Hydrothermal alteration and gold mineralization in the Witwatersrand : when, where and why?

Greg Hall, Golden Phoenix International Pty Ltd
Russell Mason, Tectonite Enterprises Pty Ltd

In Memory of Vic Wall

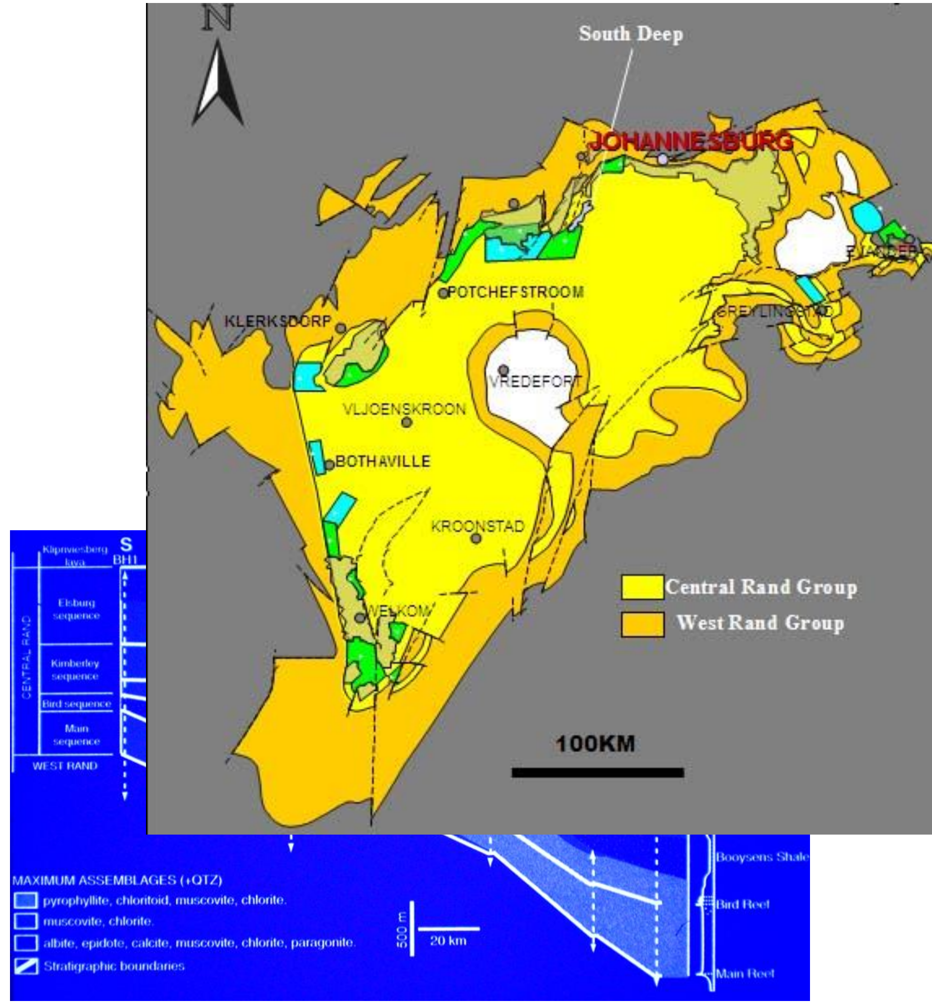
Placer: No
Dome: Yes

Acknowledgements

- Thanks to
  - South Deep geology staff
    - Theo, Adrian, Des, Kwazi, Leonard, Paul, Raymond, Romany, Thaulani
  - Randfontein Estates/Harmony for access to Lindum Reefs pits

Witwatersrand

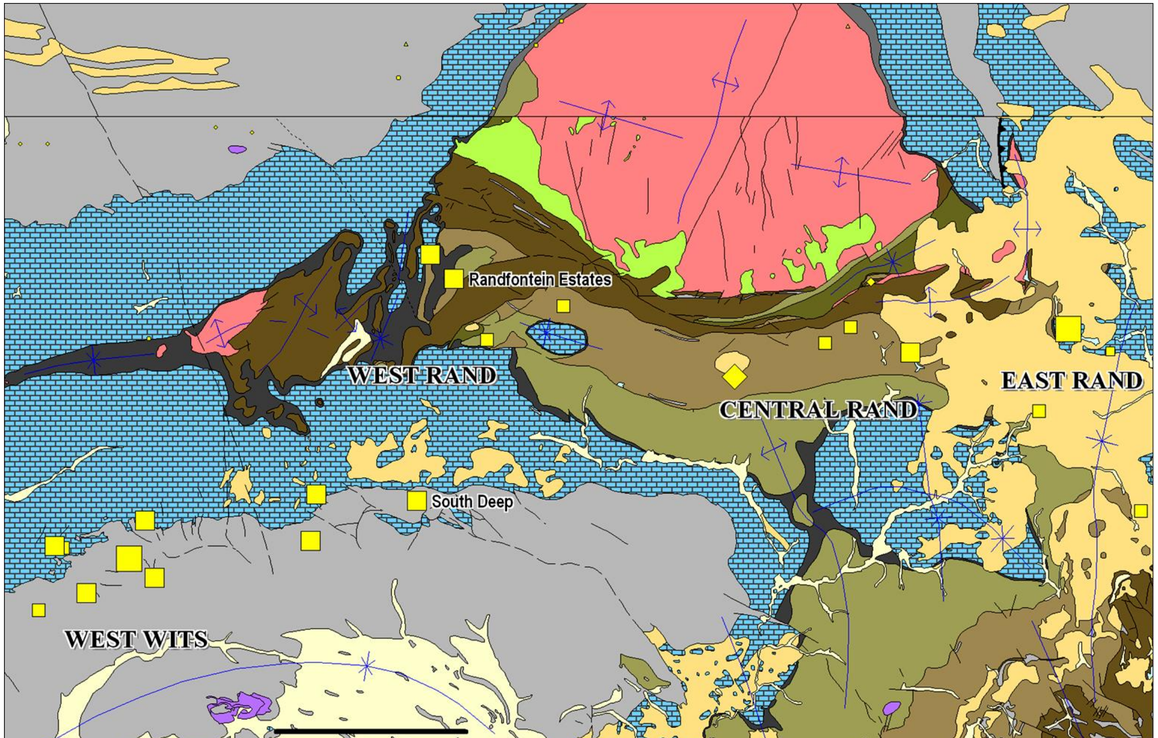
- Vast goldfields,
- enveloped by even larger hydrothermal systems,
- to which gold mineralisation has been related
    - C. Baring Horwood (1917) “Gold deposits of the Rand” *Giffin, London*
    - Phillips & Law (1980’s-)
    - Leeds Group, Anglogold (1990’s-)



Barnicoat & others,1997

Structural elements, geometry, history

- Early extensional faults (healed); uncommon
  - ? Platberg age
- Compressional deformation features
  - commonly low strain
  - widespread in Central Rand & Lower Transvaal Groups
  - recognised in core, u/g, pits etc., and comprise
    - foliations/phyllonite zones, small displacement thrusts, imbrication zones
    - earliest mappable mesoscopic structures
    - defined by near peak metamorphic/alteration mineral assemblages (eg. pyrophyllite- mica)

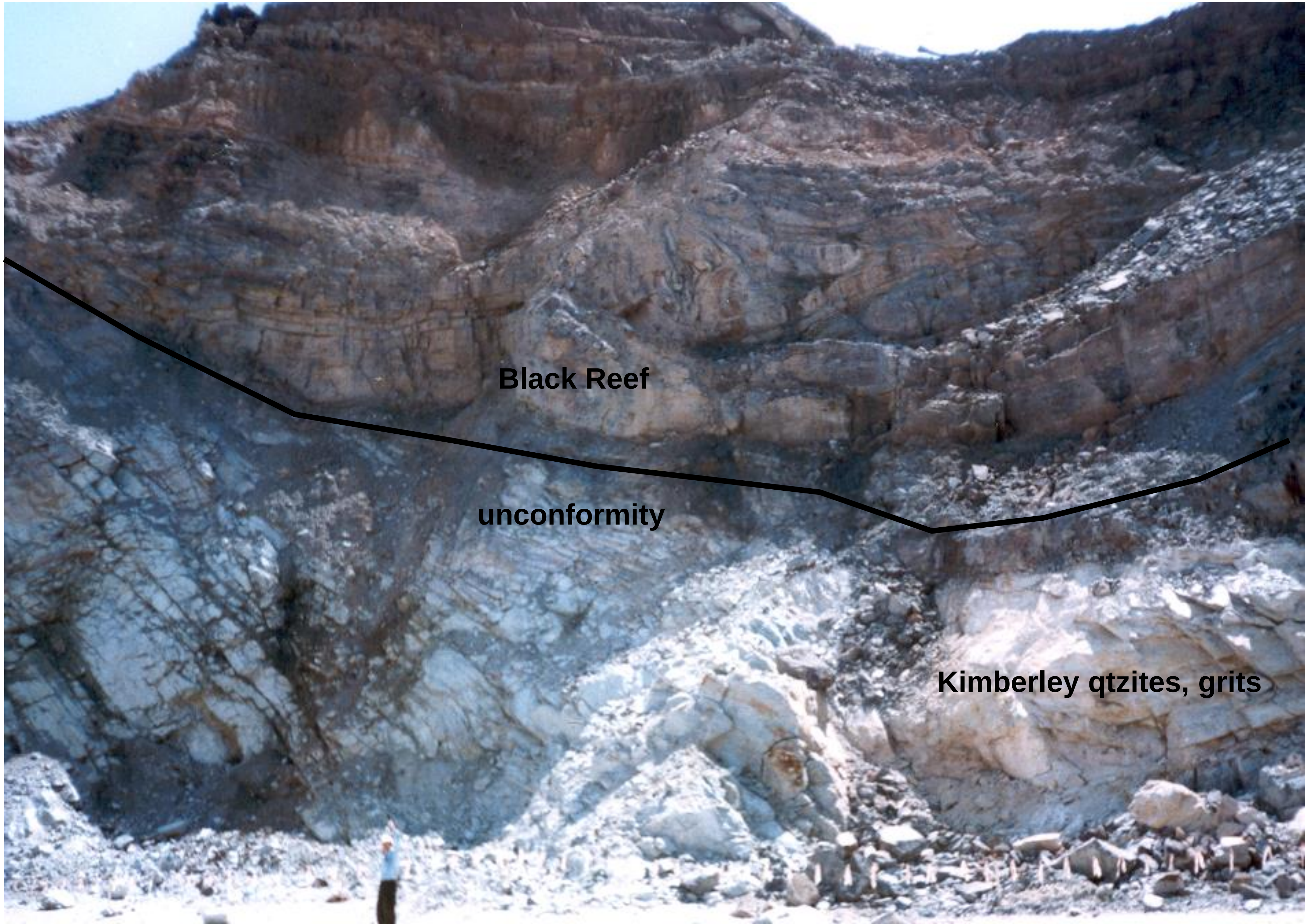


Structural elements, geometry, history

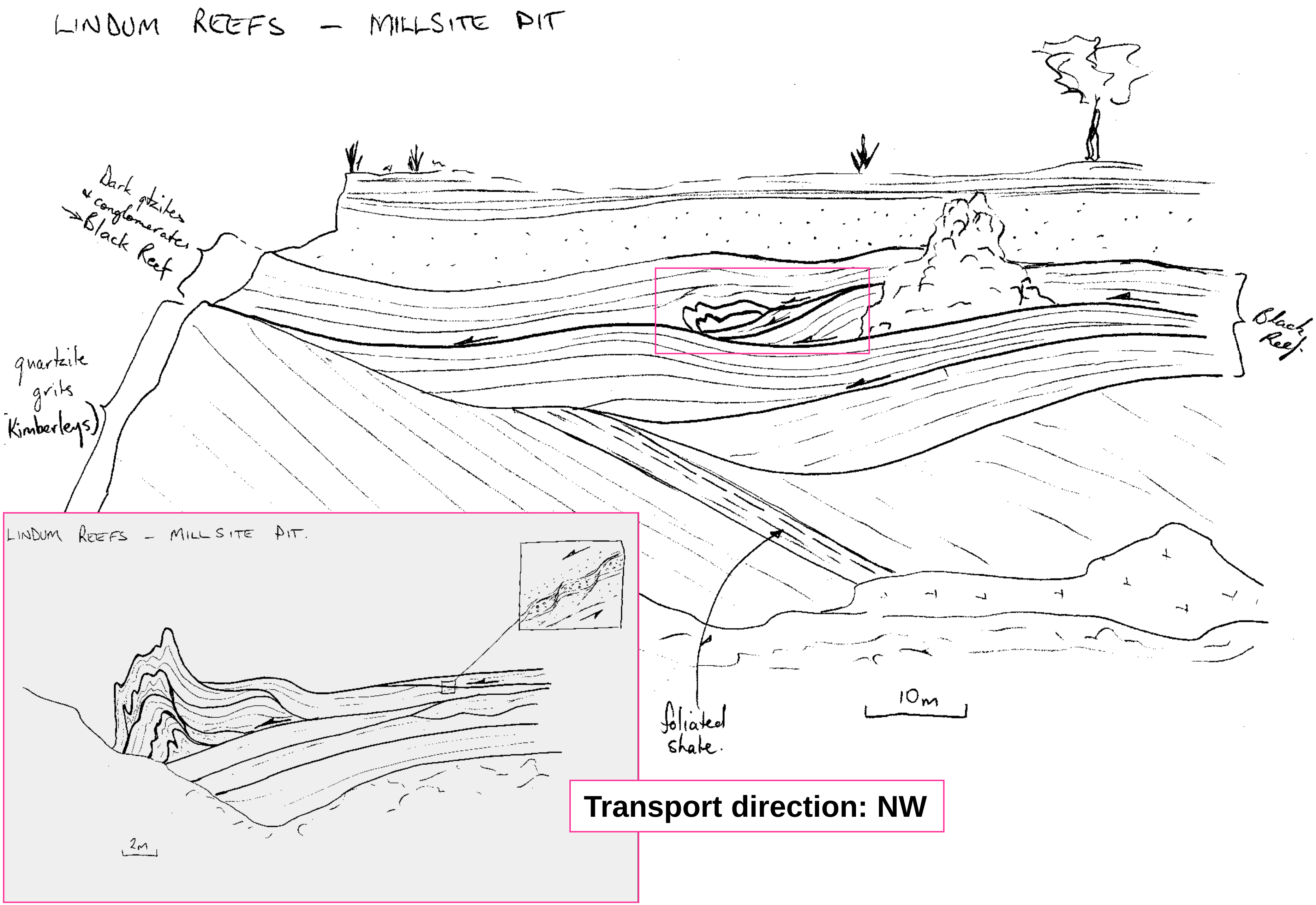
- **Thrust/fold, imbricate systems**
  - **uncommon features, focused around major unconformities/lithological contrasts (eg. 'Lava', Black Reef)**
  - **verge**
    - **east (duplex fracture arrays: 87,2W; thrust: 90,9W)**
    - **north (Western Areas surface; South Deep)**
    - **WNW (South Deep, seismic interpretation)**
    - **NW & NE (Lindum Reefs)**
    - **NE/NNE (New Modder)**
  - **related deformation produced fold interference patterns in Transvaal (& Central Rand Group?)**
  - **reflects both WNW & (?later) N/NNE shortening**

- **Foliations, phyllonite zones**
  - **subparallel to discordant with layering**
  - **common/locally strongly developed in psammites, pelites between conglomeratic packages**
    - **uncommon in conglomerates**
    - **reflects lithology-dependant strain partitioning,**
      - **different deformation mechanisms of conglomerates versus psammites, pelites**

Millsite pit: Lindum Reefs

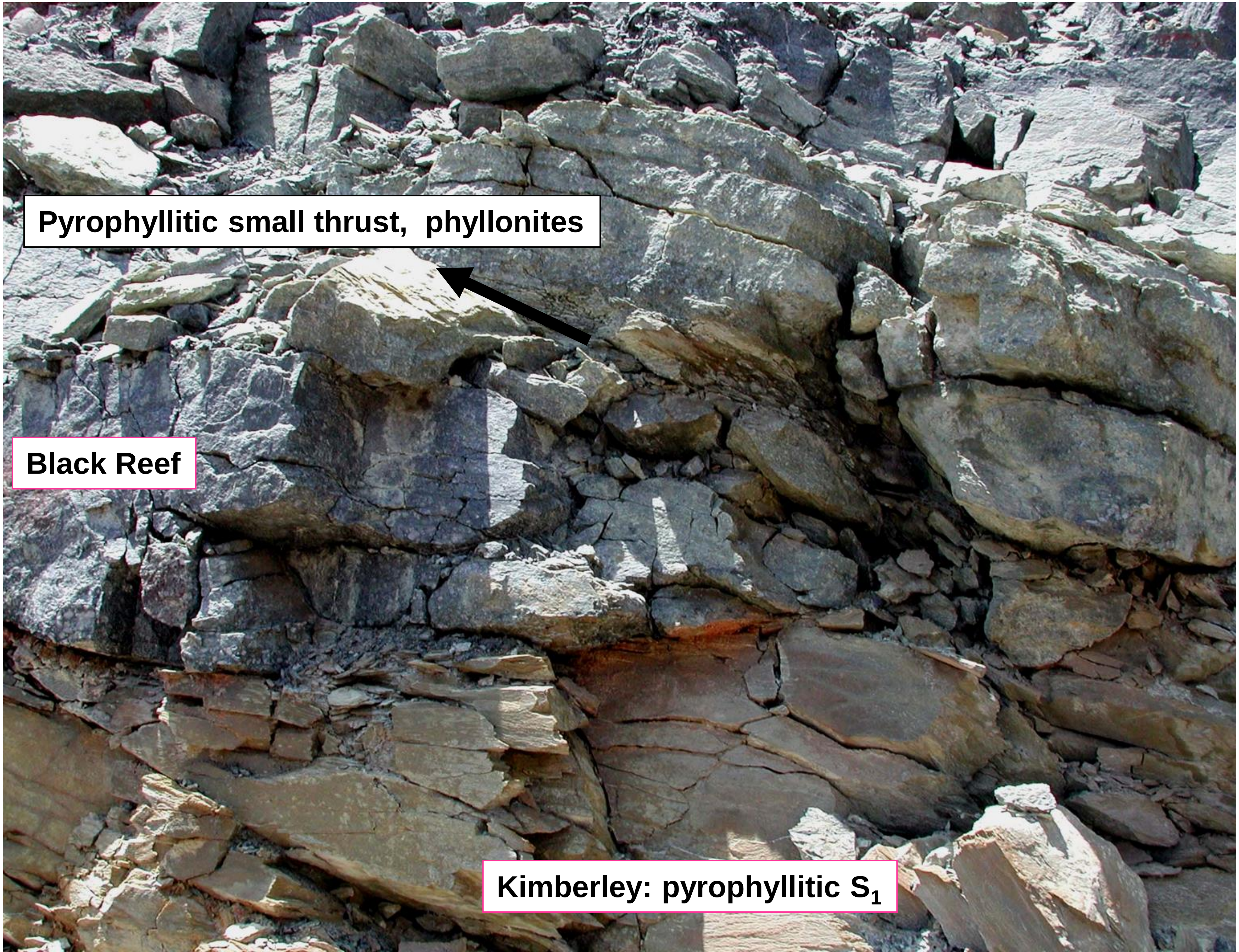


Millsite pit: Lindum Reefs



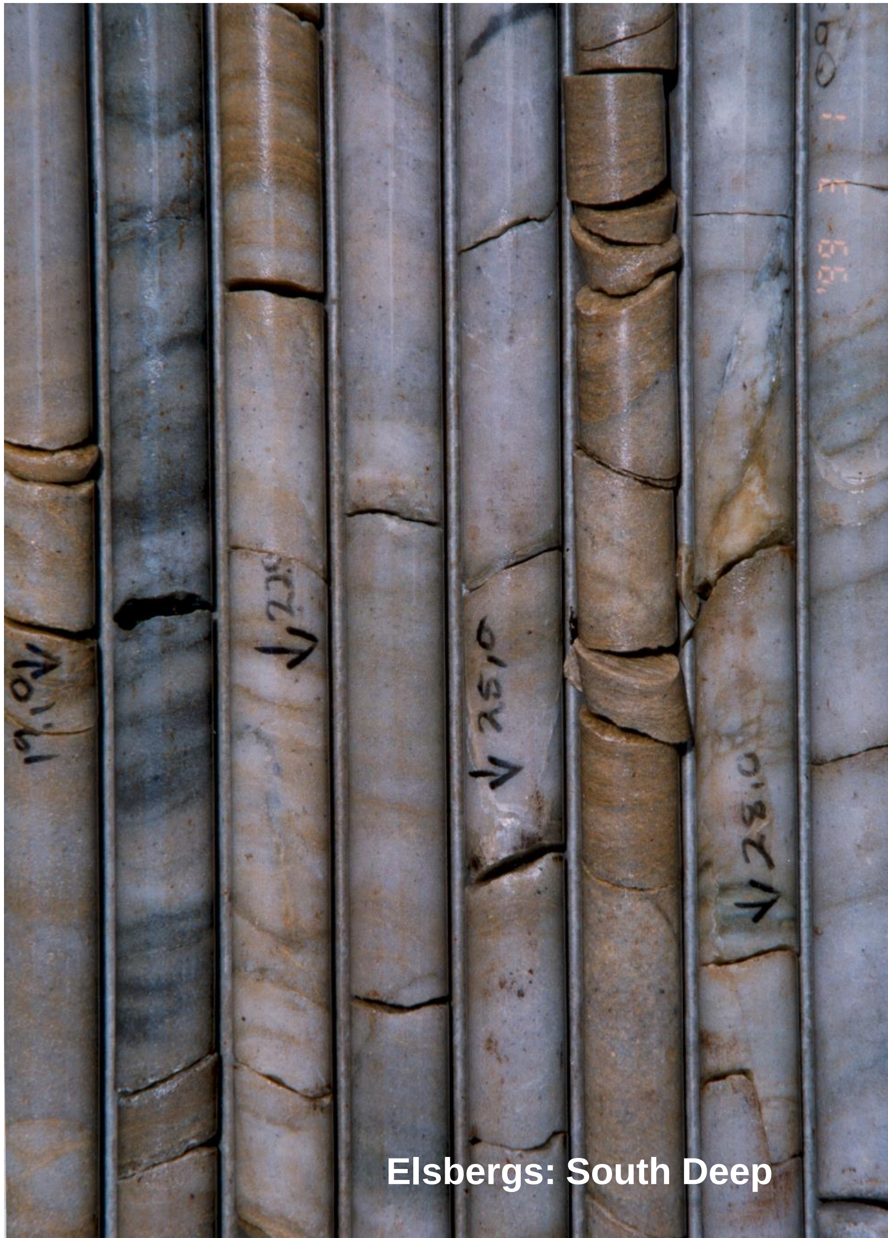
Transport direction: NW

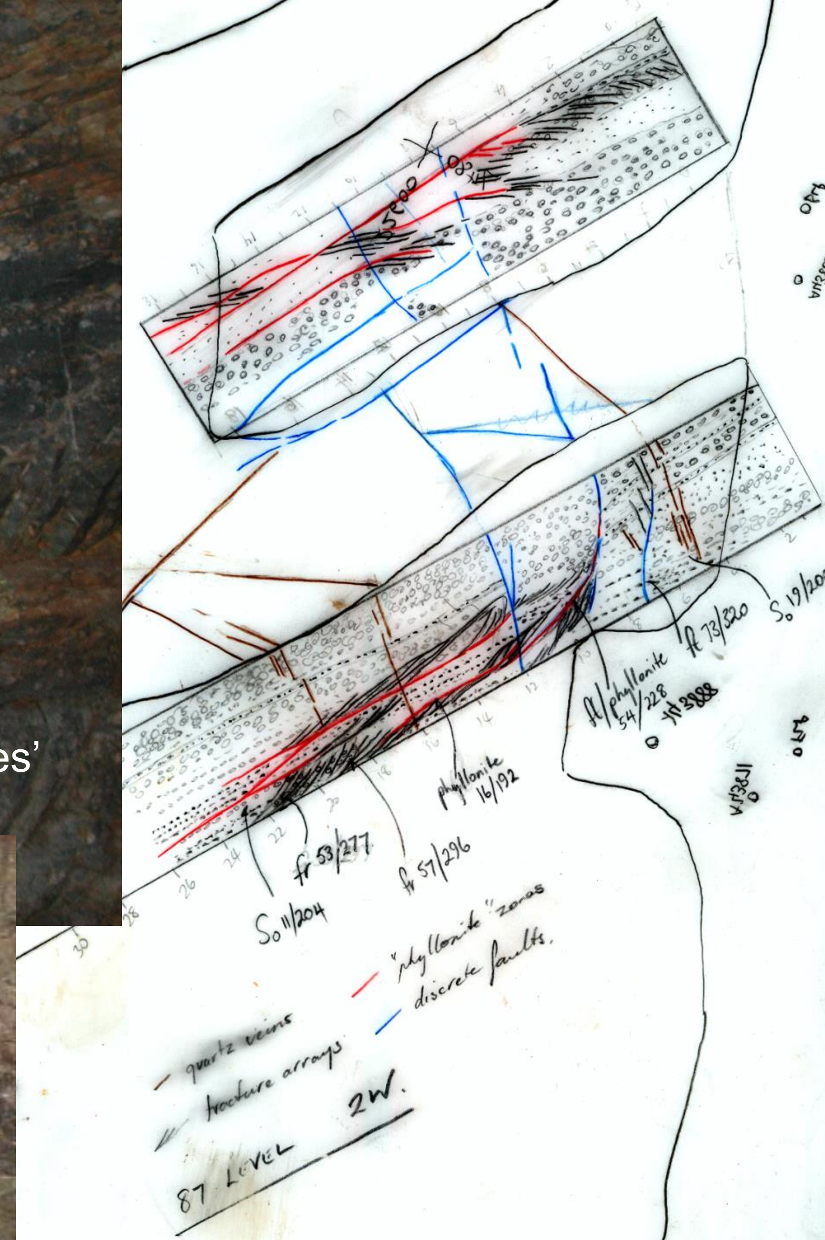
Millsite pit: Lindum Reefs



Structural elements, geometry, history

- Foliations, phyllonite zones
    - Typically anastomosing/ symmetrical fabrics,
        - lack evidence for large shear strains
        - related to regional shortening
    - defined by metamorphic/alteration minerals (micas, pyrophyllite)
    - mutually overprinting relations with alteration-related stylo-veins
    - same fabrics in Lower Transvaal, Central & West Rand Groups



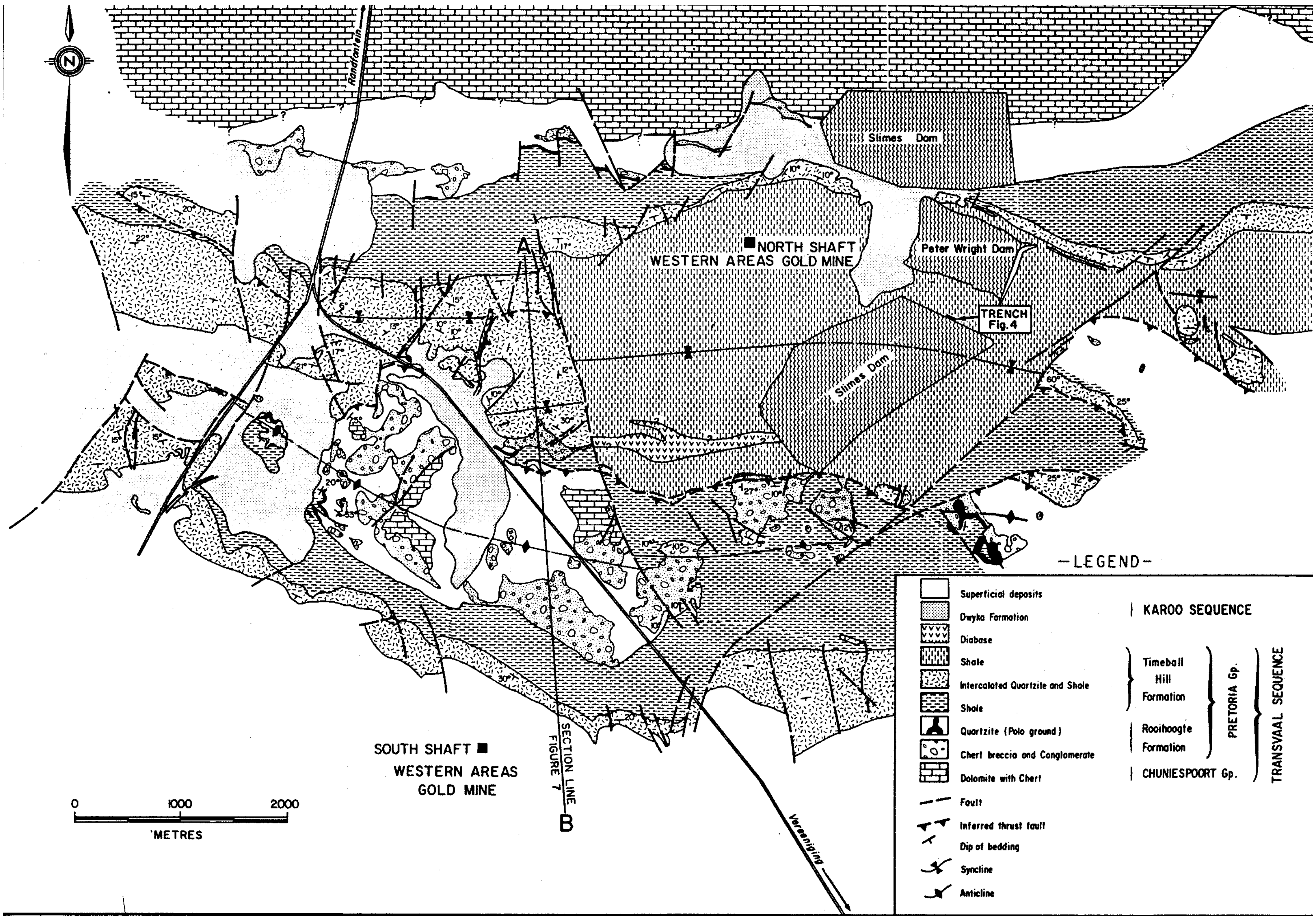


Thrust, phyllonite & fracture arrays, South Deep

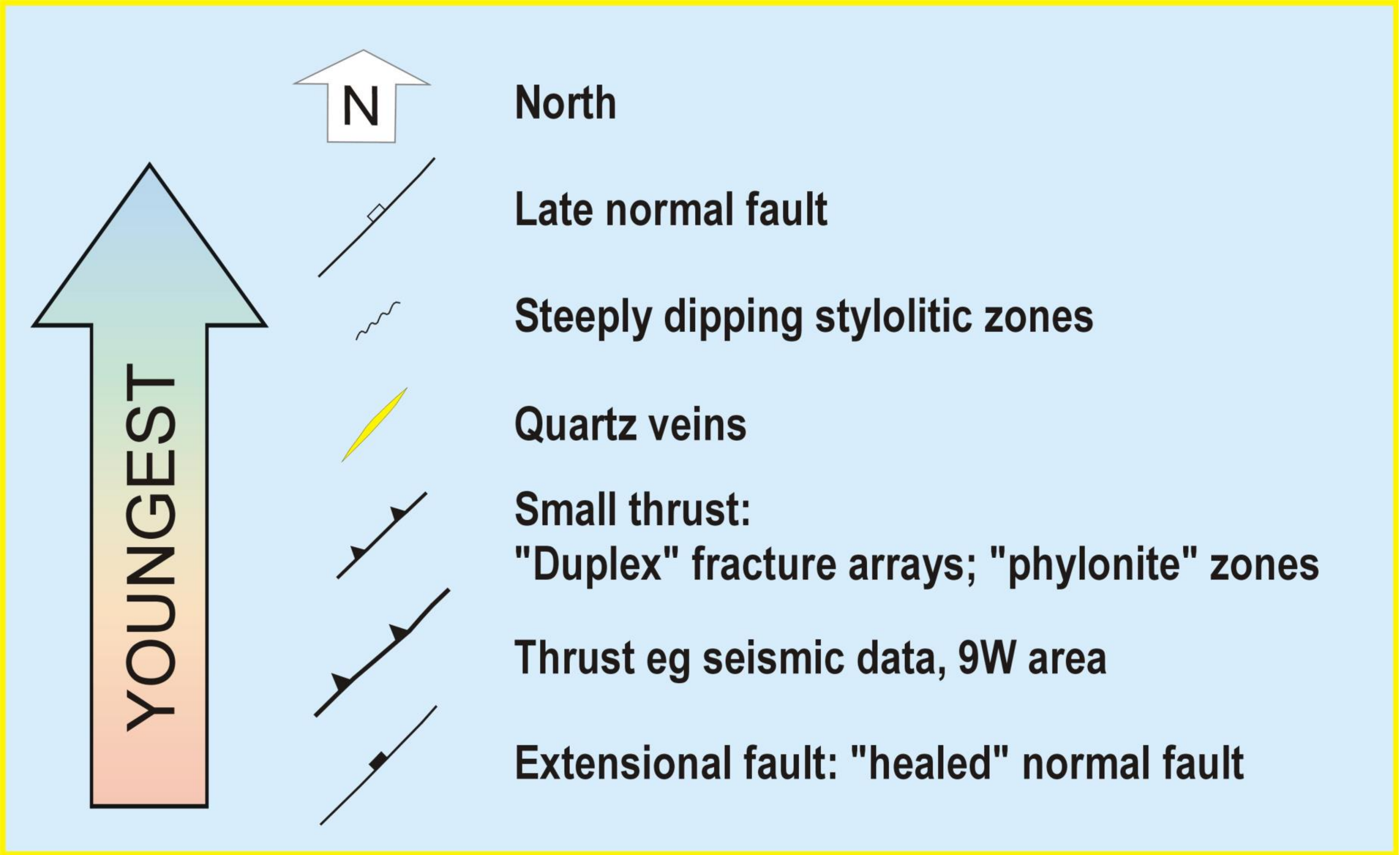
Structural elements, geometry, history

- Late fault systems
  - truncate/displace shallowly dipping structures
    - post-Transvaal movements, evident in Western Areas surface geology
  - commonly relatively steeply dipping
    - but shallowing evident in some structures
  - metres to tens metres displacement, mainly dip slip
  - ~NW trending
    - earlier than/overlap with
  - ~NE-NNE trending
    - mainly normal displacements
  - ~E-, ENE trending
    - wrench component
  - pseudotachylite-bearing
    - late reactivations of steep & shallow structures

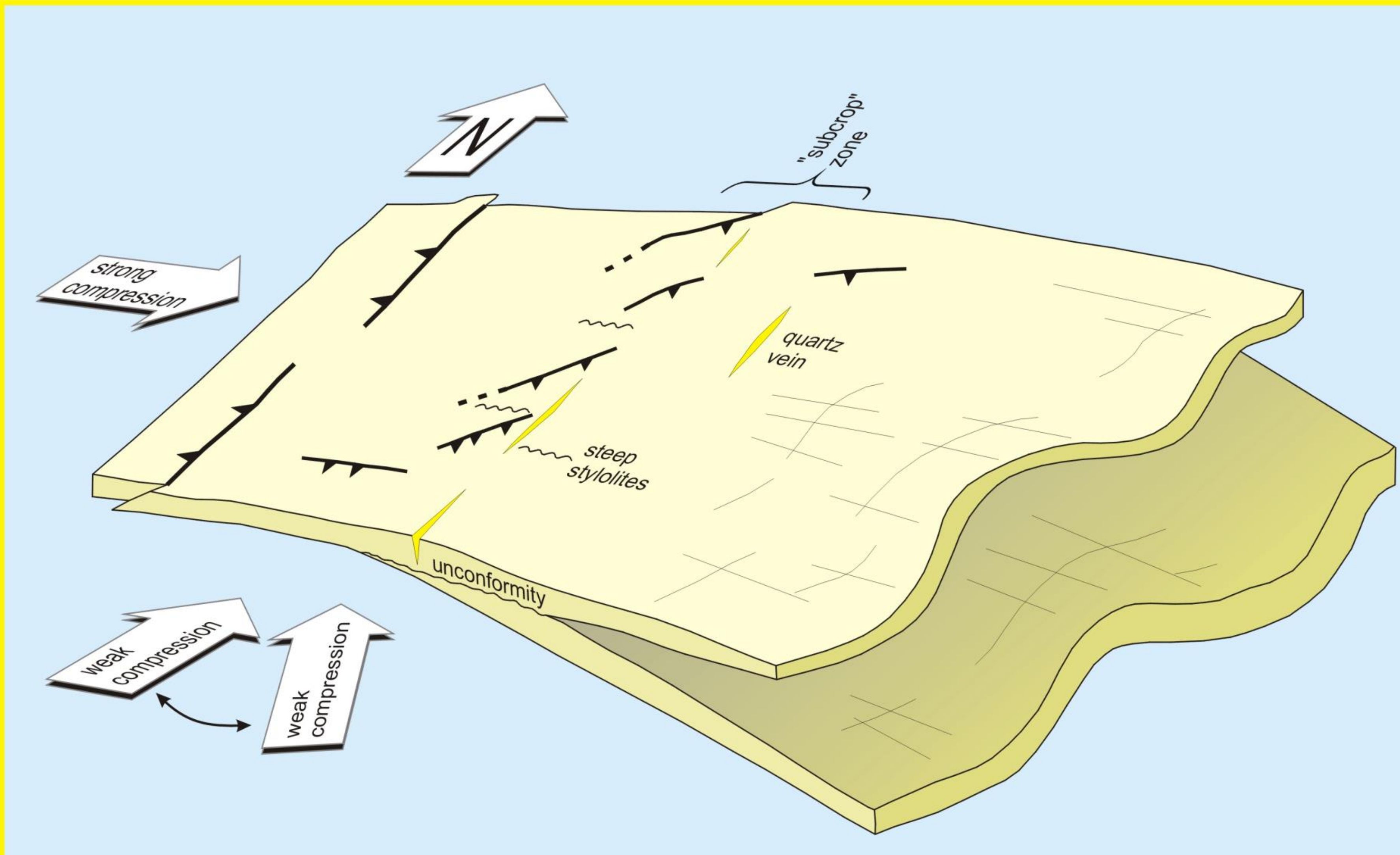
South Deep Mine: surface geology



Structural history & kinematic interpretation



Geometry of compressional structures

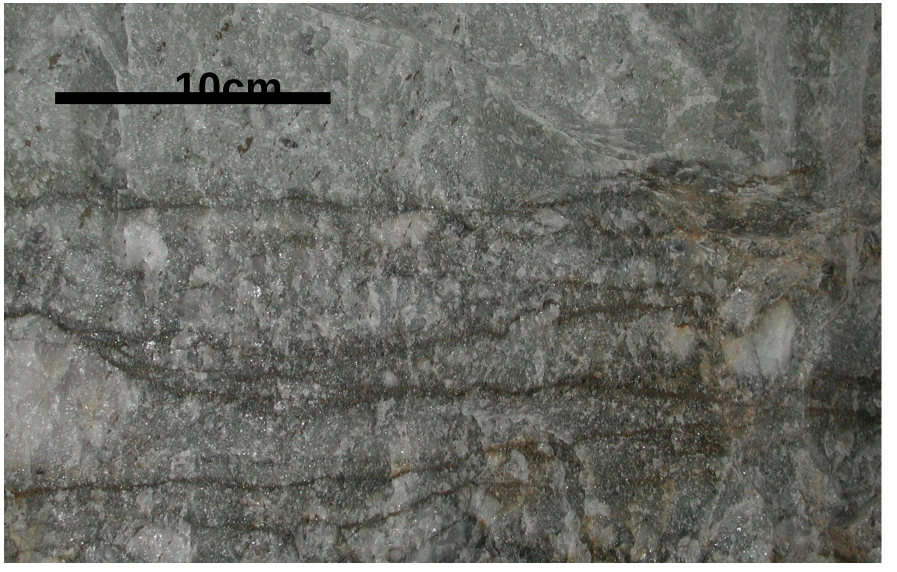


Structural elements, geometry, history

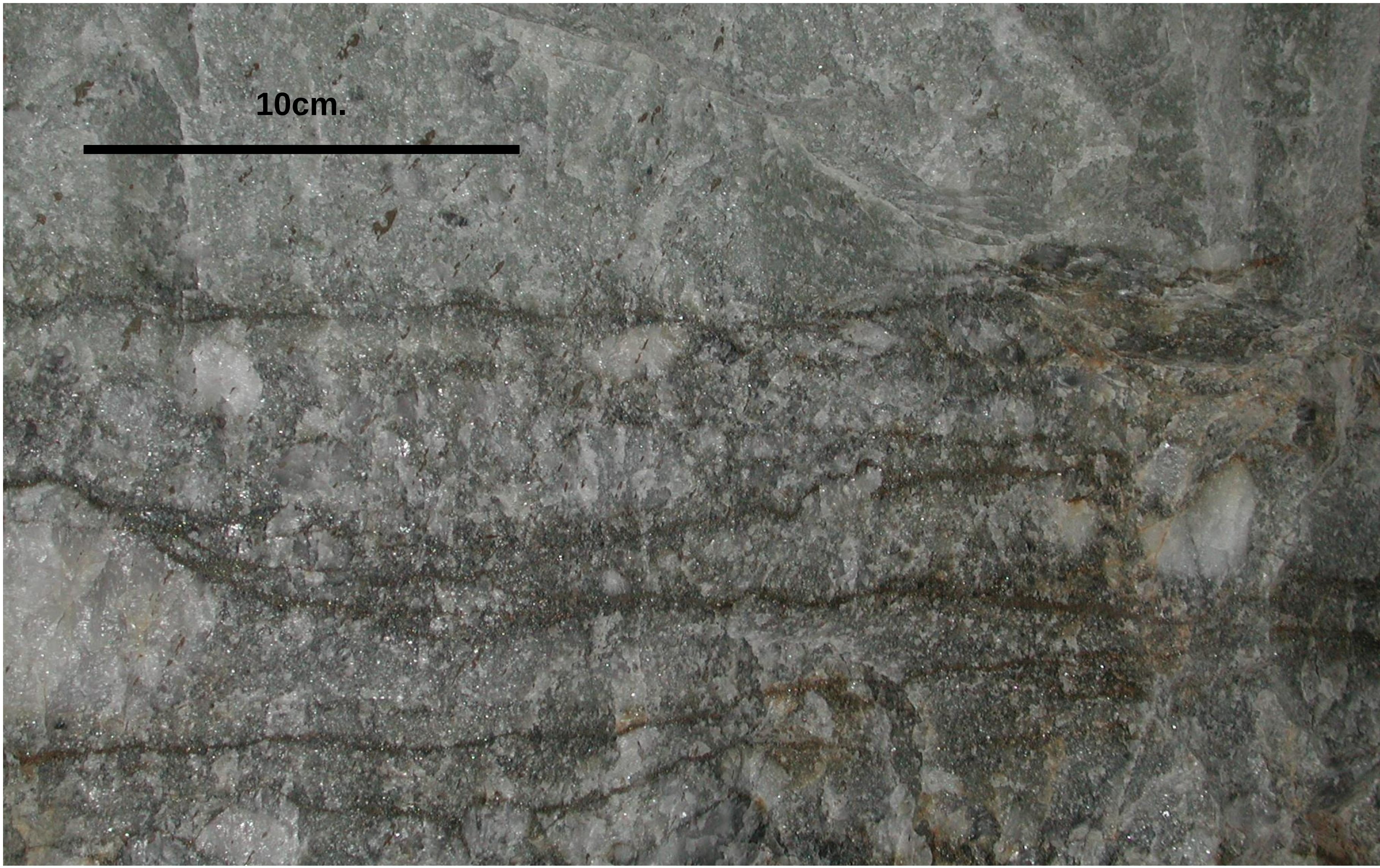
- **West Rand (& most Witwatersrand & Transvaal Supergroups)**
  - low bulk strain, but strain partitioning at all scales
    - from conglomeratic packages, Ventersdorp lavas locally to
    - regional N-S (& ?E-W) partitioning structures
      - separate major goldfields
      - bound differing structural blocks
      - may reflect reactivation of early basinal/basement structures
  - uncommonly weak regional shortening under greenschist facies conditions (6-10kms. burial)
    - post thick Transvaal Group cover
- **These features of the Witwatersrand Goldfields are major factors in the distribution and evolution of hydrothermal systems**

West Rand: alteration

- **Stylo-veins & their alteration envelopes**
  - mainly irregular, stylolitic morphologies
  - concordant to discordant with bedding
  - mutually overprinting relations with foliation/phyllonites
  - comprise mica +/-pyrophyllite, pyrite (pyrrhotite, & other sulphides, arsenides; carbon)
  - commonly auriferous & uraniferous
    - particularly where green mica-pyrite is abundant
  - most abundant in quatzites intercalated in conglomeratic packages
    - apple green (Cr-V) mica-pyrite abundant
    - less common in thick conglomerates



Discordant pyrite-mica stylo-veins in quartzite and conglomerate (South Deep)

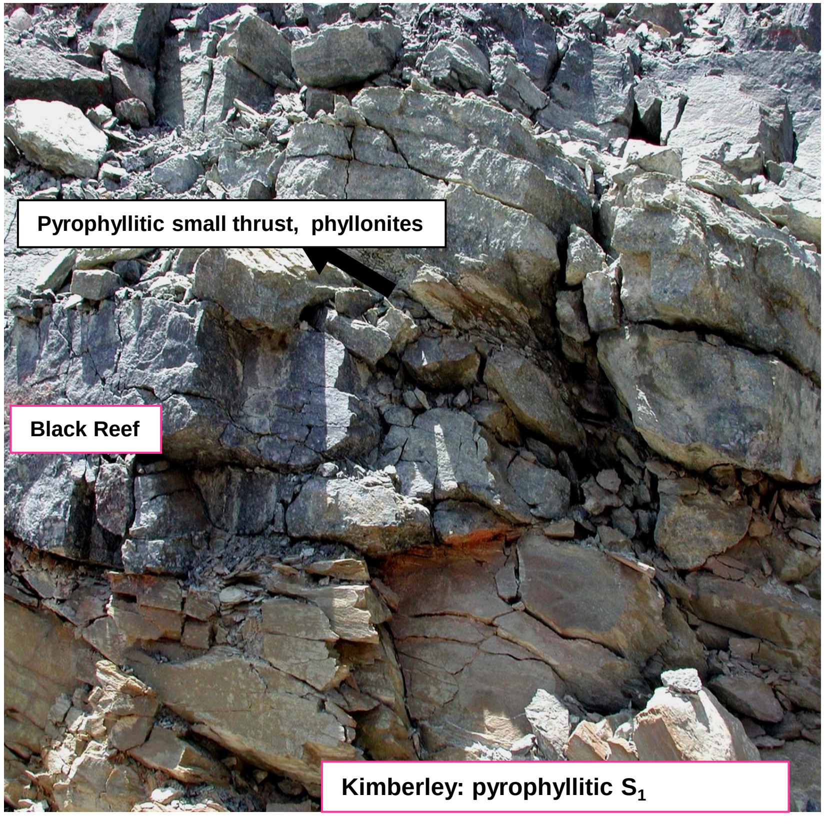


Foliations & stylo-veins: psammites

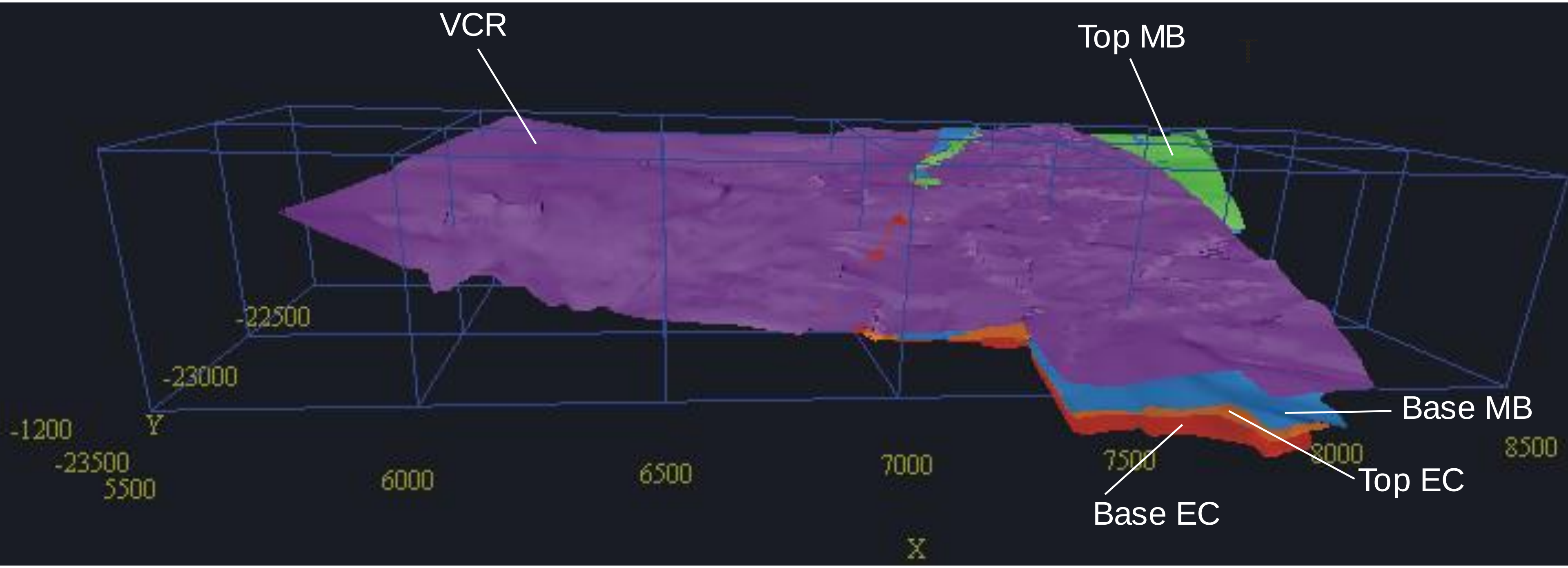
Elsbergs: South Deep

Alteration : timing & conditions

- Alteration mineralogy & textures (e.g. pyrophyllite-bearing veins & foliations) indicate
  - near peak metamorphic conditions at time of growth
    - ~350 deg C, 6-10kms. depth
- Alteration minerals (including pyrite) spatially & temporally related to compressional deformation features
- therefore deformation & related hydrothermal alteration (& gold mineralization) occurred
  - near peak metamorphic grade
  - under thick Transvaal Group cover
    - viz. Black Reef

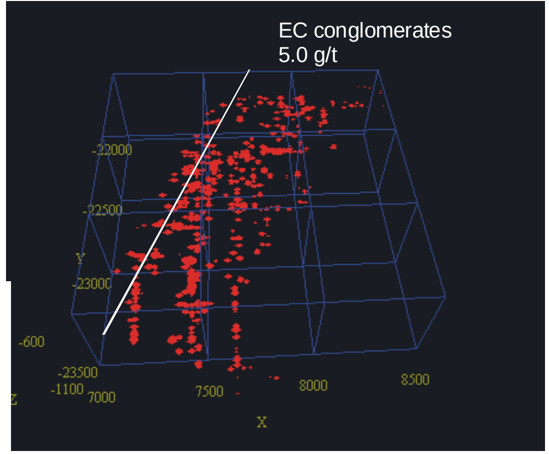


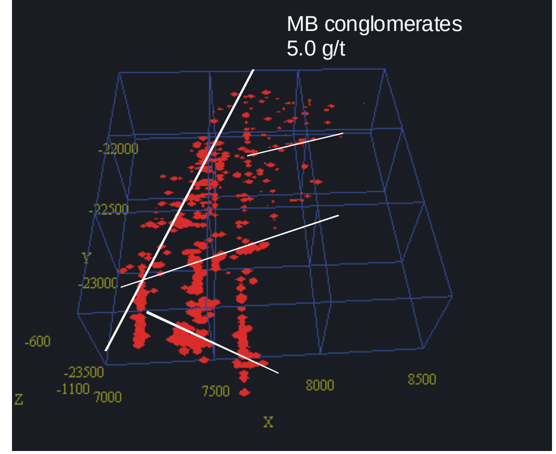
South Deep: lithostratigraphic architecture



Au grade trends: Stratigraphy

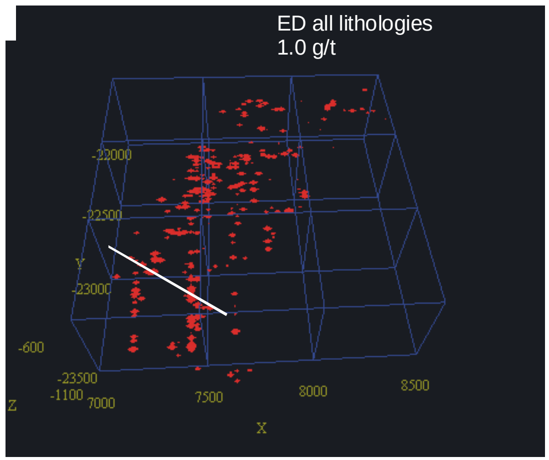
EC
conglomerates
> 5.0g/t

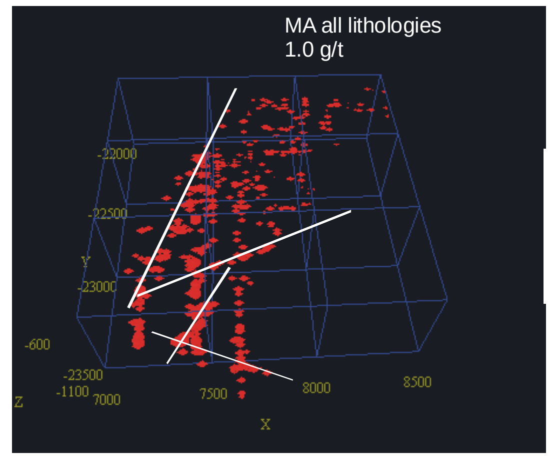




MB conglomerate > 5.0g/t

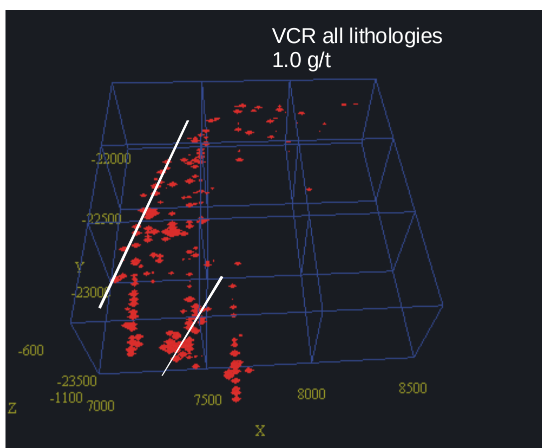
ED
all lithologies
> 1.0g/t

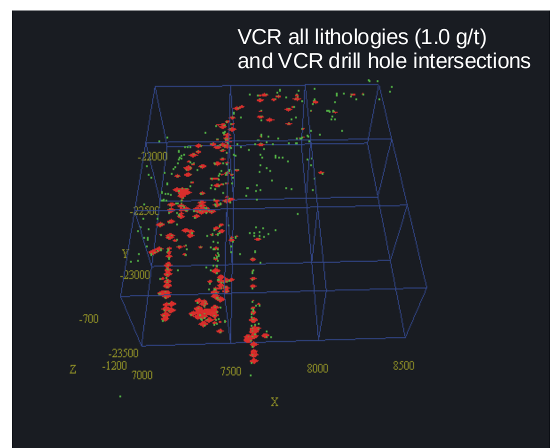




MA all lithologies > 1.0g/t

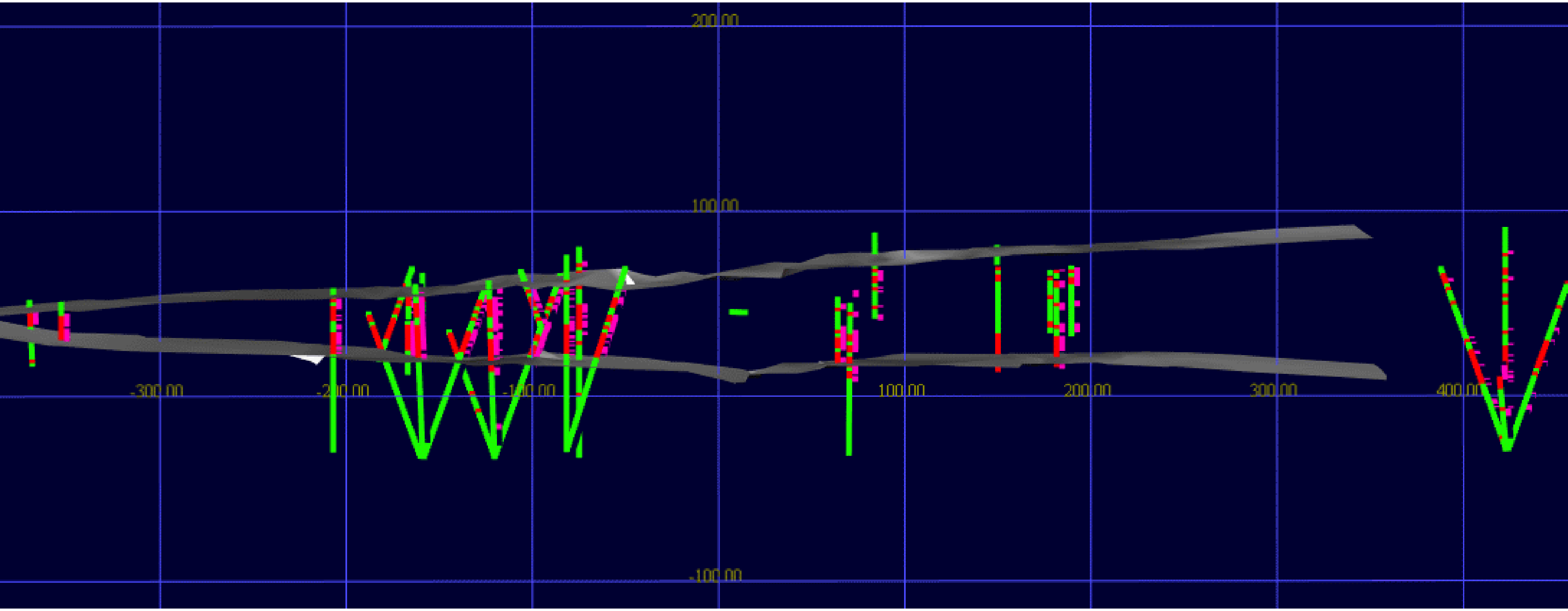
VCR
all lithologies
> 1.0g/t





VCR all lithologies and drilling > 1.0g/t

Au grade distribution: EC package

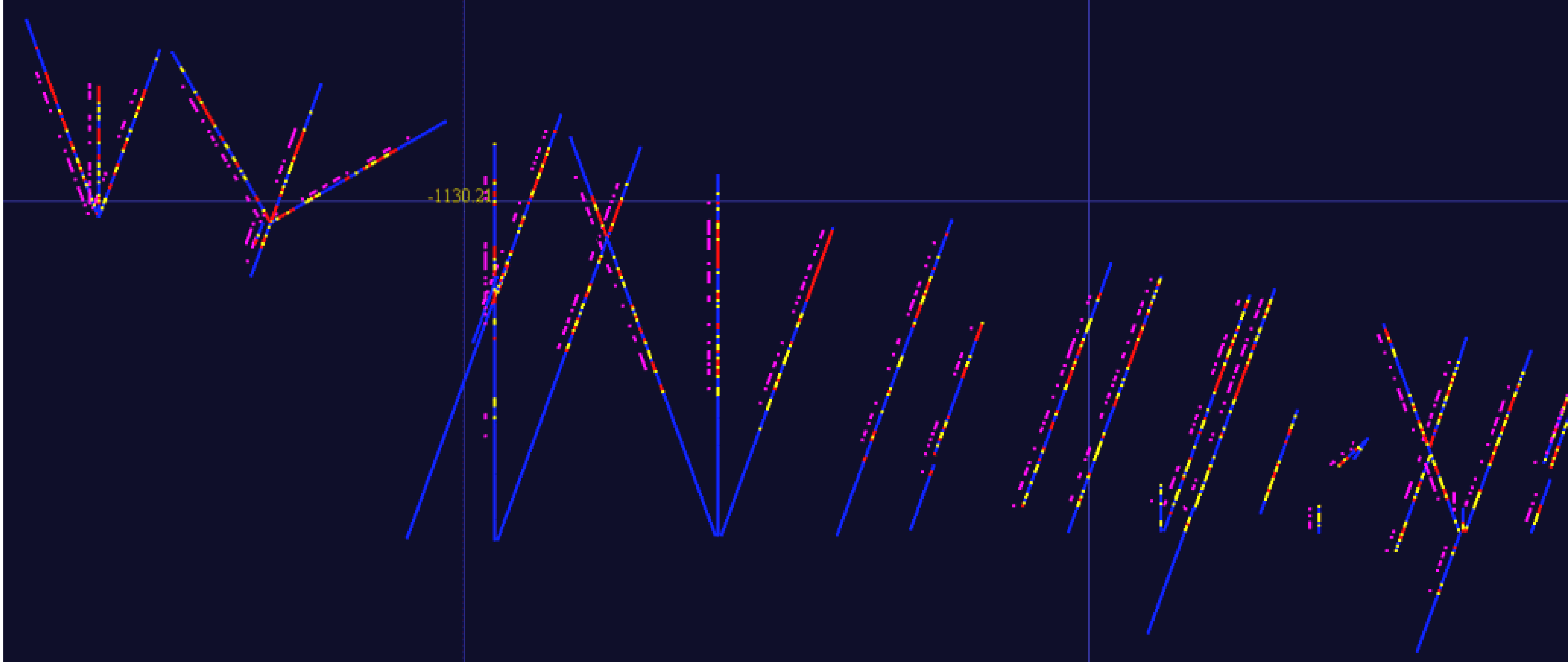


Cross-section Y-22650 (looking north) showing drilling coded for proportion of conglomerates (composited over 2m intervals) and gold.

Intervals containing greater than 70% conglomerate are red, all other intervals are green. Gold greater than 2.5 g/t is shown in magenta.

Note gold mineralisation in EC diminishes to the east whilst proportion of conglomerate in EC remains greater than 70%.

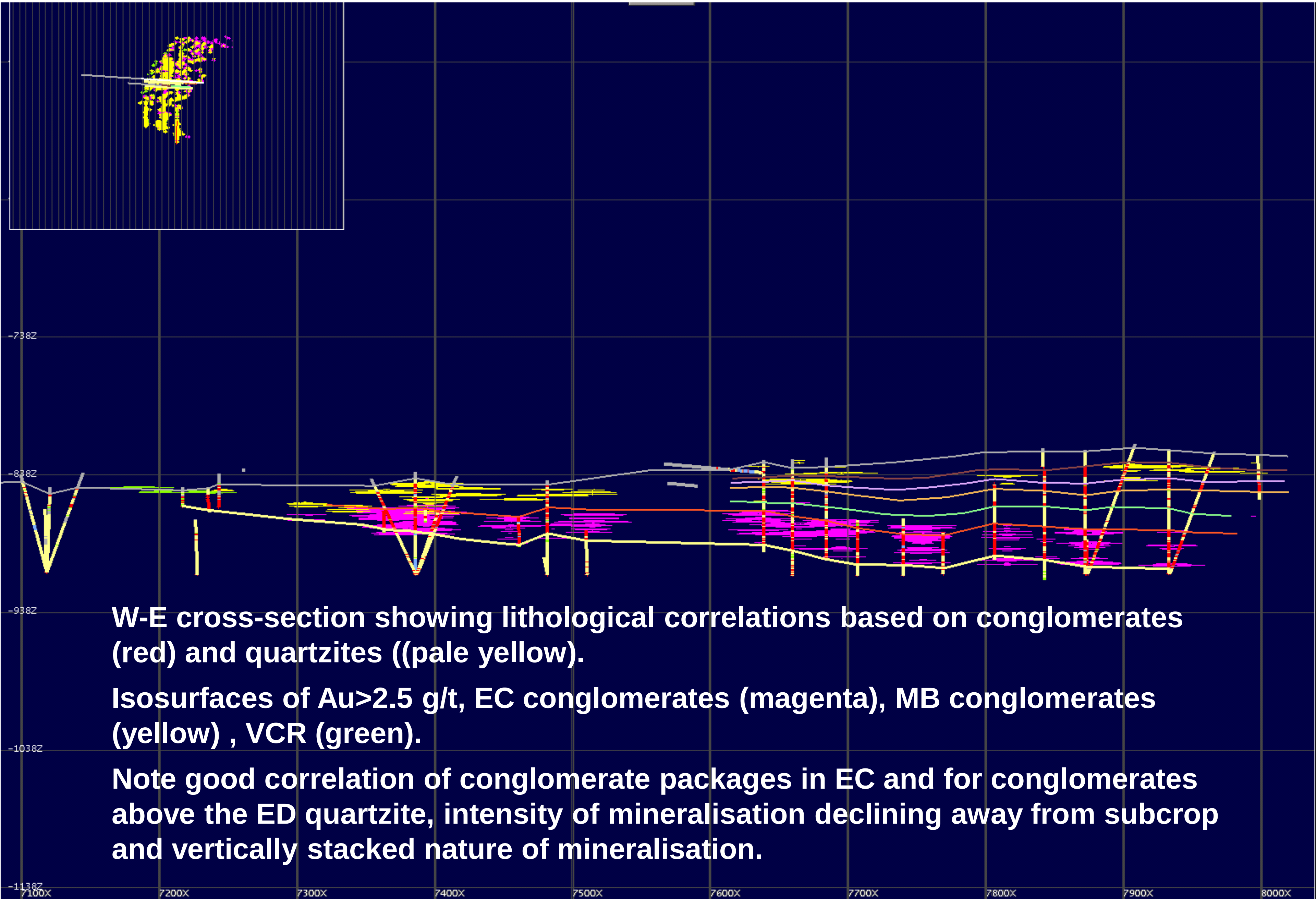
Uranium and gold correlation



Drill holes showing Au (on right: 0-2g/t blue, 2-5 g/t yellow, >5 g/t red) and U3O8 (on left: >100ppm).

Cross-section X7450.

Au grade distribution: visualisation

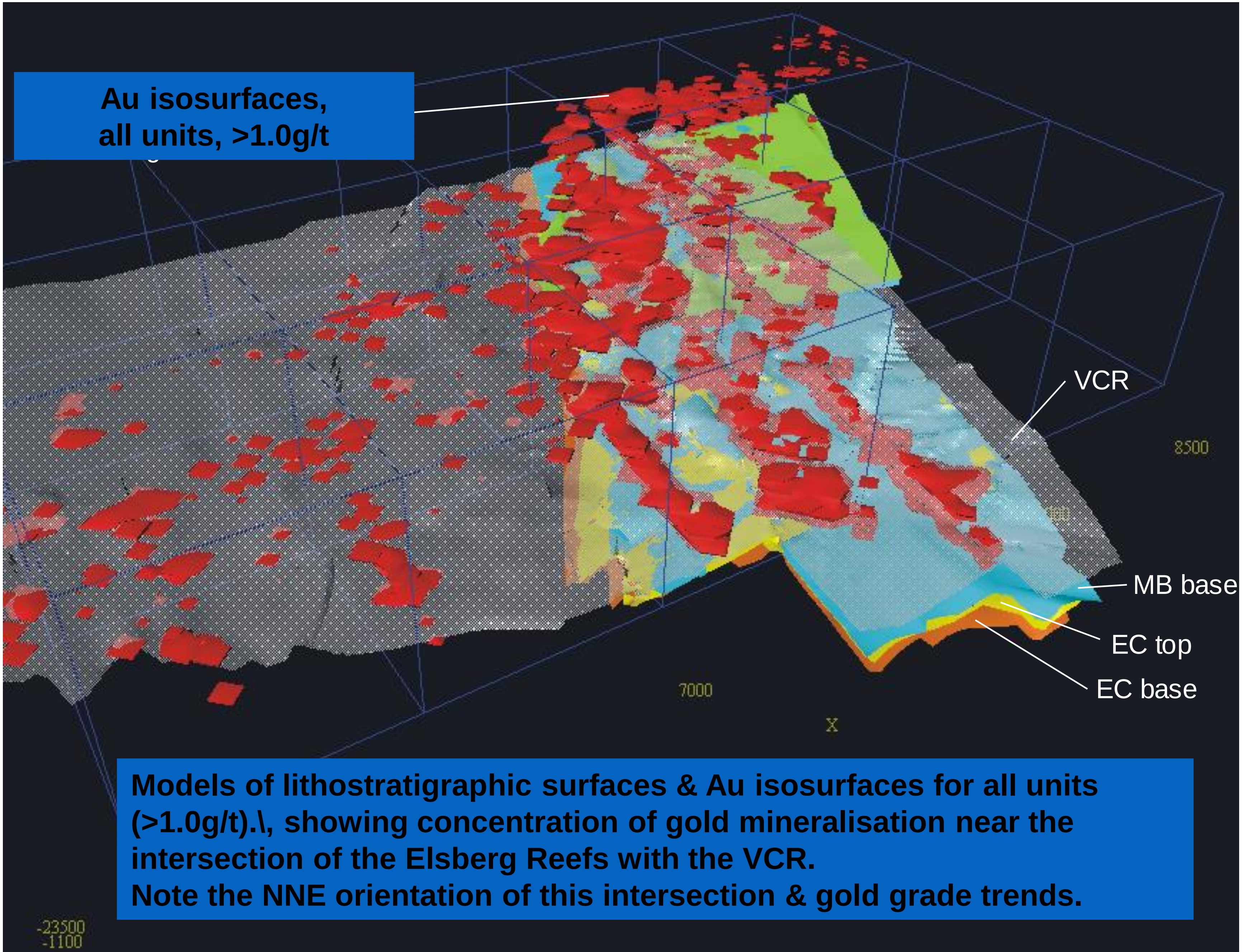


W-E cross-section showing lithological correlations based on conglomerates (red) and quartzites ((pale yellow).

Isosurfaces of Au>2.5 g/t, EC conglomerates (magenta), MB conglomerates (yellow) , VCR (green).

Note good correlation of conglomerate packages in EC and for conglomerates above the ED quartzite, intensity of mineralisation declining away from subcrop and vertically stacked nature of mineralisation.

Au grade distribution: South Deep



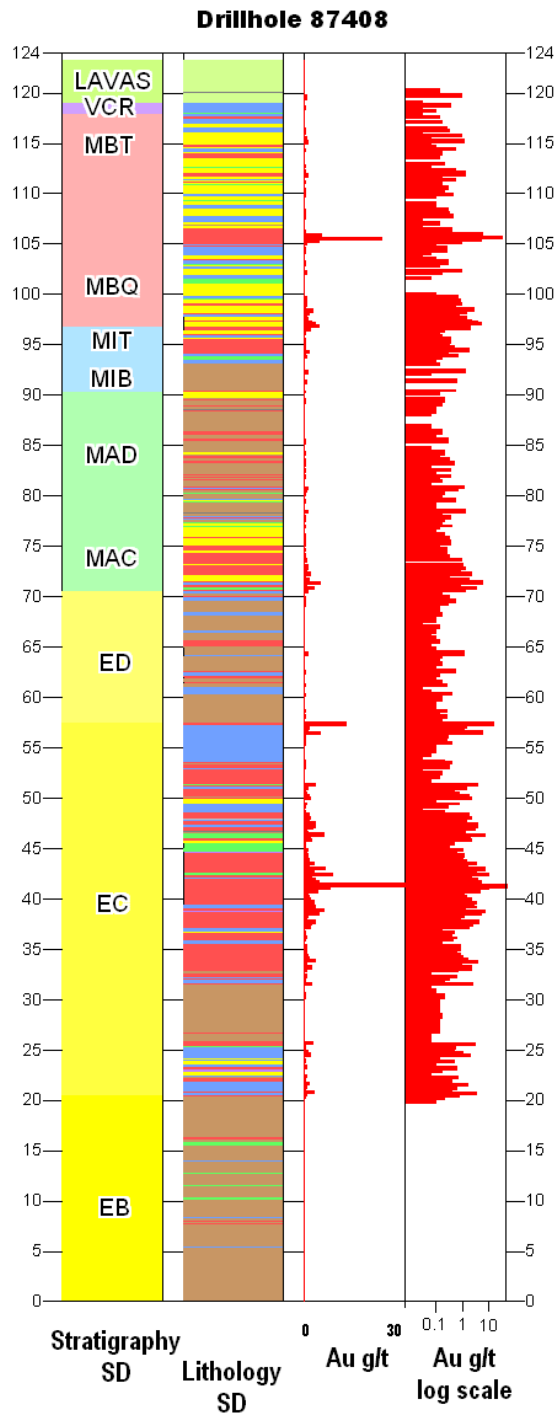
Models of lithostratigraphic surfaces & Au isosurfaces for all units (>1.0g/t).\, showing concentration of gold mineralisation near the intersection of the Elsberg Reefs with the VCR.
Note the NNE orientation of this intersection & gold grade trends.

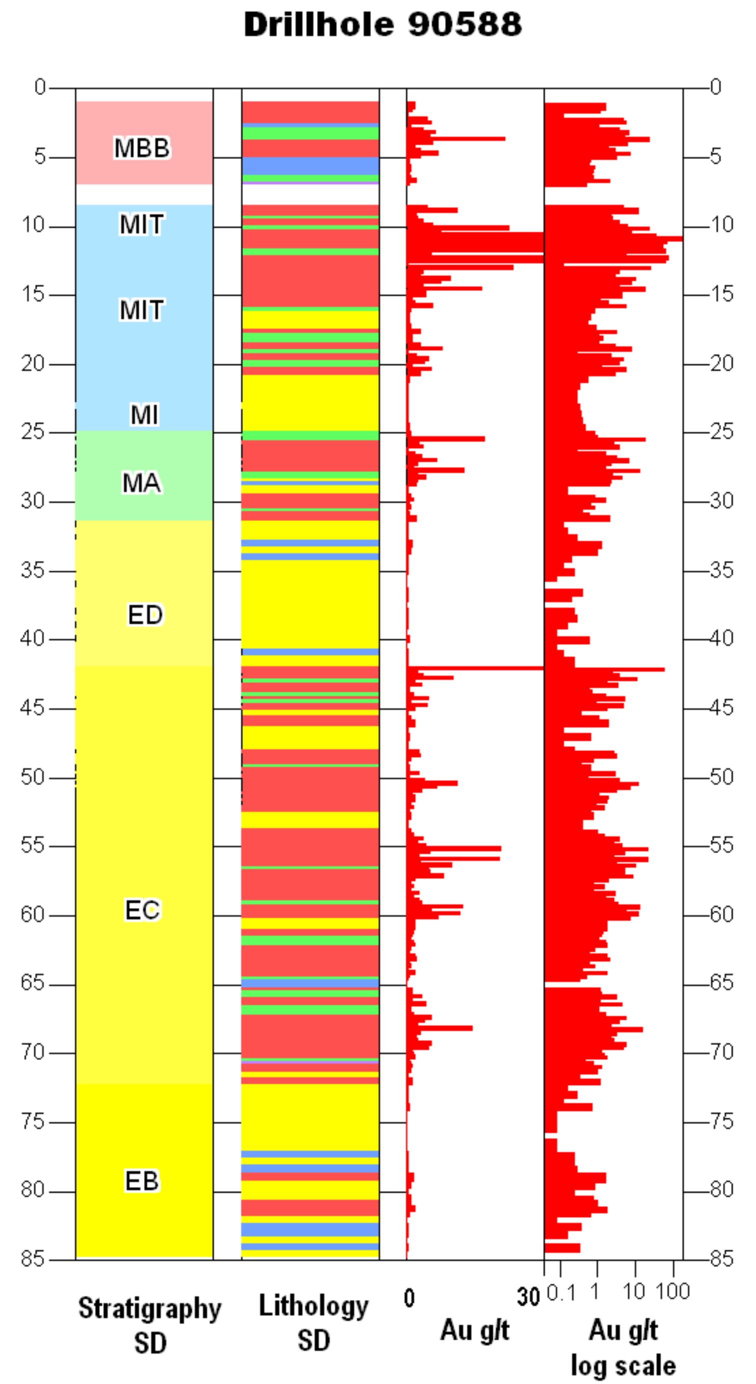
Au grade distribution: implications

- Intensity of mineralisation occurs where there are the highest proportions of conglomerates to other lithologies
  - not necessarily where the conglomerates are volumetrically greatest
  - this occurs close to the unconformity with the VCR
- All conglomeratic packages are more intensely mineralised close to the VCR unconformity
- The VCR is more intensely mineralised where underlying conglomerates abut the unconformity
- The main trend in gold mineralisation coincides with the intersection of the VCR unconformity and the underlying conglomeratic packages
- Other grade trends appear to relate to WNW zones of thickening and greater proportions of conglomerate (?channels)

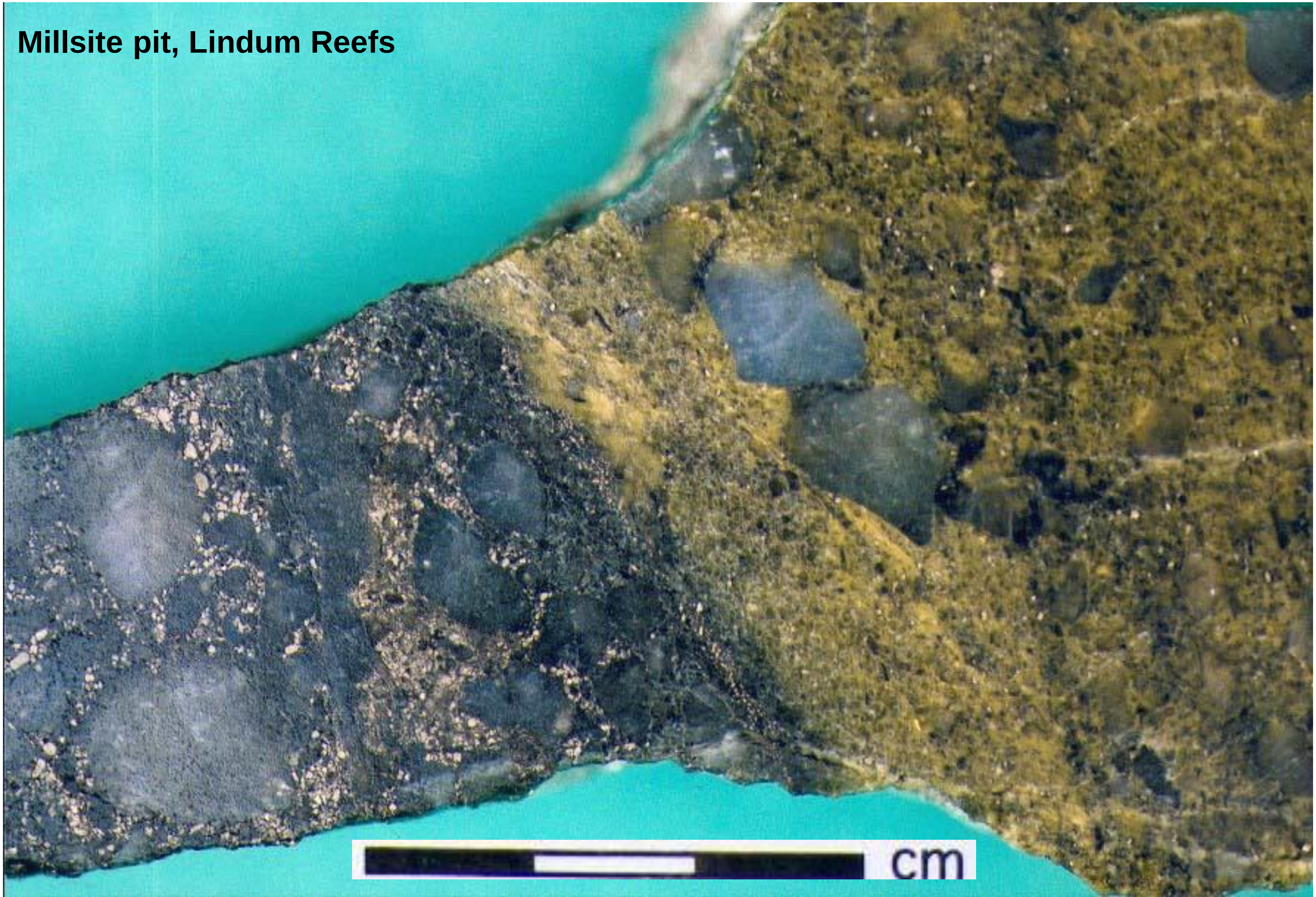
Au distributions

- Clast supported conglomerate, C
- Matrix supported, conglomerate,
- Pebbly quartzite, PQ
- Argillaceous quartzite, AQ
- Orthoquatzite, OQ
- Quartzite, Q
- Mafic volcanics, L
- Q vein
- Structure filled with quartz vein, I
- Foliated/shear zone, FS
- Mylonite, FM
- Pseudotachylite, FPT



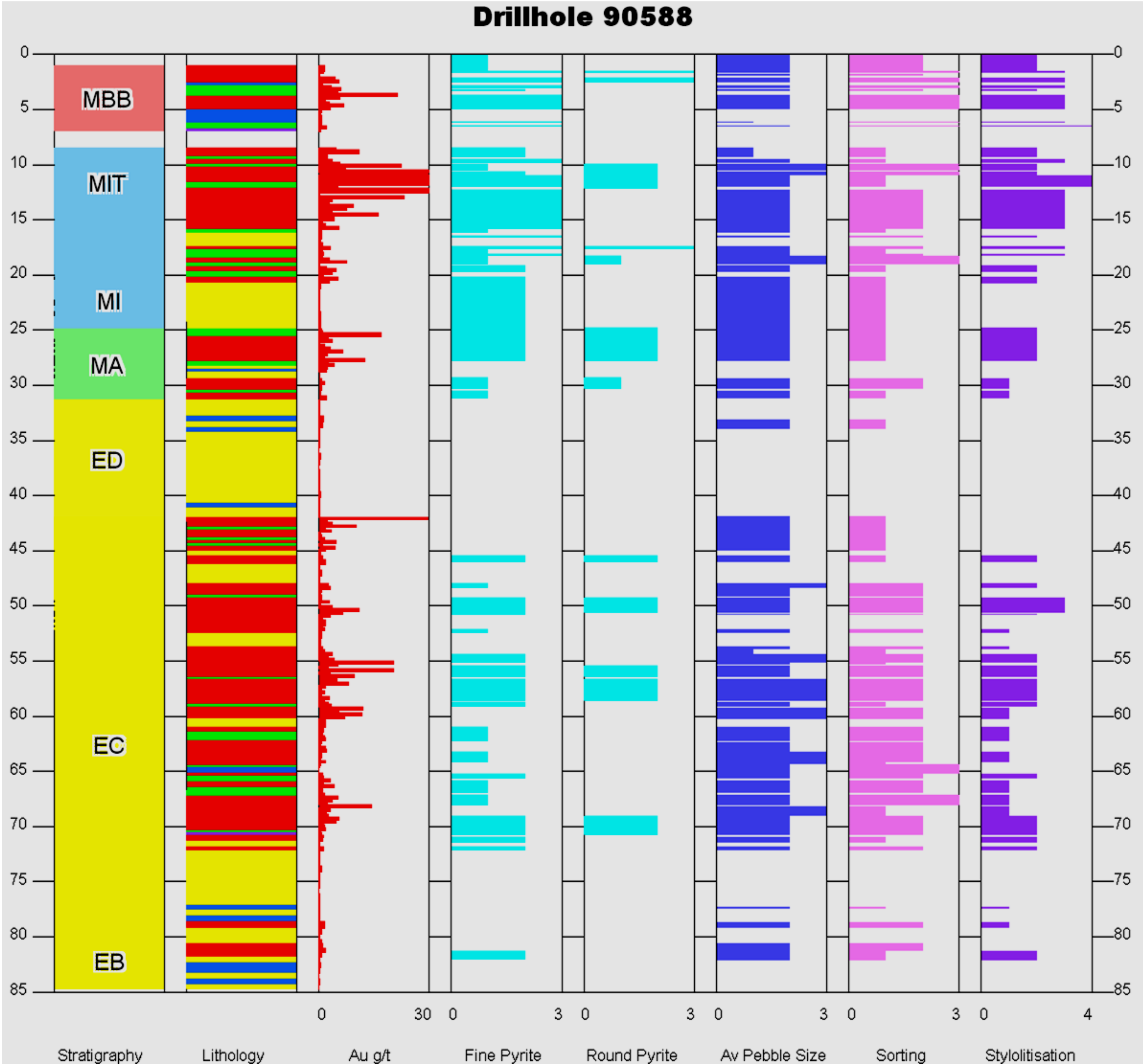


Clast- vs. matrix-supported conglomerates



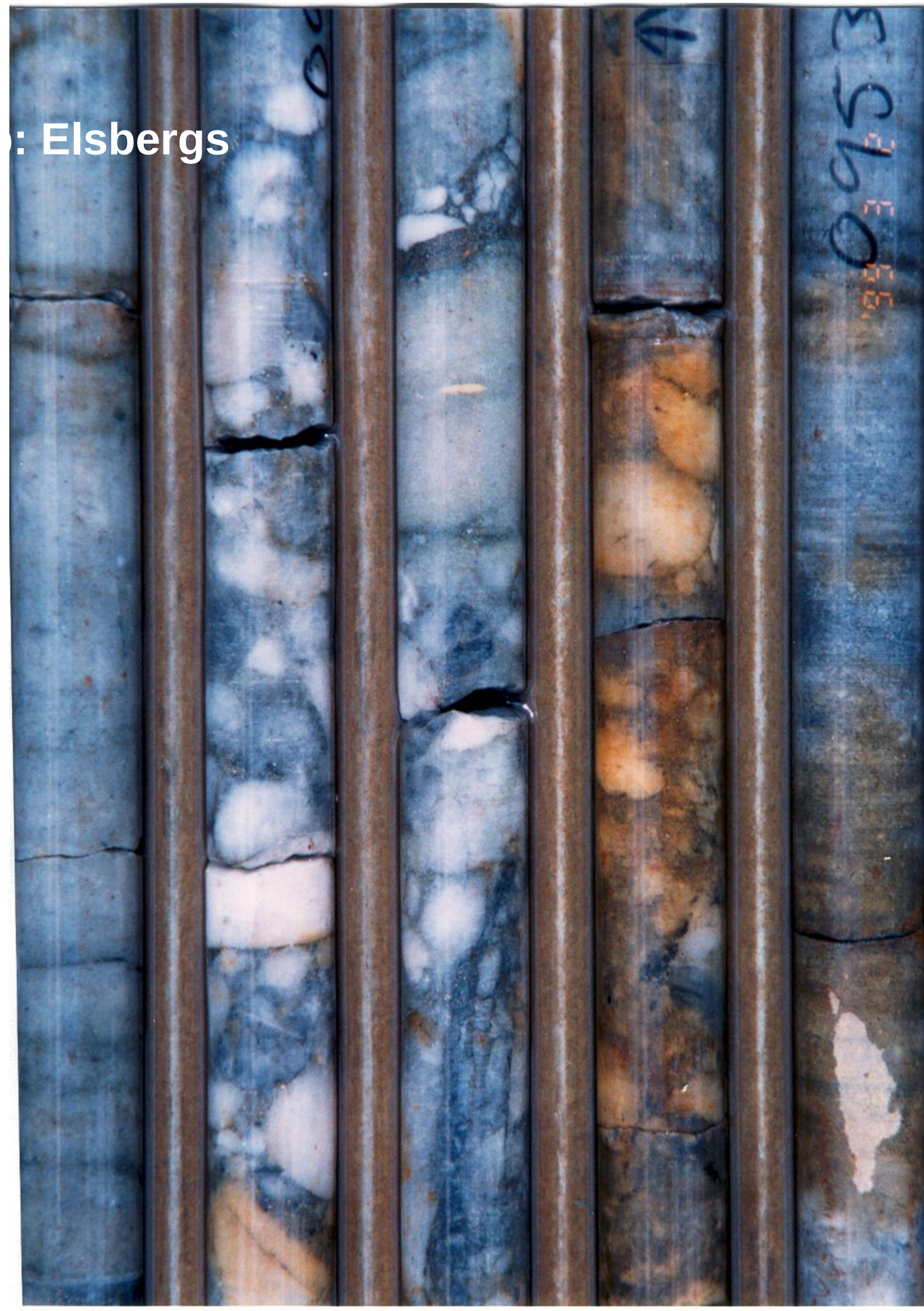
Au & Textures

Clast supported coarse pebble (32-64mm) conglomera
Clast supported medium pebble (16-32mm) conglomer
Clast supported small pebble (4-16mm) conglomerate,
Matrix supported coarse pebble (32-64mm) conglomera
Matrix supported medium pebble (16-32mm) conglome
Matrix supported small pebble (4-16mm) conglomerate,
Pebbly grit, GP
Grit, G
Grit and quartzite, coarse black clasts, GB
Undivided quartzites, grits, pebbly grits, S
Argillaceous quartzite, AQ
Quartzite, Q
Lava, L
Intrusives, dykes and sills, I
Quartz vein, VQ

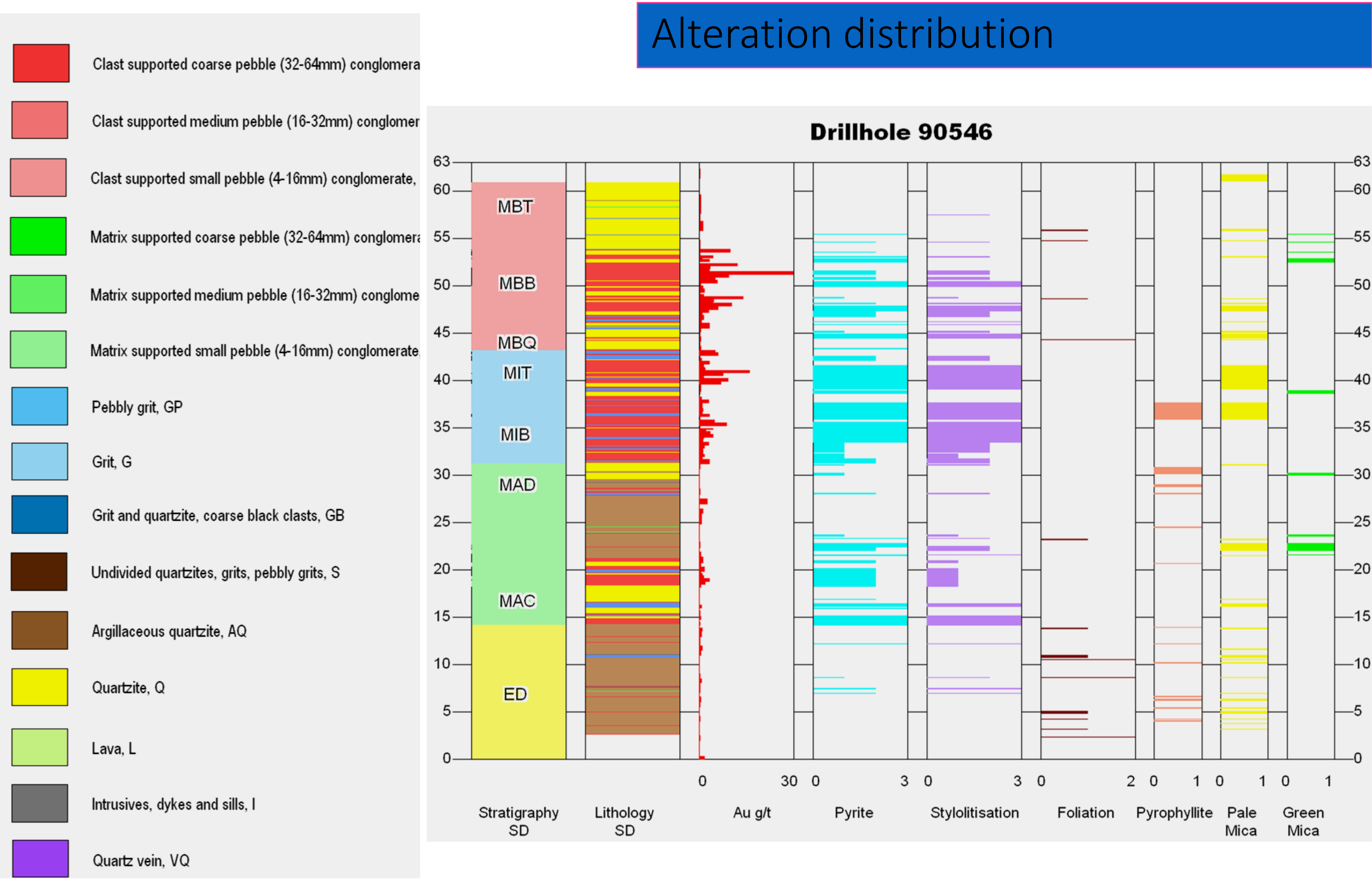


Drillhole 90588
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
MBB
MIT
MI
MA
ED
EC
EB
0
30
0
3
0
3
0
3
0
3
0
4
Stratigraphy
Lithology
Au g/t
Fine Pyrite
Round Pyrite
Av Pebble Size
Sorting
Stylolitisation

Steeply and shallowly dipping intensely stylolitized zones



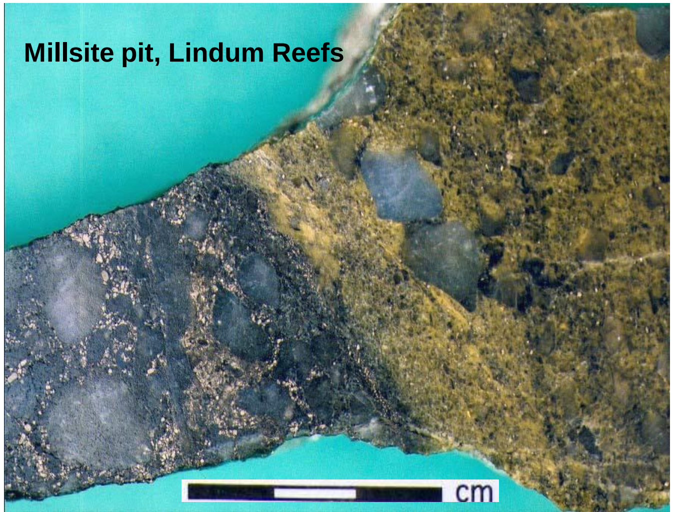
Alteration distribution



Conglomeratic packages: alteration & deformation

- Clast-supported
  - variably stylolitic clast boundaries
    - ranging from weak to intense clast boundary adjustments (degree of stylolitization)
    - intense stylolitization (CSI)
      - mainly in shallow-dipping but
      - also in steep (?E-W) discordant zones
      - may produce stylo-breccias and fractured/stylo-veined clasts (otherwise rare)
    - strong stylolitization (CSS)
      - also most common near conglomerate-psammite interfaces
      - but also in discordant, anastomosing zones
      - not related to clast size and sorting

- Matrix-supported
  - weak to strong development of mica-pyrophyllite in matrix
    - less quartz-rich matrices, more aluminous
  - but, pyrite & gold weak to absent
  - clast boundaries not stylolitic
    - strain mainly accommodated by matrix
    - cf. textures & deformation mechanism of clast-supported conglomerates



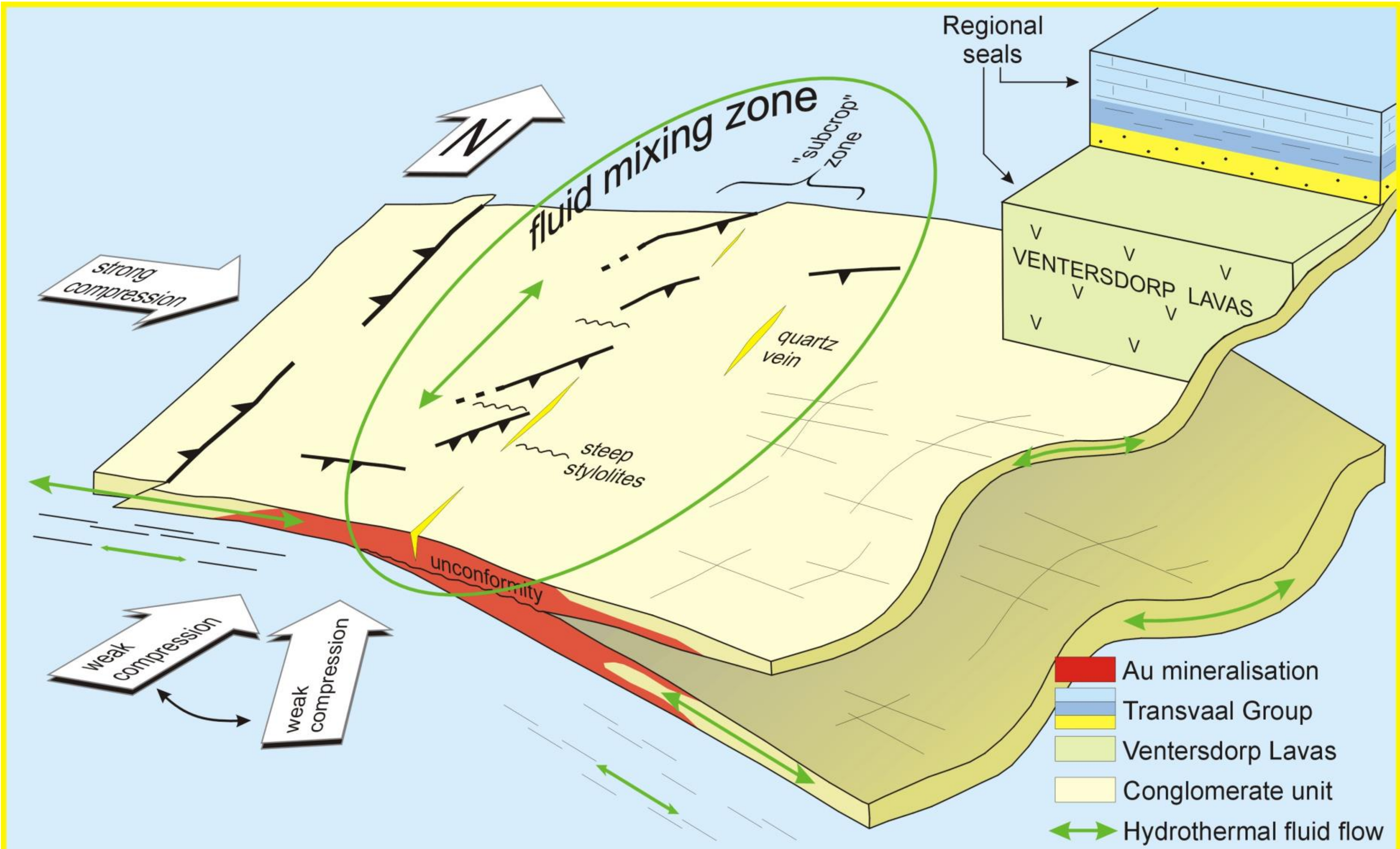
Conglomeratic packages: alteration & deformation

- Stylolitic clast-boundary adjustment was the
  - major control on packing of clast-supported conglomerates
  - main mode of deformation of these lithologies in the Wits (including Black Reef)
    - reflecting low strain, greenschist facies conditions and
    - contrasts with deformation mechanisms of psammites, pelites
  - main mechanism of permeability enhancement (& hence syn-deformational fluid flow focusing) in clast -supported conglomeratic packages
    - stylolitic clast boundary arrays formed an effective reticulate network of high connectivity & hence permeability
    - cross-clast fractures in thin conglomerate-quatzite packages also contributed to permeability (carbon seam examples)

Mineralization model: essentials

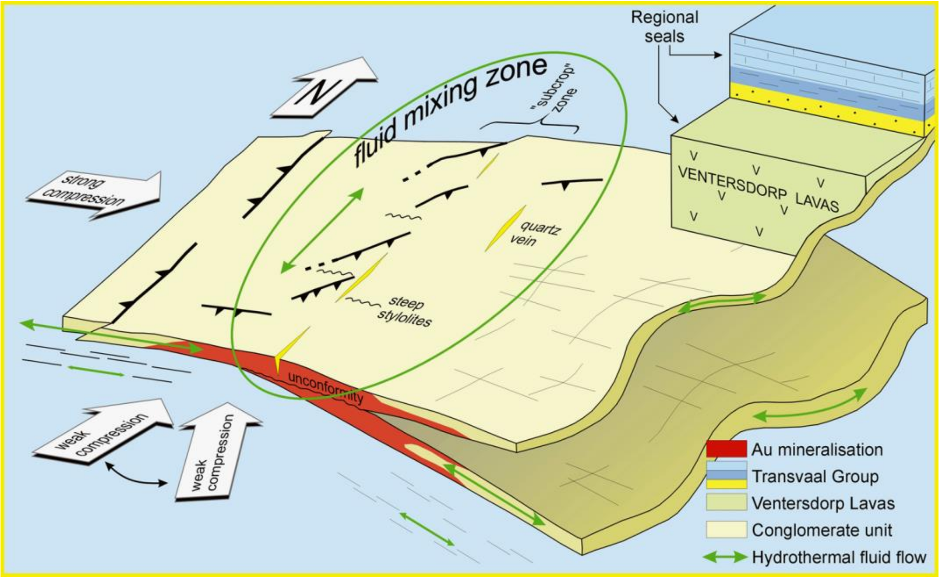
- **Gold mineralization synchronous with hydrothermal alteration**
  - near peak, greenschist metamorphic grade
  - Transvaal Group cover/burial
- **localized by lithology-controlled deformation features in stylolitized /fractured conglomeratic packages**
  - permeable zones on regional scales
- **weakly deformed unconformity-related systems**
  - in appropriate orientations
- **regional hydraulic seals**
  - Ventsdorp lavas (district)
  - Transvaal Group (basinal)

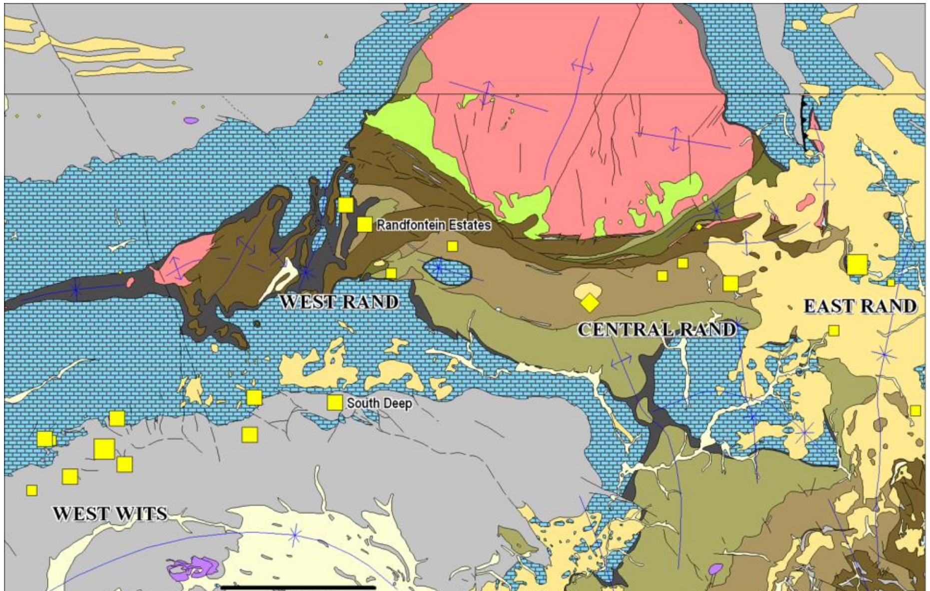
Mineralization model: Mechanics & fluid flow



Mineralization model: mechanics

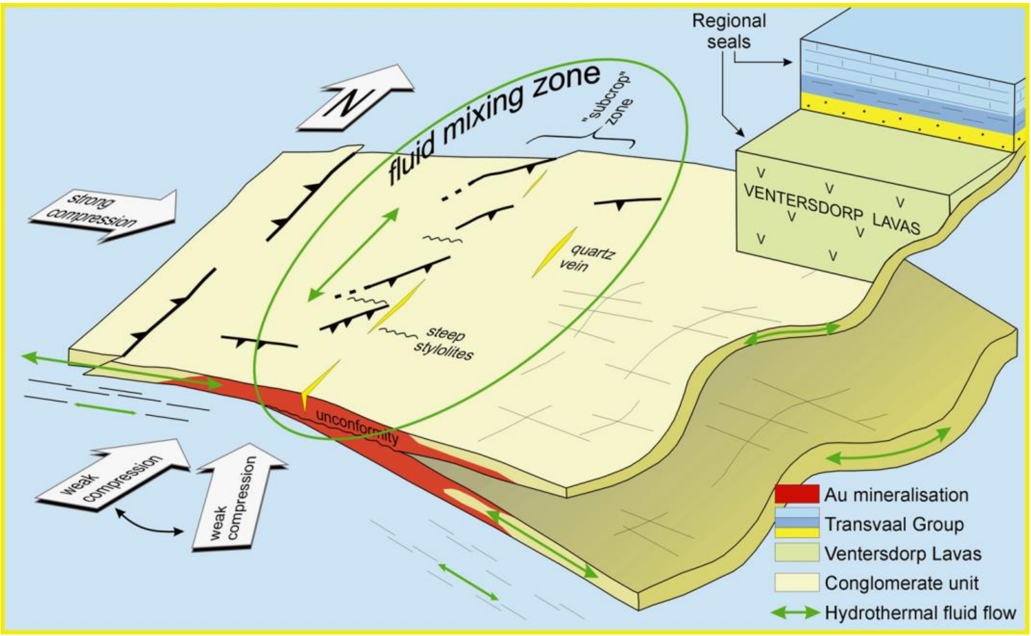
- Mechanical package comprises strongly planar anisotropy (i.e. shallowly dipping conglomerates)
  - tectonostratigraphic setting
    - Central Rand: extensive distribution of quartz-rich, clean conglomerates in part of Witwatersrand Basin
    - Transvaal Group: thick, draping cover & seal
  - lithostratigraphy
    - relatively consistent packages at district scales
  - low strain
    - shallow dips
    - continuity/little disruption of ‘ hydrothermal aquifers’





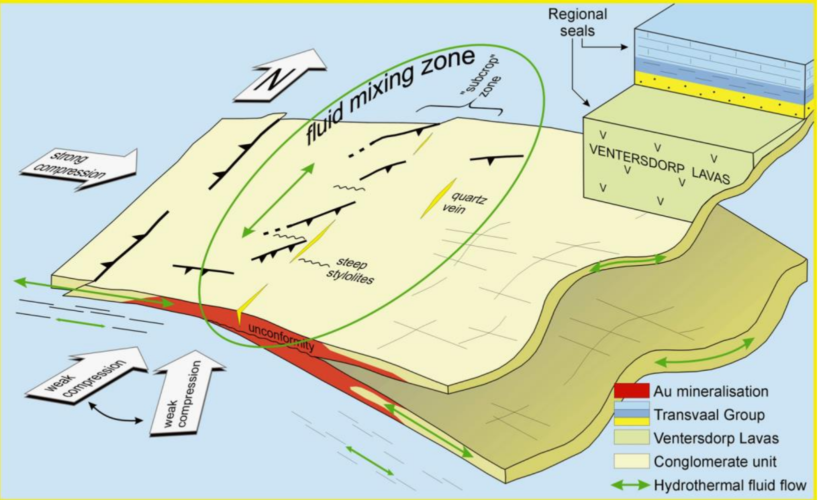
Mineralization model: mechanics

- Unconformities (? and early thrusts) generate linear competent zones,
  - formed by intersections (unconformities) (?and thrust stacks) of conglomerate packages
  - oriented N-S to NE
- Weak compression at low angles to linear competent zones creates deformation-controlled permeability & dilation
  - contrasted deformation mechanisms of clast-supported conglomerates versus other lithologies at low strain are key



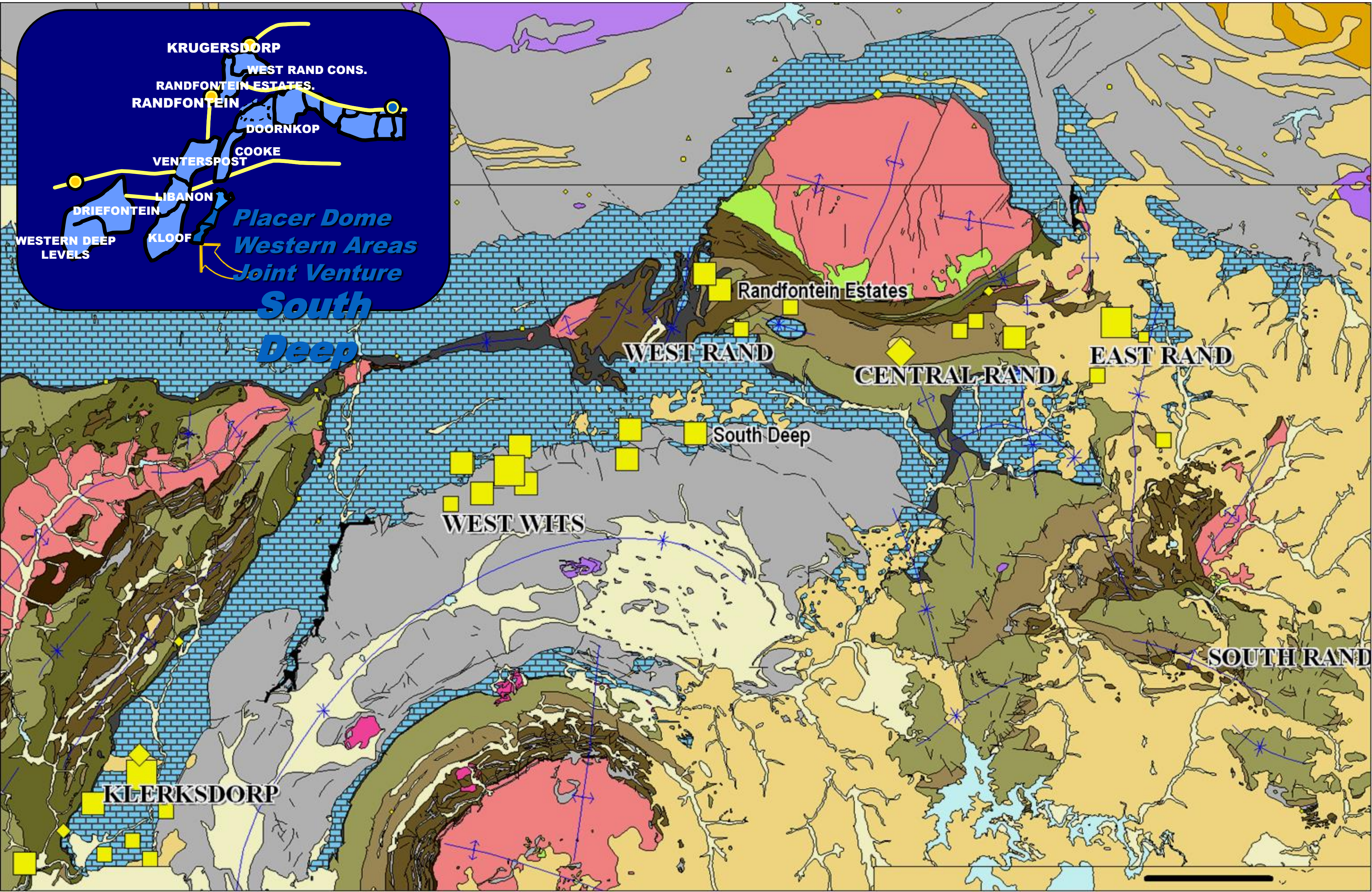
Why the Witwatersrand?

- "It's the craton, stupid"
  - apologies Willy Clinton
- "the mother of all cratons"
  - apologies Keith Kenyon &
  - S. Hussein

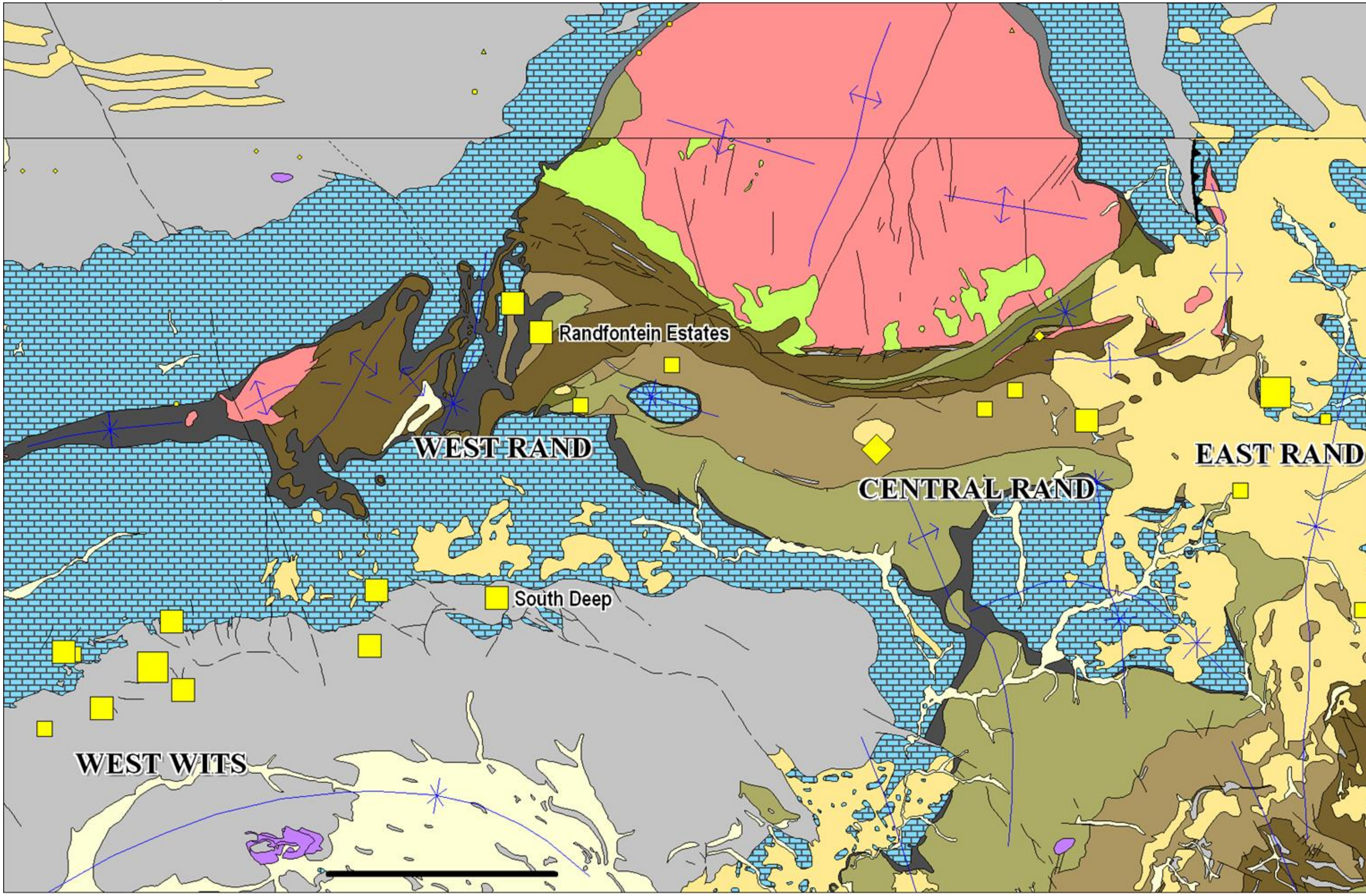


- Tectonostratigraphic evolution
  - stacked,extensive conglomerates & unconformities
  - draped by effective (Transvaal) seal
  - sources of oxidised, acidic & also reduced fluis in the rockmass
- Low strain compression under greenschist facies conditions
  - consistent, mostly shallow dips of stratigraphy
  - similar responses to regional stresses over broad areas
  - broad culmination

Placer? No
Dome? Yes



Regional structure: East Rand – West Witwatersrand



- Major post-Transvaal fold & fault systems

Conclusions

- Witwatersrand hydrothermal alteration & Au mineralization
  - post Lower Transvaal Group, pre-Bushveld (2600-2300Ma?)
  - accompanied low strain regional shortening under greenschist facies in which
  - deformation, alteration & fluid flow strongly partitioned by lithological architectures, at all scales
  - Conglomerates

Hydrothermal alteration and gold mineralization in the Witwatersrand : when, where and why?

Greg Hall, Golden Phoenix International Pty Ltd
Russell Mason, Tectonite Enterprises Pty Ltd

In Memory of Vic Wall

Placer: No
Dome: Yes