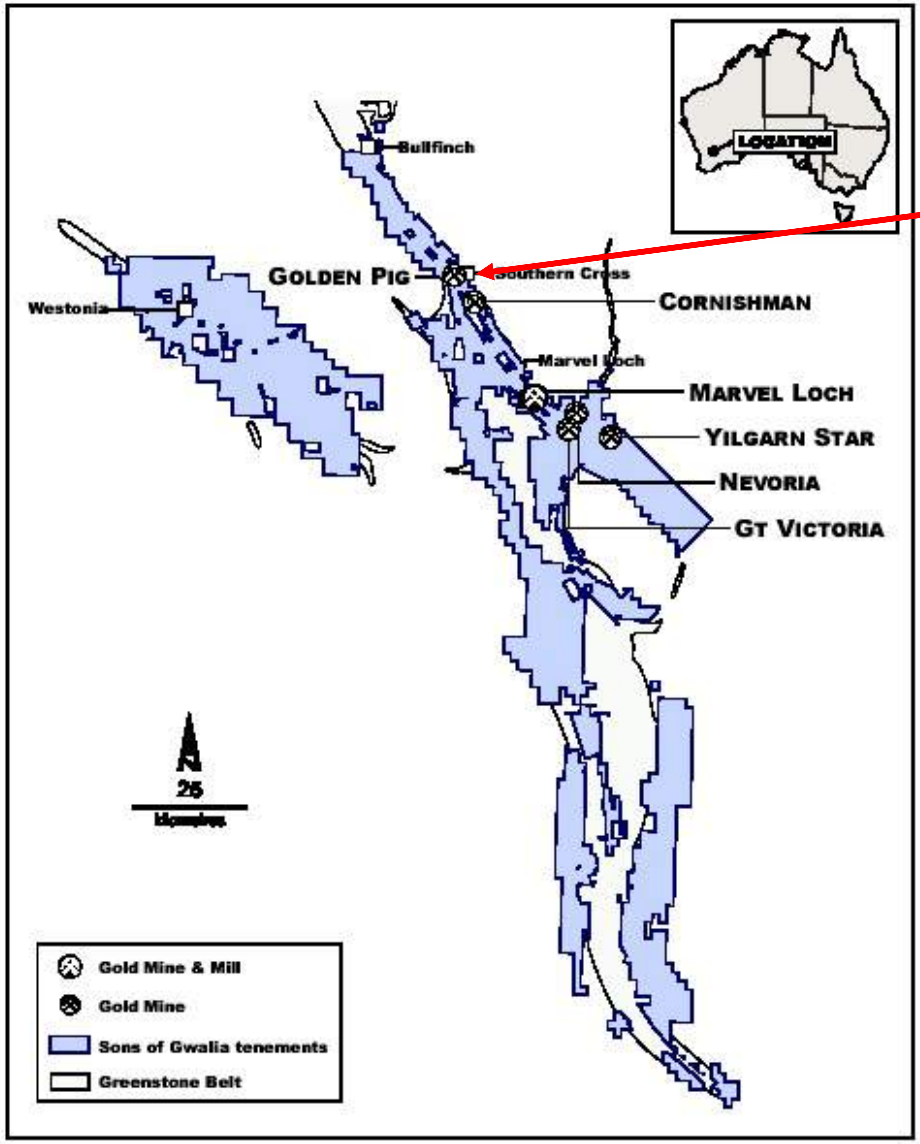
Kisters et al. 2000

Kinematics



a) Simple shear dominant
b) Pure shear dominant
Shear
Direction S
Vorticity
vector V
Shear
Direction S
Vorticity
vector V

Case Study: Golden Pig Mine, Southern Cross Greenstone Belt, Yilgarn Craton



Golden Pig mine:

- 14.5 tonnes Au produced
- Average grade 5.7 g/t
- Production ~ 50 000 oz p.a.
- Reserves = 2 years

Nugus, M. J., **Blenkinsop, T. G.** Dominy, S., and Robson, S. 2003. Enigmatic Kinematics Resolved in the Taurus Shear Zone, Golden Pig Gold Mine, Southern Cross, Western Australia: Resource Implications. Proc. 5th International Mining Geology conference, Australasian Institute of Mining and Metallurgy, 171-180.

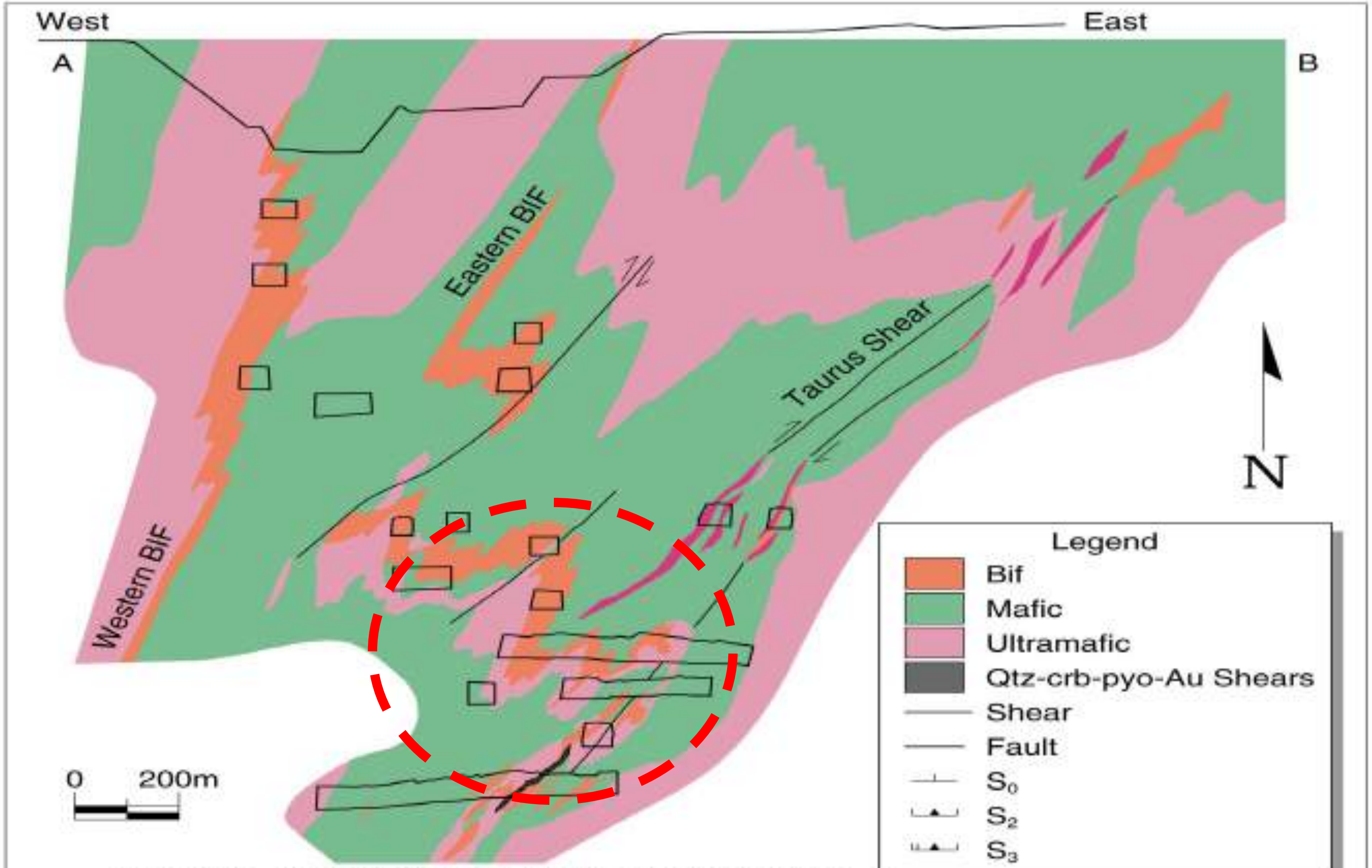


Figure 2b. Geological Cross Section 14030N (A-B)

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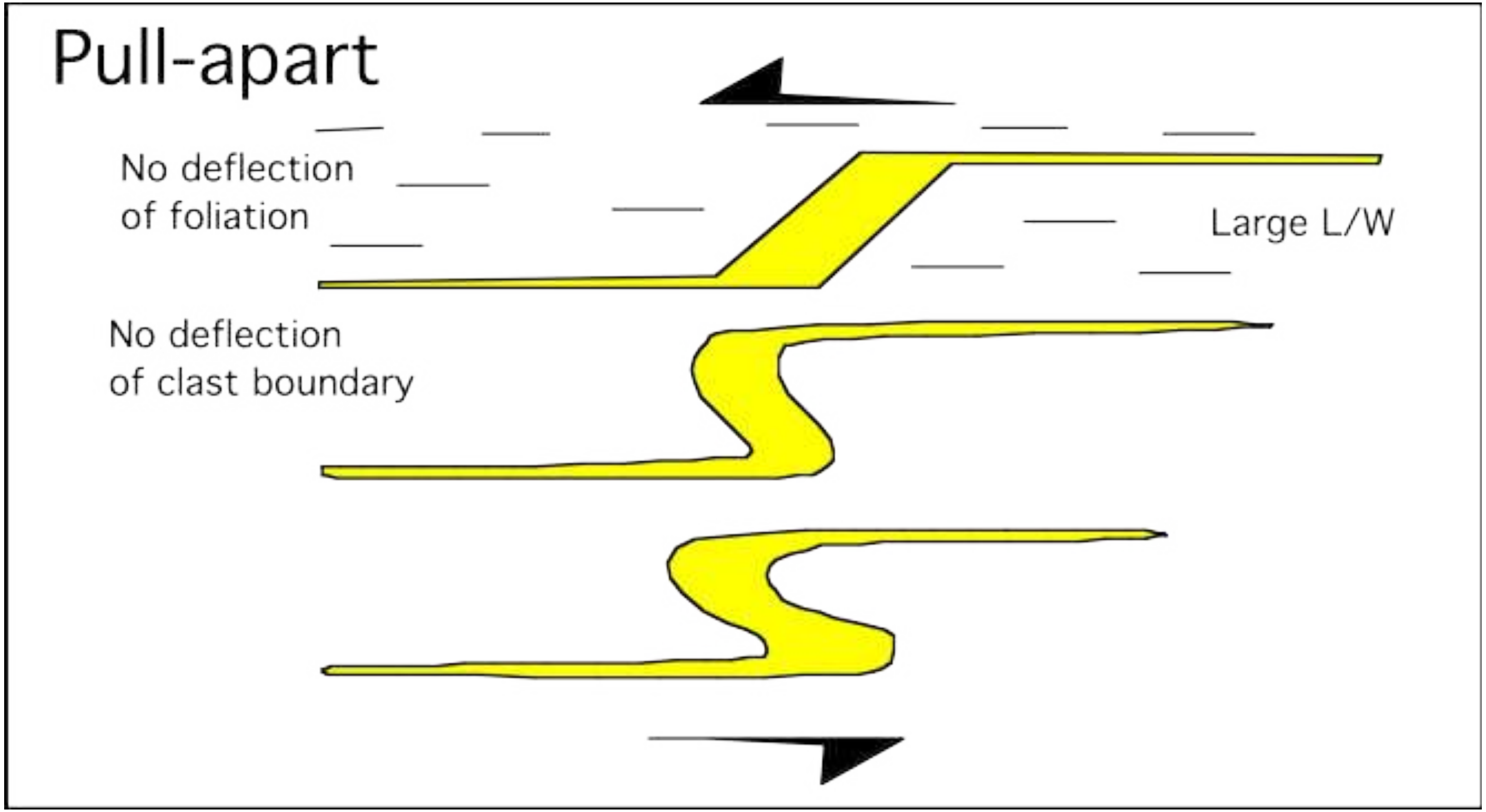
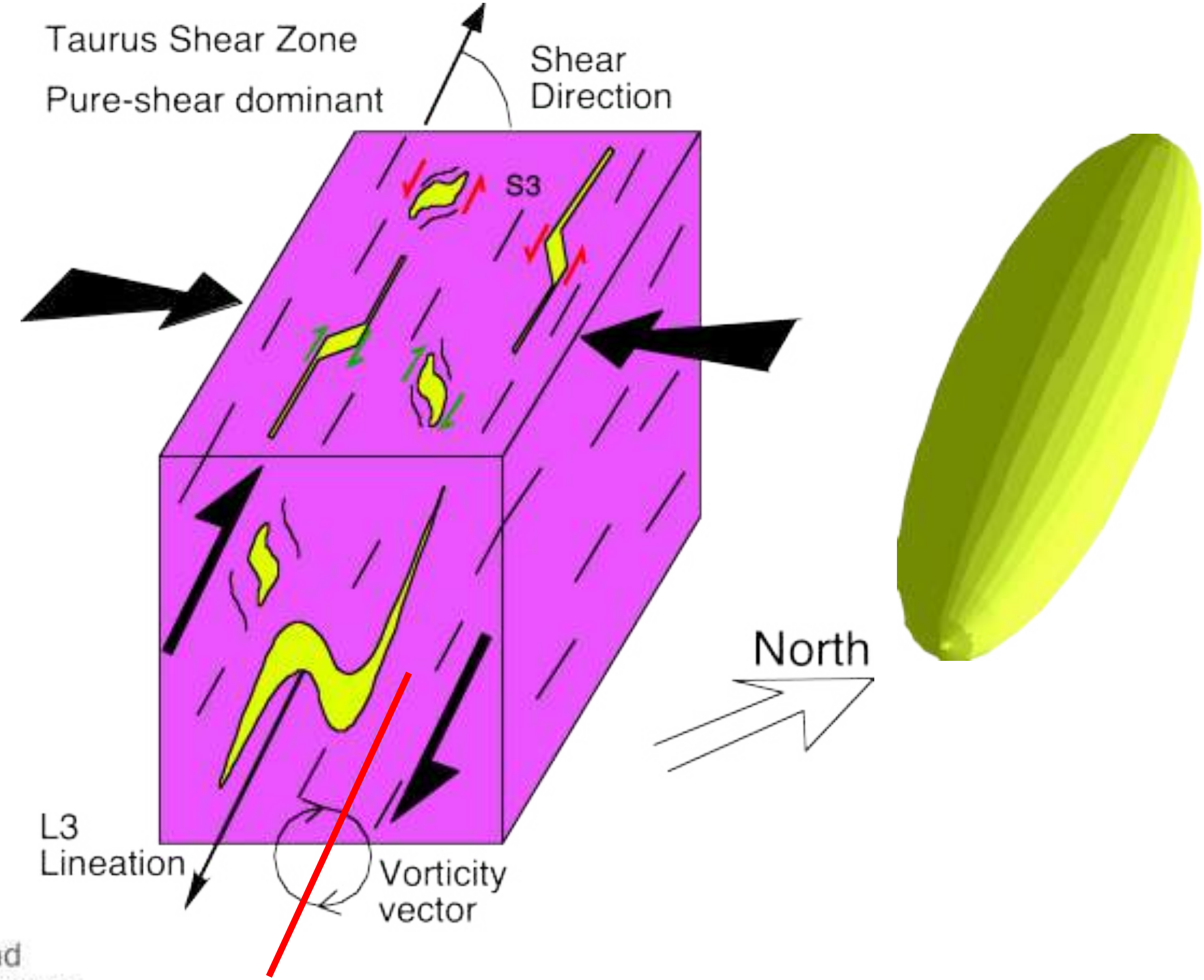
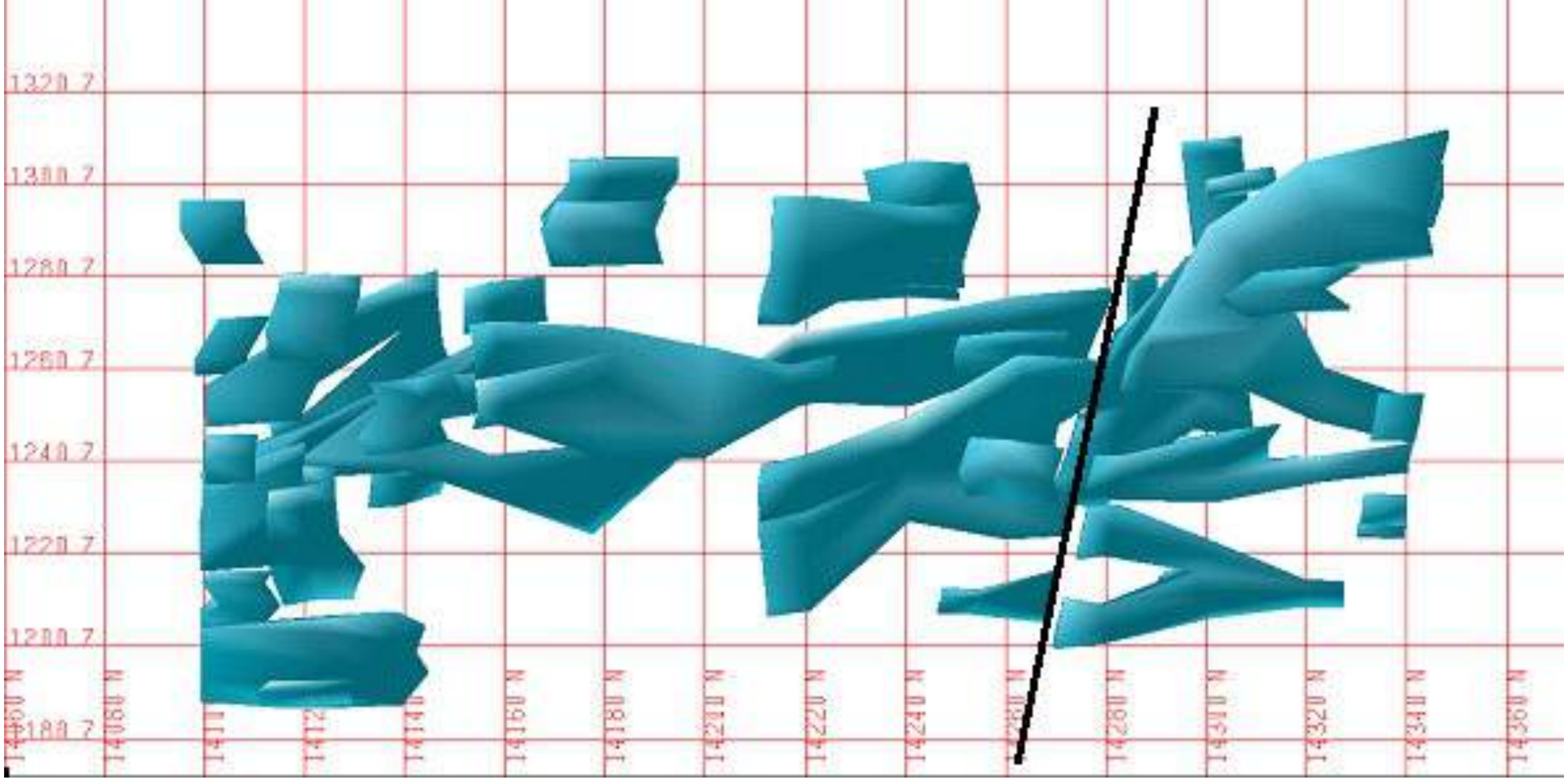

Pull-apart
No deflection
of foliation
Large L/W
No deflection
of clast boundary

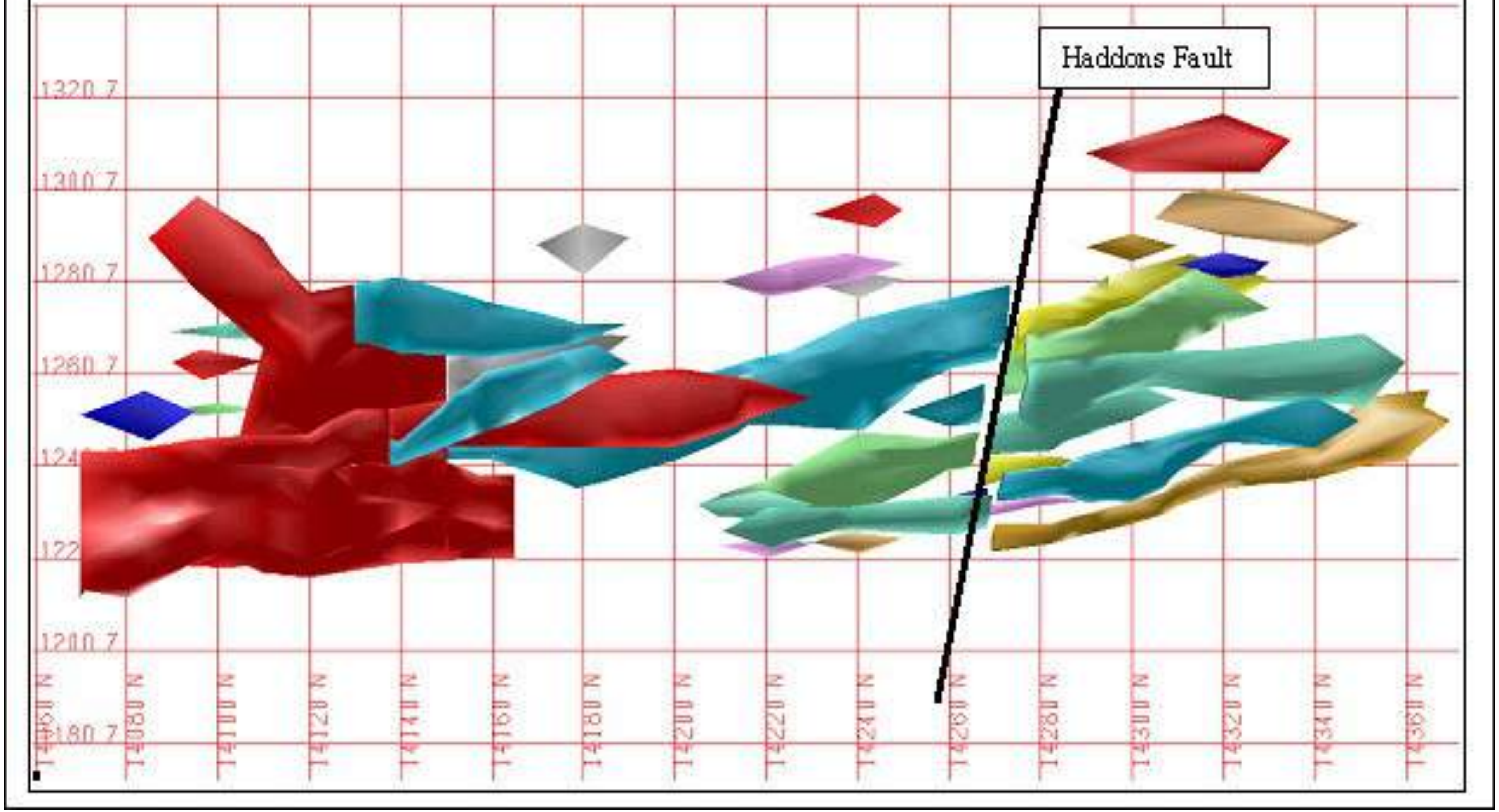


Taurus Shear Zone
Pure-shear dominant
Shear Direction
S3
L3 Lineation
Vorticity vector
North



Original Taurus wireframe in long section looking west (after Brandes, 1999).

High-grade, extensional shoot wireframe in long section looking west (after Robson, 2002)



Exclusions and Complications

1. Reactivation and obliteration of syn-mineralization fabrics

2. Strain compatibility at shear zone boundaries

3. Strain partitioning

4. Triclinic shear

5. Lack of lineation

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A practical guide to ore body orientations in shear zones:

1. Shear Zone Kinematics

↓

2. Structural Controls on Ore Body

↓

3. Orientation of Ore Bodies

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1. Shear Zone Kinematics

1a. Identify foliation, lineation

↓

1b. Find Vorticity Vector/
Plane of Maximum Asymmetry

↓

1c. Check lineation:

$\perp$ Vorticity vector, $\parallel$ to plane
⇨ simple shear dominated

$\parallel$ to Vorticity vector, $\perp$ to plane
⇨ pure shear dominated

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2. Structural Controls on Ore Body

2a. Strong fabrics ⇨ Fabric Anisotropy

2b. Shear Zone Geometry ⇨ Bends, Jogs, Splays

3. Orientation of Ore Bodies

3a. Simple Shear dominant, Fabric control ⇨ **Ore bodies || to L**

3b. Simple Shear dominant, Shear zone geometry control, (bends, jogs intersecting fabrics) ⇨ **Ore bodies ⊥ to L**

3c. Pure shear dominant ⇨ **Ore bodies || to L**

Vorticity vector, Lineation and Ore Bodies

Type of shear zone	Lineation and vorticity vector	Lineation and ore bodies
Simple Shear dominant, Fabric control	$\perp$	$\parallel$
Simple Shear dominant, Shear zone geometry control, (bends, jogs intersecting fabrics)	$\perp$	$\perp$
Pure shear dominant	$\parallel$	$\parallel$

Conclusions

- Geometric analysis of structures, networks, and orebodies is the most basic step in analyzing hydrothermal gold deposits. Geometric analysis can include network topology.

- Kinematic analysis is essential for relating ore body geometry to deformation, as well as to relate deposit-scale features to regional tectonics. Pure shear must be included in shear zone analysis.

- A dynamic analysis of hydrothermal mineralization will assess pore fluid pressure and stress, and can be used for numerical mechanical models.

- Analysis of rheology is the key in many cases to understanding the structural controls on orebodies, which are commonly located on rheological boundaries. Complex structural histories, and hence reactivation are common.

Kupol epithermal gold mine, Russia

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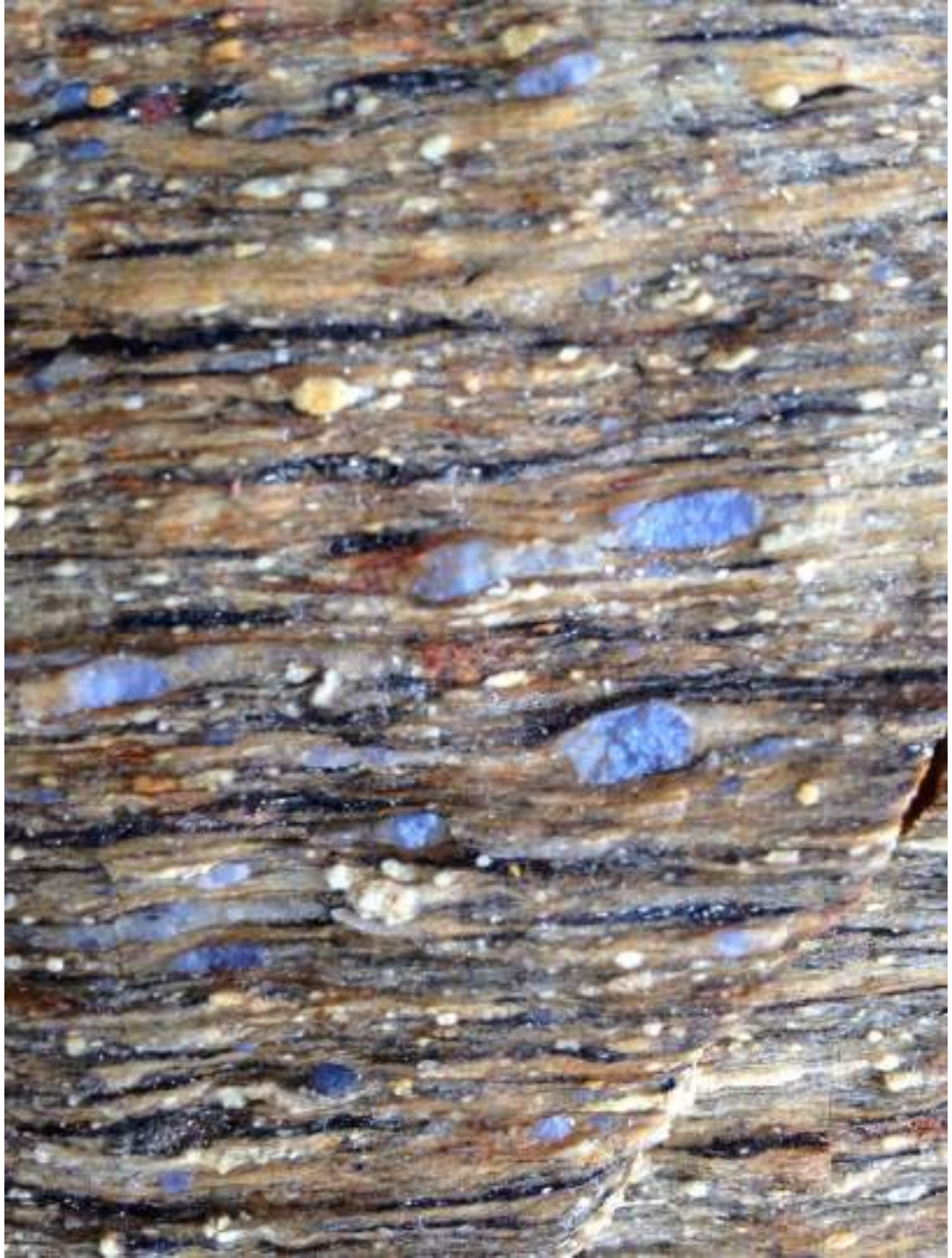
Blenkinsop, T., Oliver, N., Dirks, P., Nugus, M., Tripp, G., & Sanislav, I. (2020). Structural geology applied to the evaluation of hydrothermal gold deposits. In *Reviews in Economic Geology, v.21* (pp. 1–23). https://doi.org/10.5382/rev.21.01



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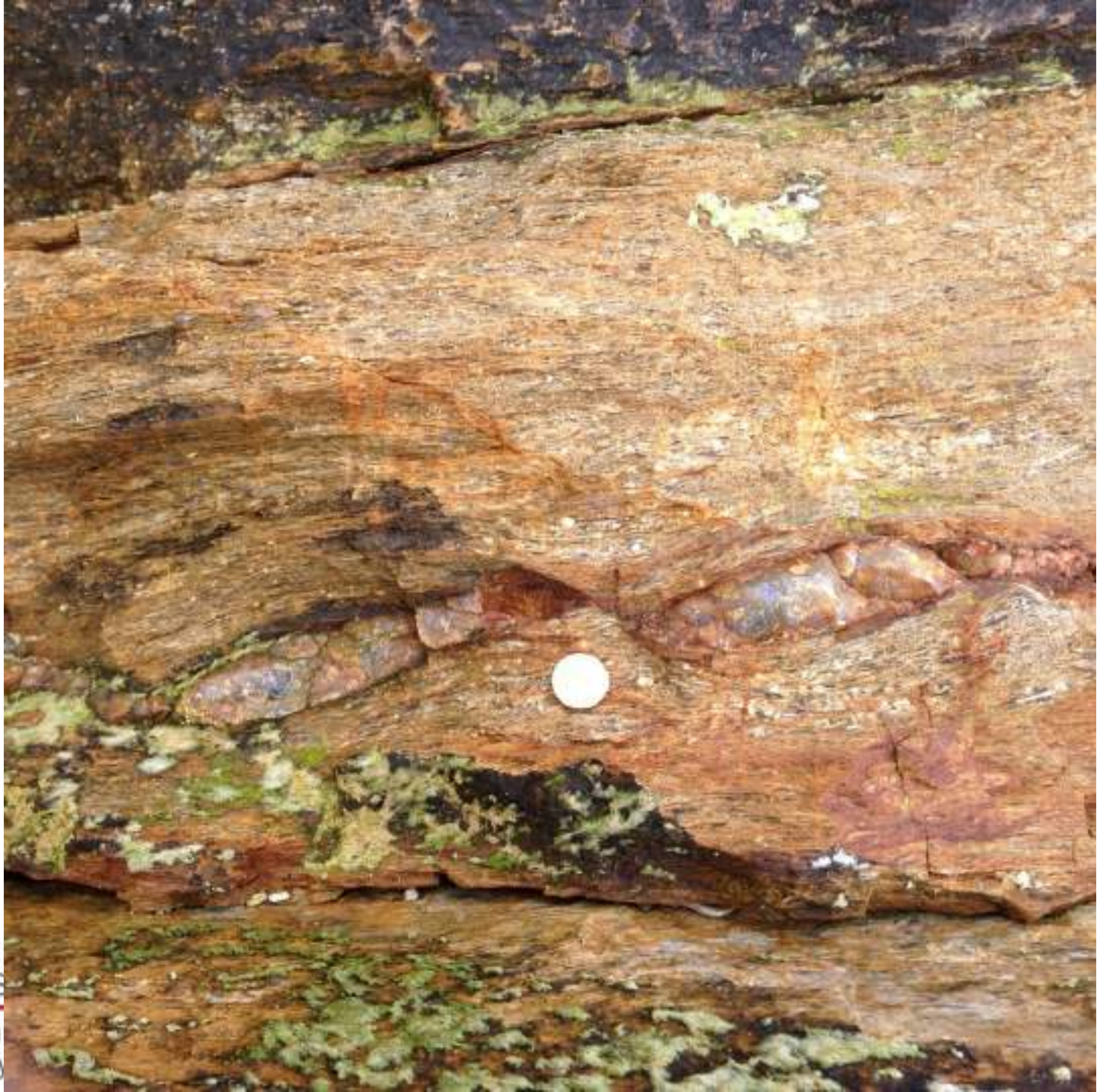

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Summary

- A new understanding of shear zones allows predictions of ore body geometry if the kinematics of the shear zones are known.
- Relations between the vorticity vector, the lineation and the shear directions are critical.
- These can be determined well in core.