Geochemistry & mineralogy of late-metamorphic shear zones:

Disseminated gold in the Otago Schist, New Zealand

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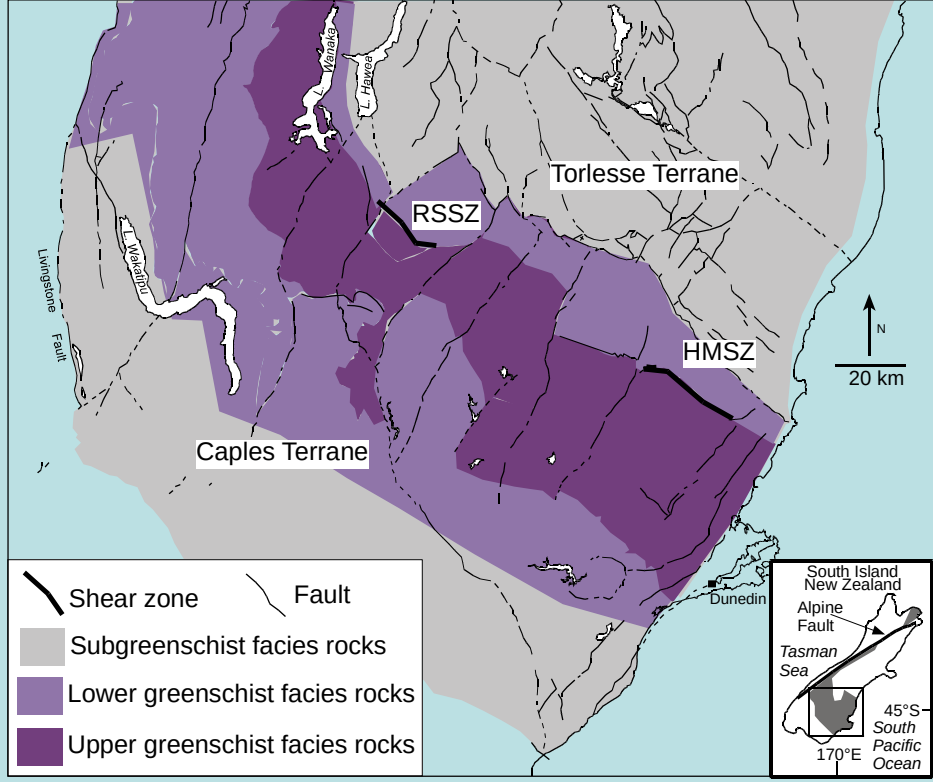
Otago Schist:

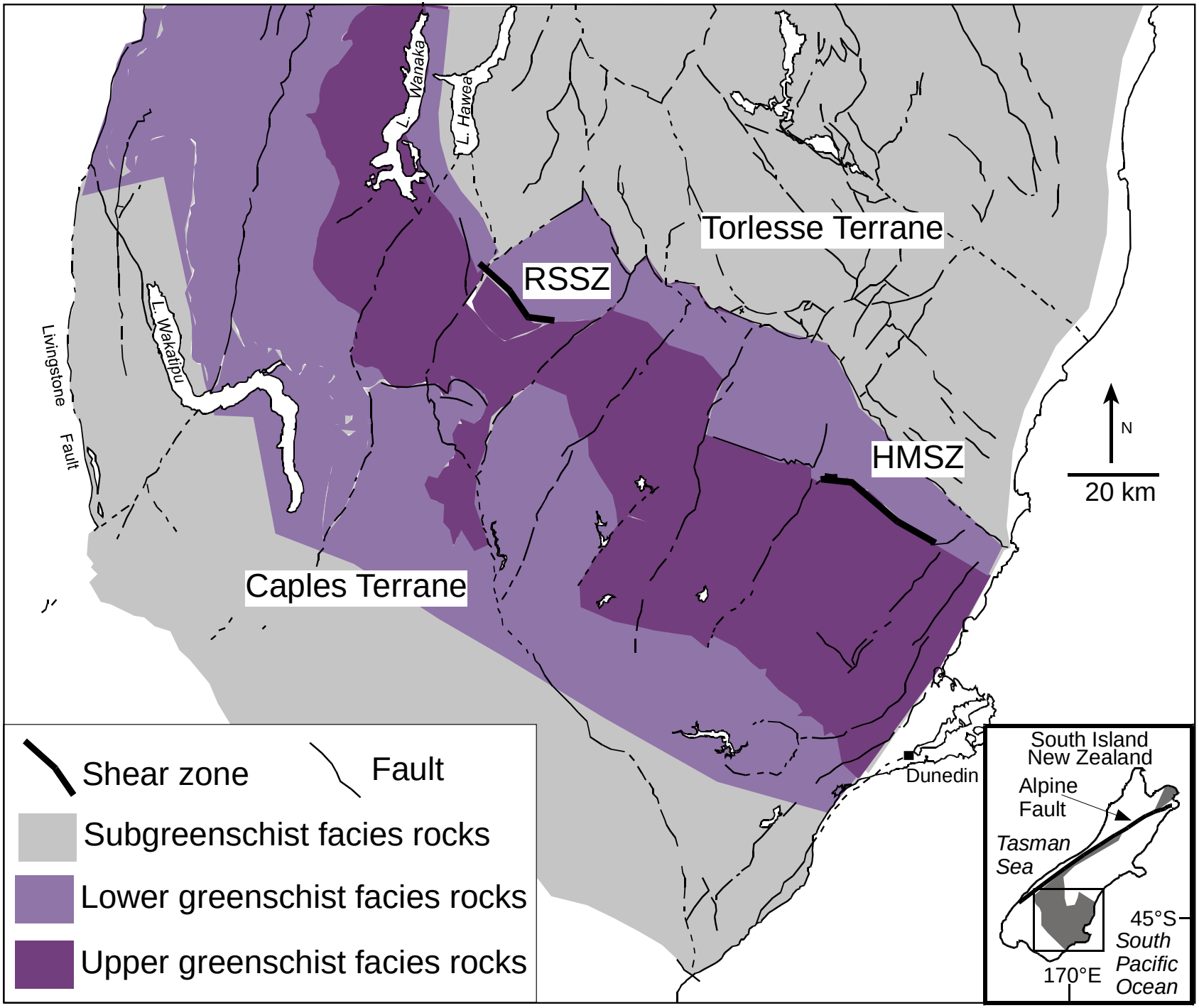
Mesozoic metasedimentary rocks

Greenschist facies

Historic alluvial Au province: 8 M oz

Minor historic Au-quartz vein mining: <400 k oz



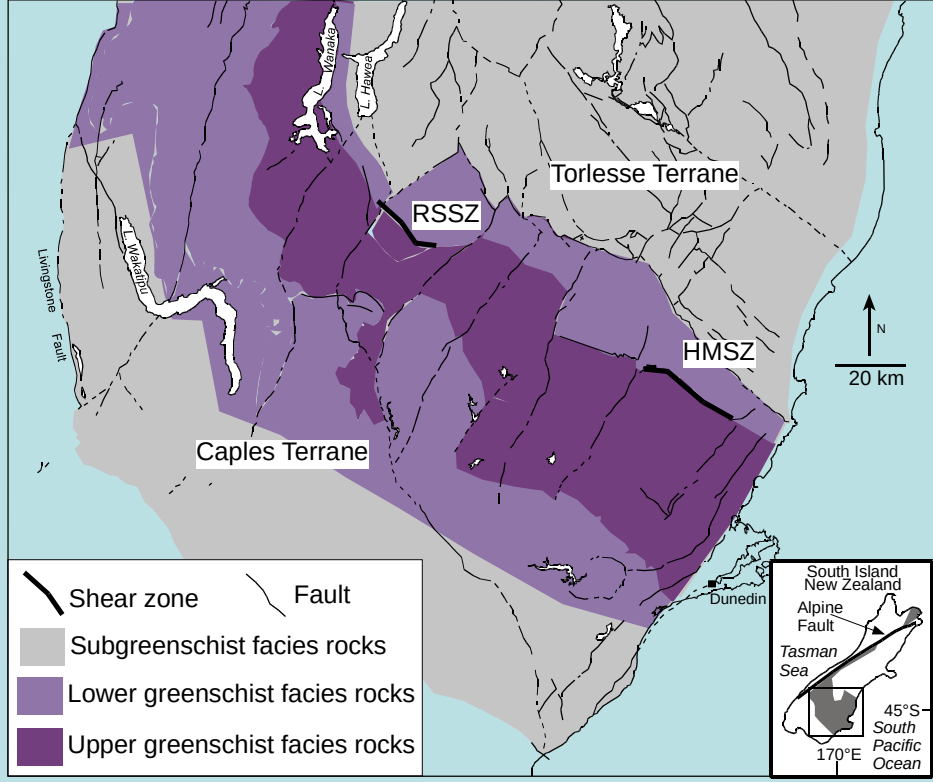

L. Wanaka
L. Hawea
Torlesse Terrane
RSSZ
L. Wakatipu
Livingstone
Fault
HMSZ
N
20 km
Caples Terrane
Shear zone
Fault
Subgreenschist facies rocks
Lower greenschist facies rocks
Upper greenschist facies rocks
Dunedin
South Island
New Zealand
Alpine
Fault
Tasman
Sea
45°S
South
Pacific
Ocean
170°E

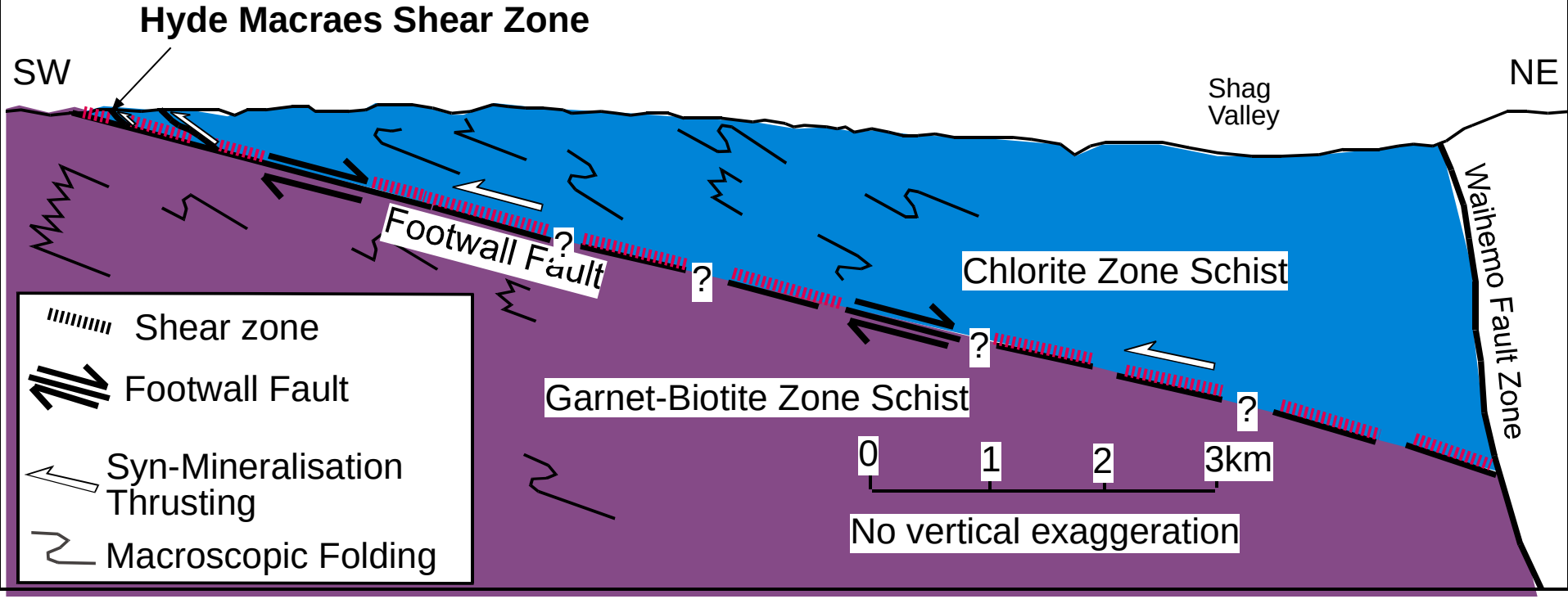
Shear zones:

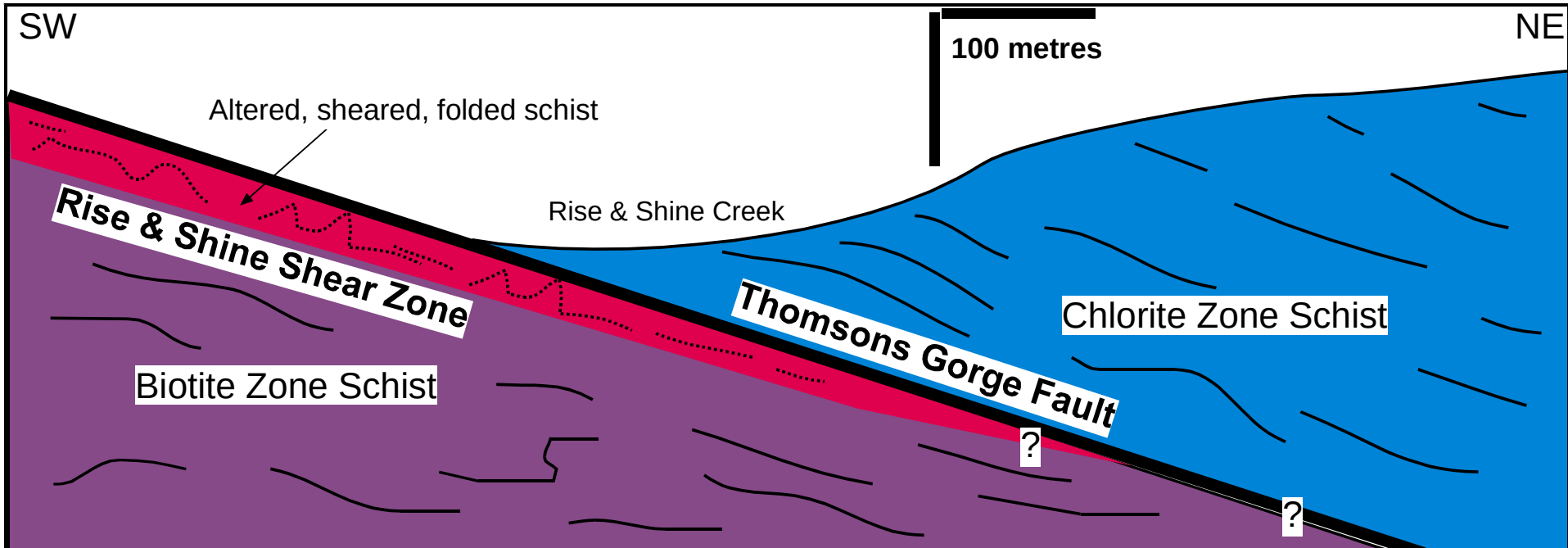
At boundary between upper and lower greenschist facies

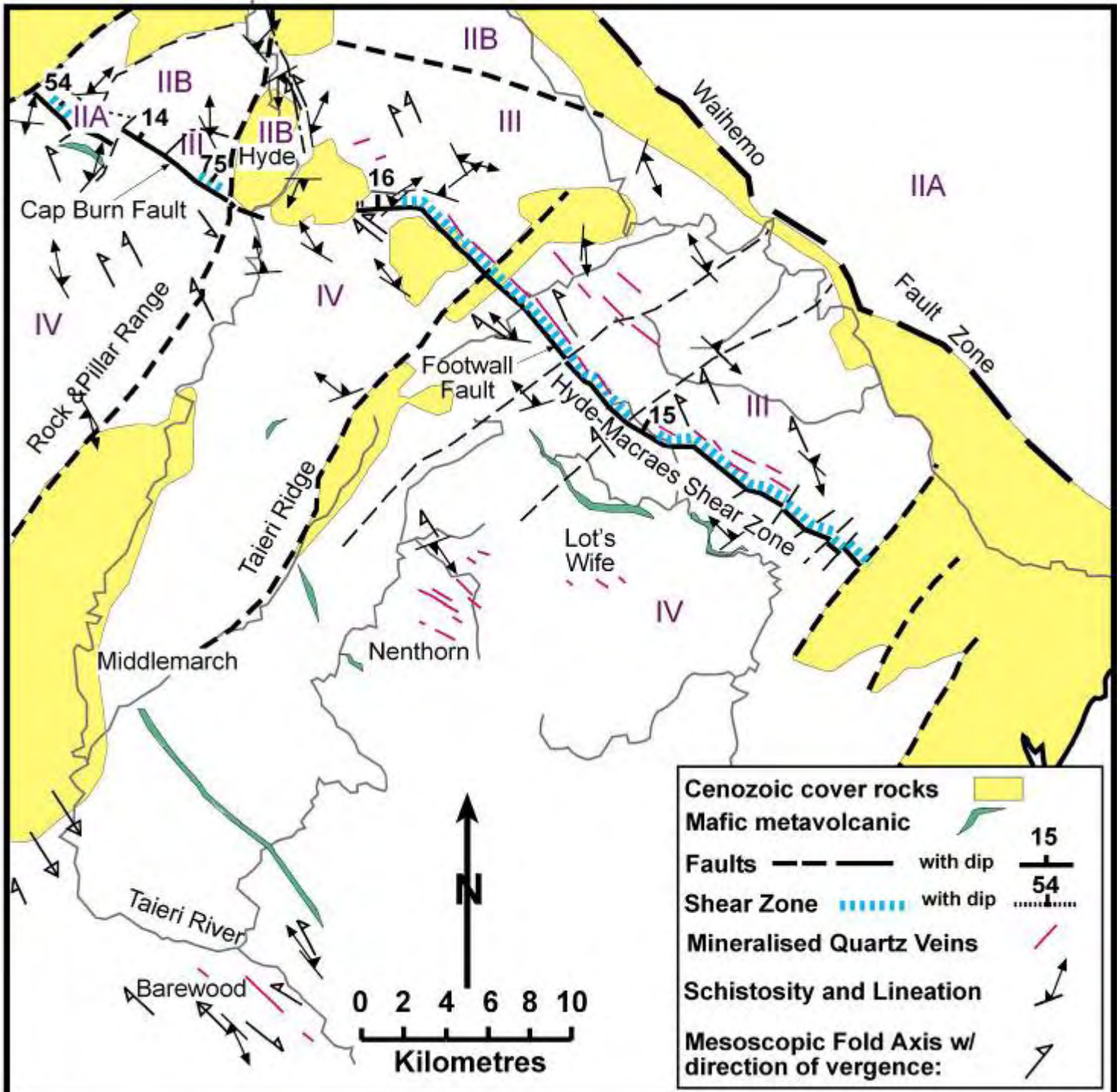
Boundary is post-shear low-angle normal faults

Au mineralisation but little quartz veining




Hyde Macraes Shear Zone
SW
NE
Shag Valley
Waihemo Fault Zone
Footwall Fault
?
?
?
?
Chlorite Zone Schist
Garnet-Biotite Zone Schist
Shear zone
Footwall Fault
Syn-Mineralisation Thrusting
Macroscopic Folding
0
1
2
3km
No vertical exaggeration


SW
NE
100 metres
Altered, sheared, folded schist
Rise & Shine Creek
Rise & Shine Shear Zone
Thomsons Gorge Fault
Chlorite Zone Schist
Biotite Zone Schist
?
?

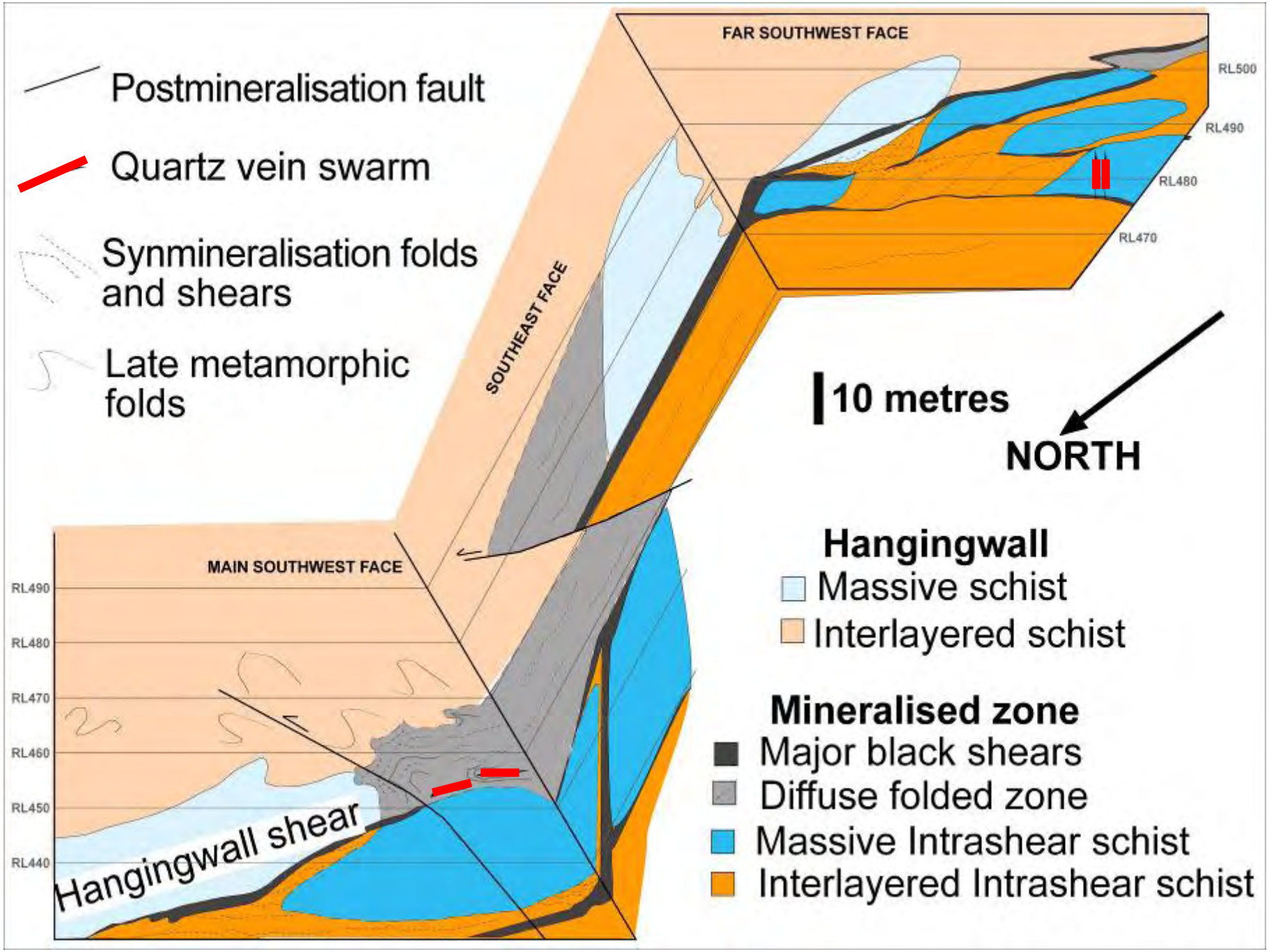

IIB
IIB
IIA
54
14
IIB
III
75
Hyde
III
Waihemo
IIA
16
Cap Burn Fault
IV
IV
Rock &Pillar Range
Footwall
Fault
Fault Zone
Hyde-Macraes Shear Zone
15
III
Taieri Ridge
Lot's
Wife
IV
Middlemarch
Nenthorn
Taieri River
Barewood
N
0 2 4 6 8 10
Kilometres
Cenozoic cover rocks
Mafic metavolcanic
Faults
with dip
15
Shear Zone
with dip
54
Mineralised Quartz Veins
Schistosity and Lineation
Mesoscopic Fold Axis w/
direction of vergence:

Macraes mine

Nearly 2 million ounces Au produced since 1990 startup of new mine

Production >170 000 oz/year, from ore with 1.5 g/tonne Au

Total resource > 5 million oz


Postmineralisation fault
Quartz vein swarm
Synmineralisation folds and shears
Late metamorphic folds
FAR SOUTHWEST FACE
SOUTHEAST FACE
MAIN SOUTHWEST FACE
RL500
RL490
RL480
RL470
RL460
RL450
RL440
Hangingwall shear
10 metres
NORTH
Hangingwall
Massive schist
Interlayered schist
Mineralised zone
Major black shears
Diffuse folded zone
Massive Intrashear schist
Interlayered Intrashear schist

Mineral transformations

metamorphic muscovite => hydrothermal muscovite => illite

titanite => rutile + calcite + quartz

epidote => kaolinite + siderite + calcite

Fe-silicates + As, S in solution => pyrite + arsenopyrite

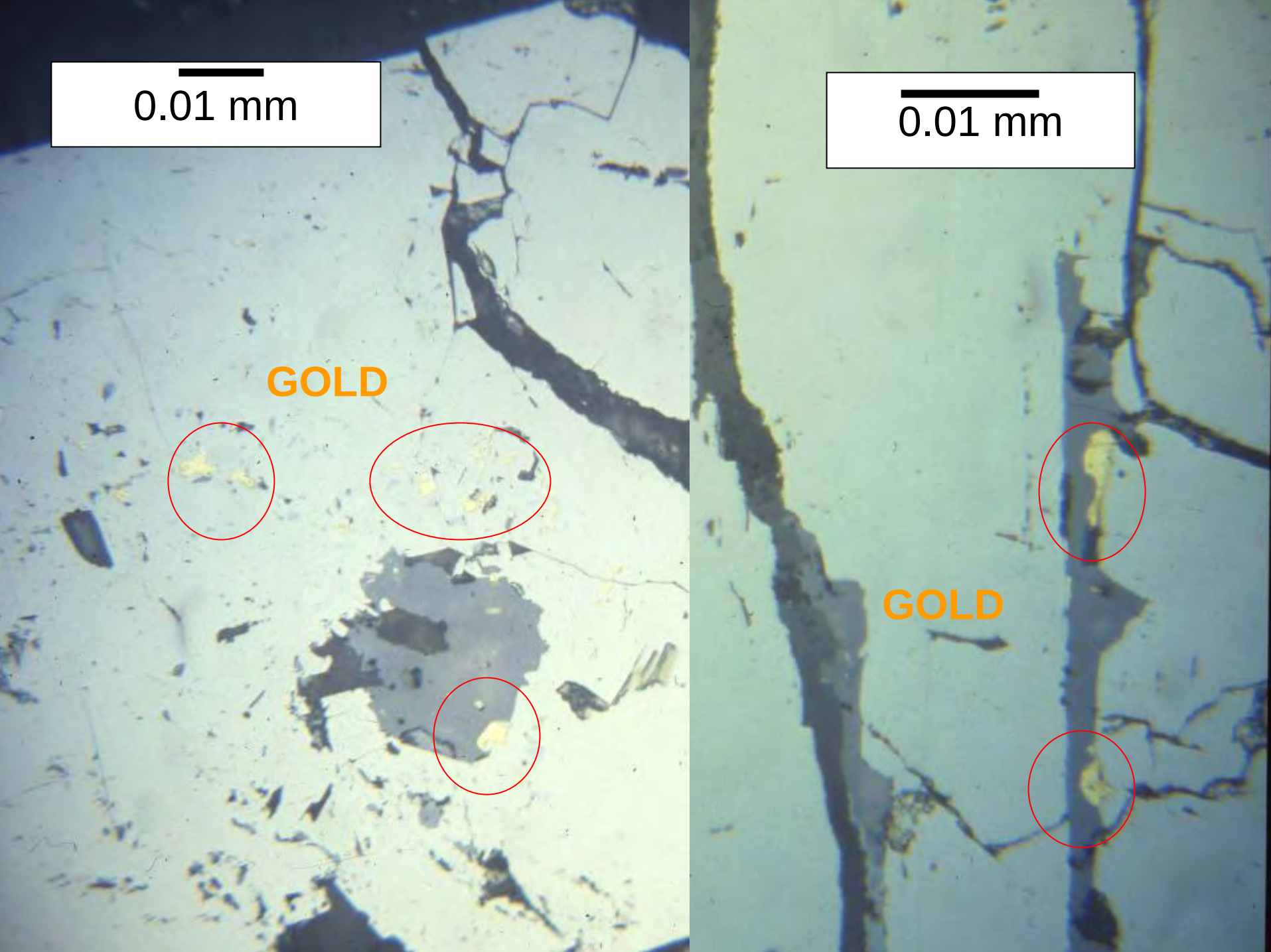
Au bisulfide complex + graphite => native gold

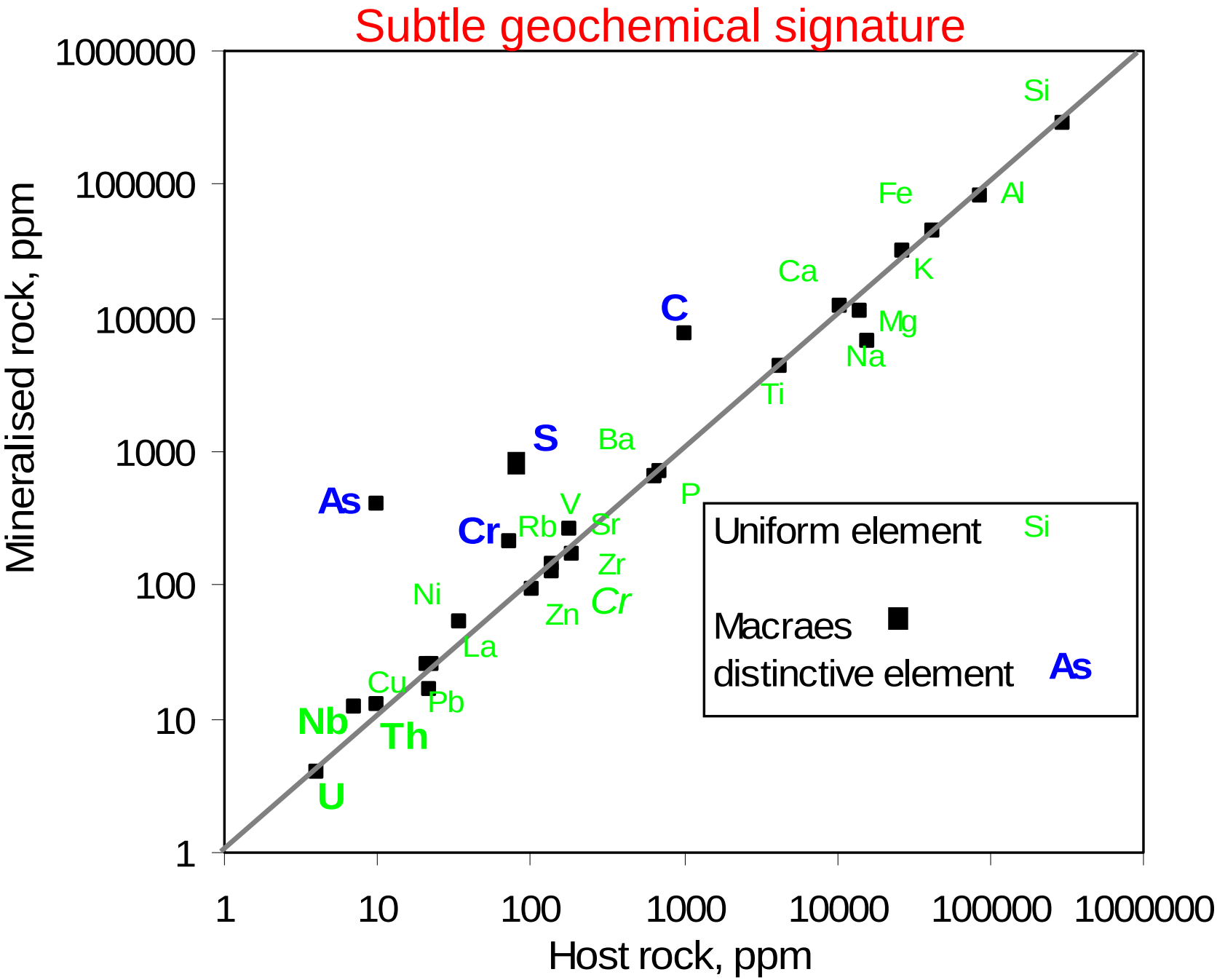
Fe-silicates + S in solution => chalcopyrite + sphalerite + galena

Subtle hydrothermal alteration

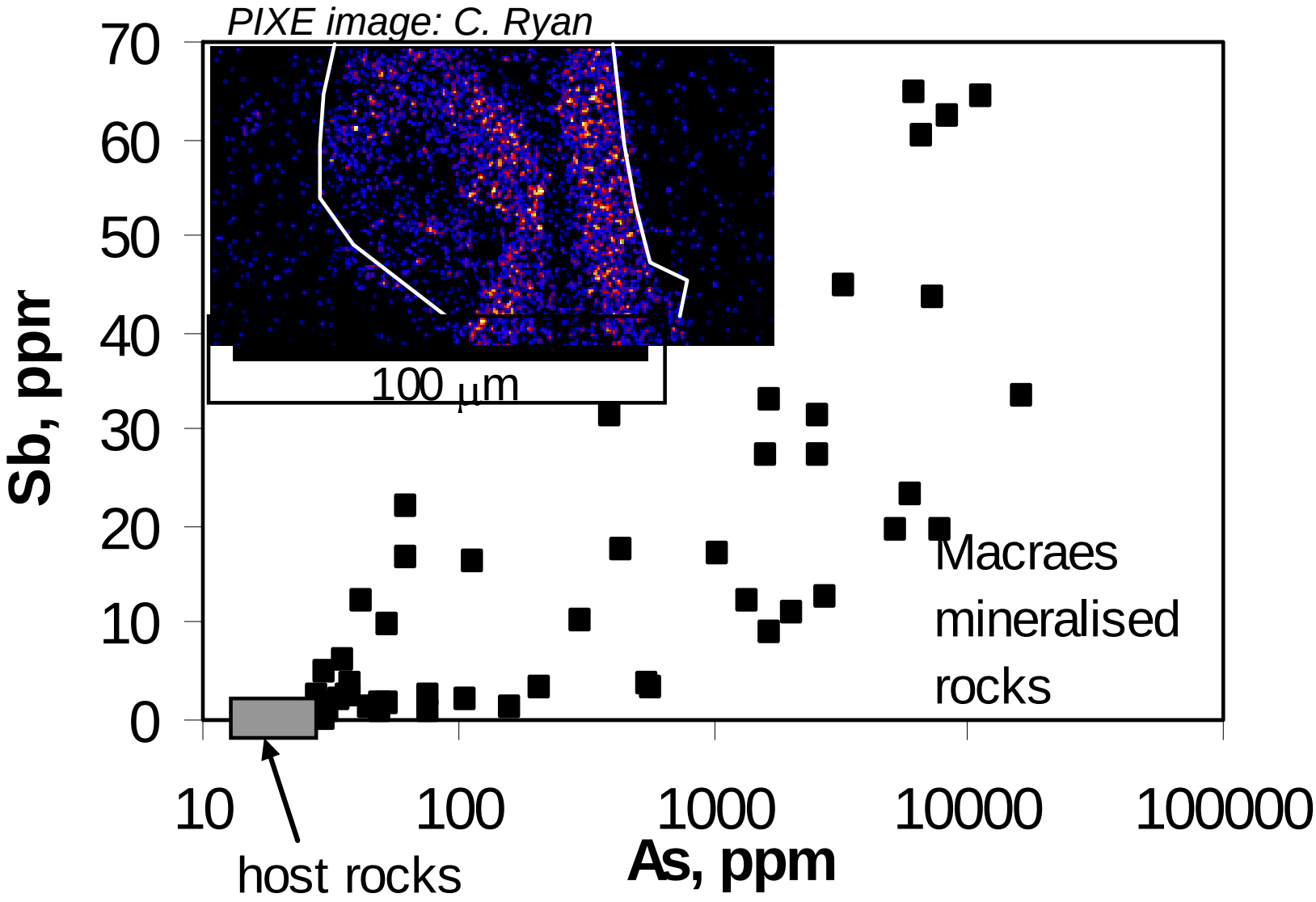
Difficult to detect in outcrop or hand specimen

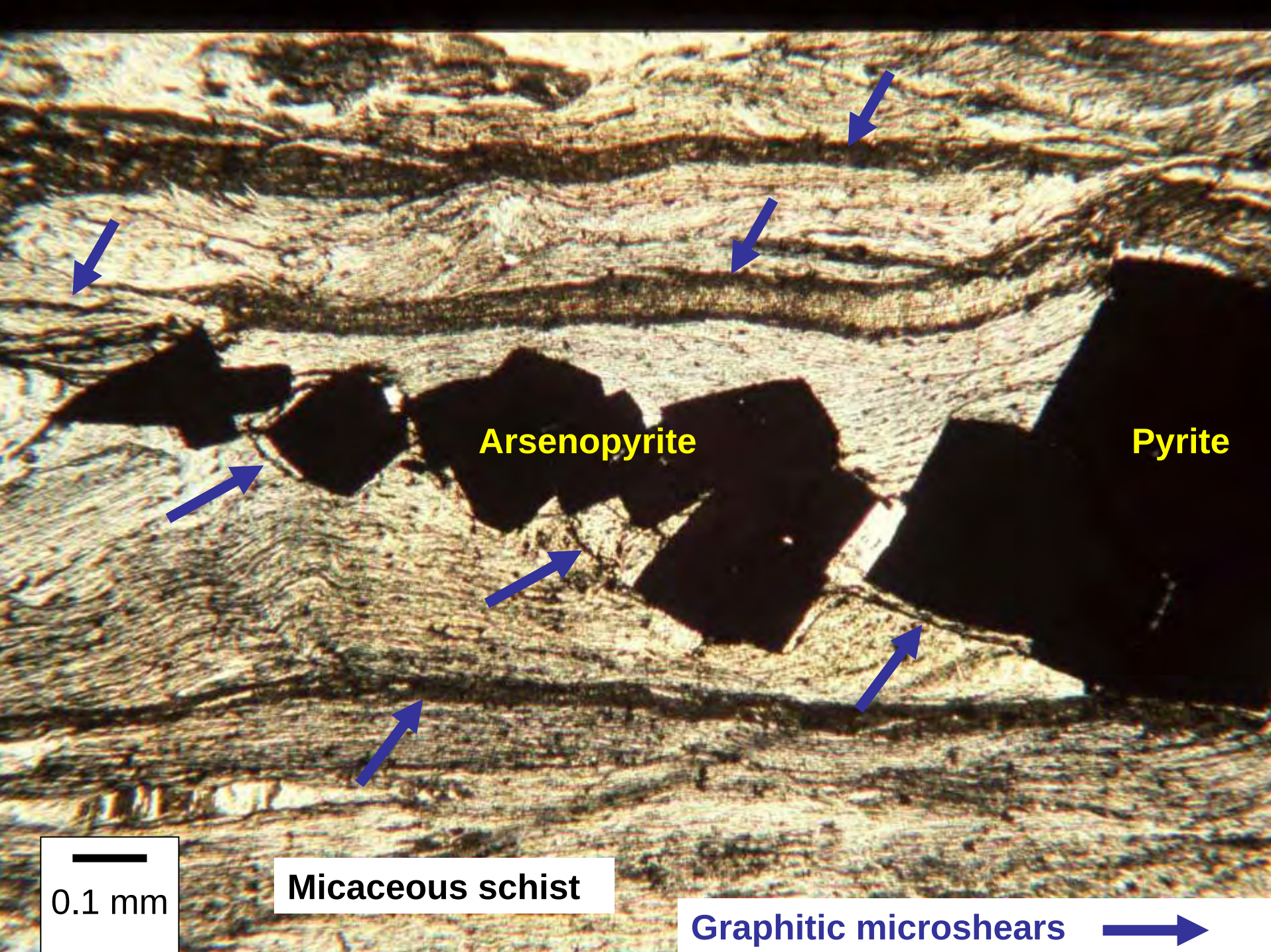
Well-defined shears are black (graphite, sulphides)


0.01 mm
GOLD
0.01 mm
GOLD

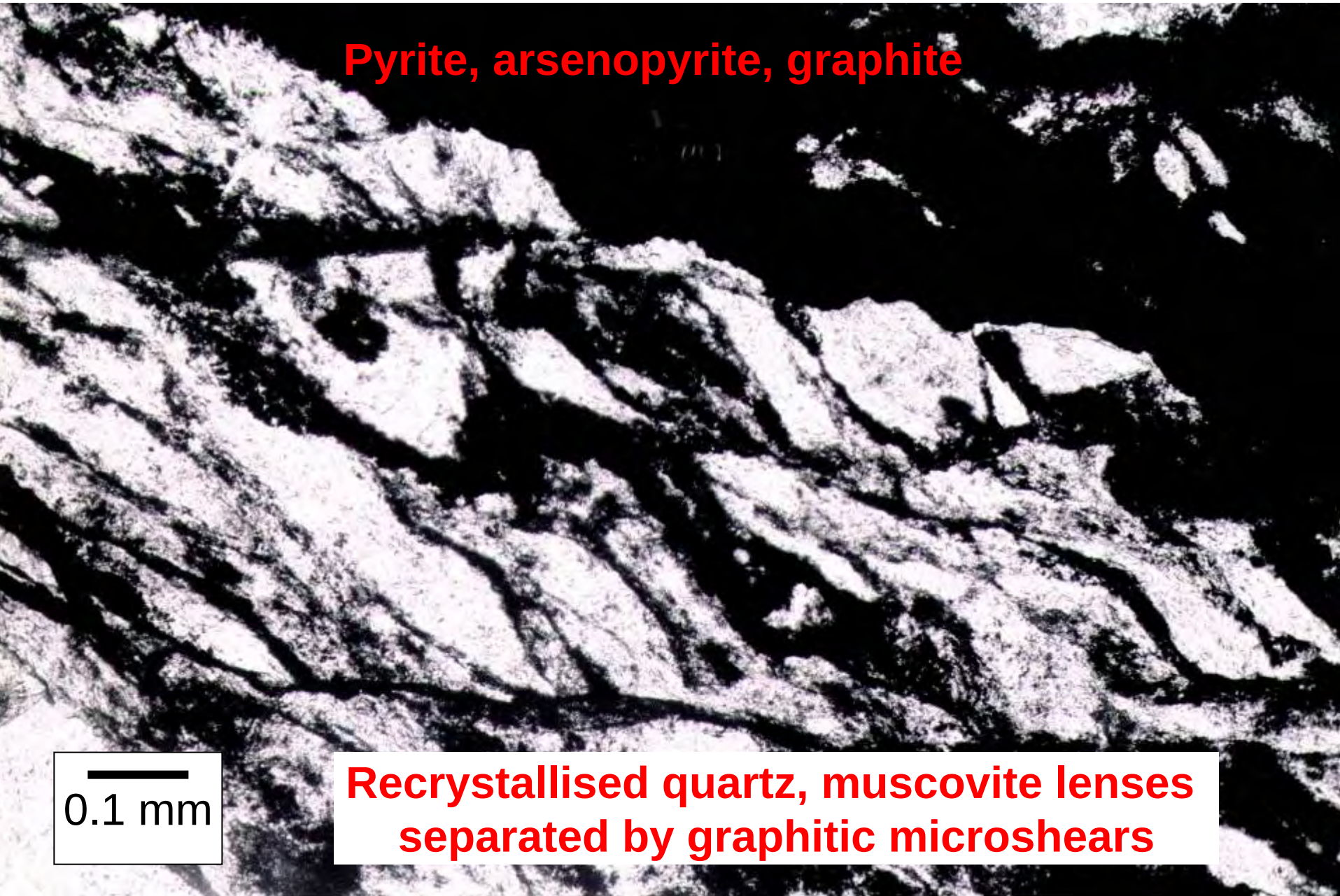

Subtle geochemical signature
Mineralised rock, ppm
Host rock, ppm
1000000
100000
10000
1000
100
10
1
1
10
100
1000
10000
100000
1000000
Si
Fe
Al
Ca
K
C
Mg
Na
Ti
S
Ba
As
P
V
Cr
Rb
Sr
Zr
Ni
Zn
Cr
La
Cu
Pb
Nb
Th
U
Uniform element
Si
Macraes
distinctive element
As

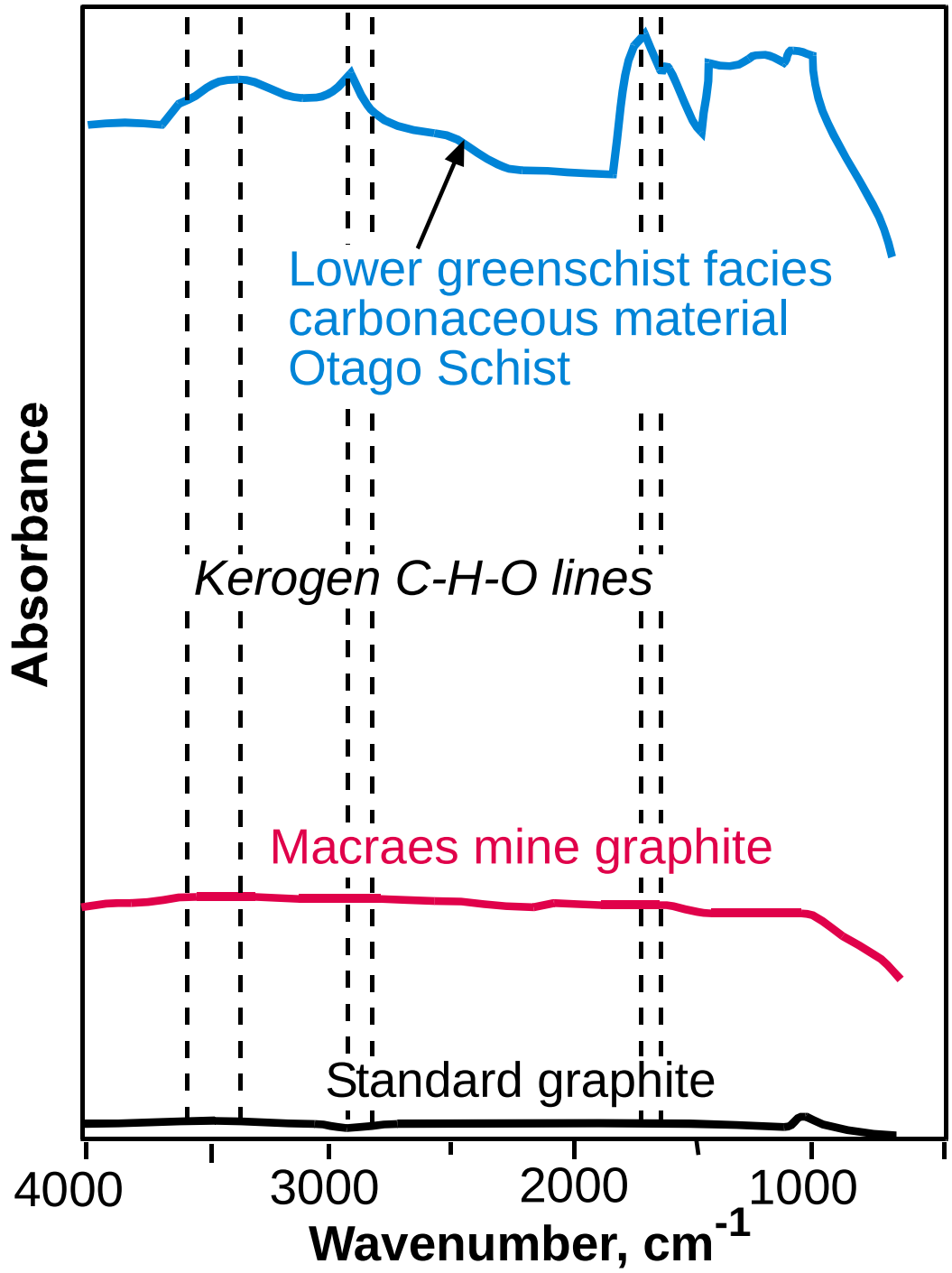
Sb locally enriched with As




Arsenopyrite
Pyrite
0.1 mm
Micaceous schist
Graphitic microshears

Intense late metamorphic alteration and brittle/ductile deformation





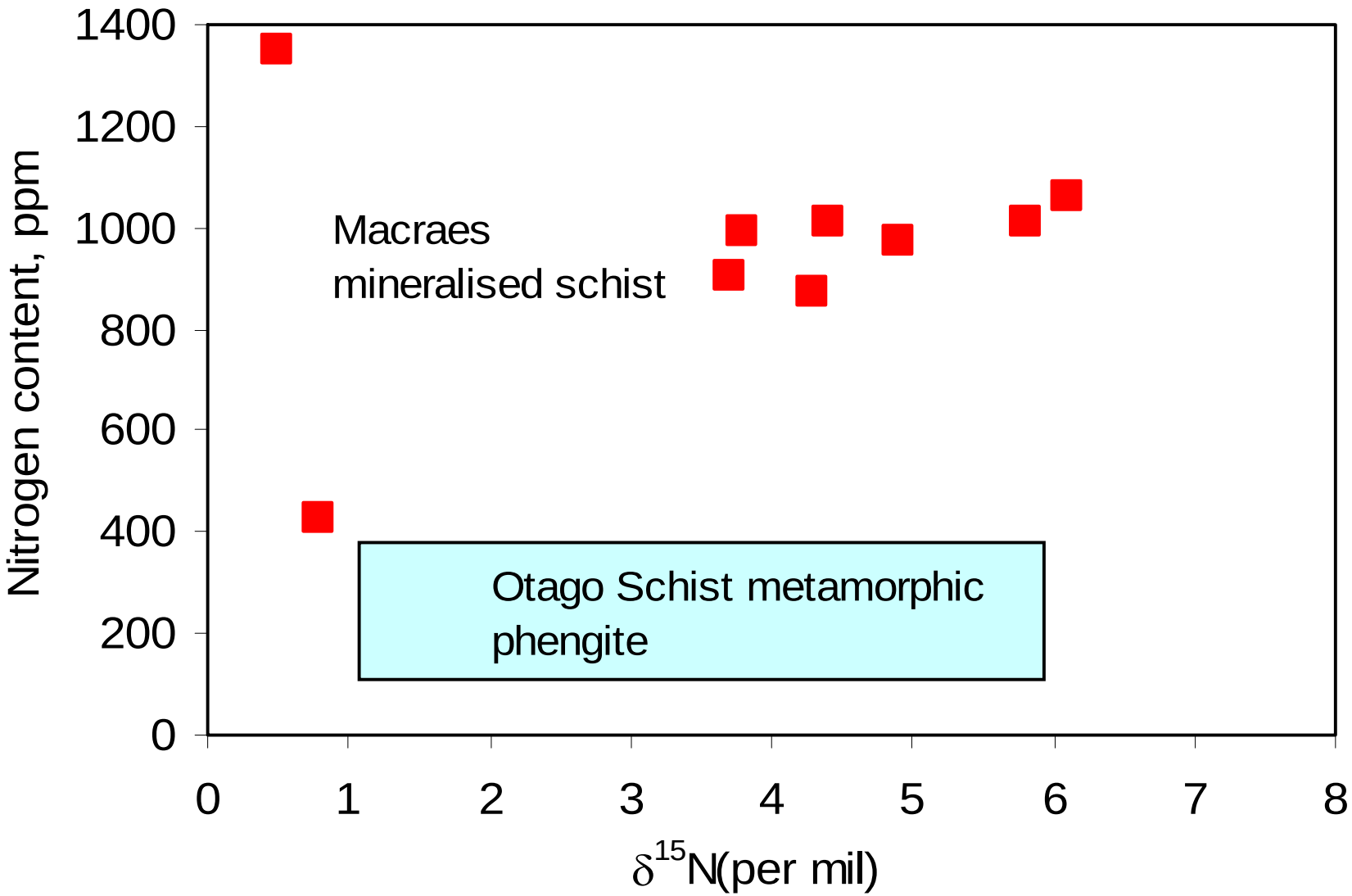
Infra-red spectroscopy

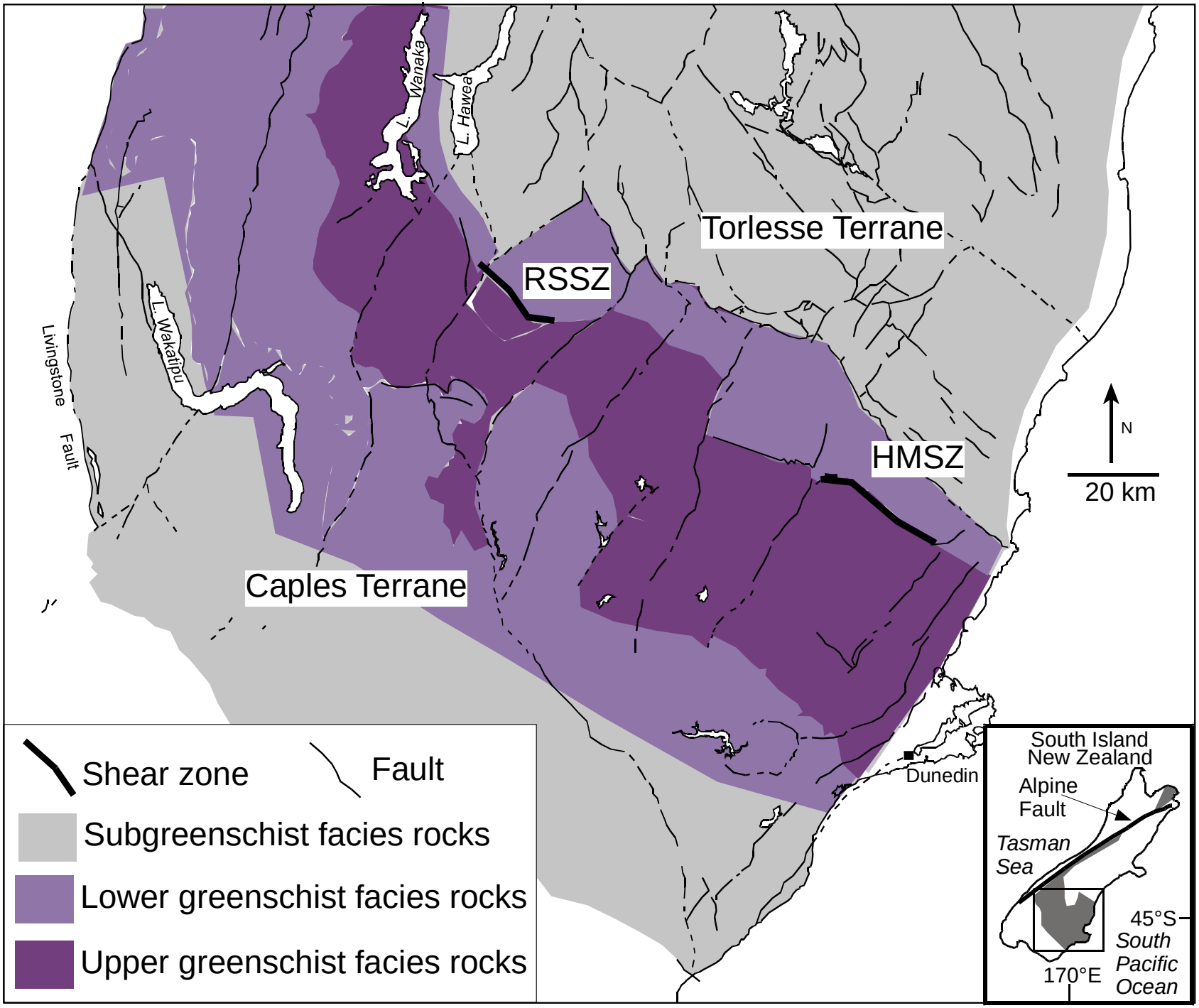
Graphitic host rock?

or hydrothermal addition?

$CH_4 + CO_2 = 2C + 2H_2O$

Elevated N content of micas

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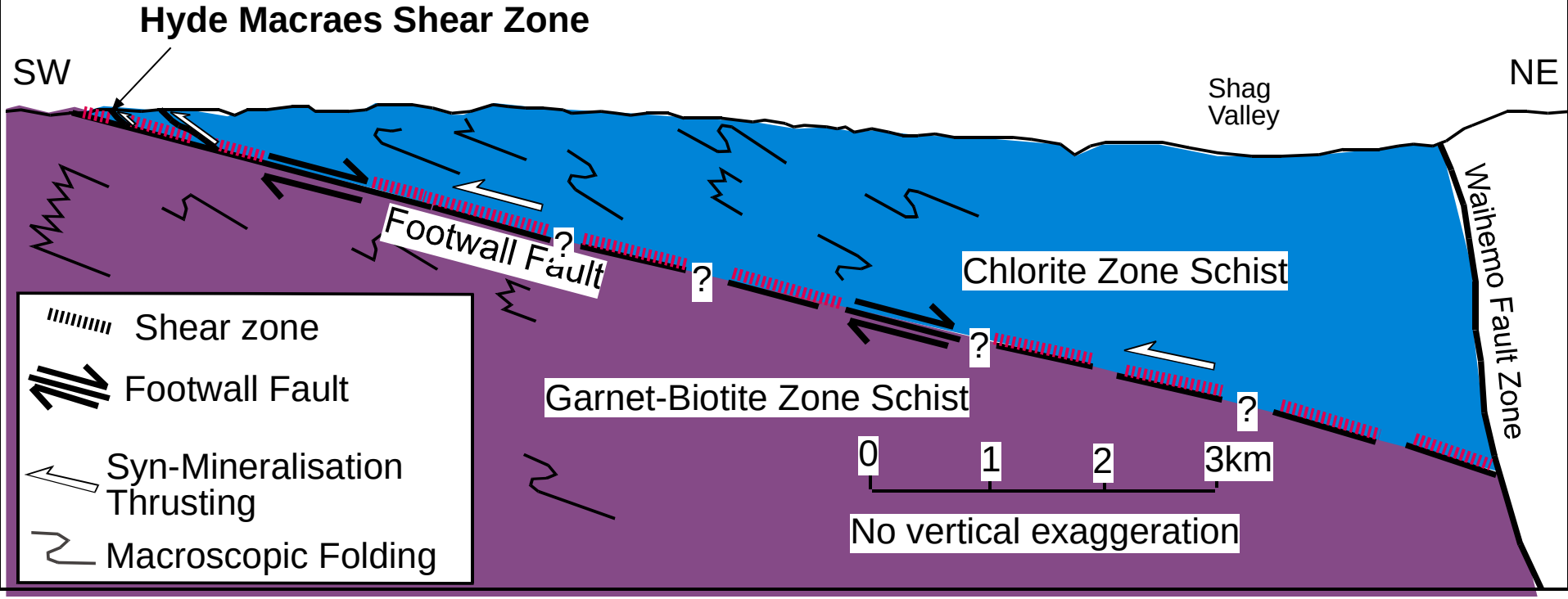
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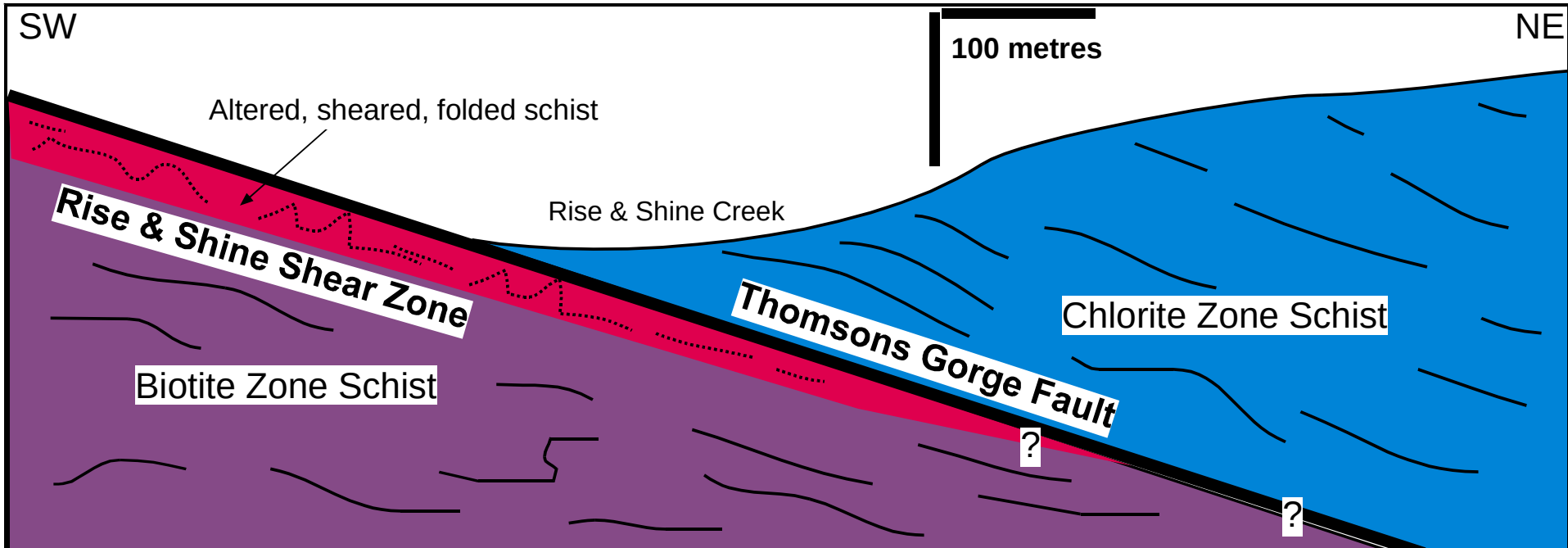
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metamorphic muscovite => hydrothermal muscovite

titanite => rutile + calcite + quartz

epidote => kaolinite + siderite + calcite

addition of ankerite

Fe-silicates + As, S in solution => pyrite + arsenopyrite

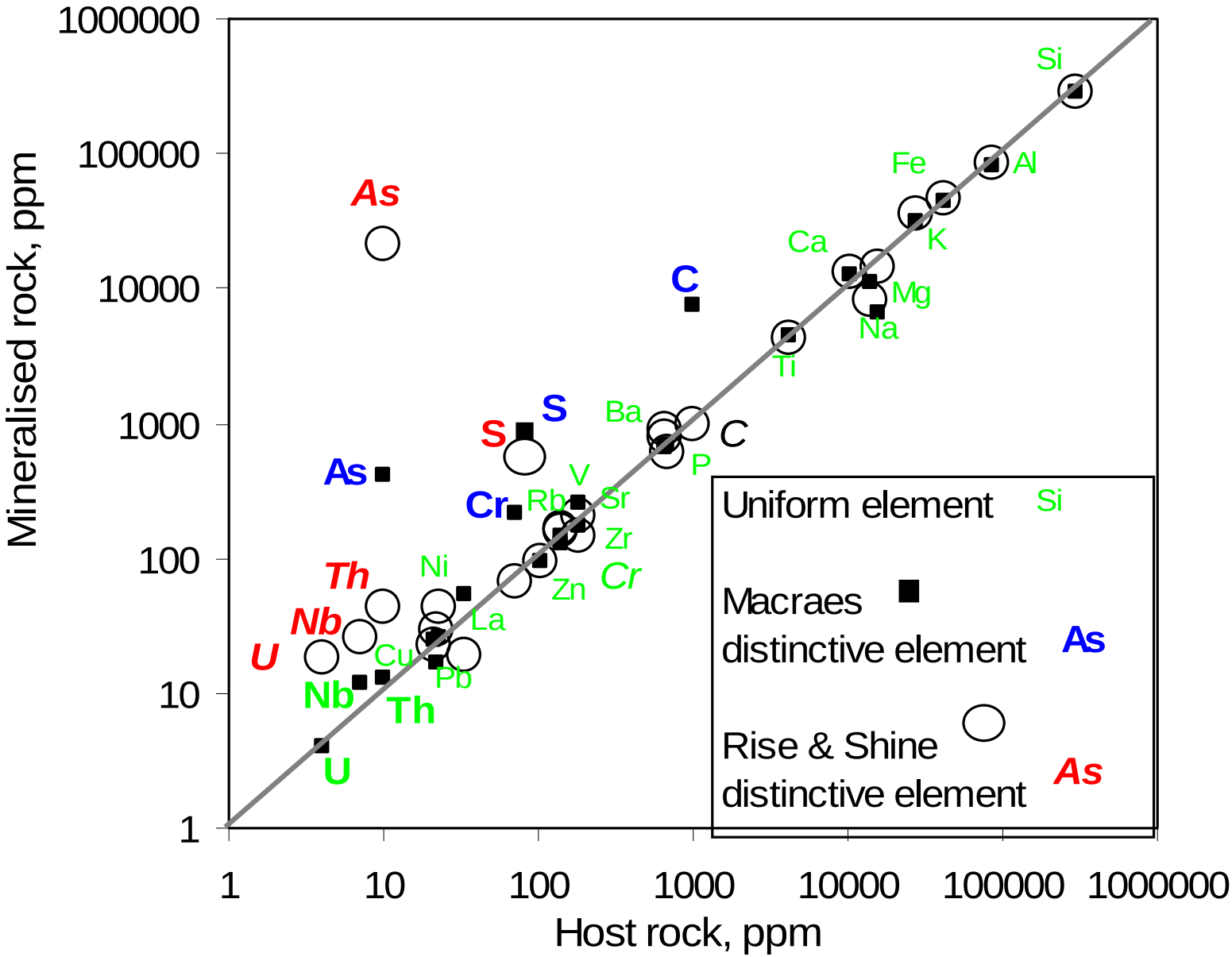
Fe-silicates + S in solution => chalcopyrite + sphalerite + galena

Subtle hydrothermal alteration, like Macraes

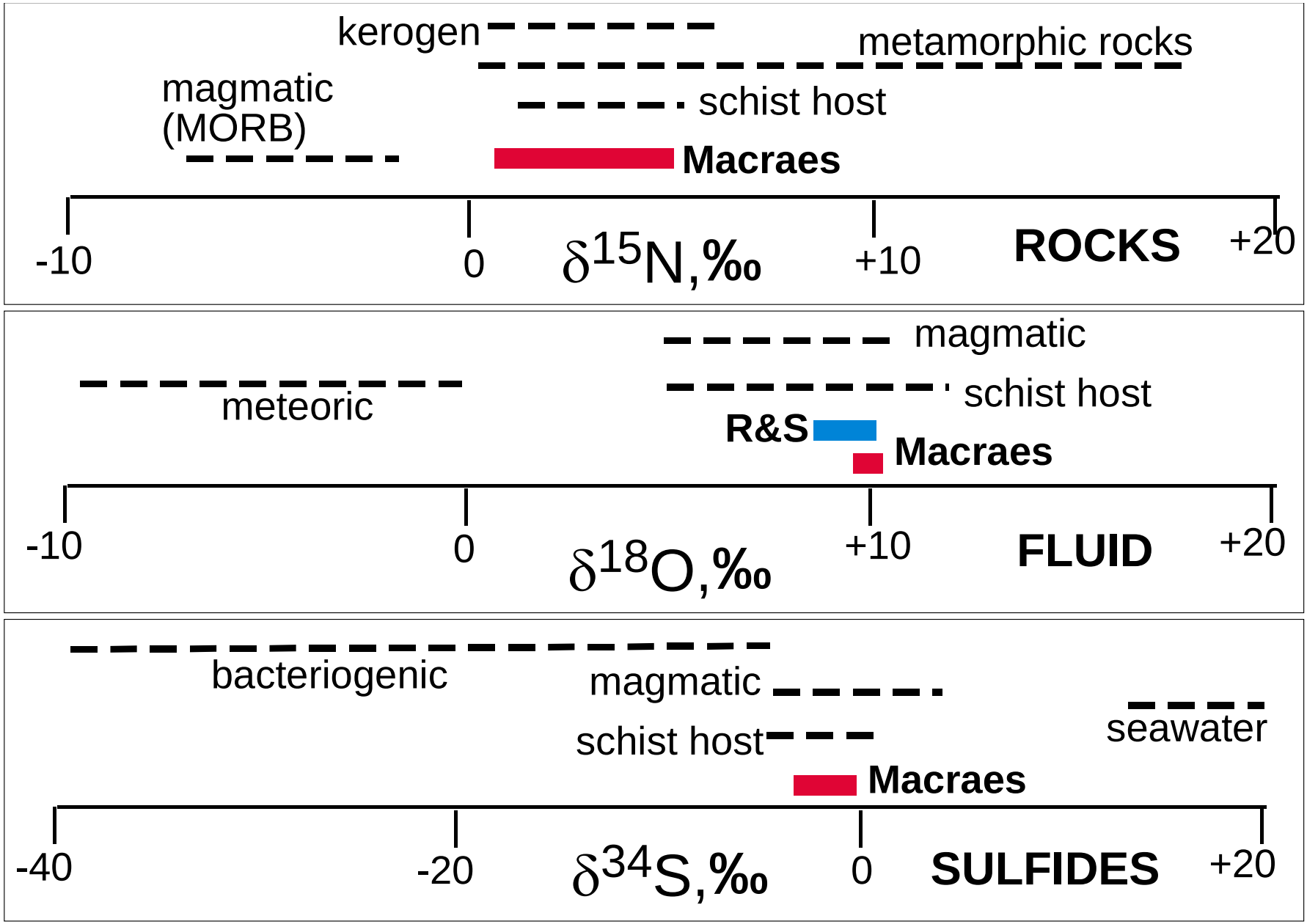
No graphite formation during mineralisation

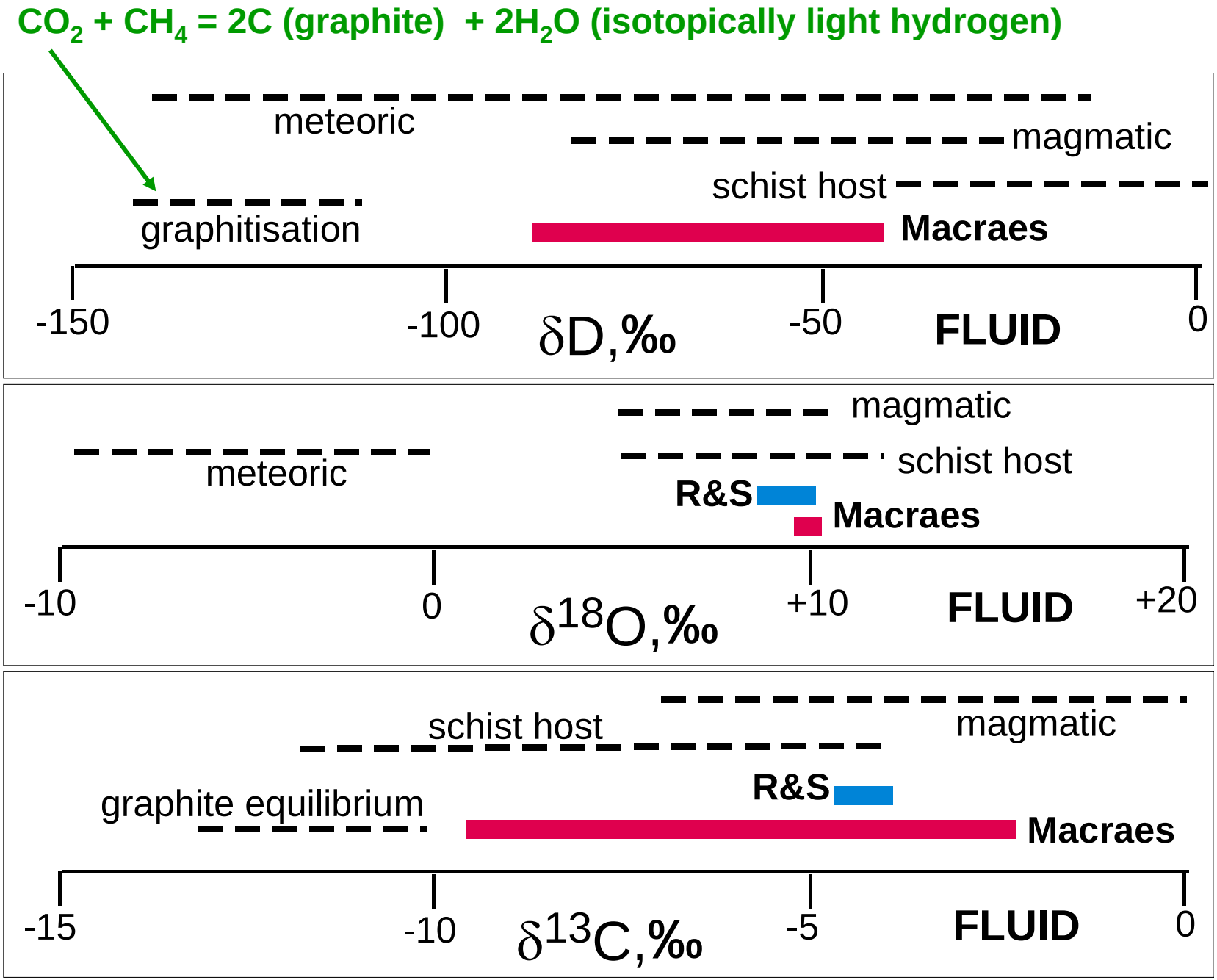
More prominent carbonate alteration than Macraes

Rise & Shine shear: geochemically subtle, but different from Macraes



N, O, S isotopes same as host rocks




$CO_2 + CH_4 = 2C$ (graphite) $+ 2H_2O$ (isotopically light hydrogen)
meteoric
magmatic
schist host
graphitisation
Macraes
-150
-100
δD,‰
-50
FLUID
0
magmatic
meteoric
schist host
R&S
Macraes
-10
0
δ18O,‰
+10
FLUID
+20
schist host
magmatic
R&S
graphite equilibrium
Macraes
-15
-10
δ13C,‰
-5
FLUID
0

Conclusions

- Late metamorphic shears without quartz veins are important exploration targets for Au, BUT:
- Alteration is geochemically subtle
- Two nearby shear zones are geochemically different
- Arsenic is the most prominent indicator, but it is localised in the most prominent shears only
- Reactions in common:
  Formation of rutile from titanite, and
  Fe-carbonate from epidote