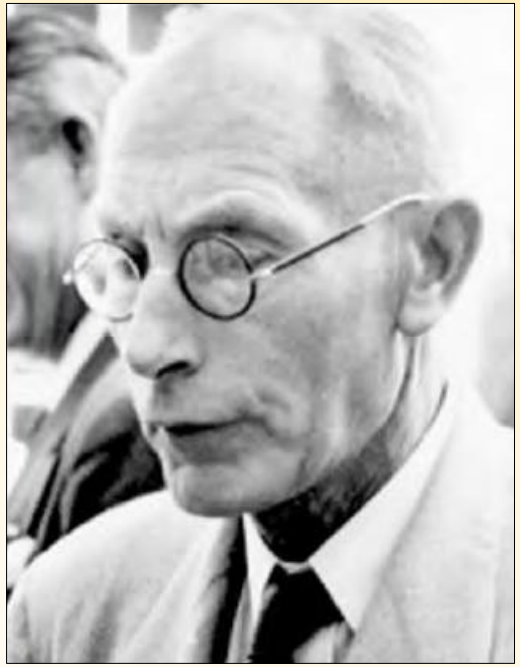
A.M. MACGREGOR: A remarkable man - a remarkable country – together re-shaping our understanding of Earth's evolution..... and gold metallogeny





AFRICAN GOLD, OROGENY, AND ZIMBABWE'S CONTRIBUTION – PAST, PRESENT, & FUTURE

A.M. MACGREGOR: A remarkable man - a remarkable country – together re-shaping our understanding of Earth's evolution..... and gold metallogeny





OUTLINE

- Early exploitation
- Establishing a superlative knowledge of geology and mineralisation
- Orogenic gold – what, why, where – and key contributors
- The Zimbabwe model? Regional implications
- An incomparable platform + demonstrated incubator – let's use it!

The first successful explorers

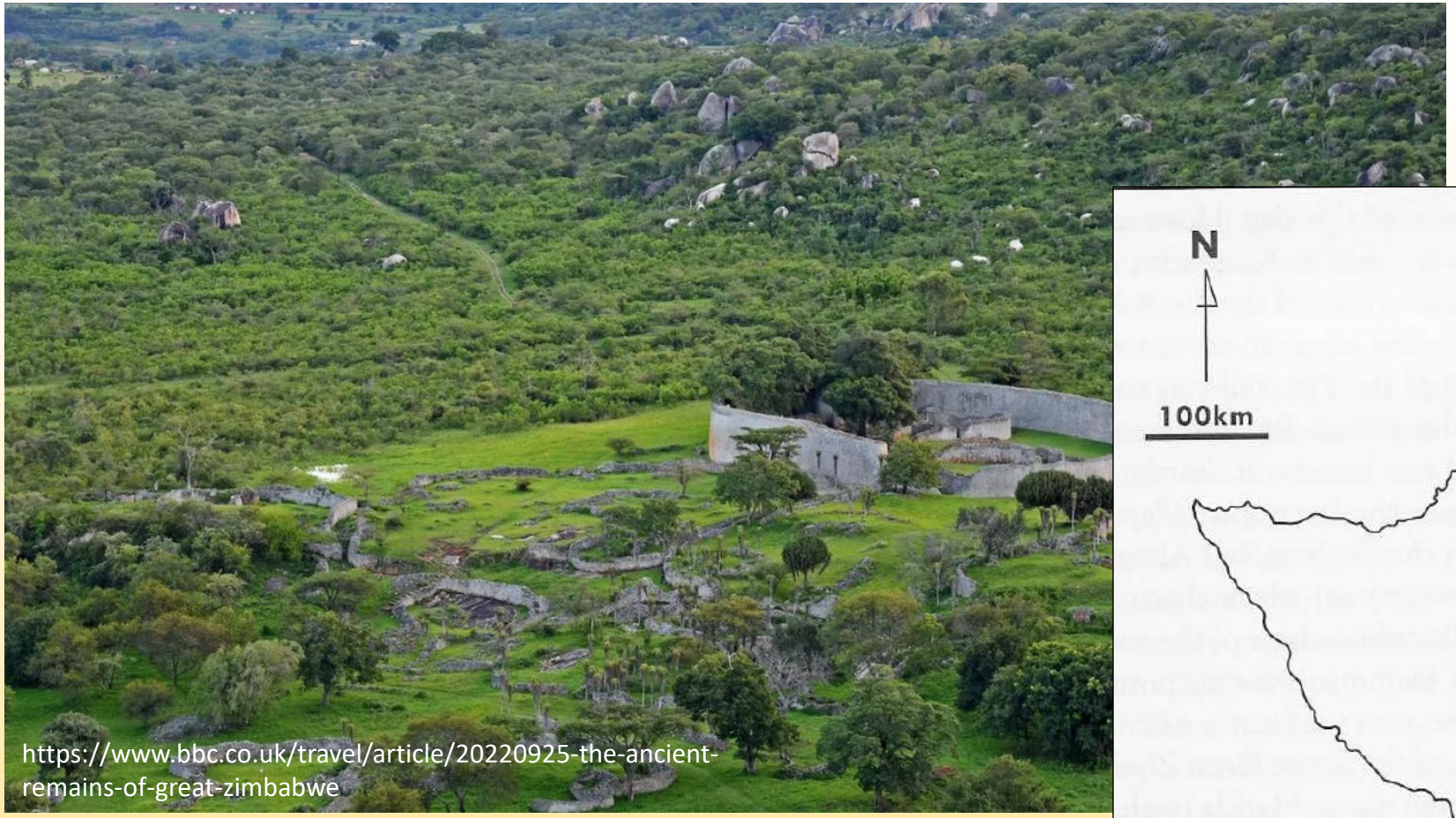


https://goldconsul.com/gold-mining-in-ancient-africa/



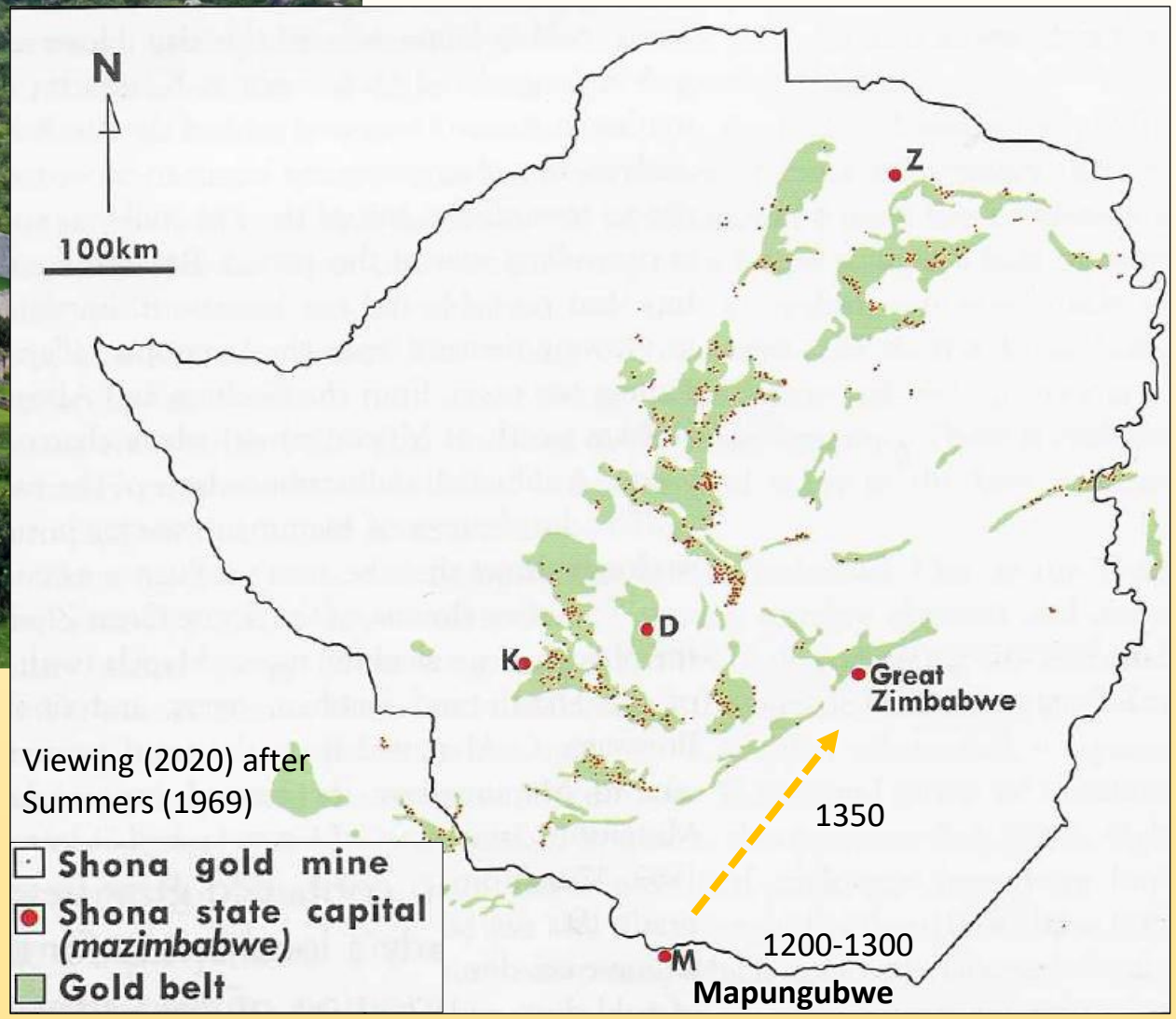
- Gold trading with Zimbabwe as early as 200 CE
- Dramatic increase in demand when Arab traders reached “Sofala” on Mozambique coast 9th-10th CE
- Great Zimbabwe became “gold central”

Zimbabwe: 2000 years of gold mining

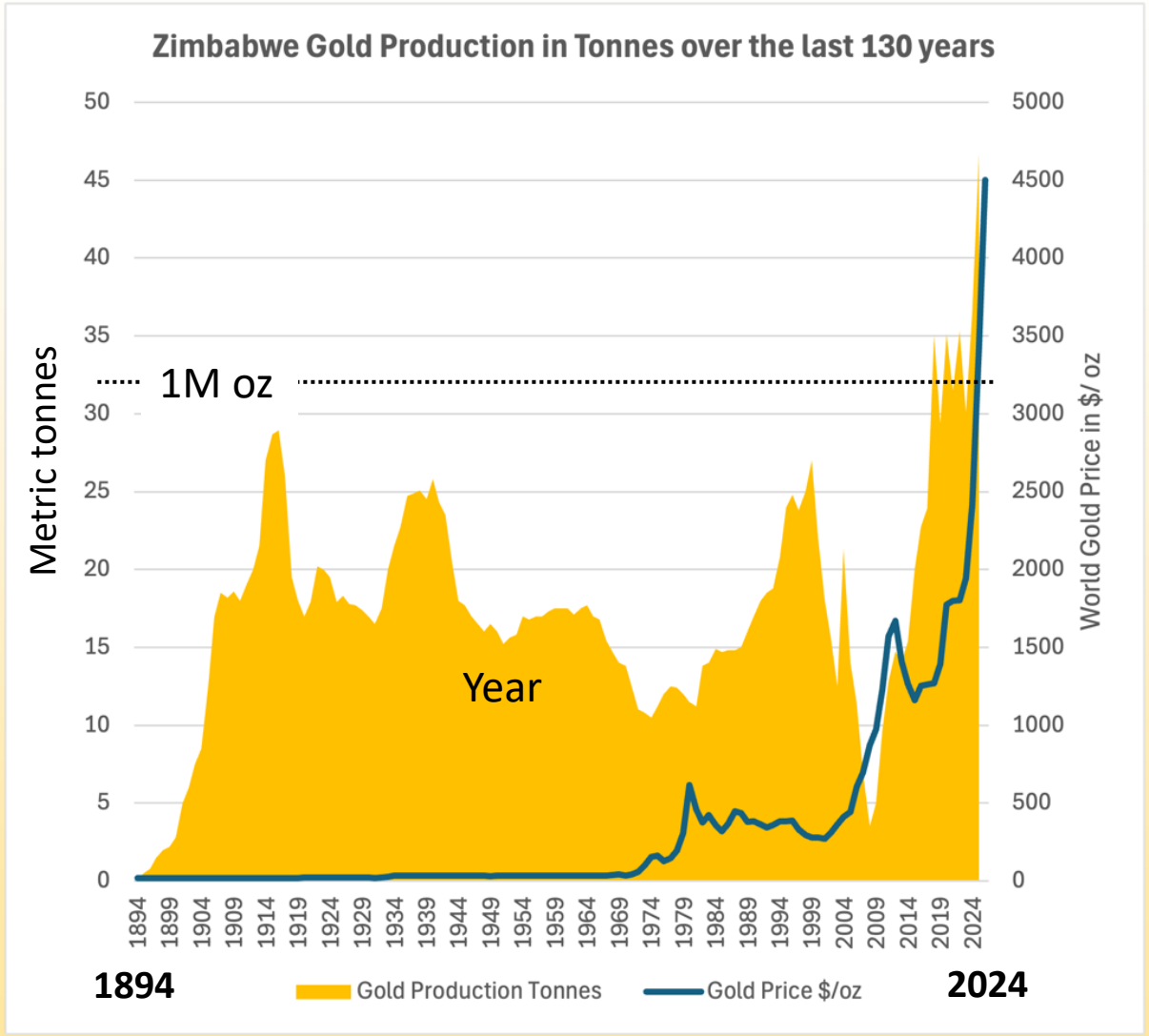


https://www.bbc.co.uk/travel/article/20220925-the-ancient-remains-of-great-zimbabwe

Great Zimbabwe
Flourished 13th C – 16th C

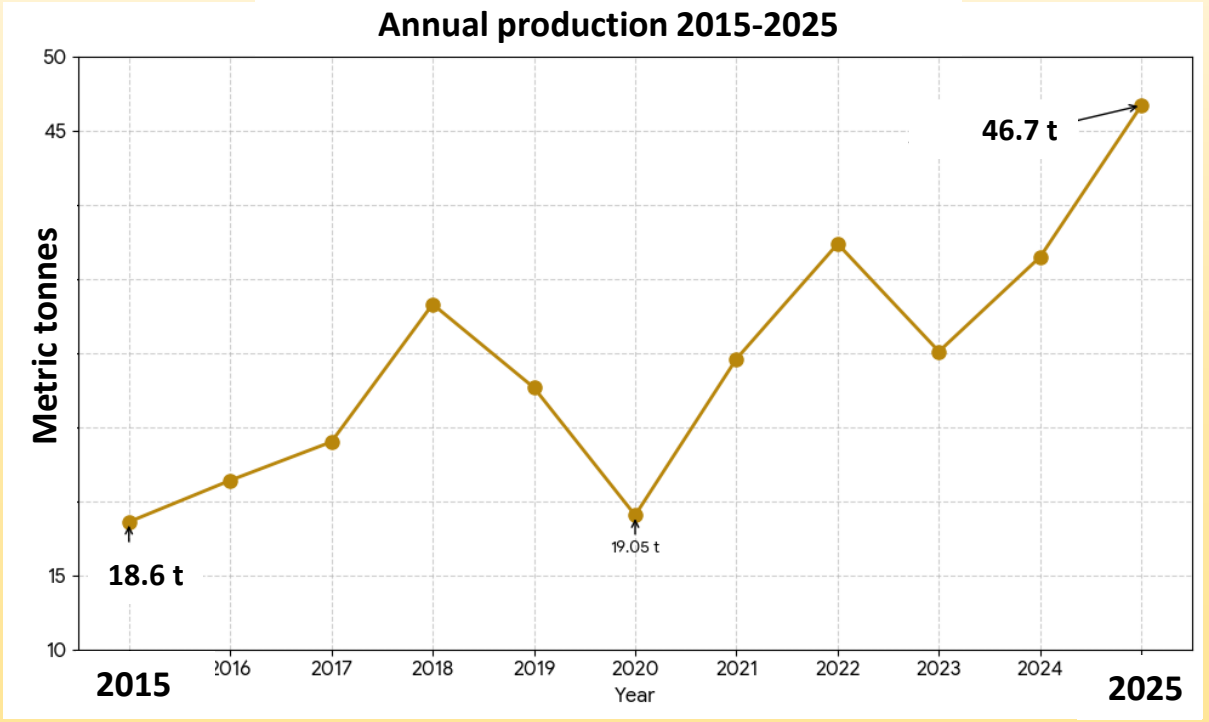


Zimbabwe's historical gold production since 1894



Year	Total Au (m.t.)	ASM %
2015	18.6	40.0
2016	21.4	40.0
2017	24.0	40.0
2018	33.3	65.0
2019	27.7	63.0
2020	19.1	49.0
2021	29.6	62.0
2022	37.4	65.0
2023	30.1	62.0
2024	36.5	65.0
2025	46.7	75.0

Substantial ASM contribution



Africa's Cratons and their gold endowment

Gold production + current resources

≥1M oz

Tasiast – 8.6M oz

Reguibat
9M oz Au
21 oz / km²

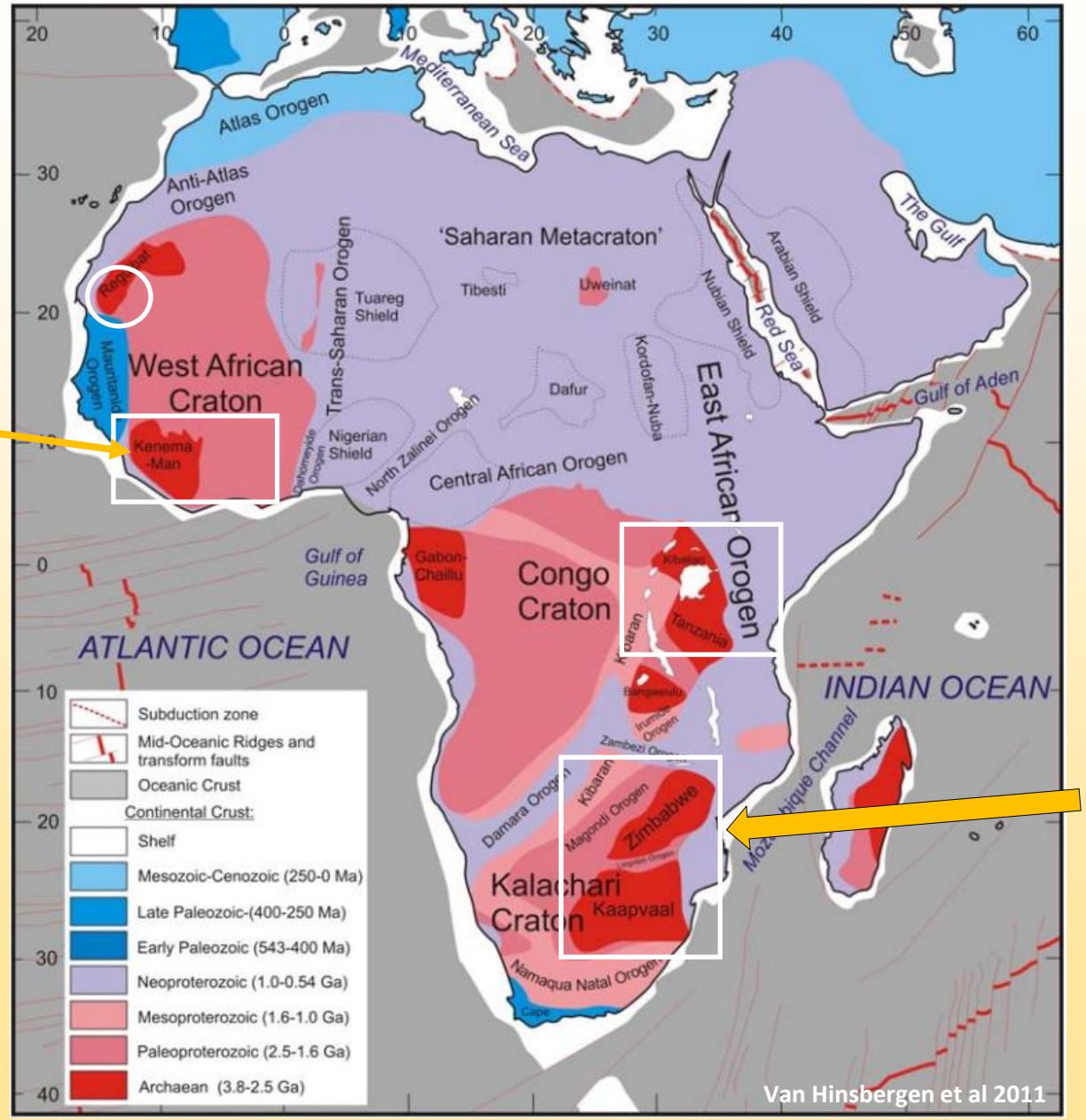
4 ≥1M oz
Max: 4.2M oz

Kenema-Man domain
12M oz Au
42 oz / km²

72 ≥1M oz
Max: 70M oz

Baoulé Mossi + KKI
448M oz Au
591 oz / km²

Best estimates *ca.* 2024
New discoveries constantly expanding resources



NE Congo:
Tanzania
59M oz Au
124 oz / km²

13 ≥1M oz
Max: 17.1M oz
(Bulyanhulu)

& DRC
Kibali **c.21.5M oz Au**

Zimbabwe
>61M oz Au
185 oz / km²

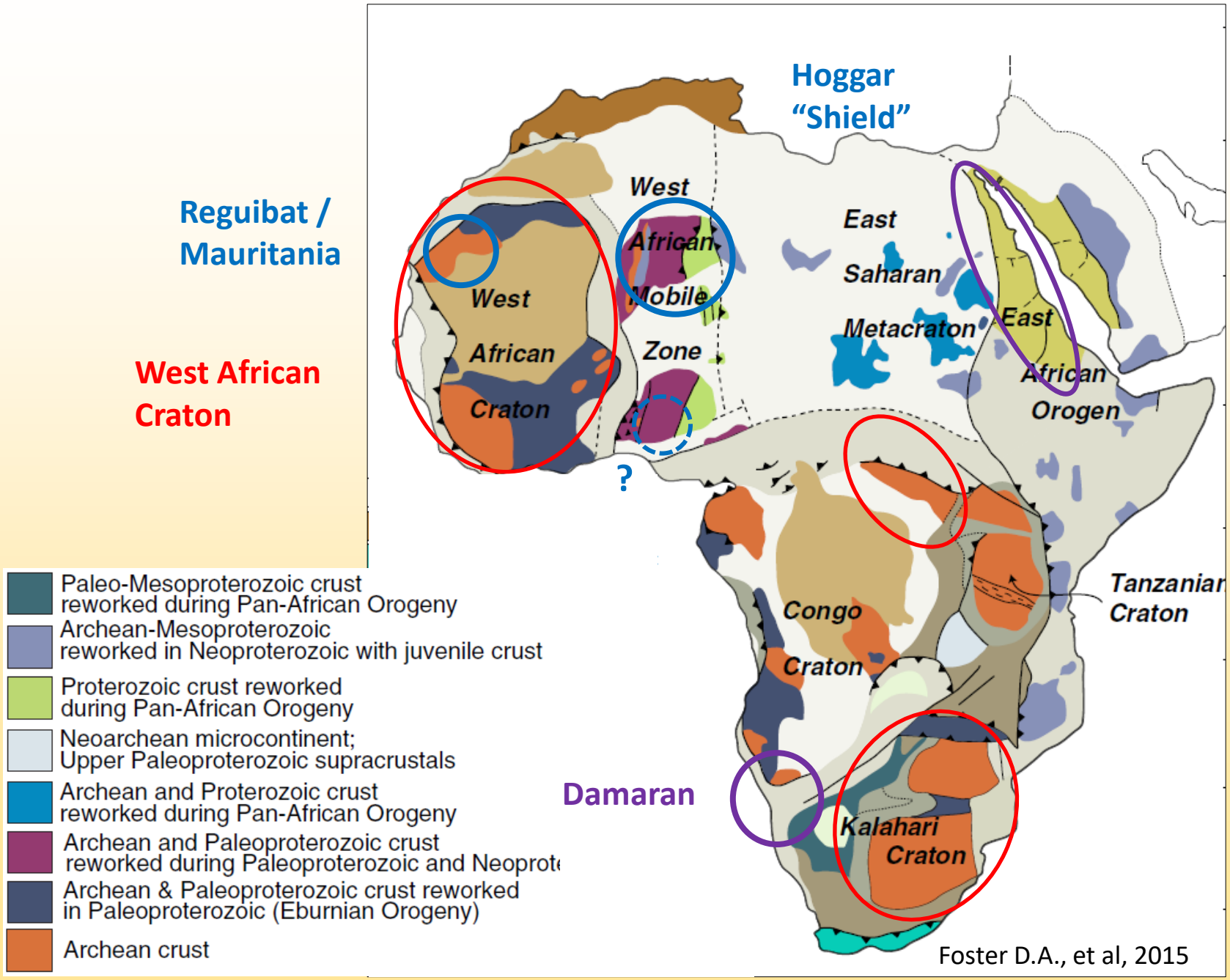
16 ≥1M oz
Max: 10.6M oz
(Shamva)

Kalahari total
>85M oz Au
172 oz / km²

Barberton-only
24M oz Au
306 oz / km²

4 >1M oz
Max: 3.9M oz

Africa: Major “gold terranes” – not only Archean



Reguibat / Mauritania

West African Craton

ANS – Egypt [& Sudan]

ANS - Ethiopia

NE Congo Craton

Under-explored

Damaran

Kalahari Craton
Witwatersrand

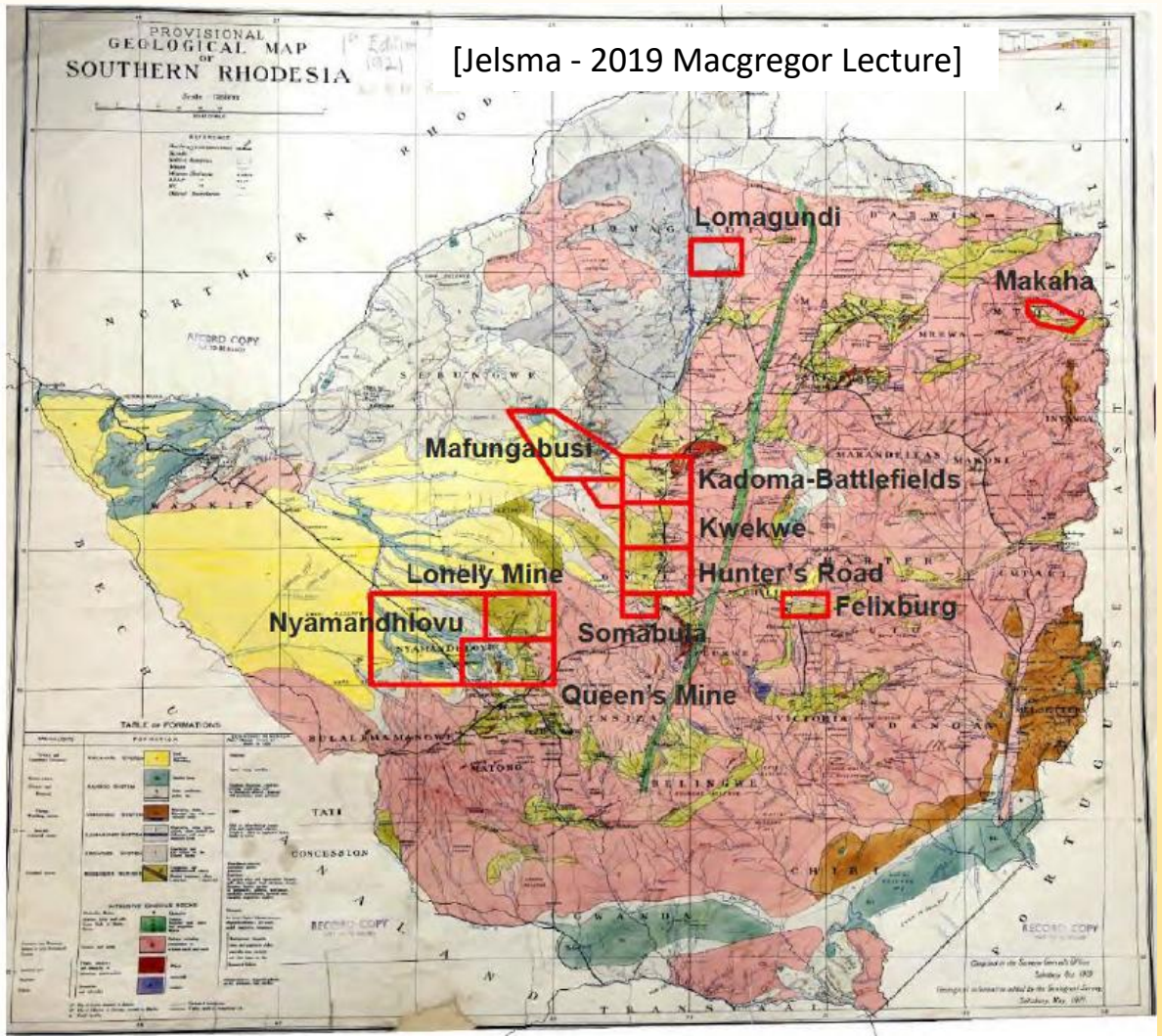
Zimbabwe: understanding gold endowment

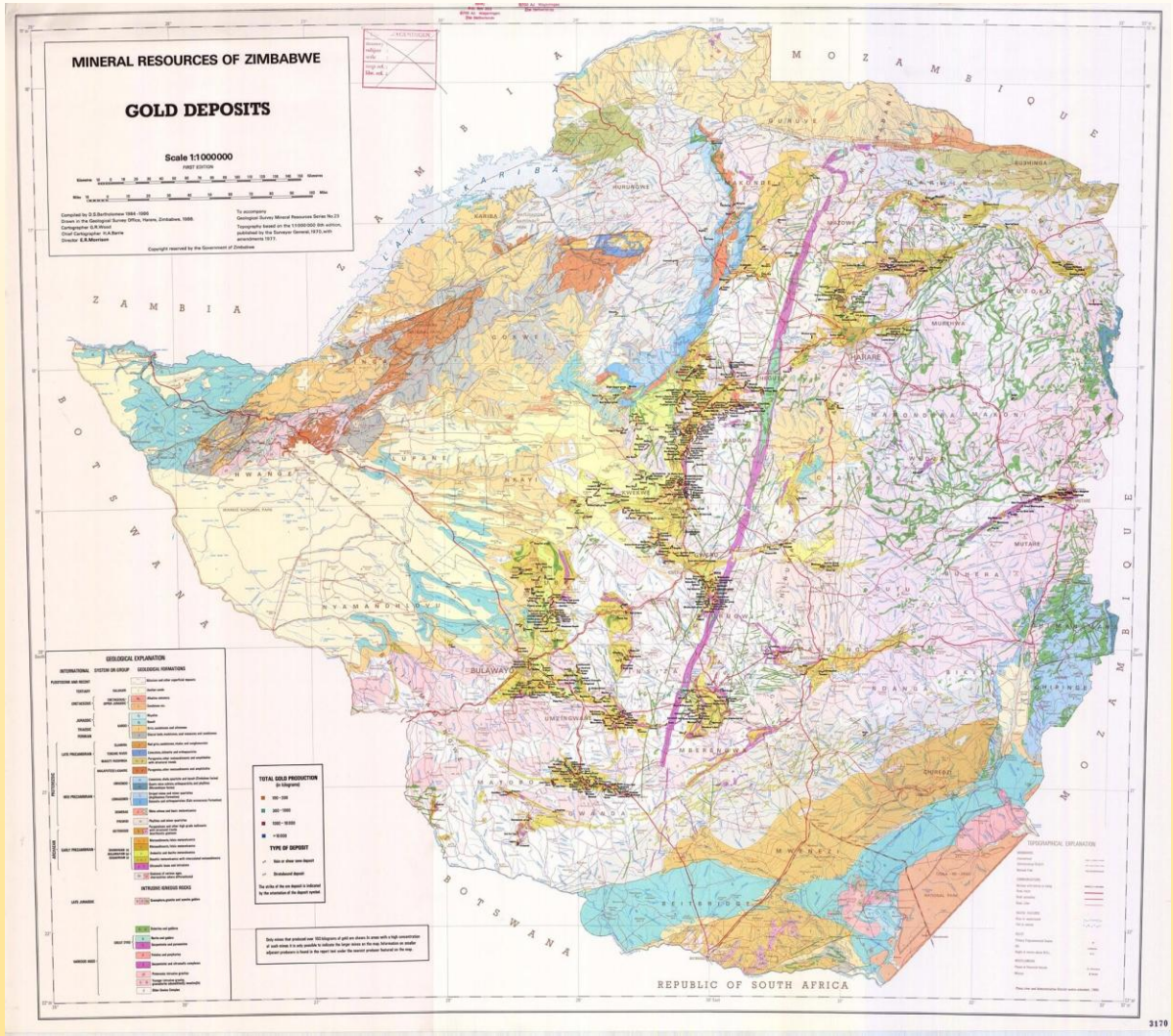


Built on detailed mapping and reporting by Macgregor and colleagues at GSZ

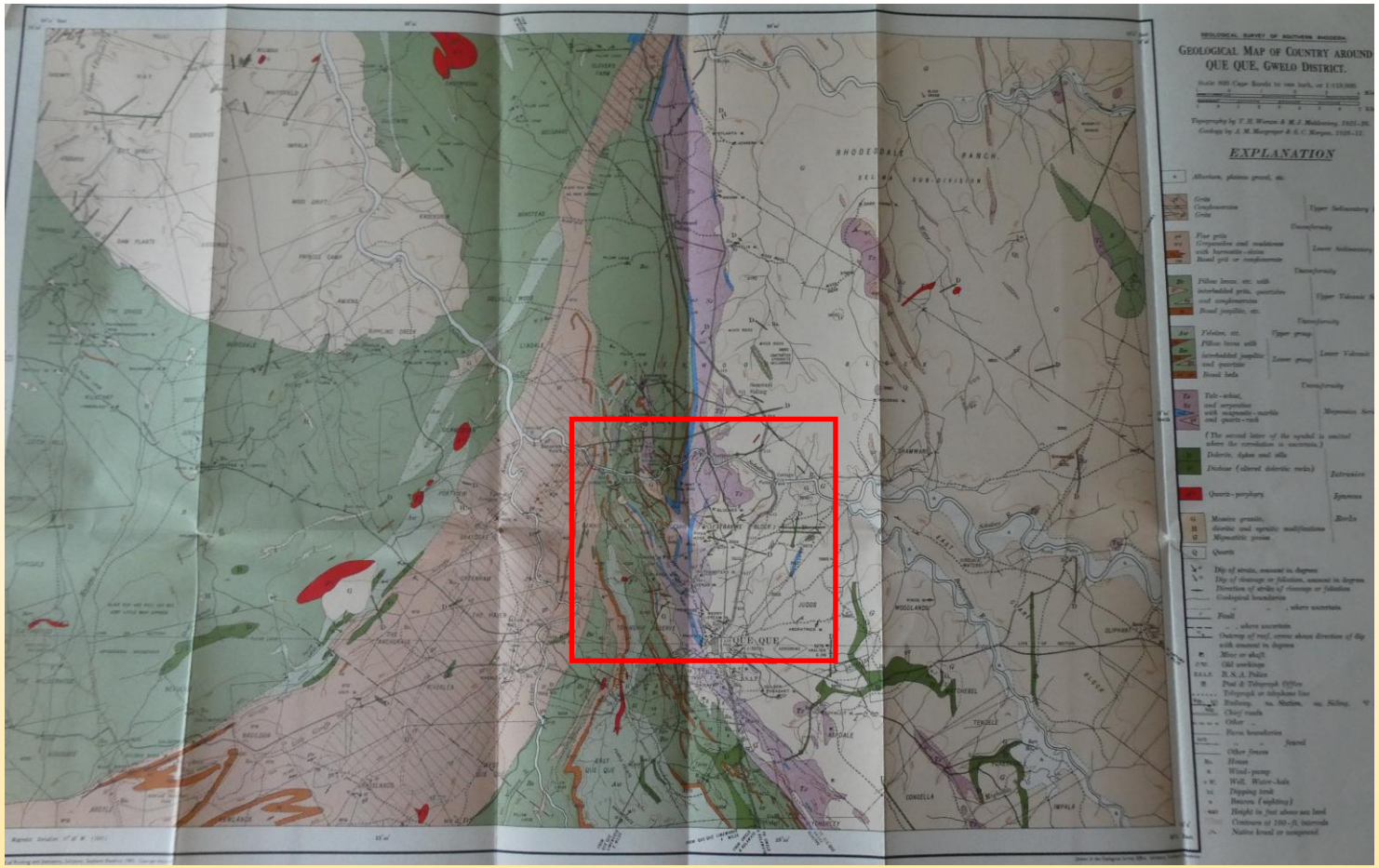
A.M. MACGREGOR
Maufe and Macgregor (1921), 1st Edition

1988 edition
(incl. gold deposits)

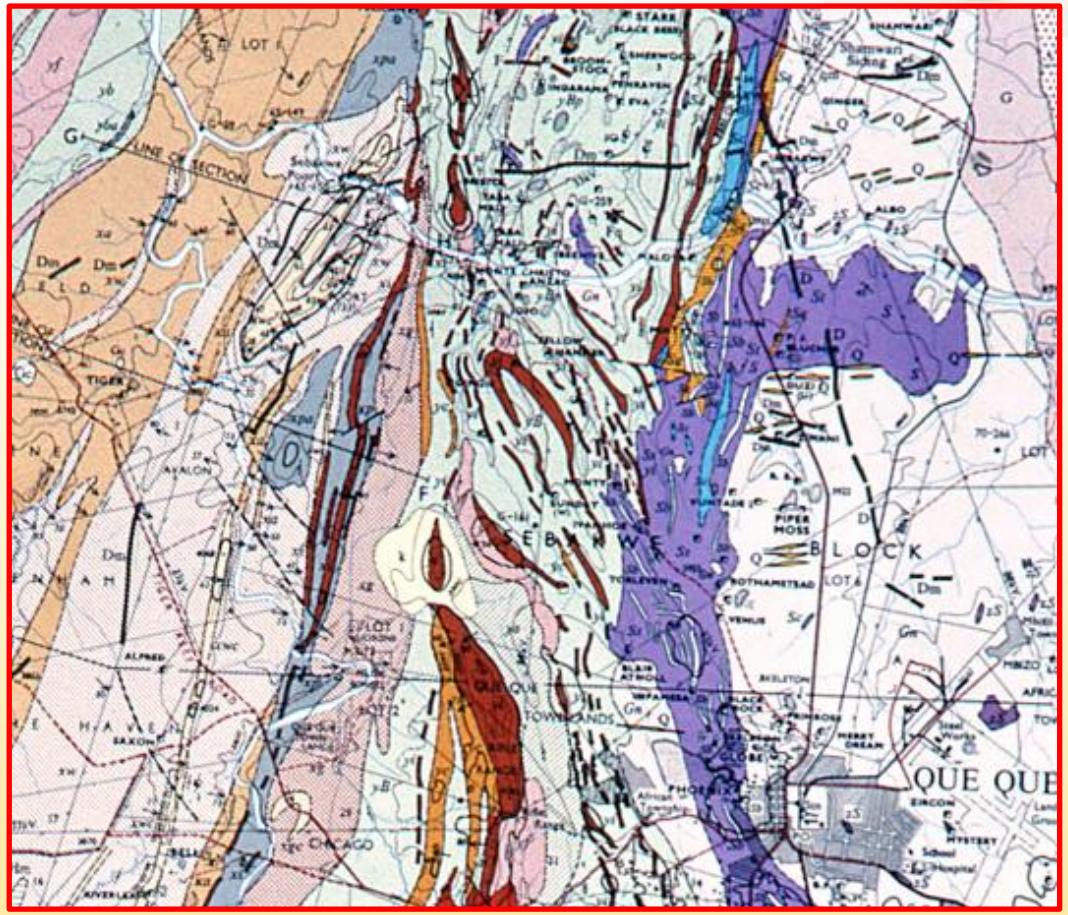




Macgregor mapping: data treasure trove!



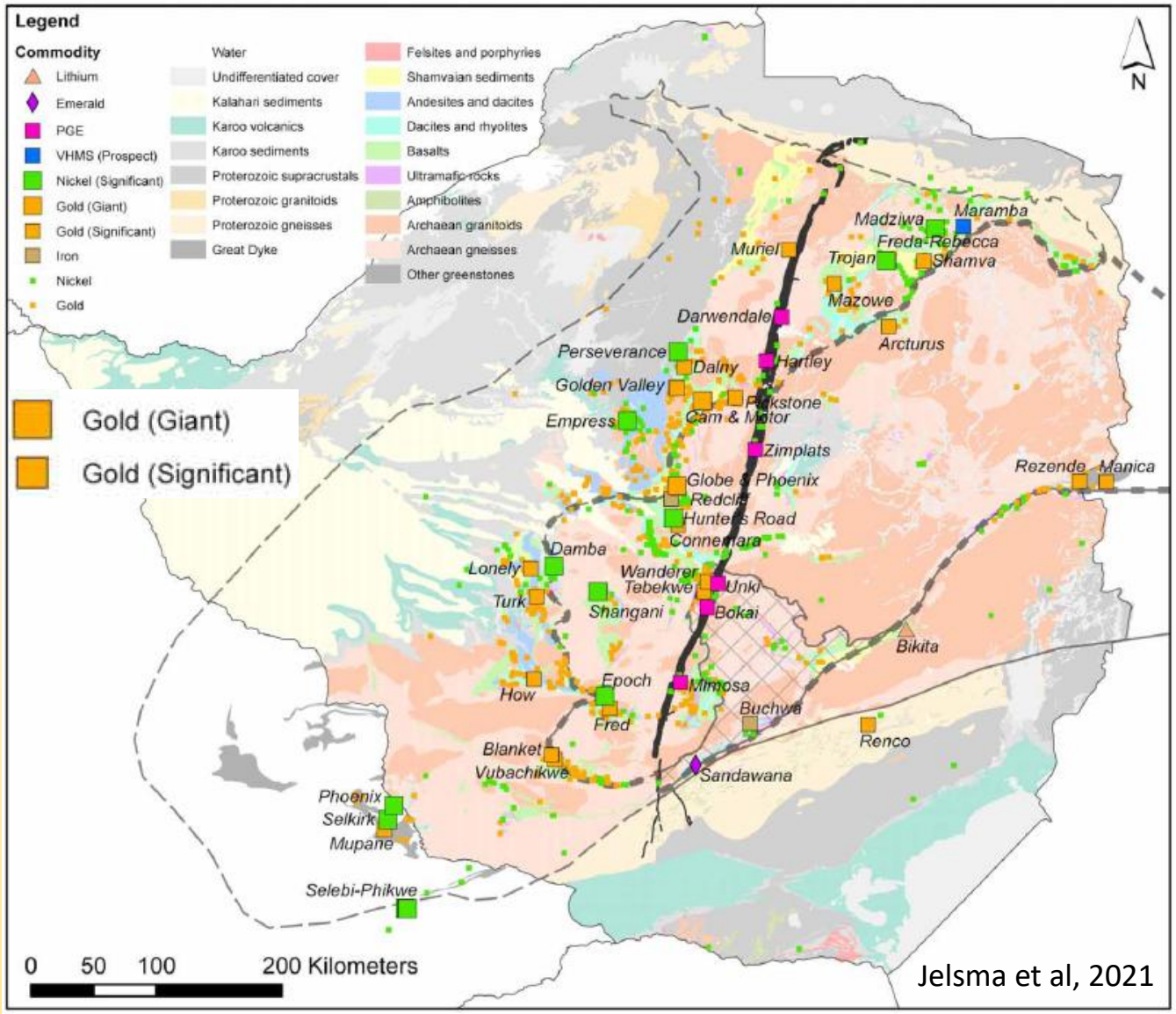
Que Que (Kwekwe) District
(Macgregor - Bull. 20, 1932)



Que Que (Kwekwe) District
(Harrison - Bull. 67, 1970)

Geol Surv Zimbabwe: database that continues to underpin gold exploration in Zimbabwe

Zimbabwe: gold endowment



Jelsma et al, 2021

c. 6,000 deposits mined but only *ca.*400 > 10,000 oz

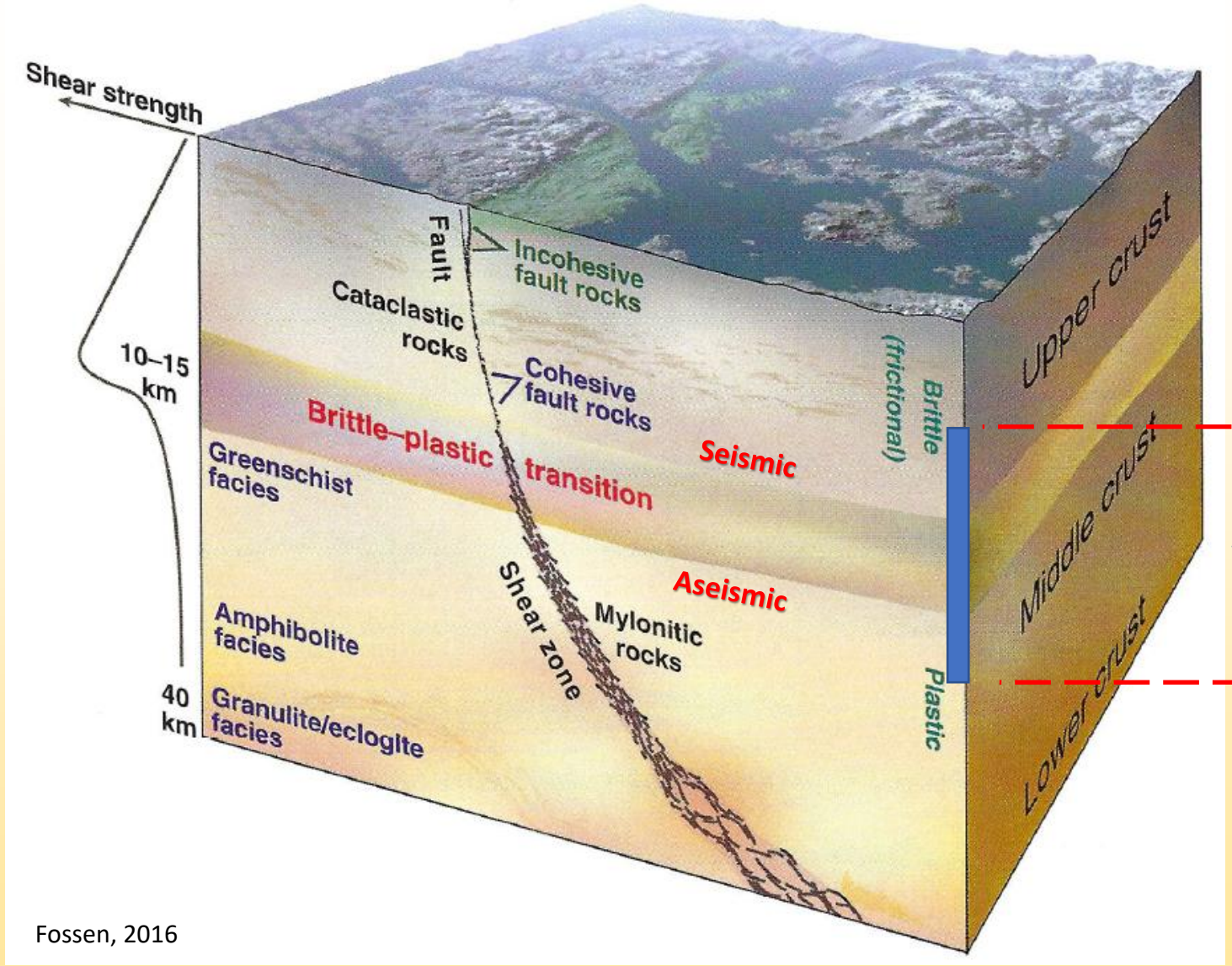
- **Note dominance of "Western Succession"**

Archean gold deposits: 16 ≥1M oz (historical grades to 1980)

- **Shamva** 10.6M oz (incl 7.6M oz MI&I)
- **Cam & Motor** 5.1M oz
- **Globe & Phoenix** 4.0M oz
- **Dalny** 2.5M oz (@ 7.8 g/t)
- **Rezende** 2.2M oz (@ 10.4 g/t)
- **Mazowe (Jumbo)** 2.2M oz (incl 1.21M oz MI&I)
- **Freda Rebecca** 2.0M oz
- **Blanket** 1.9M oz
- **How** 1.8M oz
- **Vubachikwe** 1.6M oz
- **Dokwe** 1.4M oz
- **Wanderer** 1.2M oz (@ 4.1 g/t)
- **Eureka** 1.2M oz
- **Arcturus** 1.2M oz (@10.2 g/t)
- **Lonely** 1.1M oz (@ 17 g/t)
- **Golden Valley** 1.0M oz (@ 22 g/t}

Orogenic gold deposits – but what is an "orogenic gold deposit"?
[NB: always challenge "models"!!]

It’s all about fluid flow – at all scales



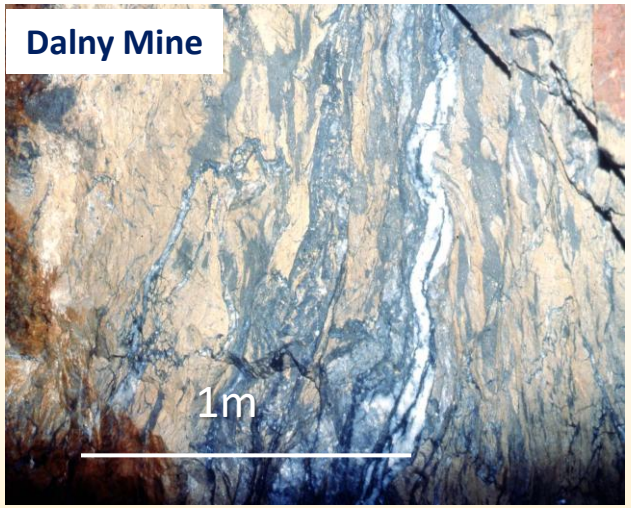
Fossen, 2016

Fluid flow in Earth’s crust

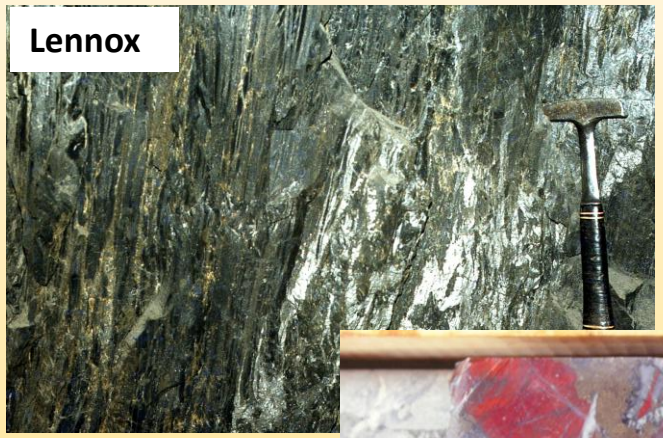
- **Seismic**: brittle - fracturing
- **Aseismic**: ductile = steady-state flow

Dictates fluid flow and type of gold deposit

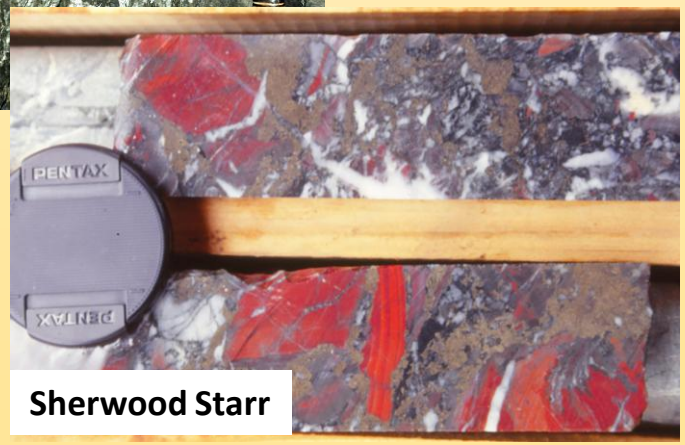
Some orogenic deposits in Zimbabwe







BIF-hosted



Orogenic gold fluids

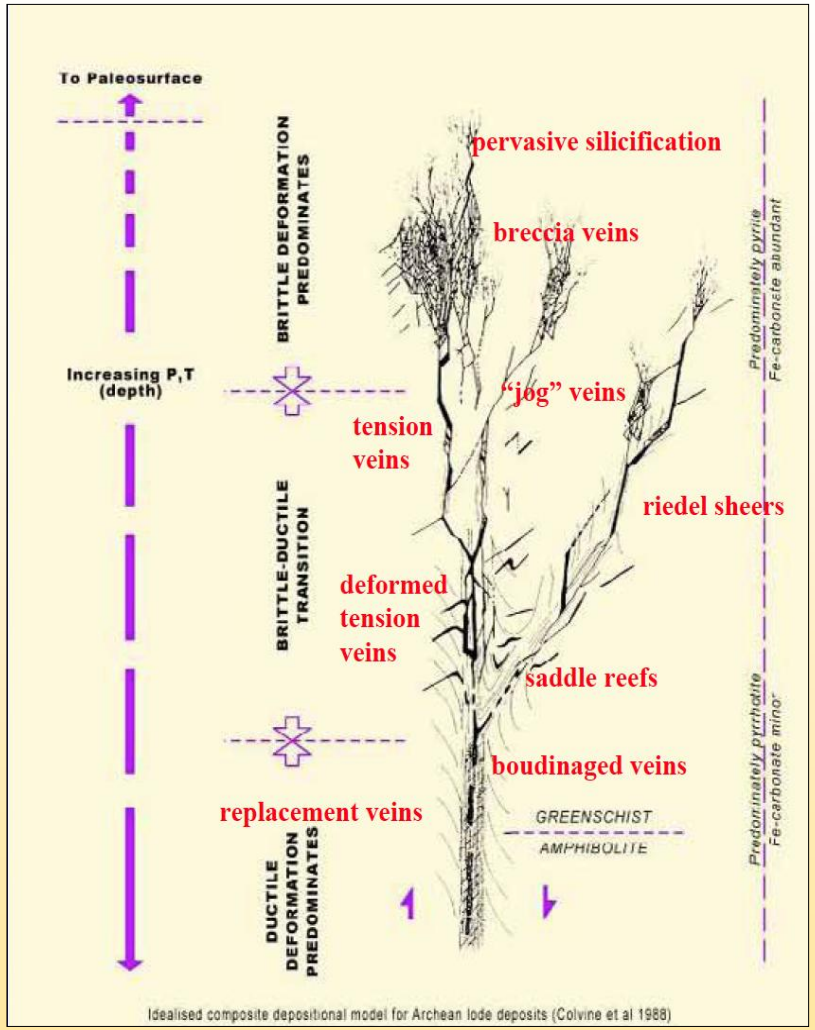
- **Temperatures** **~ 250-400 ^{o}C**
- **Pressure** **>1-4 kb**
- **Fluid comp** **H_2O-CO_2 + CH_4, N_2, H_2S**
- **Salinity** **<5-8% NaCl eq**

FLUIDS CONSISTENT WITH THOSE PRODUCED VIA METAMORPHIC DEVOLATILIZATION BETWEEN 300° AND 500°C

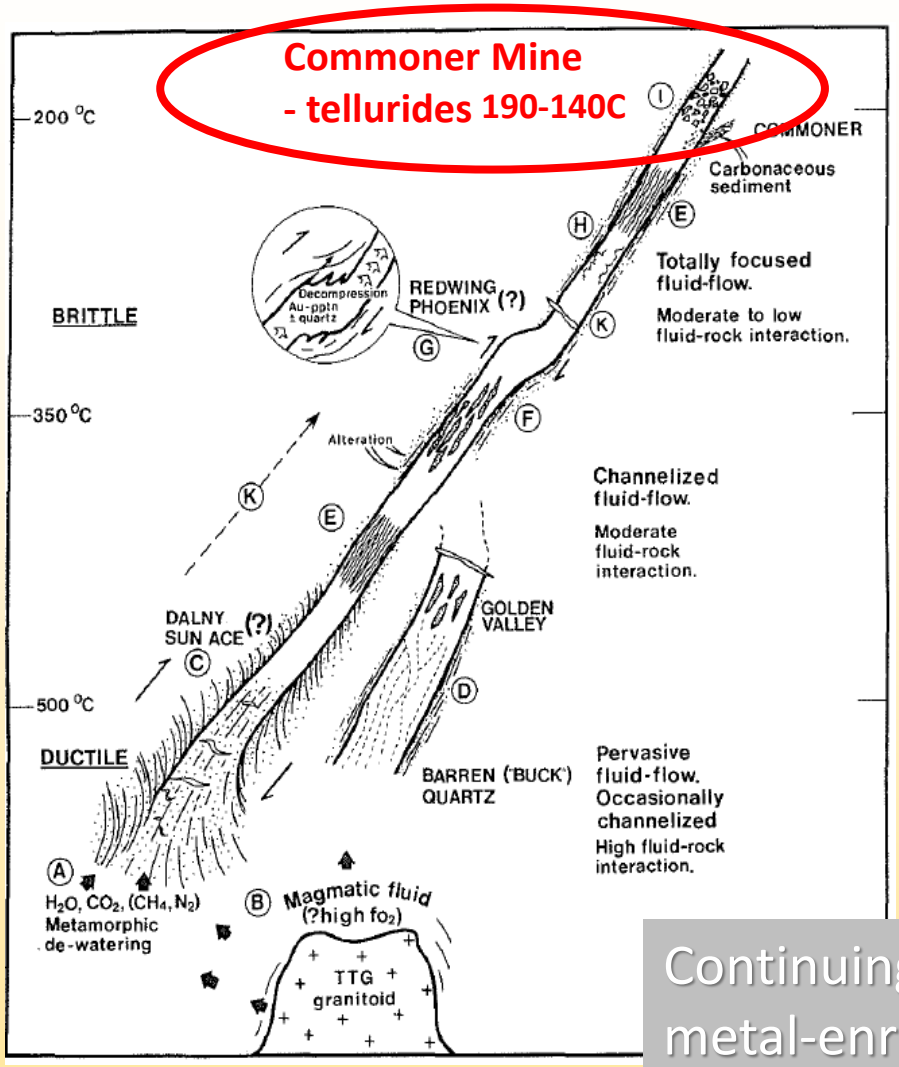
Areas of contention

- "Intrusion-related" gold deposits – magmatic fluids? Or just strain-focus?
- Transcrustal conduits tapping "fertile mantle"

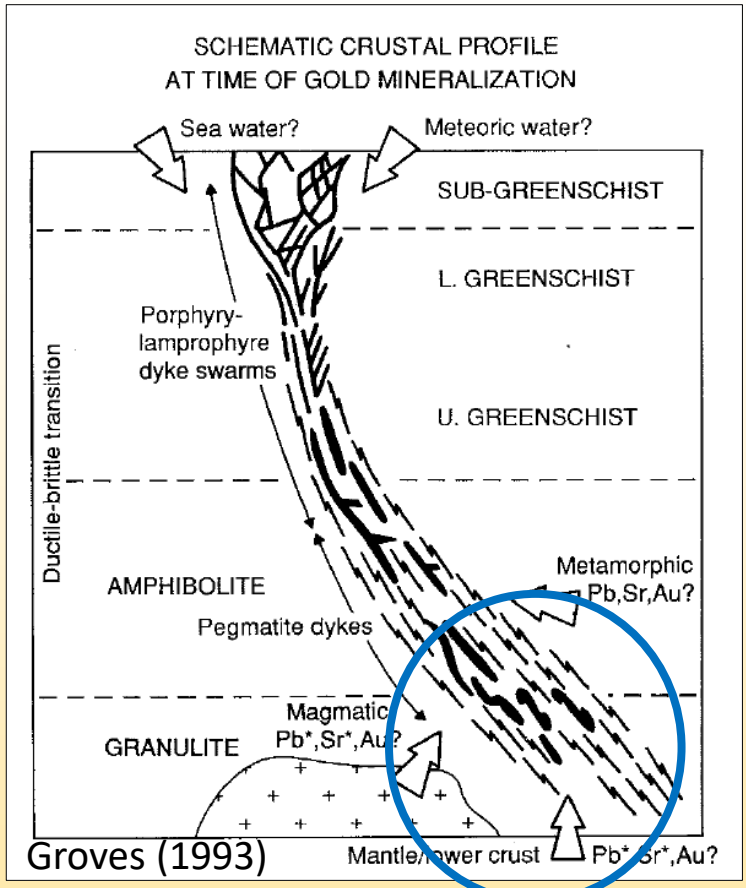
Early contributions to concept of "crustal continuum"



Sandy Colvine (1988) – and Macgregor Lecture 1987



Foster (1988) - based on Zimbabwe occurrences



Groves (1993)

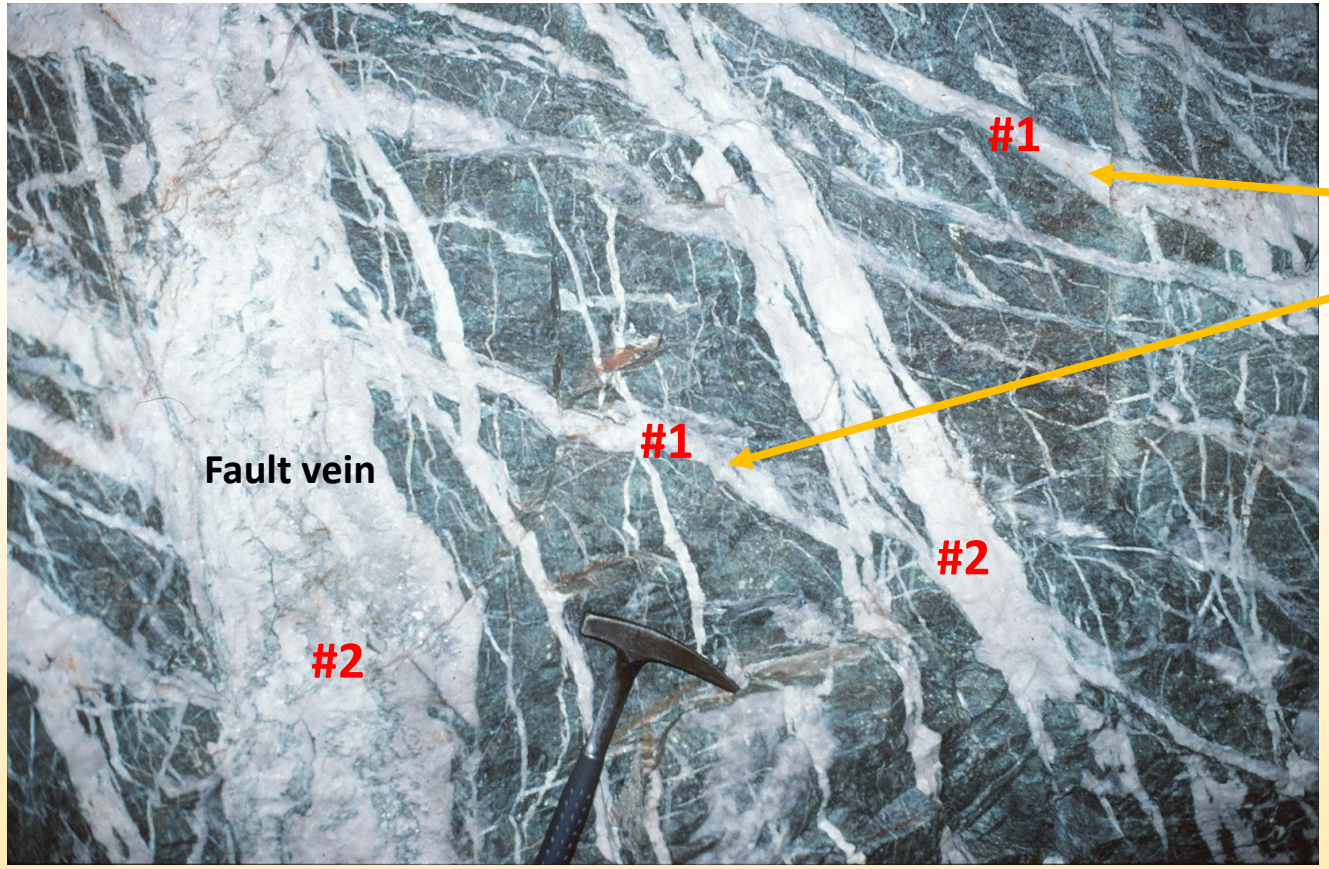
Continuing debate on mantle fluids and metal-enriched "**fertile mantle**"
Multi arguments against .....
Total agreement that major crustal structures are key – BUT "transcrustal"?

Gold '88 Melbourne

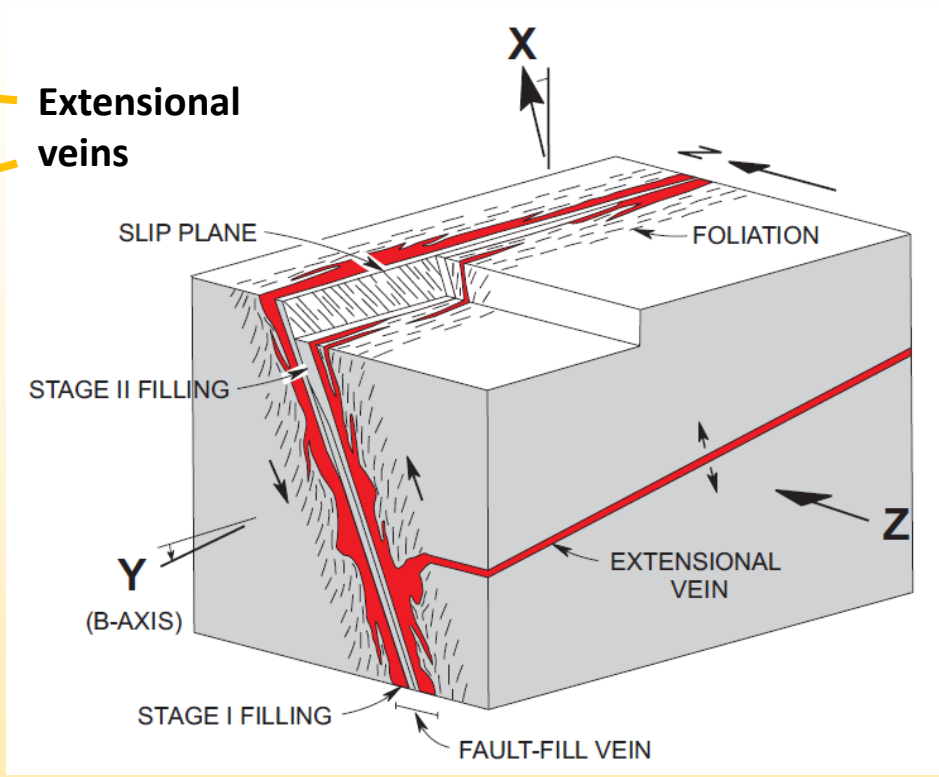


Snapshot insights of Zimbabwe's orogenic gold mineralization

Globe & Phoenix: typical cogenetic extension & fault vein array



Extensional veins



Stage 1: pre-rupture fluid pressurisation

- Opening of extension veins at low differential σ1 – σ3

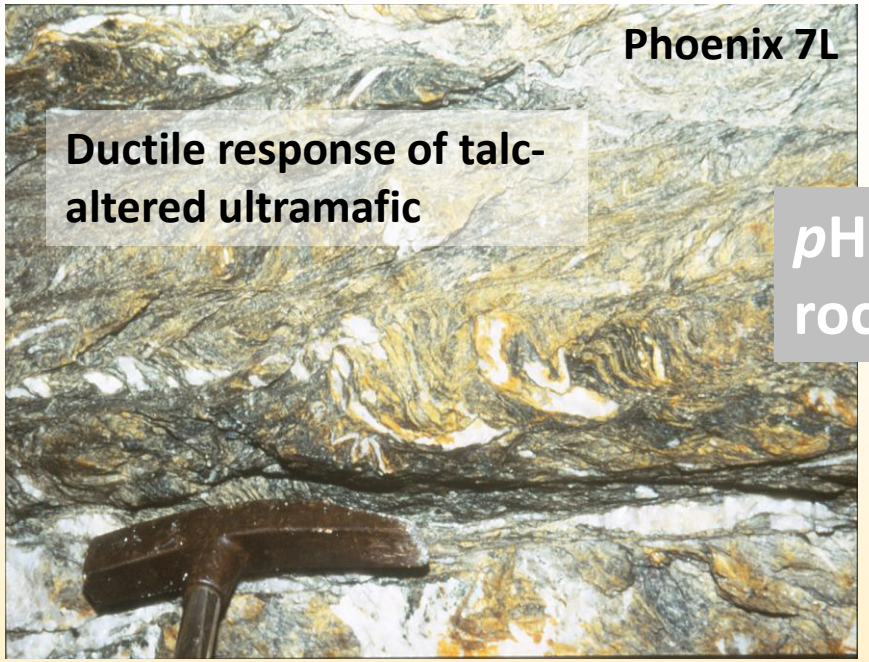
Stage 2: rupture propagation

- Dilation along rupture surface
- Rupture-dilation ⟹ fluid flow and growth of fault veins

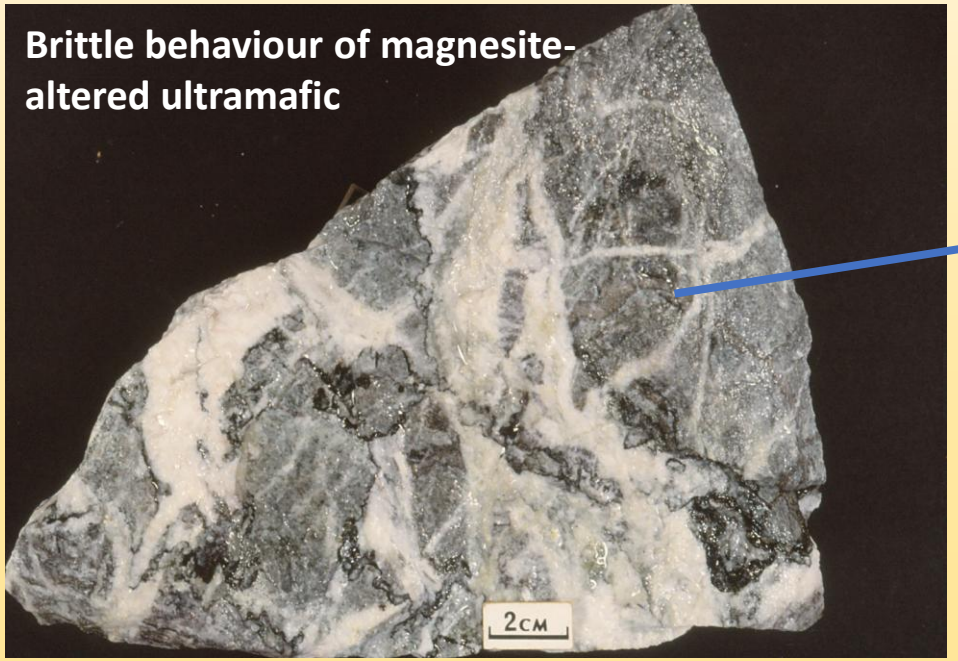
Dube & Gosselin, 2007
After Robert, 1990

Cyclical failure ⟹ dilation ⟹ fluid flow ⟹ fracture- sealing: generates substantial mineralized systems

Hydrothermal alteration of mafic rocks: can dictate ongoing deformation response



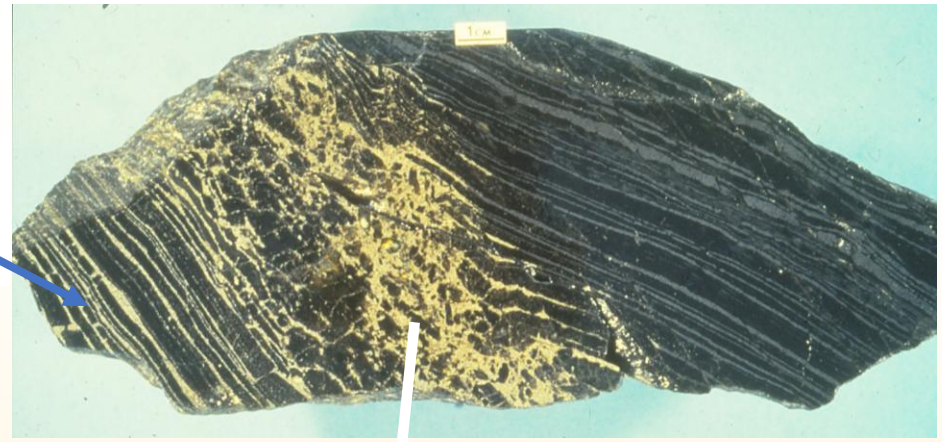
*p*H2O & *p*CO2 and host rock mineralogy important

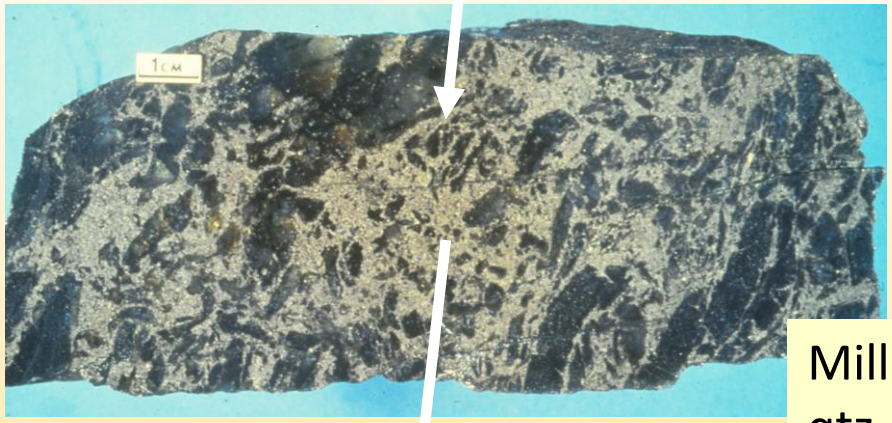




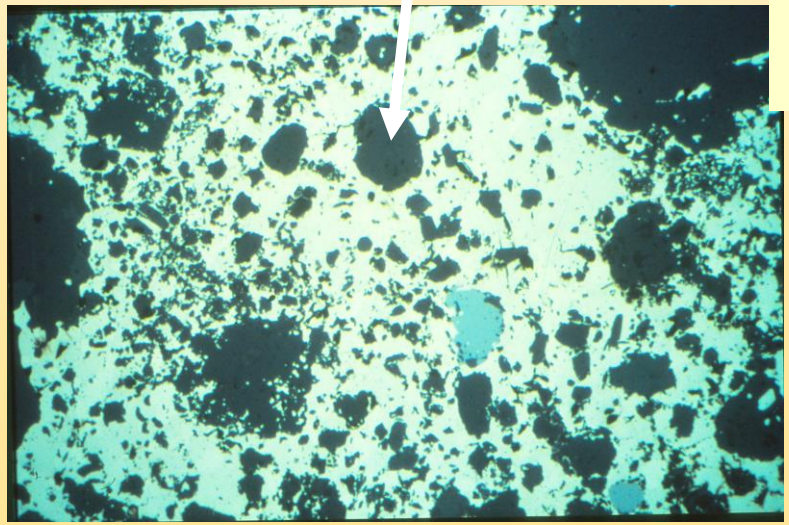
Alteration-controlled deformation: sulfidation

Complete sulfidation **(pyrrhotite)** of magnetite bands

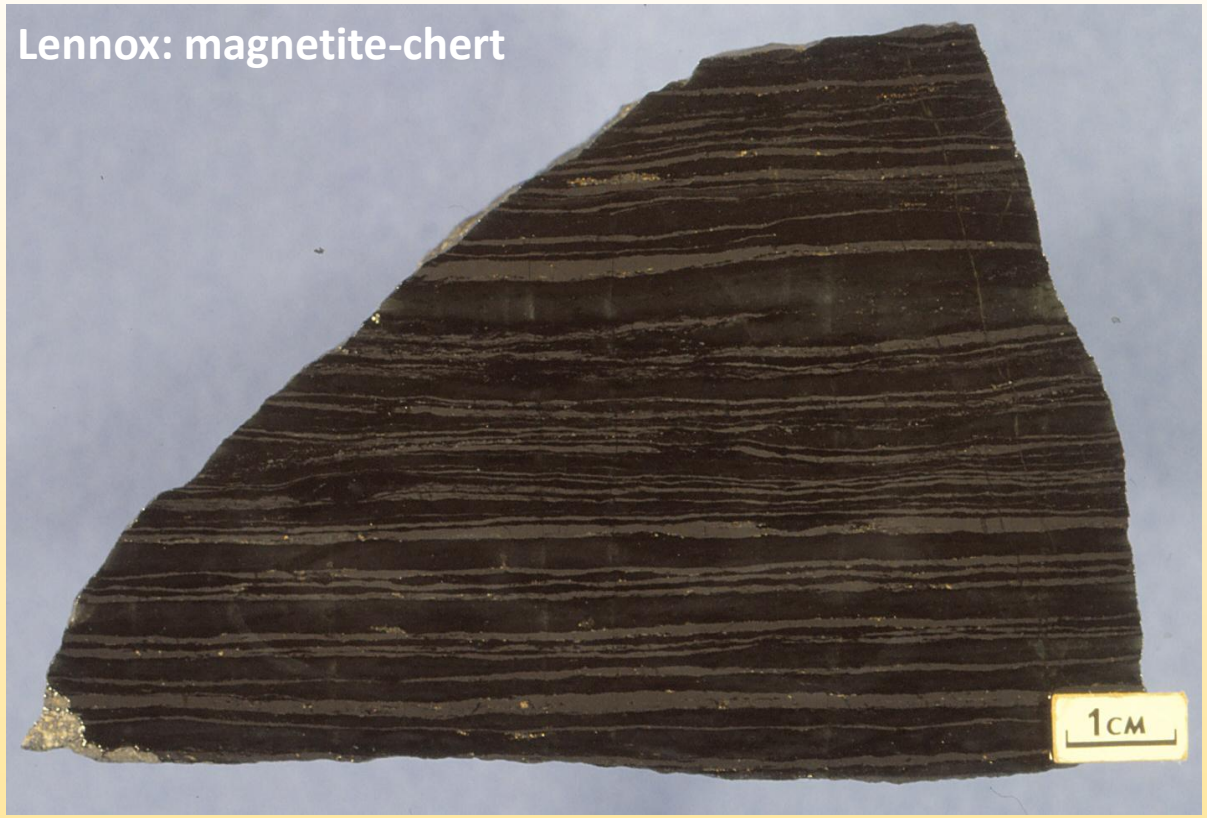




Milling texture - qtz & mgt clasts in **pyrrhotite** matrix

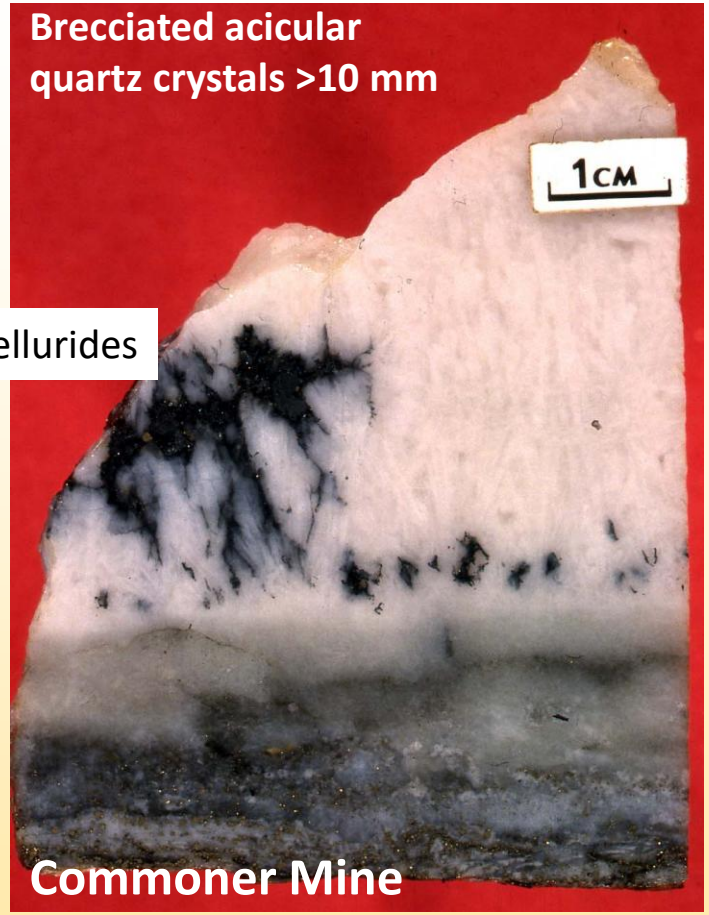


Photomicrograph - reflected light

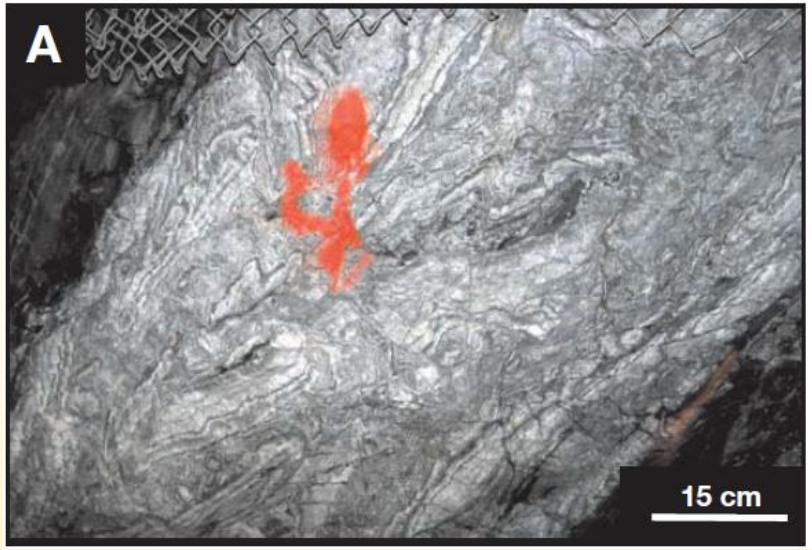


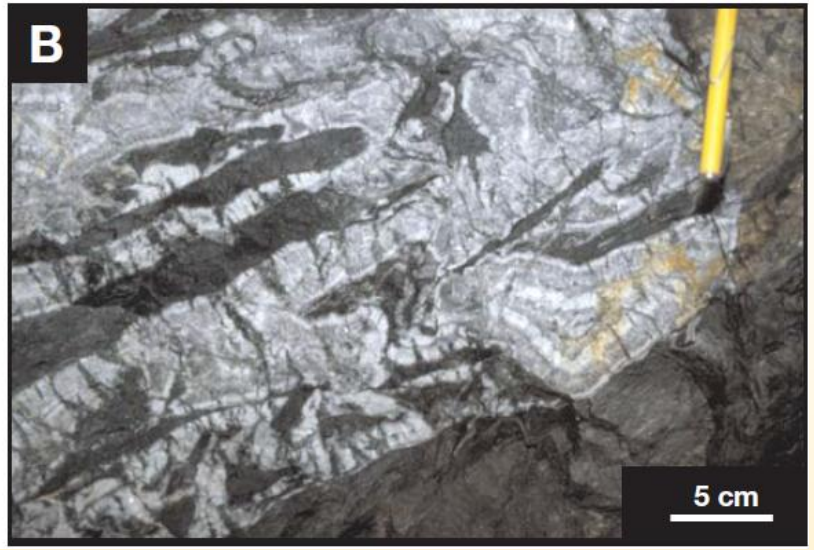
Colloform-crustiform textures

Red Lake Mine – Superior Province



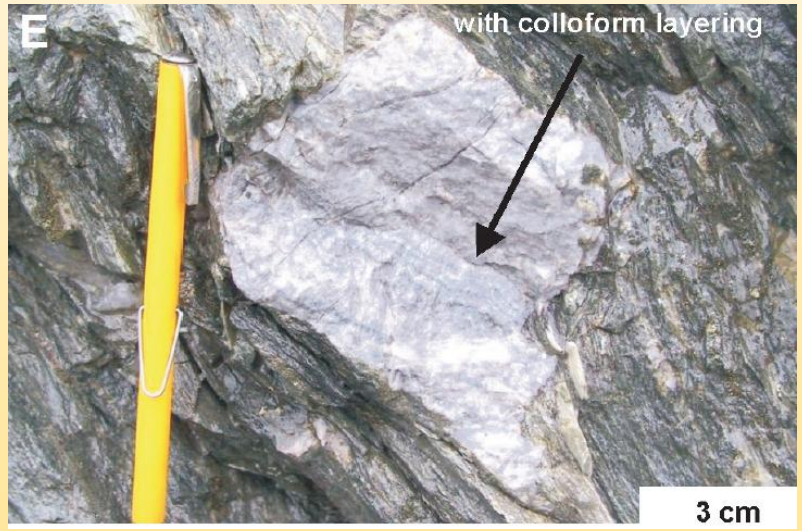
Telluride assemblage = 190-140C





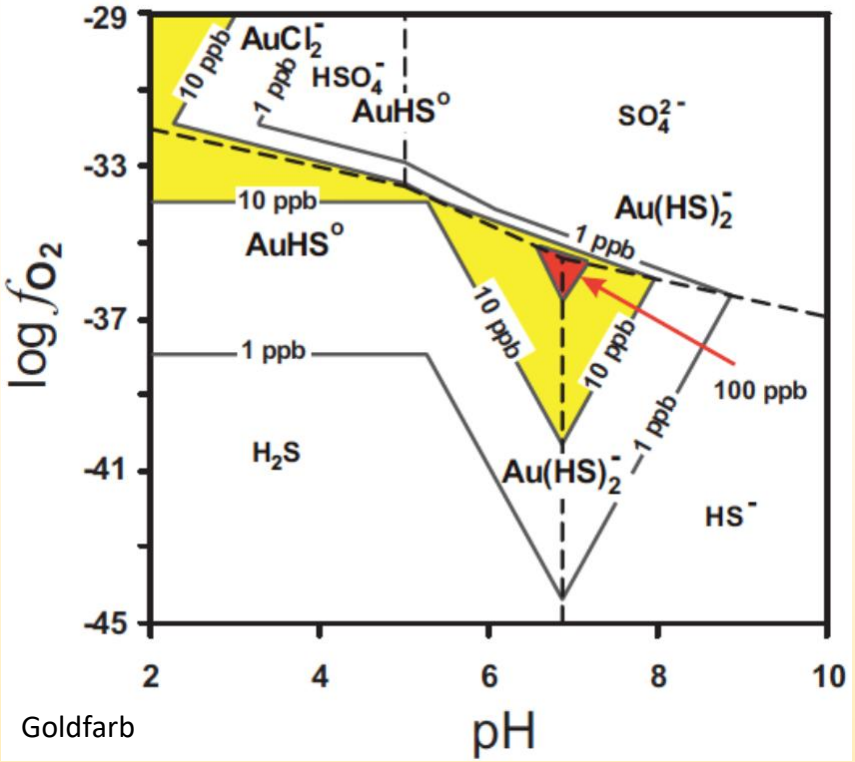
Colloform-crustiform textures in qtz-cbt veins

[Dube et al, 2003, 2004]



Don't assume all open-space textures = high crustal level
Transient – hydrofracturing at depth?

GOLD PRECIPITATION: AuHS(aq) & $Au(HS)^-_2$ <400C



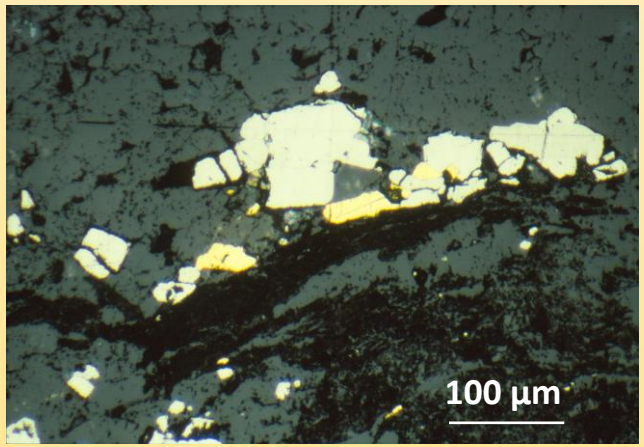
Goldfarb

Important precipitation controls:

- ✓ decrease in *f*O2 – reduction
- ✓ Oxidation – less likely?
- ? Limited control by pH – strongly buffered by wallrocks *ca.* pH 5-6

X Cooling: probably only important > 400°C

? Mixing of different fluids unlikely



"Fe-SULFIDATION REACTIONS"

$FeO + HAu(HS)_2 + ¼\ O_2 \longleftrightarrow FeS_2 + 3/2H_2O + Au$

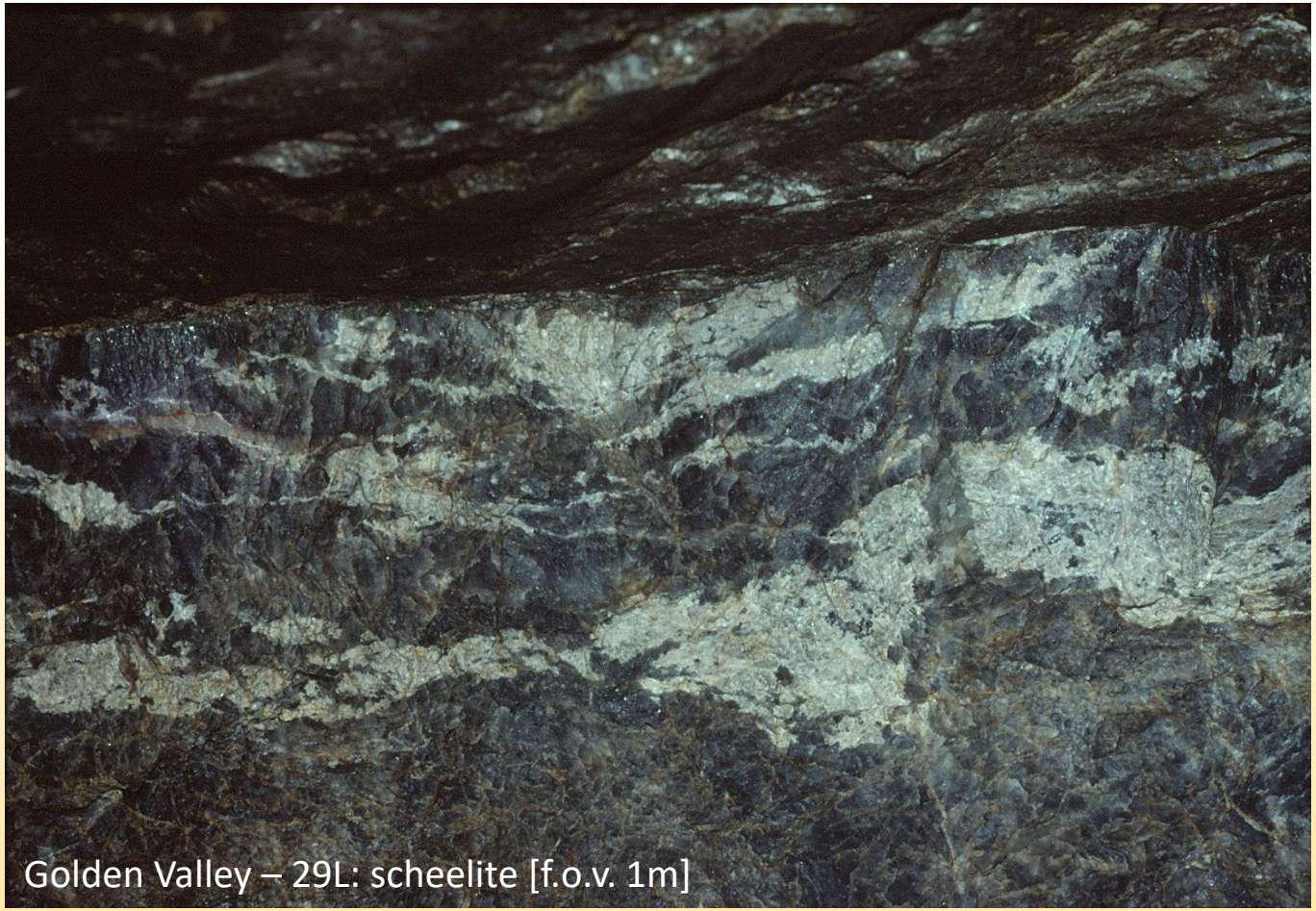
silicate — pyrite — gold

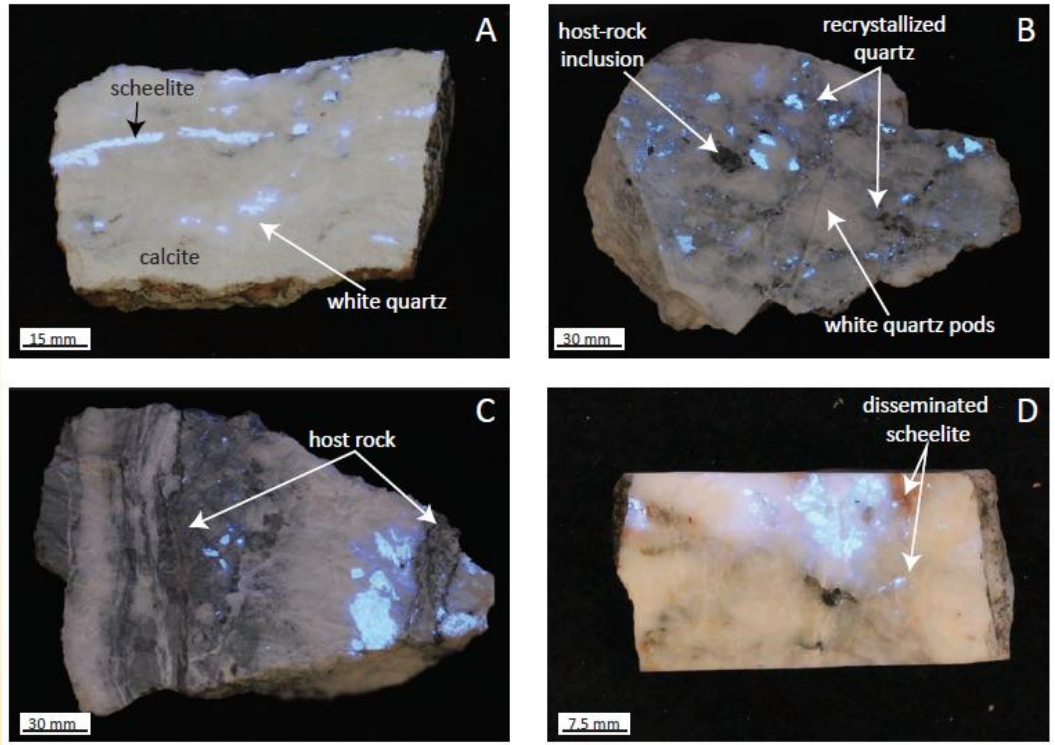
$Fe_3O_4 + 3HAu(HS)_2 + ¼\ O_2 \longleftrightarrow 3FeS_2 + 9/2H_2O + Au$

magnetite — pyrite — gold

$[AuHS]_{aq}$ + chlorite/mgt/hornblende/etc → Au + Py [Po] + Qtz + Silicates

Gold v scheelite?





Scheelite in auriferous lodes, NZ
[Scanlan et al, 2018]

- Broadly paralleling vein margins
- Massive scheelite pods
- Later cross-cutting veins

W price +*ca*.350 % in past year
Don't ignore!

Direct correlation with gold often unclear

$Au(HS)_2^-$ ± AuHS

$H_2WO_4^0$, $H_2WO_4^-$, WO_4^{2-}

Very different aqueous species

Way in which mineralized fracture/shear evolves controls fluid-rock interaction



Commoner – 21 level

- Matrix-supported dilational breccia
- Brecciation of both brittle basalt and ductile phyllite wallrocks

Significant implications for precipitation of gold – at all scales

Brecciation

“Jacking”

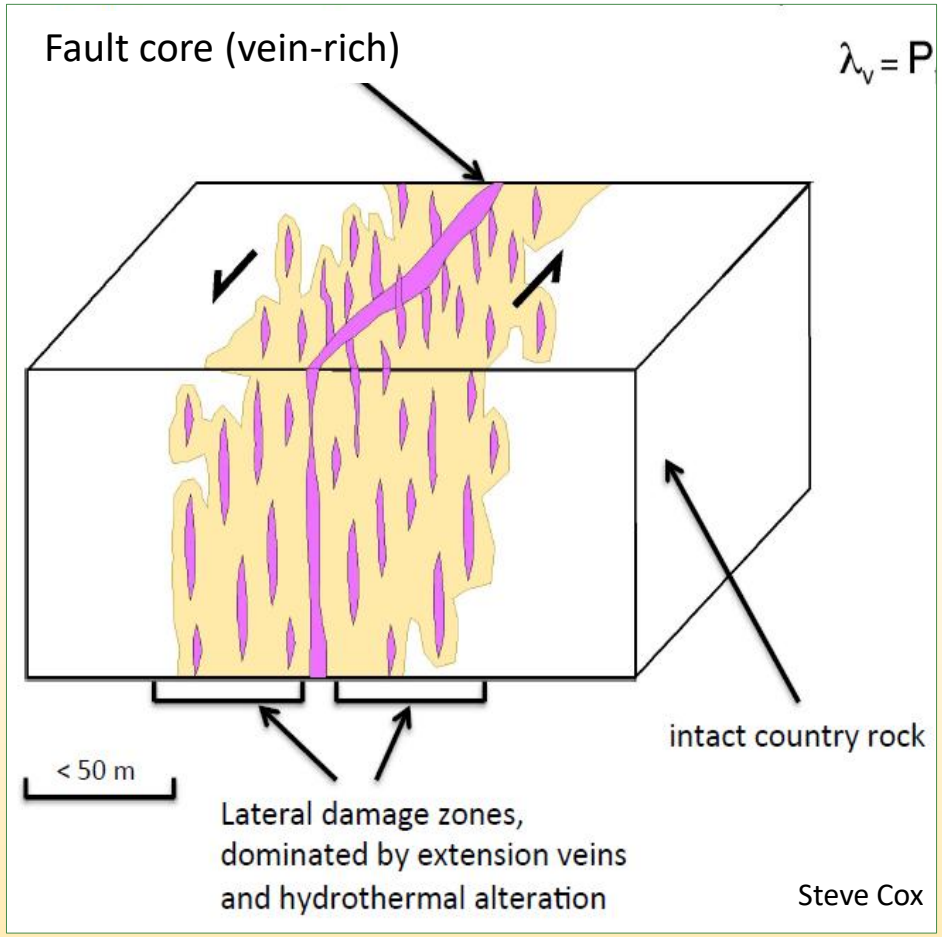


Sunace – 4 level

- Fluid-pressure-driven brecciation at contact
- Hydraulic jacking along vein walls

Fluid flow and wallrock alteration





Fluid <u>permeation</u> of wallrocks controlled by:

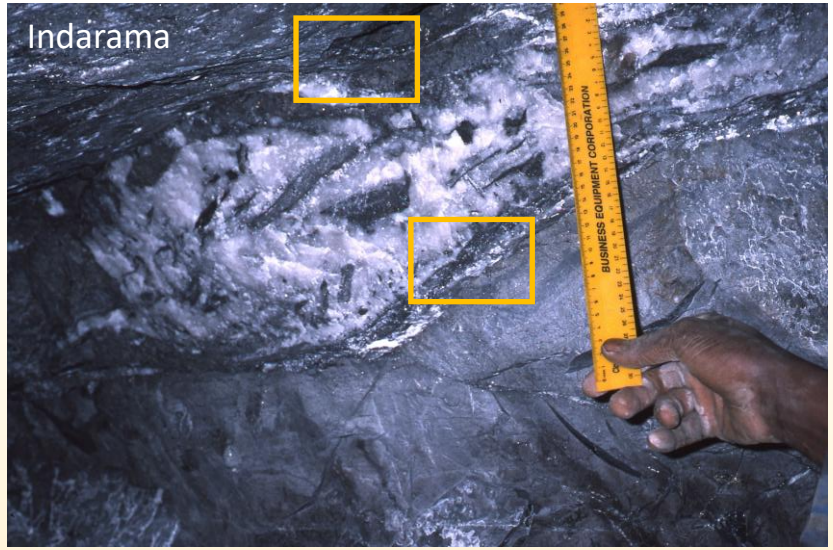
- Inherent [metamorphic] porosity & permeability
- Lateral damage zones – extension veins, micro-fractures, micro-breccias
- Progressive [ongoing] deformation

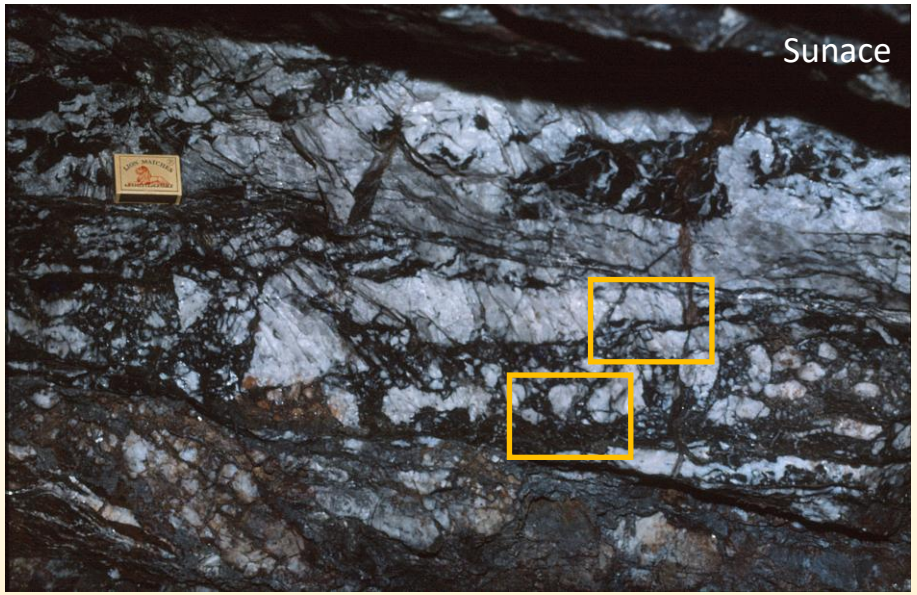
Alteration <u>intensity</u> controlled by:

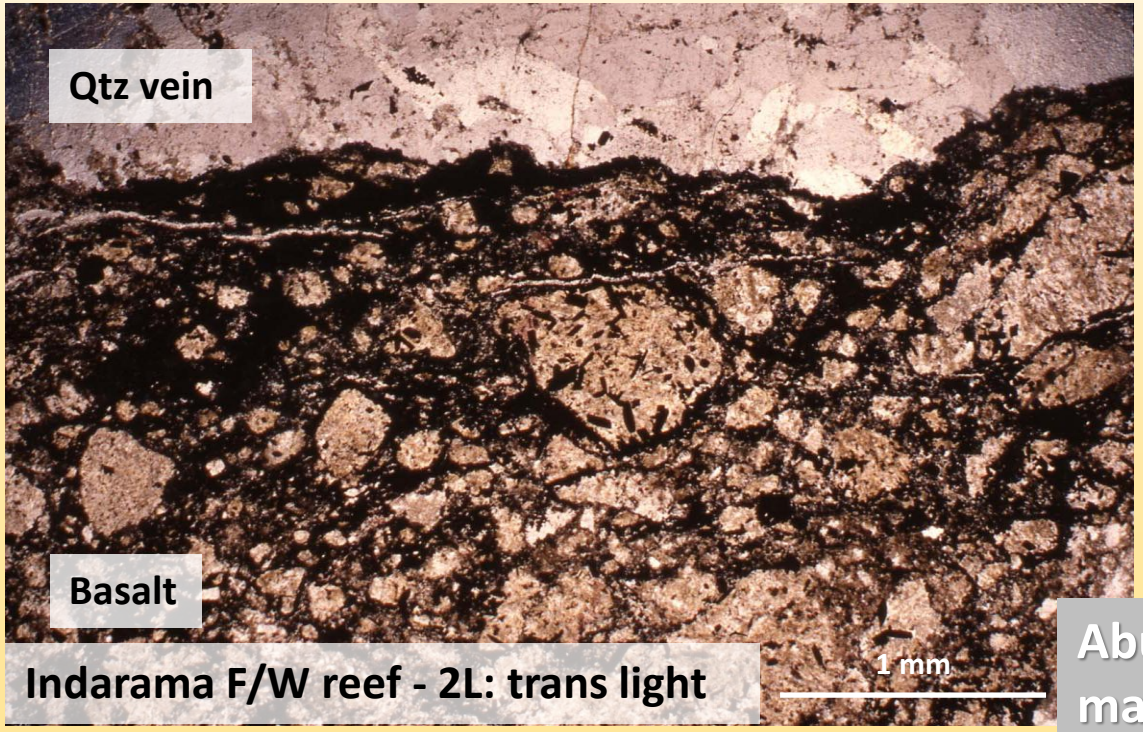
- Wallrock permeability [damage zones]
  Also ....
- Fluid-rock ratio
- Fluid P-T-x
- Wallrock mineralogy

All important controls of gold precipitation

Micro-fractures, veins, damage zones and gold + sulfide precipitation

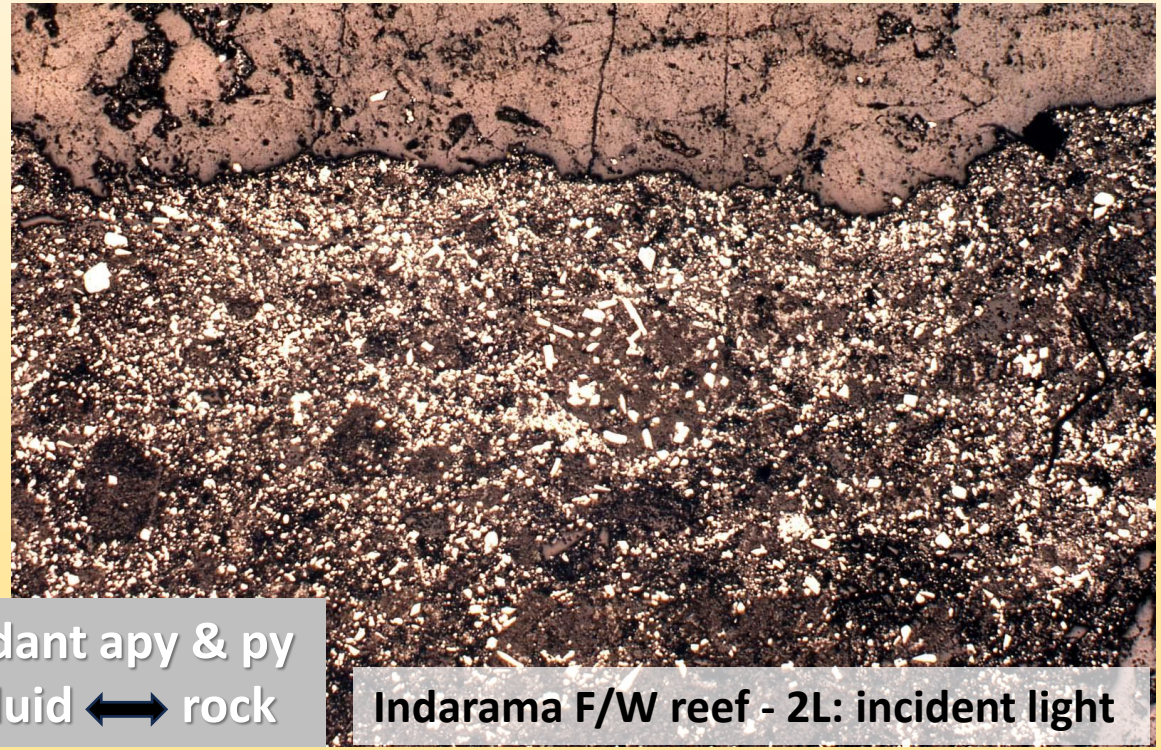






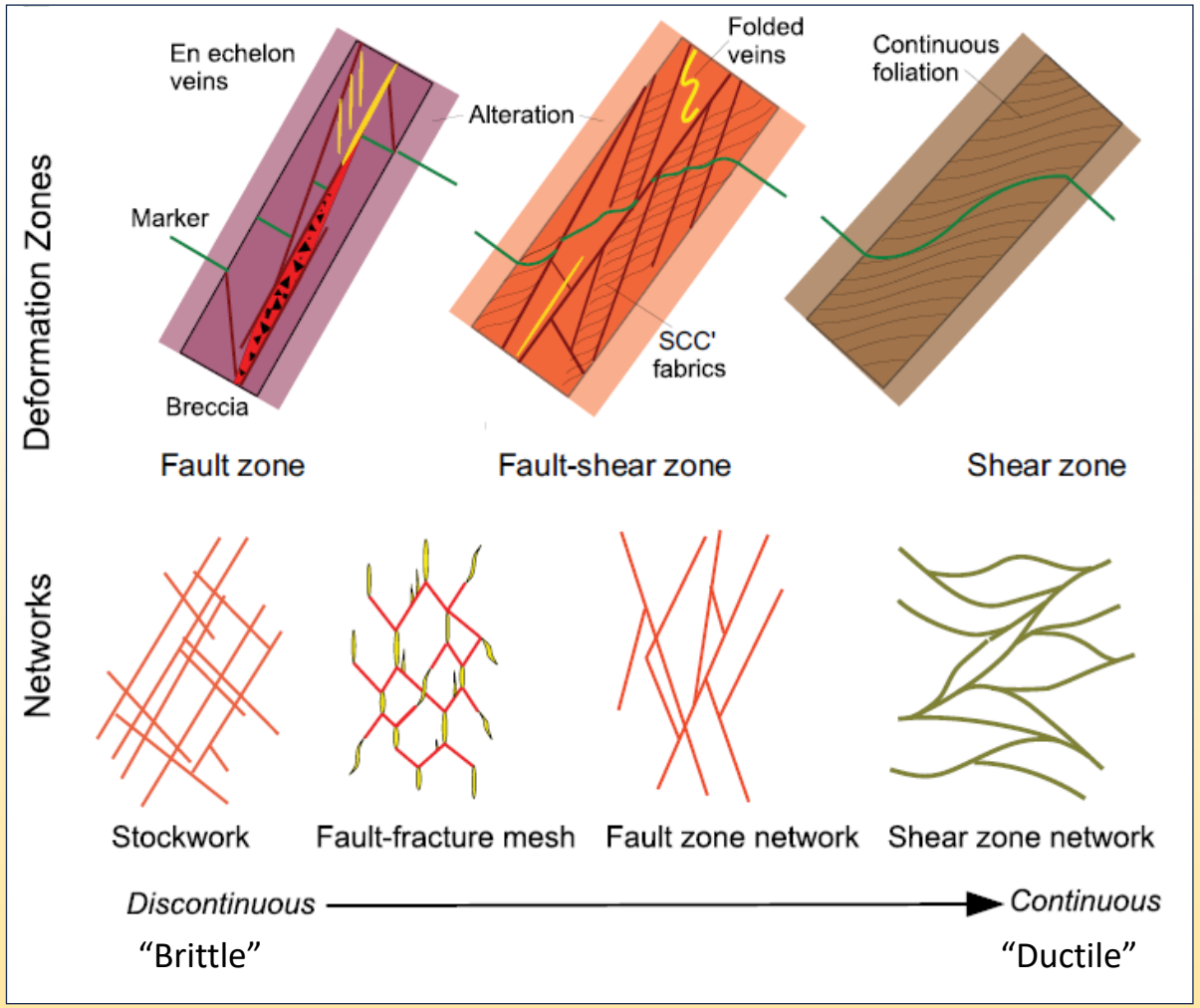
Indarama F/W reef - 2L: trans light

Abundant apy & py
max fluid ⟷ rock



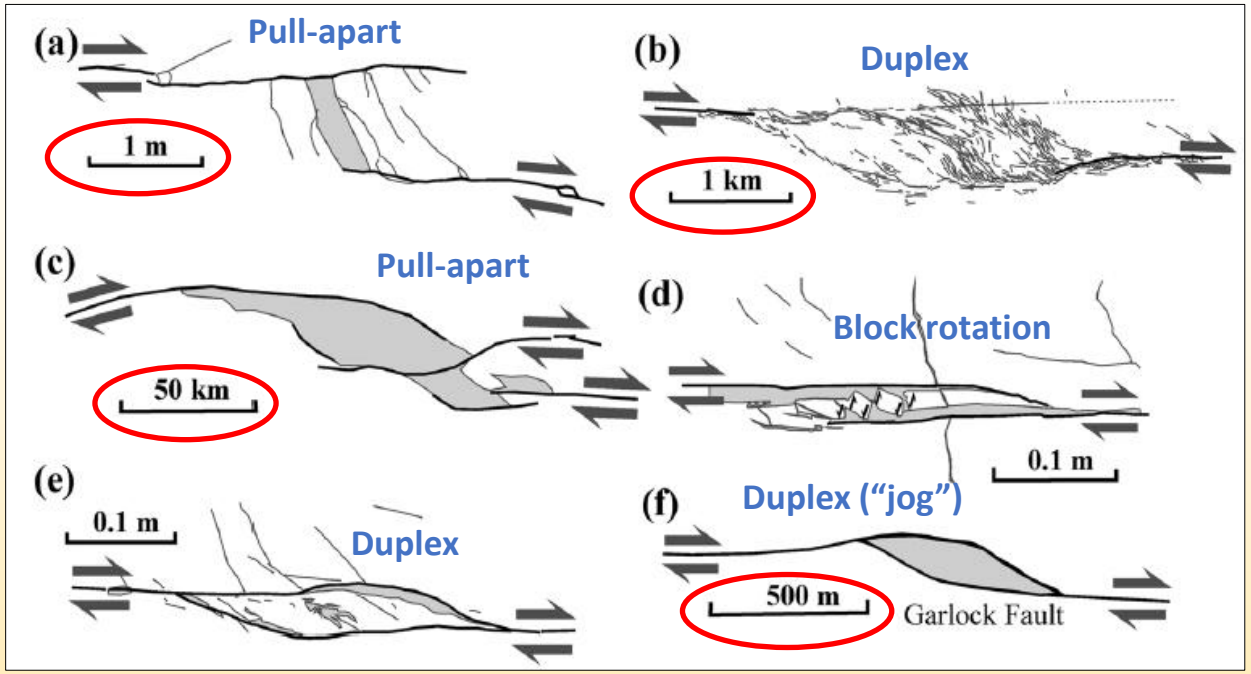
Indarama F/W reef - 2L: incident light

It's all about structurally controlled fluid flow – at all scales



Planar deformation features

[Blenkinsop et al (2020) and 2013 Macgregor Lecturer]



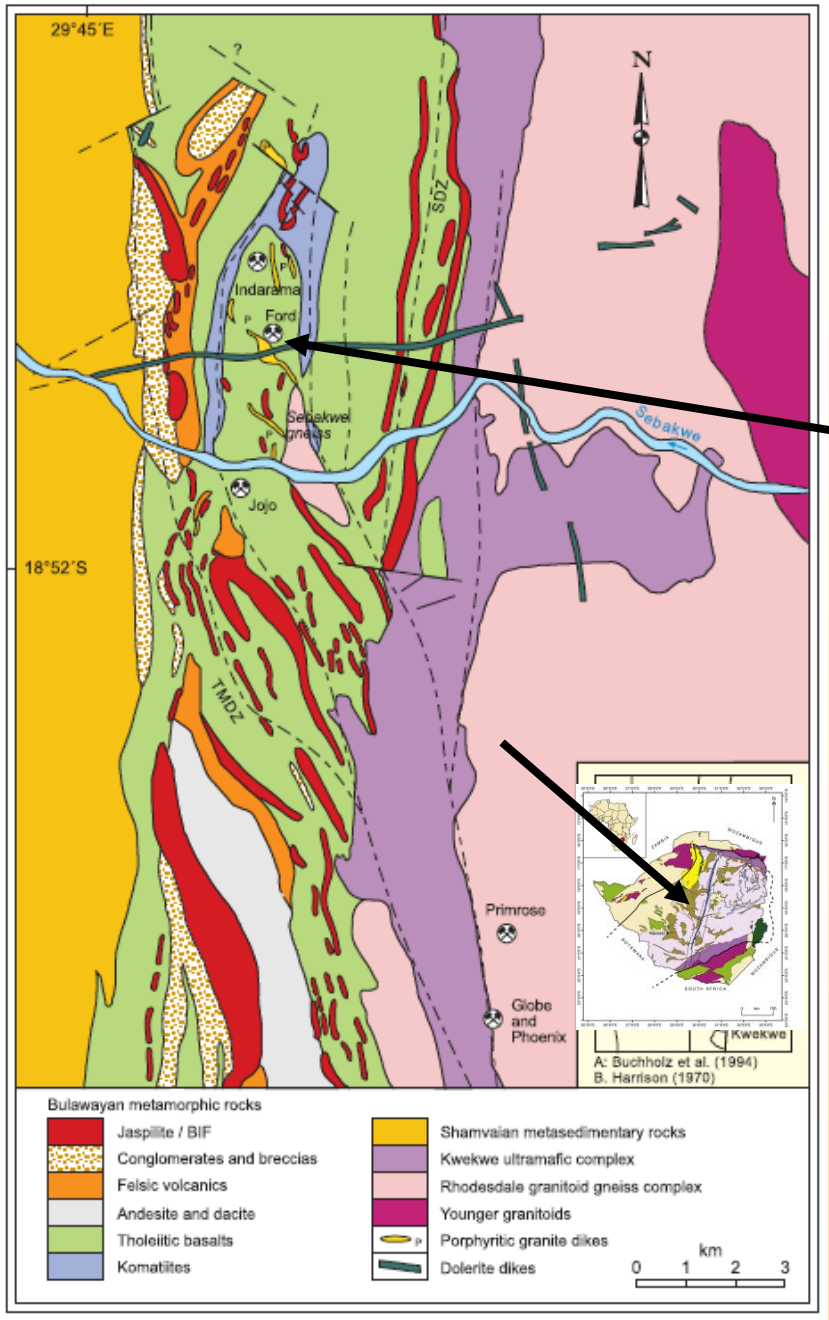
Kim et al, 2004

Damage zones in **strike-slip** fault zones

(**Also** dip-slip component in transpressional & thrust regimes)

All critical to fluid flow and precipitation of gold + sulphides

Ford Mine: porphyry-hosted gold – extreme example of “pervasive fluid flow” within dyke

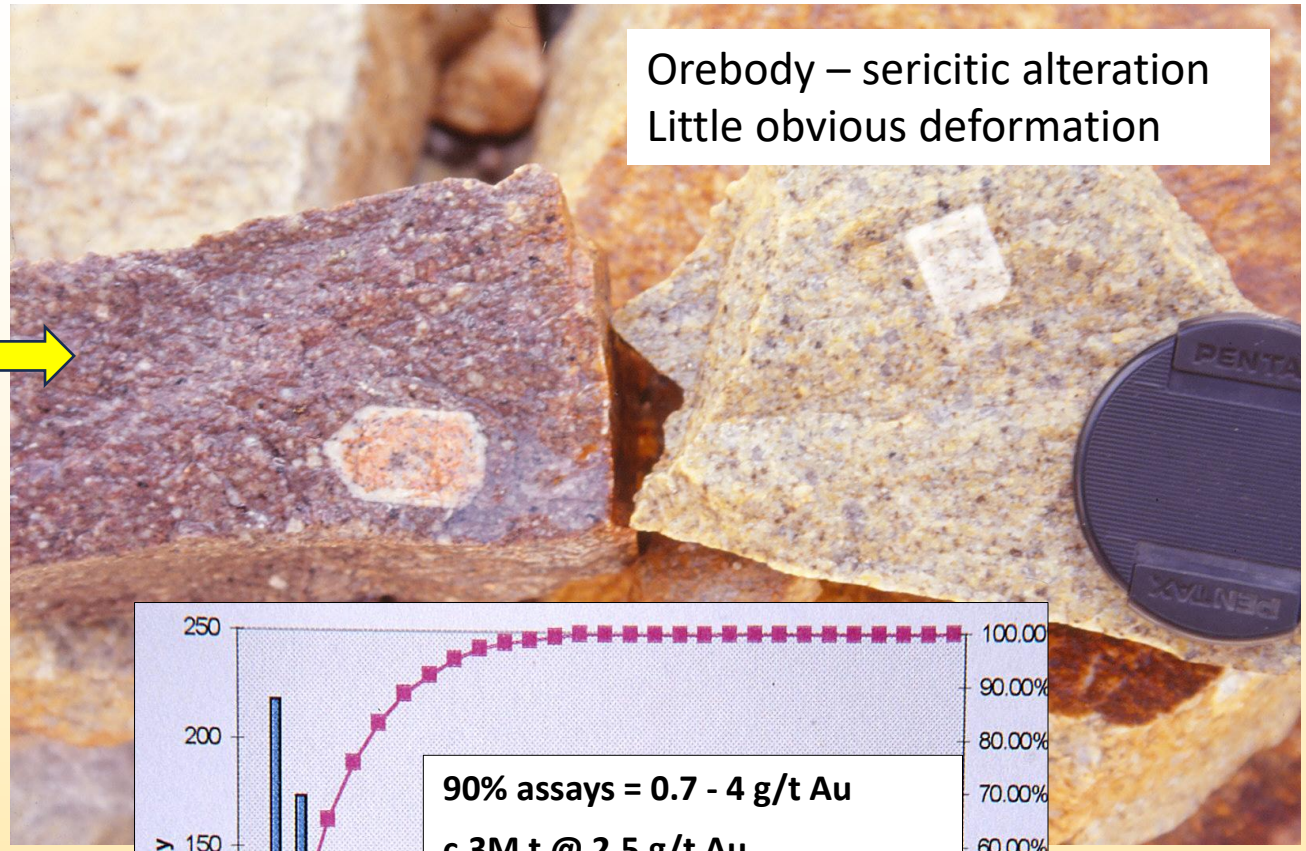




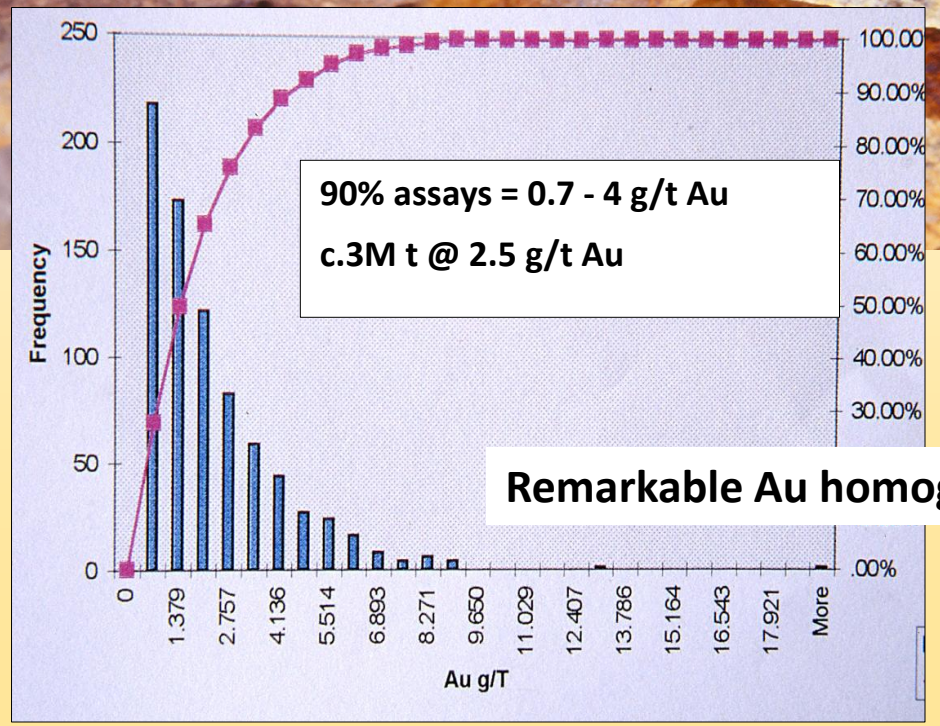
Buchholz et al, 2007

Ford Mine: porphyry dyke–hosted mineralization



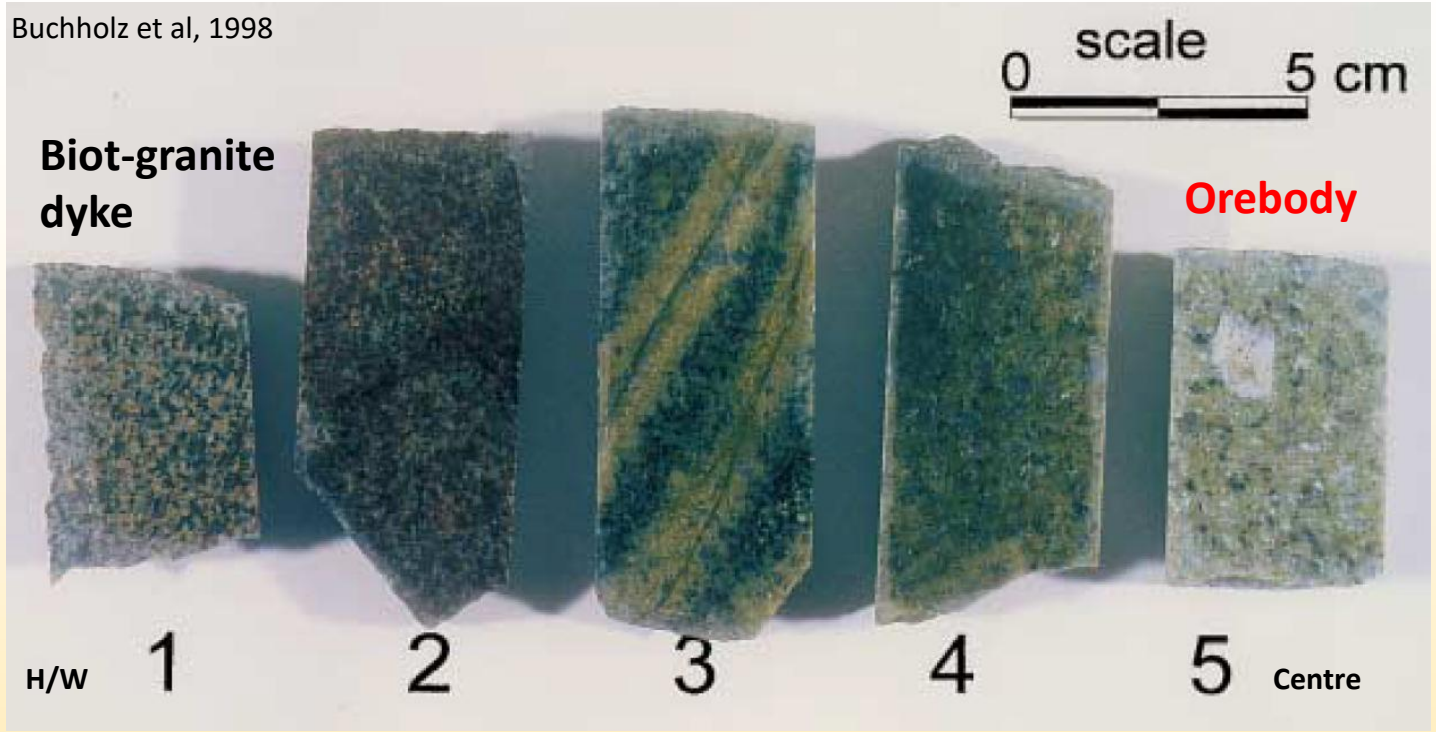


Orebody – sericitic alteration
Little obvious deformation



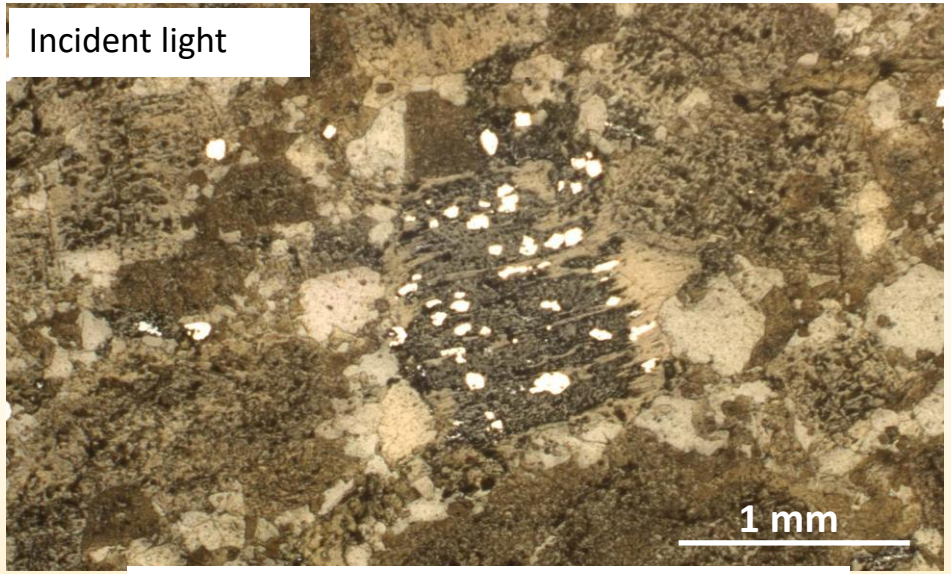
Remarkable Au homogeneity

Ford

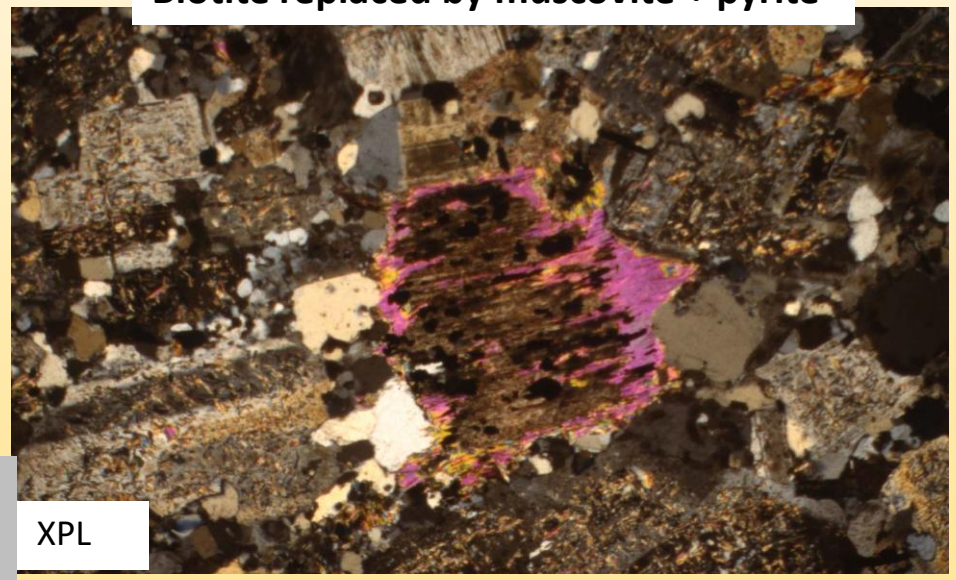


Kfsp-alb pheno → Kfsp-alb-seri-py

- Extensional reactivation of host structure
- Low-salinity fluids 220-330°C



Biotite replaced by muscovite + pyrite



Strain focused primarily along dyke contacts but .... pervasive [grain-boundary-controlled?] fluid flow

Also - sericitic alteration causes volume decrease → grain-scale permeability



Some mining districts (camps) and significant mines in Zimbabwe

Harare – Mazowe – Shamva
Midlands
Gwanda

Insights to orogenic systems – what we know now and where to build on this knowledge

Insights to orogenic systems: the major contributions by Campbell & Pitfield (1994)



ZIMBABWE GEOLOGICAL SURVEY

BULLETIN NO. 101

Structural Controls of Gold Mineralization in the Zimbabwe Craton — Exploration Guidelines

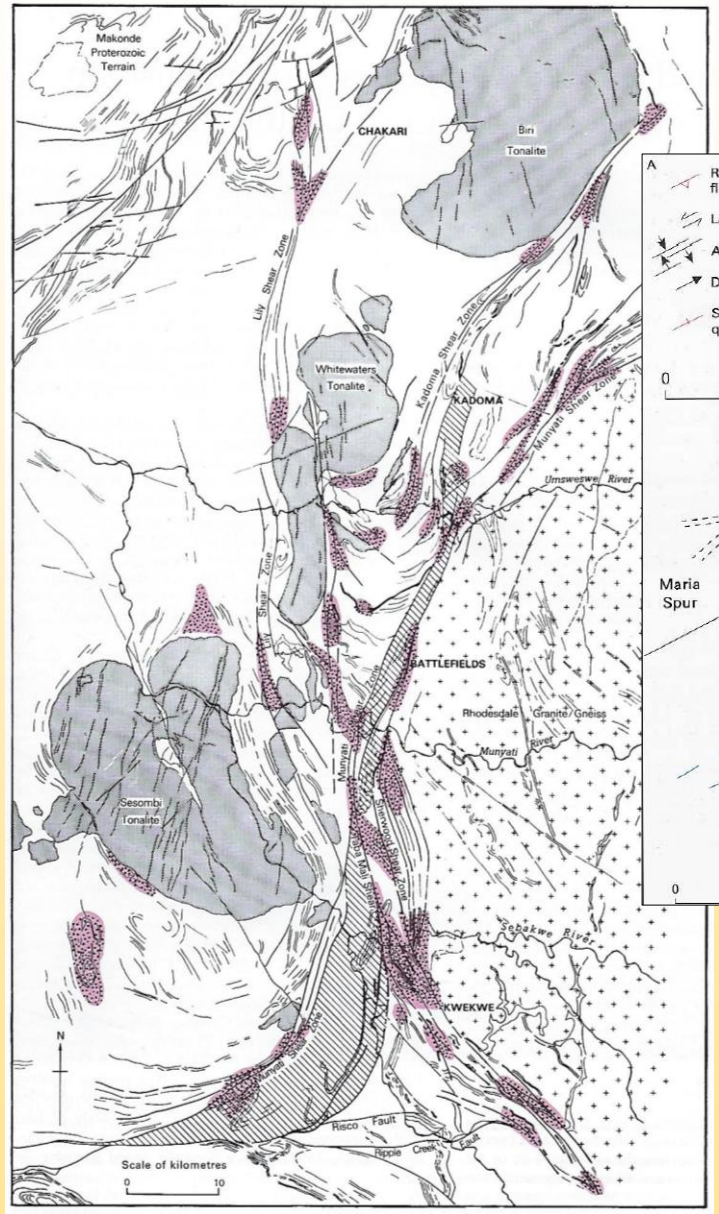
by

S D G CAMPBELL and
P E J PITFIELD

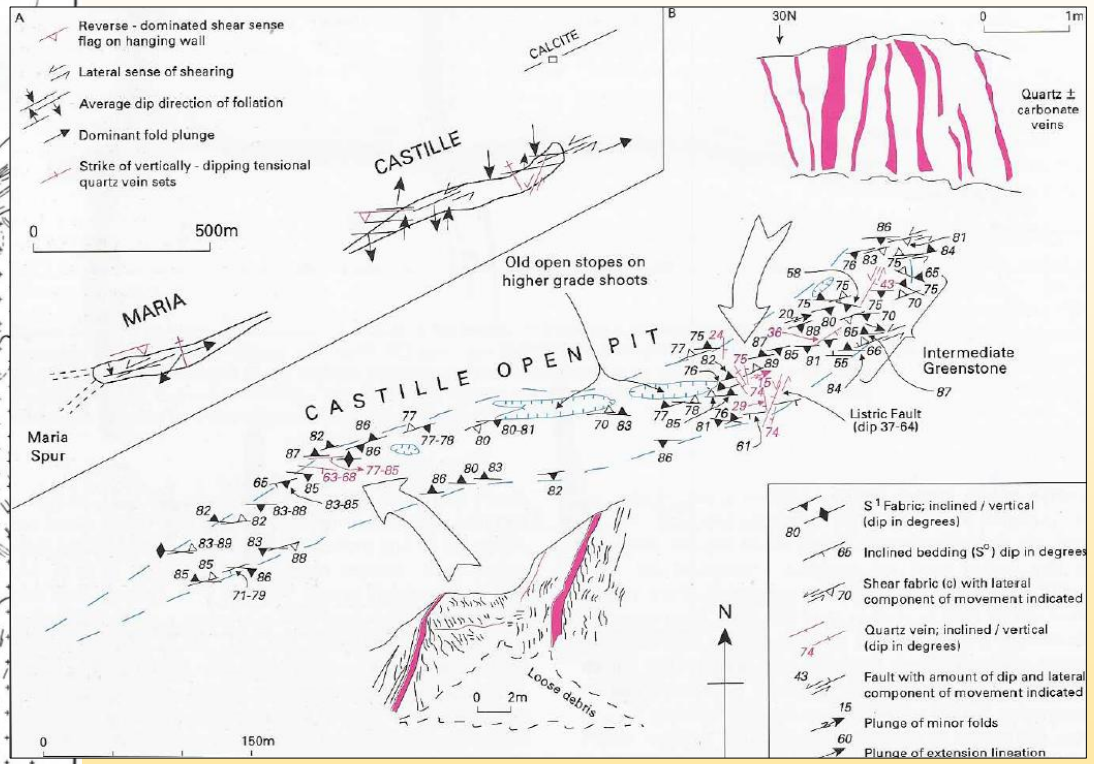
ISSUED BY AUTHORITY

HARARE — 1994

Photo-interpretation (± aeromag) on regional & greenstone belt scales

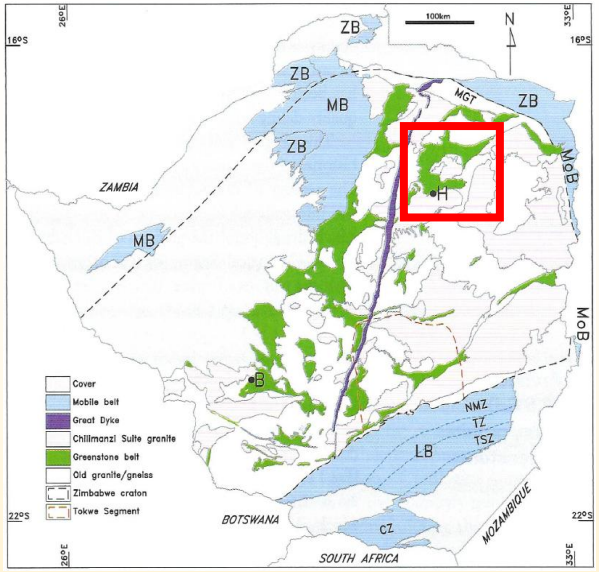


Isabella Mine, Bubi



Detailed mapping on mine scales

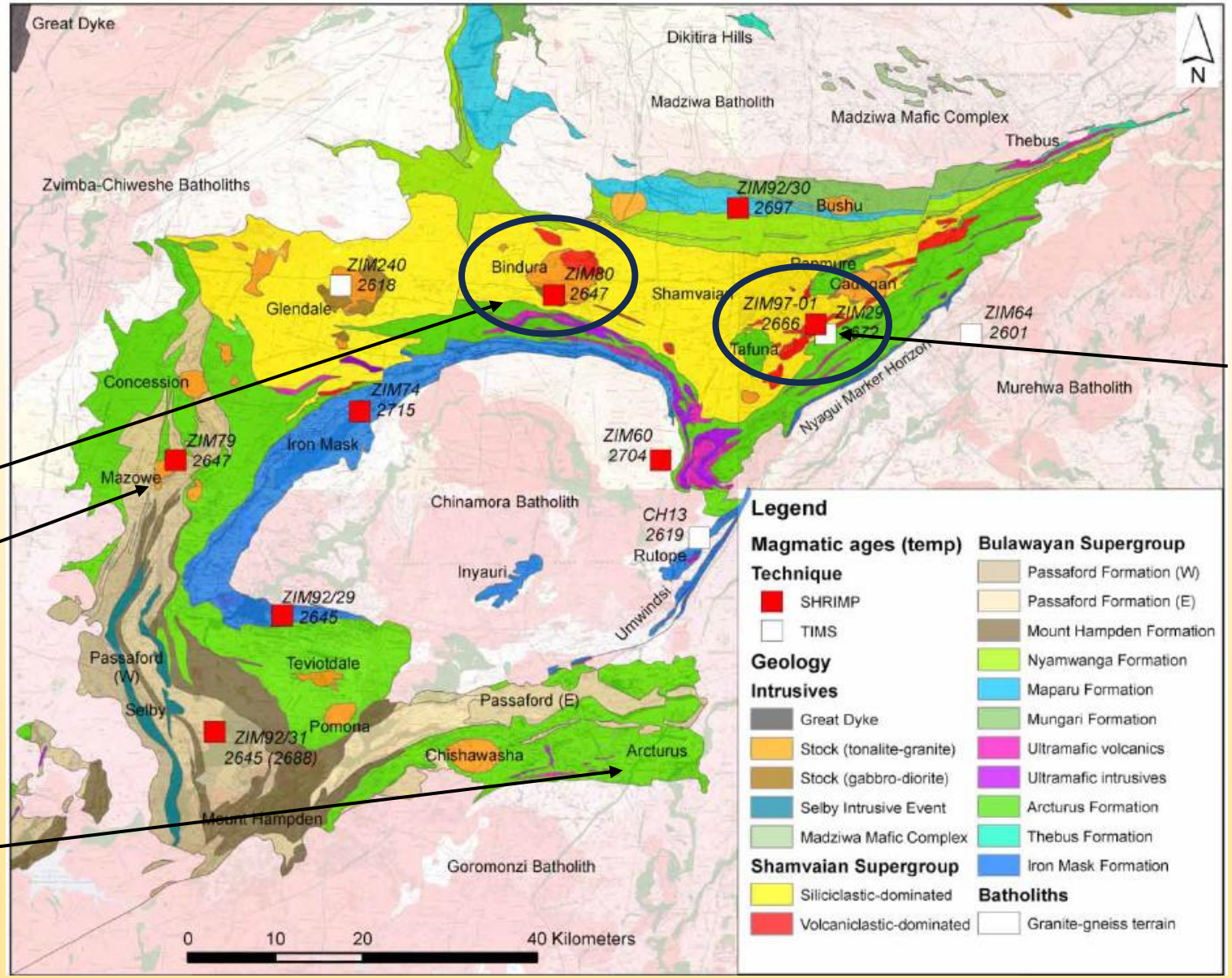
Gold districts in Harare-Bindura-Shamva greenstone belt



Freda-Rebecca: 0.6M oz

Mazowe: 1M oz

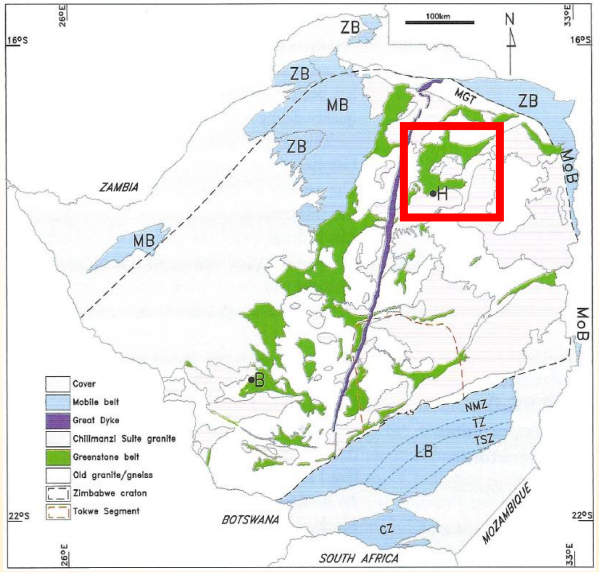
Arcturus: 0.8M oz

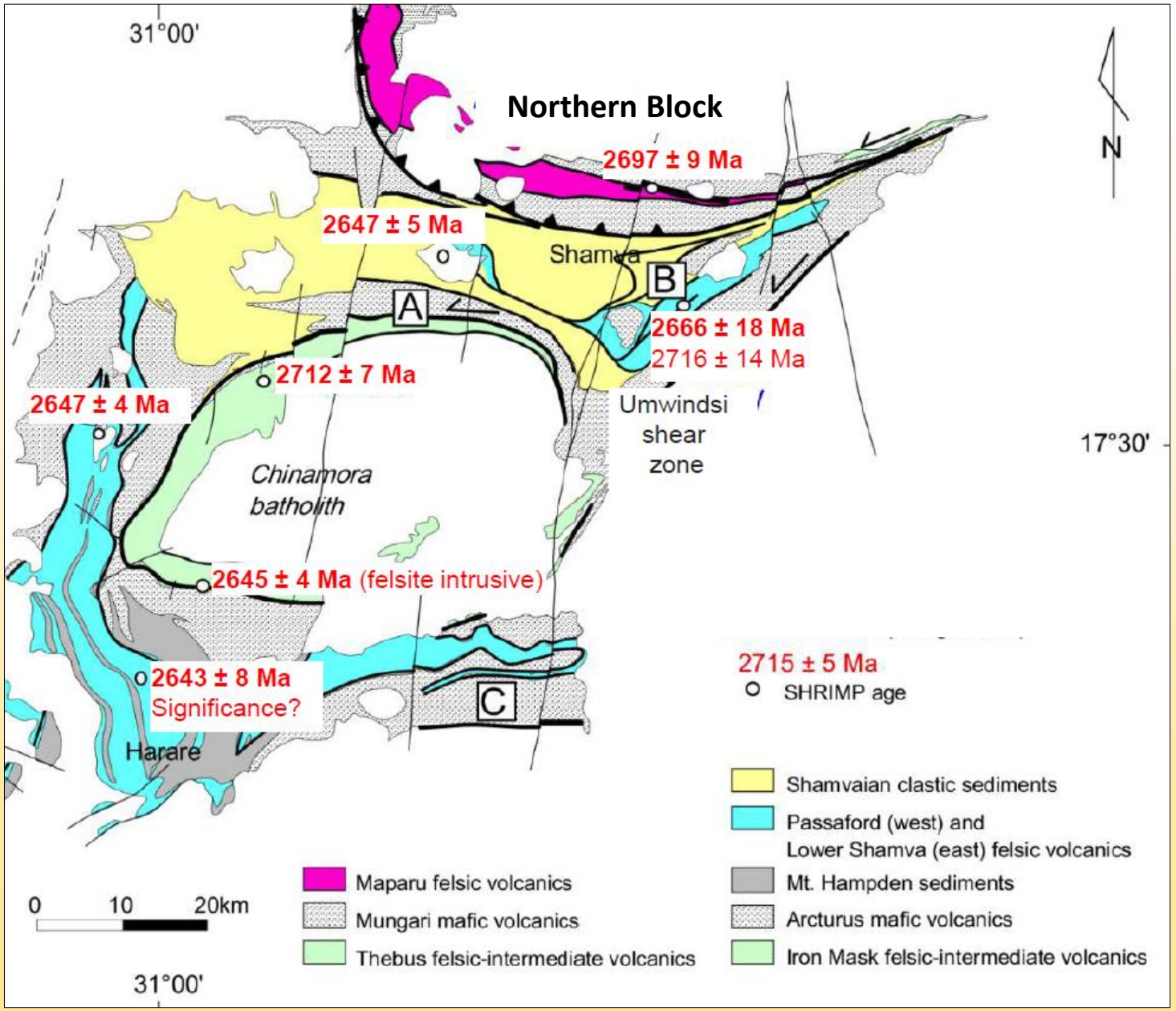


Shamva
10.6M oz

Jelsma et al, 2021 (■ sample locations for age dating)

Gold districts in Harare-Bindura-Shamva greenstone belt





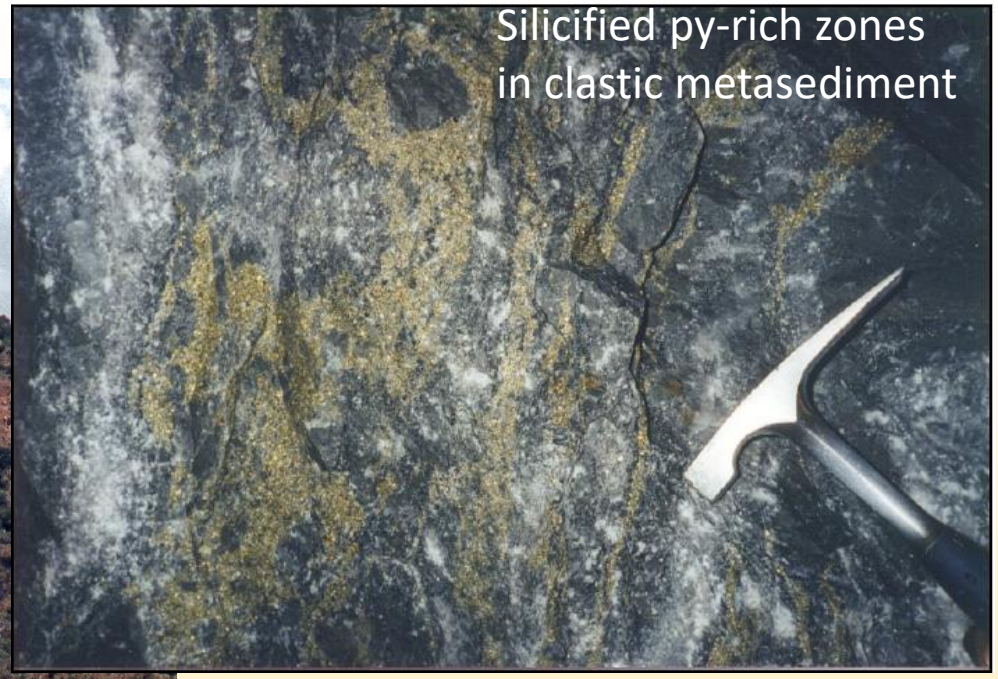
Key factors from informed geo-database

- Upper Bulawayan & Shamvaian Groups
- Substantial Shamvaian sequence
- Northern Block over-thrust on Shamvaian
- Significant strike slip faulting
- Chinamora Batholith predated deformation

Jelsma (2020)

Shamva: 10.6M oz Au (Kuvimba - 2025 GSZ visit)





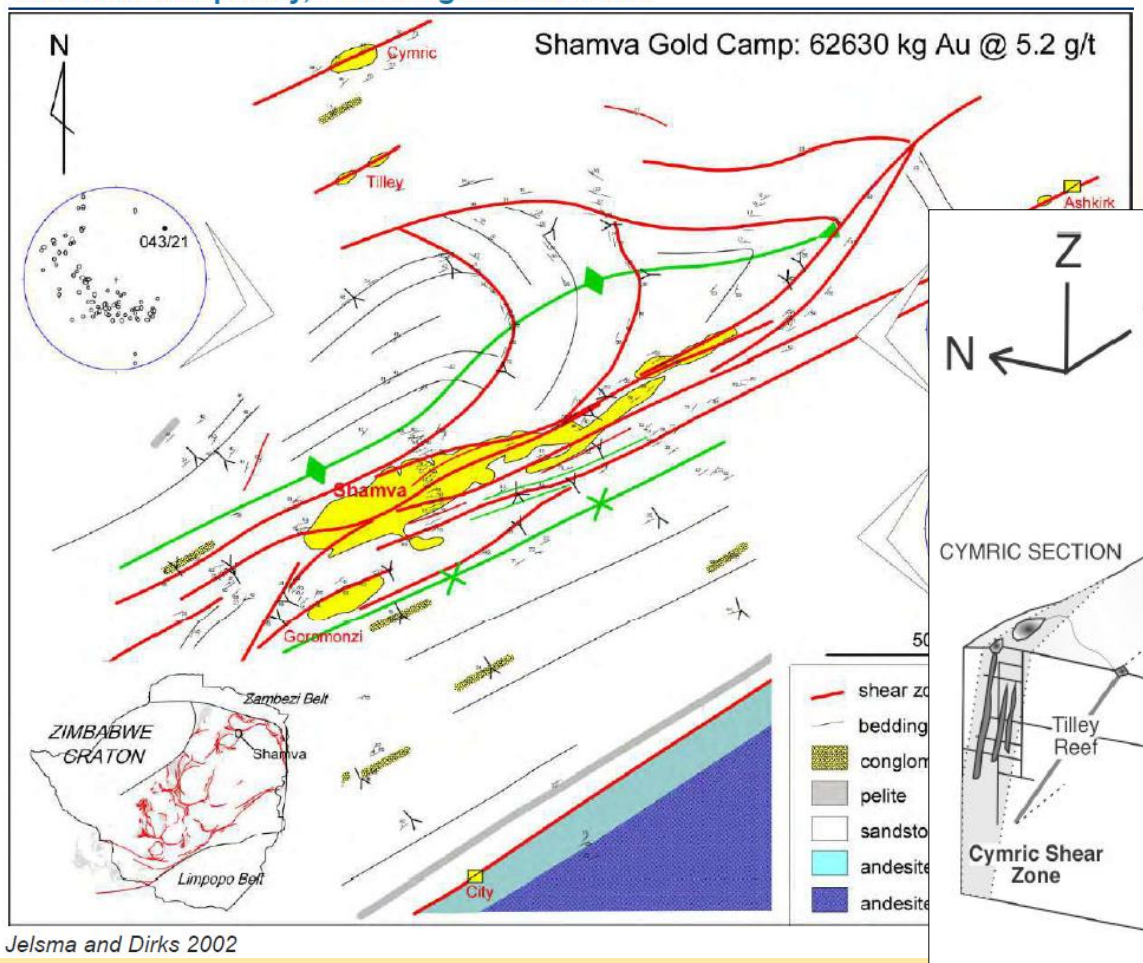


- ***c.*2.67 Ga Shamvaian epiclastic & volcaniclastic host rocks**

Shamva

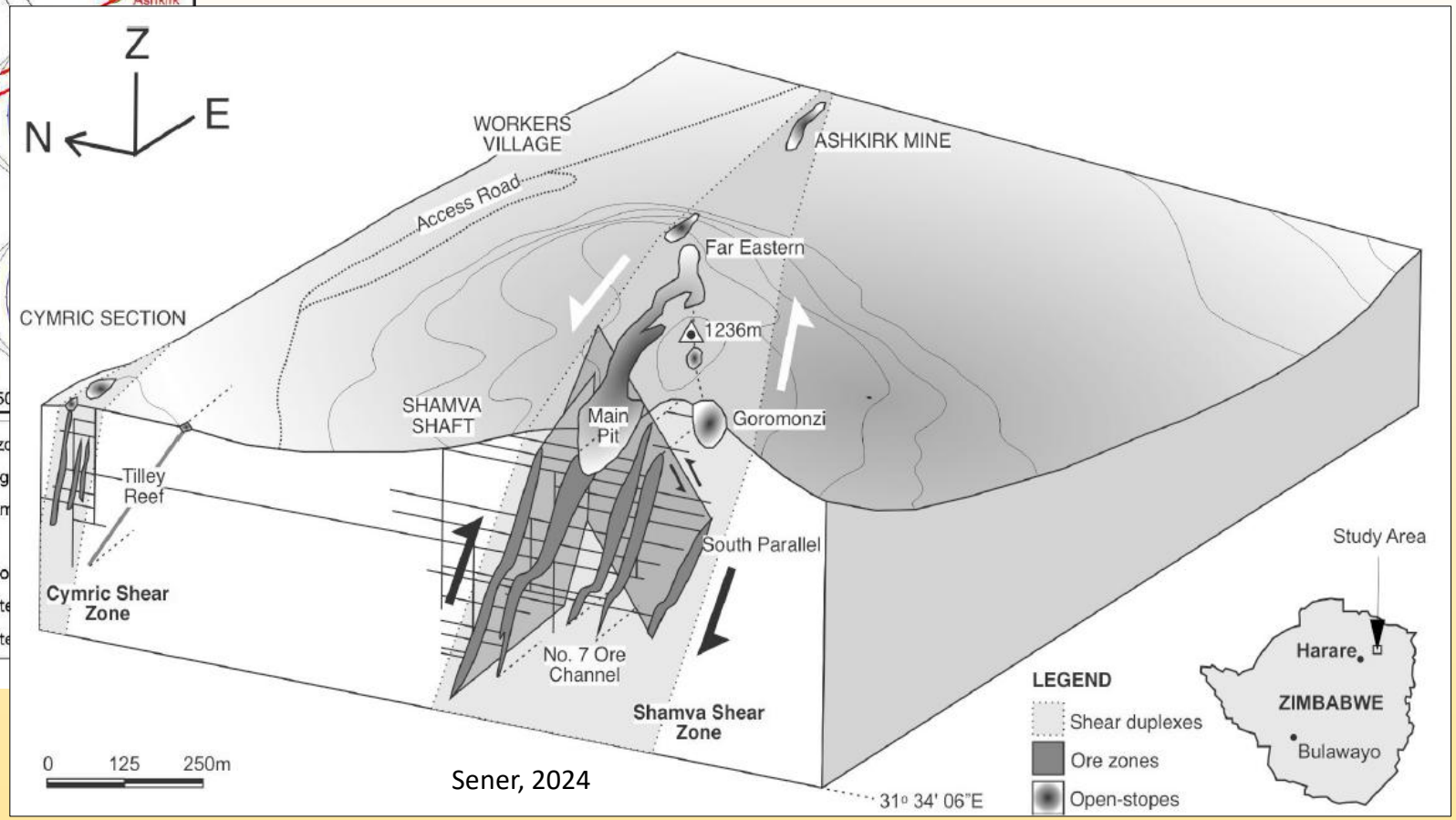


Structural complexity, Shamva greenstone belt



Jelsma and Dirks 2002

Jelsma (2019)

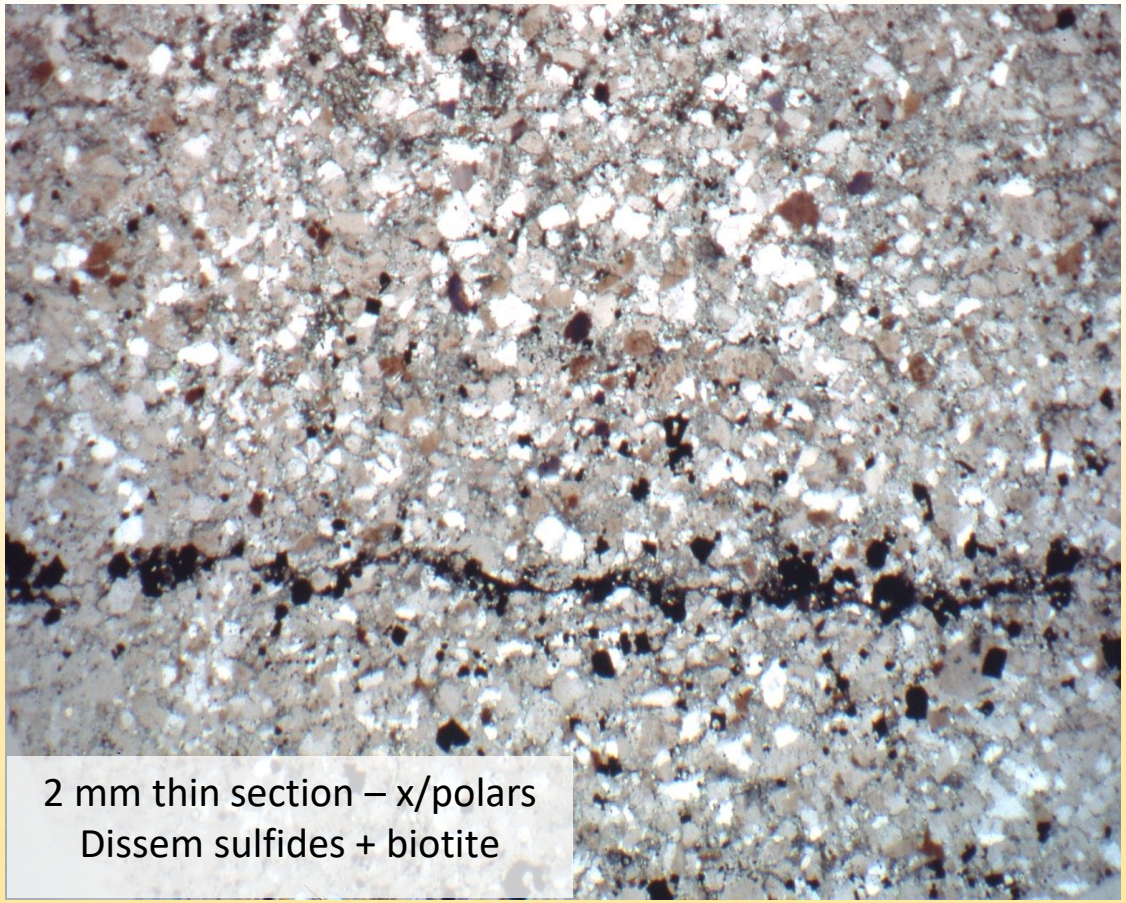


Sener, 2024

- **ENE brittle-ductile duplex system - 2.5 km x 250 m**
- **Major orebodies at intersection ENE- & NE-shear zones**

Shamva: another contributory factor?

Intense potassium metasomatism (biotite) plus **marked enrichment** of As, Mo, Ba, Cu, Pb, Zn in clastic sediments



2 mm thin section – x/polars
Dissem sulfides + biotite

.... attributed to syn-sedimentary hydrothermal activity

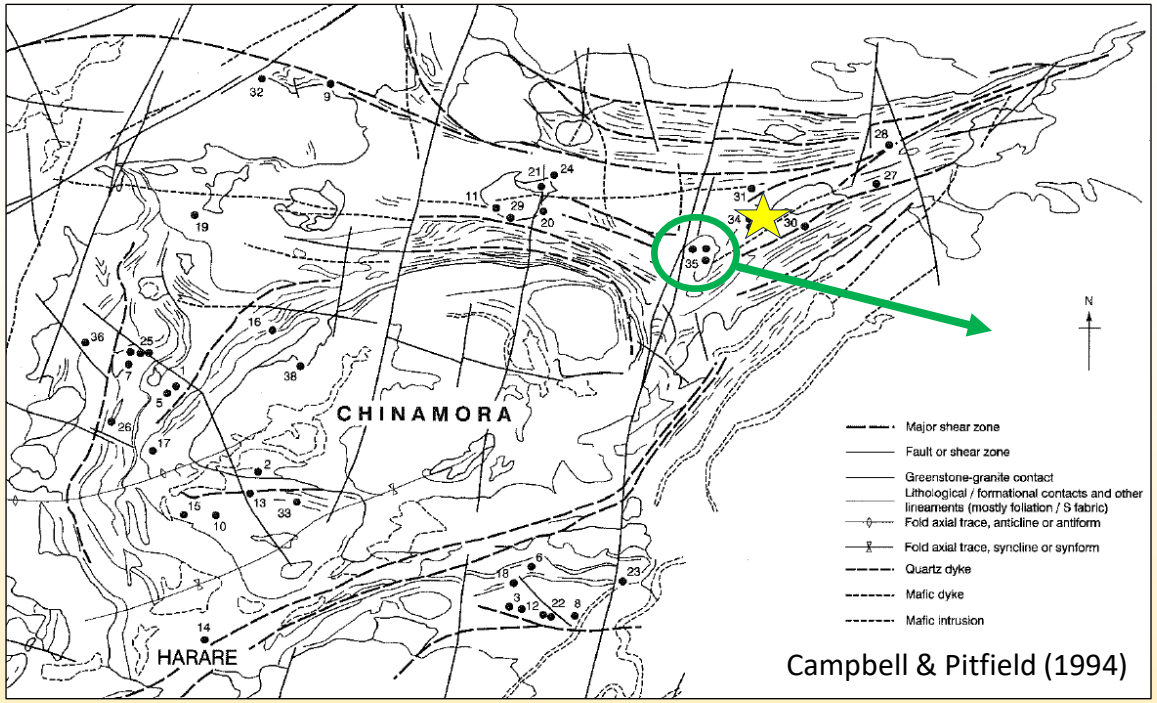
Foster et al (1986)



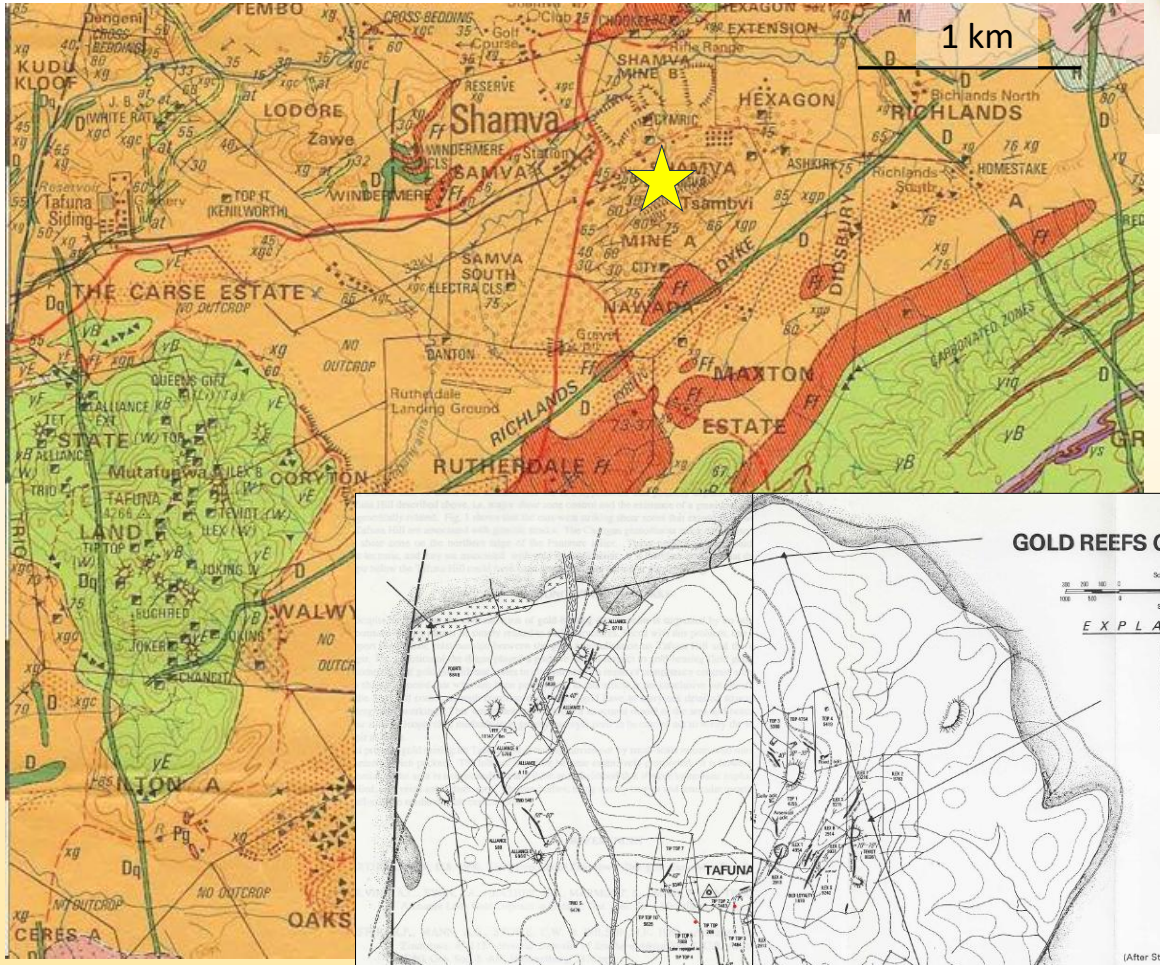
Syn-sedimentary intrusion of andesite-dacite porphyries into unconsolid seds @ 2.672 Ma (Sener, 2024)

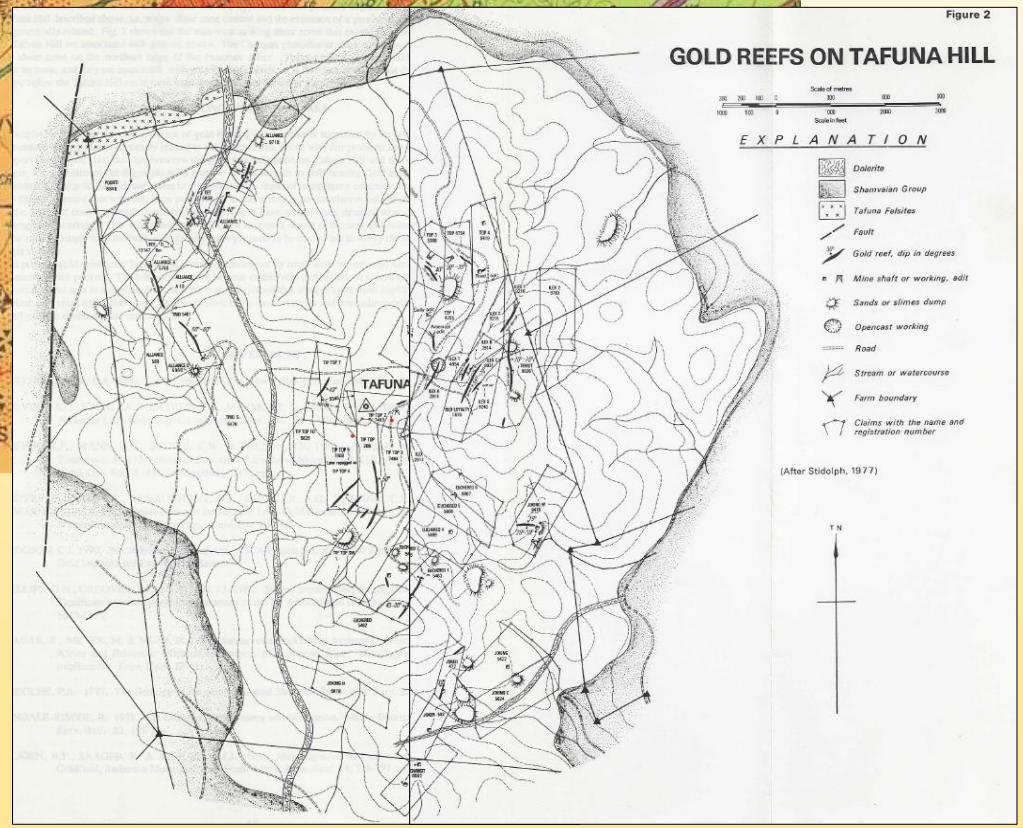
- ✓ No doubt key structural controls .... but possible syn-sed gold enrichment ??
- ➢ Keep open mind?

Tafuna Hill – different “animal”? [Mugumbate, 1990)



Campbell & Pitfield (1994)

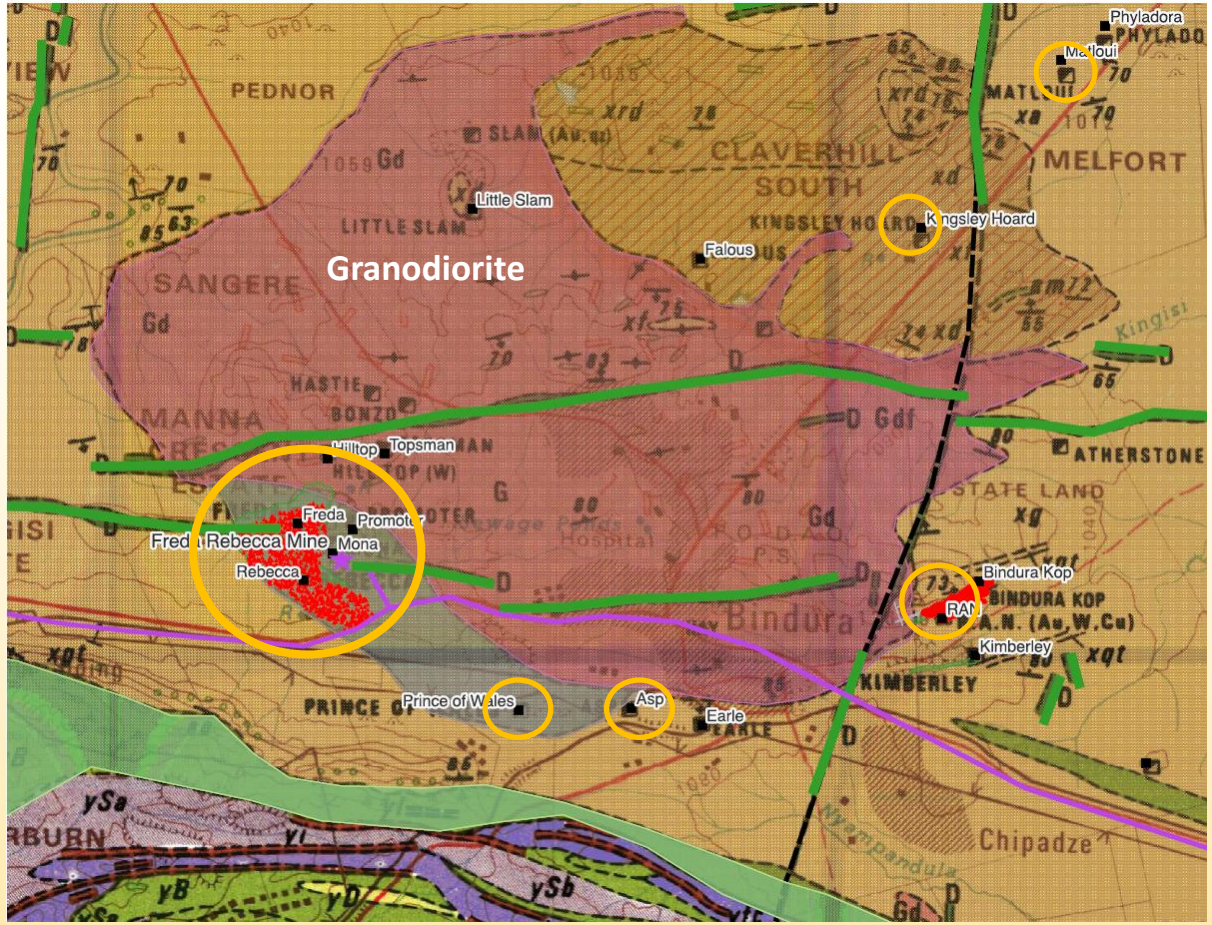


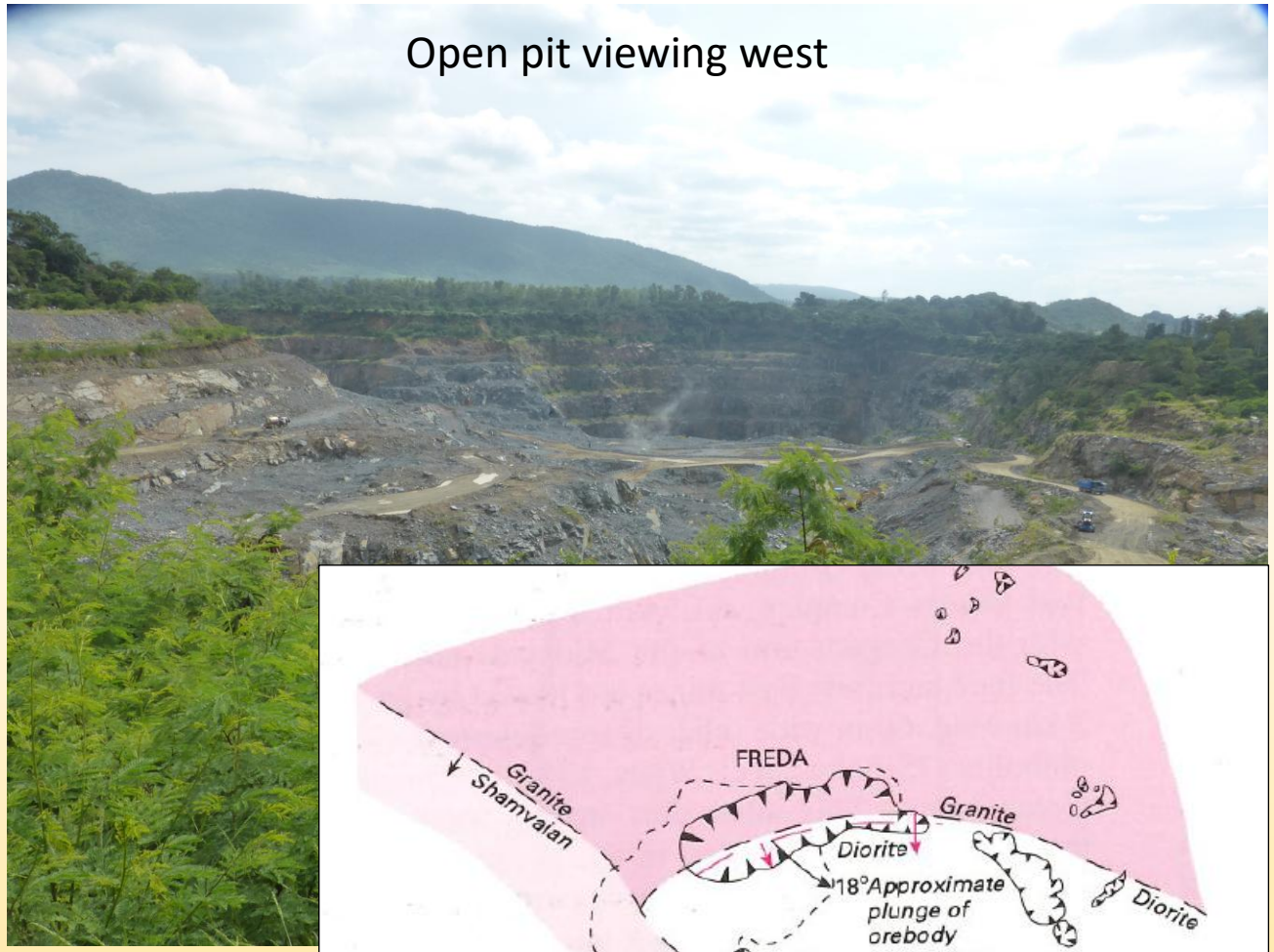


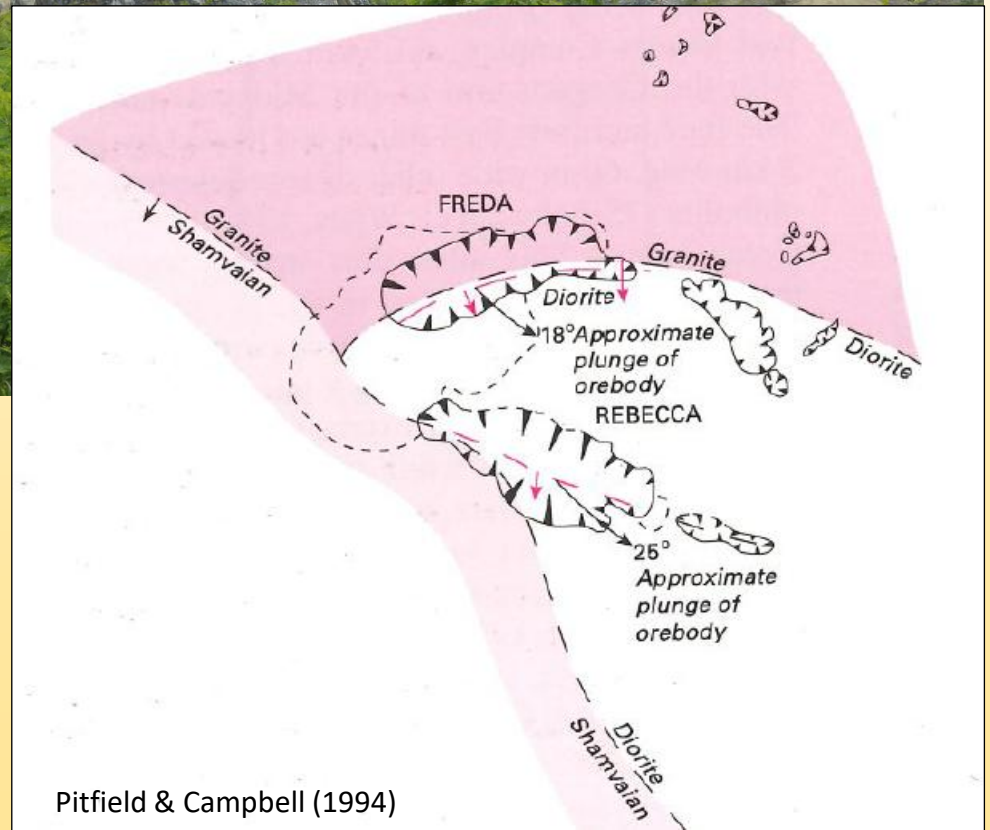
Remarkable concentration of gold “reefs”

- 11 mines – 7,500 kg Au; 14.5 t scheelite
- Qtz-cbt lenses & stringers; 20-100 cm wide
- Scheelite common; minor py, apy, cpy
- Mined to -260 m
- Most strike NNW or NNE
- Dominantly metabasalt & mafic agglomerate
- Tourmaline around margins
- Greenstones more competent than Shamvaian seds?

Freda-Rebecca





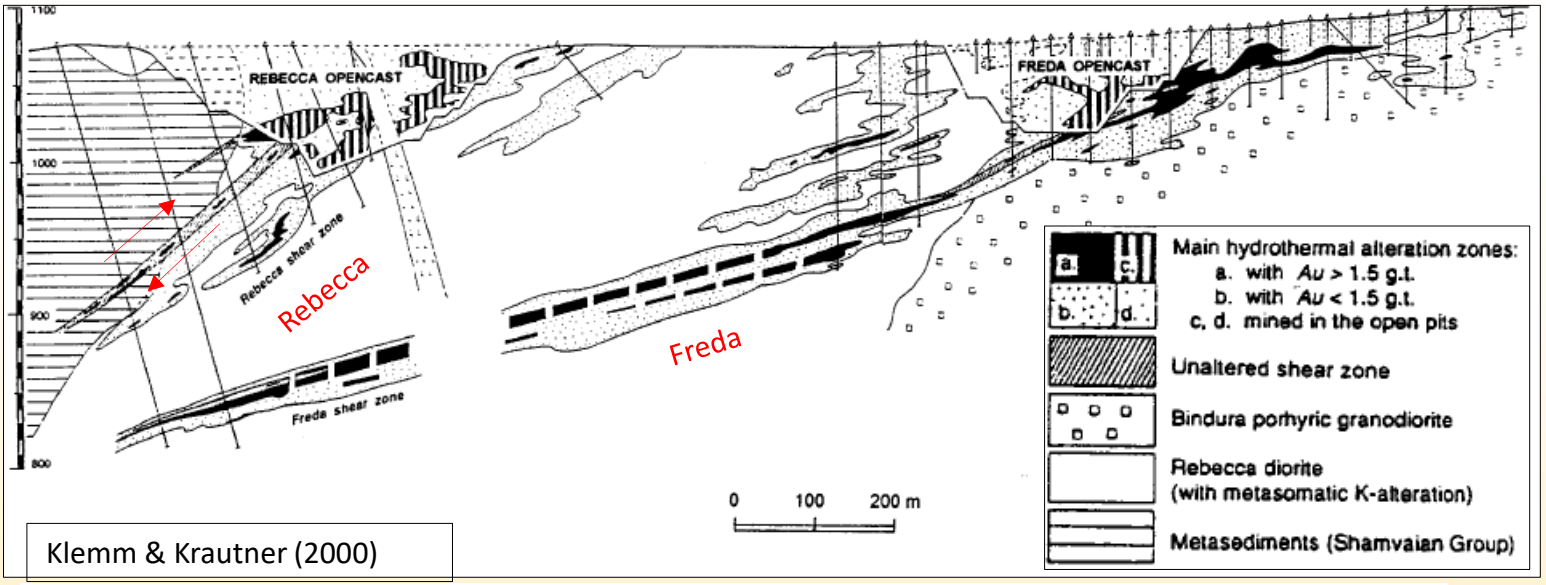


Pitfield & Campbell (1994)

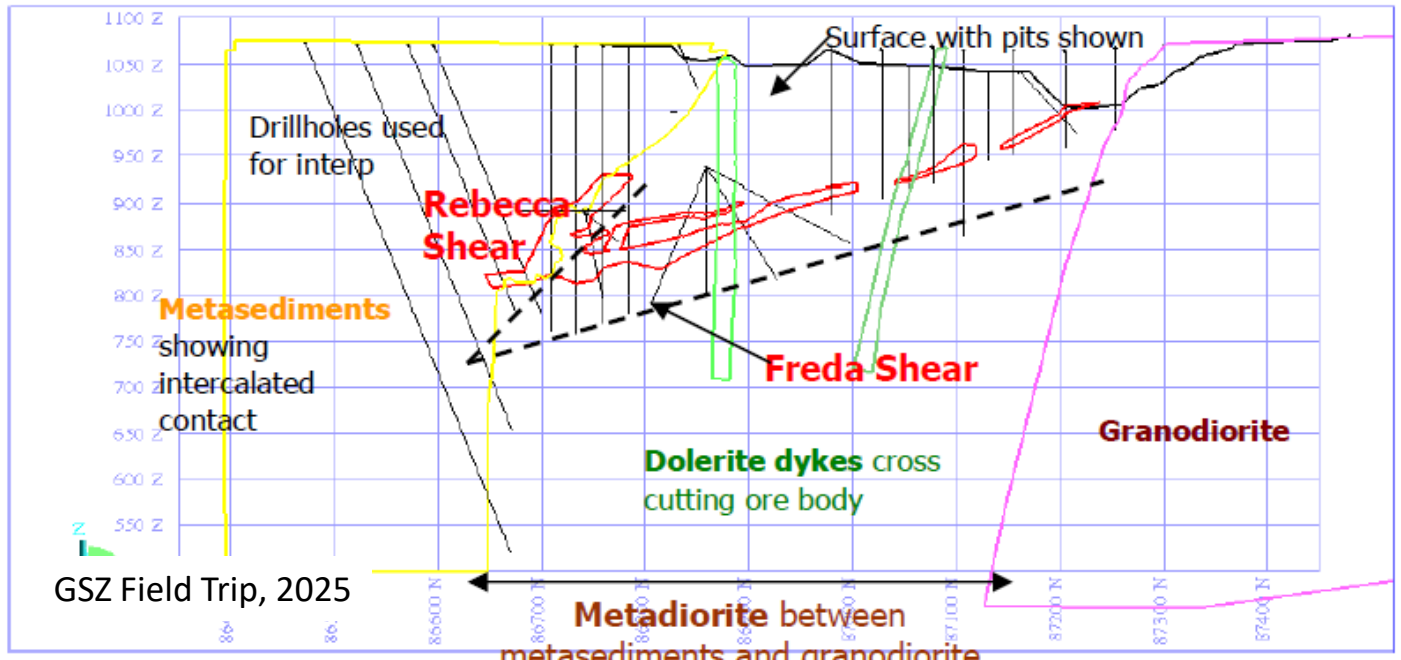
Multiple gold orebodies proximal to and in
"Bindura Granite" = granodiorite-diorite complex

Diorite intruded along metased - gd contact
= subsequent focus of strain & fluid flow

Freda-Rebecca

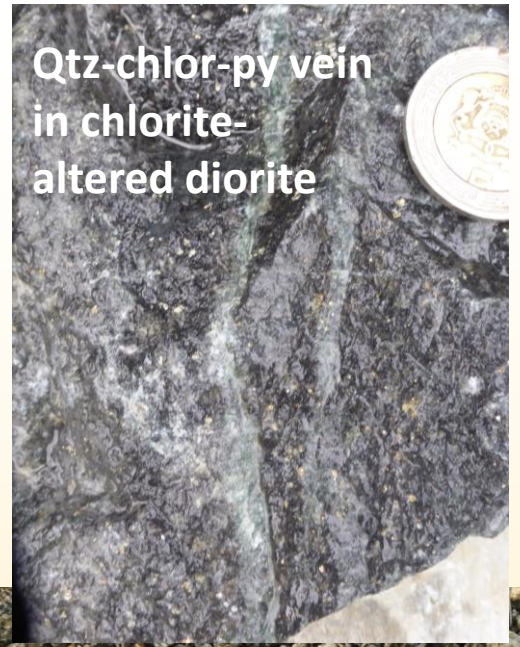


Klemm & Krautner (2000)



GSZ Field Trip, 2025

Figure 13: *Schematic section showing the Freda and Rebecca shear*

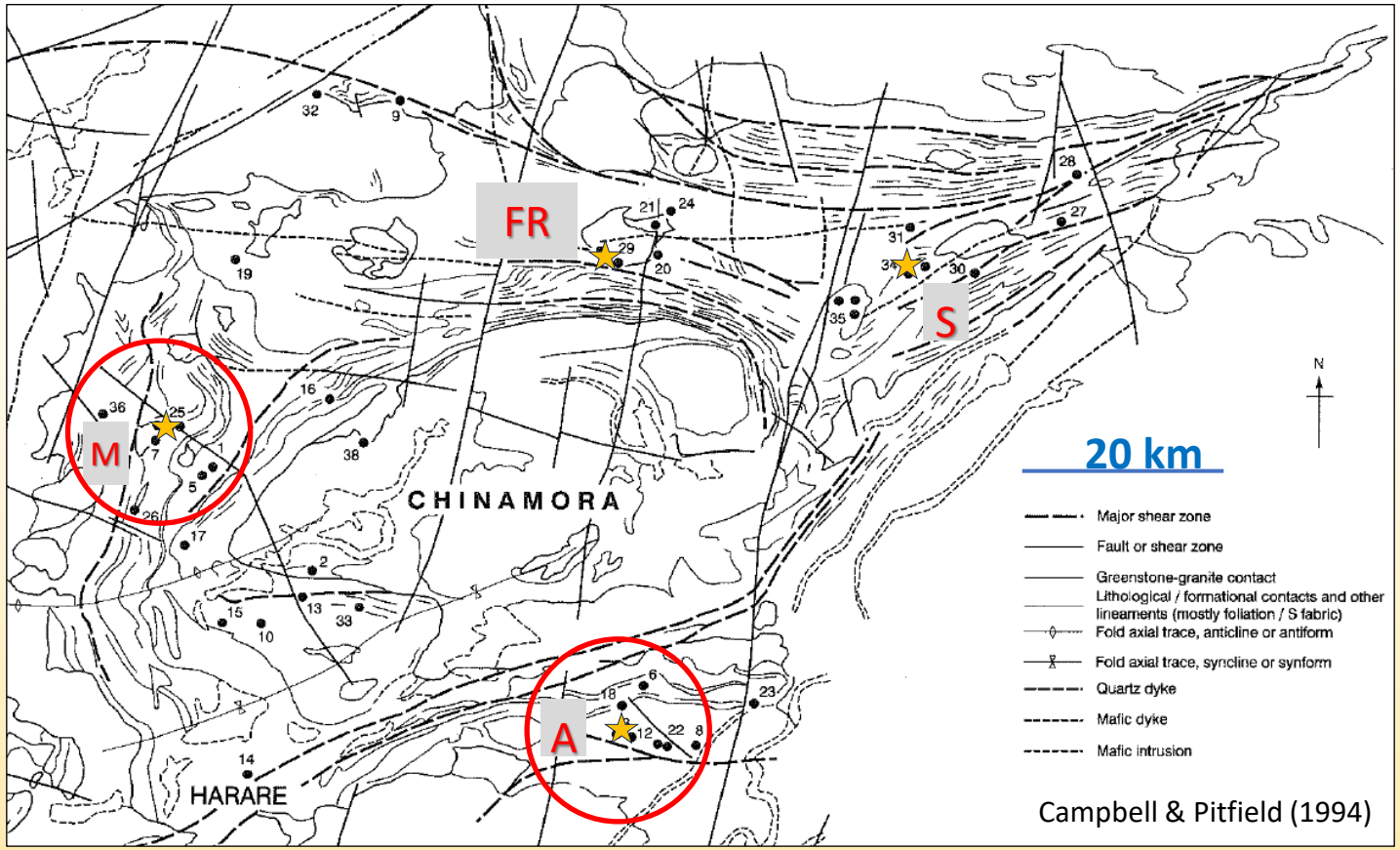






- ✓ Brittle failure of diorite
- ✓ Fe-mafic host rock
- ? Oblique reverse dextral SZ's

Harare - Mazowe – Shamva Greenstone belt: synthesis



Campbell & Pitfield (1994)

A: Arcturus

FR: Freda Rebecca

M: Mazowe

S: Shamva

Arcturus

- **12 km shear zone – 500 m: ESE-WNW**
- **Intercalated basalt – felsite – ultramafics**
- **?S-verging thrust – reverse/oblique dip slip**

(Campbell & Pitfield, 1994)

Mazowe Group

- **Syn-D2/D3 mineralization**
- **Orebodies linked to N-S shortening**
- **Not related to major regional shear zones**
- **Not related to batholith intrusion**

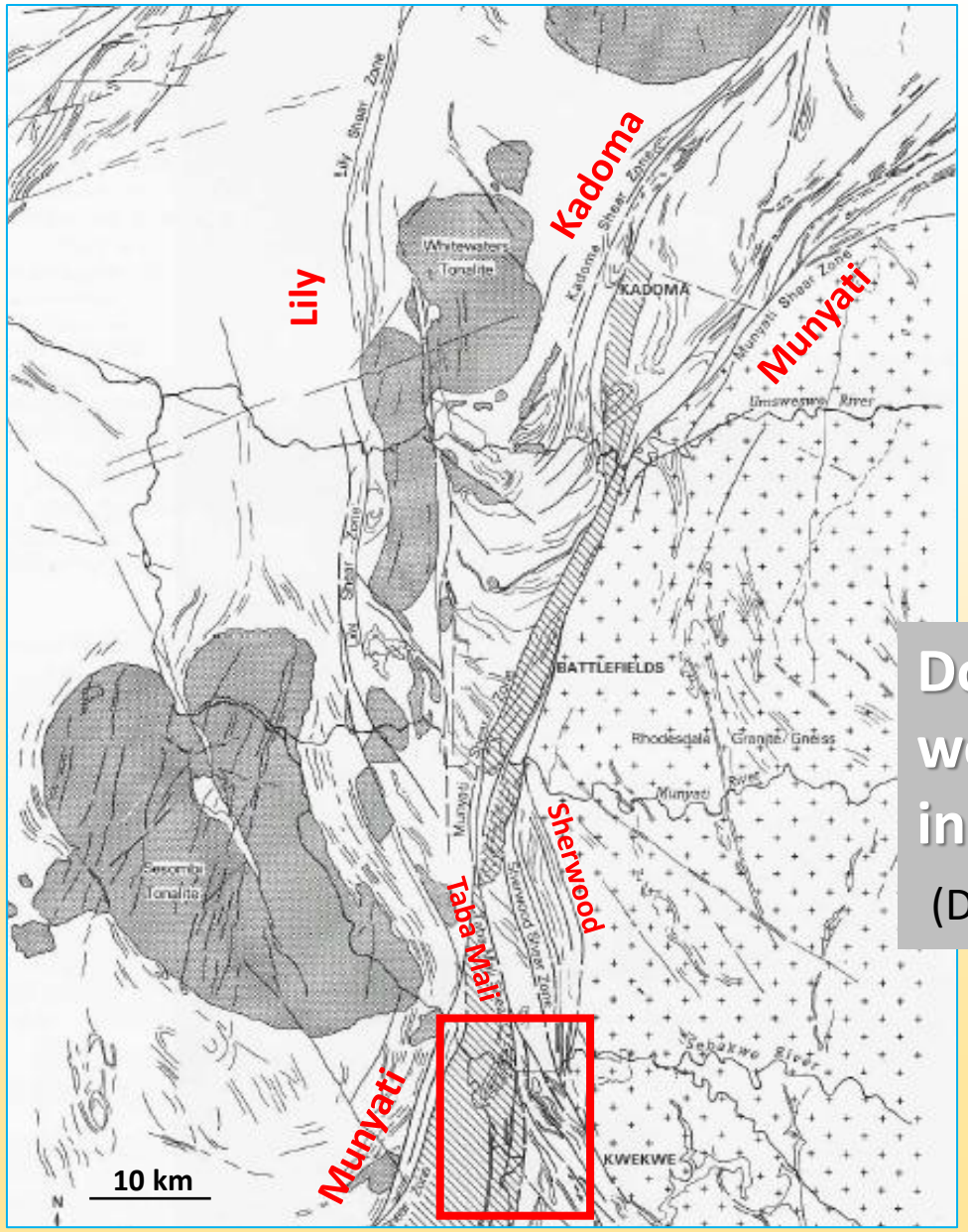
(Blenkinsop et al, 2000)

H-M-S Greenstone Belt: key factors

- Au not related to major regional shear zones
- Not related to intrusion of Chinamora Batholith
- Crustal shortening, thrust tectonics

Midlands Greenstone Belt

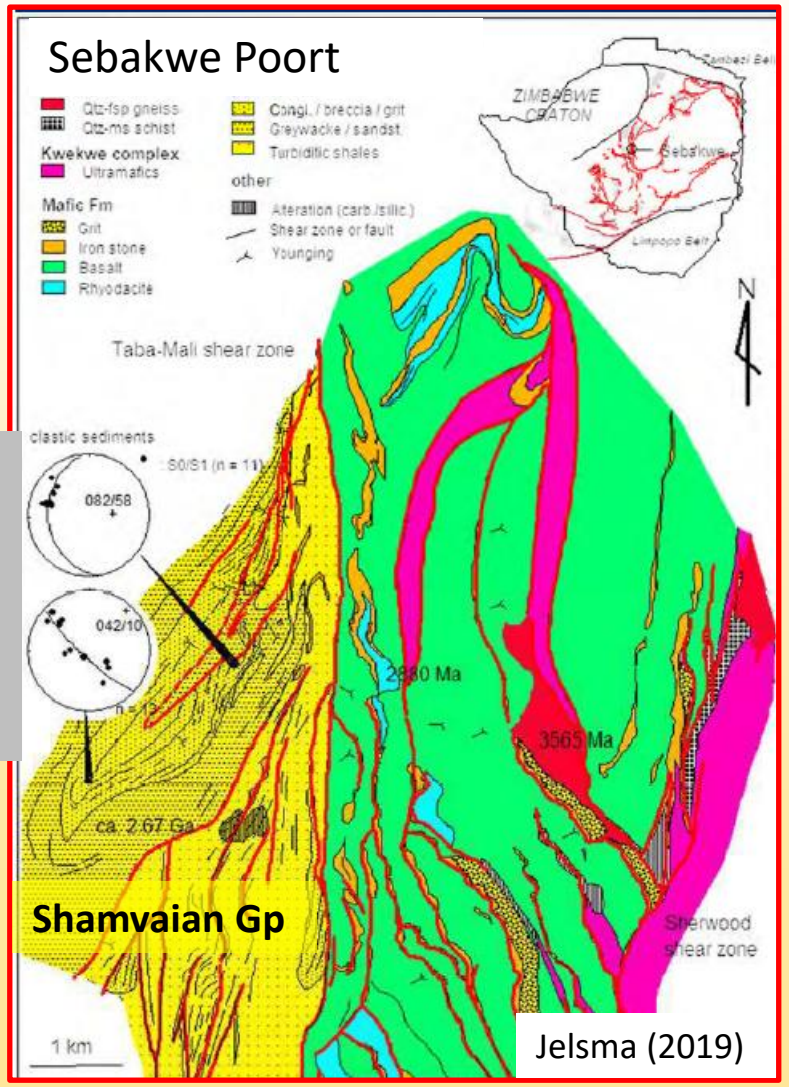
First-order high-strain "structural corridors" 10's - >100 km
Munyati DZ >100 km, up to 3 km wide
Gold-bearing sz's up to 3 km strike, up to 6 m wide



Campbell & Pitfield (1994)

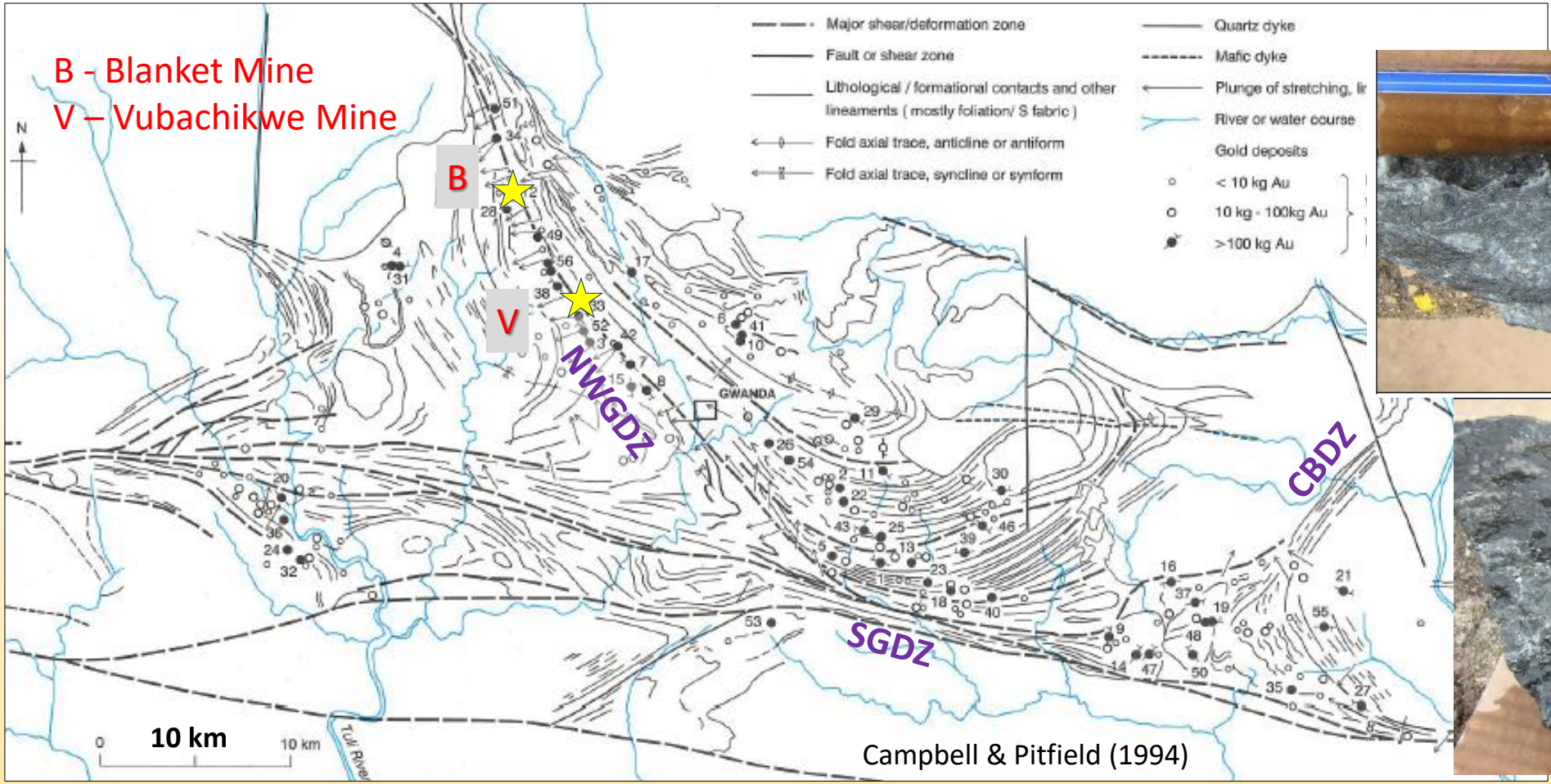
Documented evidence of west-verging thrust stacking, including Sebakwe Poort area

(Dirks, Jelsma)

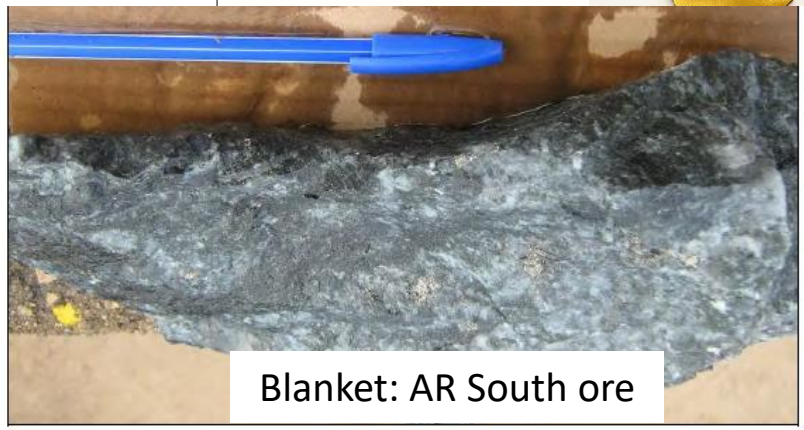


Jelsma (2019)

Gwanda Belt: Deformation



Campbell & Pitfield (1994)



Blanket: AR South ore



Blanket: Lima ore

South Gwanda DZ

>100 km

WSW-trending splay from craton NMZ

D2 reverse sinistral & D3 oblique dextral

NW Gwanda DZ – marked gold endowment

Anastomosing SZ - 2 km wide, c.18 km (40 km?)

Low angle – dominantly reverse: N-verging

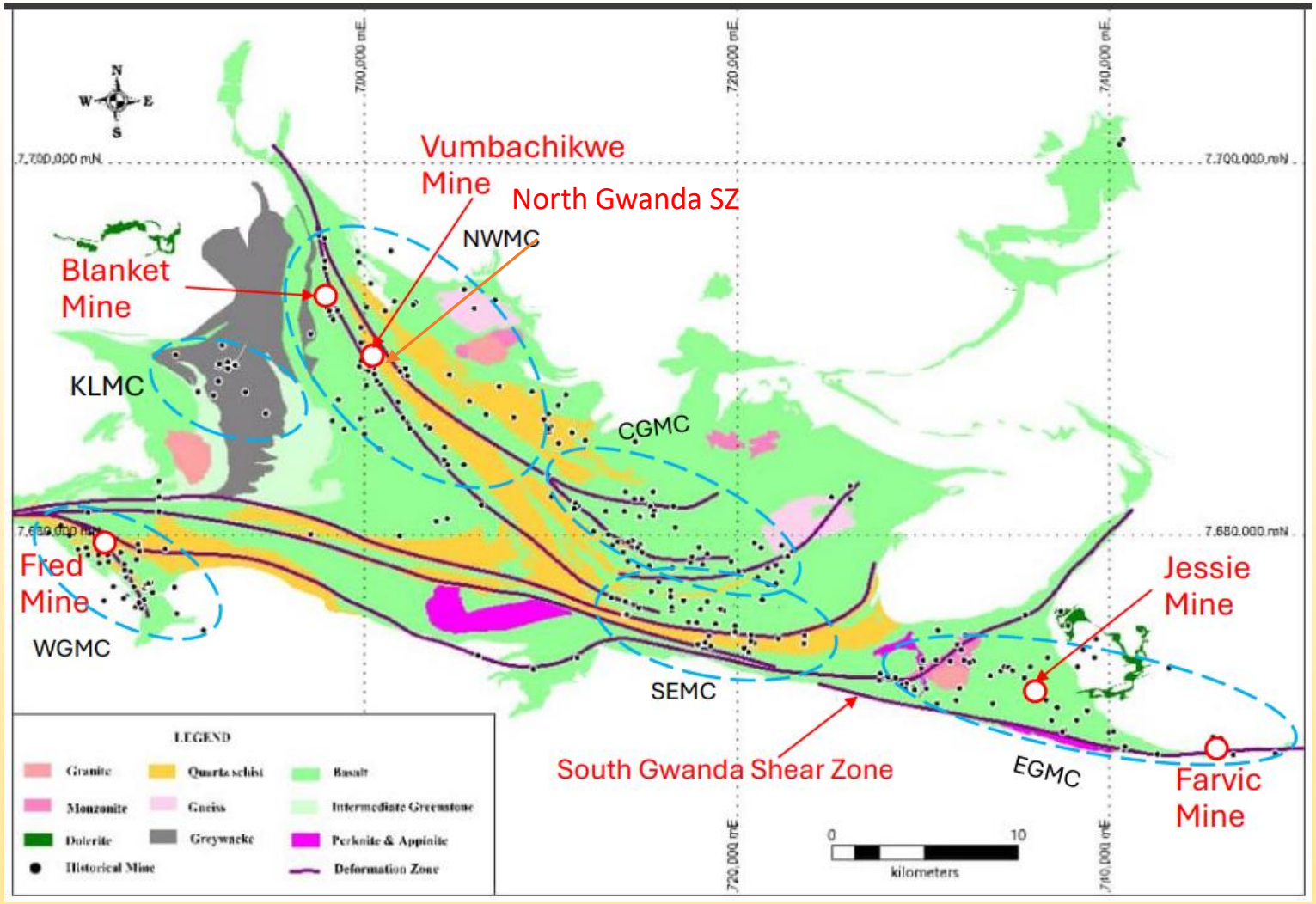
Colleen Bawn DZ

Near-vertical mylonitic zones along gneiss-gnstn contact

Dextral reverse

NW gold district (“camp”): Blanket & Vubachikwe. Role of Quartz Schist Group?





Chagondah et al (GSZ - 2025)

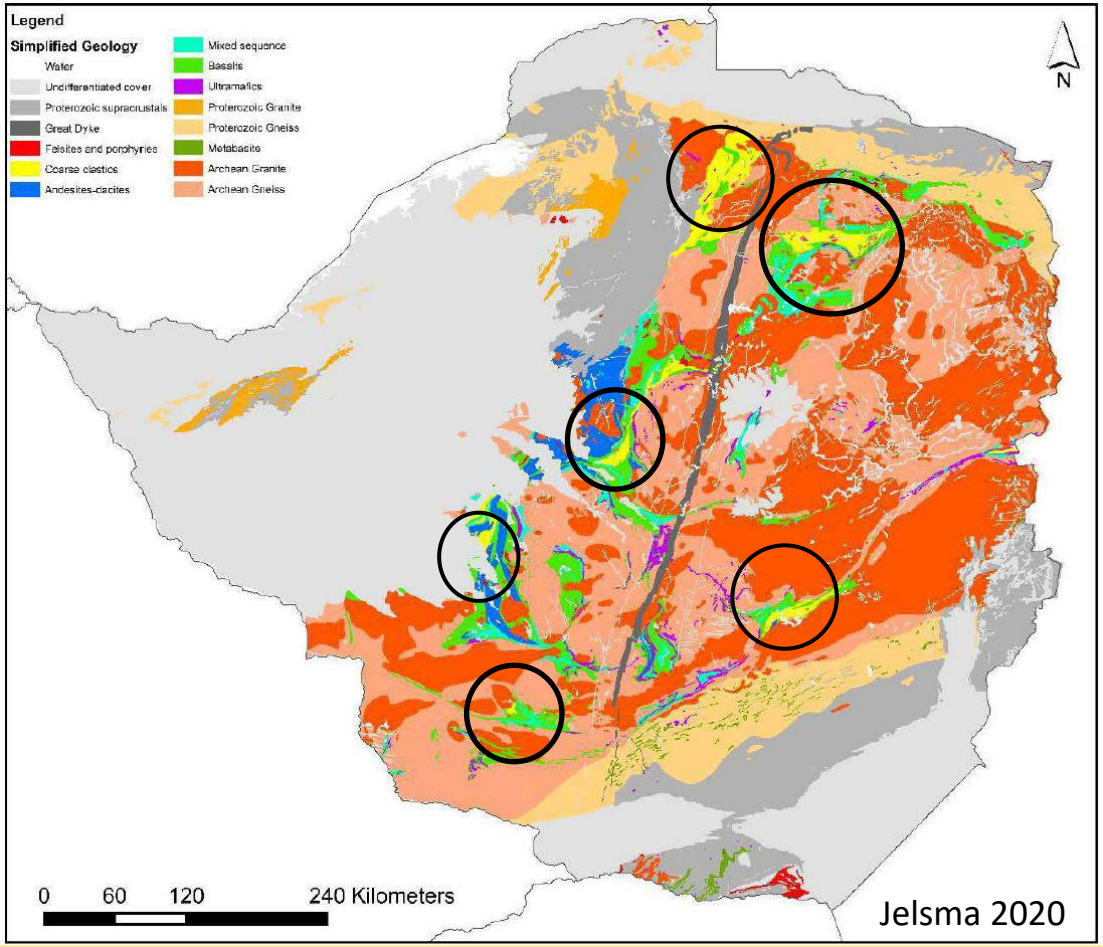
NW Gwanda Deformation Zone

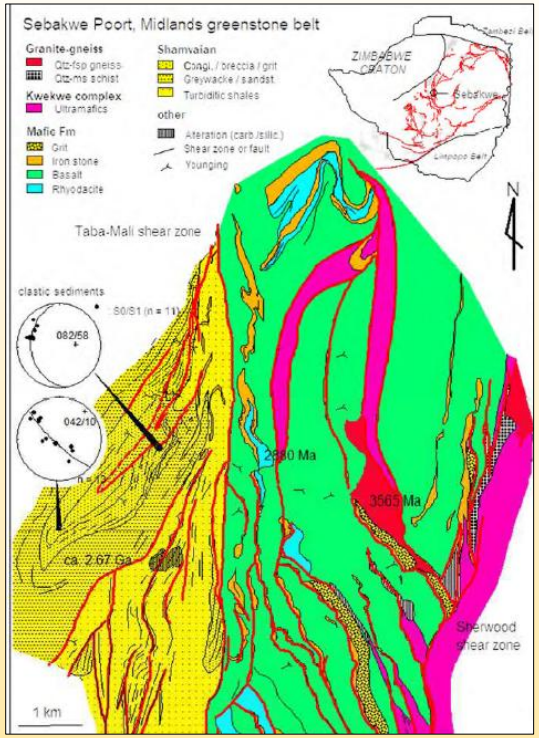
Thrust detachment along contact of QSG – siliciclastic sediments
(Fuchter; Campbell & Pitfield)

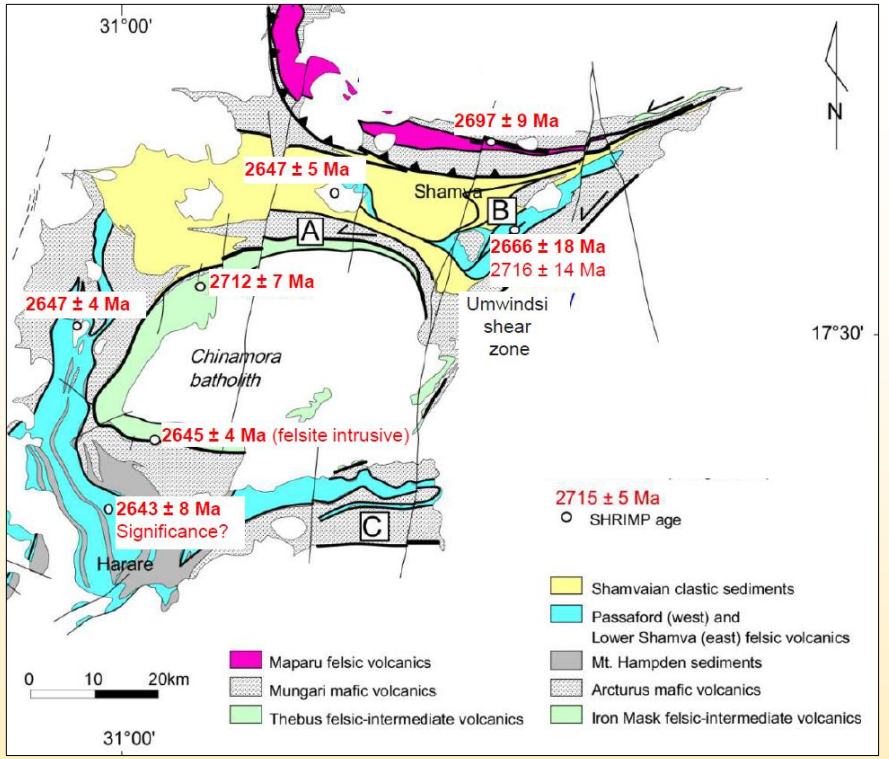
Thrust repetition *within* QSG?
Thrust duplexing – enhanced fluid flow

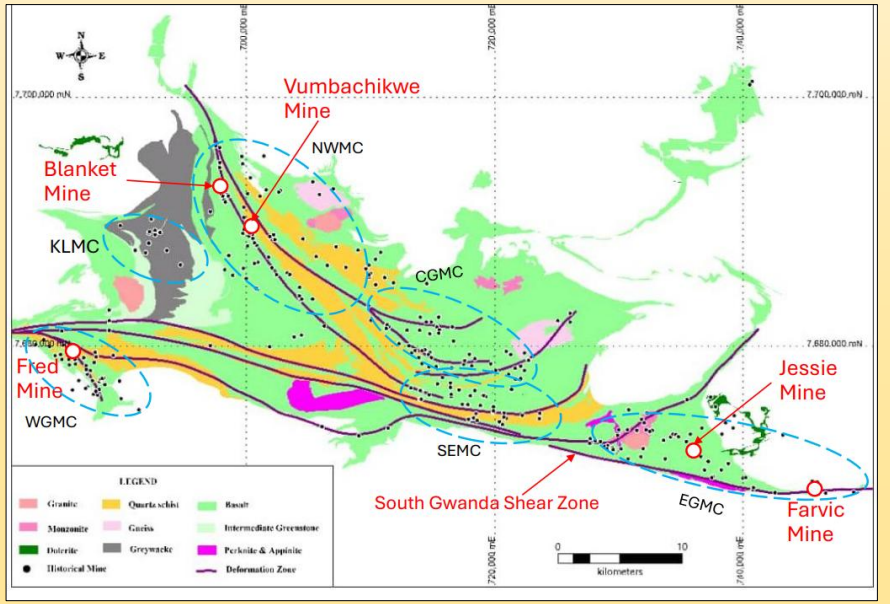
- **Simply strain loci or....**
- **Reactivation of fundamental extensional (rift-basin) fault?**

Significance of coarse clastic sedimentary packages?









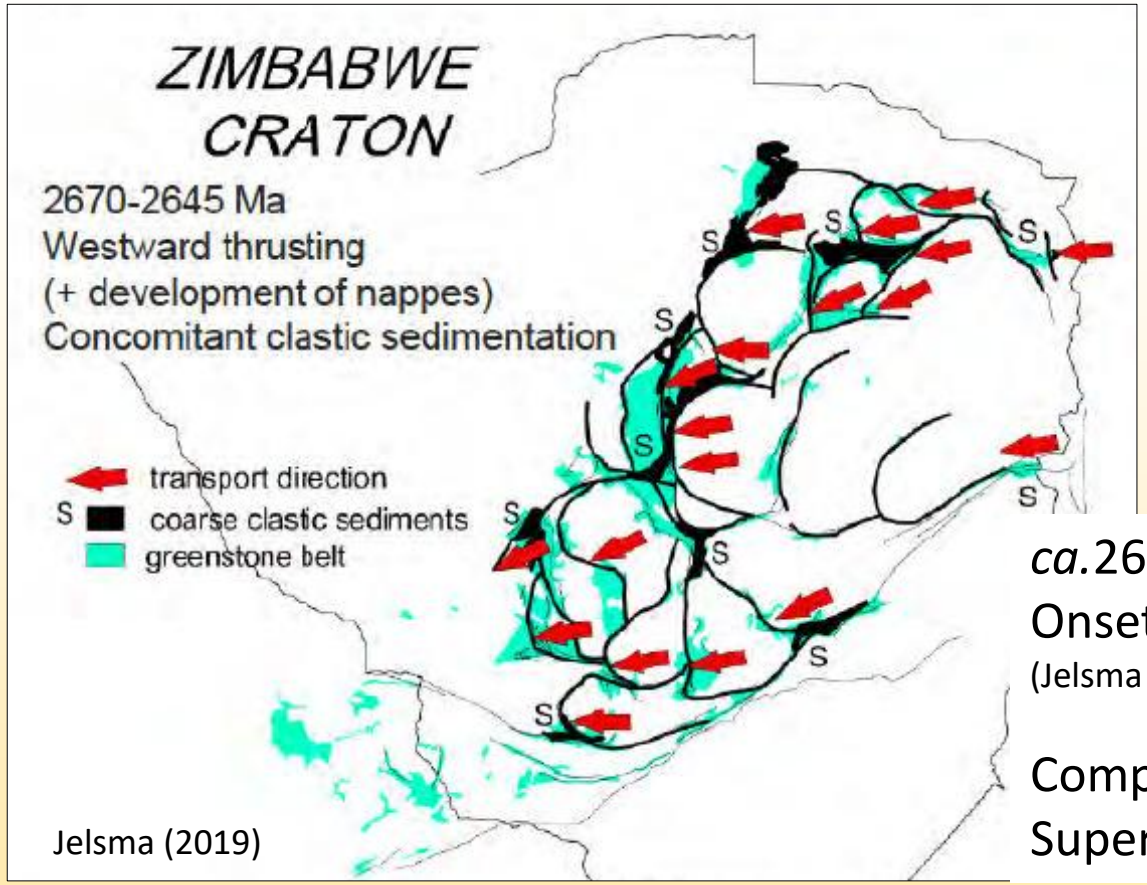
Clues to GB development? Early rifting? .....

..... Subsequent foreland basin development – clastic seds?

Timing vs late-Archean magmatism?

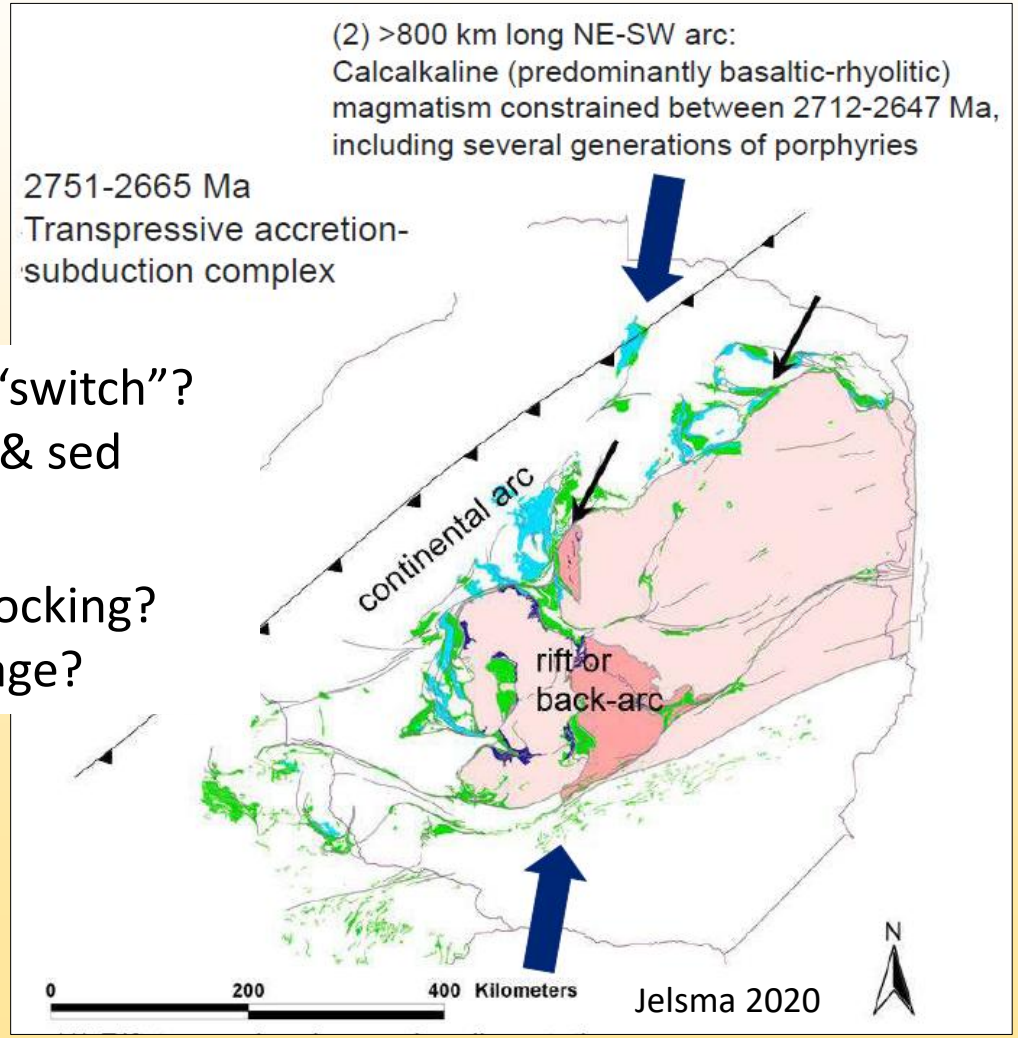
Irrespective – locus for thrust tectonics & Au fluids

Craton-wide considerations: Late-Archean shift σ_1 E-W to N-S - trigger?



Jelsma (2019)

Transpressional regime critical for orogenic Au??



Jelsma 2020

*ca.*2670 Ma "tectonic "switch"?
Onset Shamvaian volc & sed
(Jelsma et al, 2021)

Complex multi-plate docking?
Super-craton assemblage?

Deformation and strain focusing dictated by:

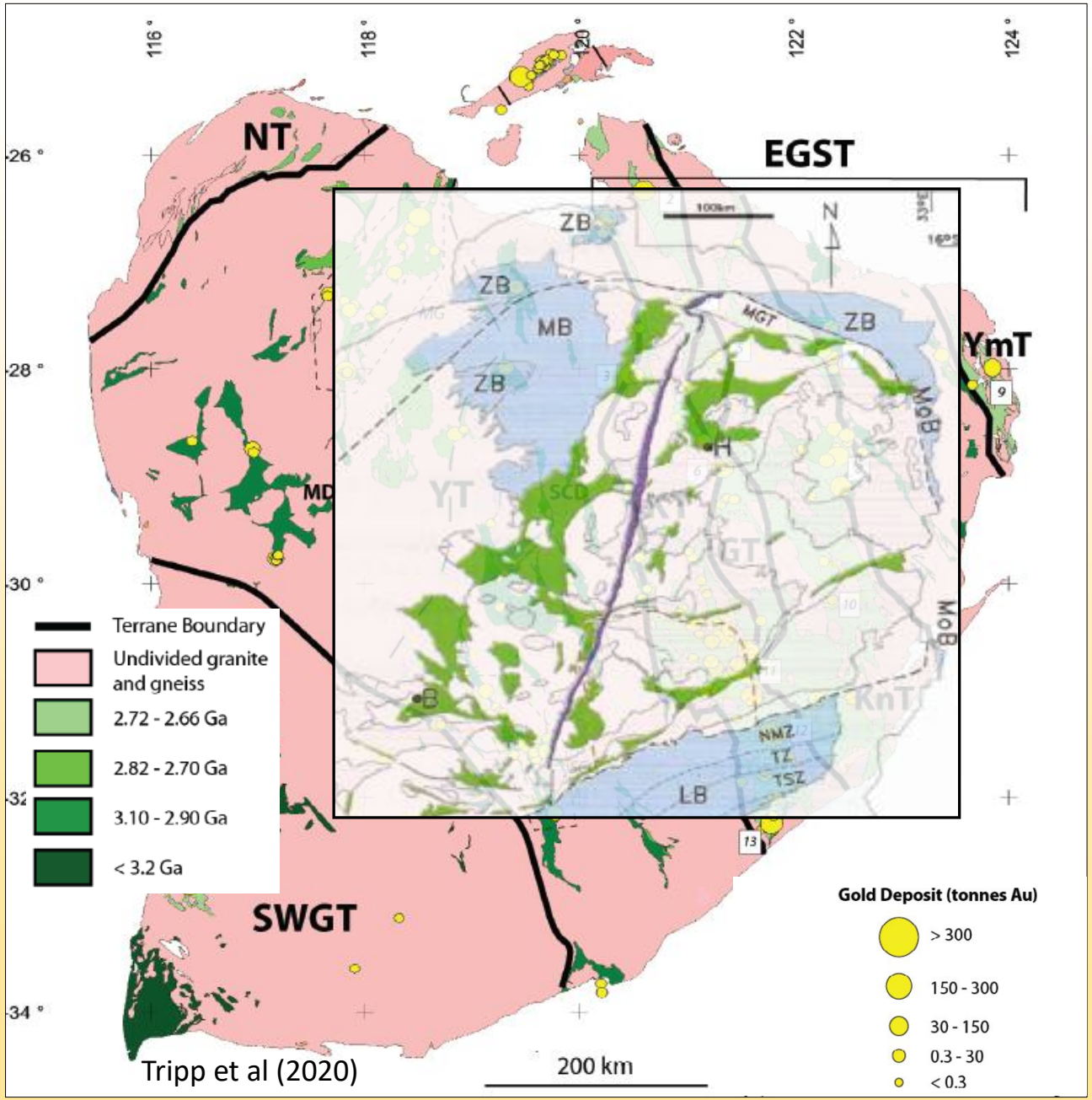
- **Ancient granite-gneiss domains and …..**
- **Timing of syn-orogenic / pre-gold plutons**
- **Multiple W-verging thrust terranes (Dirks, Jelsma, others)**
- **Was "switch" to transpression critical factor for gold?**
- **No major >200 km linear shear zones – predom 10-100 km**



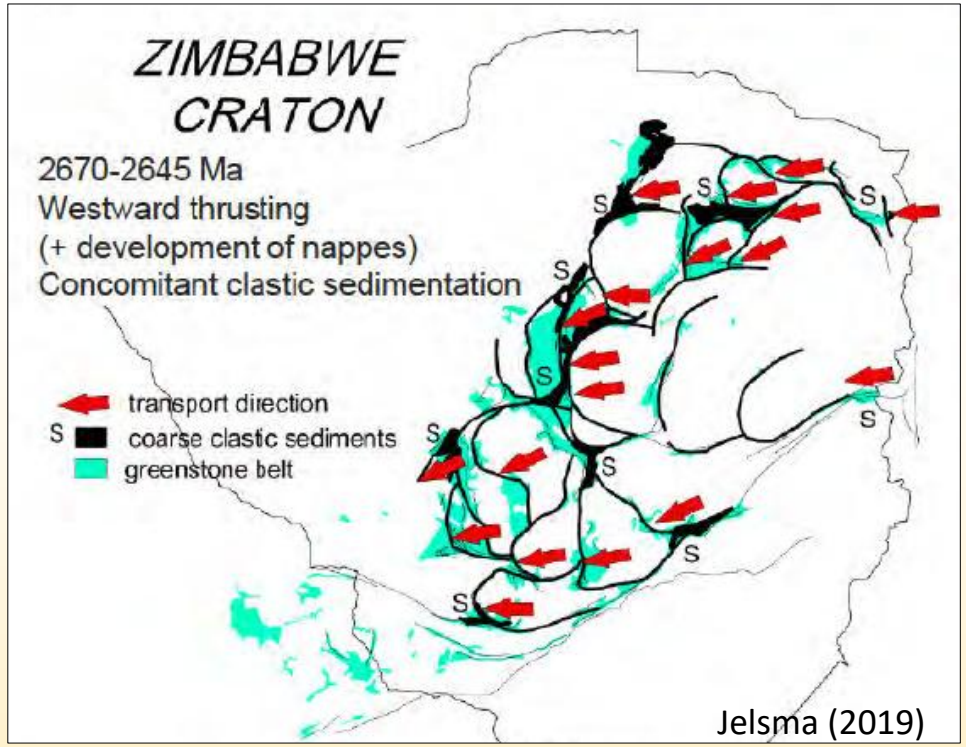
How did craton deformation generate the internal architecture of the greenstone belts?

Relevance to gold metallogenesis?

Lessons from other Archean cratons...?



Tripp et al (2020)



Jelsma (2019)

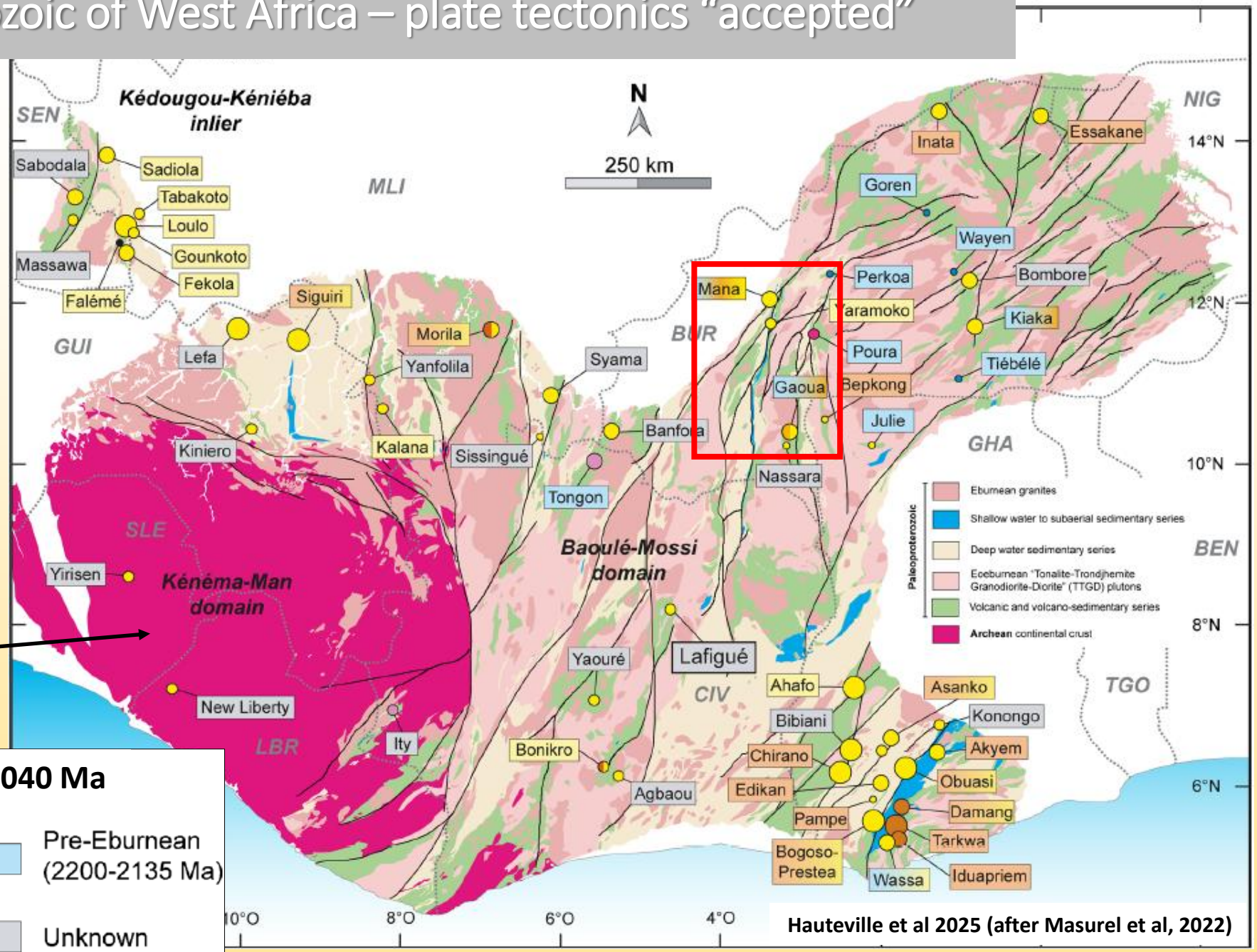
Was the tectonic evolution of the Zimbabwe Craton very different?

Are major terrane boundaries important?

Absence of major terrane boundaries explain paucity of Tier 1 gold deposits in Zimbabwe Craton?

Lessons from Palaeoproterozoic of West Africa – plate tectonics "accepted"

Major structural zones >1,000 km; multiple "linear" belts



Orogenic Au

Paleoproterozoic

- Eburnean granites
- Shallow water to subaerial sedimentary series
- Deep water sedimentary series
- Eoeburnean "Tonalite-Trondjhemite Granodiorite-Diorite" (TTGD) plutons
- Volcanic and volcano-sedimentary series
- **Archean** continental crust

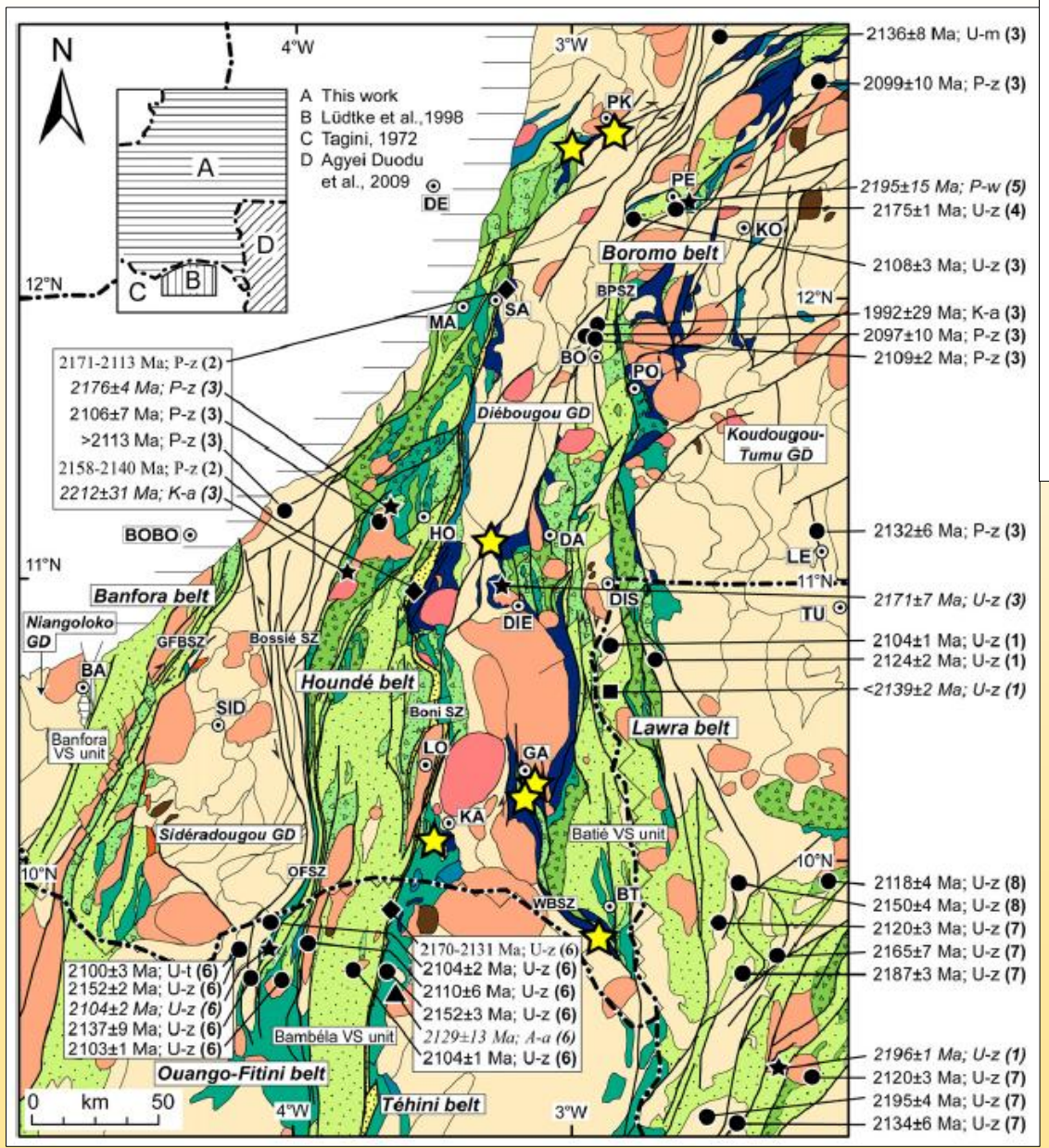
Gold mineralisation 2200-2040 Ma

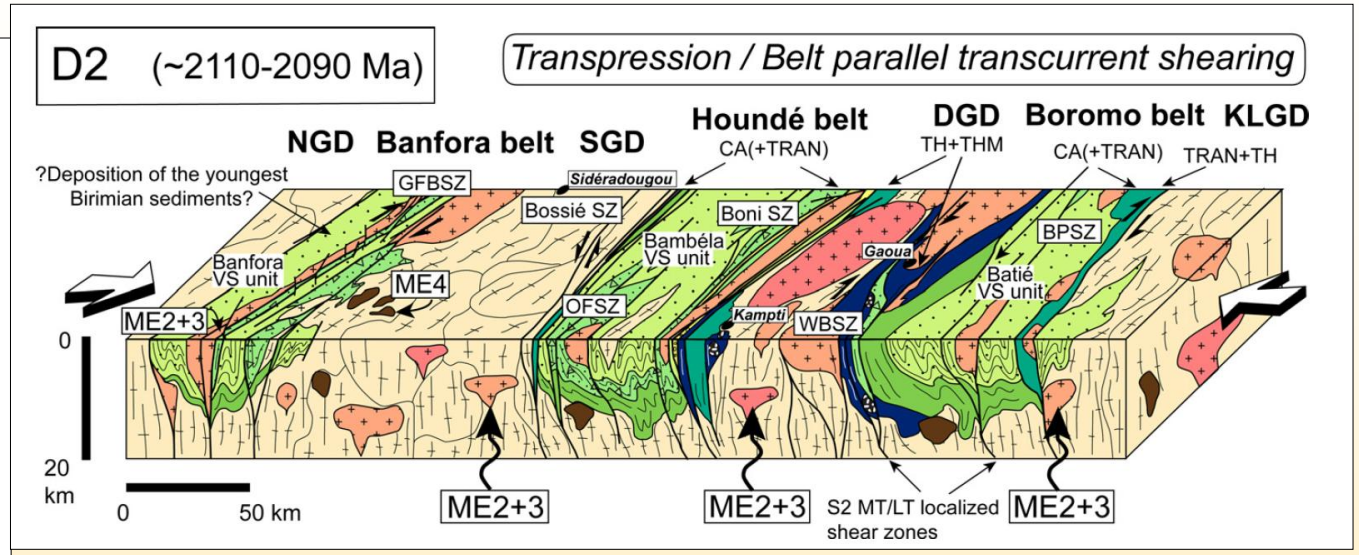
- Late to post-Eburnean (2095-2040 Ma)
- Pre-Eburnean (2200-2135 Ma)
- Early to syn-Eburnean (2135-2095 Ma)
- Unknown

Hauteville et al 2025 (after Masurel et al, 2022)

Orogenic gold: Burkina Faso perspective

Late Eburnean transcurrent events and orogenic gold





Baratoux et al, 2011

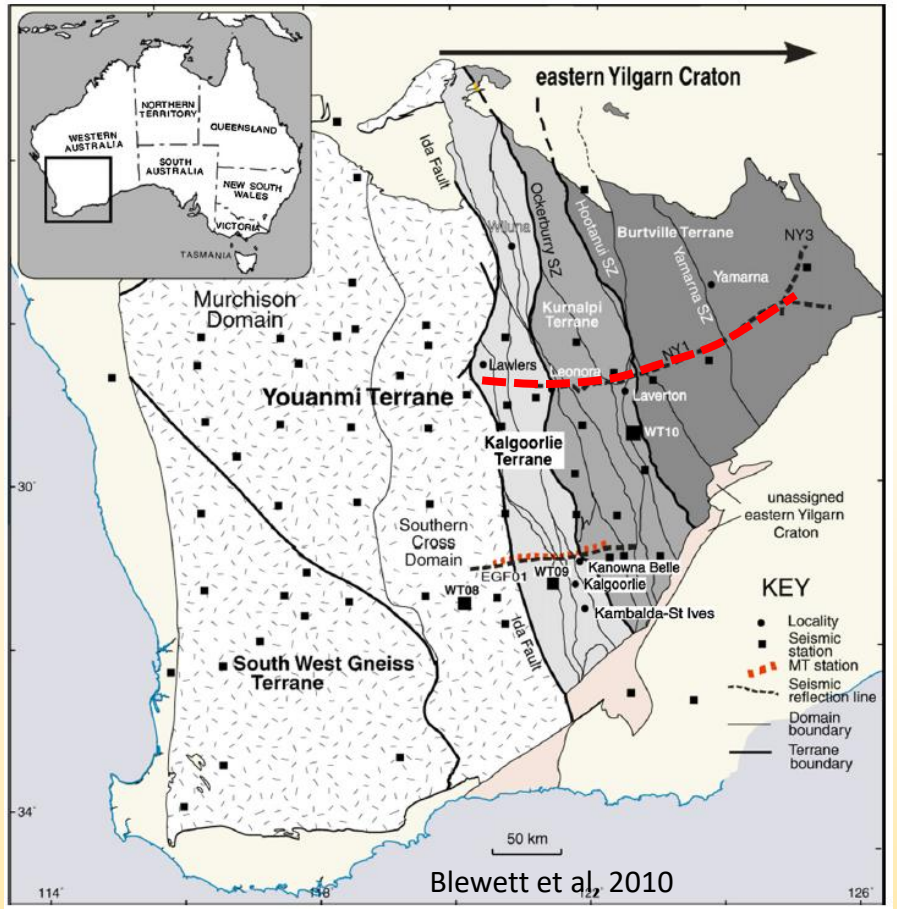
- ➢ Change from transtensional to transpressional regime
- ➢ Strike-slip along earlier thrusts with some reverse sense
- ✓ **Main gold event in West Africa – but complex D3-D5 tectonism – not surprising during late-craton collision**
- ✓ **BUT evidence of continuous terrane boundaries and related gold mineralization limited!**

NOT ENTIRELY APPLICABLE TO ARCHEAN

How important are “superterranes” and their boundaries?

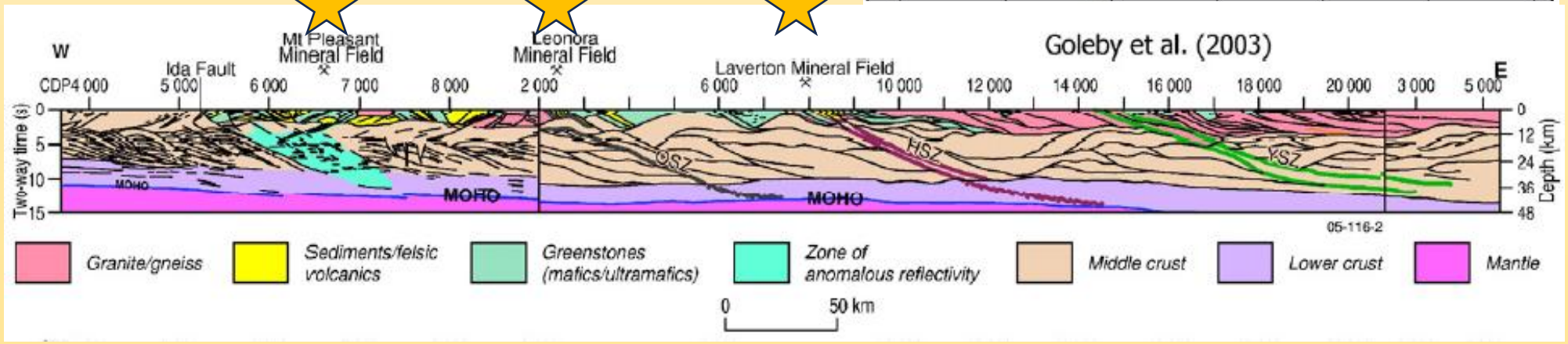
Crustal architecture varies across any craton –
e.g. Eastern Yilgarn

- Important gold camps in specific terranes ca.50-100 km wide between E-dipping crustal shear zones
- Network of low-angle shear zones intersect major crustal shears – focus syntectonic fluid flow up/into greenstone belts
- Pluton emplacement facilitated by within-belt extension/transtension and subsequently dictate stress regimes on district scale

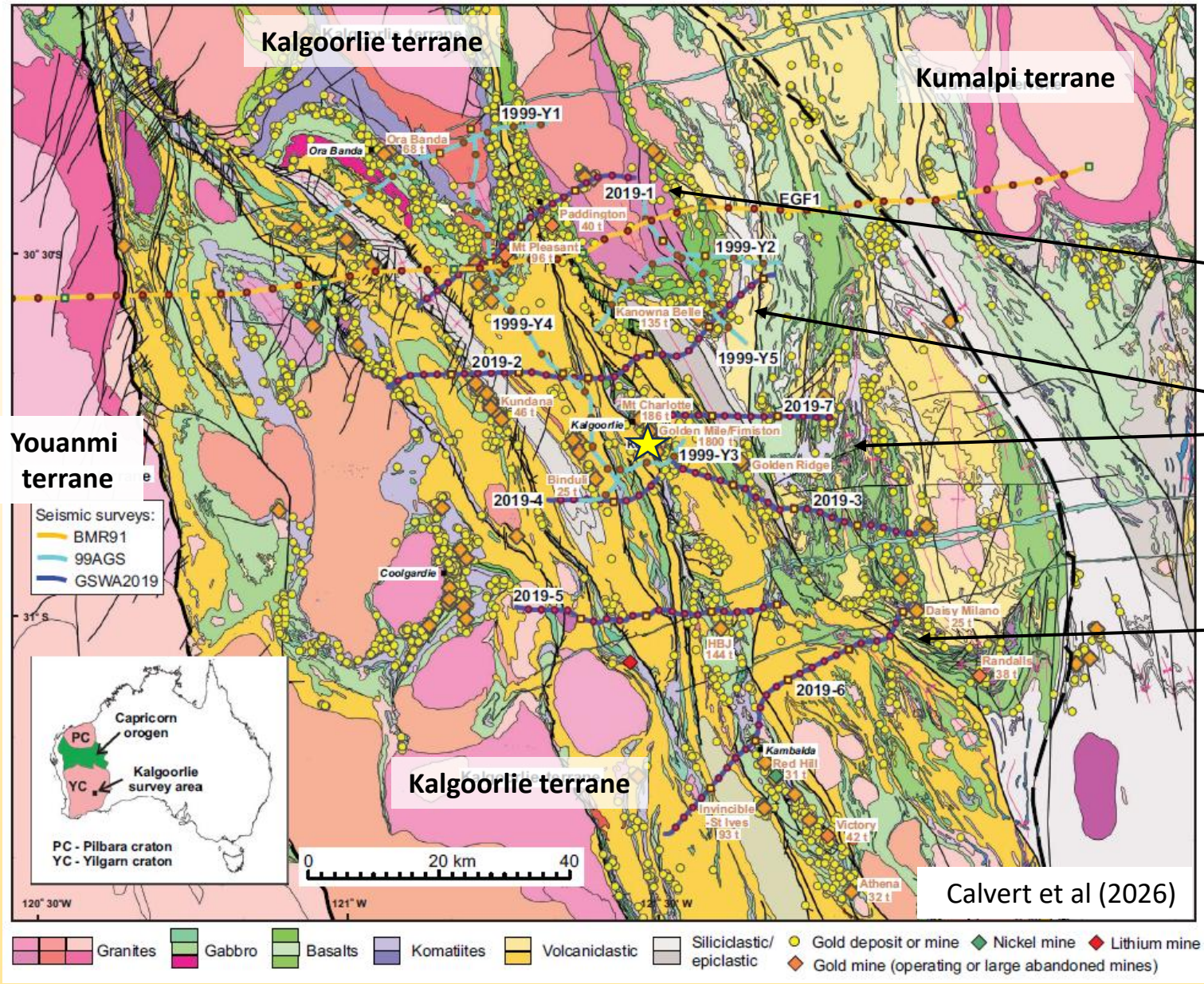


Very differing “internal” architectures = differing prospectivity

Seismic profile



Kalgoorlie Rift: seismic reflection imaging



Calvert et al (2026)



Seismic reflection lines



across

Northern (Ora Banda) domain

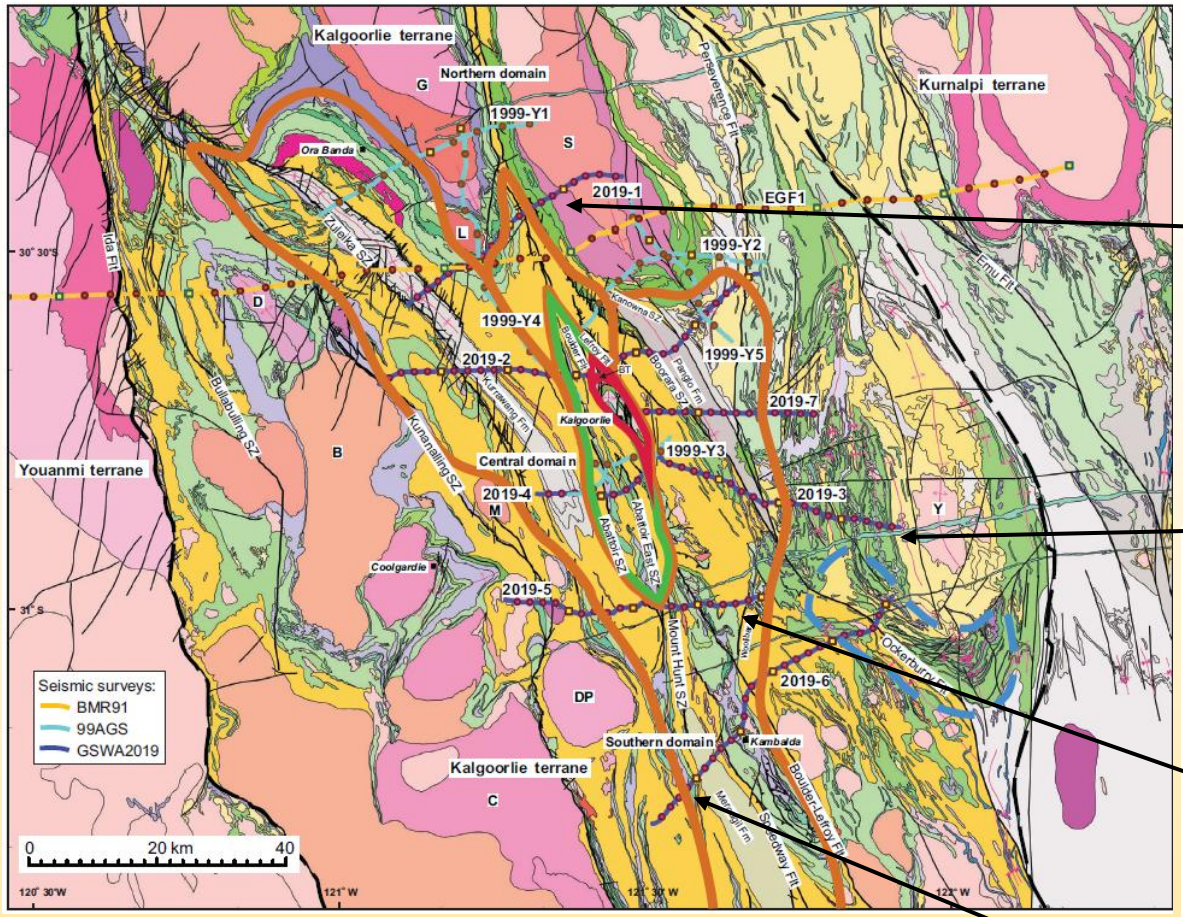
Central (Kalgoorlie) domain - N & S

Southern (Kambalda) domain

Much greater complexity when interrogated on this scale

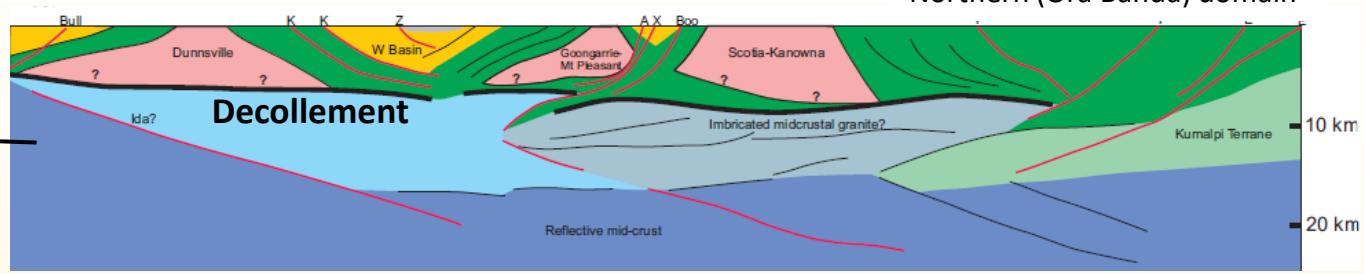
☆ Kalgoorlie – Golden Mile

Kalgoorlie Rift: seismic reflection imaging

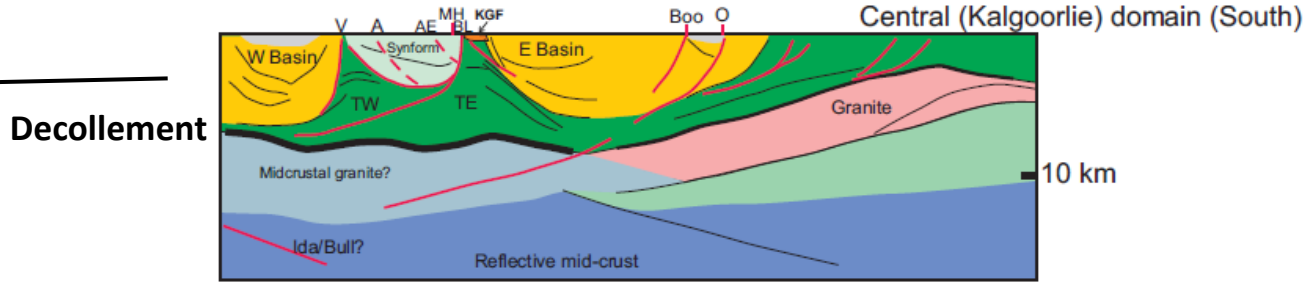


Inferred structural basins

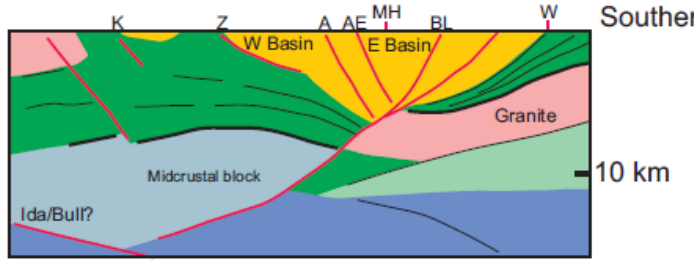
Northern (Ora Banda) domain

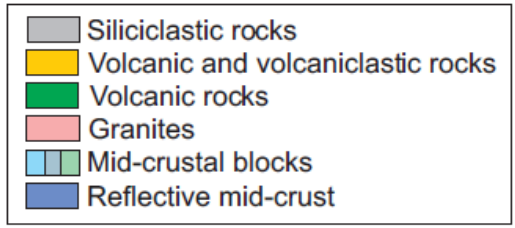


Central (Kalgoorlie) domain (South)

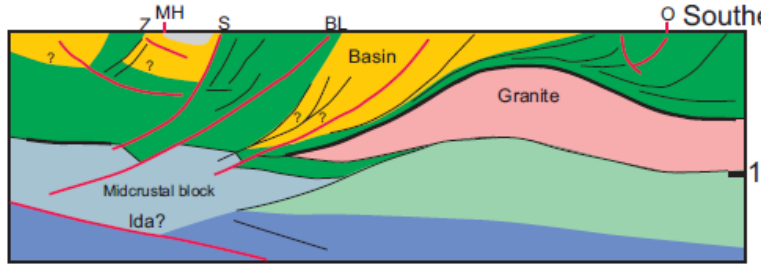


Southern (Kambalda) domain (North)





Southern (Kambalda) domain (South)



No decollement – W-dipping Boulder-Lefroy fault system

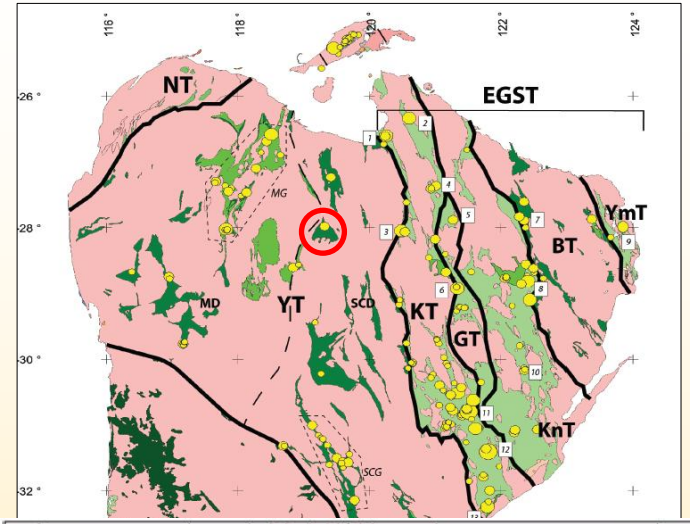
Key fluid/gold controls

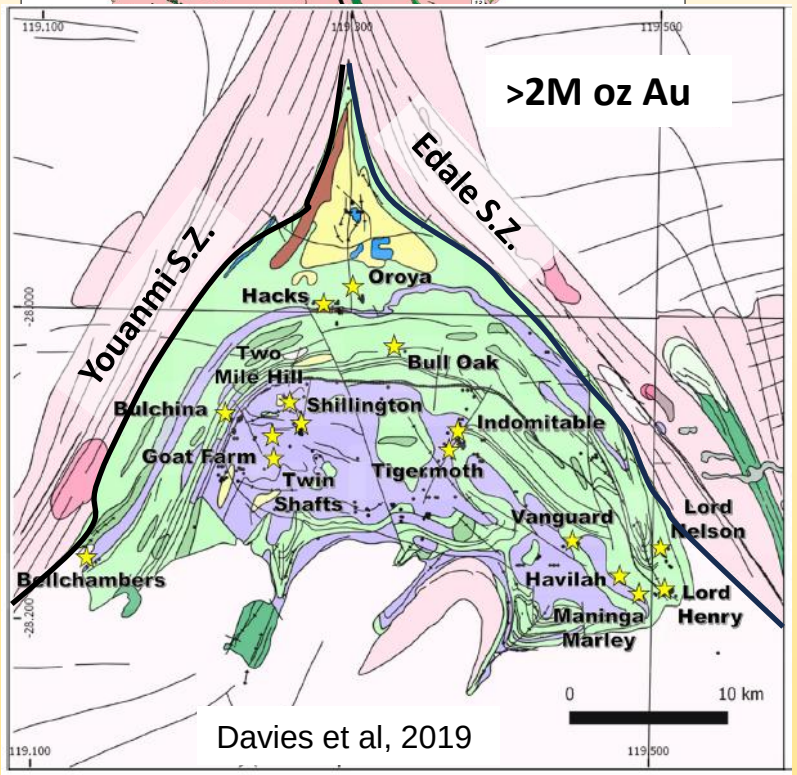
- "Local basins" - very different architecture
- Structural inheritance (early rift faulting?)
- & strain partitioning during subsequent crustal shortening. **Orogenic collapse?**
- Early/syn-tectonic granites – Ora Banda

Calvert et al (2026)

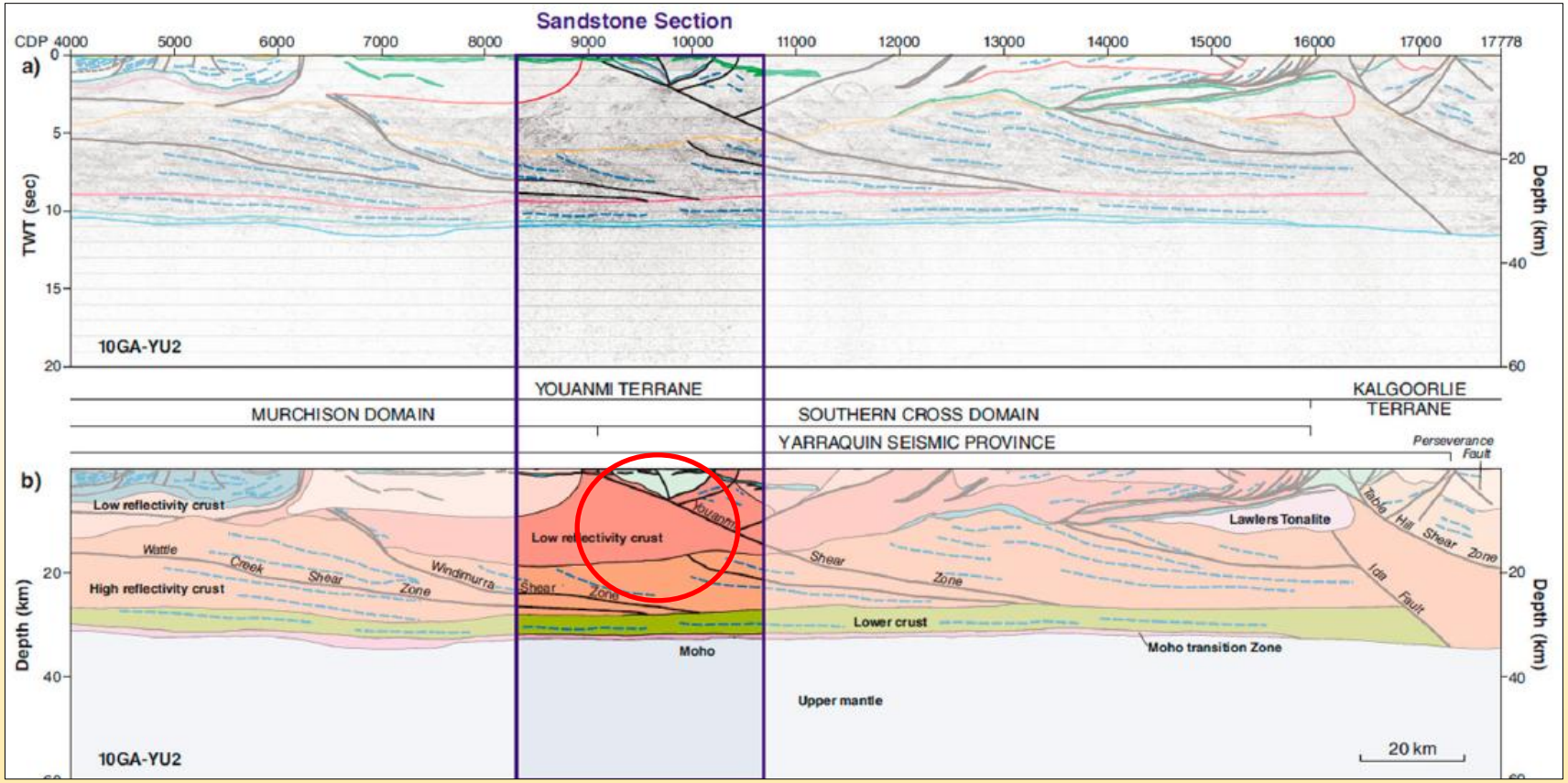
Transcrustal structures? Youanmi Terrane

3.1-2.9 Ga Sandstone GB: seismic traverse





Davies et al, 2019



Crustal-scale bounding shears but not “superterrane” boundaries

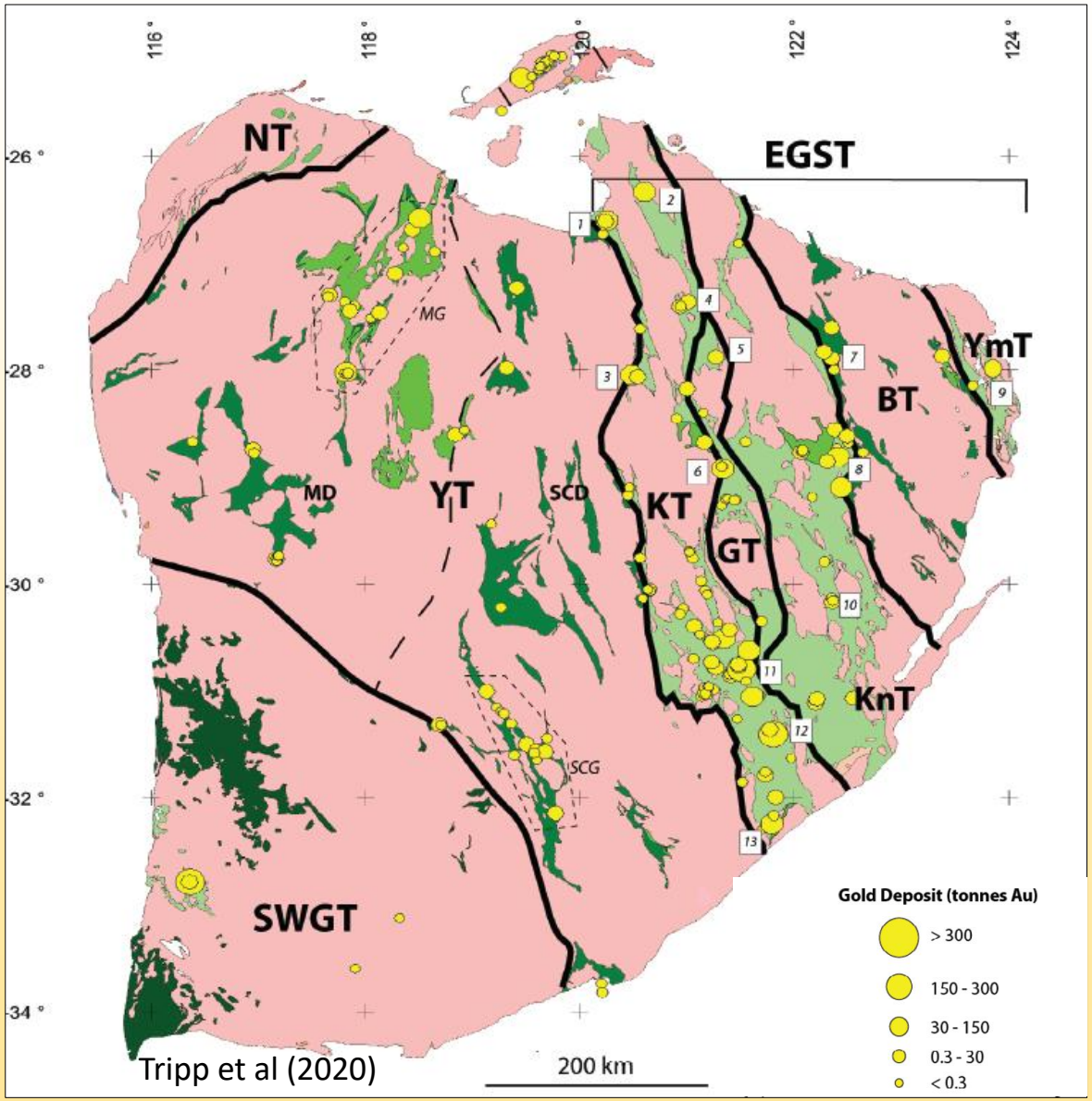
Asymptotic as approach lower crust

Low strain, greenschist facies

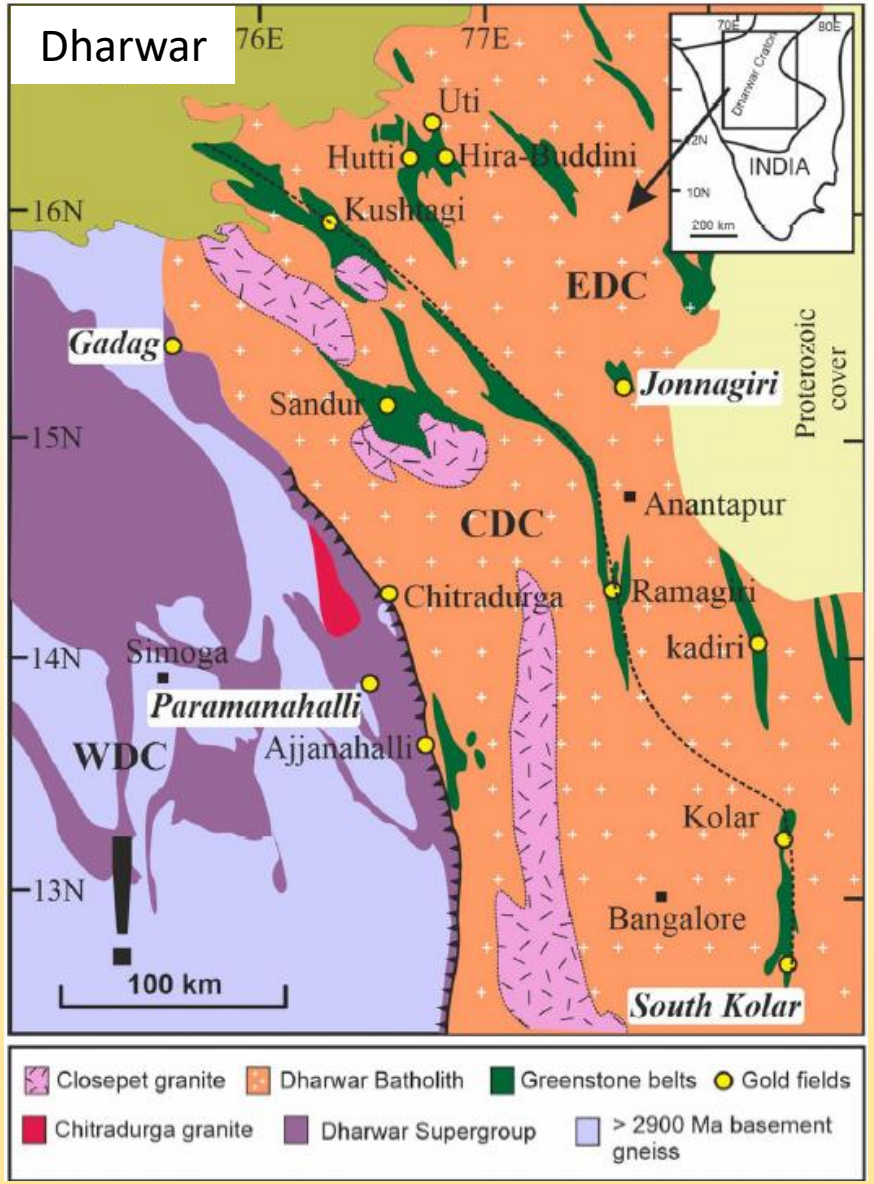
Gold mineralisation related to complex internal architecture -

.... esp flexural slip, axial planar failure, fold lock-up

Broadly linear greenstone belts: consistent with craton assemblage reflecting growth of new volcano-sedimentary basins and subsequent crustal shortening



Tripp et al (2020)



Chinnasamy (2025)

Major gold fields

Hutti (>4M oz)

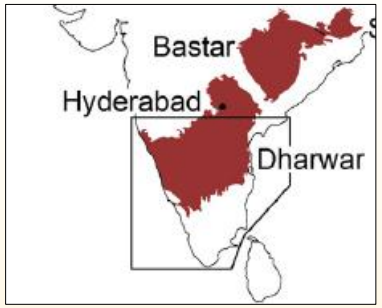
Gadag

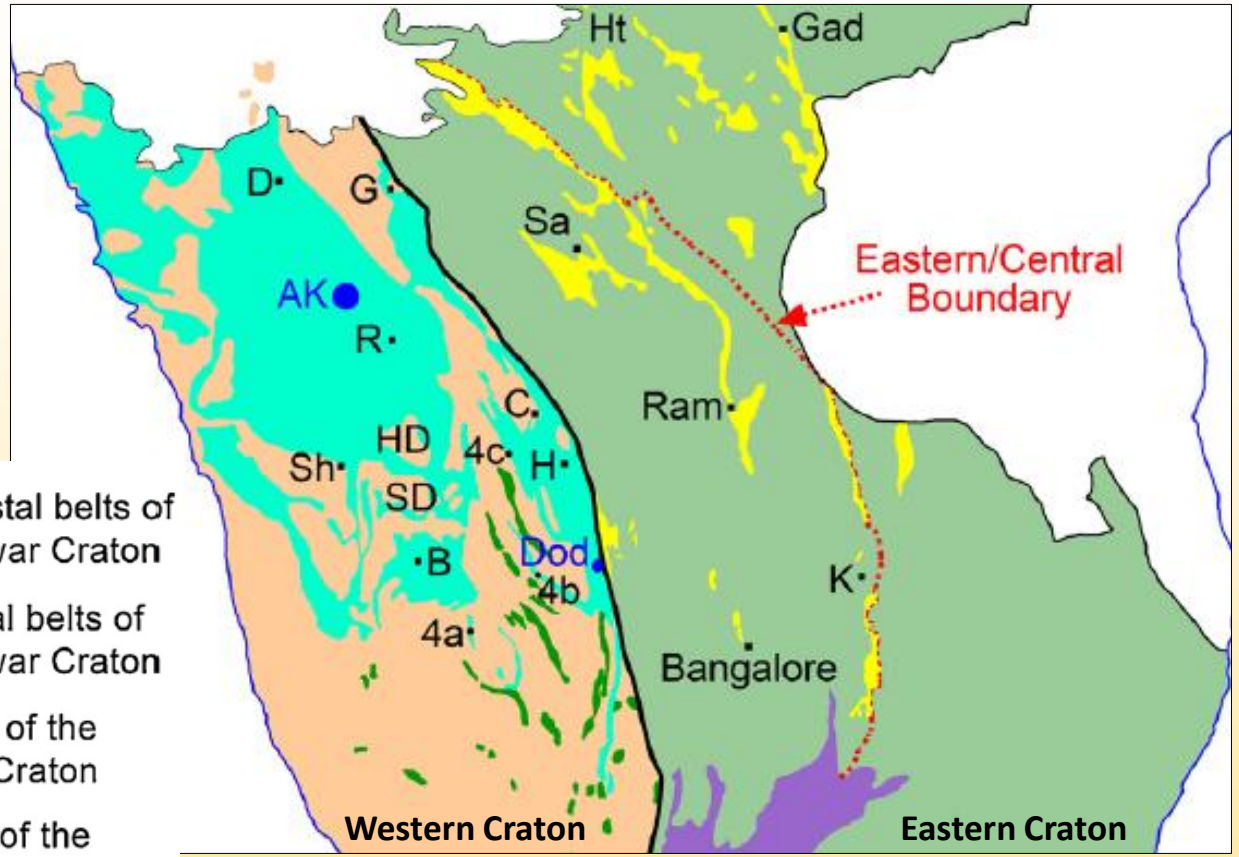
Ramagiri

Chitradurga

Kolar (29M oz)

Broadly linear greenstone belts: consistent with craton assemblage reflecting growth of new volcano-sedimentary basins and subsequent crustal shortening





Krapez et al (2020)

- Dharwar supracrustal belts of the Western Dharwar Craton
- Sargur supracrustal belts of the Western Dharwar Craton
- Granitoid & gneiss of the Western Dharwar Craton
- Supracrustal belts of the Eastern Dharwar Craton
- Granitoid & gneiss of the Eastern Dharwar Craton

Dharwar Craton

Dharwar Supergroup *(docking = Au)*
2.54 Ga SW-verging fold/thrust belt

Chitradurga Gp (eastern – best preserved)
2-stage back-arc basin:
- turbidites, basaltic & felsic volc

unconformity

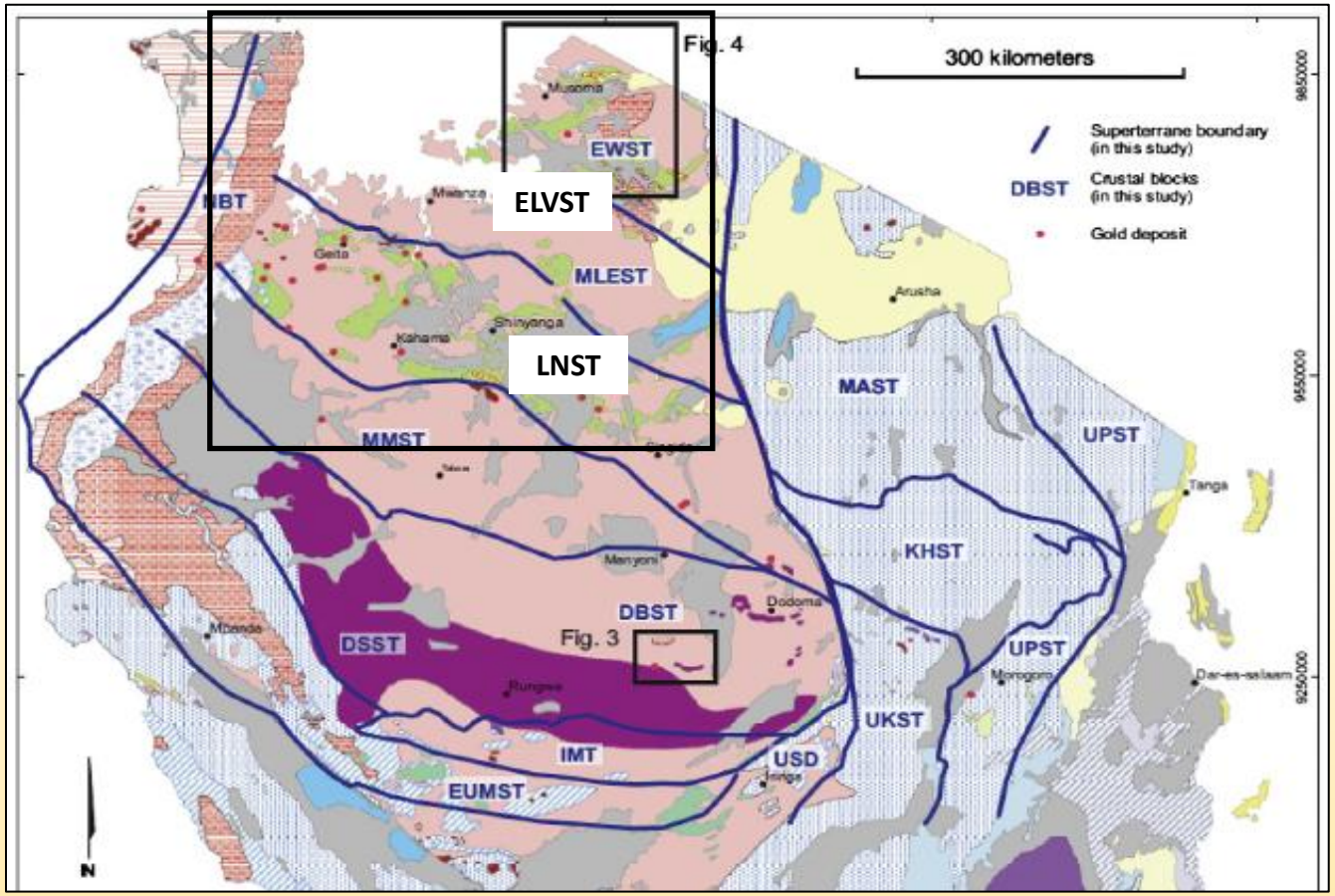
- 2.60 Ga siliciclastic fluvial & shallow to deep marine seds

Babudan Gp (western – best preserved)
- 2.68 Ga convergence, uplift, folding
- ca.2.76 Ga divergent margin intracontinental rift

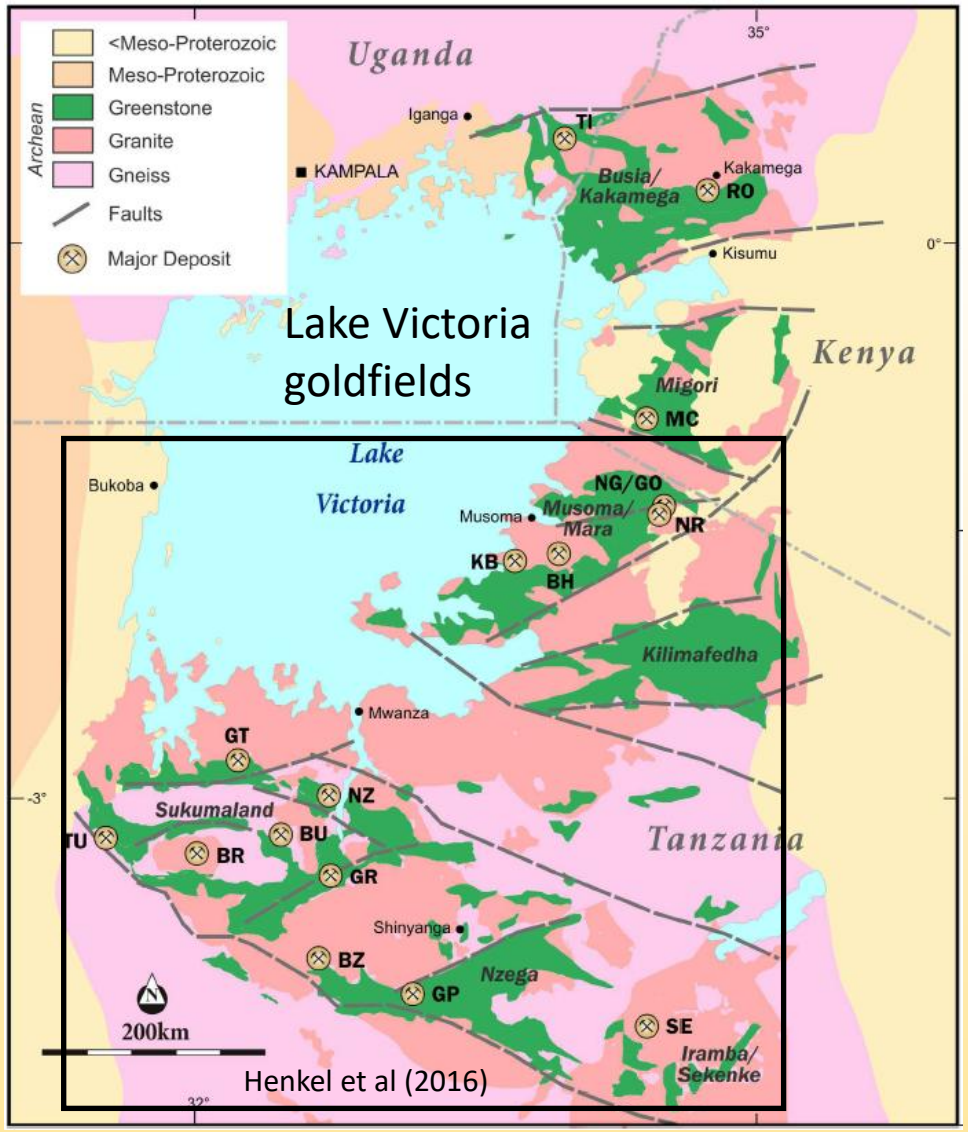
>2.9 Ga "Basement" - west & east

Consistent mid- to late-Archean crustal development across multiple cratons
Lessons to be shared!

Au v crustal growth: superterranes (?) and greenstone belt development - Tanzanian Craton



Superterranes (after Kabete et al 2012)



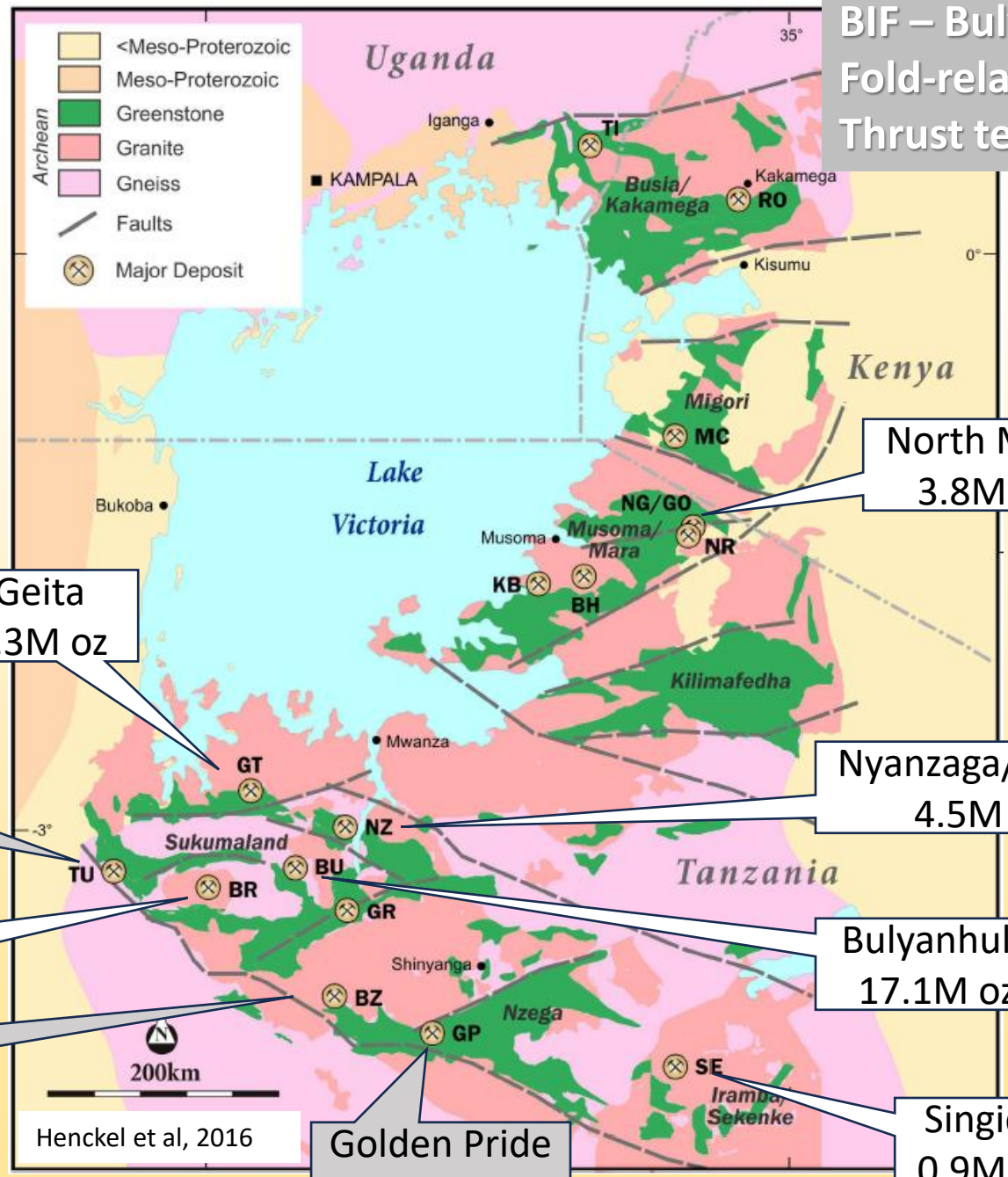
- LNST: Lake Nyanza ST
- EWST & MLEST: East Lake Victoria ST's

<2.85 Ga gold but early crustal growth within continental domain >3.11 Ga
Broadly similar Archean "history" to Zimbabwe, Yilgarn, Dharwar – and Kaapvaal

Tanzania

Active

Closed mine



BIF – Bulyanhulu, Geita, (Nyanzaga?), Kibali
Fold-related ore shoots – Bulyanhulu, Geita, Nyanzaga
Thrust tectonics – Nyabirama, Kibali

North Mara 3.8M oz

Geita 7.3M oz

Tulawaka 1.0M oz

Nyanzaga/Tusker 4.5M oz

Buck Reef 3.8M oz

Bulyanhulu 17.1M oz

Buzwagi 2.7M oz

Golden Pride 2.2M oz

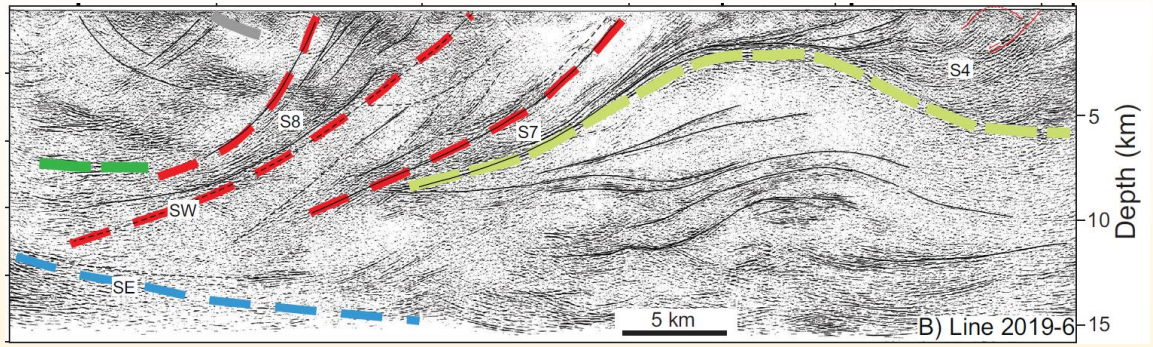
Singida 0.9M oz

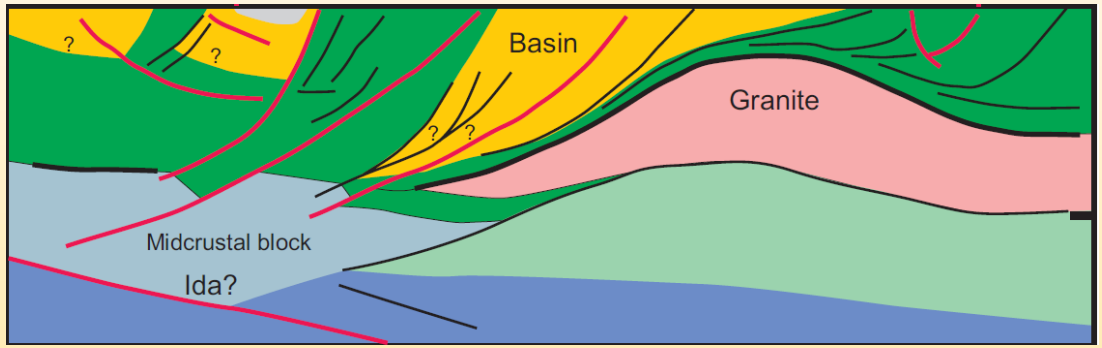
Mines with first gold production since 2000

- **Geita – 2000** [AGA]
- **Bulyanhulu – 2001** [Barrick/AGA]
- **North Mara – 2002** [Barrick/AGA]
- **Tulawaka – 2005** [African Barrick]
- **Singida – 2023** [Shanta]

No direct association with “superterrane” boundaries

Greenstone belts and gold endowment – deep thinking!





Southern Kambalda (Calvert et al, 2026)

No Au association with major terrane-boundary faults: shear zones commonly <100 km

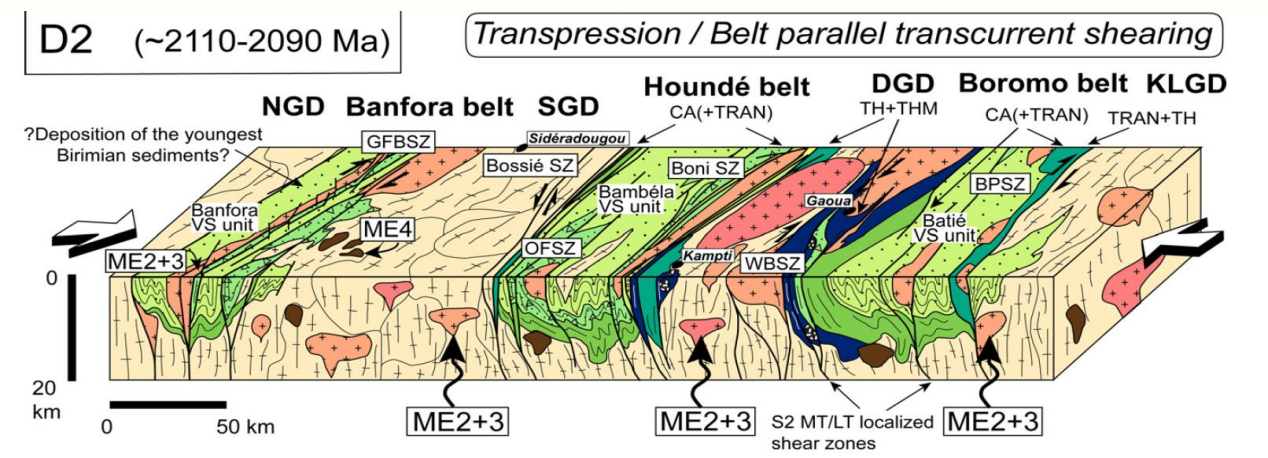
Major gold districts often related to thickest, lithologically most complex, internal GB architecture

Au Likely reflects deep-crustal structural connectivity – maximum fluid generation – and focused flow

Lithological heterogeneities = optimum strain locus & upper-crustal fluid flow

Deep-crustal architecture is a critical factor
Necessitates crustal profiling to assist sensible interpretation of mapped greenstone belts ….and assess potential gold endowment

Greenstone belts and gold endowment – unravelling evolution



Thick multi-lithological packages? Back-arc & foreland environs – most complex lithogically & structurally

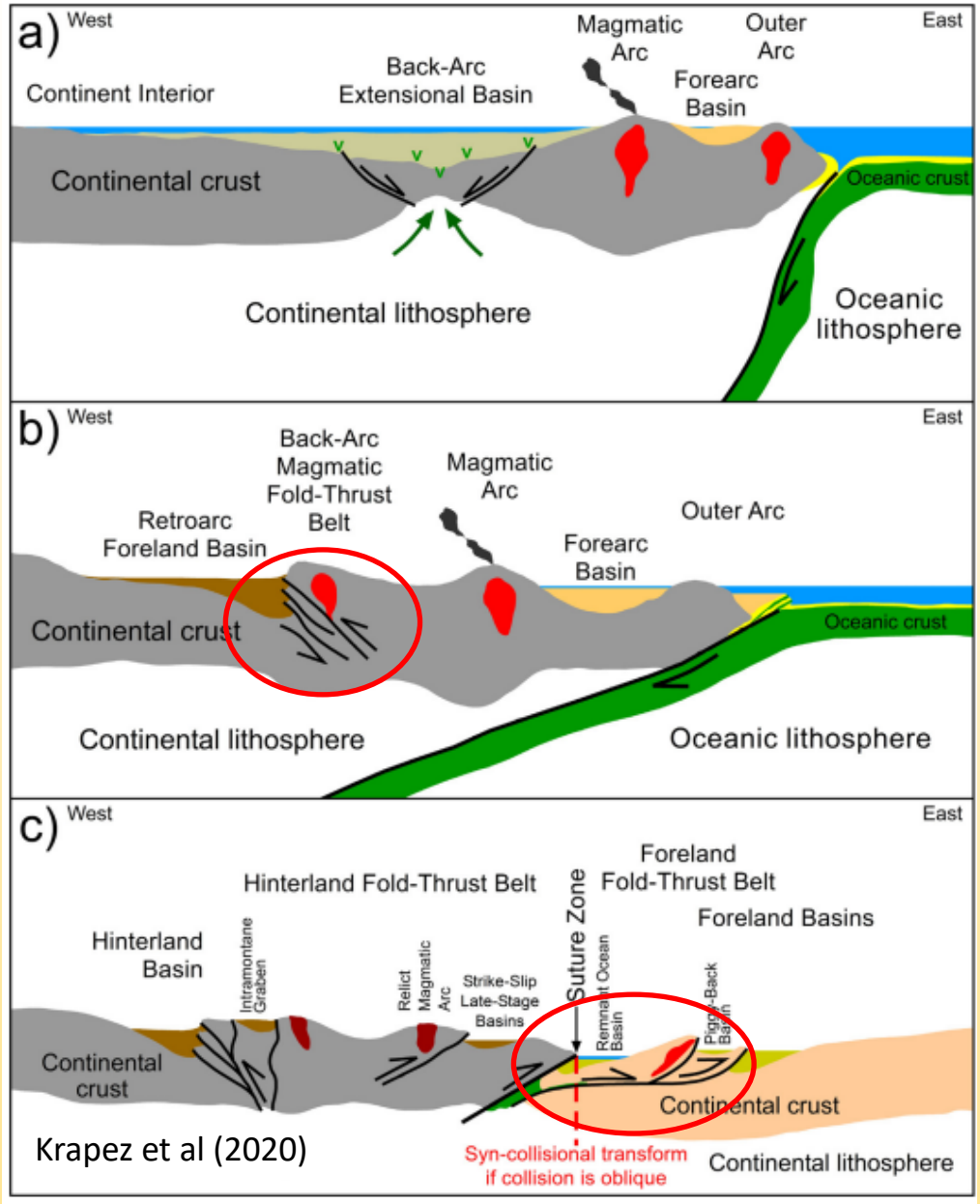
- **Don't ignore sedimentary units – indicative of rifting *and* uplift**

***Some* spatial association with late-Archean coarse clastic seds in Zimbabwe** – Upper Bulawayan & Shamvaian

Crustal shortening .....

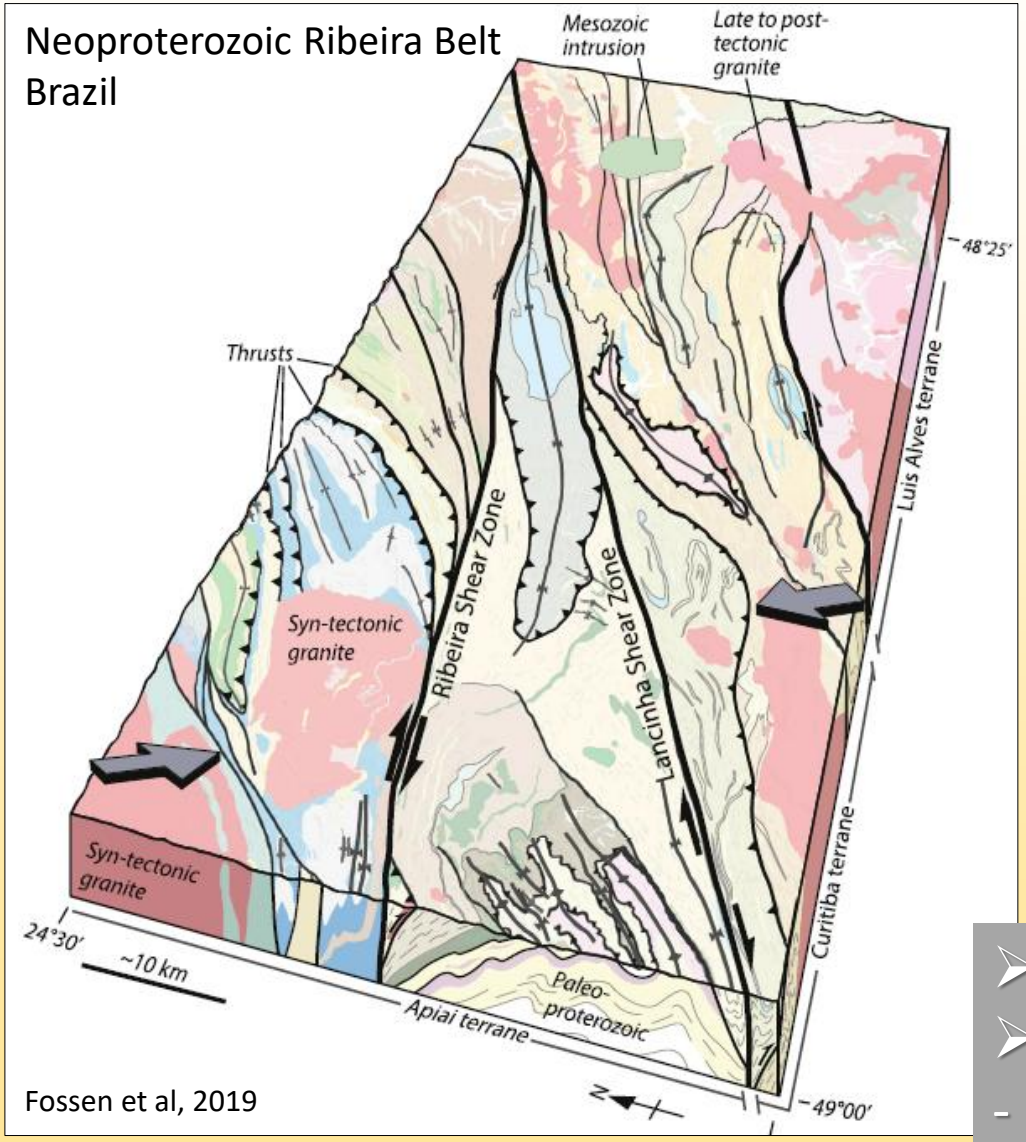
- Erosion of uplifted volcano-seds = clastic shedding
- Culminating in thrust tectonics within / margins of clastic units ...

- **Significant shear zones may be reactivated basinal faults**



Krapez et al (2020)

District-scale prospectivity factors: all about terranes, not "superterranes"



TERRANE = fault-bounded block with distinct "internal" geologic history

Terrane margins: first-order shear zones – km's wide but rarely host major deposits

Strain focus on internal components (intrusions, rheology contrasts, etc) = 2nd , 3rd , nth- order shear zones ("fractal")

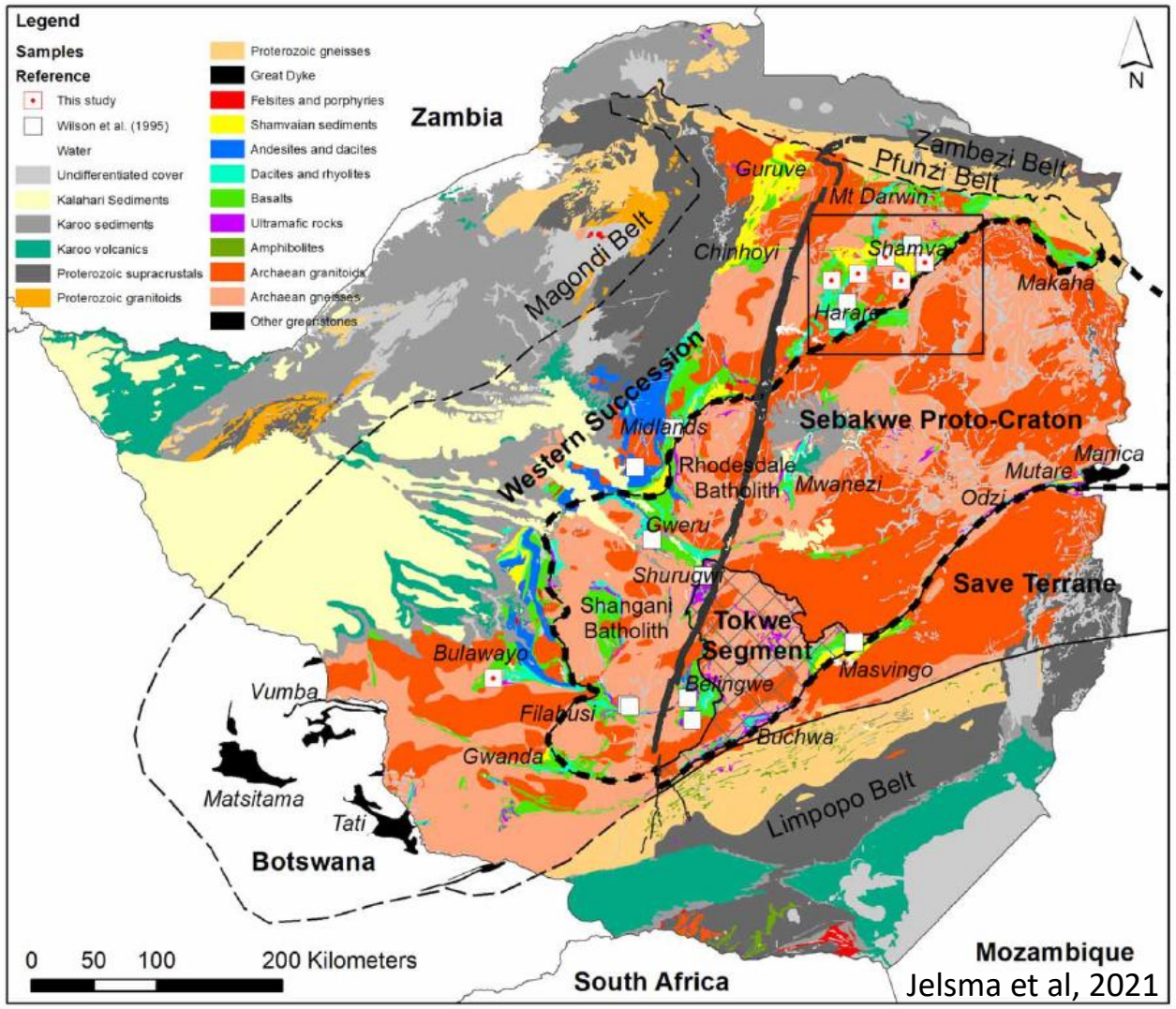
Far-field stress: craton-craton-driven accretion: complex changes in σ1 during late stages of collision, reorientation, & docking

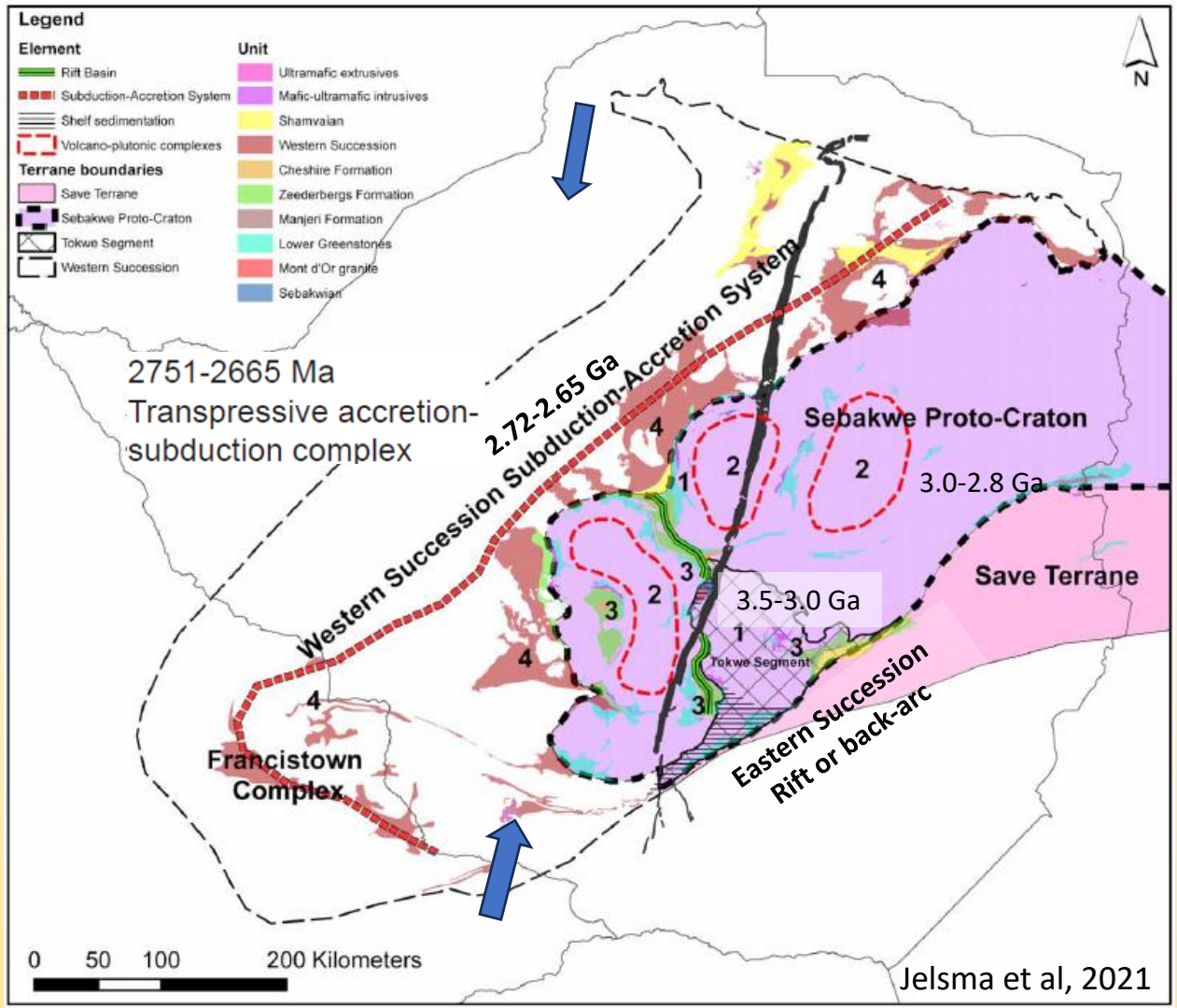
Multiple "D events" often reported – not necessarily time-consistent but key to exploration *on district scale*

- Deformation events & sequence will differ **between** terranes
- And **within** a single terrane

- Be wary of linking mineralisation to a single event across a GB

Zimbabwe Au: unravelling terrane (GB) evolution during Archean





3.5-3.0 Ga: Tokwe & Sebakwe Proto-Craton

3.0-2.8 Ga: proto-craton re-working (2)

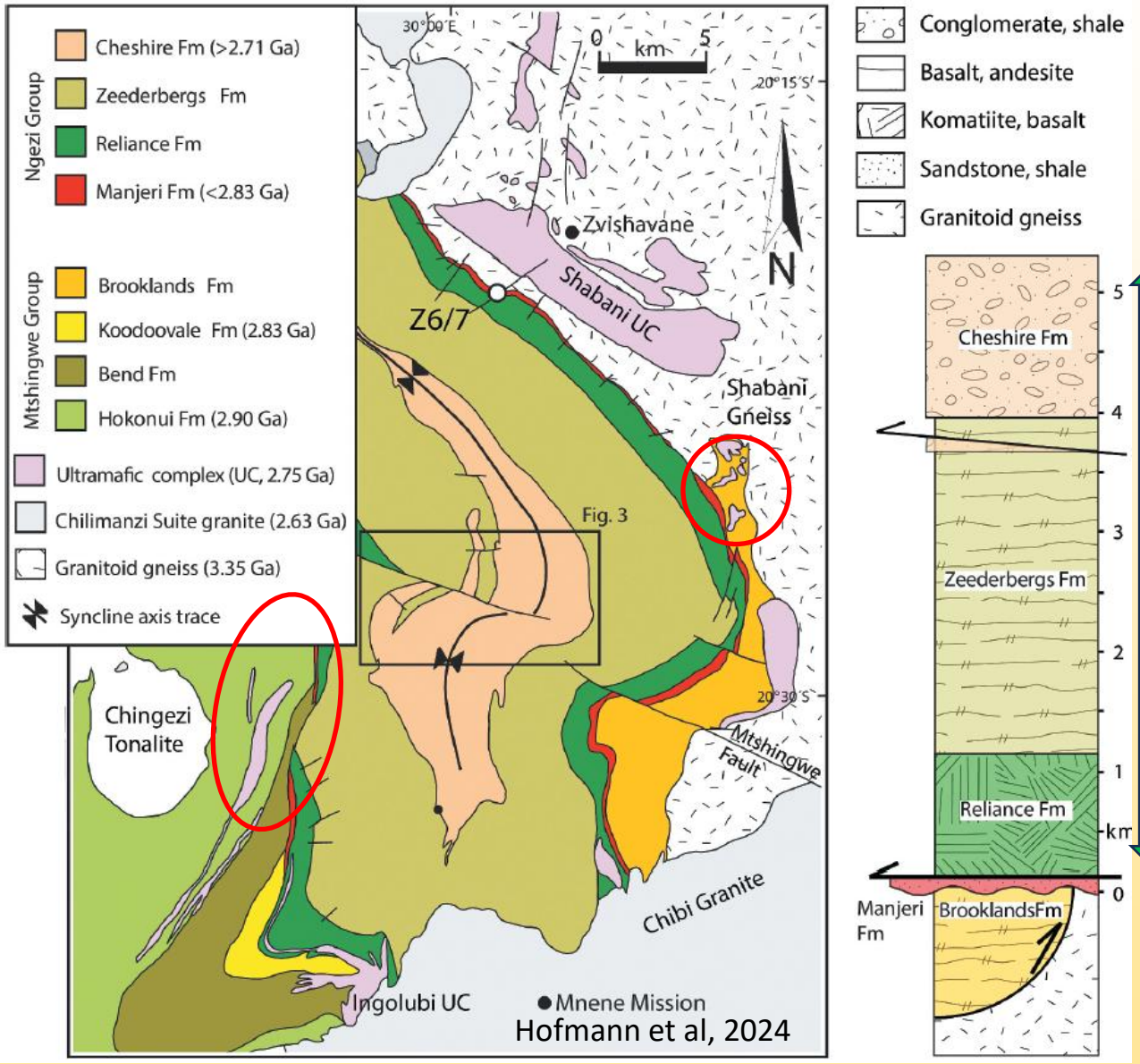
2.8-2.7 Ga: Eastern Succession rift- or back-arc volcano-sed (3)

→ 2.72-2.65 Ga: Western Succession accretion (4)

"West" v "East" gold endowment?

Zimbabwe craton evolution: Eastern Succession - Mberengwa clues?

- Rift and foreland-basin sedimentation
- Older than Western Succession
- Subsequent compressional tectonism



>2.71 Ga foreland(?) sedimentary basin

Upper Greenstones

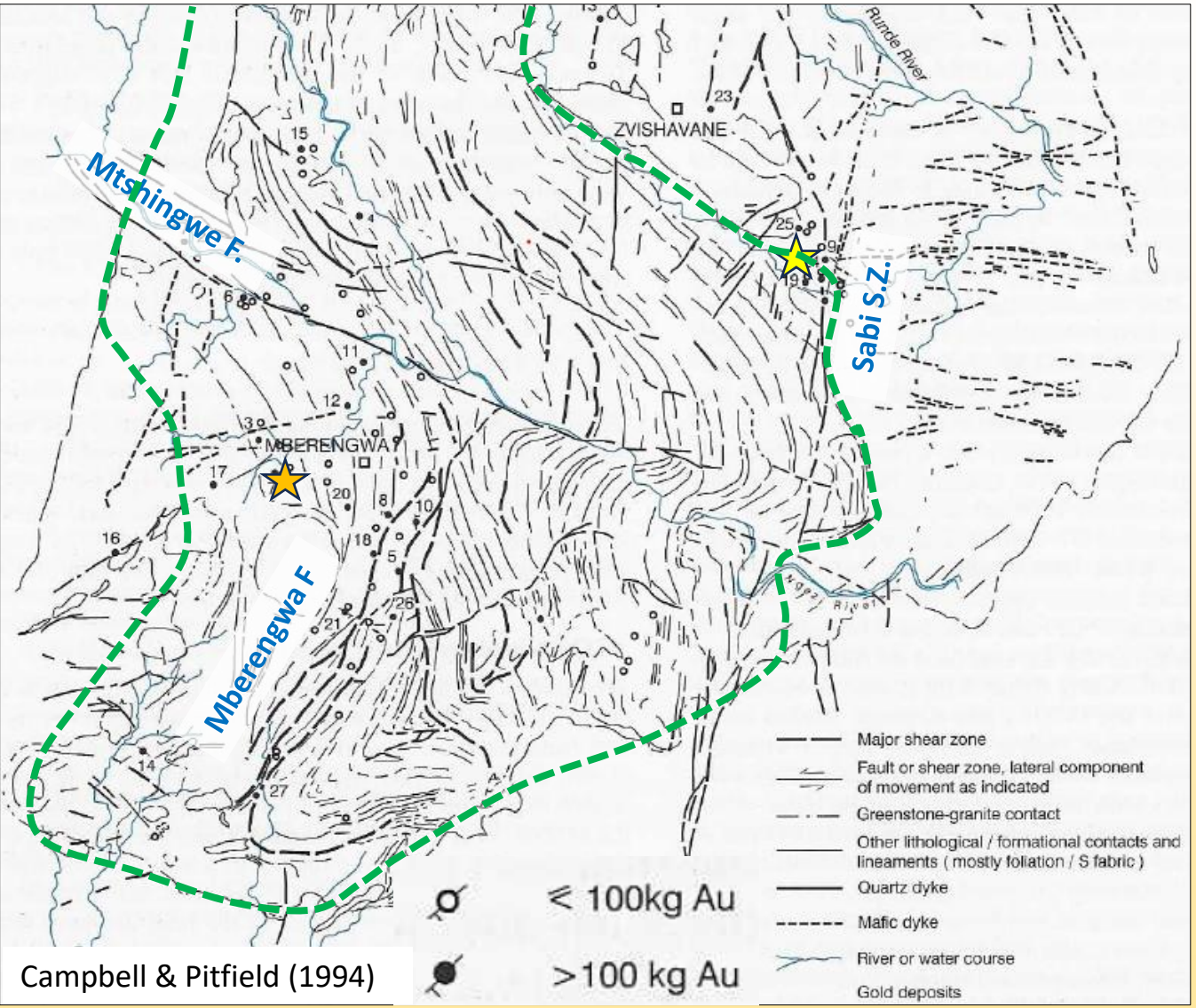
Continued subsidence – voluminous submarine (back-arc?) volcanism (>4 km)

Detachment: southern (eastern) greenstones obducted NW (?)

Manjeri Fmn: subsidence – transgressive sed

Clusters of gold deposits – 2.9-2.78 Ga Lower Greenstones host?

Zimbabwe craton evolution: Eastern Succession - Mberengwa clues?



Campbell & Pitfield (1994)

Low gold endowment – why?

Mugumbate (2017) & Chagondah (2021)

26 gold deposits > 3,000 oz production

13 gold deposits >10,000 oz production

3 gold deposits >30,000 oz production

- Berea – *c.*39,000 oz
- C mine – *c.90*,000 oz ☆
- Sabi – *c.*154,000 oz ☆

May not reflect post-1991 production

Pitfield & Campbell (1994):

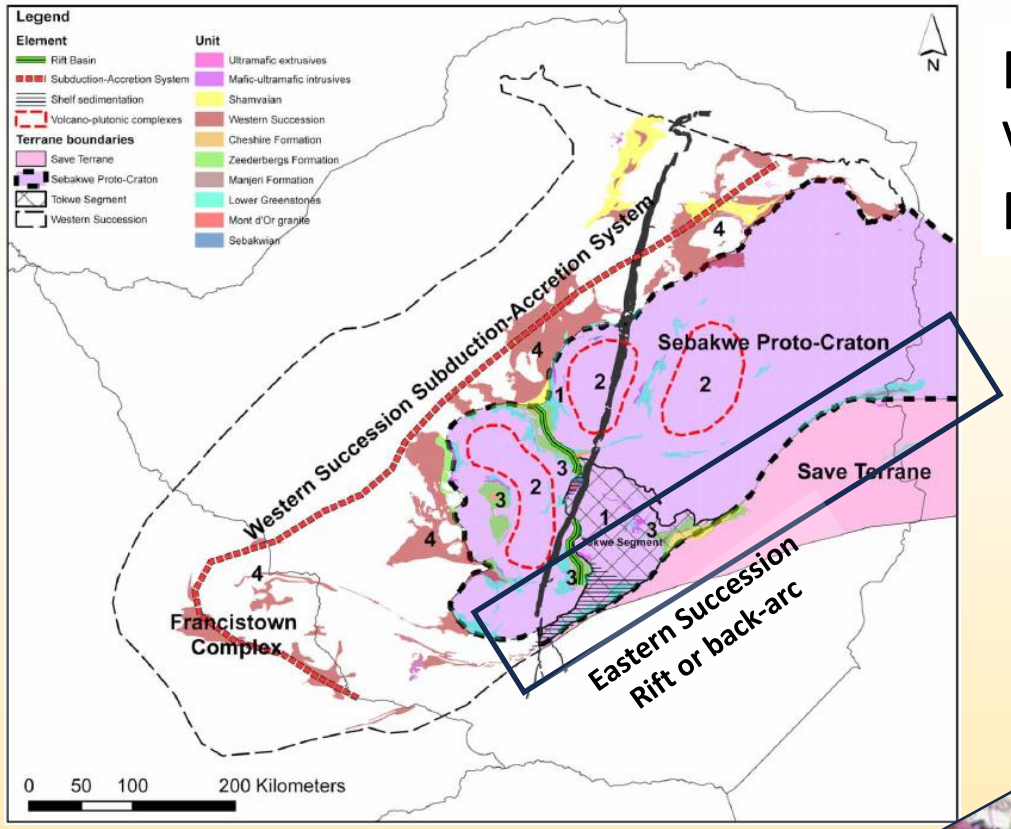
- Low strain
- No regional-scale structures

Chagondah (2021):

- Gold pre-dates Upper Bulawayan?

Hofmann et al (2024): D2 & D3 folding - cleavage syn-greenschist meta; D3 = NMZ thrusting. [Gold event?]

Eastern Succession: low gold endowment - why?



Rift environment - source rocks?
Very different tectono-thermal evolution?
Mutare v Masvingo & Buhwa

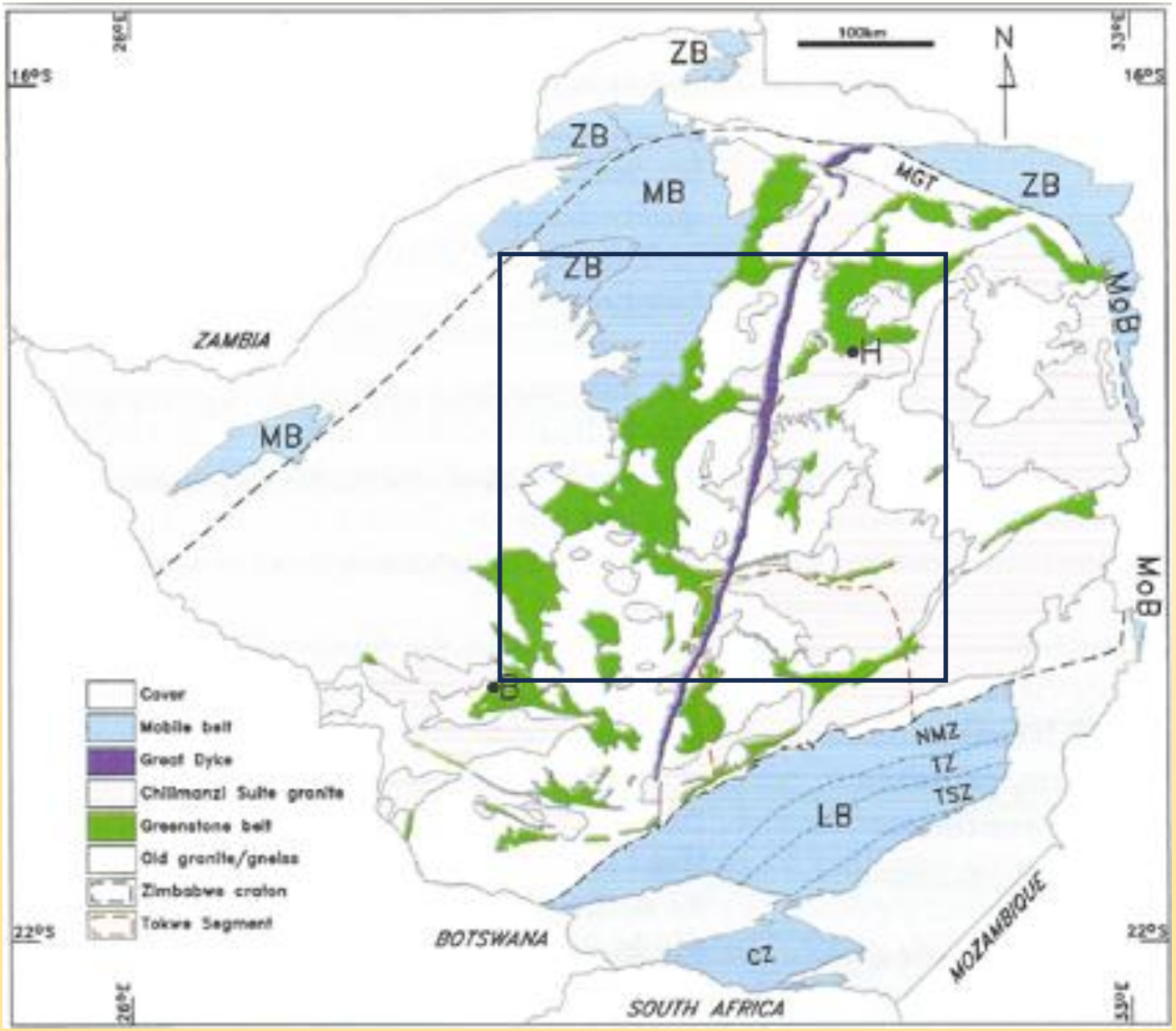
Mutare – Penhalonga GB
Multiple gold deposits – **why?**

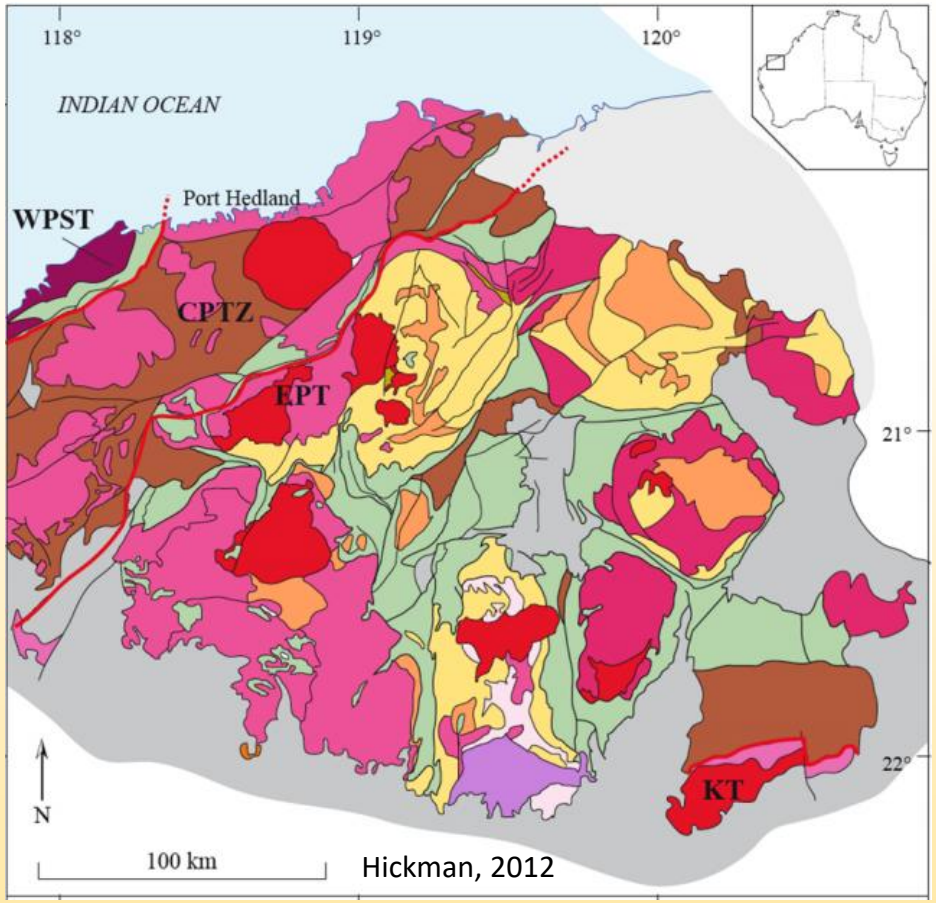
Masvingo GB – low Au

Buhwa GB – low Au

Role of north margin of *ca.*3.4 Ga Save Terrane?
Early/mid-Archean GB development?
Neoarchean / Early Proterozoic reactivation?

Is Pilbara a better analogue for Zimbabwe's GB development?

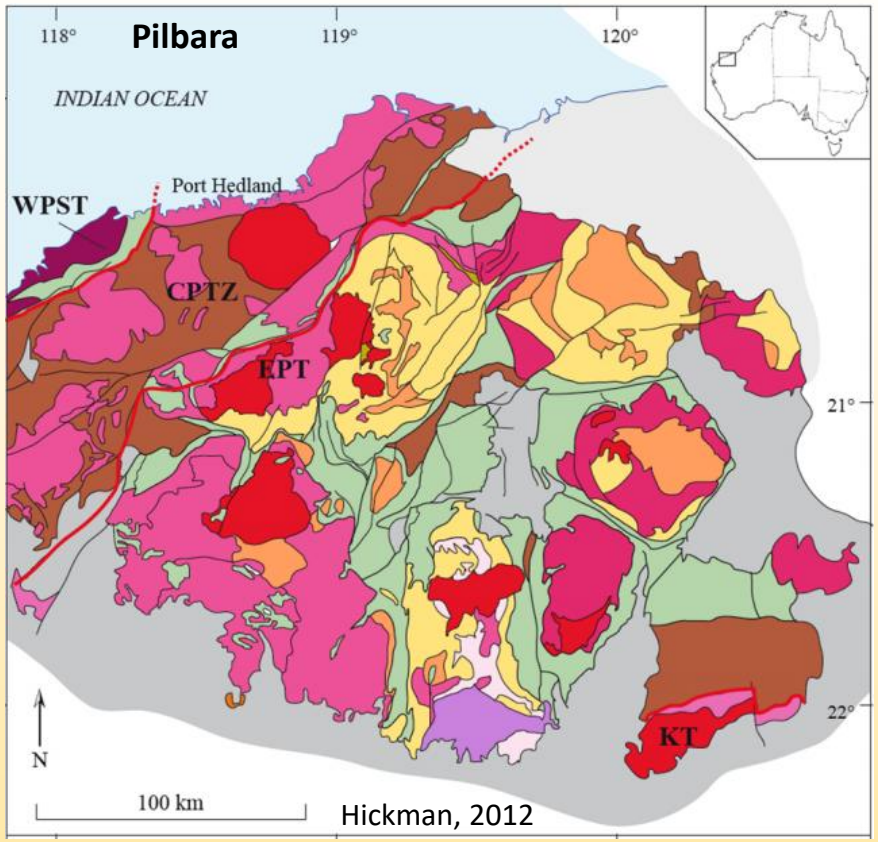




Hickman, 2012

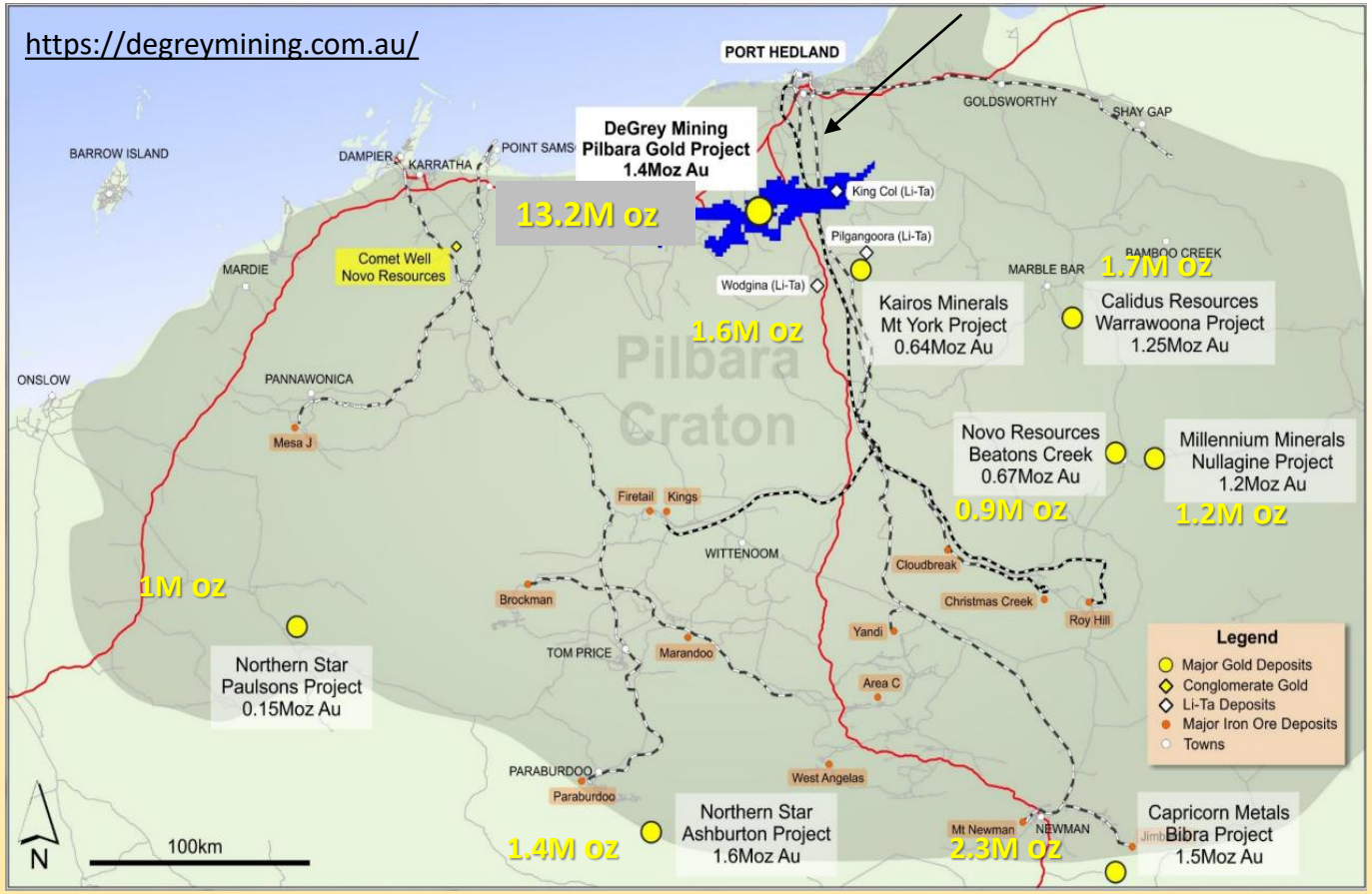
BUT different early-Archean evolution .....?

Granitoid domes flanked by low-grade synclinal volcano-sed greenstone belts



Hickman, 2012

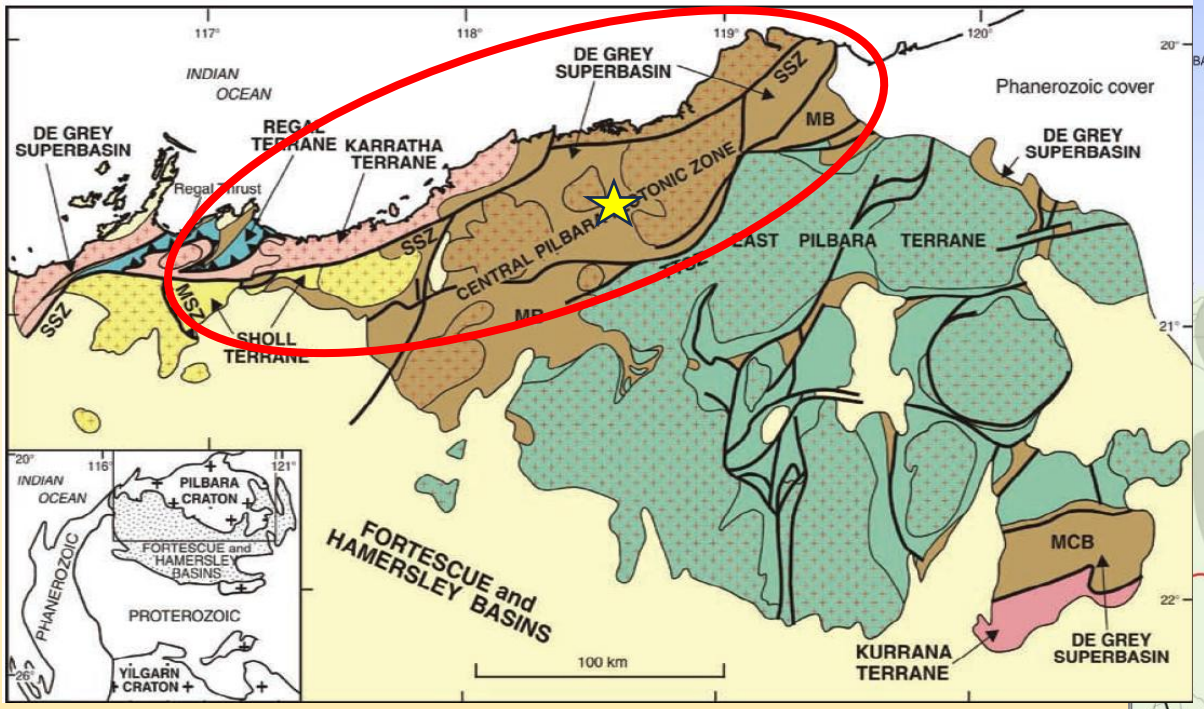
Acquired by Northern Star in 2025



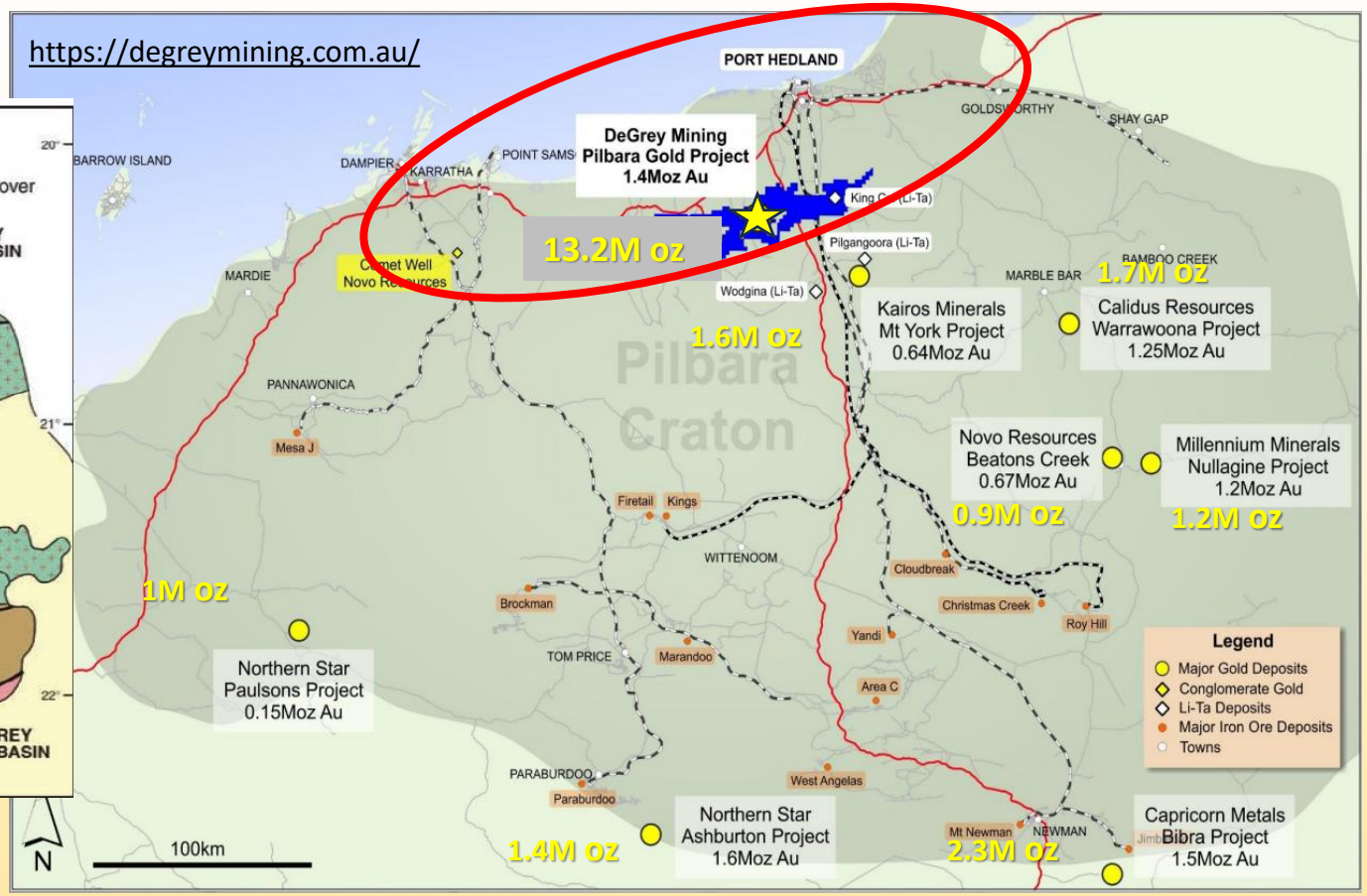
- 3.5-3.2 Ga mantle plume – volcanic plateau and large volumes intrusive granite
- Arguments for early-Archean dome & keel “vertical tectonics”?
- Later diapiric emplacement of granitoids dictated subsequent structural architecture

24M oz: latest available resource data 2025

Granitoid domes flanked by low-grade synclinal volcano-sed greenstone belts

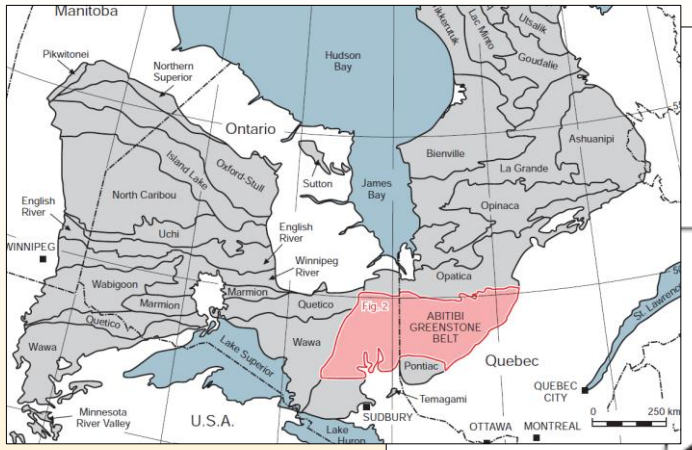


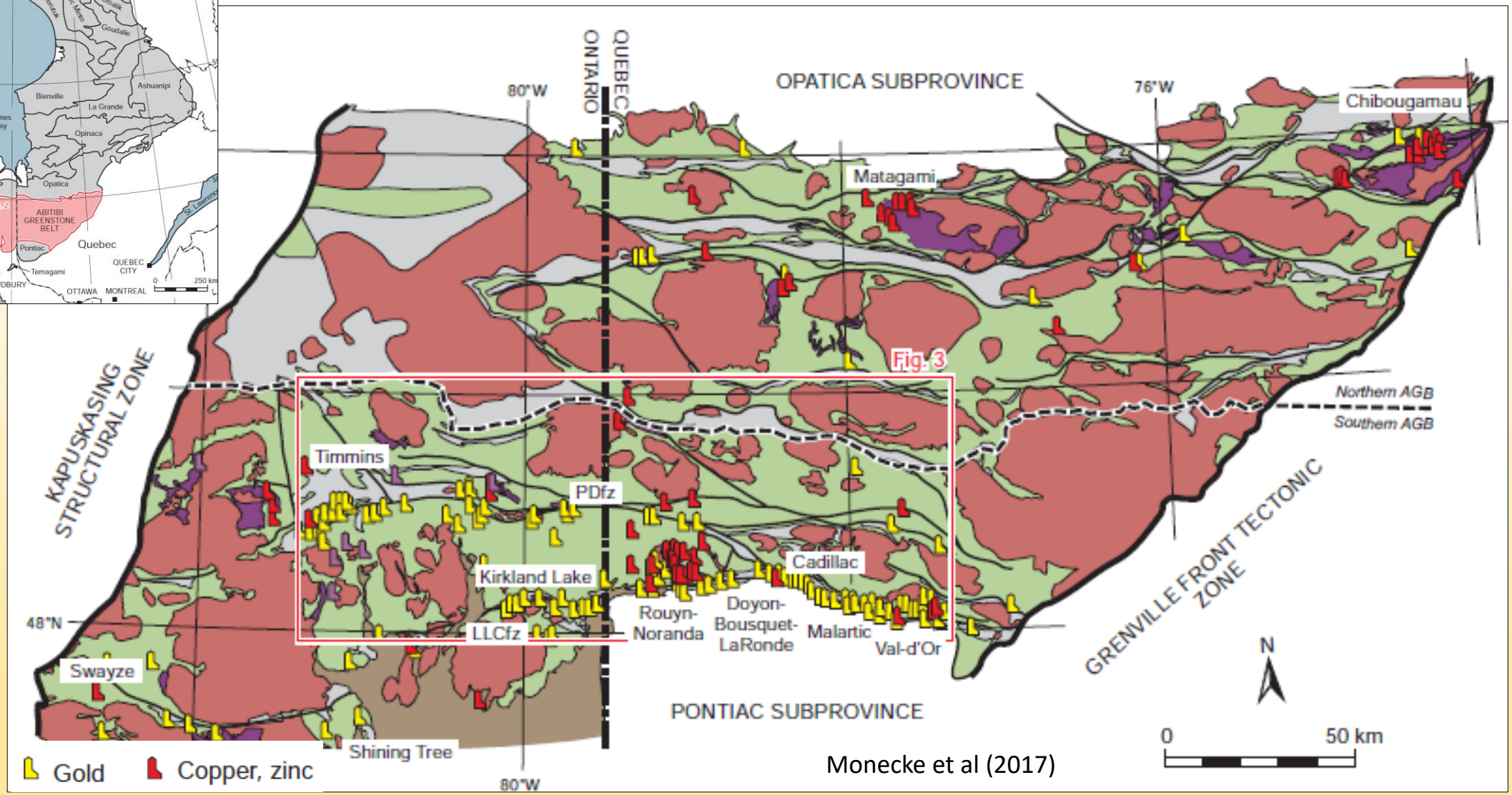
Hickman & Van Kranendonk, 2012



- **Importance of post-3.16 Ga NW-SE plate convergence in NW Pilbara**
- **But million-ounce deposits have been identified elsewhere – more to discover?**
- **Not as prospective as Yilgarn (?) but both superterranes host million-ounce deposits**

Superterranes, terranes, & “second order” structural zones: fact, fiction, relevance?
Abitibi greenstone belt – a “classic” example (?)





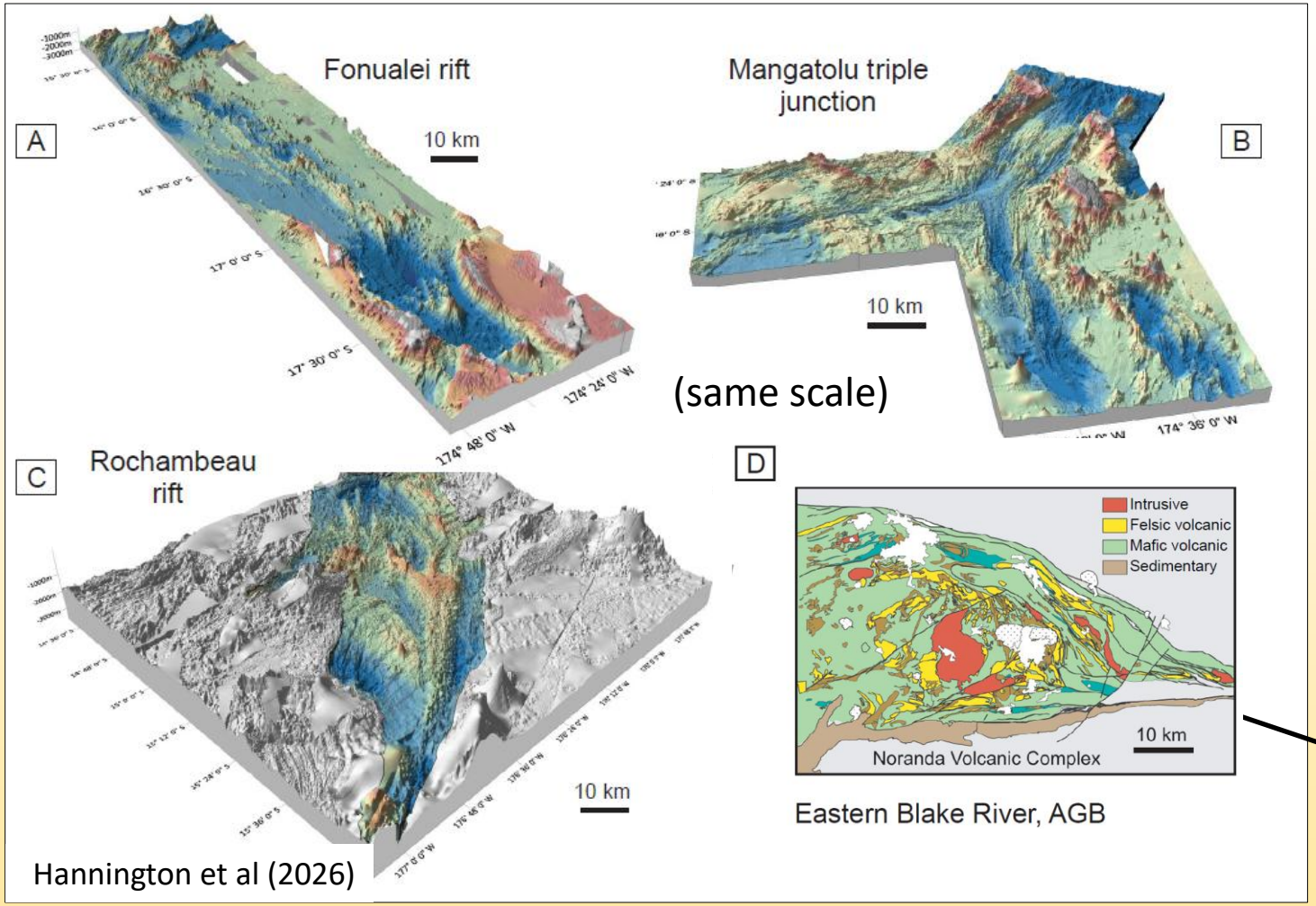
Monecke et al (2017)

Major gold camps associated with 200-km shear zones – “breaks”

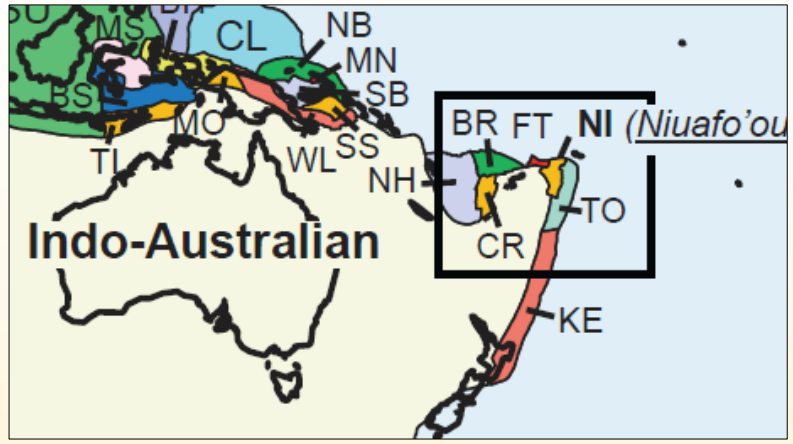
Also multiple VMS

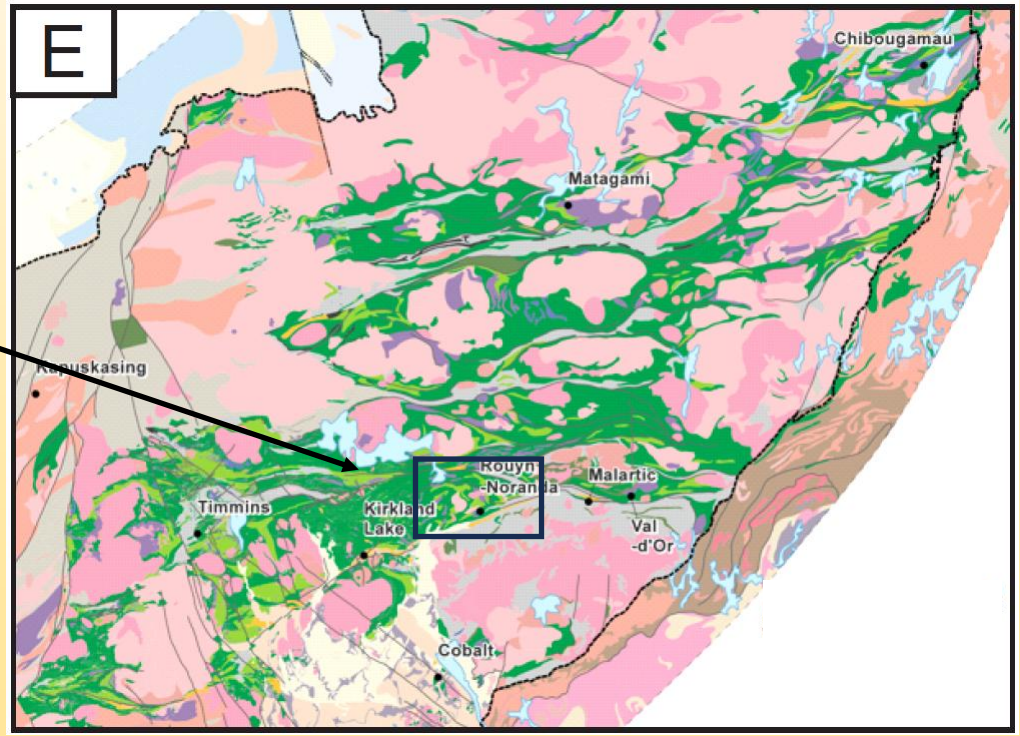
Greenstone belt construction?

Back-arc basins & volcanic complexes - NE Lau Basin



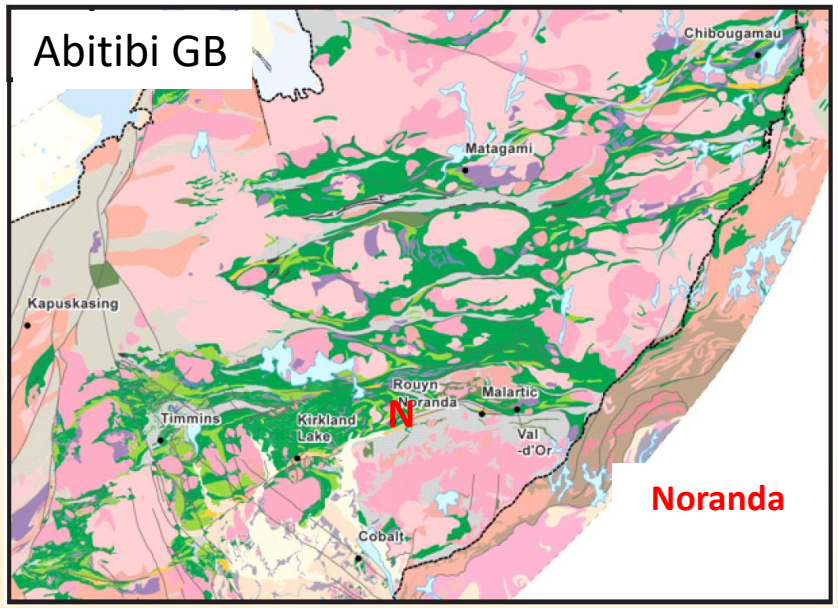
Hannington et al (2026)

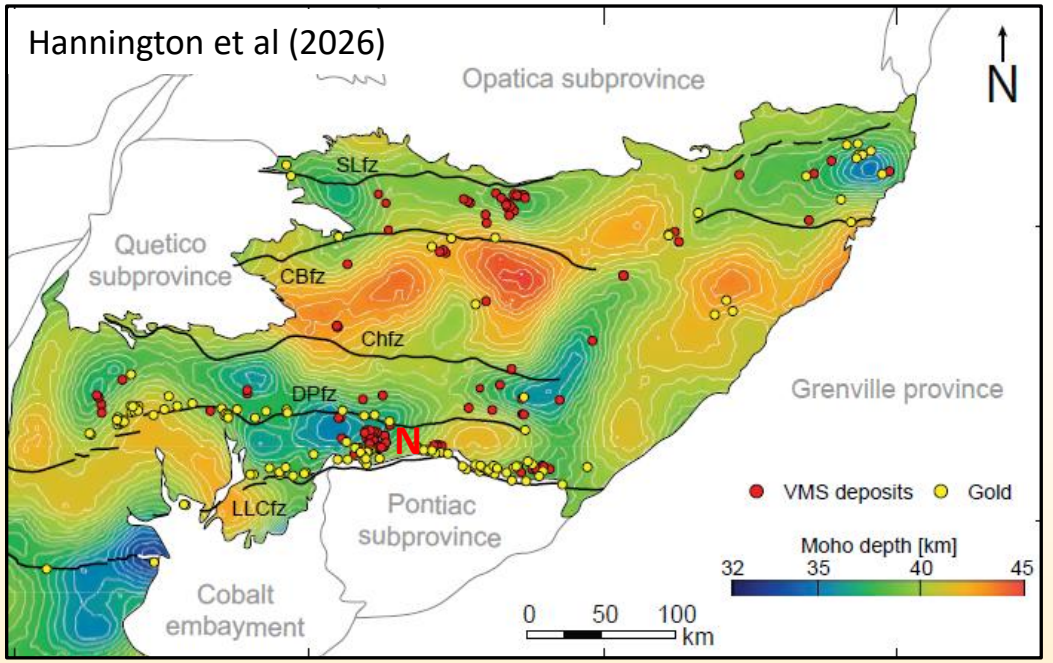




Greenstone belts no larger than modern back-arc basins
["Zimbabwean greenstone belts perhaps developed in... discrete, structurally determined, evolving basins" - Campbell et al, 1990]

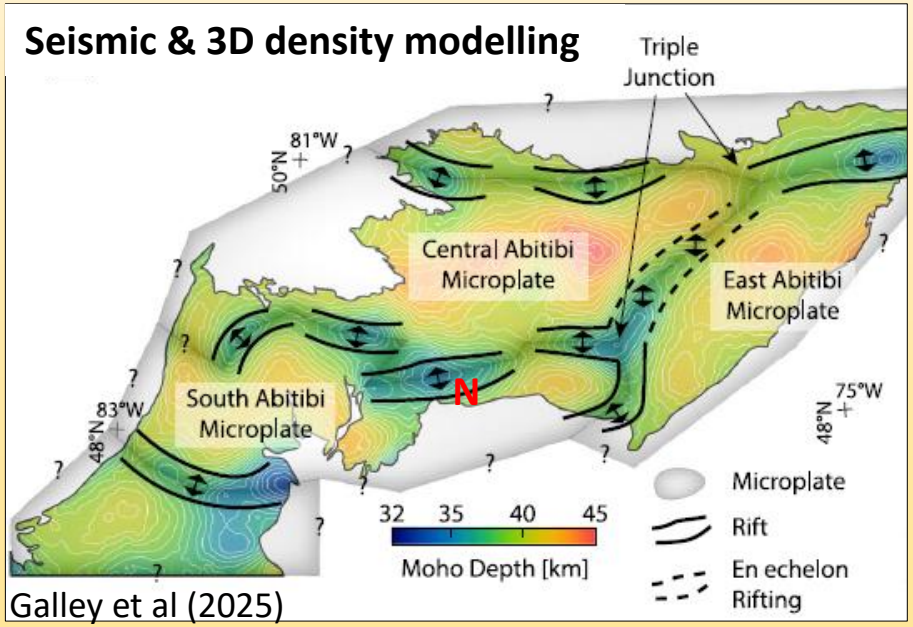
Abitibi microplates?







Seismic & 3D density modelling



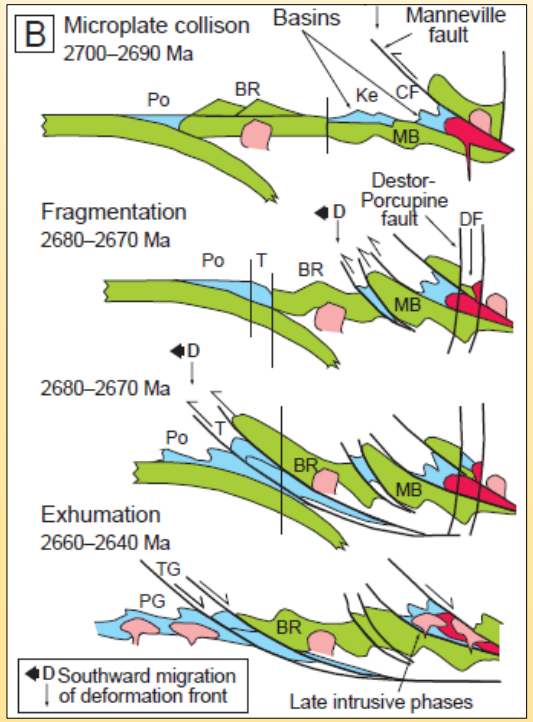
Galley et al (2025)

- Archean mantle hot - 2700 Ma peak magmatism
- Slow spreading rates – but across multi plate boundaries
- Locii for VMS (but is Superior Prov unique?)

- Driven by "distant subduction zone"
- But is microplate construction relevant to other cratons?

Microplate collision 2.7-2.6 Ga

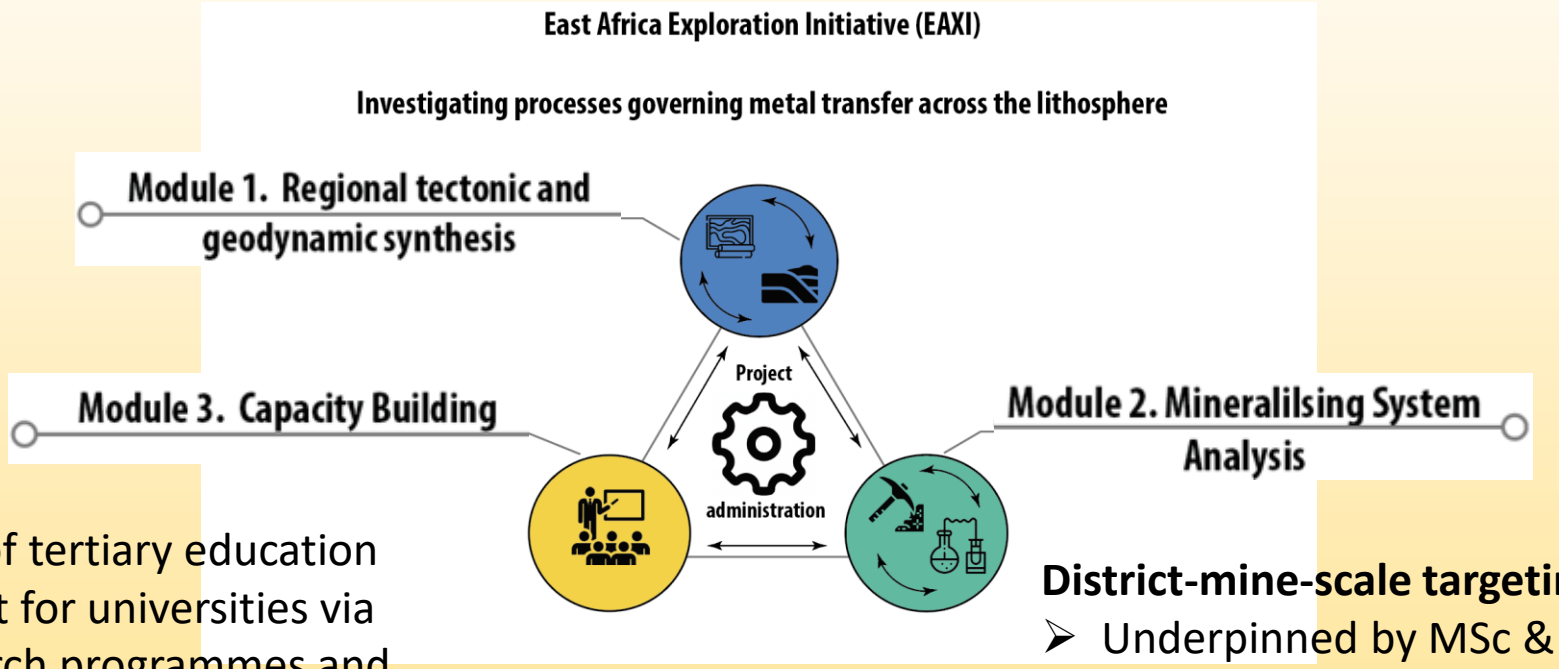
S ← N



EAXI: BUILDING ON HUGELY SUCCESSFUL OUTCOMES IN WEST AFRICA

Big picture:

- New regional exploration initiatives
- Supporting in-country operators
- Attracting interest of major companies



Human resources:

- Enhanced levels of tertiary education
- Enhanced support for universities via funding for research programmes and staff support
- International cooperation thro' shared research and training programmes

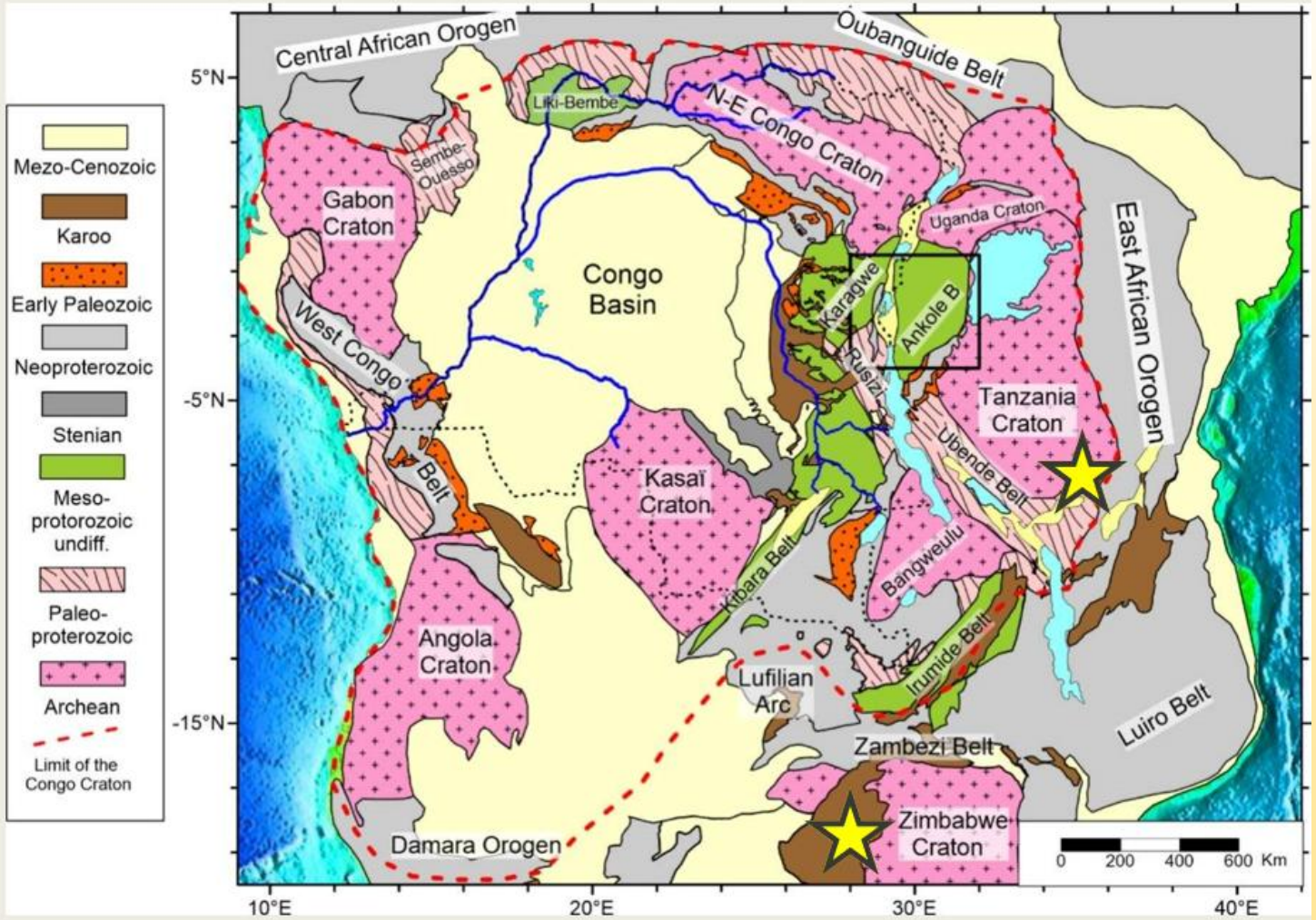
District-mine-scale targeting:

- Underpinned by MSc & PhD studies
- Key structural & lithological controls identified
- Enhanced confidence in district-scale exploration and resource modelling

EAXI: EXPANDING KNOWLEDGE PLATFORMED ON ZIMBABWE'S HUMAN AND NATURAL RESOURCES – AND A WORLD-CLASS DATABASE

PROGRAMME FOR EAST AFRICA – EAXI PROJECT

- In the planning stages – proposed kick off date JULY 2026
- To look at Archaean Gold in Zimbabwe and Tanzanian Cratons
- Covers predominantly Zimbabwe and Tanzania, but includes Uganda, Kenya at this stage



EAXI
East African Exploration Initiative

Gayle Hanssen – July, 2026

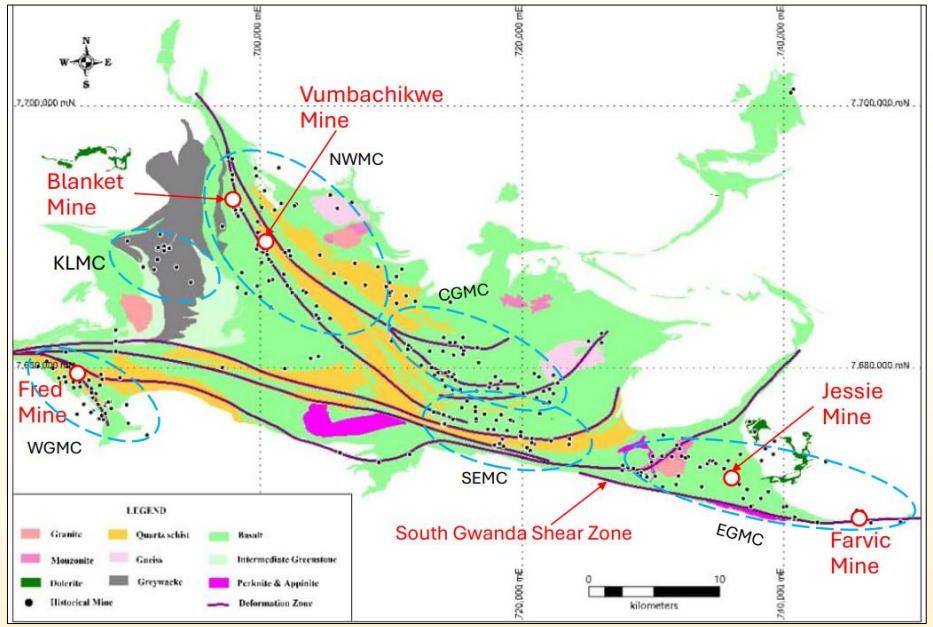
Zimbabwe has a superb database and a plethora of excellent studies delivered in recent years – but still much to understand

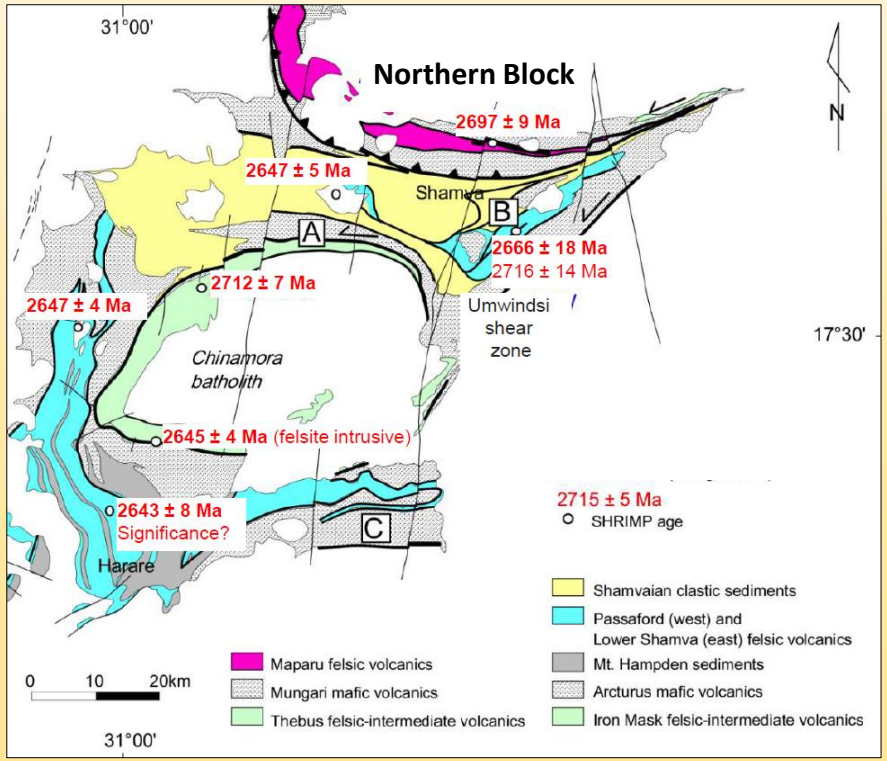


How could ZAXI / EAXI take our knowledge to the next level and assist in-country regional resource development?
Some areas for consideration

ZIMBABWE: SOME FUNDAMENTAL QUESTIONS







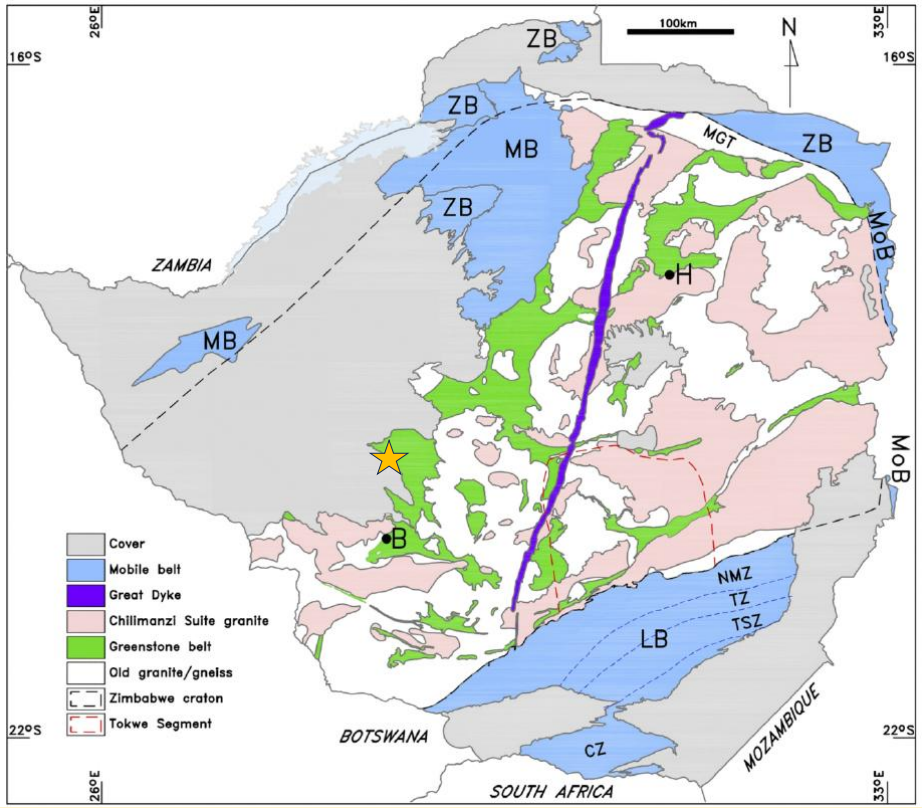
Coordinated integrated studies across individual greenstone belts – build on current exploration activities & expertise

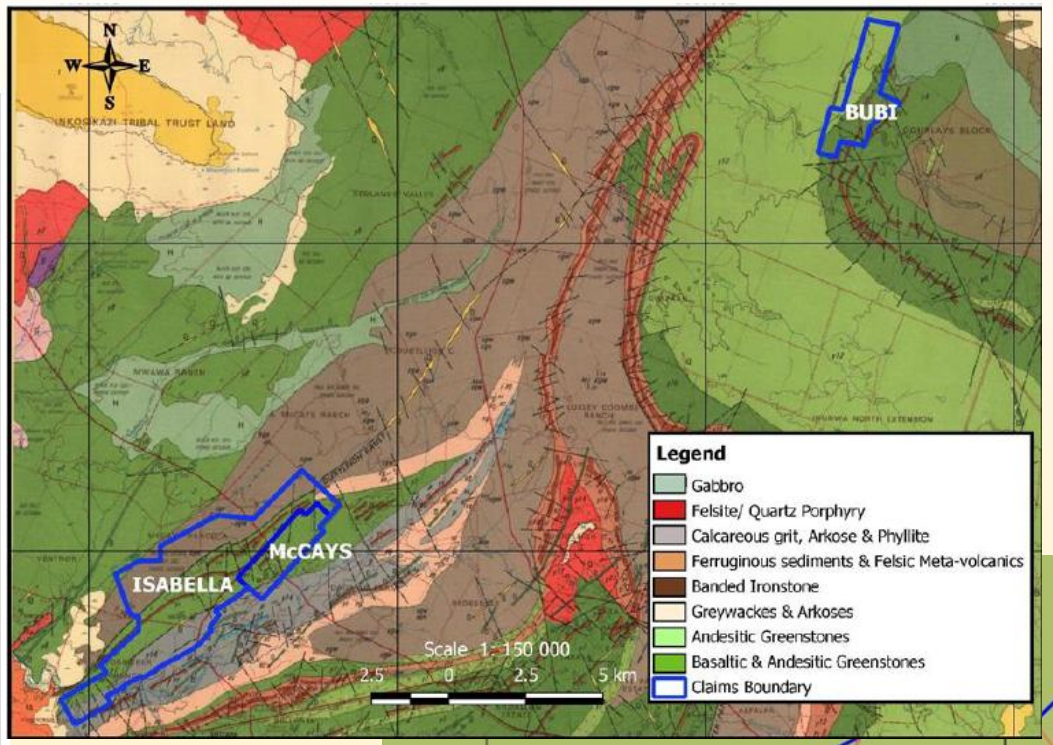
- **Architecture: lithotectonic controls - sedimentation & tectonism**
- **Do fundamental (3.5-3.0 Ga?) extensional faults play key role in subsequent development of some GB's?**
- **Or 2.8-2.7Ga rift faults important?**
- **Thick clastic seds – clues to late-Archean tectonics ...**
- **.... or primarily strain locus on district scale?**

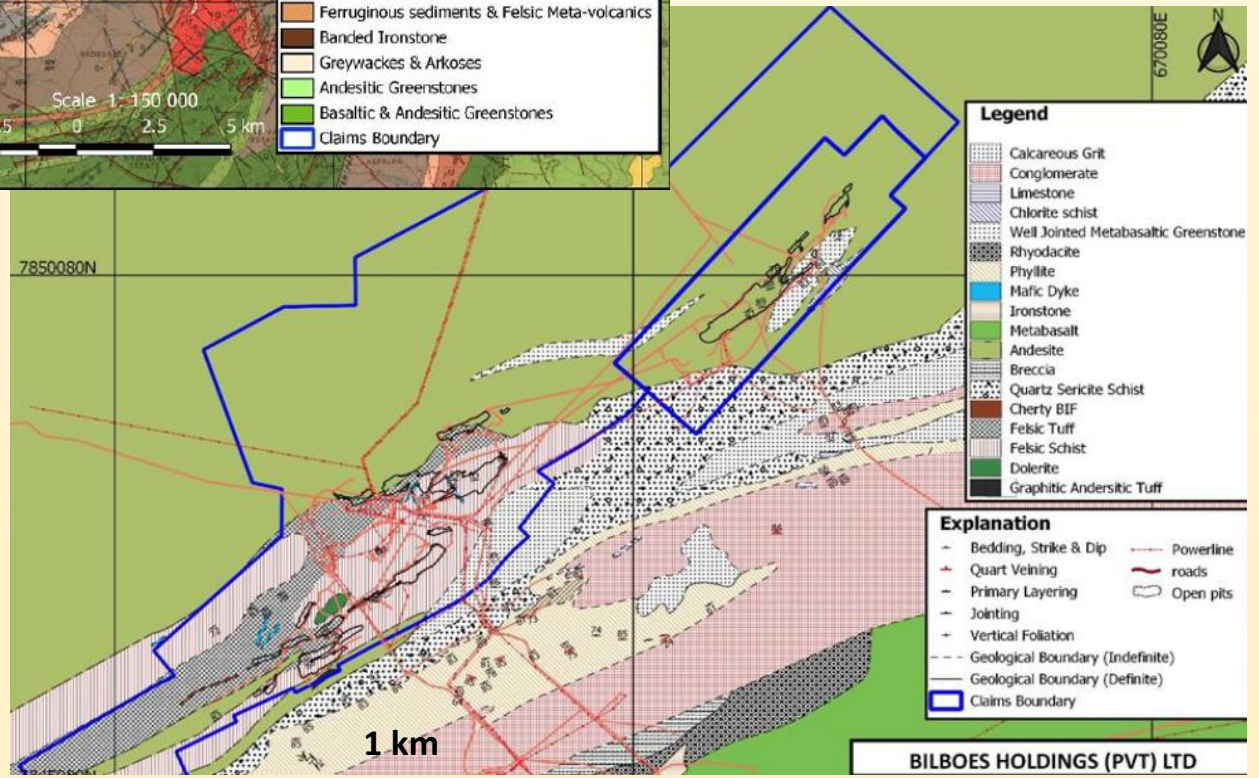
- **Terrane controls within endowed GB's vs low-gold terranes – strain focus & timing**
- **Do major gold districts really relate to thickest, lithologically most complex, internal GB architecture?**
- **If so, how did prior crustal evolution contribute?**

Companies already unlocking prospectivity of greenstone belts and gold “camps”

All about terrane analysis







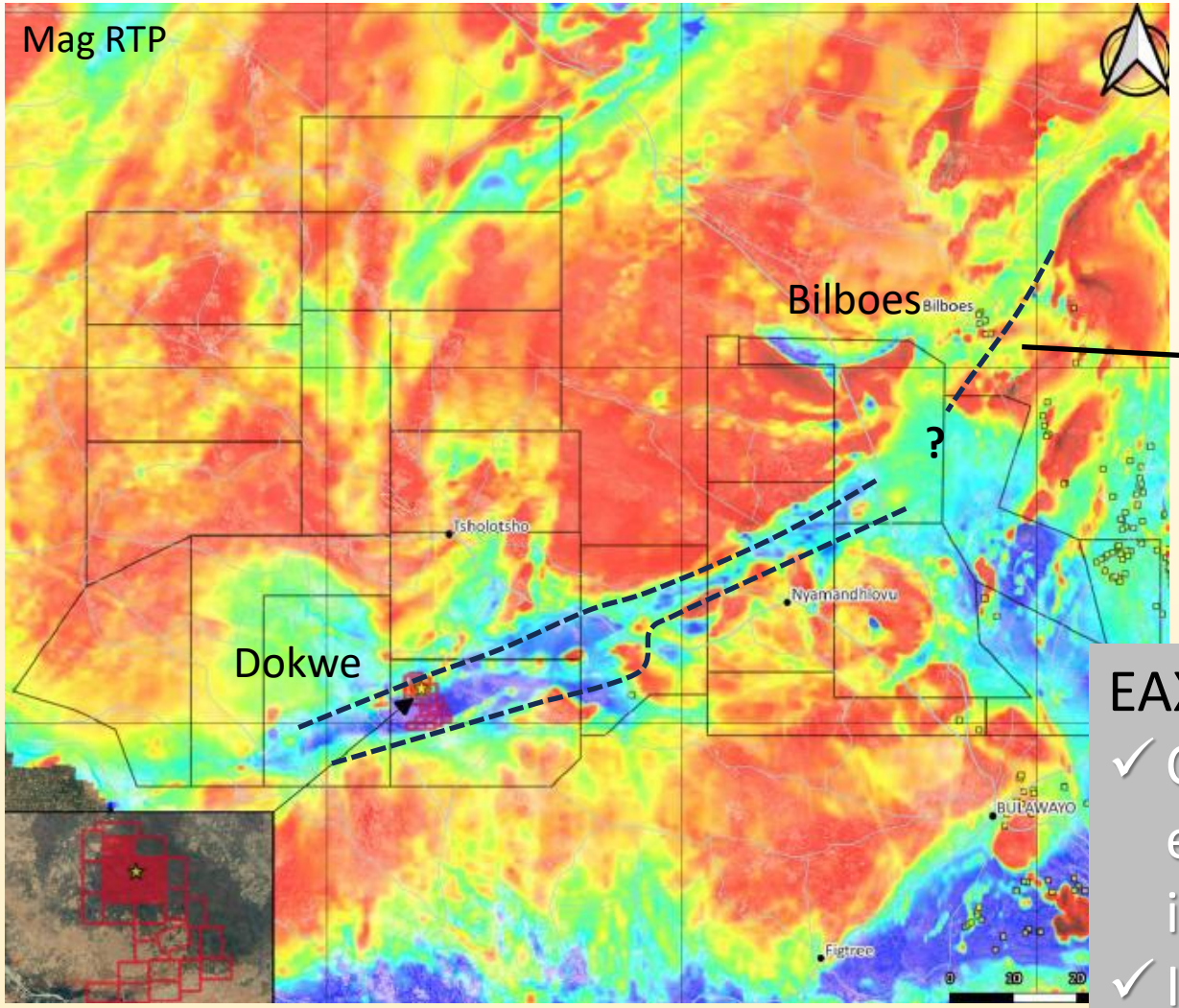
Sheared multi-lithology sequence - felsic/intermediate volcanics & volcaniclastics
First production 1989 as large-tonnage, low-grade OP
2009: sulphide MRE = 534k oz Au

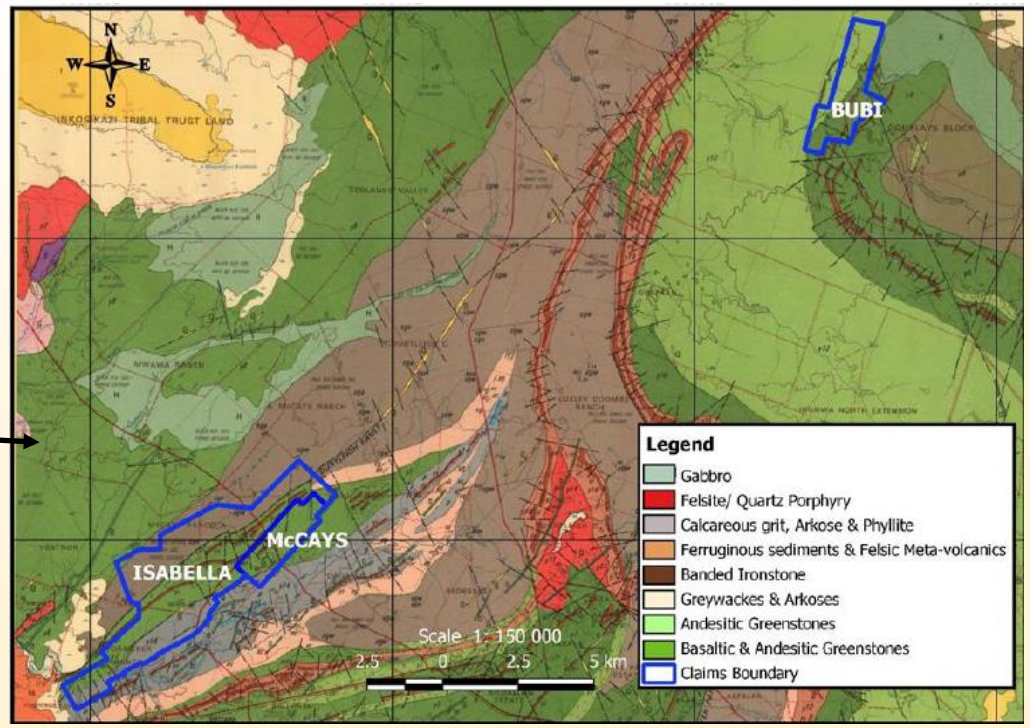
Caledonia Mining

Bilboes
3.3M oz resource
50% reserves

Forecast 140k oz per annum from 2029

Innovative science– Dokwe (Ariana / Collett, 2024)



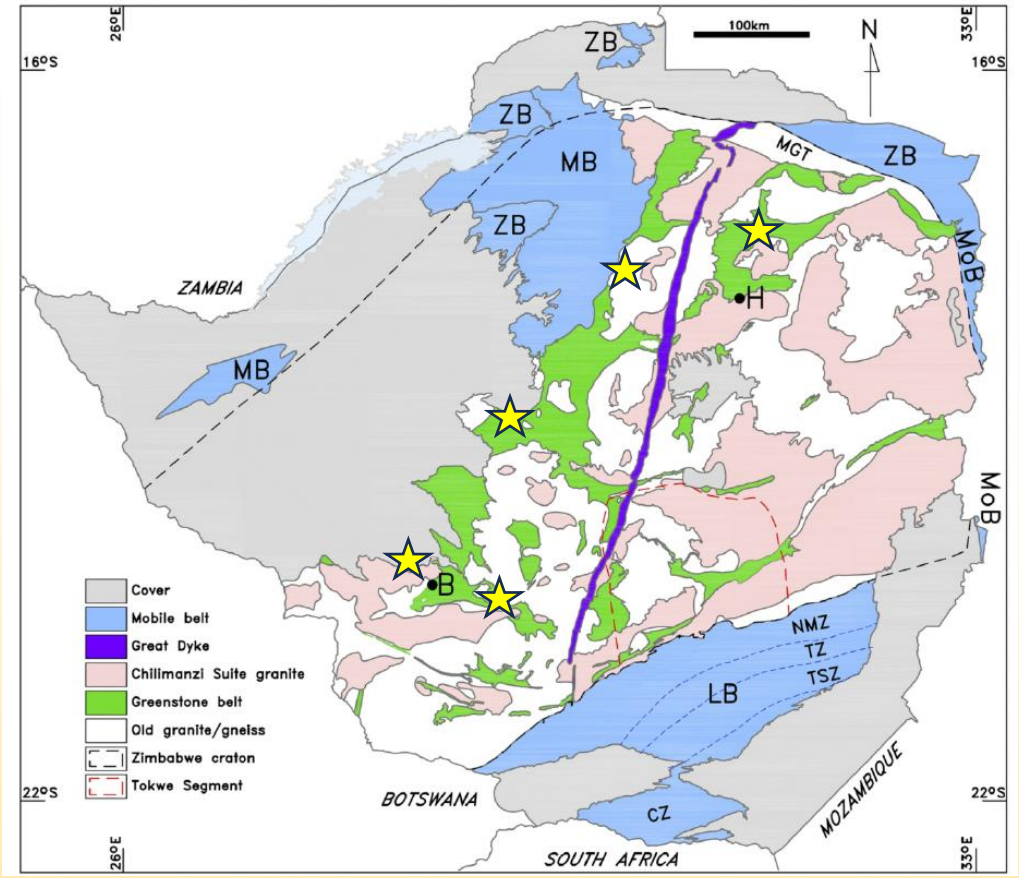


- Concealed Tsholotsho Greenstone Belt
- High-sense geochem anomaly through up to 40 m Karoo + Kalahari
- 1.6M oz MI&I
  (A remarkable discovery by Rockover Resources!)

EAXI: Terrane analysis & prospectivity enhanced by:

- ✓ Collation of historical company magnetic and electromagnetic survey data – confidential but integrated results shared
- ✓ Incorporation of academic syntheses of **magnetic & gravity data**
- ✓ **Magnetotellurics** – natural transmitters + 3D inversion modelling

Zimbabwe: crucible for innovative geologists and entrepreneurial explorers – Nick Graham



Rockover Resources (pvt)
*ca.*2002: Dokwe – high-sense geochem anomalism thro' 40 m cover:
now I.6M oz MI&I resource (Ariana)



Cluff Resources: Zimbabwe
1983: ***Royal Family***: OP/leach Marvel Mine area, Filabusi
1987: ***Freda-Rebecca***: OP of Promoter-Botha group

Reunion Mining: Zimbabwe
1995: ***Maligreen*** geochem discovery: Cluff purchased & Pan African JV - 20k oz pa 2000-2002; current resource c.900k oz (Caledonia Mining)
1995: ***Sanyati Copper*** JV with ZMDC – successful hydromet & SX/EW
Extensive diamond exploration programmes

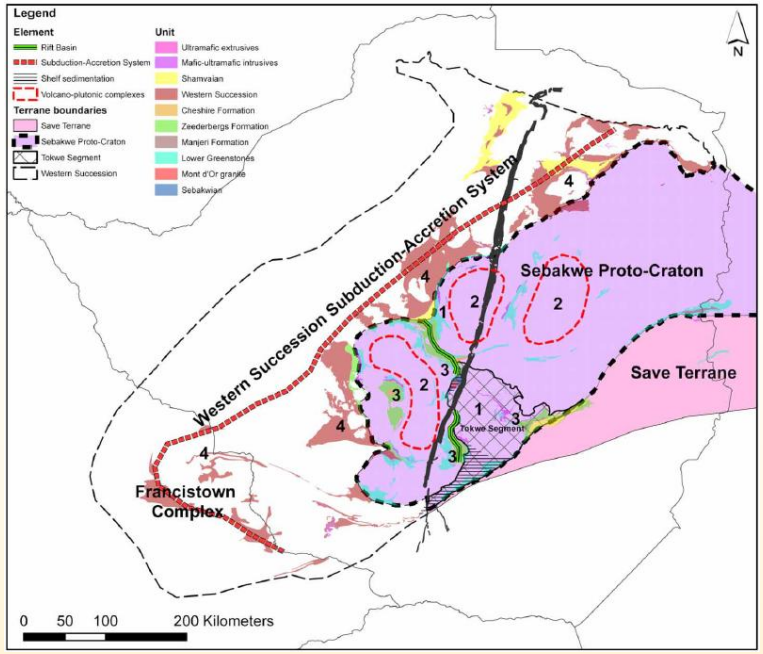
Reunion Mining: Namibia & Zambia
Namibia - 1996: 60% ***Skorpion Zinc*** JV with AngloAm; proven SX/EW;
- AA re-acquired 60% for £37M
Zambia – ***Dunrobin***: re-opened Reunion 1997 OP – >500 kg Au p.a.

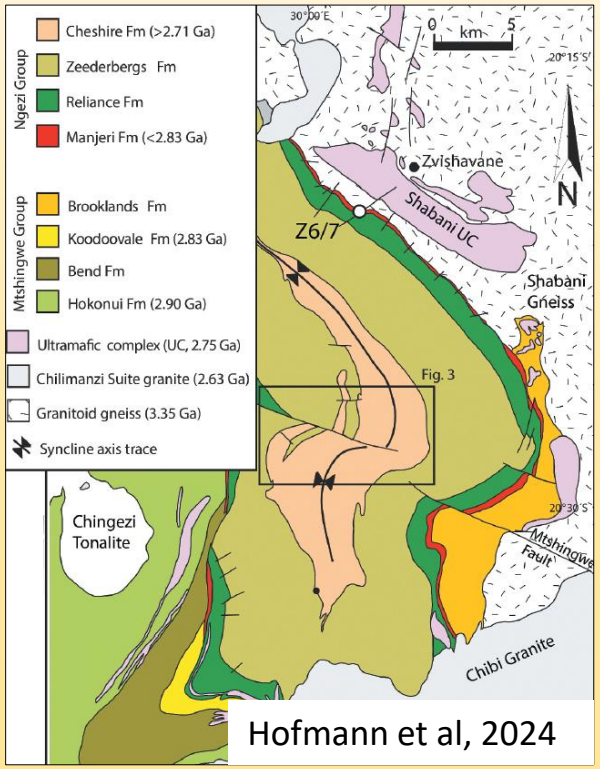
Rockover Resources (pvt)
Mozambique: *ca.*2005-2020 - multiple Au, Ni-Cu & VMS occurrences in Cabo Delgado
Gabon: *ca.*2003-2016 substantial O&G interests

ZIMBABWE: SOME FUNDAMENTAL QUESTIONS



Consider greenstone belt development across craton: western vs central vs eastern crustal evolution





Hofmann et al, 2024

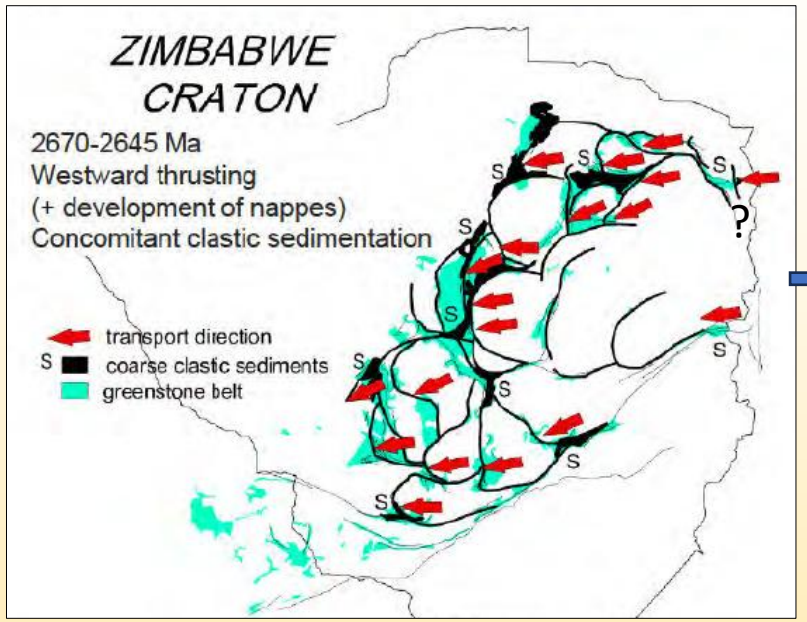
- **Role of Save Terrane in evolution of eastern-margin GB's? Mutare, Masvingo, Buhwa.**
- **Gold-endowed Umtare GB vs negligible gold of Masvingo**
- **Crustal growth and tectonism at margins of proto-cratons: lithologies, tectonism & fluids?**

Mberengwa GB key?

- ✓ **Focus of detailed studies since Martin (1978) Bull.83**
- **Reactivation of early extensional (rift) faulting?**
- **Fluid migration vs peak greenschist metamorphism?**
- **Tectonic architecture?**

ZIMBABWE-FOCUSED STUDIES

Wider considerations of craton evolution



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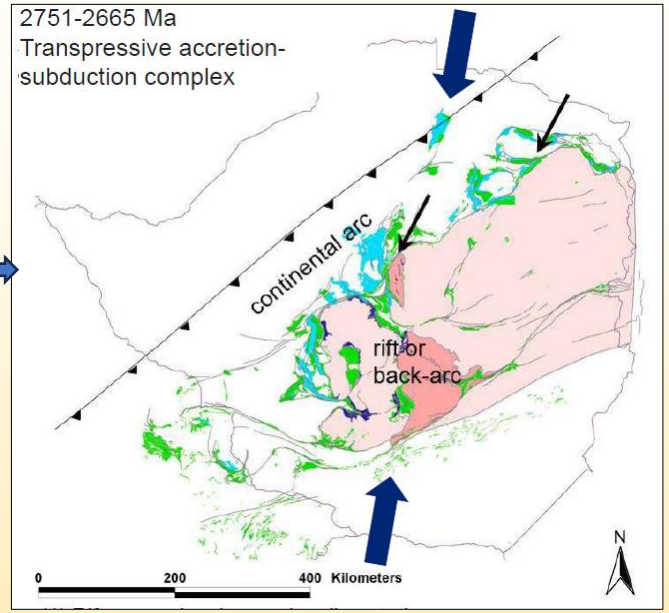
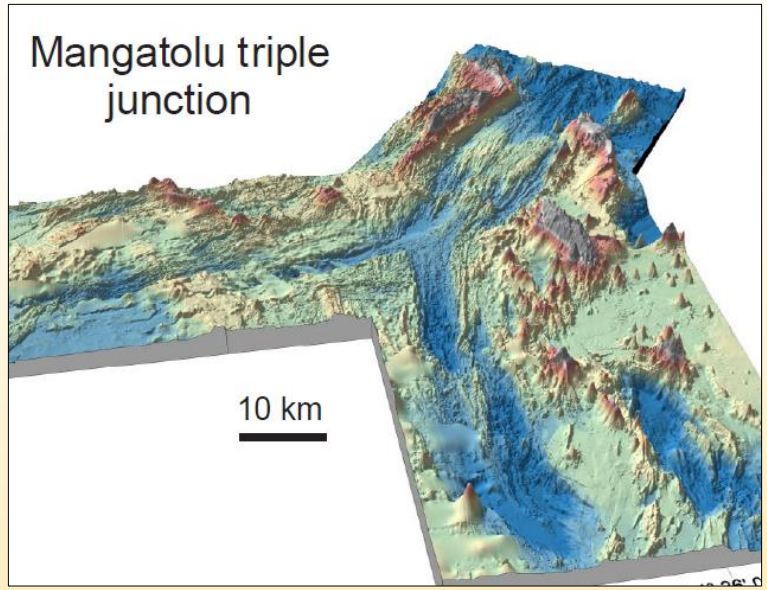
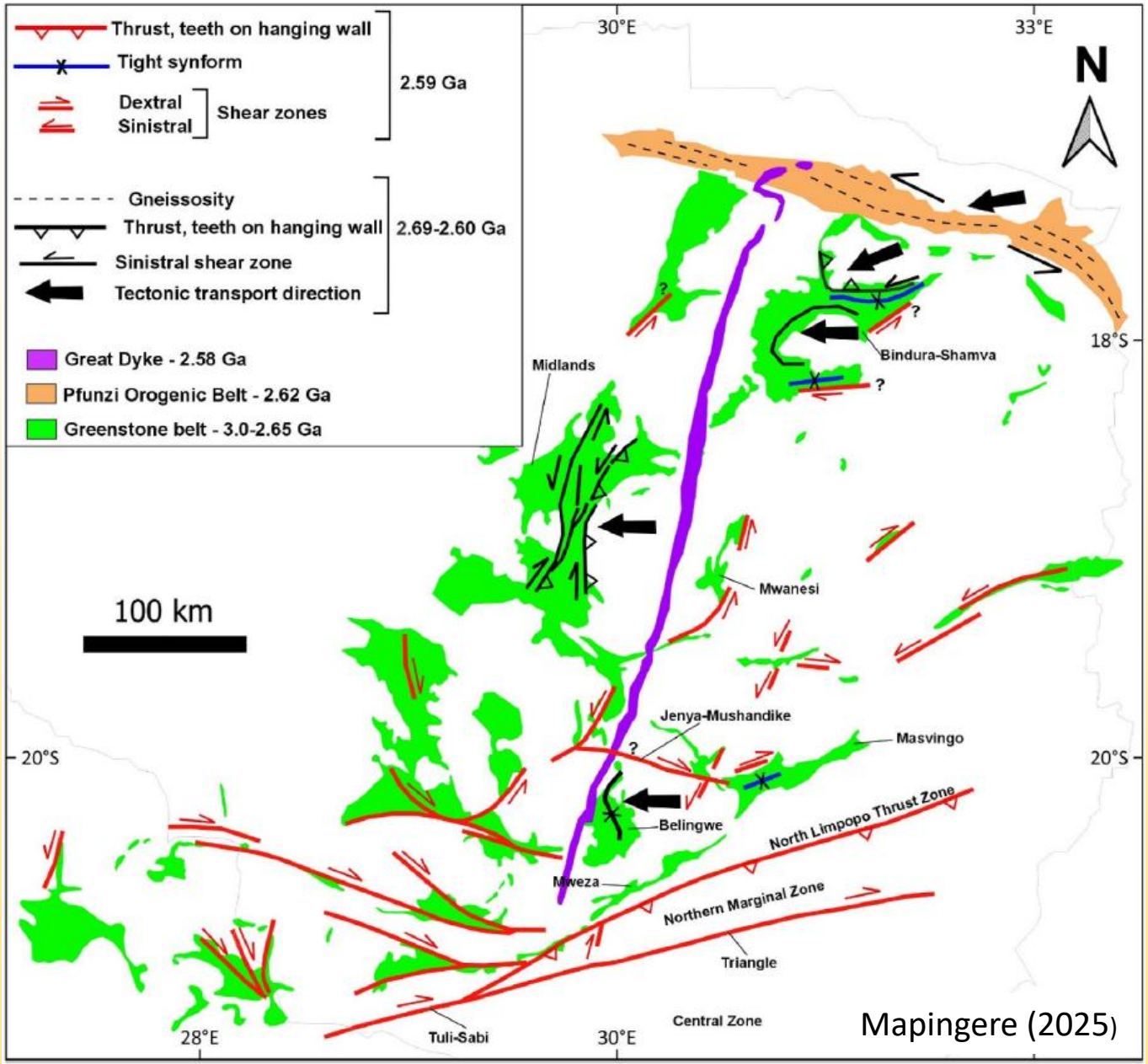




- Thrust regime vs transpressional – progressive or a critical transition for fluids & gold metallogenesis?
- Triggered by far-field shift in σ_1 or "locally" terrane-controlled?
- What inter-craton tectonics were generating that late-Archean σ_1?

- Or could micro-plates be a consideration?

Wider considerations: Neoarchean-Palaeoproterozoic transition

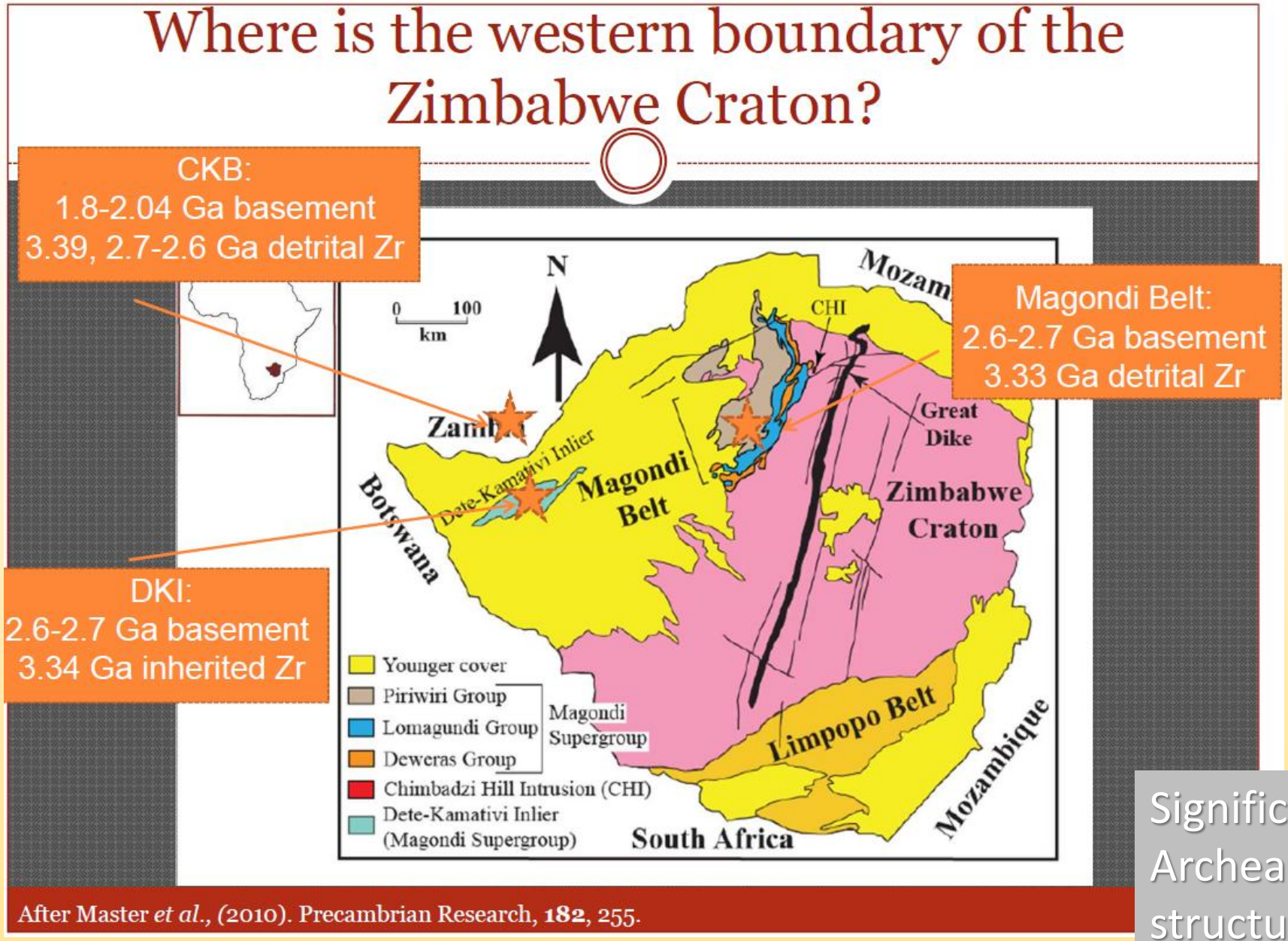


Mapingere (2025)

- Role of tectonism *ca.*2.5 Ga & LMB: post-Archean fluid mobilization?
- Reactivation or overprinting of Archean gold occurrences?
- 2.5 - 2.0 Ga evolution?

The western boundary of the Zimbabwe Craton? Metallogenic implications





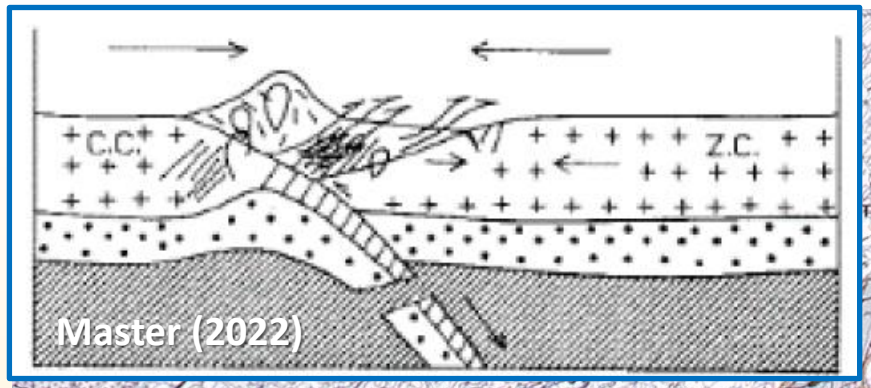
Extensive formation of Andean-type arcs along western margin of craton?

Magondi Supergroup & Archean basement intruded by magmatic arc rocks *c.*2.0 Ga – followed by collision with unknown continent to west

[Master et al (2015); Glynn et al (2015)]

Significant implications for post-Archean terrane accretion and structural controls of mineralisation

Diatremes & mineralization in Magondi Belt



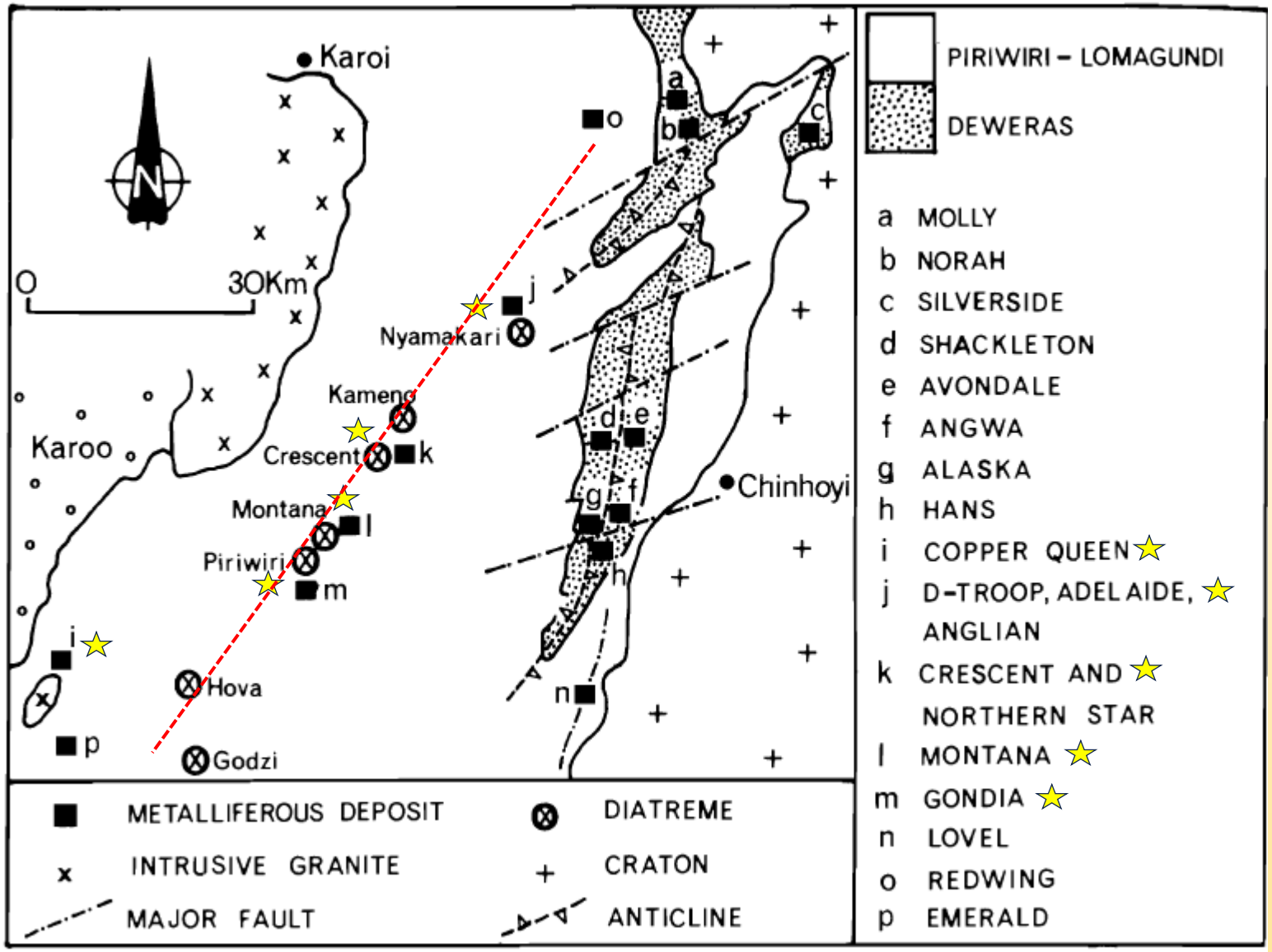
Intriguing pointers

Volcanic centres

- Limited extent 00m x 00m
- Agglomerate
- Crystal & banded tuffs
- "Saccharoidal felsite" **– H-S?**
- Abundant "pale grey felsite" **?**
- **Qtz-cbt veins, "ore minerals", tourmaline**
- Fragments of qtz-tourm rocks
- Cherty with qtz veins
- Pyritiferous felsite

Passive margin, thermal subsidence or back-arc setting? (Master et al, 2010)

Mineralization and diatremes in Magondi Belt



Leyshon & Tennick (1988)

D-Troop & Anglian: various qtz veins & stockworks in graphitic & sandy argillites – NNE-trending steep folds; 3m-wide folded glassy blue qtz vein

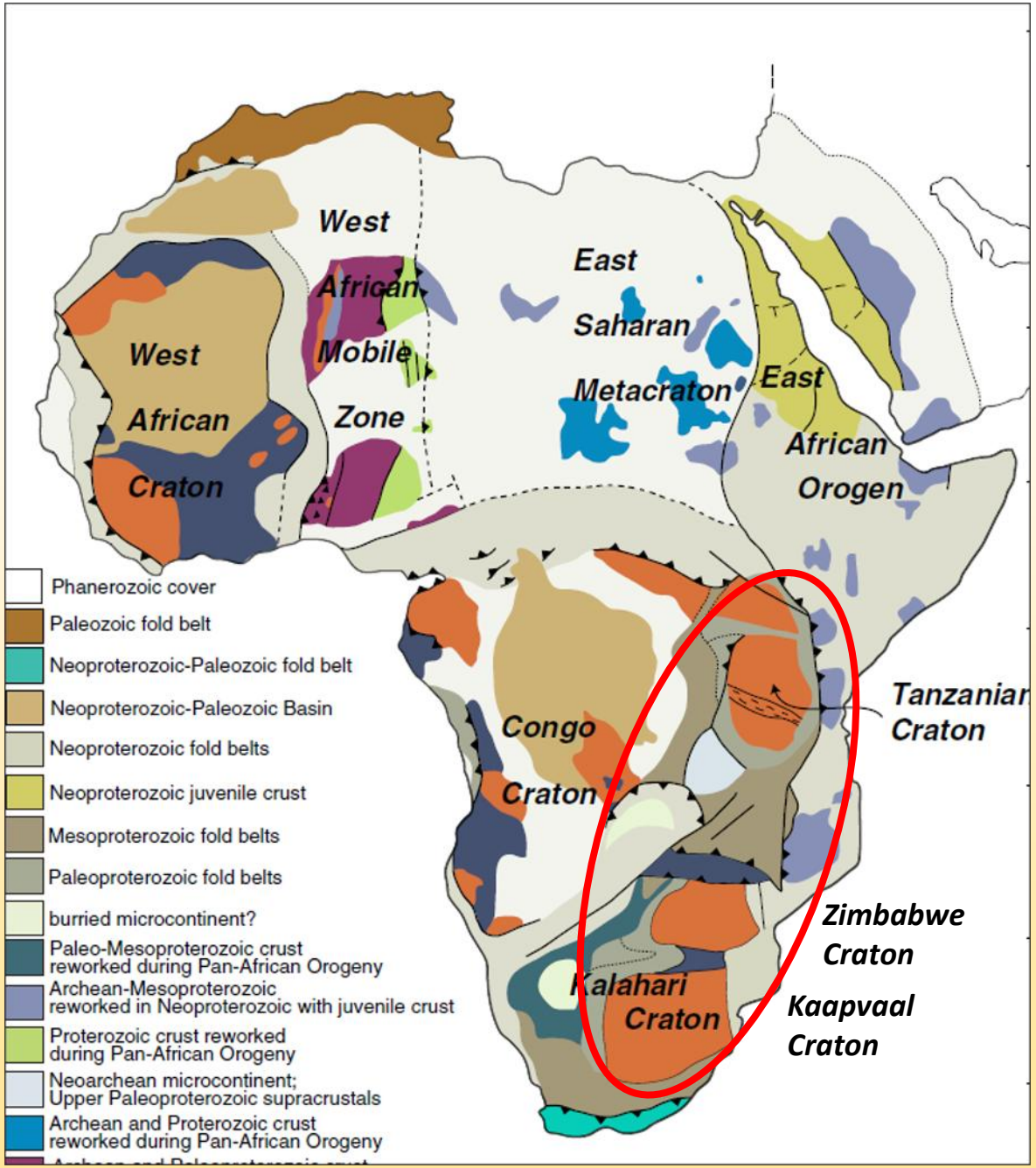
Crescent: qtz-cbt vein in graphitic slates; f/w crush-breccia, prob agglom. Cu + minor Au

Montana: Cu + minor Au

Gondia/Piriwiri: massive qtz-cbt vein; Cu + minor Au

Copper King & Copper Queen "domes": lenses in skarn or syngenetic stratabound?

Kirkpatrick (1976) - Bull. 75

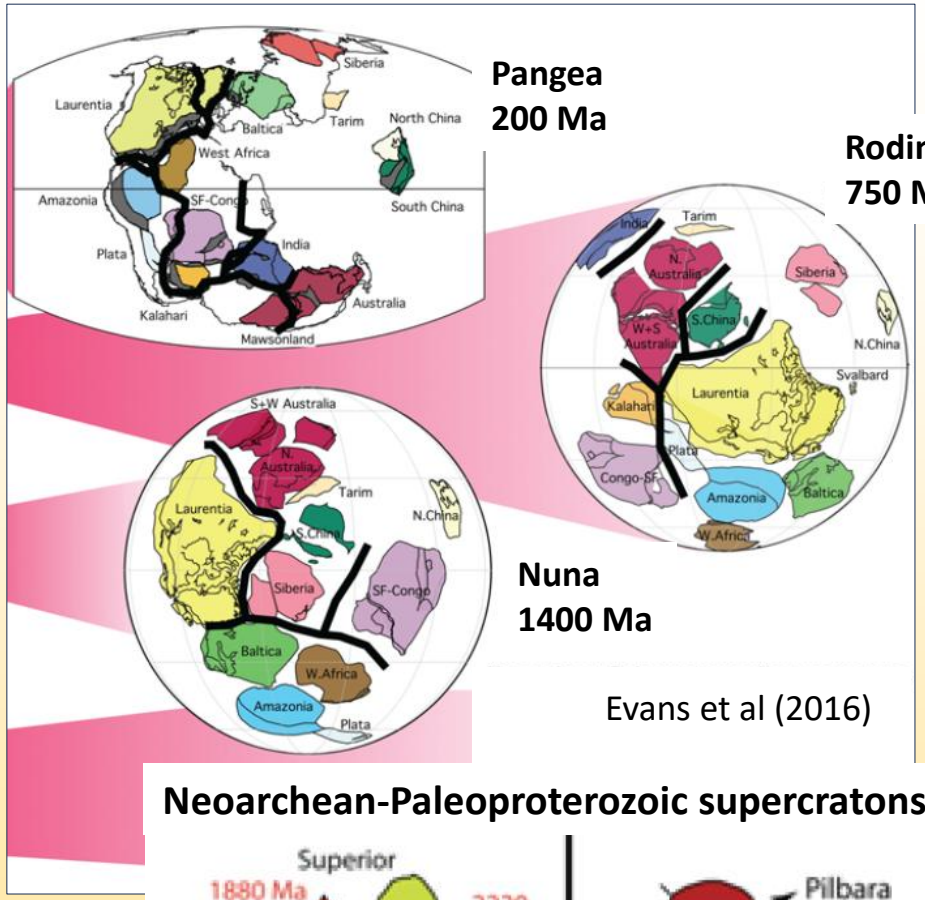




Opportunity to address
BIG PICTURE?

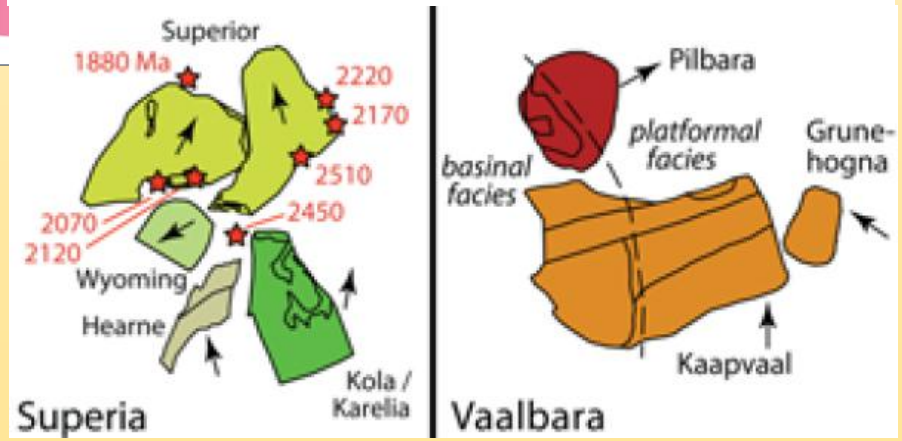
Tanzania vs Zimbabwe vs Kaapvaal cratons

Unravelling Neoarchean supercraton construction – a major challenge!

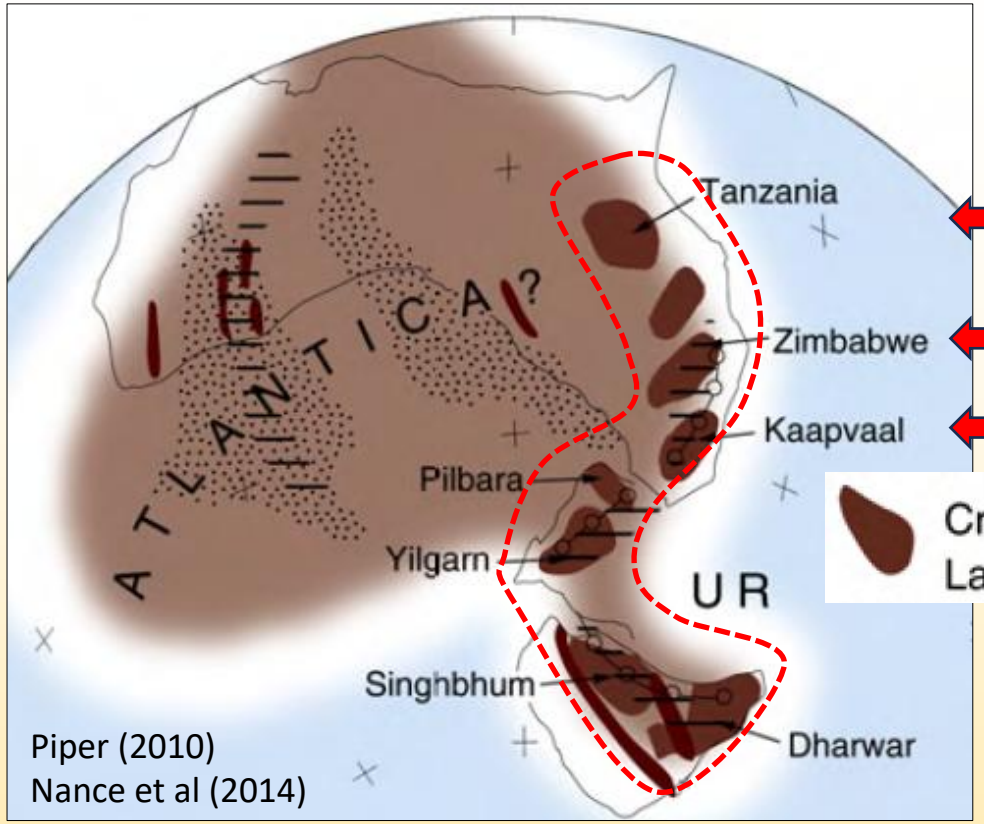


Evans et al (2016)

Neoarchean-Paleoproterozoic supercratons??



ca.2500 Ma



Piper (2010)
Nance et al (2014)

Palaeomag-based construction

c.3.0 Ga "Ur": S & E Africa, West Australia & Dharwar

c.2.0 Ga "Atlantica": W Africa & S America

Do the "Ur" cratons have shared history of proto-crustal evolution and tectonism?

➢ **Include Kaapvaal Craton in EAXI?**

Potential for Zimbabwe–Tanzania knowledge sharing: an Ur link??

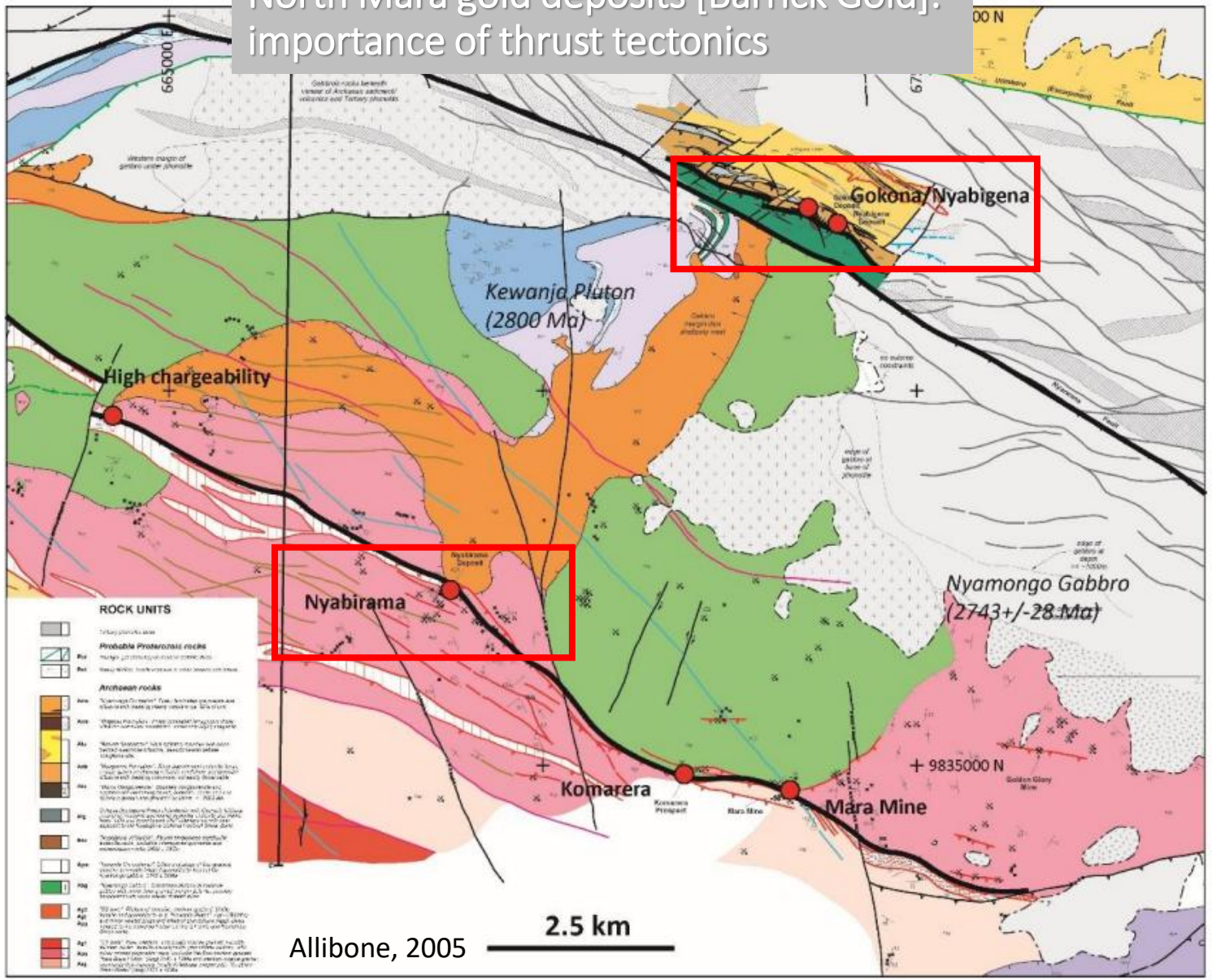


North Mara gold deposits [Barrick Gold]: importance of thrust tectonics

Musoma-Mara GB

- Lower Basement Complex metavolcanics
- Upper metaseds

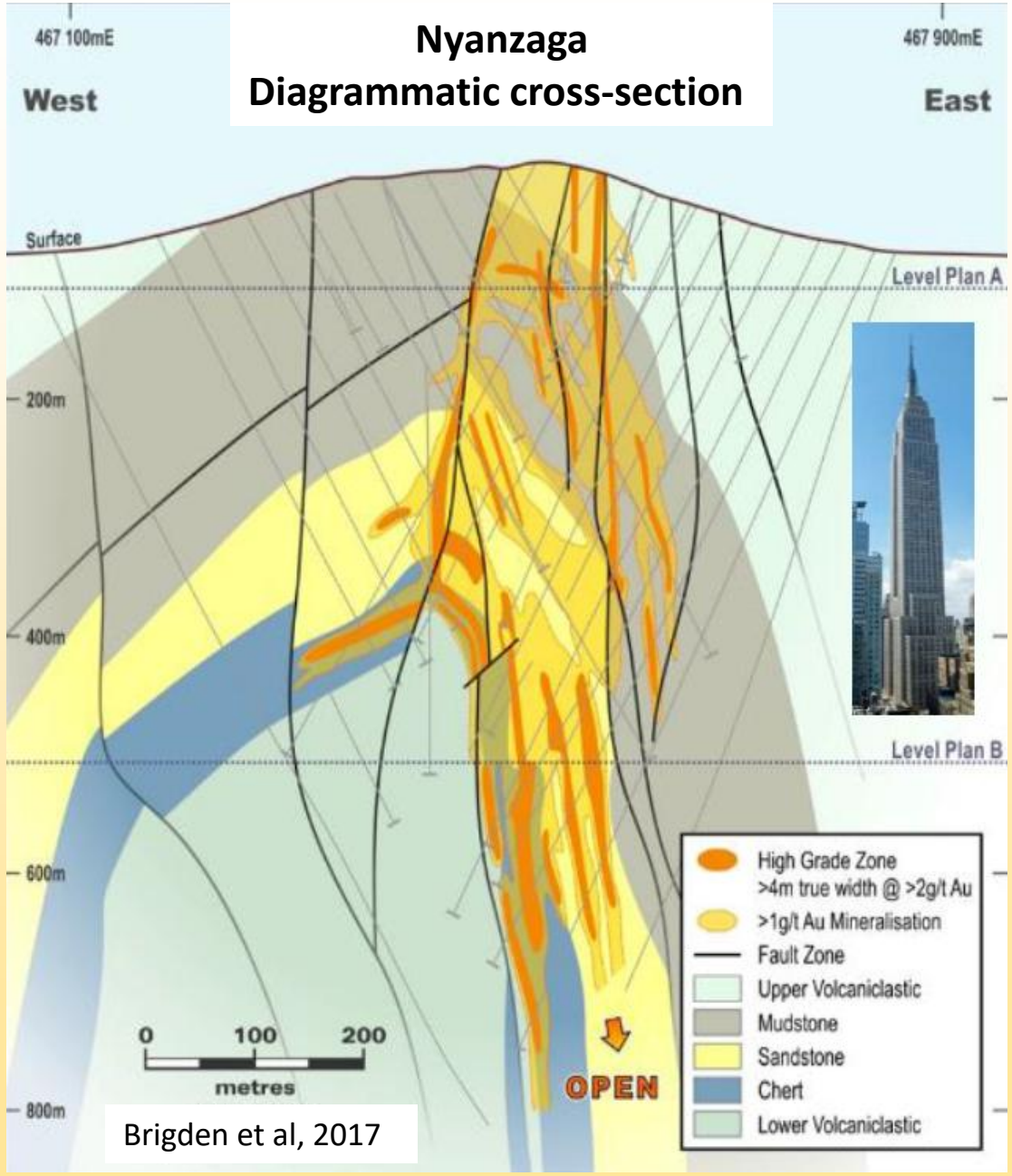
Nyabirama Granite-hosted



Gokona & Nyabigena

Thrust contacts of mafic volcanics + dolerite and FW metasediments + andesitic volcanics

Potential for Zimbabwe–Tanzania knowledge sharing: an Ur link??



Brigden et al, 2017



Nyanzaga (Perseus Mining): fold & lithology controls

Key factors

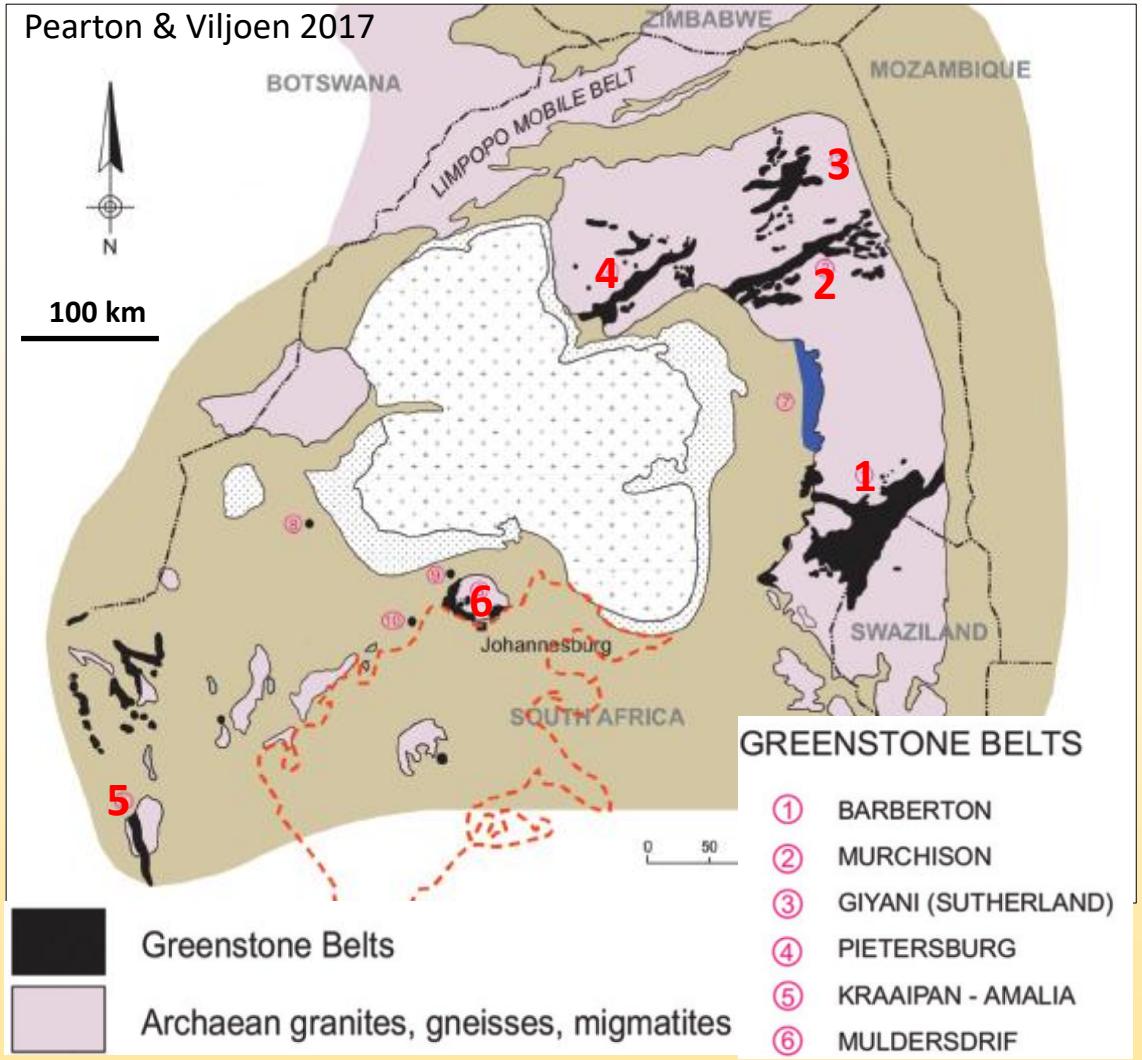
- **Competency contrast** between lower epiclastic units and chert/mudstone units
- **Alternating siltsone-sandstone ± chert units** throughout host sequence
- Early hydrothermal **carbonate embrittlement** of some units
- **Shortening, folding, bed-parallel flexure, axial-planar faulting & thrust/shear-reactivation** = extensive fluid flow
- Fluid flow enhanced by **brittle failure** of cherts and carbonatized units

EAXI will facilitate valuable exchange of ideas and experience

EAXI and Kaapvaal Craton? Insights to Ur: mid-Archean tectonics and 3.0 Ga gold

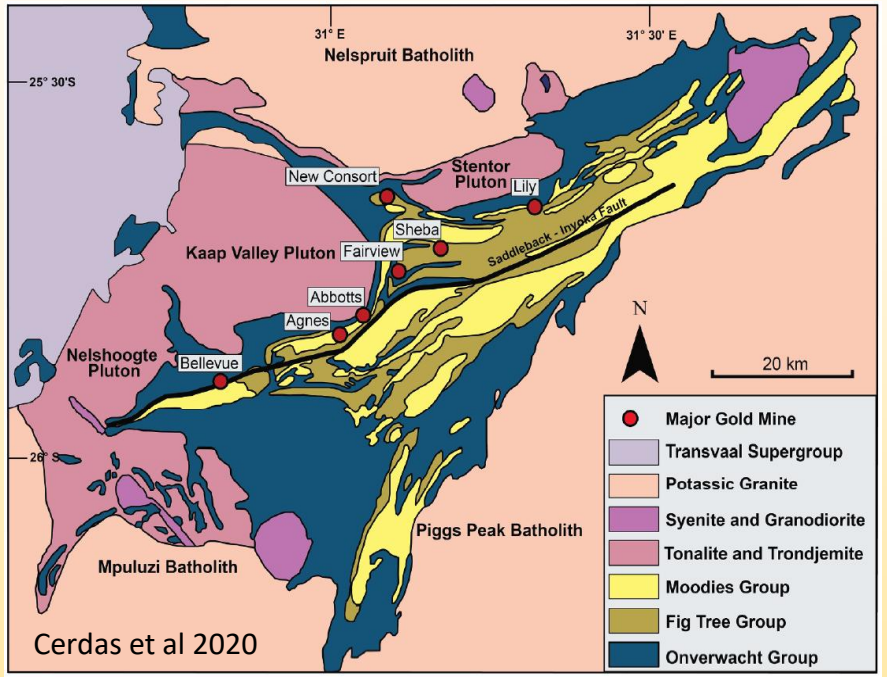


Pearton & Viljoen 2017



2. Murchison (Block et al, 2013)

- 3 shear-bounded 3.1-2.9 Ga tectono-metamorph
- N-S compression ca.2.95 Ga = collision of two terrains
- Sb-Au but minor gold endowment



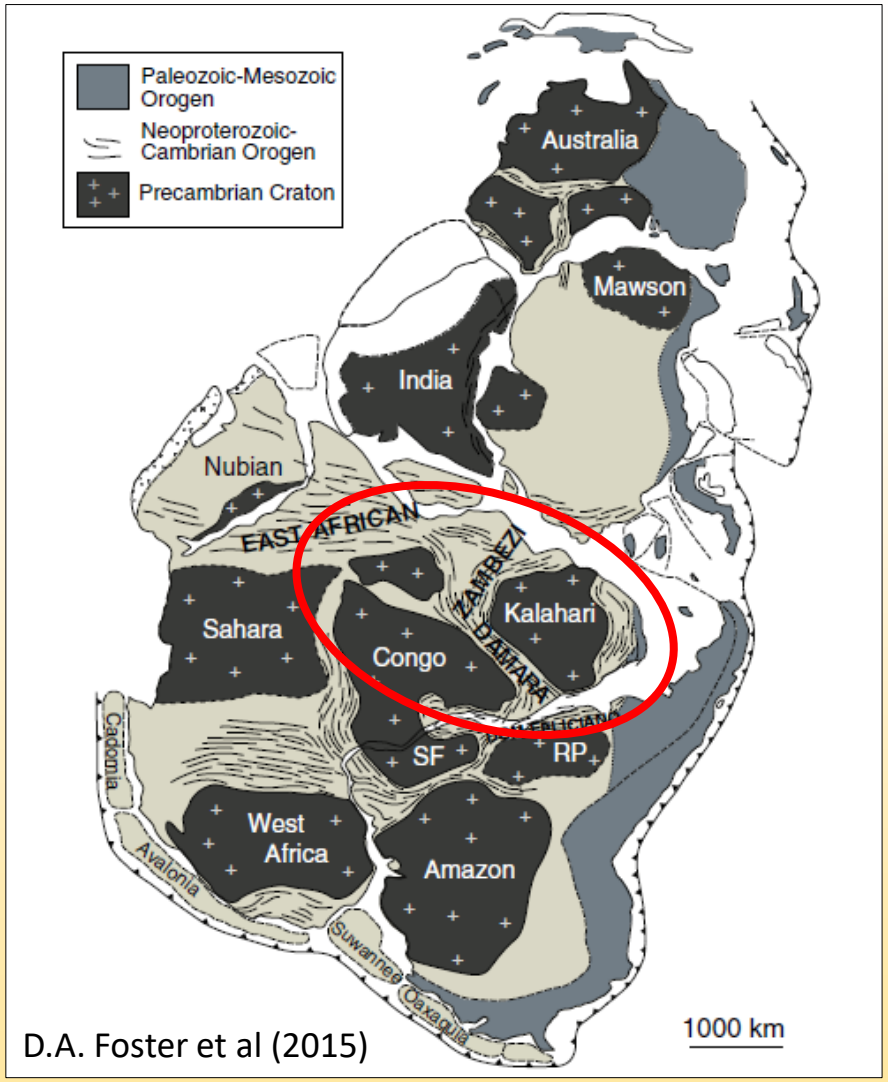
Cerdas et al 2020

4. Barberton

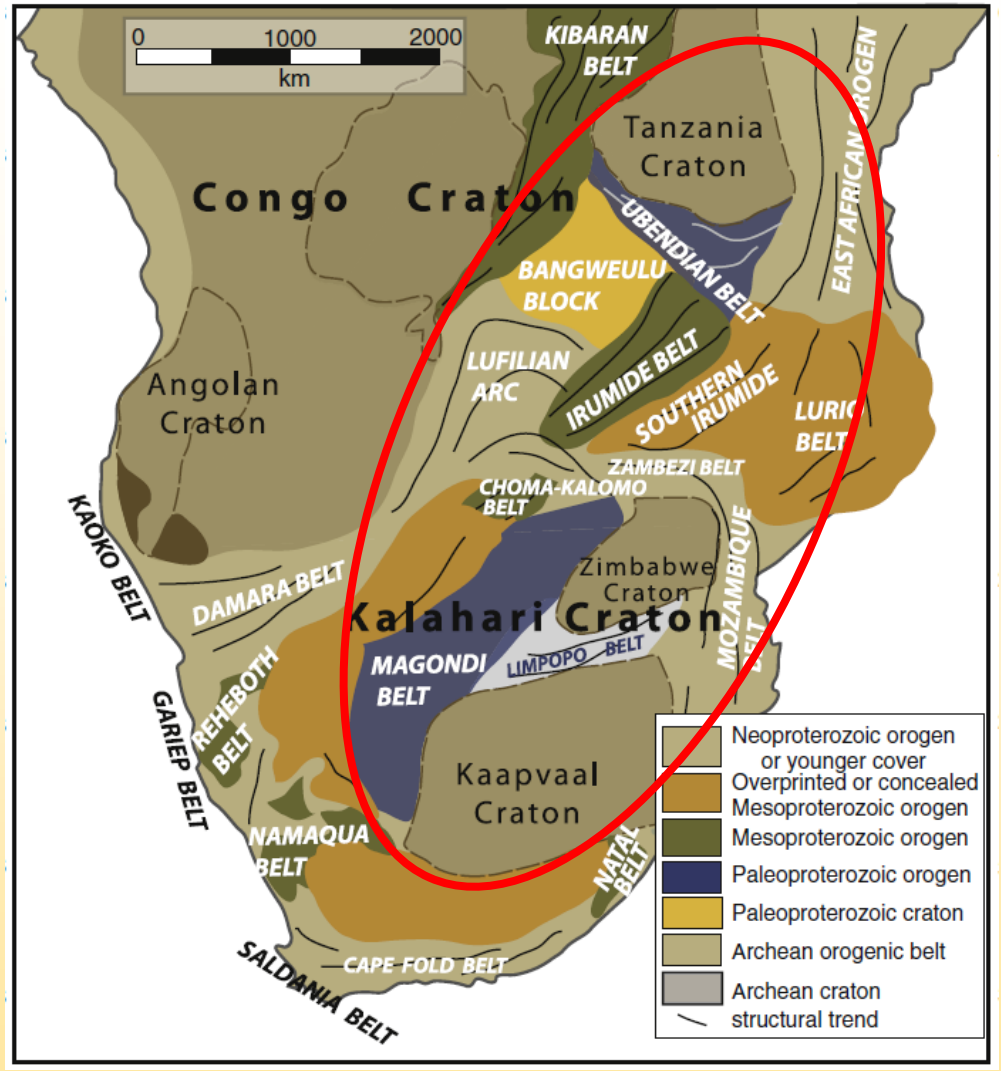
- Only major gold endowment GB: >380t gold produced
- 3.5-3.0 Ga host rocks; ca.3.05 Ga gold
- **Complex tectonic architecture**
- Granitoids - buttressing v diapiric reactivation of structures?

Mid-Archean greenstone belt construction
Why different timing *vs* Zimbabwe & Tanzania?
Relevance to Tokwe & Sebakwe proto-cratons & Au?

Future objectives? Proterozoic to Pan African tectonics: ZAXI / EAXI upside – Phase IV?



D.A. Foster et al (2015)



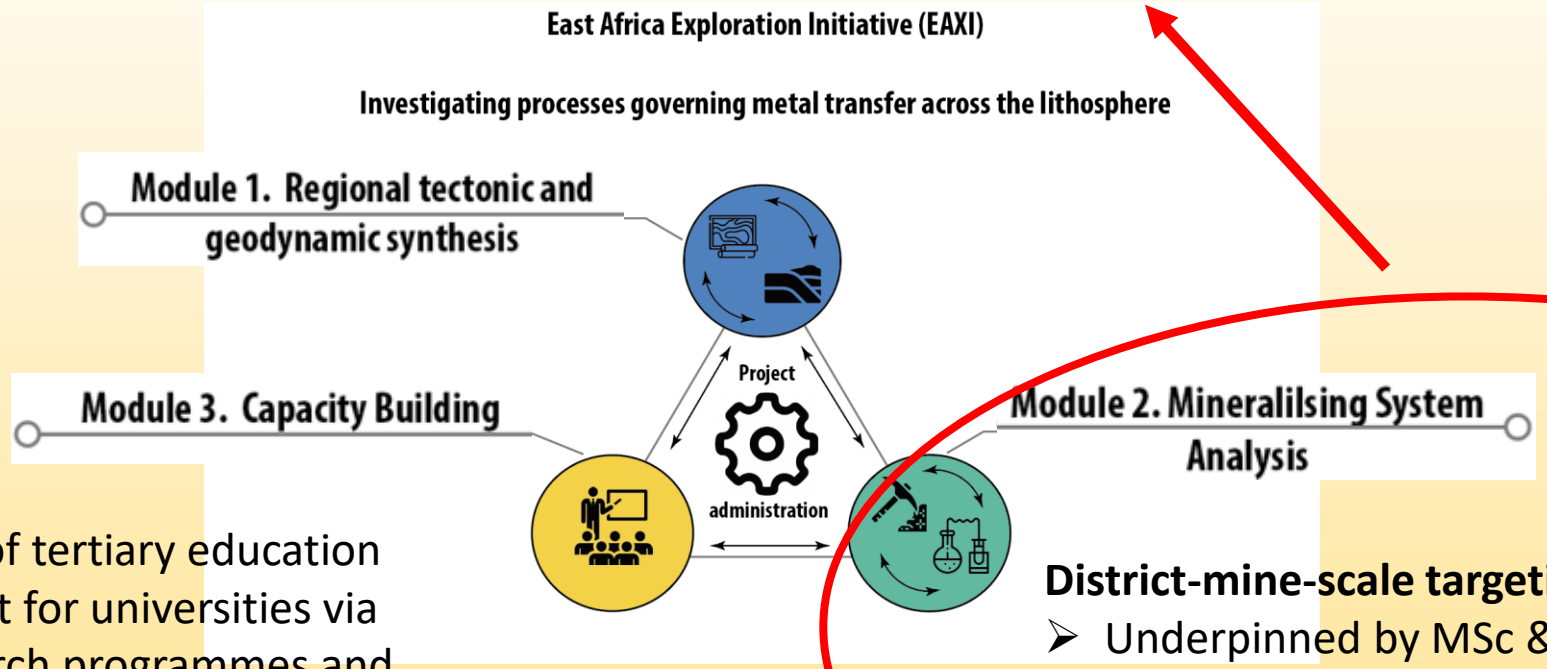
- Greatly revised Archean and Proterozoic-wide tectonic & lithostratigraphic framework
- Enhanced understanding of metallogenesis and prospectivity – Palaeo-, Meso-, Neo-Proterozoic
  - **Not just gold!**

EAXI: BUILDING ON HUGELY SUCCESSFUL OUTCOMES IN WEST AFRICA



Big picture:

- New regional exploration initiatives
- Supporting in-country operators
- Attracting interest of major companies



Human resources:

- Enhanced levels of tertiary education
- Enhanced support for universities via funding for research programmes and staff support
- International cooperation thro' shared research and training programmes

District-mine-scale targeting:

- Underpinned by MSc & PhD studies
- Key structural & lithological controls identified
- Enhanced confidence in district-scale exploration and resource modelling

EAXI + ZAXI: EXTENDING THE KNOWLEDGE DATABASE
ZIMBABWE'S POTENTIAL ROLE



Zimbabwe has the tools and the people ….and a world-class database thanks to ……

Dr Alexander Miers Macgregor

And his Geol. Survey colleagues past and present for creating that database …

Underpinned by research by many Zimbabwe-focused geoscientists *including* ….

- Jim Wilson
- Bob Nesbitt
- Tony Martin
- Tom Blenkinsop
- Sharad "The Master"
- Mike Vinyu
- Martin Prendergast
- Heilke Jelsma
- Paul Dirks
- Axel Hofmann
- Forbes Mugumbate
- Godfrey Chagondah
- Brian Mapingere

+ Geol Soc Zimbabwe for continuing stimulus & promotion of geoscience

Time to build on this superb platform – via EAXI / ZAXI