GSA and AIG members get registration discount

Fieldtrips / workshops open to all - no need to attend conference

5 DAY FT4 - MACQUARIE; ARC or RIFT? – Blevin and Glen

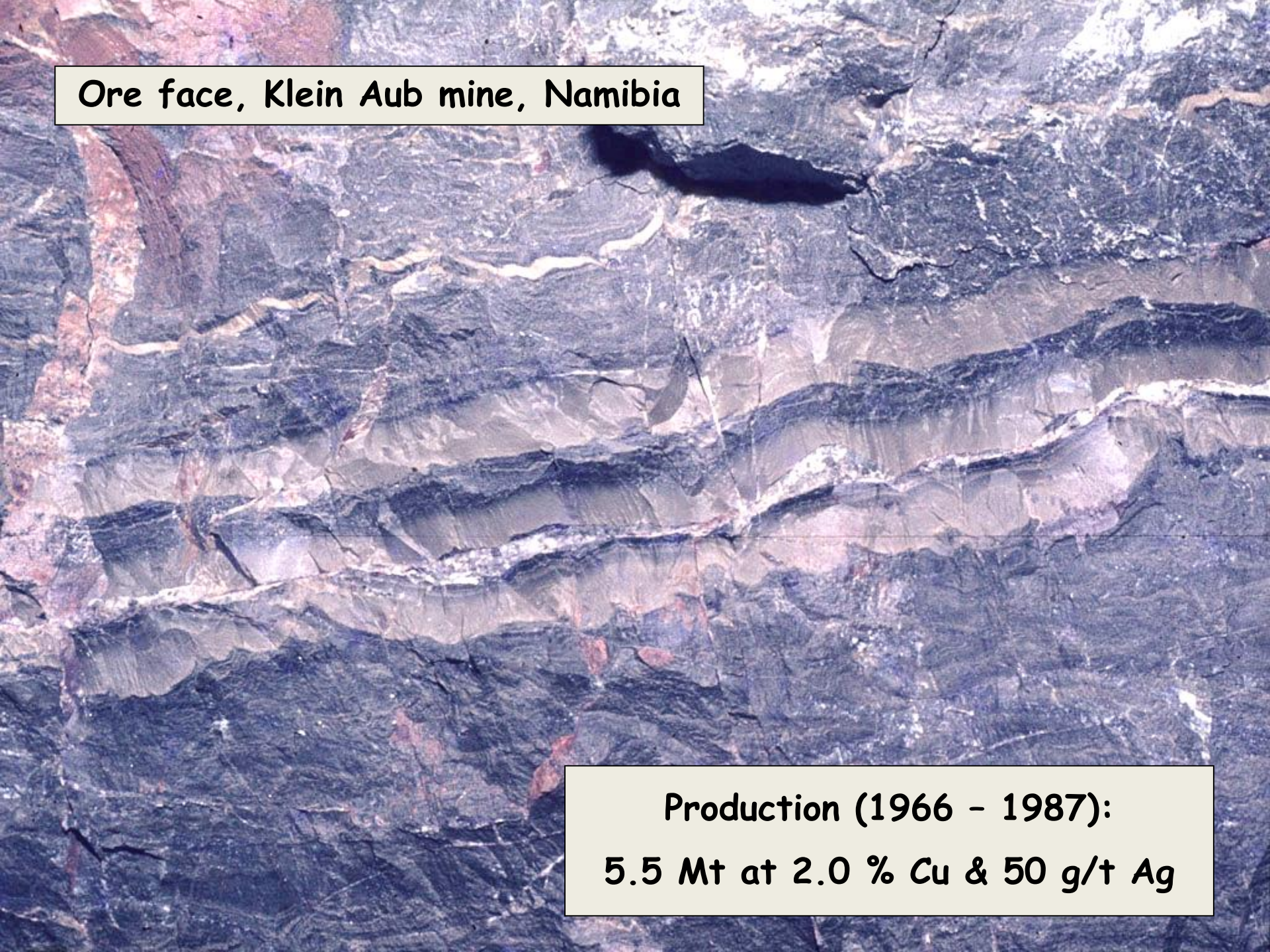
EXPLORATION MODELS -

YOU CAN FLIRT WITH A MODEL ...

… YOU SHOULDN'T MARRY ONE

With thanks to
Aurizon ASRA Mining
for financial support

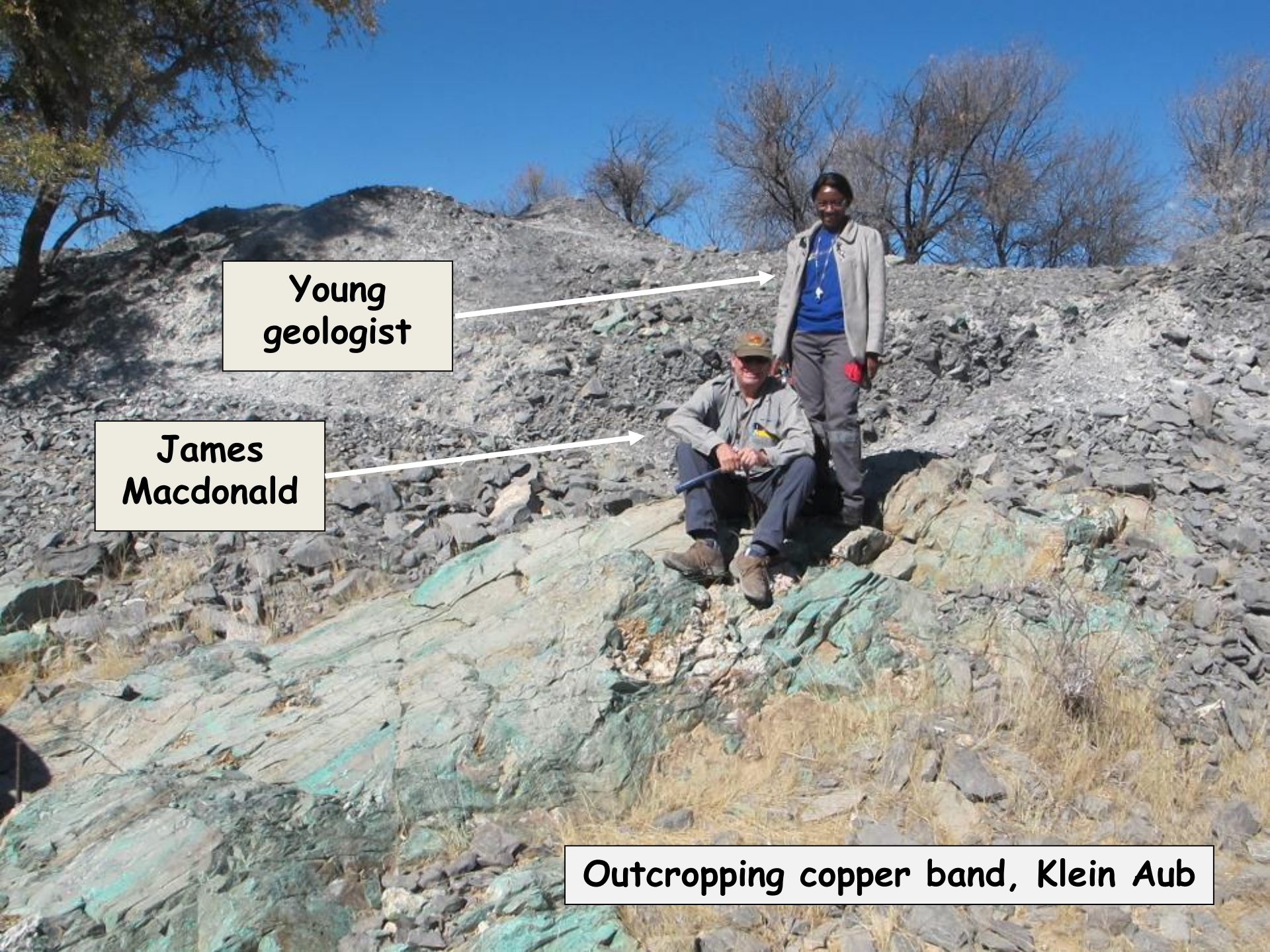
Ken Maiden
SMEDG
28 February 2019

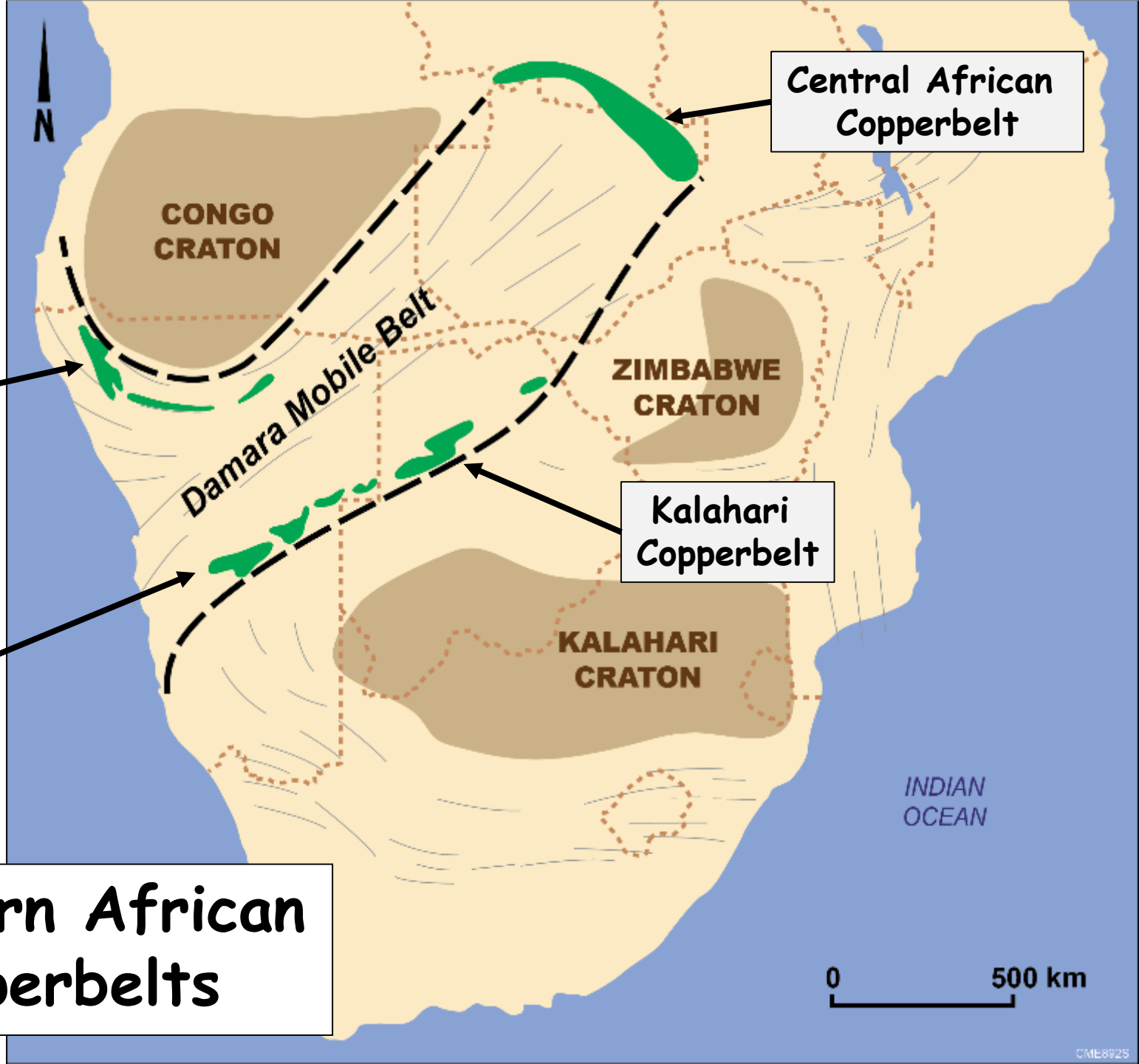


Ore face, Klein Aub mine, Namibia

Production (1966 – 1987):

5.5 Mt at 2.0 % Cu & 50 g/t Ag


Young geologist
James Macdonald
Outcropping copper band, Klein Aub



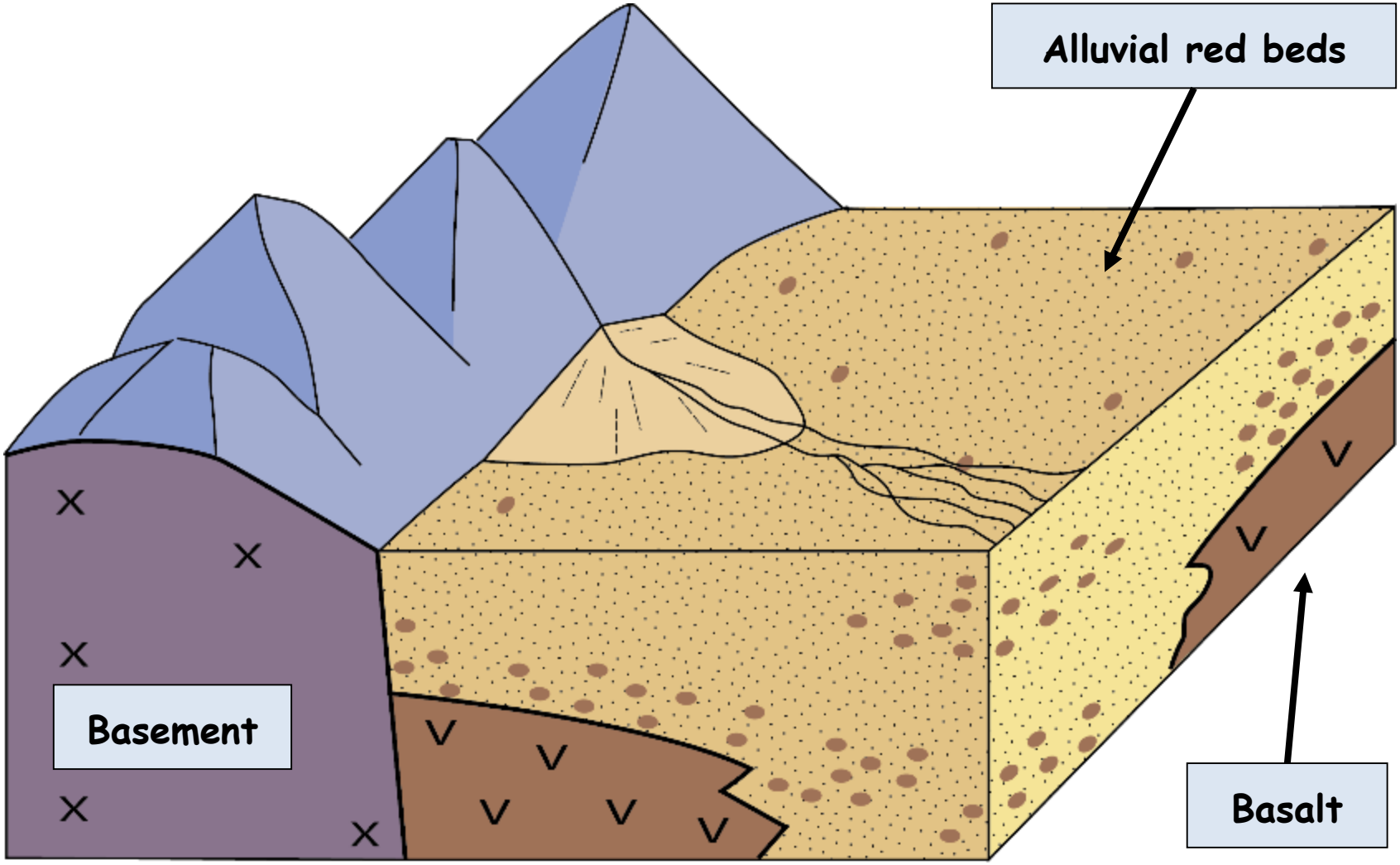
Southern African Copperbelts


Garry Baglin getting excited
Kojeka prospect
Kalahari Copperbelt
Central Namibia

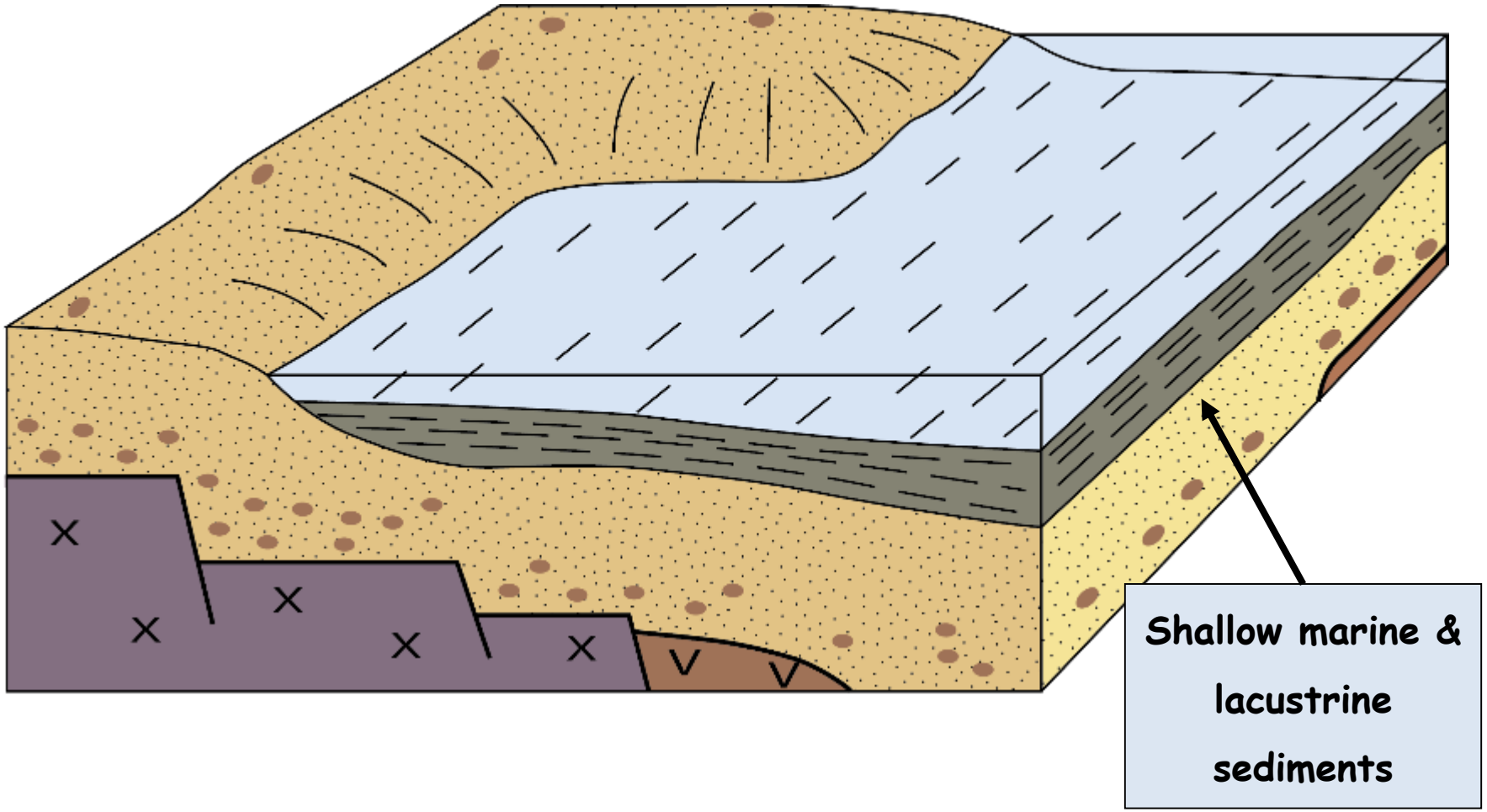

Bob Ilchik getting excited


Copper-bearing phyllite

Kalahari Belt Evolution, Stage 1 - Rifting



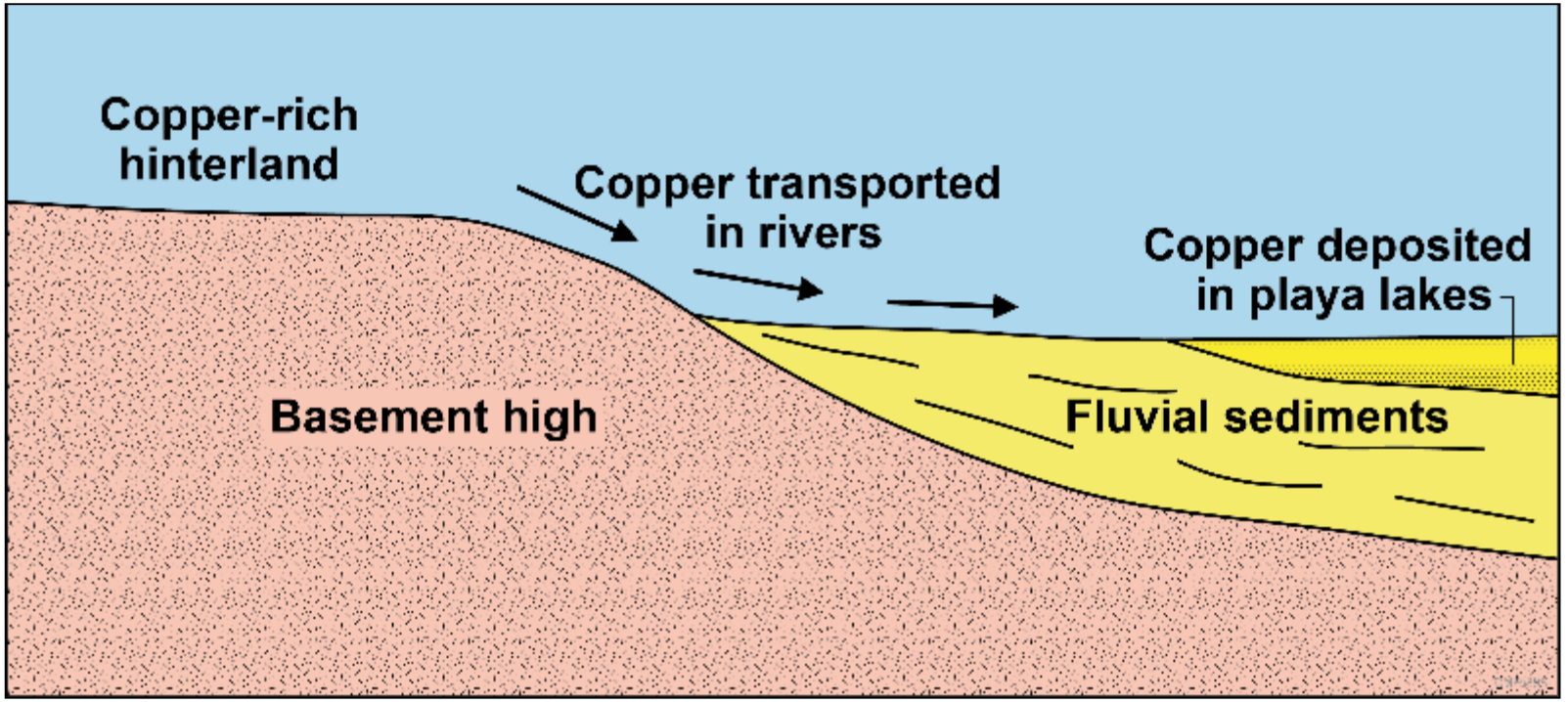
Evolution, Stage 2 – Basin Subsidence



Klein Aub Deposit - Observations

1. Adjacent to a basement high
2. Stratigraphy -
    - Basalt & red beds (conglomerate & quartzite)
    - Overlain by pyritic quartzite & black slate
3. Copper concentrated in black slate bands
4. Elevated copper over many kilometres of strike

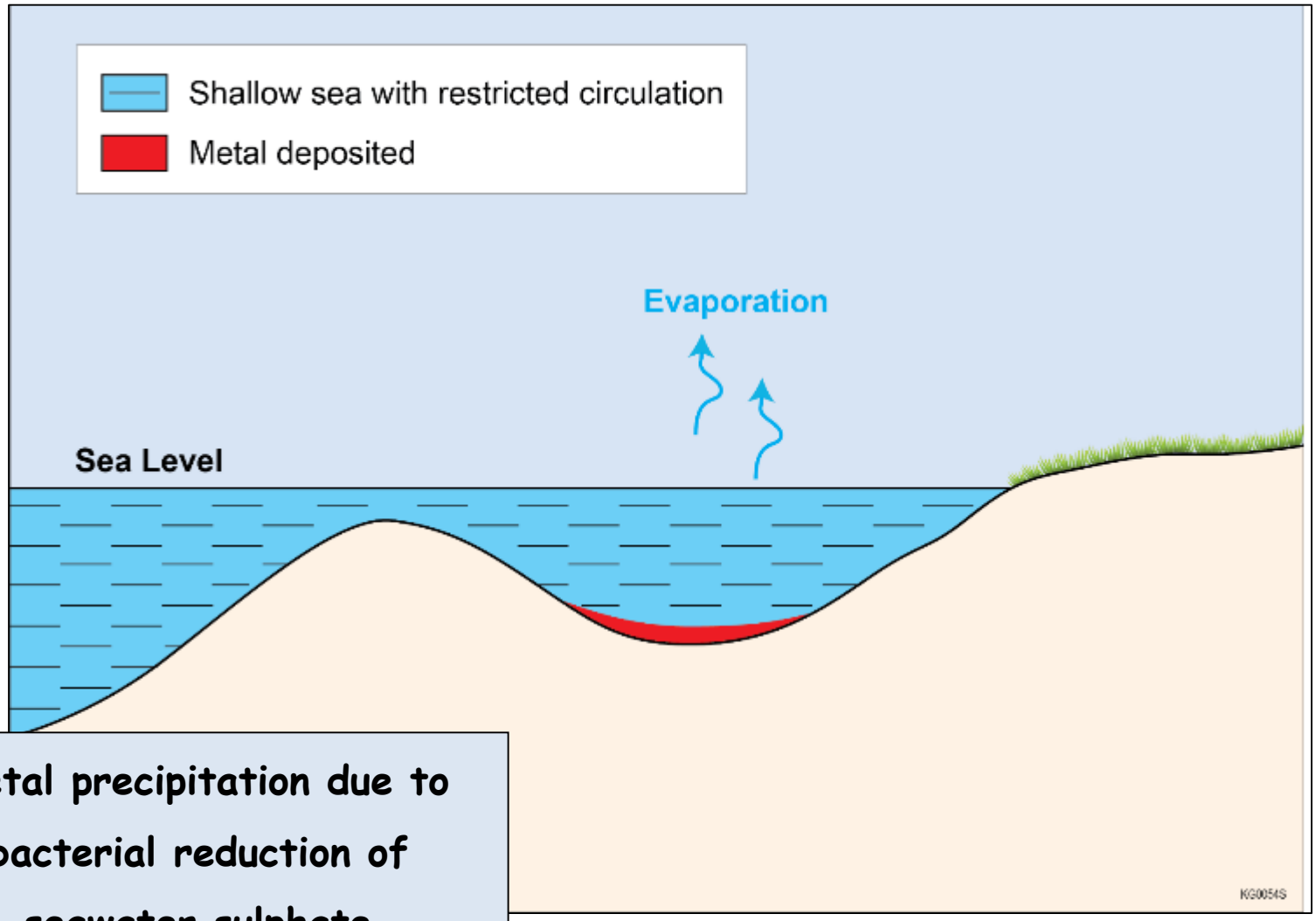
Klein Aub – Syngenetic Model (1981)



1. Copper leached from hinterland
2. Transported by streams
3. Deposited in reducing environments in playa lakes

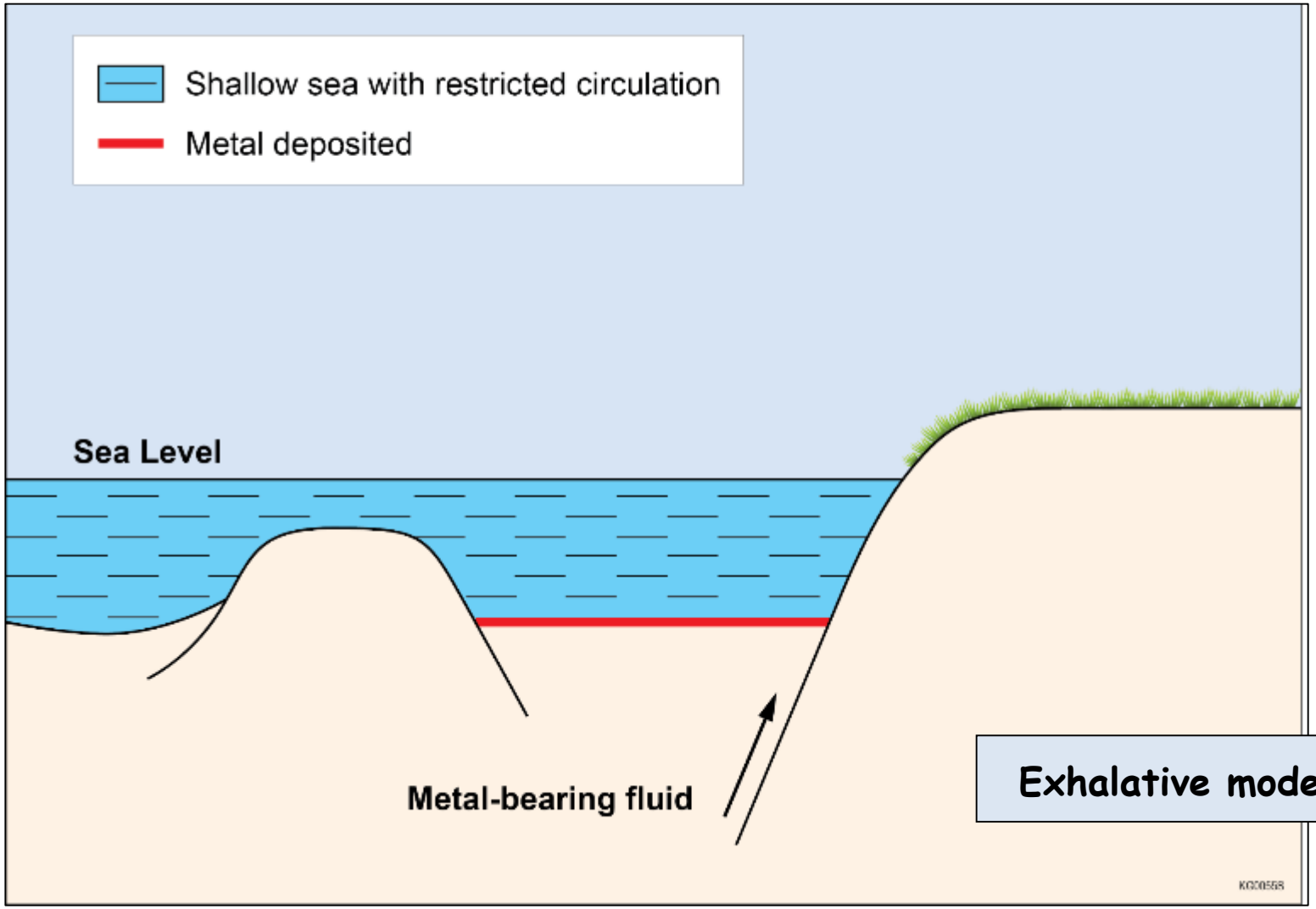
This is basically the model developed for the Zambian Copperbelt in the 1960s

Syngenetic Model - Variations



Metal precipitation due to bacterial reduction of seawater sulphate

Syngenetic Model - Variations

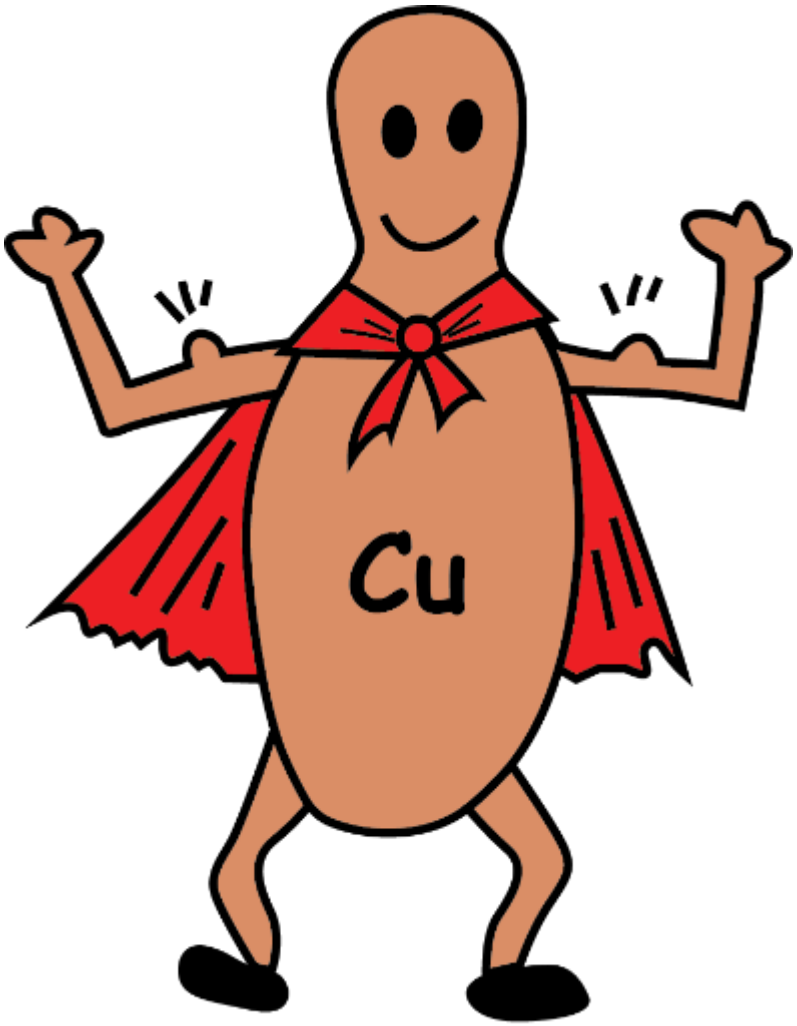


Mangula Copper Paint

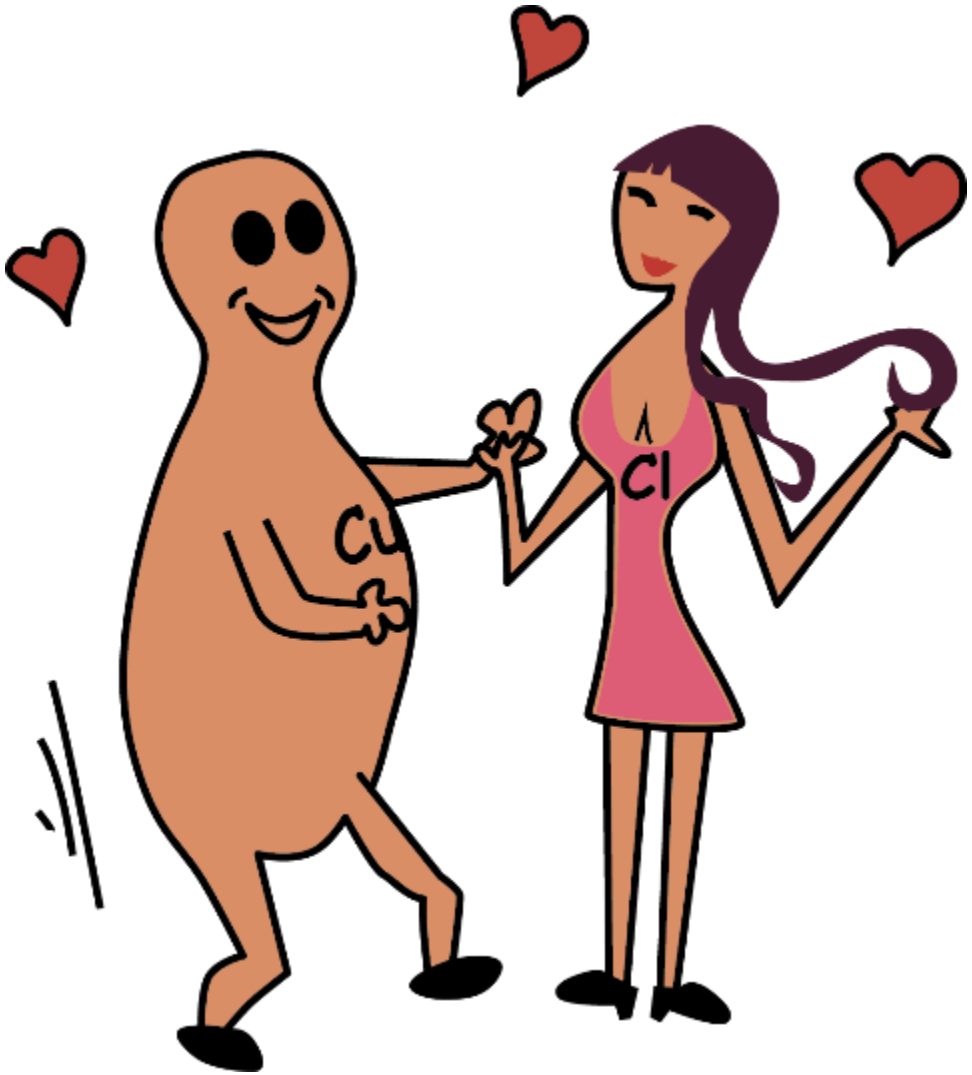
H_2S reduces molybdate (Mo^{4+}) to molybdenum blue (Mo^{3+} or Mo^{2+})

Chalcocite in silt & fine sand bands

NOT in fine-grained (clay) bands



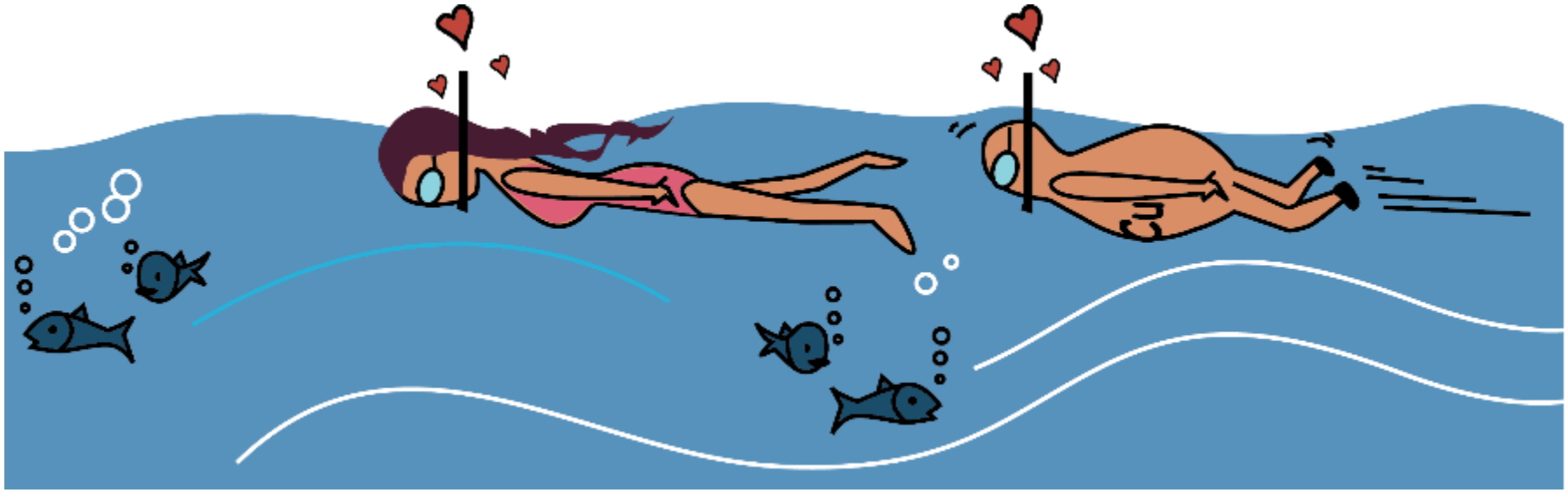
Hi ! My name is Cupric. I am a Copper Ion



I love

Chlorina - &

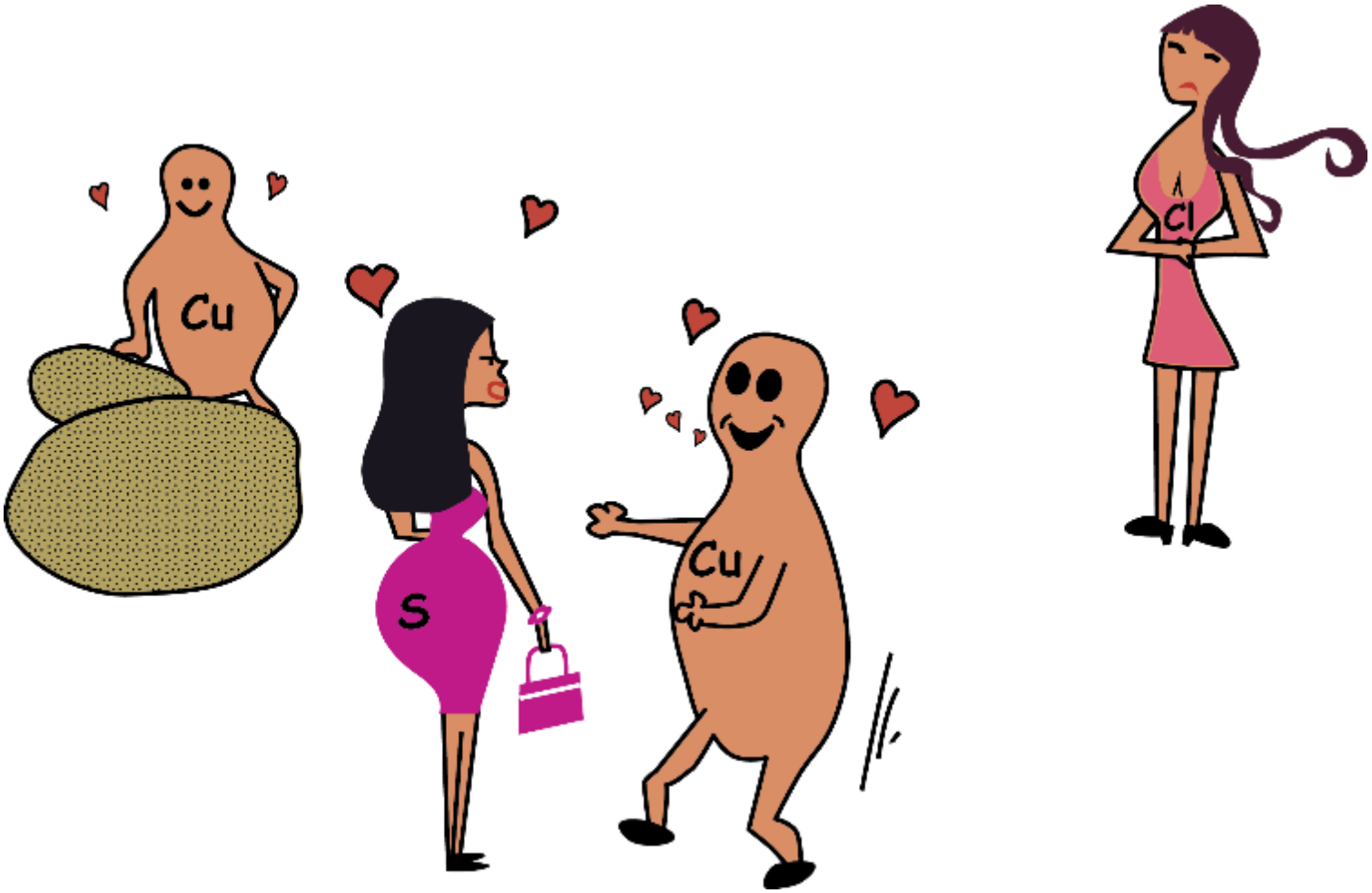
she loves me



Chlorina & I hang out together

(It's a complex relationship)

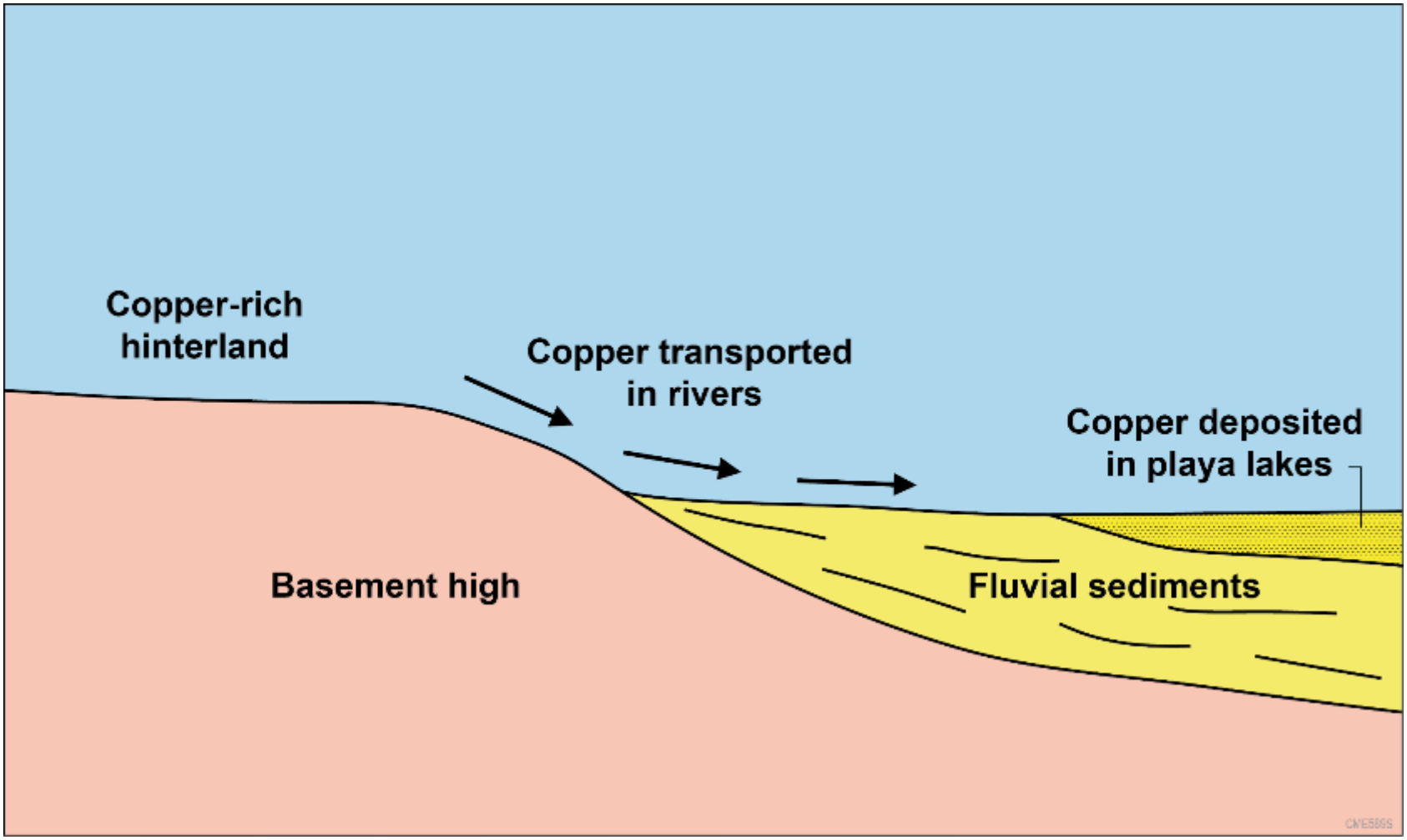
But then Sulphura comes on the scene



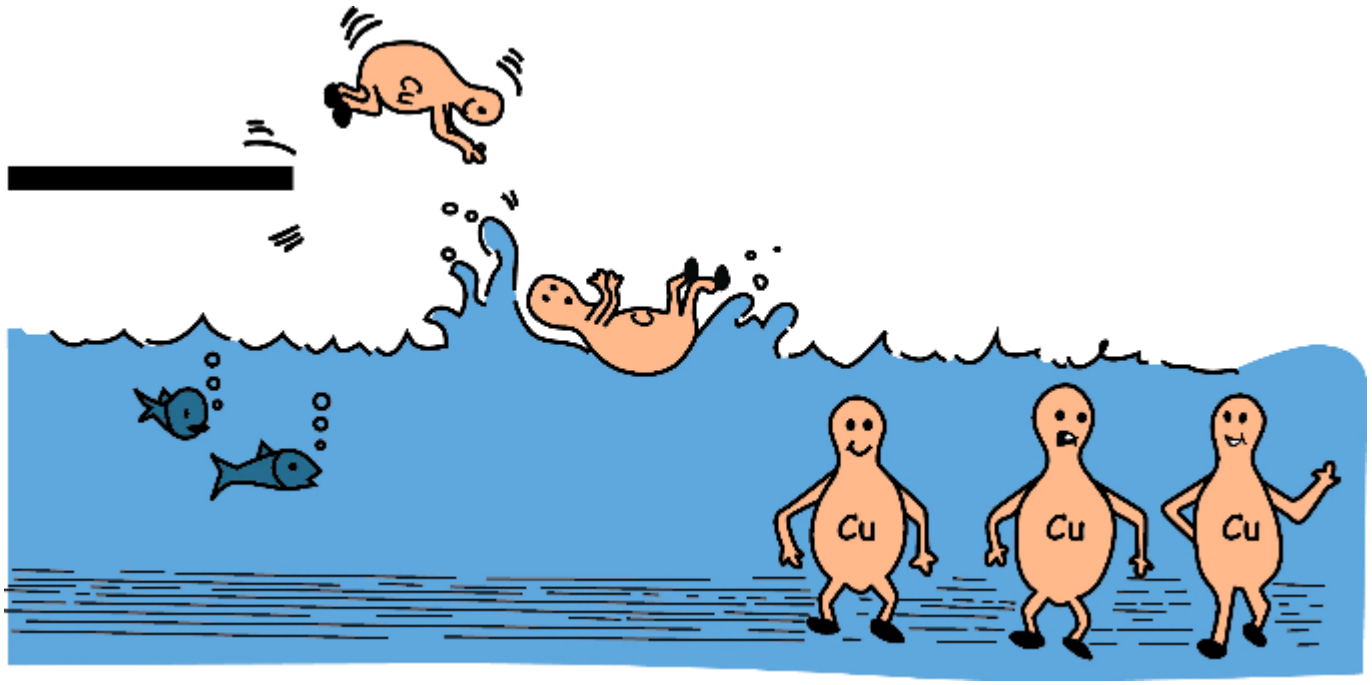
We settle down together …

… and live happily ever after (until a greedy mining company digs us up)

Syngenetic Model

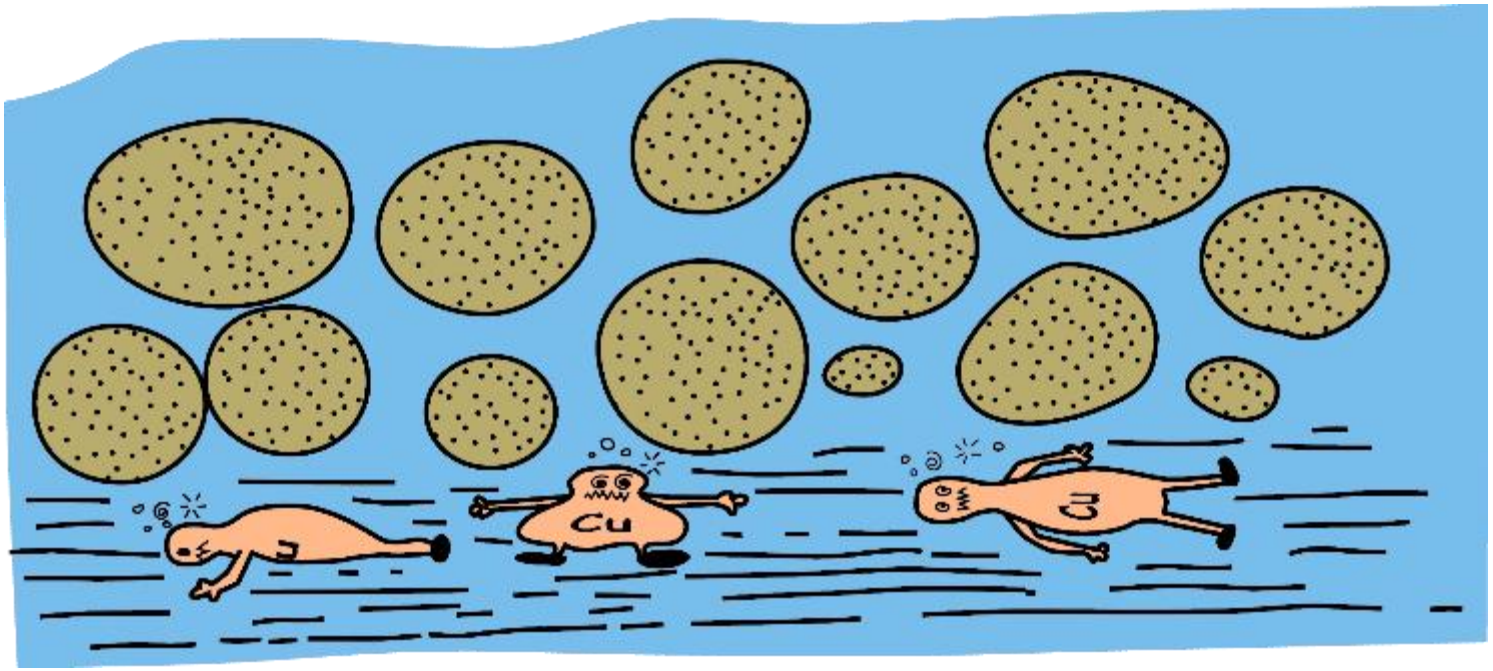


Syngenetic Model - Deposition

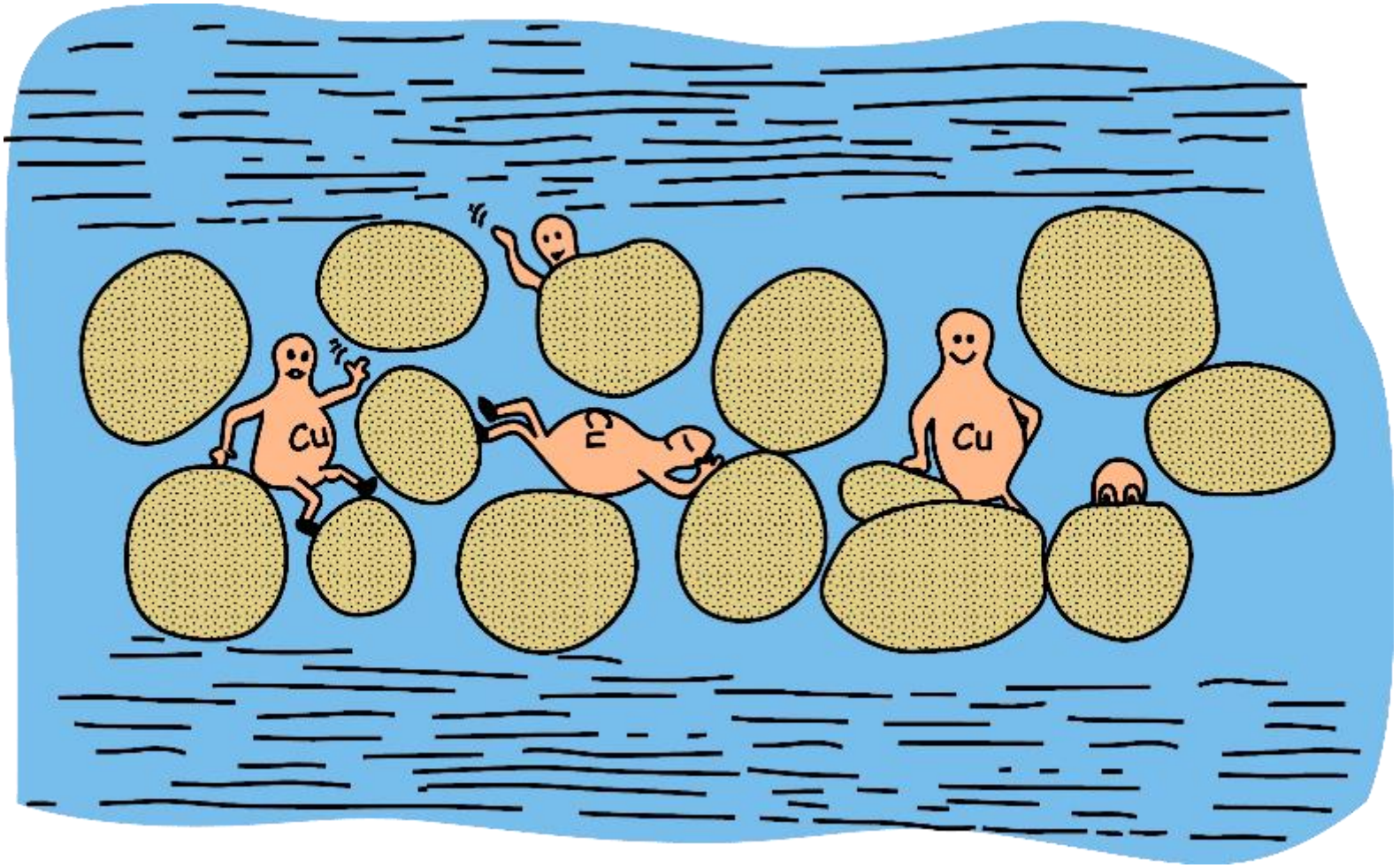


(I should show them holding hands with sulphura)

Syngenetic Model - Compaction



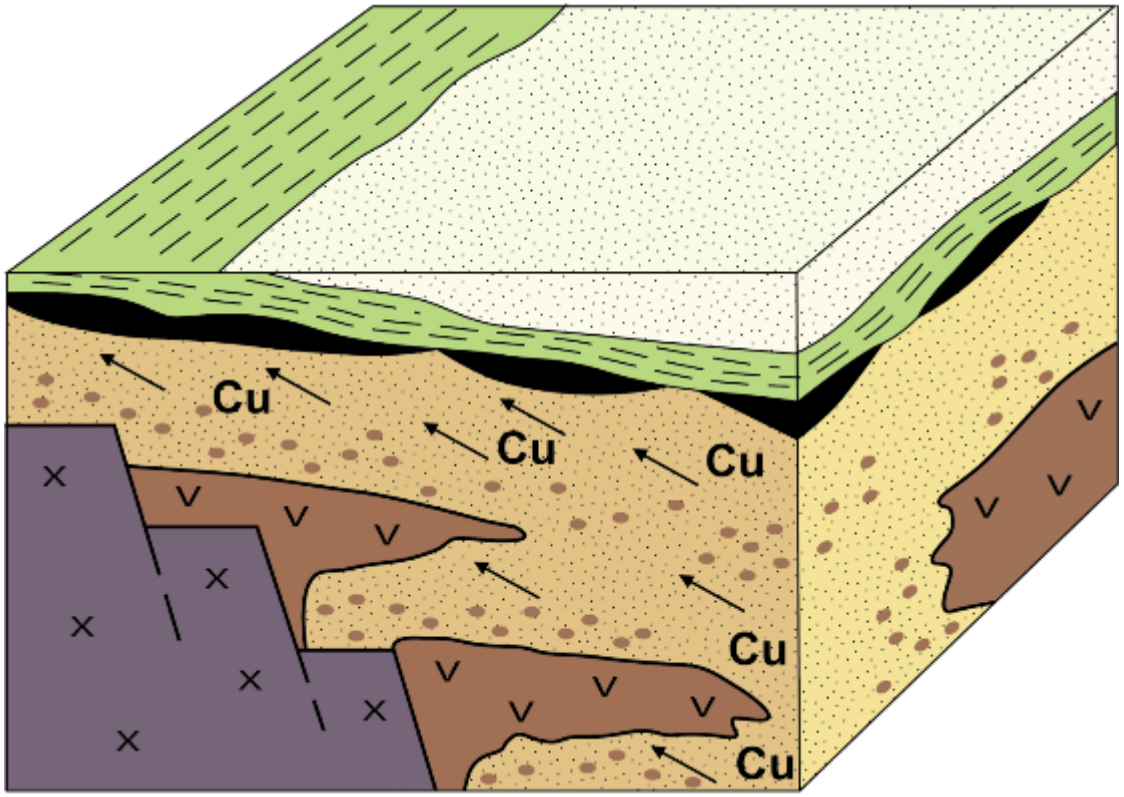
Copper should be in fine-grained bands …



It's not. In detail, copper sulphides are in silty & sandy bands

→ Permeability control

Diagenetic Model - Basin Compaction



- Copper leached from basalt & red beds
- Driven towards basin margins
- Precipitates in sulphur-bearing reduced strata

Syngenetic vs Diagenetic Models

Does this make a difference to the exploration approach?

NOT MUCH -

- **Onlap onto basement high**
- **Reduced strata above red beds**
- **Mapping & geochemistry to locate copper-bearing zones**
- **I.P. lines over geochem anomalies**
- **Drill to intersect copper beds down dip**

Exploration Planning

We need to define the target concept

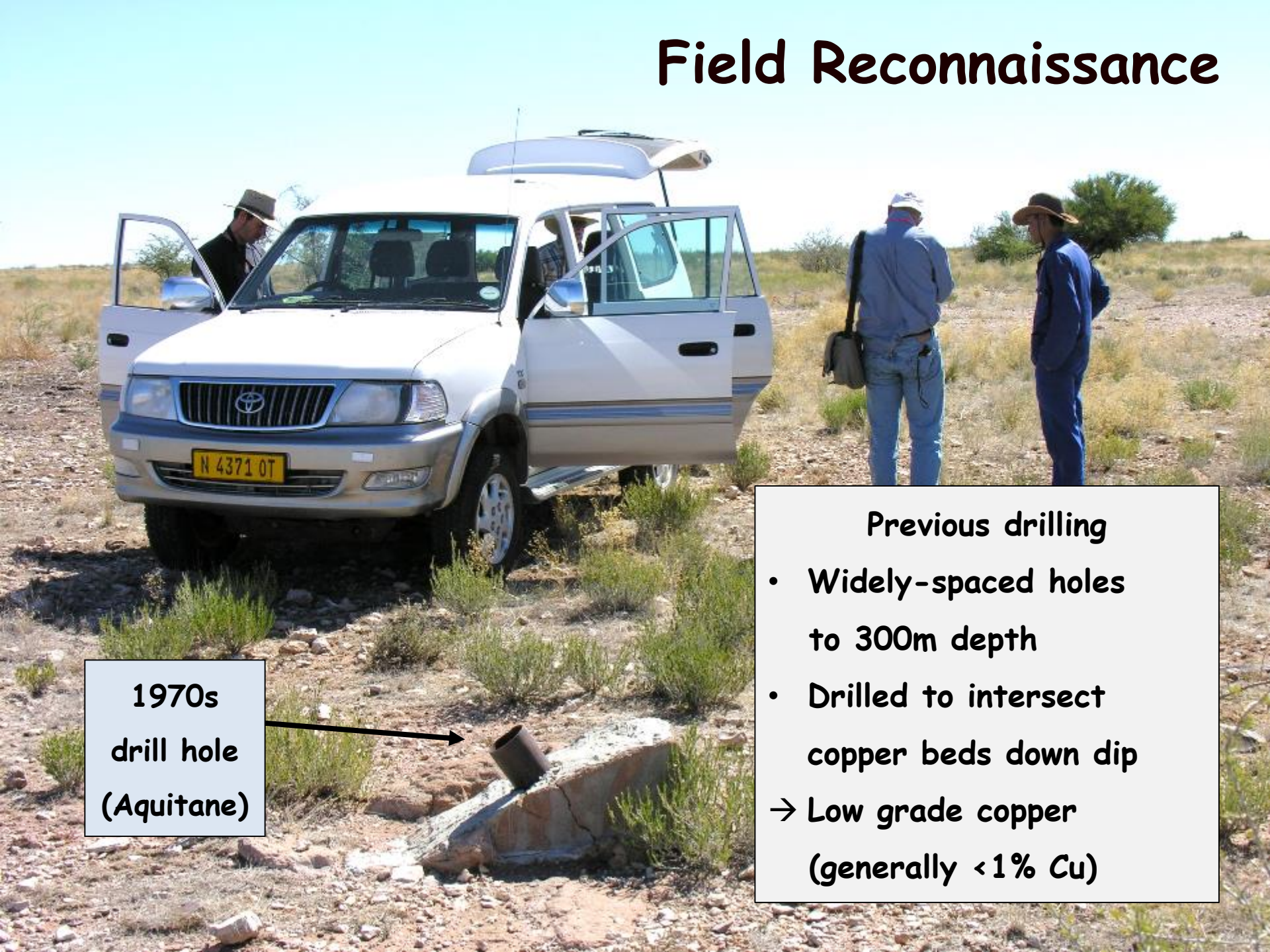
We need to convince the Board

We need an Exploration Permit

We need a program and a budget

And we need a team

Field Reconnaissance

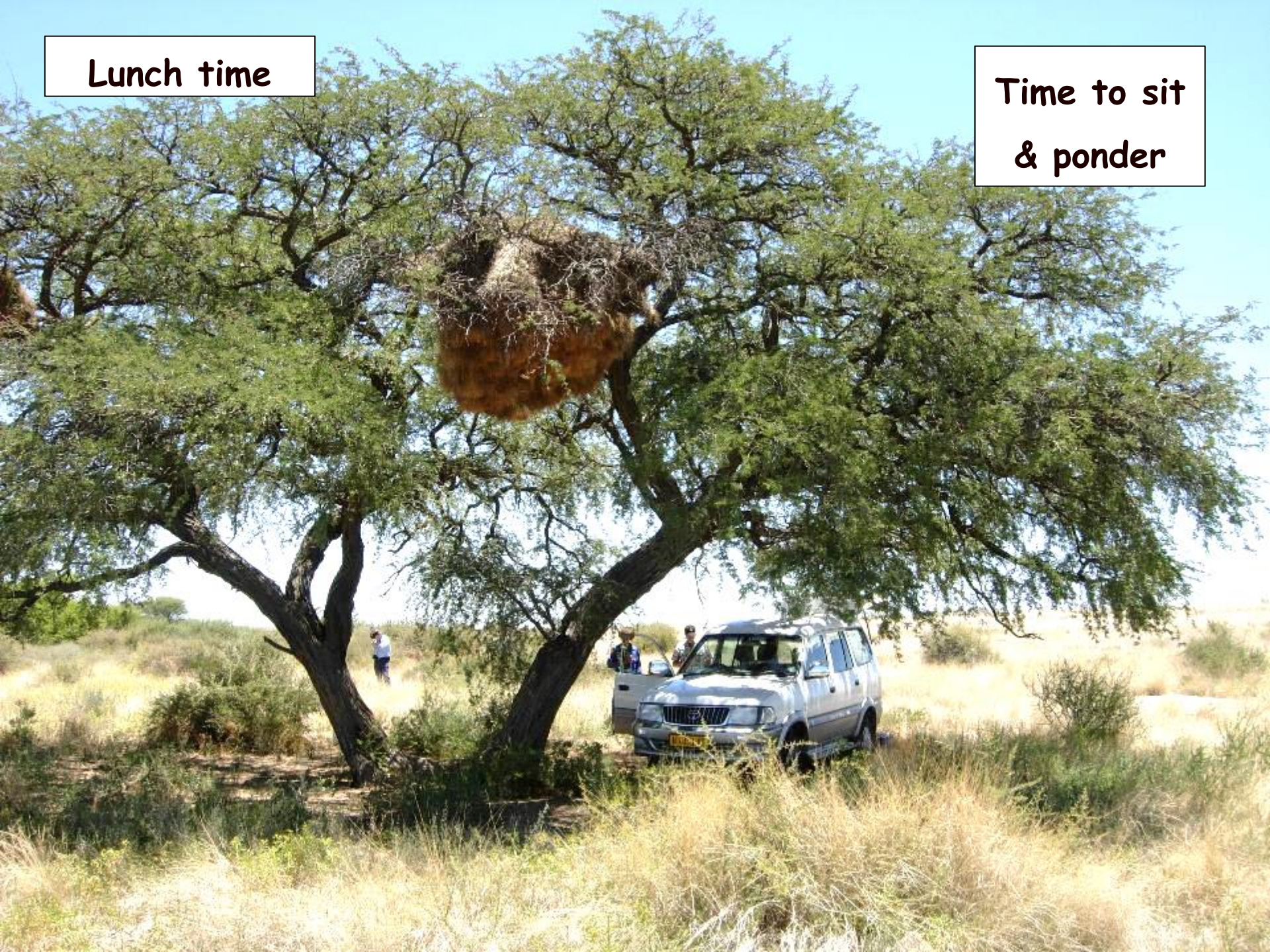


1970s drill hole (Aquitane)

Previous drilling

- Widely-spaced holes to 300m depth
- Drilled to intersect copper beds down dip

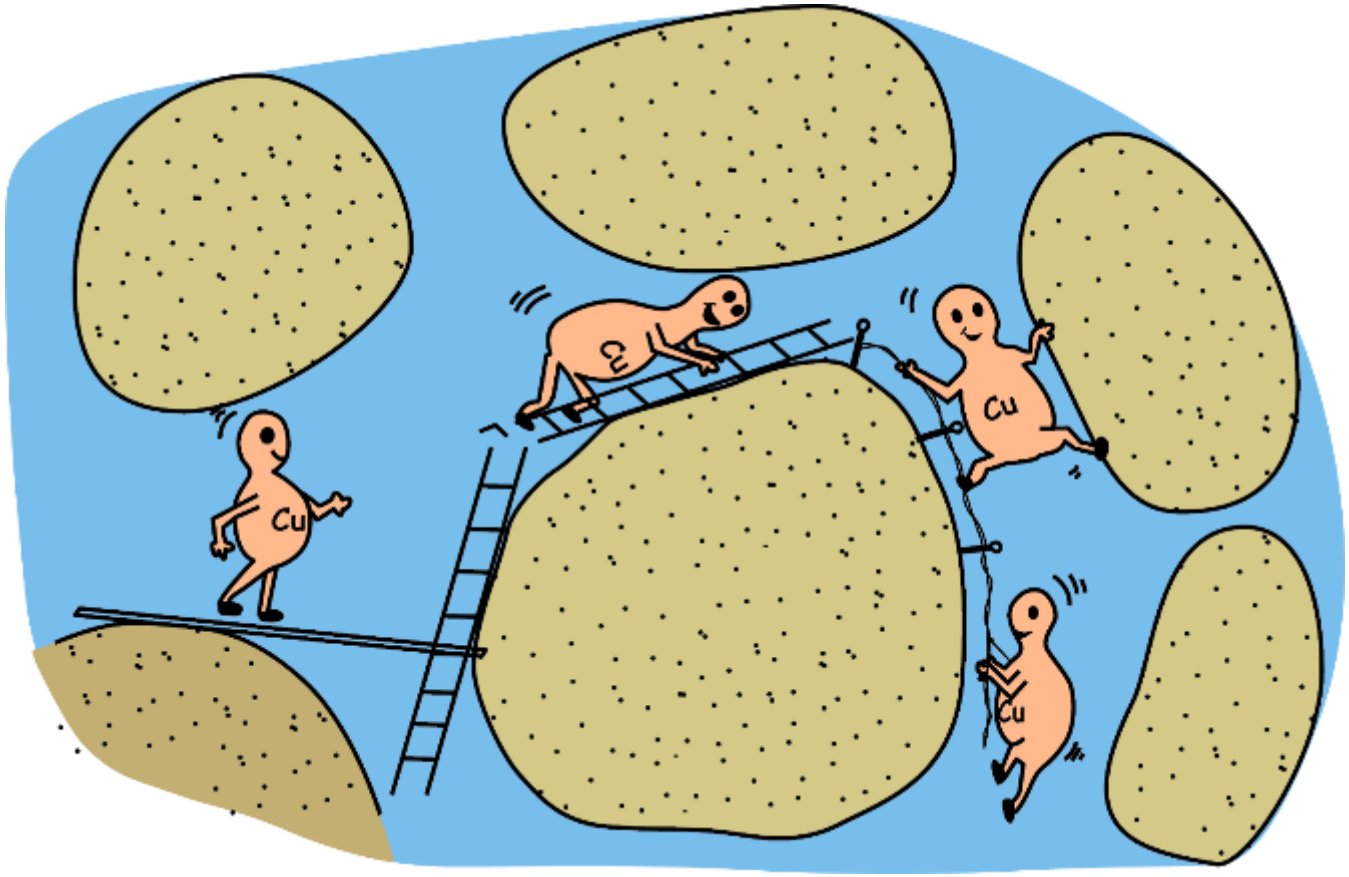
→ Low grade copper (generally <1% Cu)


Lunch time
Time to sit & ponder

Sitting & pondering

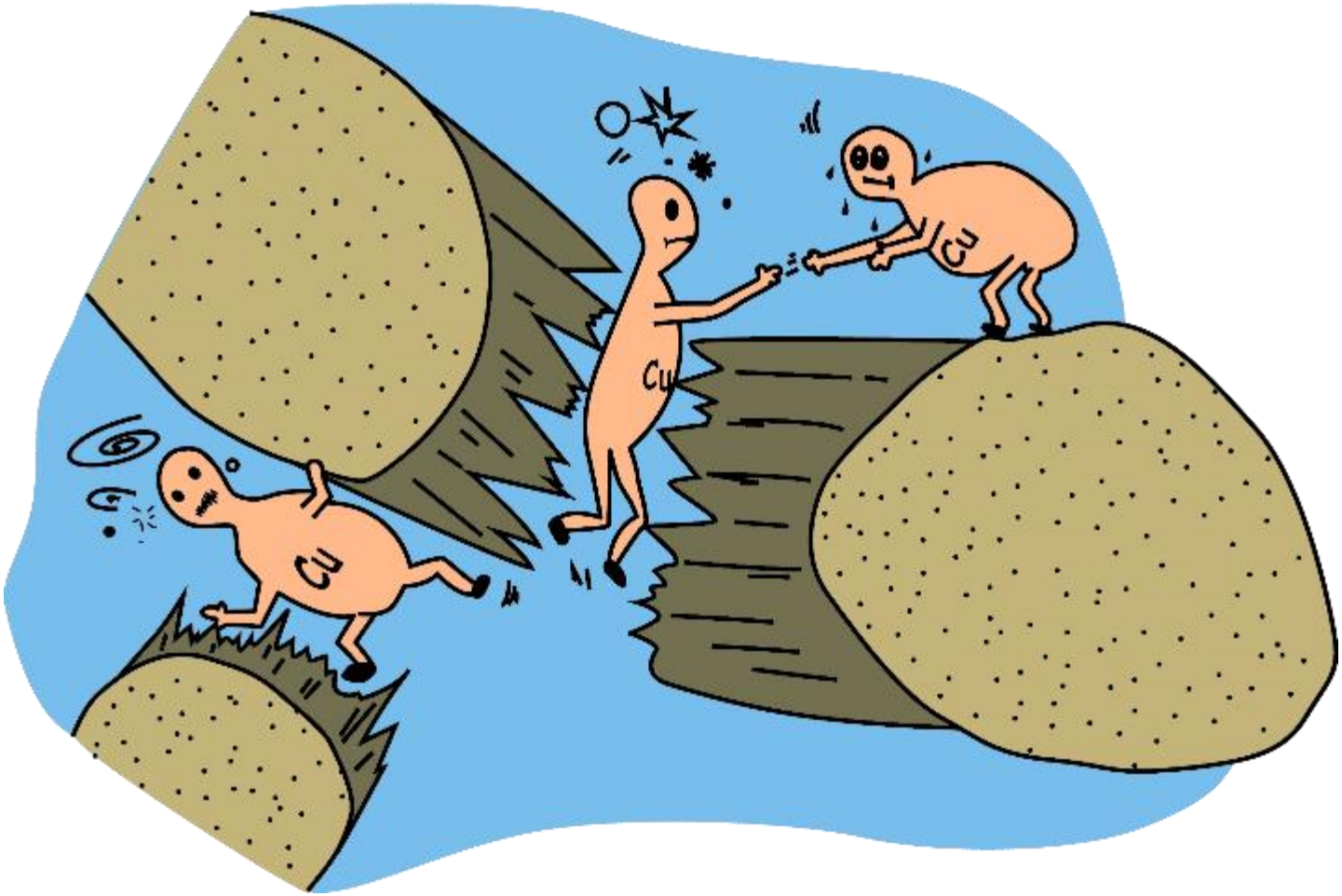
Was copper introduced much later, after lithification of host rocks ?

Diagenetic Models - Unconsolidated Sediment

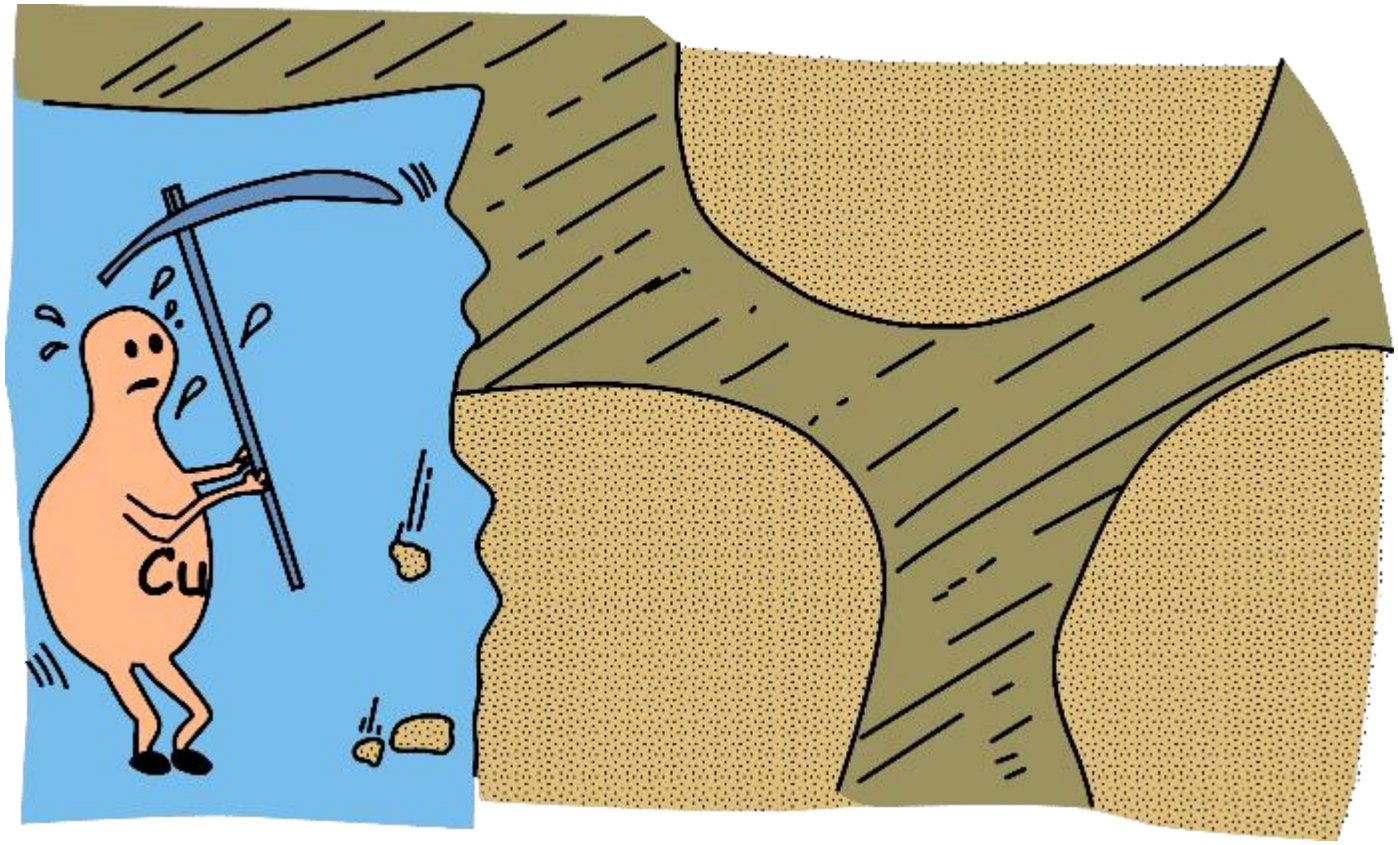


Fluid moves freely

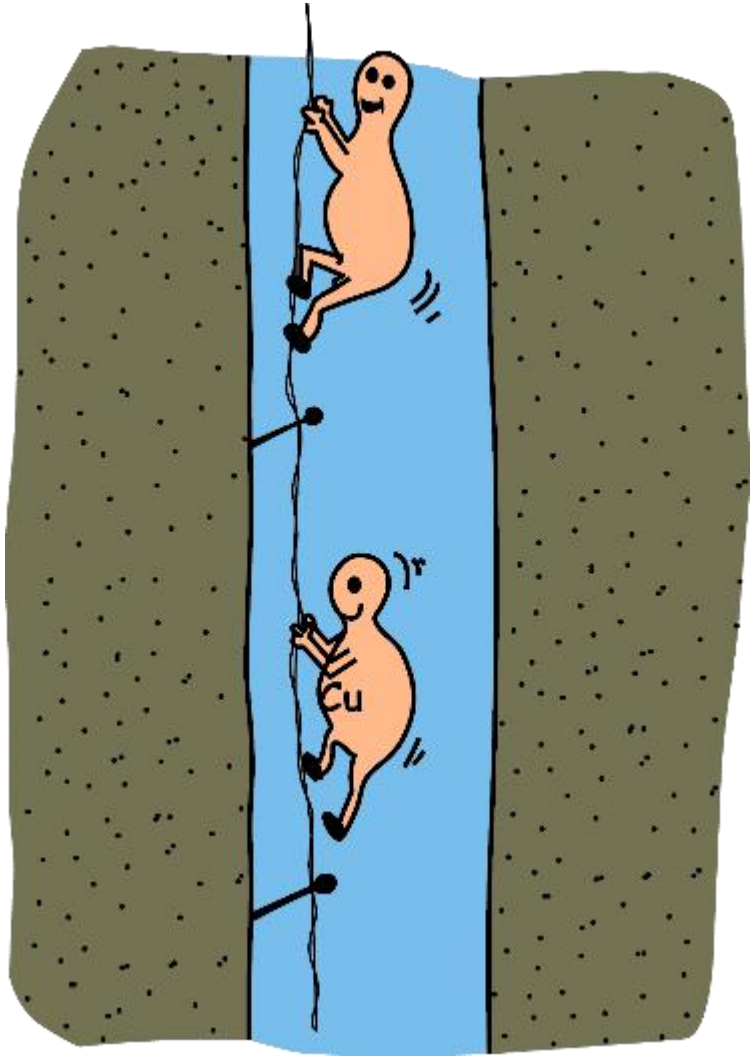
Partly Consolidated Sediment

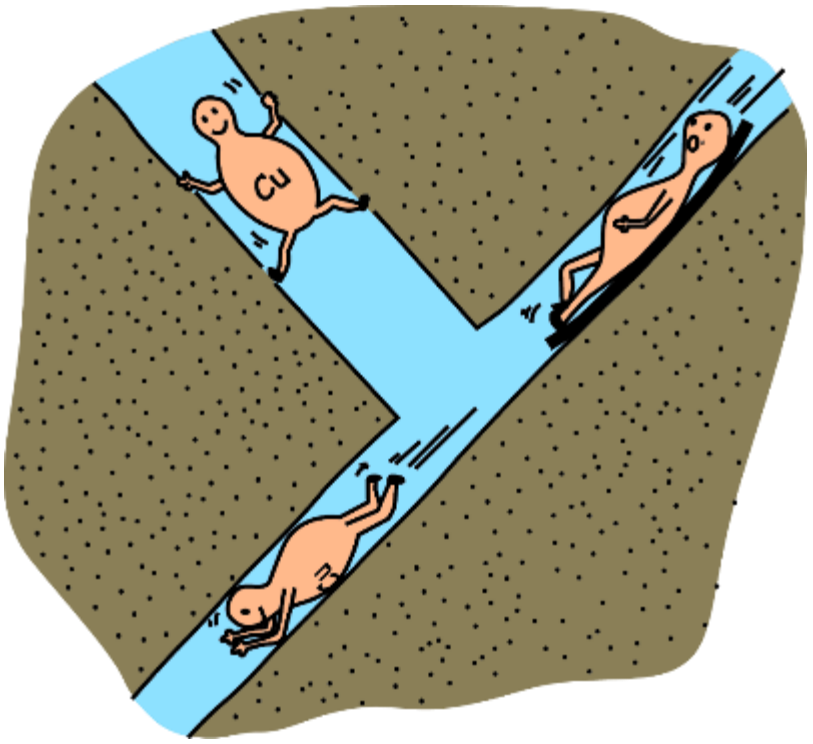


Consolidated Sediment

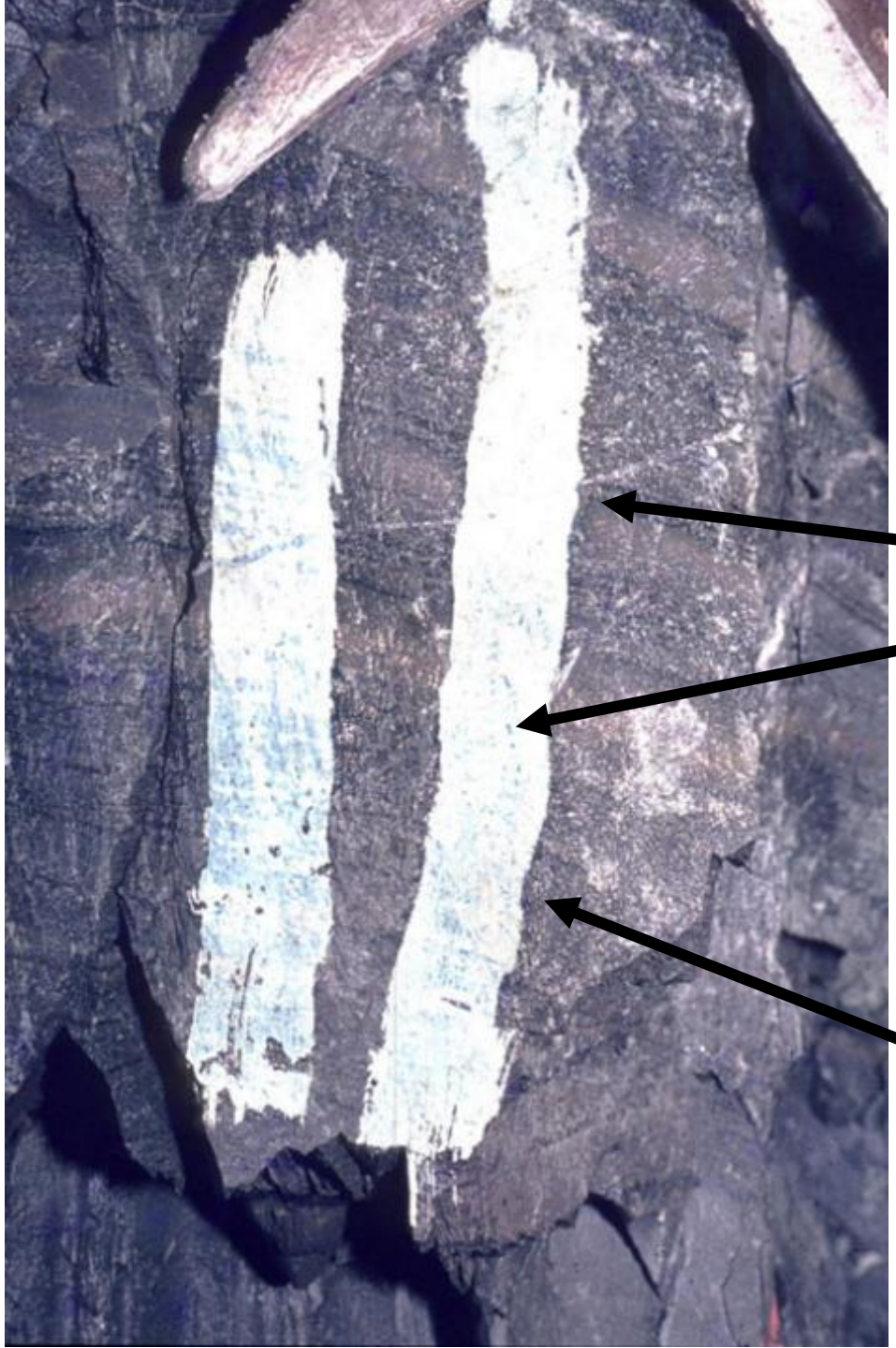


No fluid movement through consolidated rocks …





… except where openings exist or are created



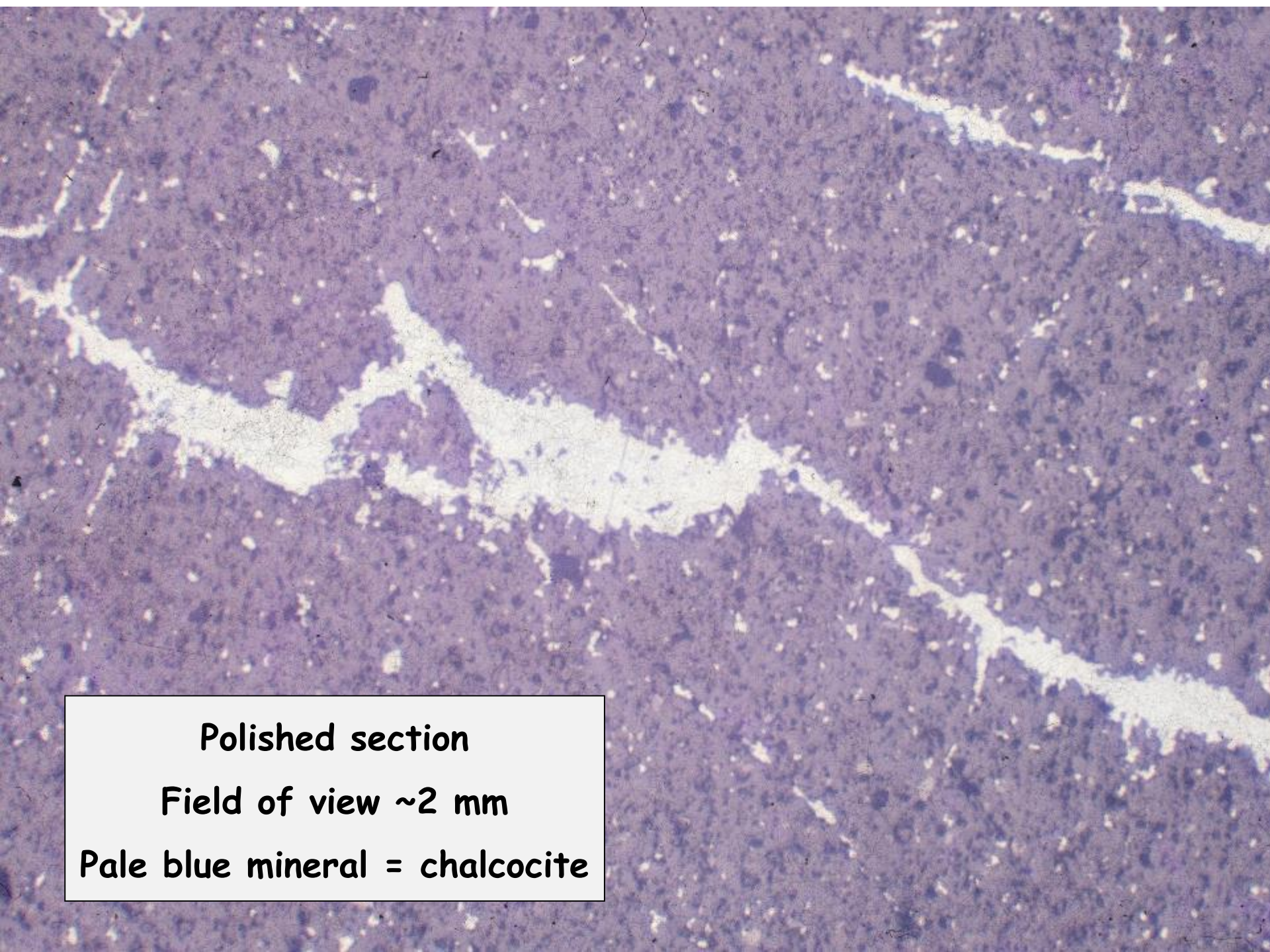
Ore Face, Klein Aub Mine

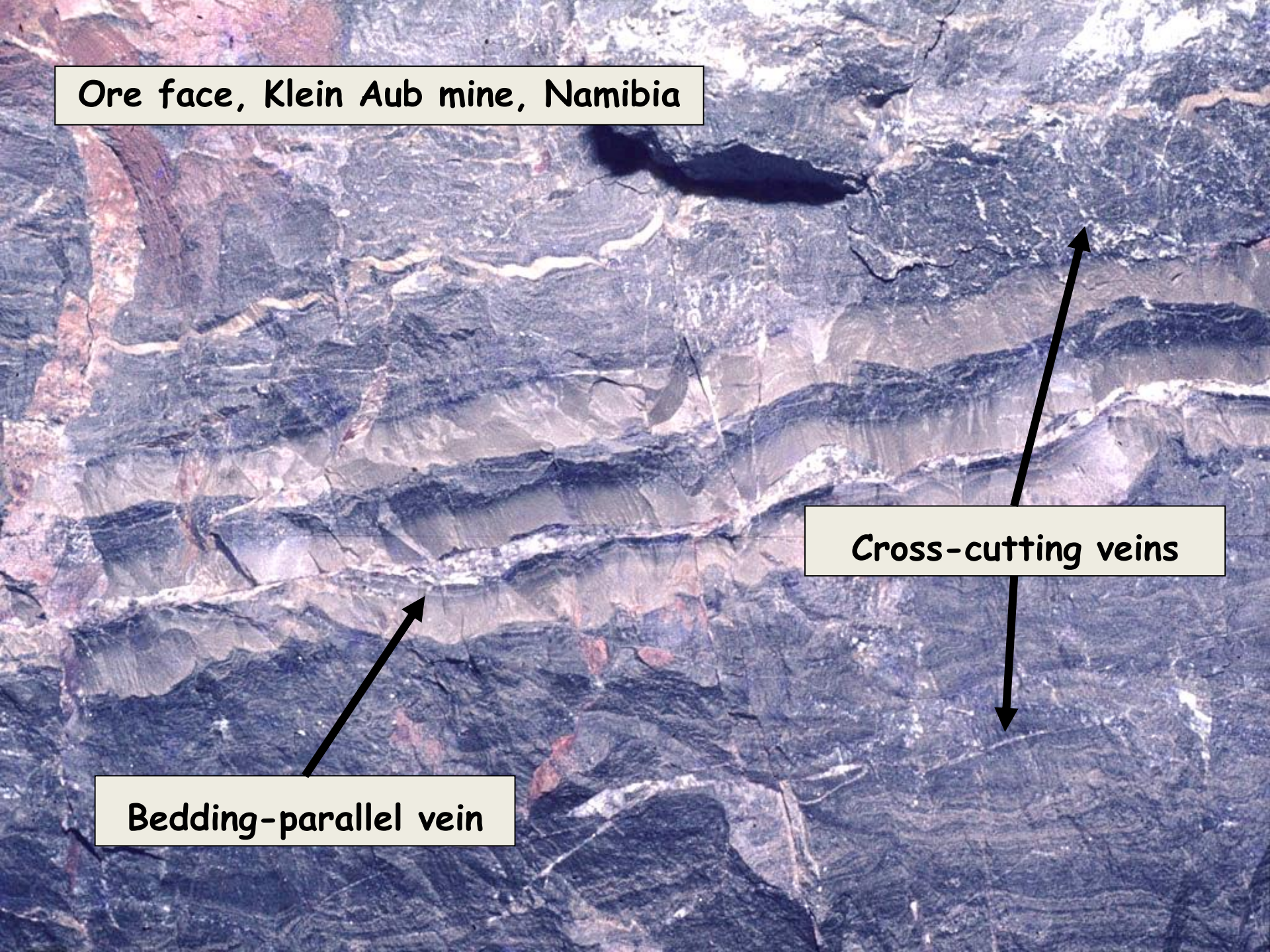
Chalcocite in veins & brittle fractures cutting across cleavage

Chalcocite in silt & fine sand laminae

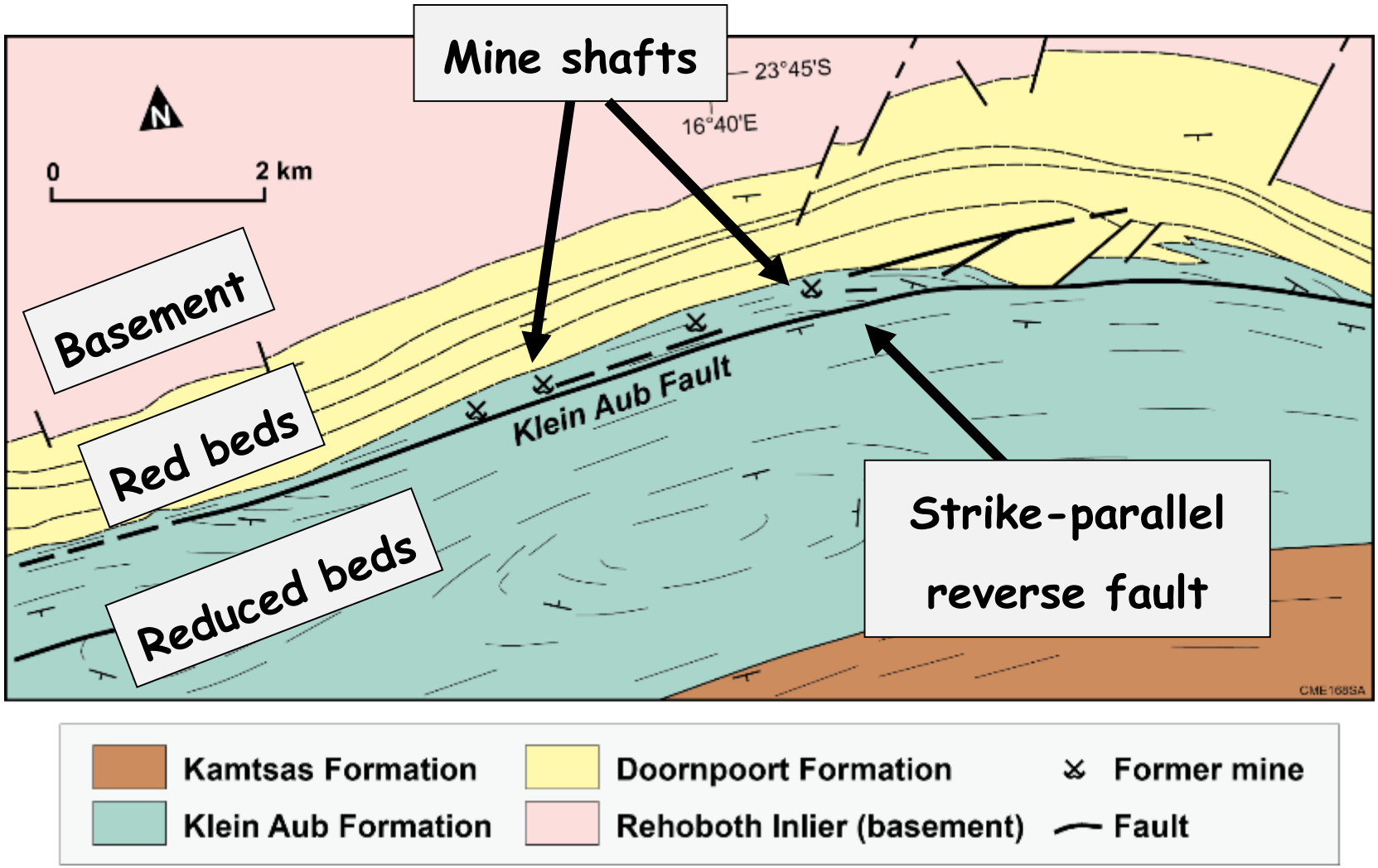
Polished slab of ore
Field of view ~12 cm
Chalcocite in fracture fillings & quartz veins

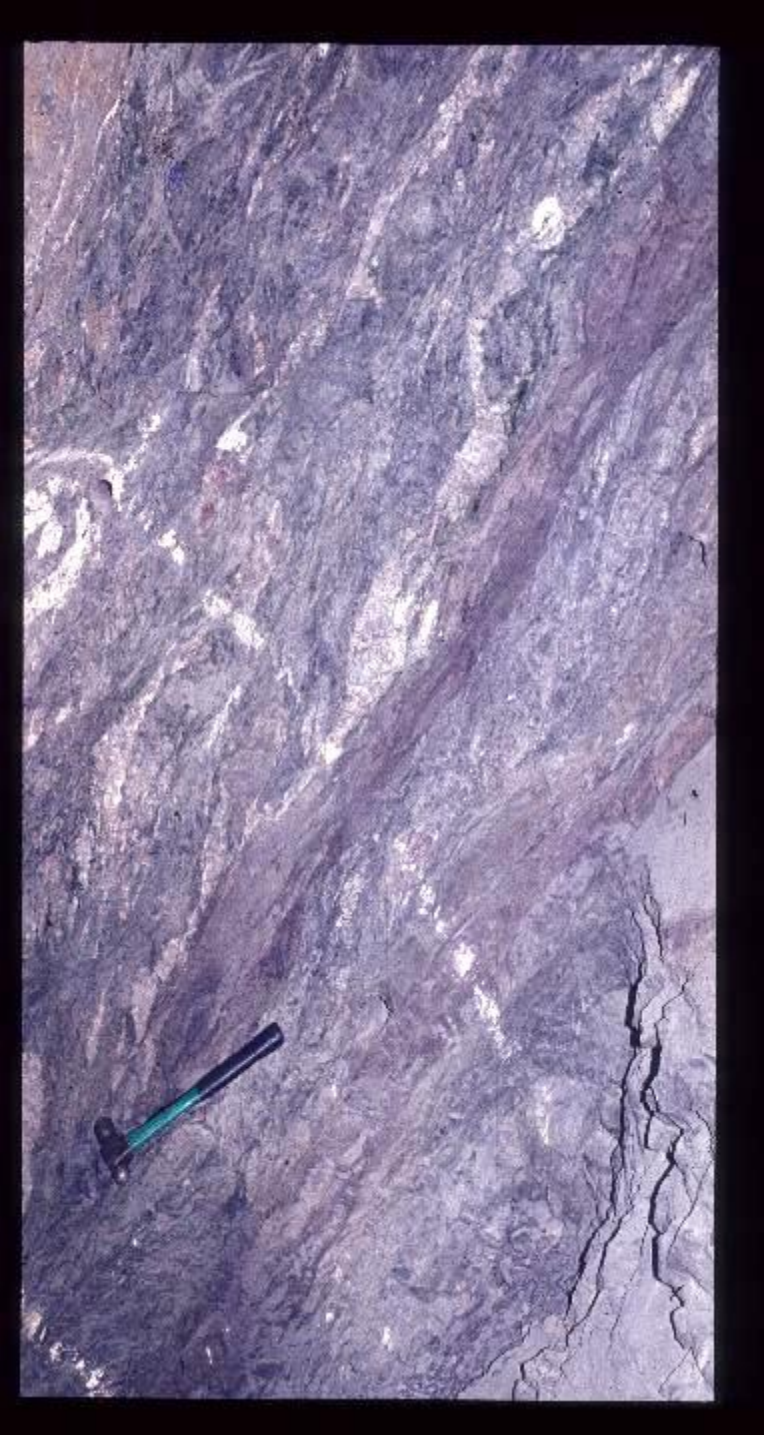
More than 50% of the copper is in structures which cut across bedding


Polished section
Field of view ~2 mm
Pale blue mineral = chalcocite


Ore face, Klein Aub mine, Namibia
Cross-cutting veins
Bedding-parallel vein

Geological Map, Klein Aub (Handley, 1965)





Structural History

D_1 Syn-sedimentary extension

D_2 compression (Damaran) ~ 530 Ma

→ Large-scale folds, regional cleavage

D_3 transpression (late-Damaran)

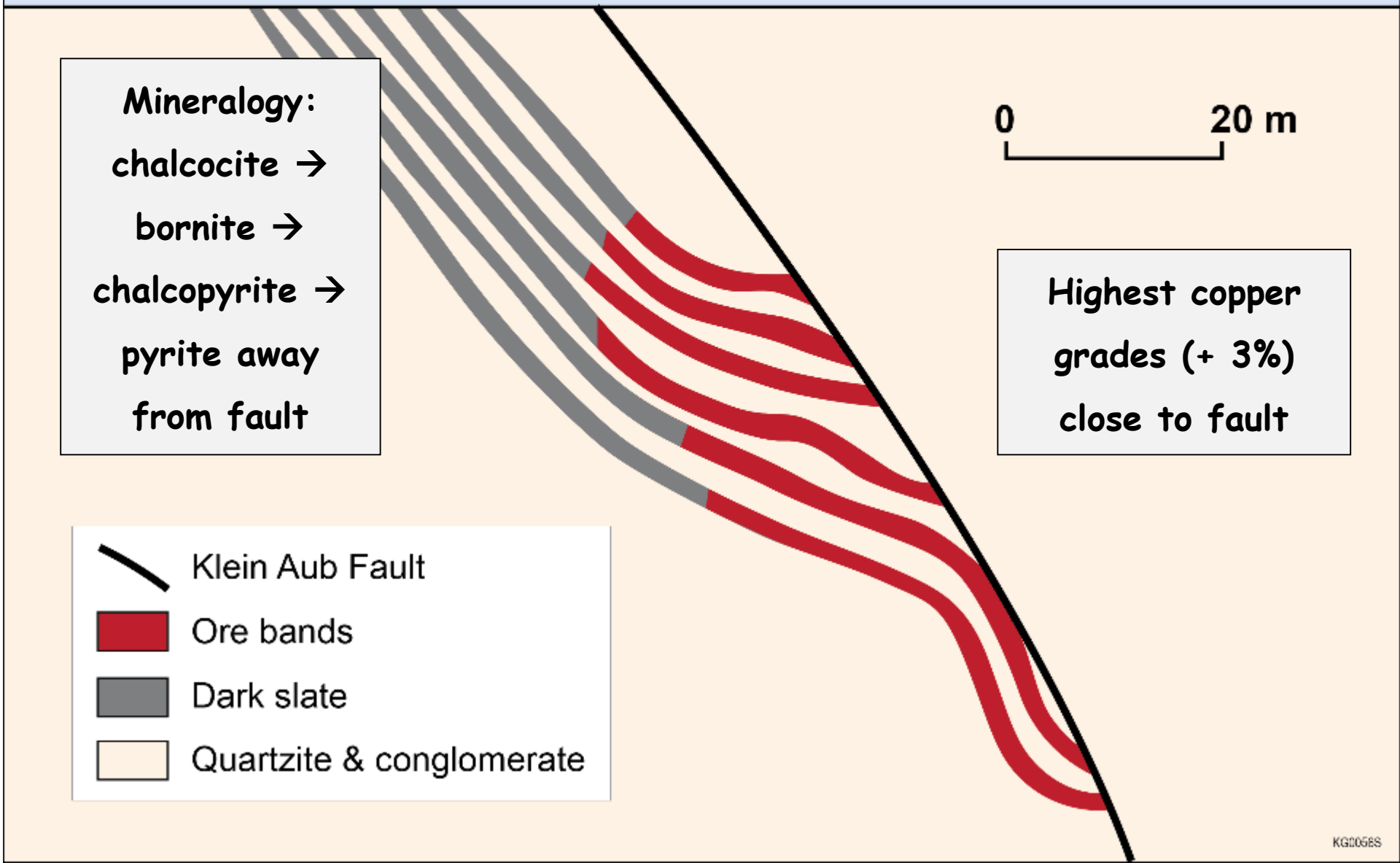
→ Reverse motion on Klein Aub Fault

→ Thrusts, faults, drag folds near Klein Aub Fault

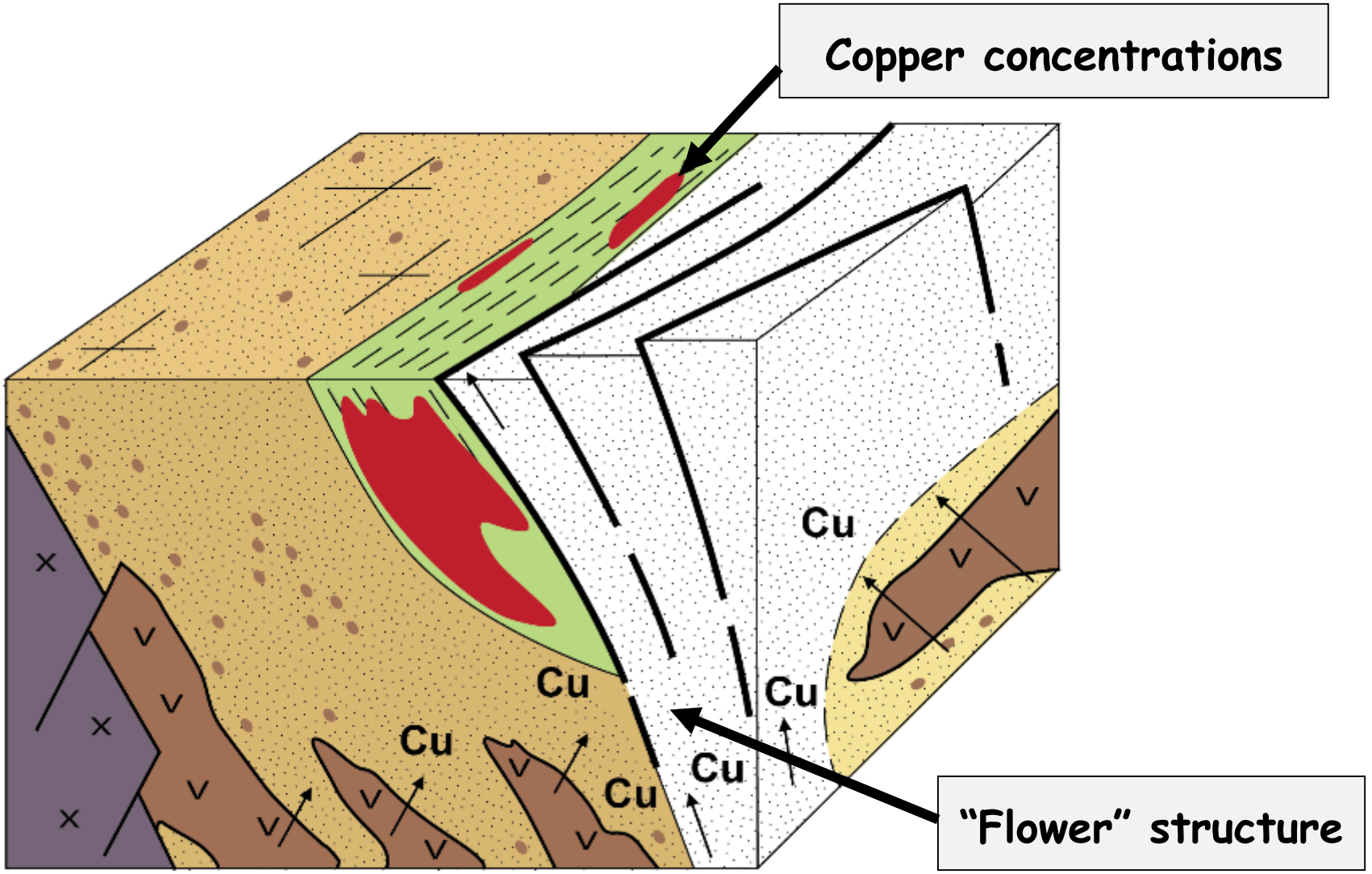
→ All explained by dextral wrench / flower structure on Klein Aub Fault

Mine exposure of Klein Aub Fault

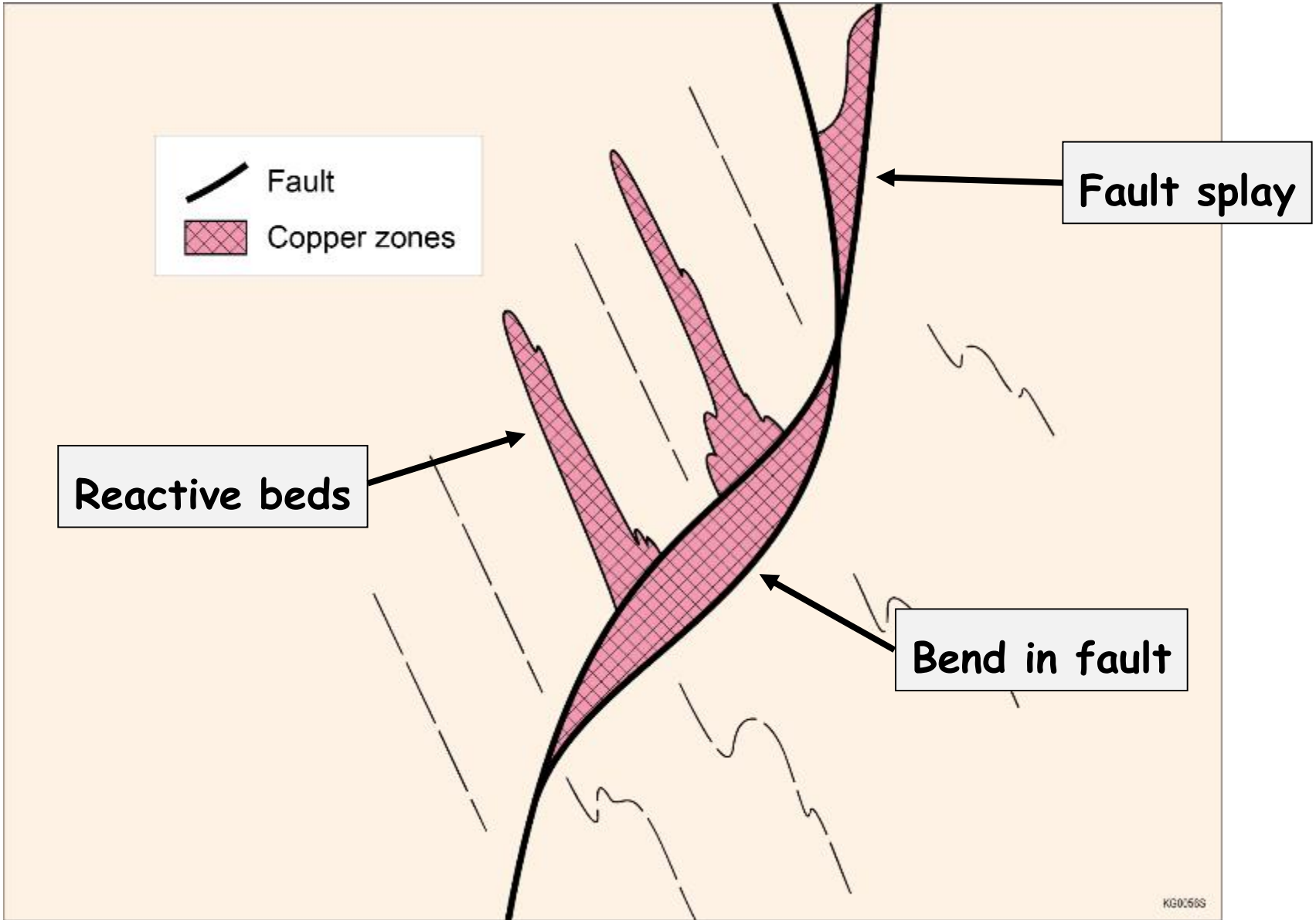
Klein Aub - Sketch Section



Late Epigenetic Model

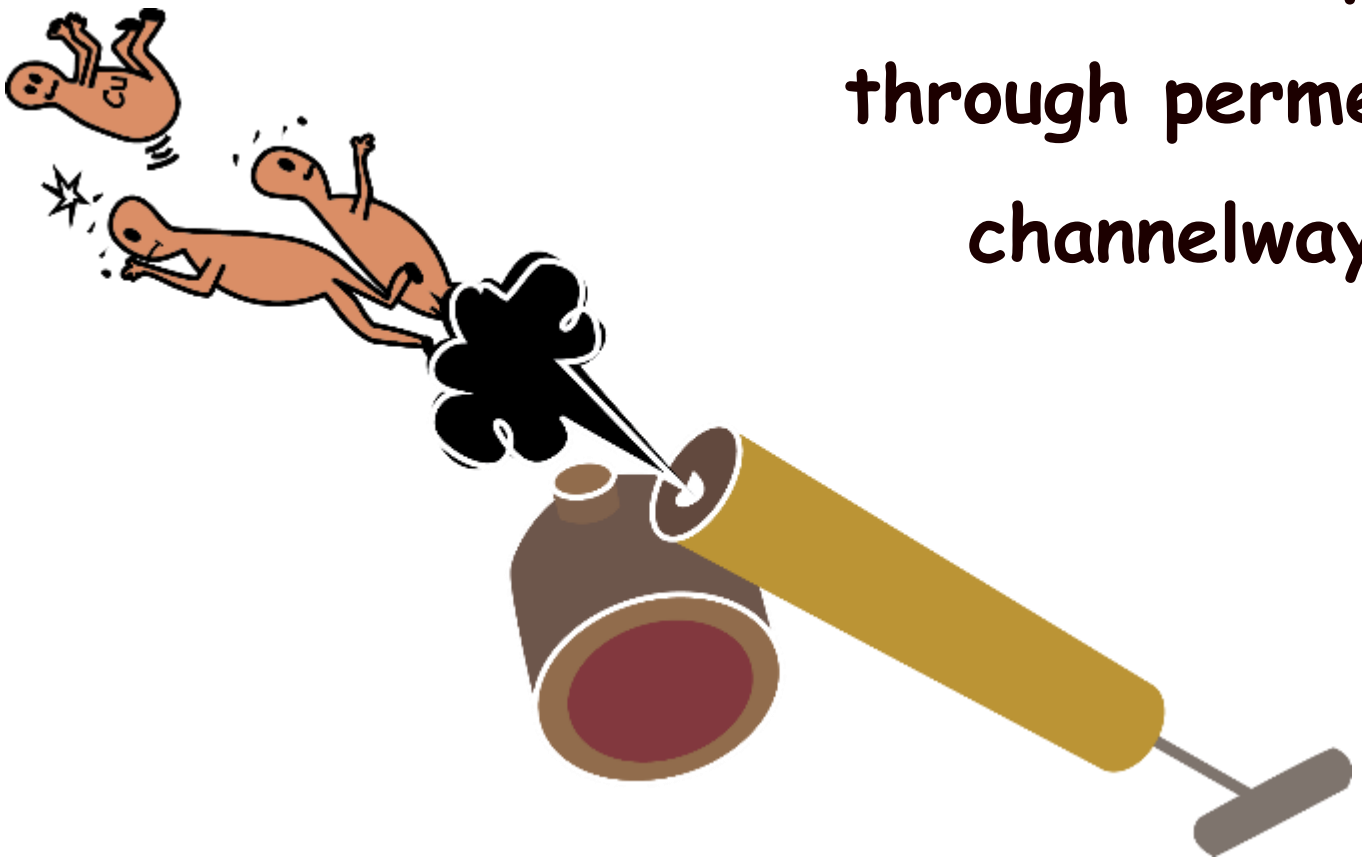


Late Epigenetic Model: Possible Ore Niches

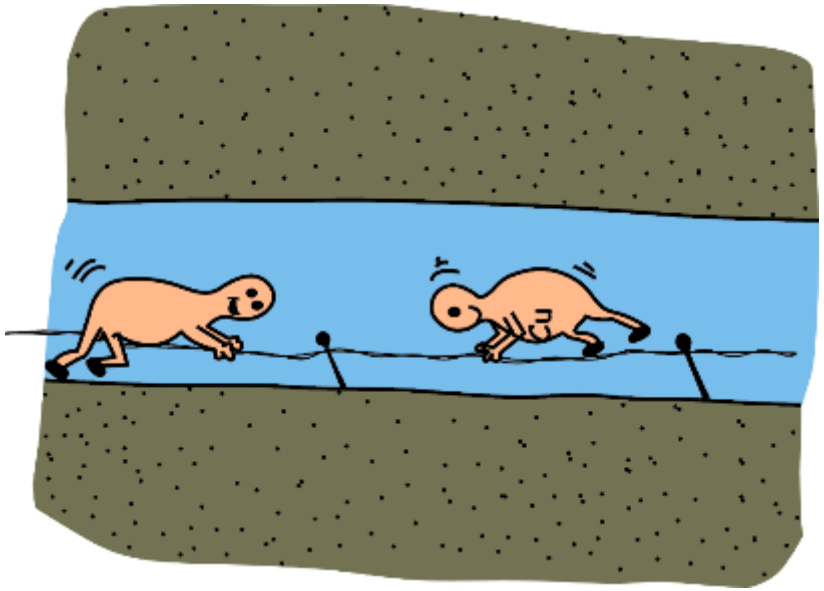


During deformation …

… fluid can be pumped through permeable channelways

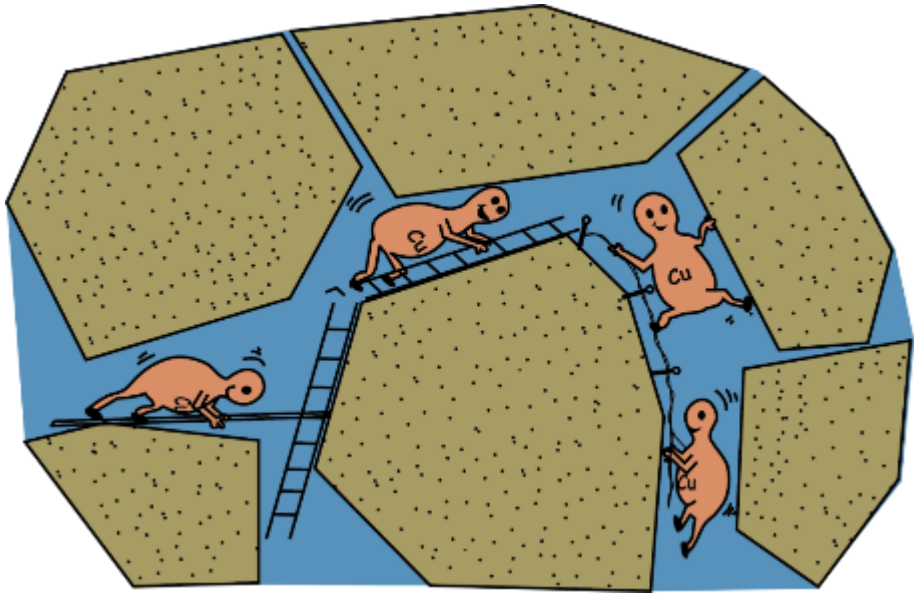


So we find copper concentrated in …

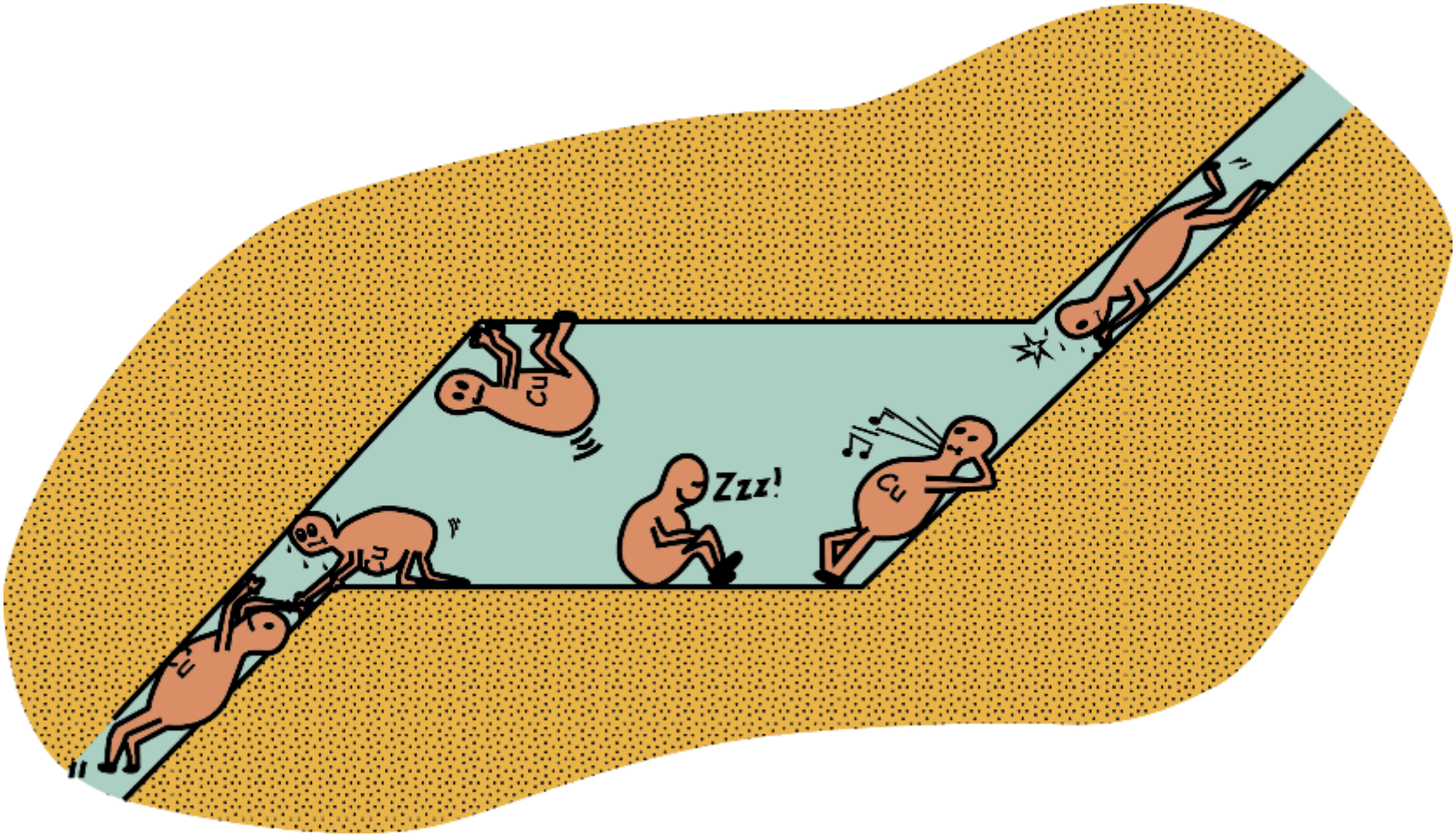


… brittle fractures,

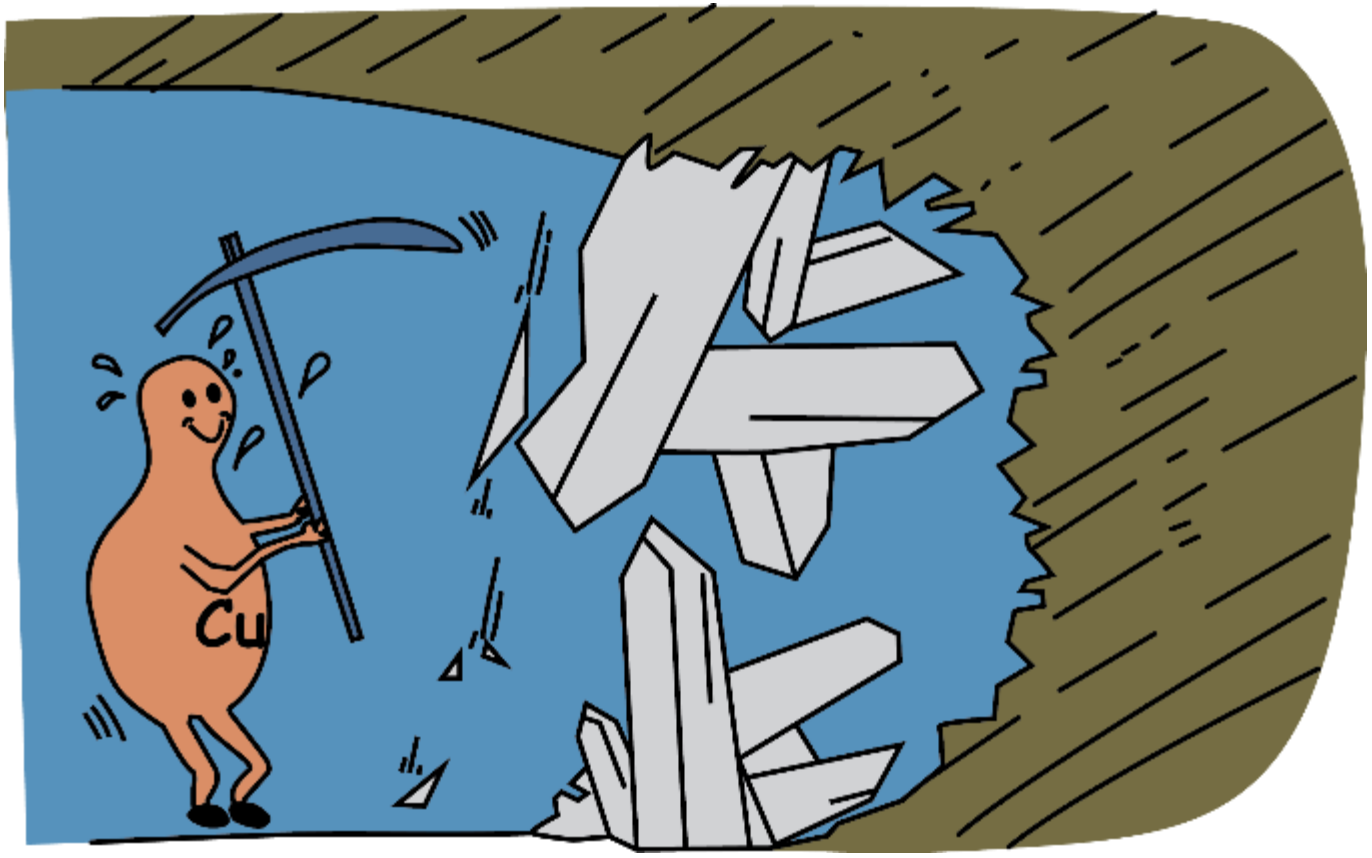
… veins



… breccia zones



… dilatant sites

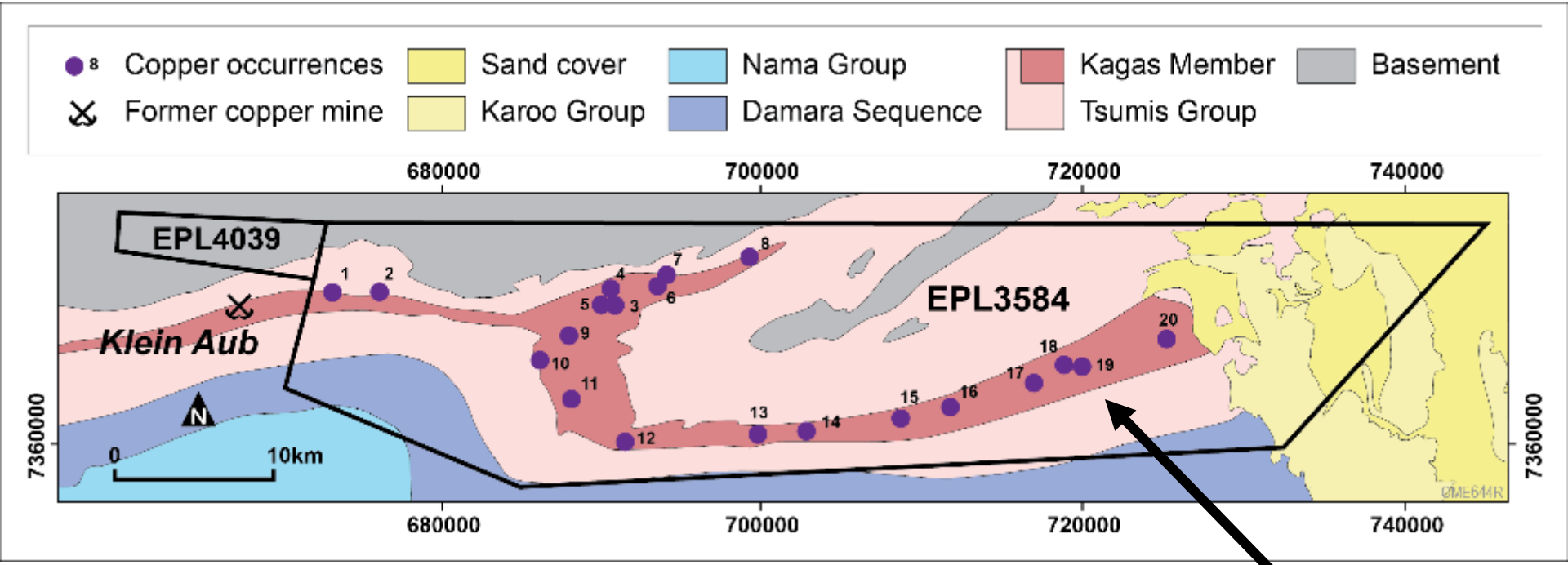


… and replacing reactive minerals

A Klein Aub- Style Target ?

- Underground mine
- Narrow ore bands 1 – 2 m
- Production: 5.5 Mt at 2.0 % Cu & 50 g/t Ag
- Is another Klein Aub a viable target ?
- **NO**

Regional Target: Kagas Member



- Enriched in copper over 60 km strike
- Copper occurrences in limestone & dark phyllite

Kagas Member

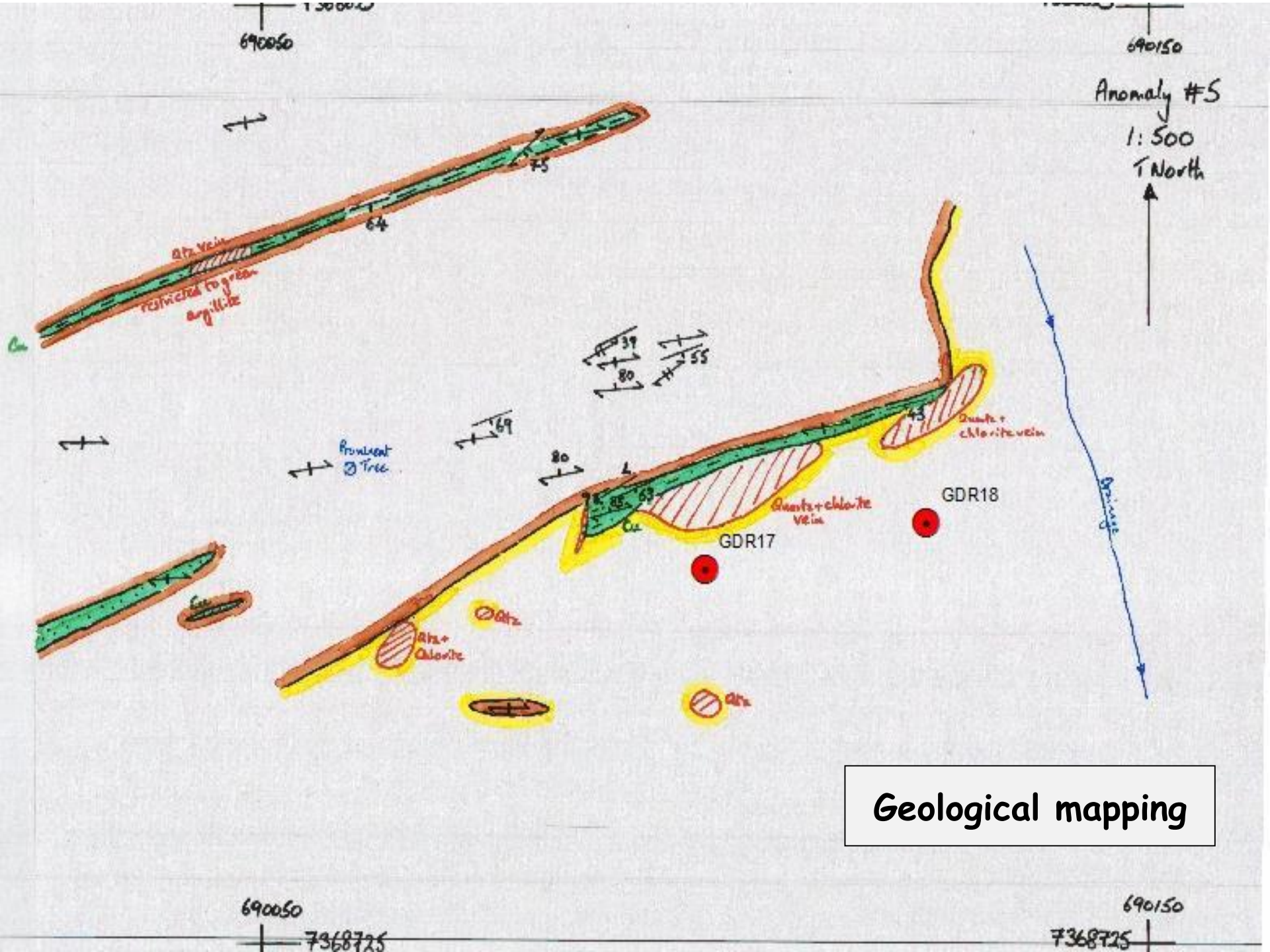
Is There Another Exploration Angle ?

Georgette Geologiste has some bright ideas

A Couple of Ideas

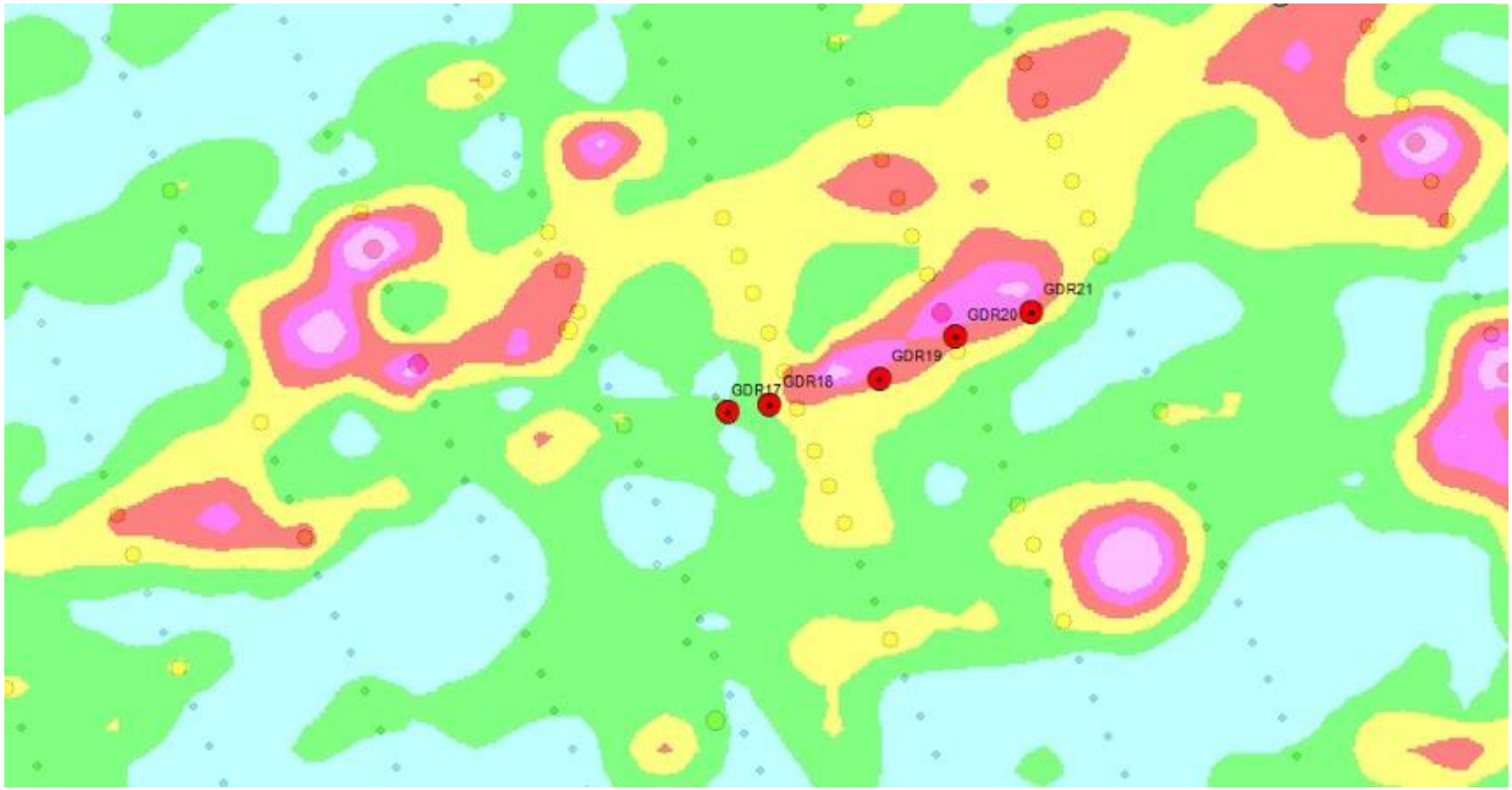
Target -

- Structural thickening (e.g. in hinges of folds)
- Shallow open-cuttable deposit (→ lower mineable grade)
- Multiple closely-spaced bands (→ bulk-mineable)
- Oxide copper (→ SX-EW operation)



Geological mapping

Soil Geochemistry

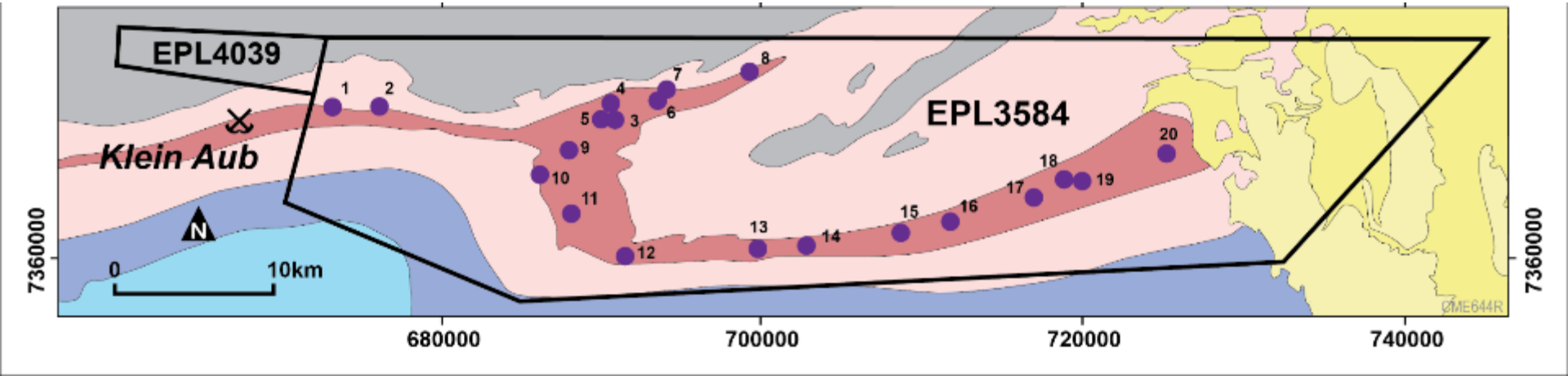


50m line spacing, 10m sample spacing

Klein Aub Area - Exploration

- Interpretation of remote sensing imagery
- Regional soil geochemical traverses
- 20 targets defined for detailed follow-up

  - ground magnetics, mapping & soil geochemistry
- 47 shallow RC holes on priority targets



Exploration Results 2012

- Most holes intersected target zone at 10 – 30m depth
- Narrow intersections of low grade copper
- Best intersection 8m at 0.41% Cu
- Highest assay 3m at 1.1% Cu
- **NOT VERY EXCITING**

Company Strategy 2012

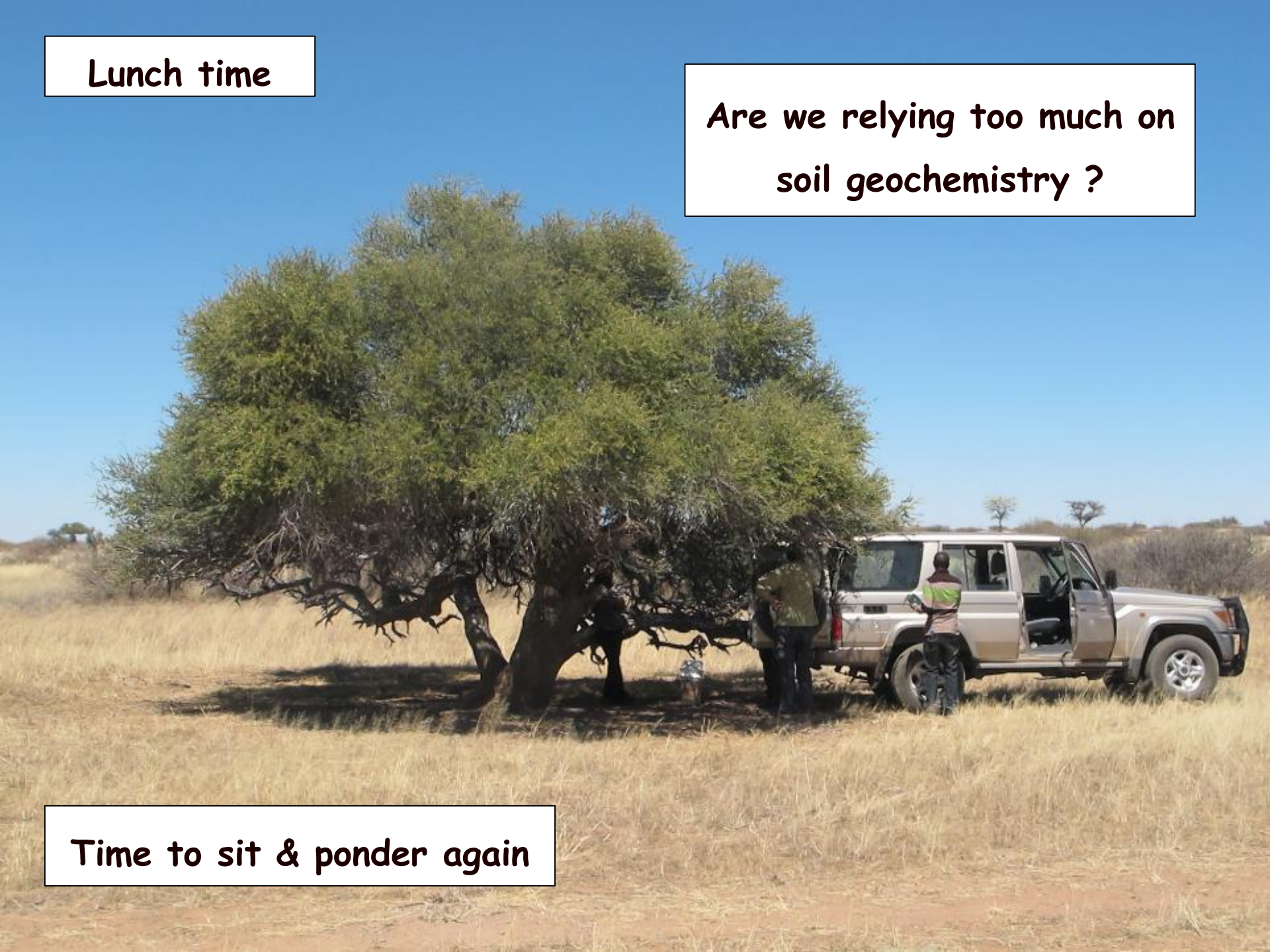
- "In summary, the company's quite extensive exploration to date has been unsuccessful in identifying potential for a substantial near-surface copper deposit"
- "Our Kalahari Copperbelt strategy needs to be reinvigorated"
- The Board decided not to continue funding the project
- Exploration permit not renewed

Did We Miss Something ?

On the positive side -

- There is an enormous amount of copper
  - copper-bearing beds extend for hundreds of kilometres
- In the Botswana segment of the Kalahari Copperbelt, there are several deposits +50 Mt at ~2% Cu with Ag credits

What else could we have done ?

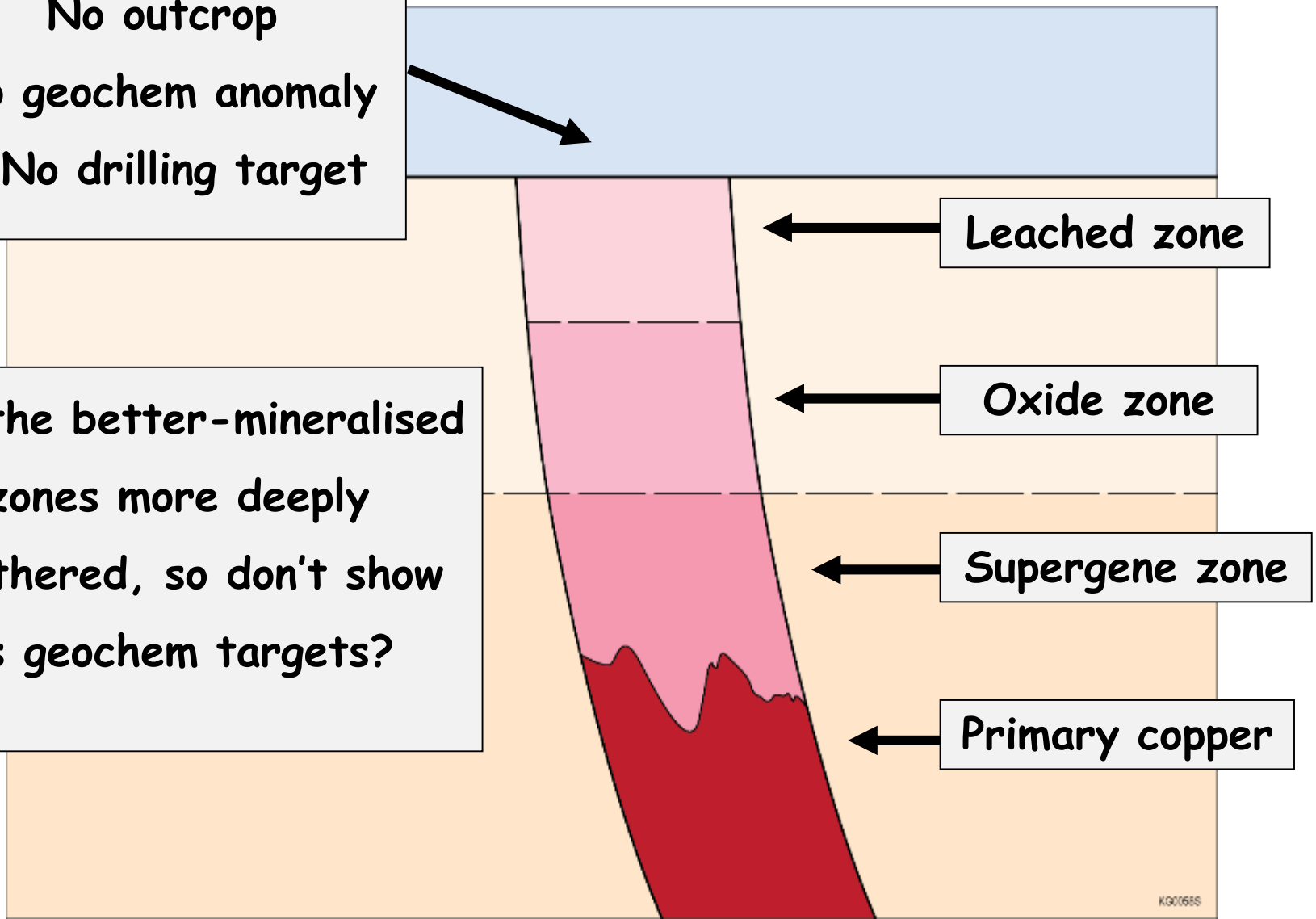

Lunch time
Are we relying too much on soil geochemistry ?
Time to sit & ponder again

Weathering of Copper Sulphide Deposits

No outcrop

No geochem anomaly

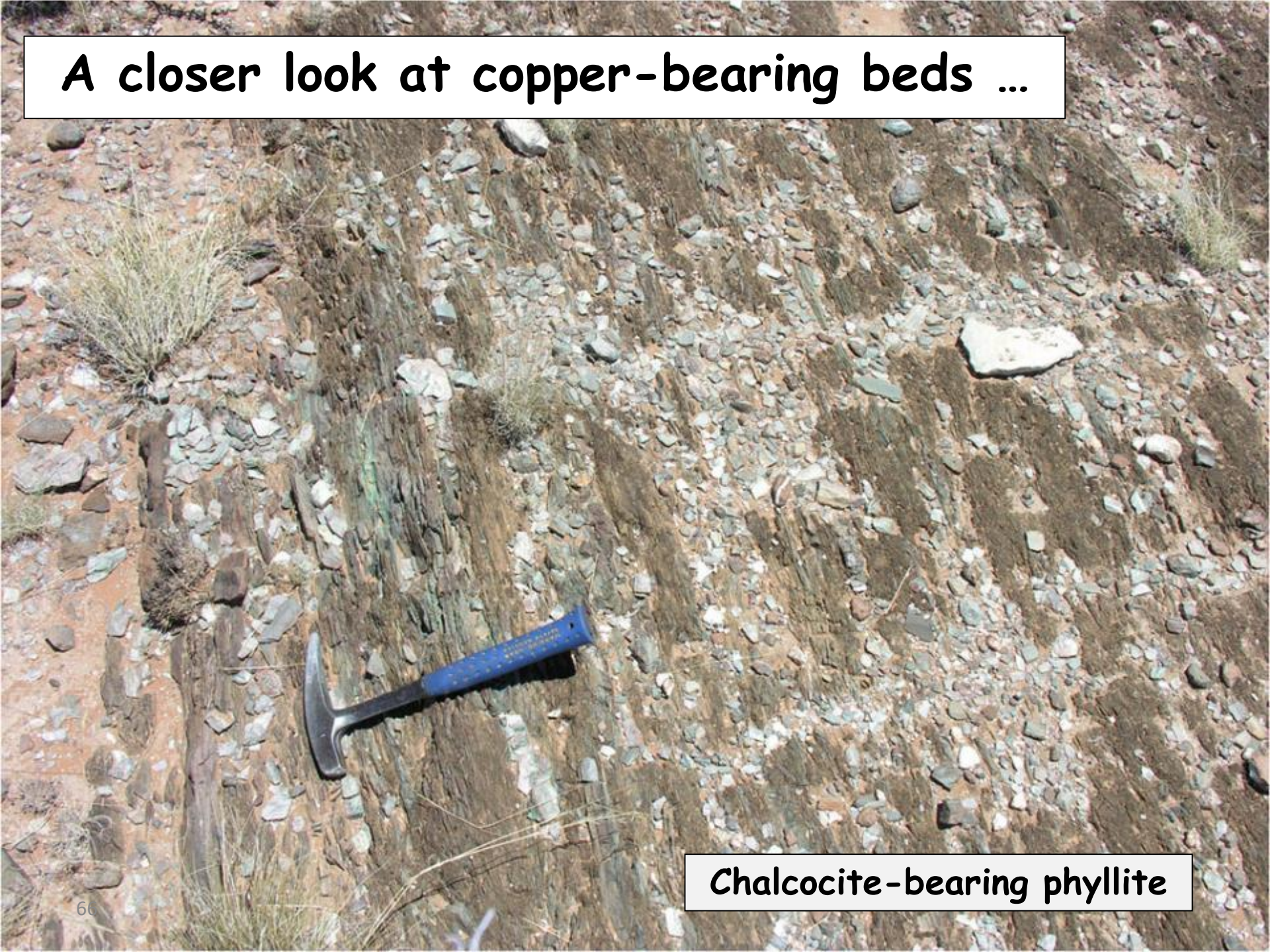
= No drilling target



Are the better-mineralised zones more deeply weathered, so don't show as geochem targets?


Mapping & Sampling,
Klein Aub Area
Is soil geochemistry effective in an area like this?

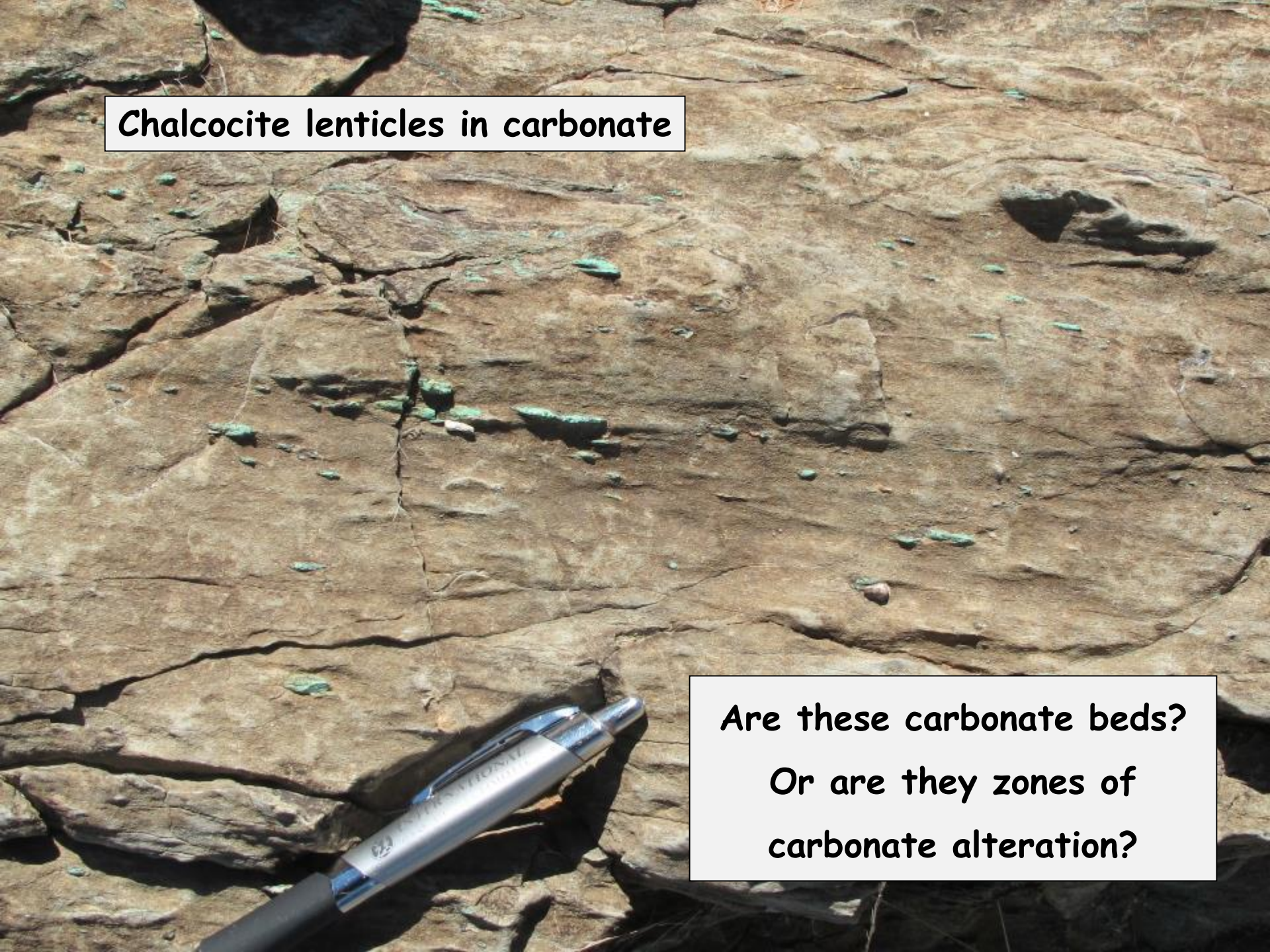
A closer look at copper-bearing beds …



Chalcocite-bearing phyllite


In detail, the copper-bearing phyllite is more strongly deformed than adjacent rocks


These look like sheared & altered rocks
Are these beds? Or are they bedding-parallel shear zones?


Chalcocite lenticles in carbonate
Are these carbonate beds?
Or are they zones of
carbonate alteration?

Possible Alteration

Likely alteration minerals -

muscovite quartz

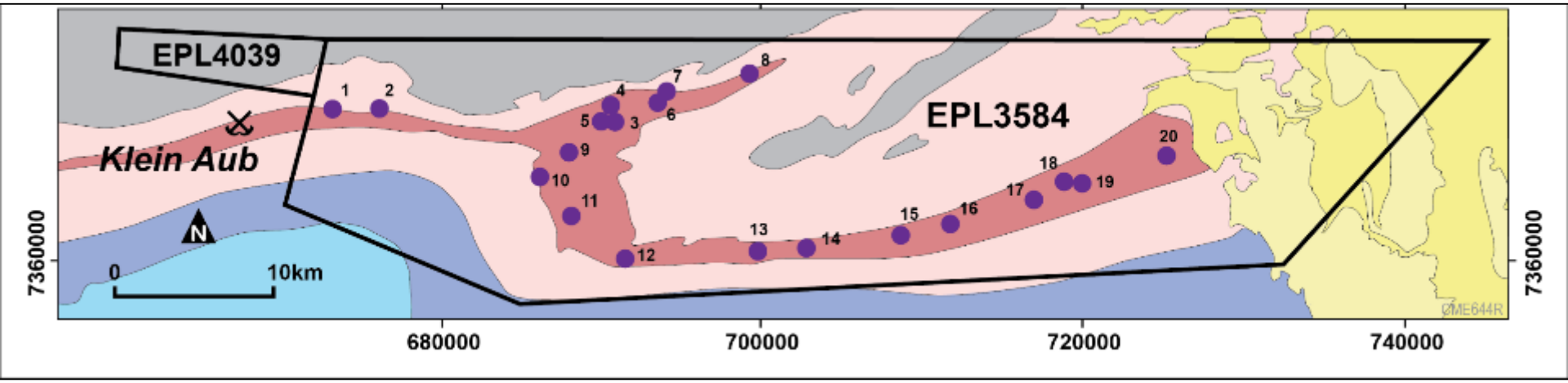
carbonate chlorite

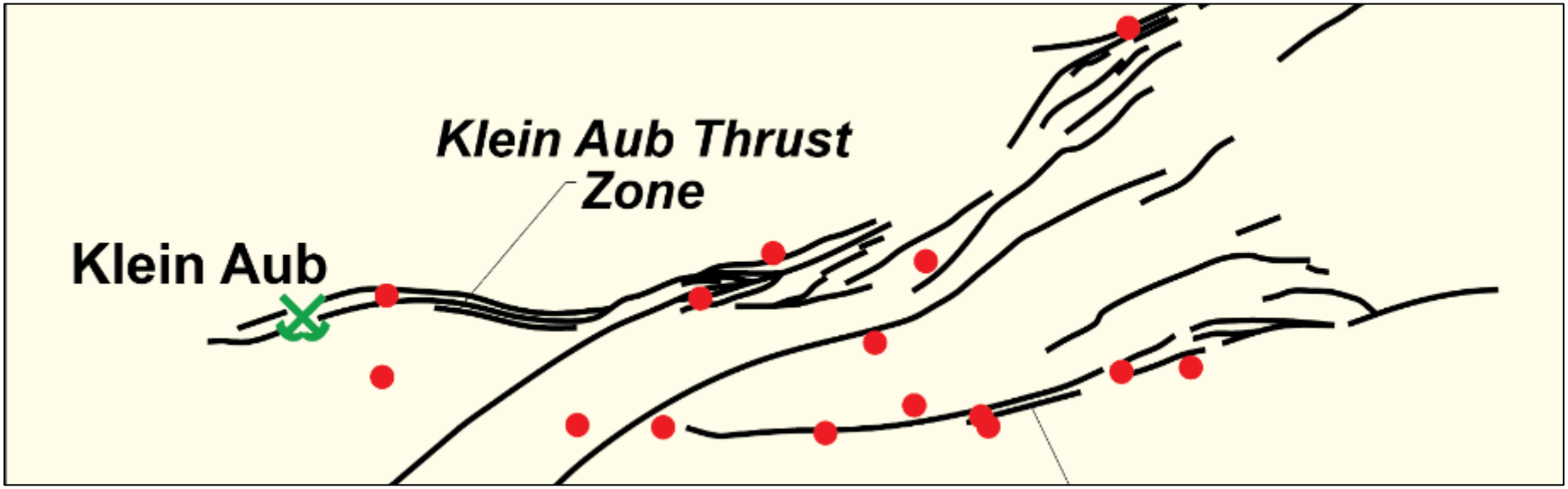
albite ?

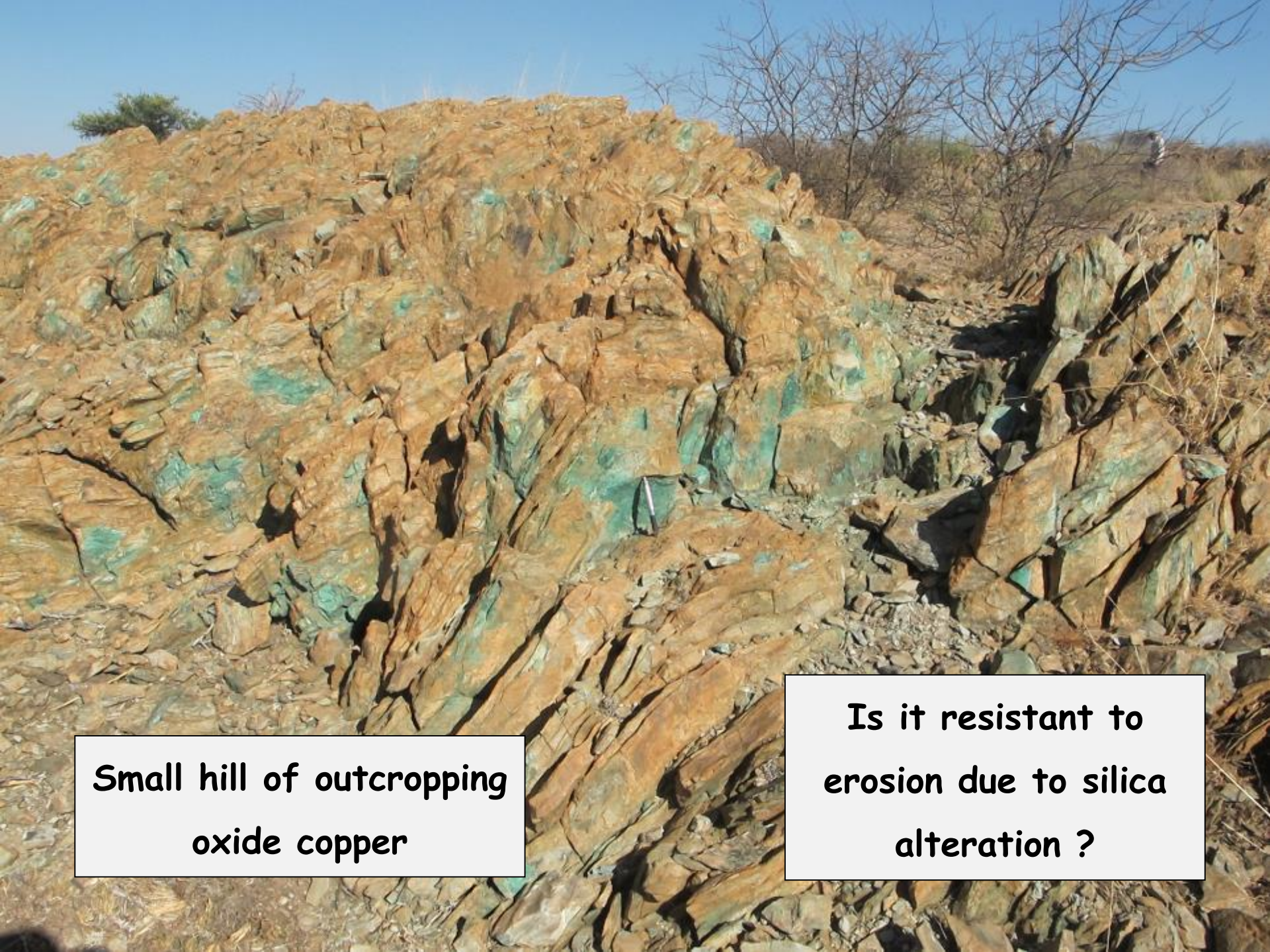
If it is alteration, how extensive is it ?

We don't know - it hasn't been mapped and there's been no petrology

Klein Aub - Regional Geology

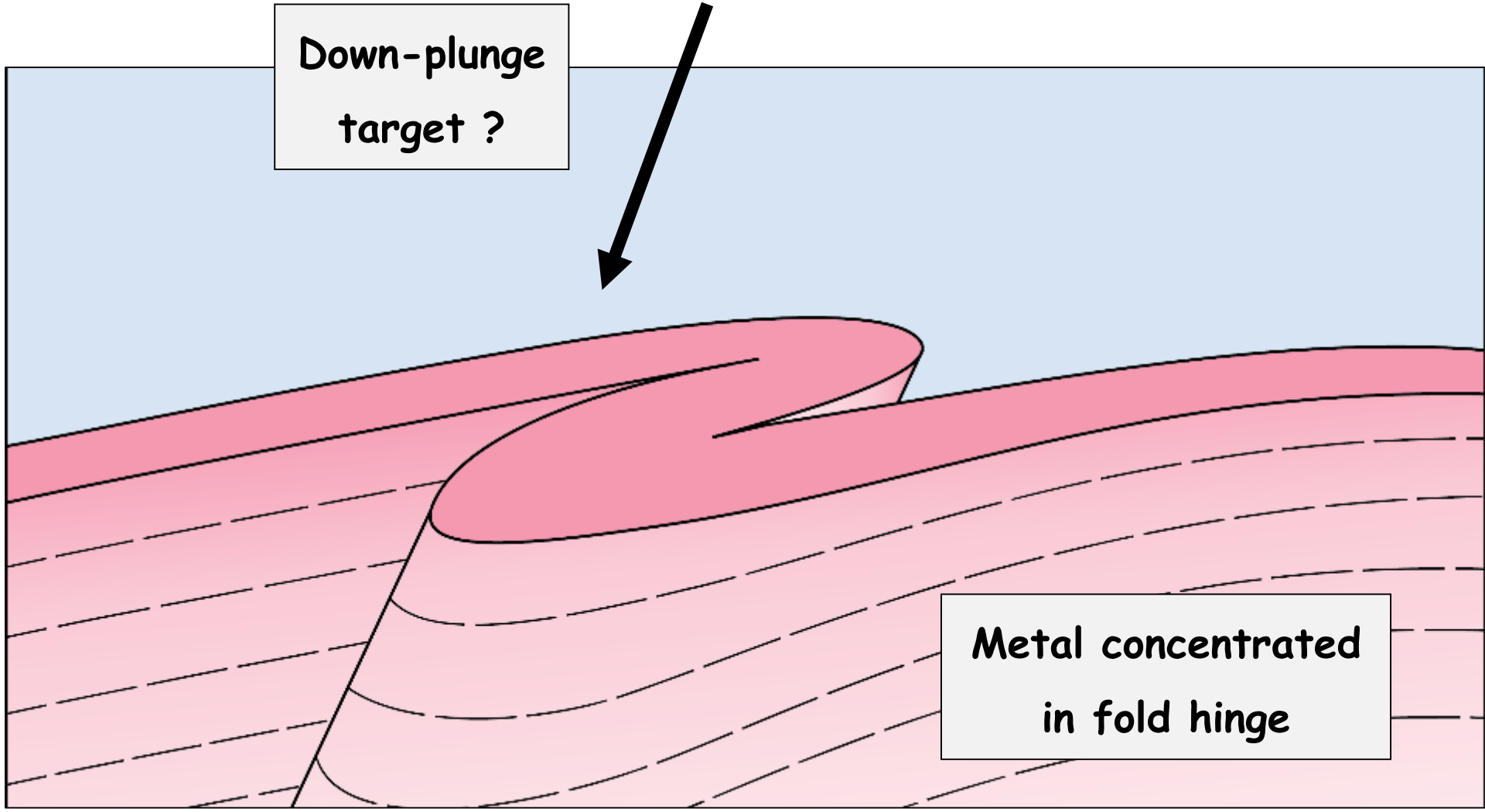





Small hill of outcropping oxide copper
Is it resistant to erosion due to silica alteration ?


Possible enhanced thickness &
metal concentration in a fold

Possible Structural Control



Is This Something to Get Excited About ?

Kalahari Copperbelt - Mineralisation Styles

- Disseminated grains - mainly in silty & fine sandy laminae; possibly replacing anhydrite and/or carbonate
- In cleavage-parallel lenticles
- In brittle fractures
- In quartz-carbonate veins
- In zones of tectonic breccia

How do we find a model that accounts for these different styles of mineralisation ?

Kalahari Copperbelt - Conceptual Models

- Copper emplaced during basin compaction and partially remobilised during deformation & metamorphism
- Early (syngenetic or diagenetic) copper significantly upgraded by later deformation-related hydrothermal events
- Epigenetic - Copper pumped up faults & shear zones during Damaran (Cambrian) deformation events

Conceptual Models

Do conceptual models matter ?

Do they change our exploration approach ?

Exploration models are used ..

.. to interpret controls on ore localisation ..


.. and to design
exploration programs

Conceptual Models

It's the difference between a carefully-thought-out exploration program, based on understanding controls on ore localisation …

Mineral exploration in theory

… and just charging ahead

Mineral exploration in practice

Conceptual Models - Problem

Assume a detailed knowledge of the ore-forming process

BUT … Our understanding might be wrong or incomplete

Exploration Targets -

Syngenetic & Diagenetic Models

→ focus on stratigraphy

→ especially reduced beds near a basement high

→ identify targets based on geochemistry

→ firm up targets with I.P. lines

→ drill to intersect copper beds down-dip

RESULT:

- Lots of low grade copper intersections
- No significant ore discoveries

Exploration Targets - Epigenetic Models

- Yes, we need reactive strata
- Yes, we need lots of geochemistry
- Regional interpretation to identify possible controlling structures
- Detailed mapping to:

  (a) Understand geological structure

  (b) Understand the interplay between structure & stratigraphy

  (c) Identify zones of alteration
- Deep geophysics to identify drilling targets
- Lots of drilling

HASN'T YET BEEN DONE

Stratigraphic Controls - Exploration Heritage

Because of the former focus on stratigraphic controls (the 'favourable horizon') -

- Drilling tested along strike and down-dip; not down-structure
- Copper occurrences not in the 'favourable horizon' were not adequately tested
- Copper in veins was considered as 'minor remobilisation' rather than potentially part of the halo to a larger structurally-controlled deposit

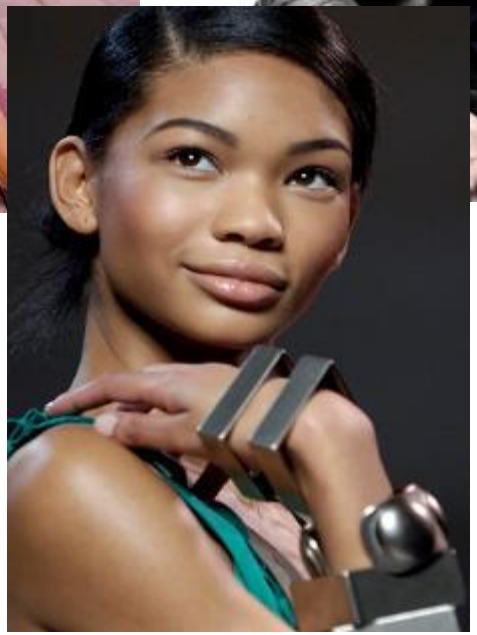
→ Many targets remain to be explored

Implications of Epigenetic Models

- Much previous exploration poorly directed
- Many copper occurrences ignored or under-explored
- Expect deposits associated with alteration & brecciation
- May be a range of deposit styles, with differing
    - host rock types
    - geometry
    - alteration assemblages
    - structural relationships to host rocks

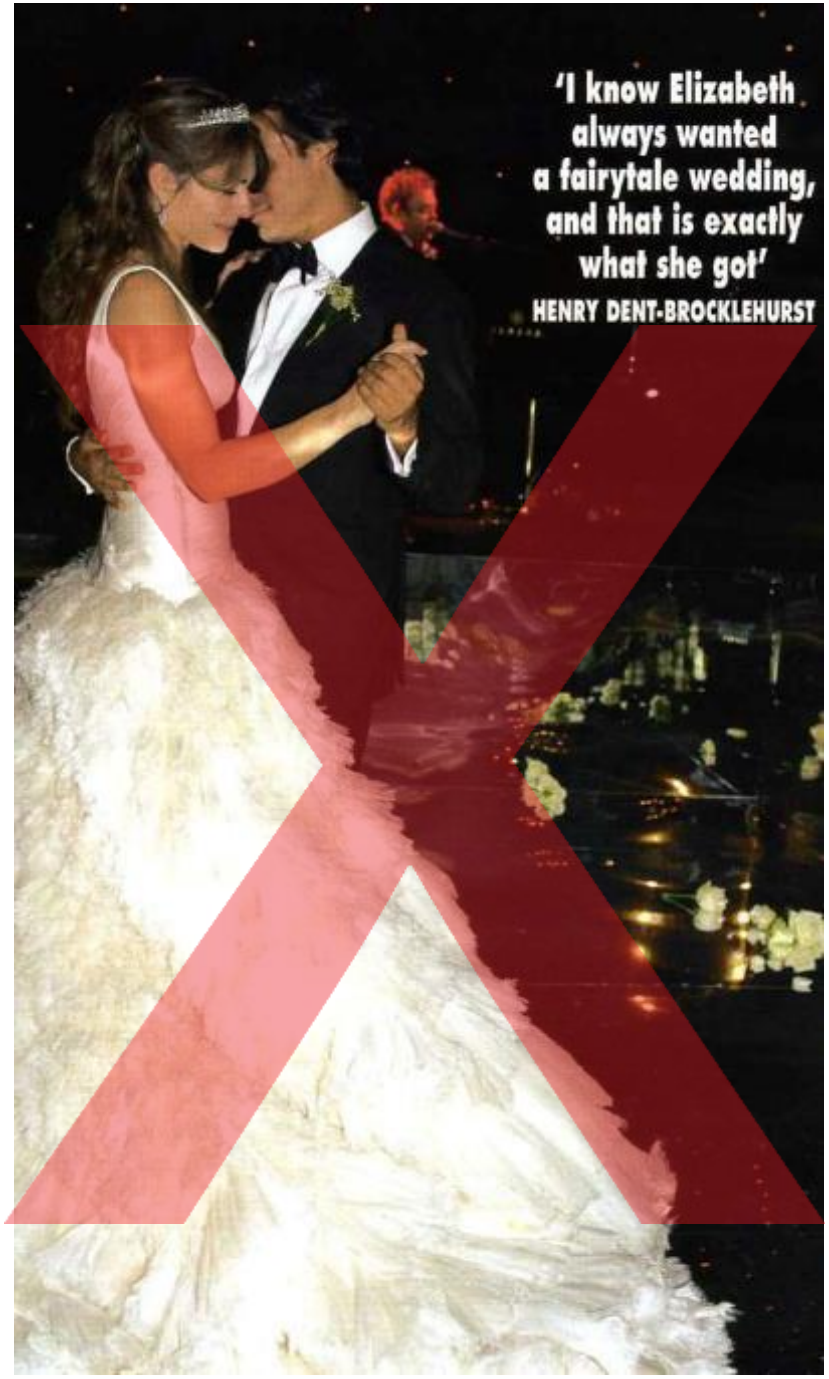
You can flirt with a model ...

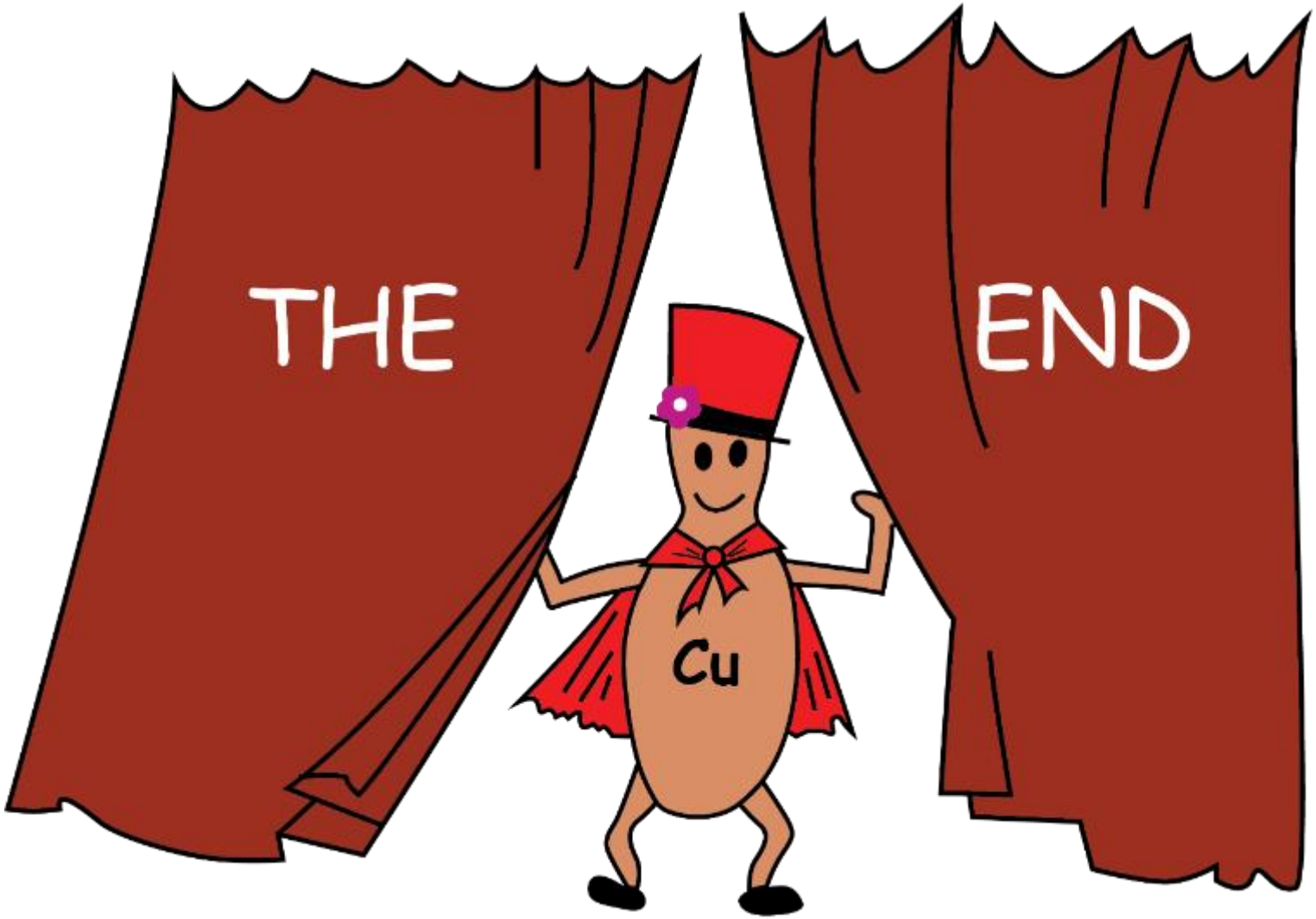
… in fact, you should flirt with lots of models...



(The technical term is Multiple Working Hypotheses)

… but you shouldn't marry one!




THE
END
Cu

Thanks to Aurizon
ASRA Mining for
financial support