A review of the geology and Au-Ag mineralization in the Gwanda Greenstone Belt: Implications to exploration

GSZ Summer Symposium_01 Nov 2024

Bulawayo, Zimbabwe

Godfrey S. Chagondah[1], Mbongeni Manyere [1]and Peter T. Zizhou[2]

[1] *Department of Chemistry & Geological Sciences, University of Zimbabwe, Mt Pleasant, Harare, Zimbabwe*

[2]*131, Iona Road, Killarney, Bulawayo, Zimbabwe*

Email: geolochagondah@yahoo.com

ENESIA RESOURCES

G Z S

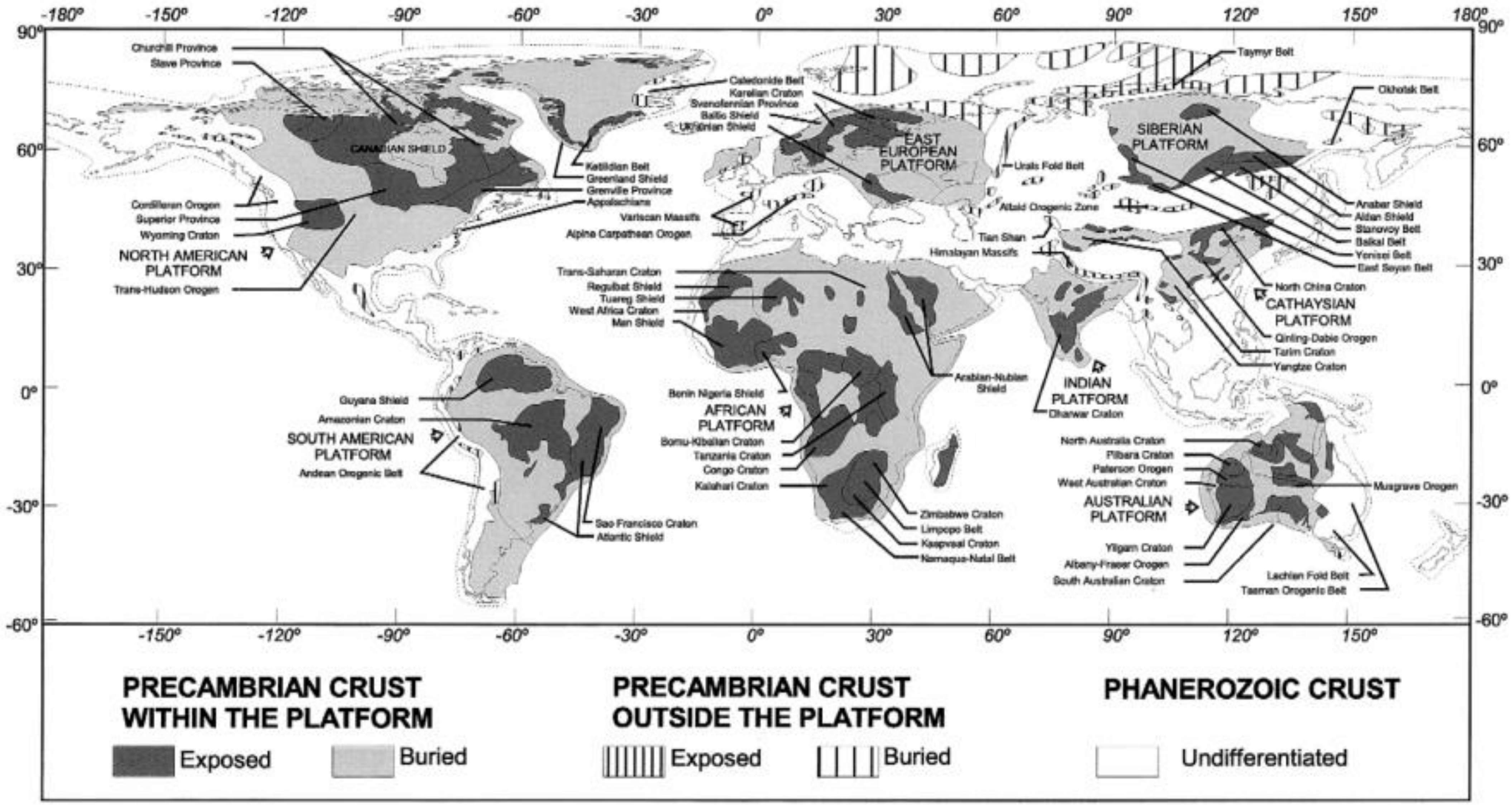
UNIVERSITY OF ZIMBABWE

Talk format

1. Overview & distribution of orogenic gold deposits.
2. Structural controls on gold mineralization using YILGARN examples.
3. Overview of the Zimbabwe Craton geology.
4. Geology, deformation, metamorphism, alteration-mineralization in the Gwanda greenstone belt (GGB).
5. Review findings
6. Implications to exploration
7. Future studies to close the knowledge gap in the GGB & Zim geology at large.

Global distribution of Precambrian cratons and shields & Phanerozoic mobile belts.

(Goldfarb et al., 2001)



- The important periods of Precambrian orogenic gold-deposit formation: 2.8 –2.55 and 2.1–1.8 Ga and Phanerozoic mobile belts.

- Preserved major Archaean goldfields occur in greenstone belts of the Yilgarn, Superior, Dharwar, Zimbabwe, Slave, Kaapvaal (e.g., Barberton & Murchison Greenstone Belt), Sao Francisco and Tanzania cratons.

Overview on orogenic gold deposits: (structurally-controlled)

- Refers to gold deposits that are typically associated with deformed, metamorphosed, altered mid-crustal host rocks, particularly in spatial association with major crustal structures (Groves et al., 2001).

- The 1st -order control on world-class orogenic gold districts is their location adjacent to crustal- to lithospheric-scale fault or shear zones at the regional scale (Groves et al., 2000; Goldfarb et al., 2005).

- 2nd order interconnecting faults & shear zones may have been important conduits/pathways for CO2-bearing fluids & metals.

- Fe-rich metavolcanic rocks & BIFs provided favourable chemical traps for gold mineralization.

- Studies in different Archean cratons show δ13C values of -5 to -4 ‰: indicate derivation of ore-forming fluids from deep external sources: deep-seated intrusions, the lower crust & the lithospheric mantle (Good & de Wit, 1997; Agangi et al. 2024).

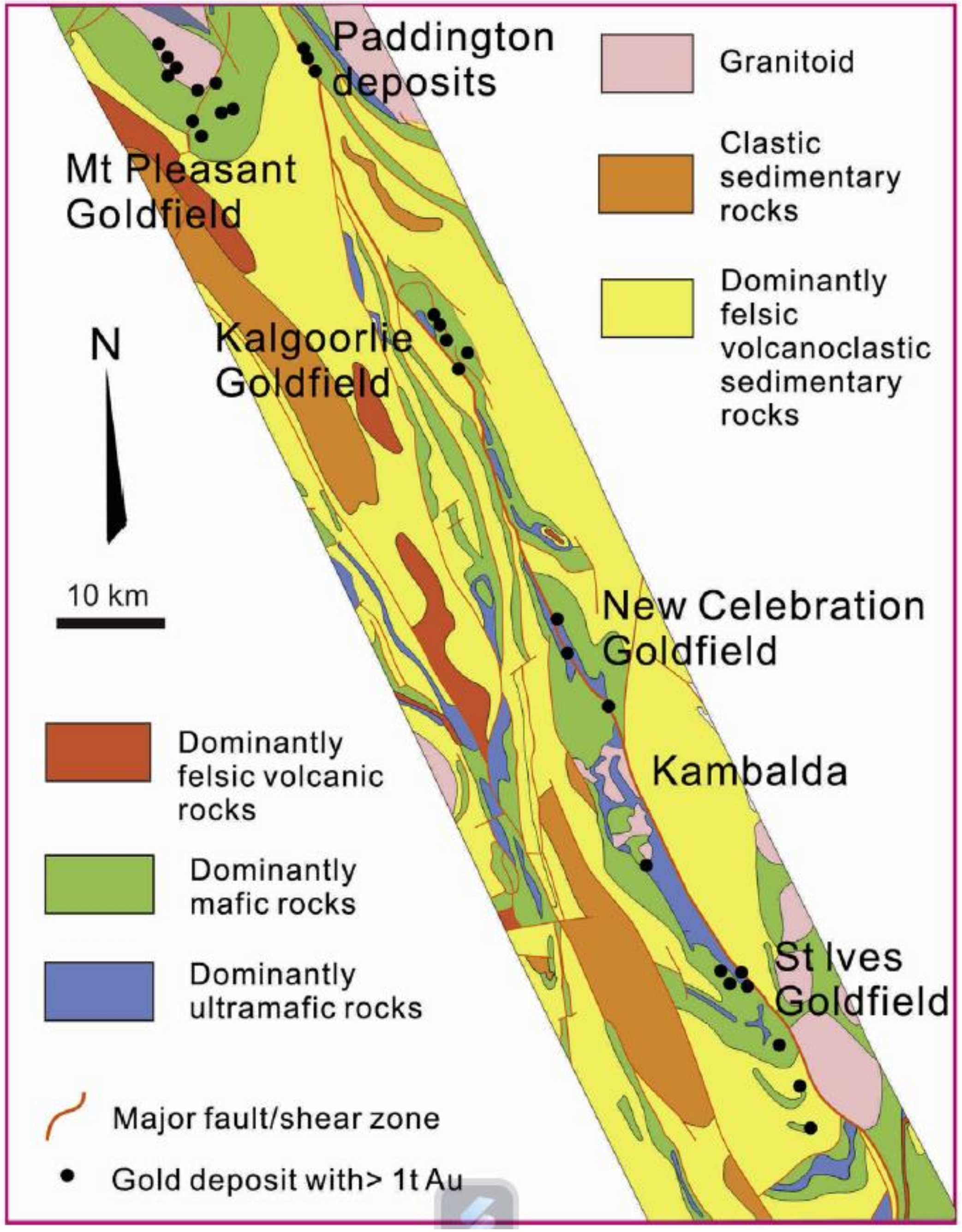
- Lithosphere-sourced lamprophyre dykes: indicate a deep lithospheric connection for fluid conduits.

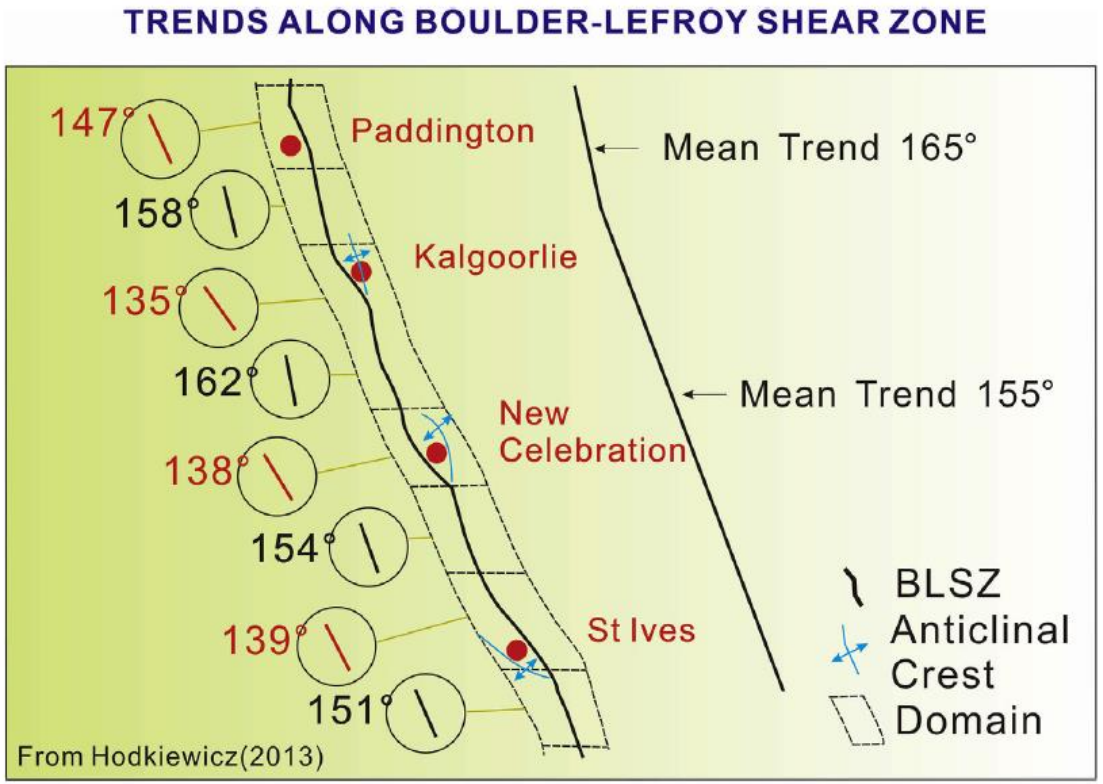
- Crustal-sourced felsic porphyry intrusions are associated with mineralized zones.

- However, the dykes & felsic porphyry intrusions are not sources of the ore fluid themselves (they lack Au mineralization).

- Less-endowed orogenic gold provinces (e.g., Zimbabwe gold provinces; Klondike province; Seward Peninsula of Alaska) lack these first-order structures and associated deeply-sourced lamprophyres (Groves et al., 2018): IS THIS TRUE?

Examples of structurally controlled (orogenic gold deposits) in the YILGARN Craton



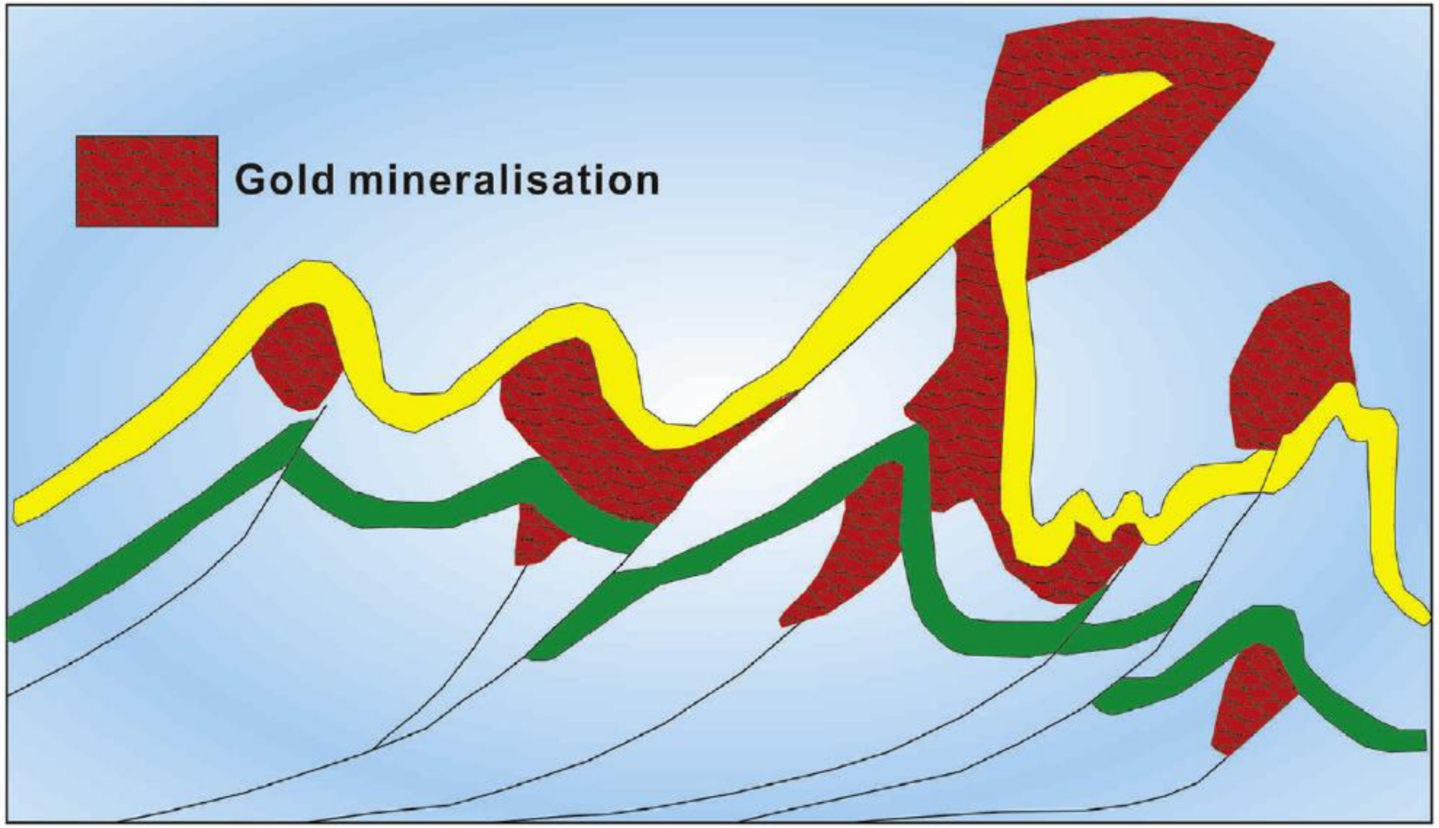


Regional geological map of the southern Kalgoorlie Terrane, Yilgarn Block, in the Eastern Goldfields of W. Australia showing world-class orogenic Au deposits along the crustal-scale Boulder-Lefroy Fault (Groves et al., 2018).

It is along the curvilinear segments of the 1st -order structures, where segments of the structures jog into an anomalous orientation, normally 10-25 to the mean trend, that the larger orogenic gold districts are located (Weinberg et al., 2004).

Deposits are at tens of kms intervals in mature gold provinces (e.g., 30-35 km).

Schematic Fig showing locked-up fold and associated fractures

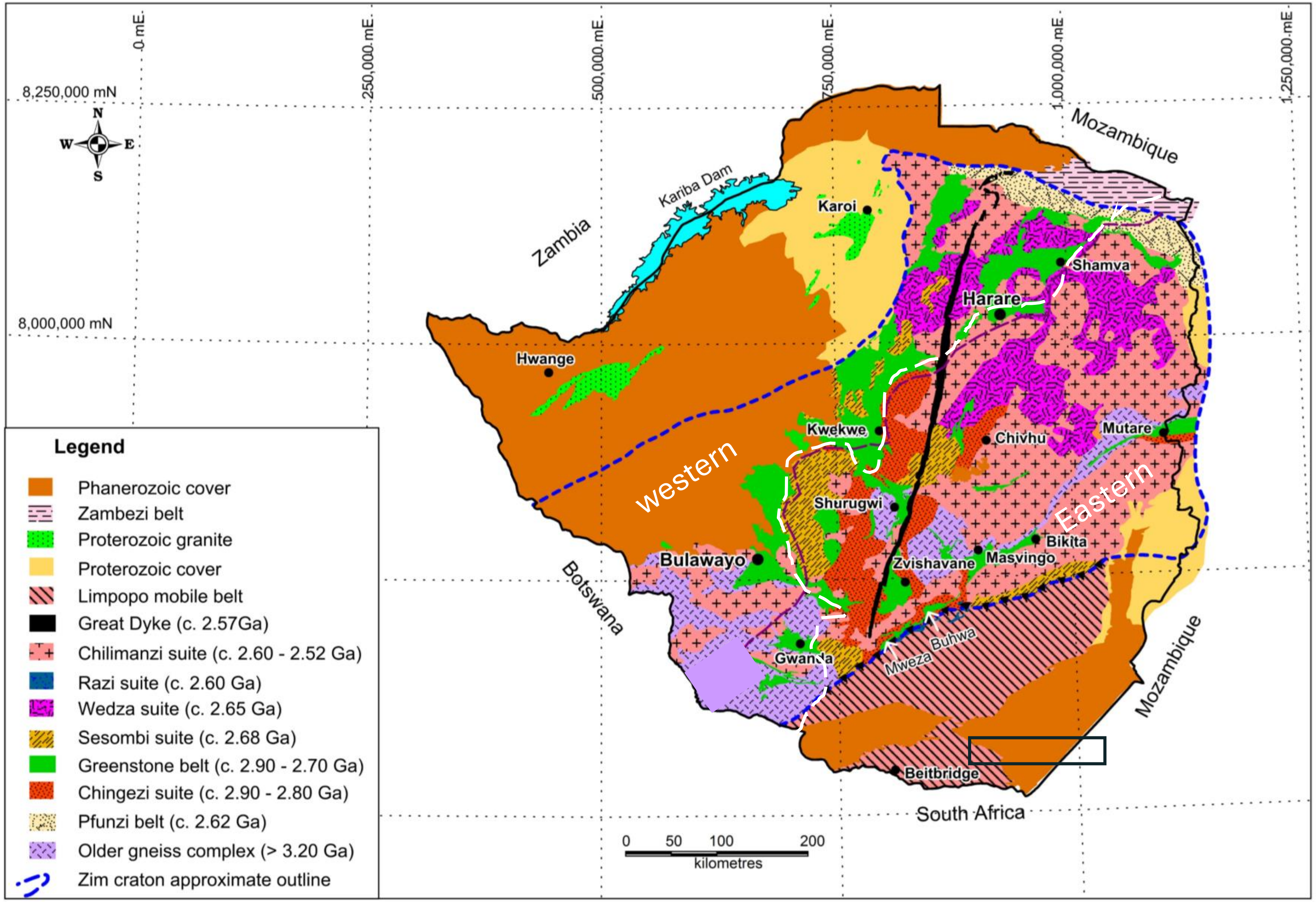


(Groves et al., 2018)

District- to deposit-scale anticlinal or antiformal folds with c. 30° apical angles.

Au mineralization is predicted to be along fold hinges.

Geology of the Zimbabwe Craton



(Hofmann & Chagondah, 2018)

60% of Zimbabwe's land surface is Archaean terrain.

Consistent spatial & temporal association of greenstones with granitoids indicates that melts & fluids were both inherent products of thermal events.

Greenstone-granite pair.

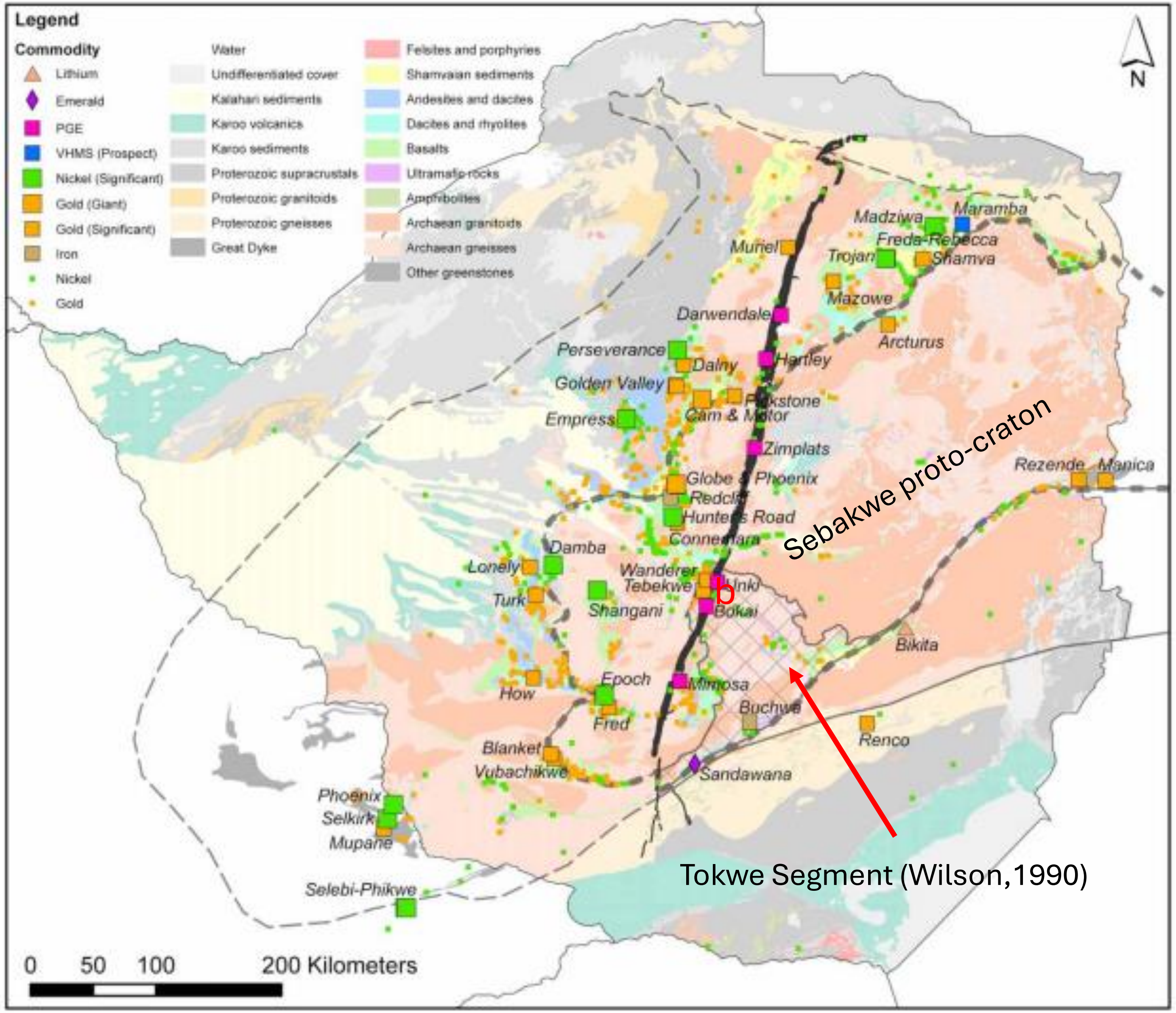
Current geometry of GBs: deformation competency contrasts between GBs & granitoids: more shearing in GBs relative to granitoids.

Deformation & associated metamorphism: necessary percussor process (conduits) for hydrothermal systems for Au mineralization.

Progressive alteration-mineralization: late timing of Au mineralization.

Younger Chilimanzi granites: cratonisation: reflect an extensive, crustal-scale melting event.

Overview of selected mineral resources in the ZC



(Jelsma et al., 2021)

Eastern succession GBs: rift-related:
Belingwe, Buhwa-Mweza, Masvingo & Bepe-Odzi belts.

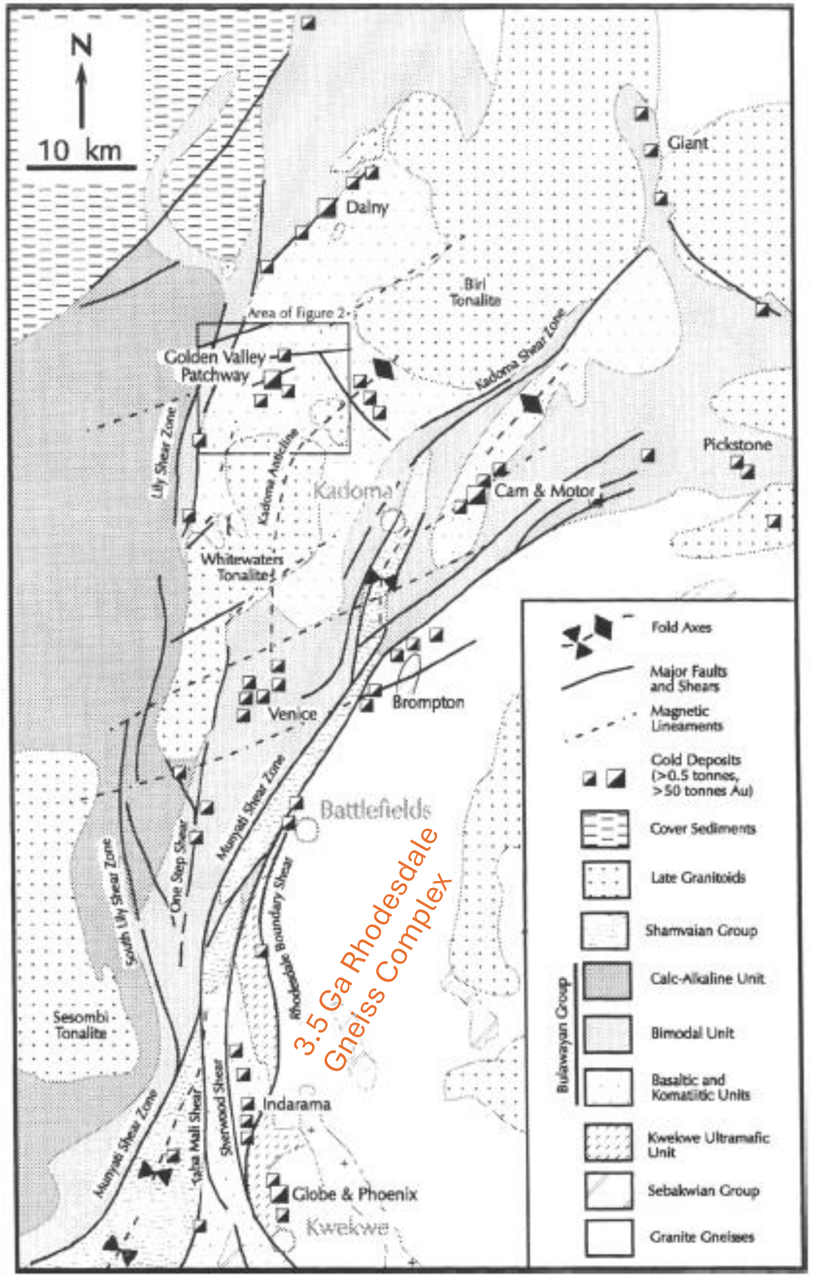
Western succession GBs: subduction-accretion system:
Harare-Shamva, Chinhoyi, Midlands, Bulawayo & Gwanda belts.

ZC: wide diversity of world-class mineral resources including gold.

Zim: Precambrian orogenic gold deposits occur:

(a) within the Archean Craton and
(b) Proterozoic mobile belts: Magondi & NMZ (Limpopo).

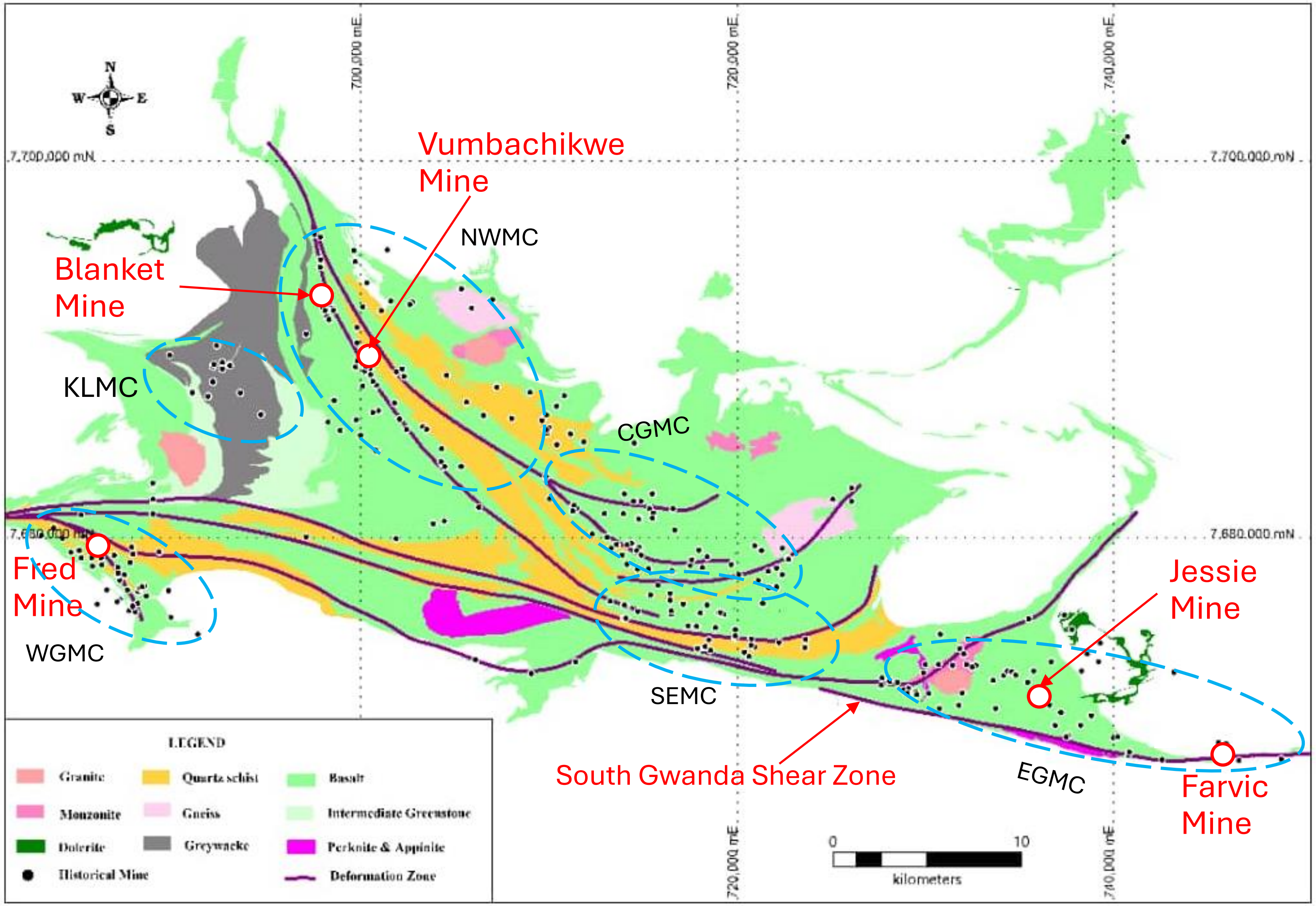
Examples of structurally controlled (orogenic gold deposits) in the Midlands GB: ZIM Craton



- In Zim Au mineralization is structurally controlled (Campbell & Pitfield, 1994; Herrington, 1995; Kalbskopf & Nutt, 2003).
- Linear zones of crustal- to lithospheric-scale faults and shear zones generally lack economic gold deposits (Groves et al., 2018).
- 1st order structures: Sherwood Shear Zone, Munyati, Lily, South Lily, Taba Mali, Kadoma Shear zones
- Au mineralization is associated with 2nd order structures (Dalny, Brompton Mines).
- Jogs coincide with large-scale anticlinal structures (Kadoma anticline: Venice mine), a major association with orogenic gold deposits.

Geology & distribution of orogenic Au deposits in the GGB

✓ One of the most productive GBs in Zim.



(Tyndale-Biscoe, 1940; Fuchter, 1990)

5 Au mining camps (Fuchter, 1990).

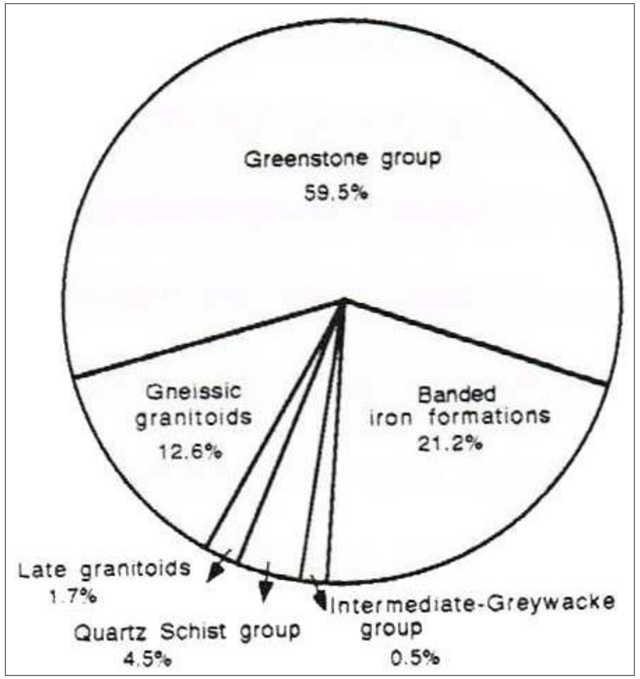
Caledonia: Blanket Mine
Largest deposit, c. 80 000 oz per yr.
Development: new shaft completed in 2020.

Vumbachikwe, neighbor to Blanket Mine …
2nd largest in Gwanda belt.

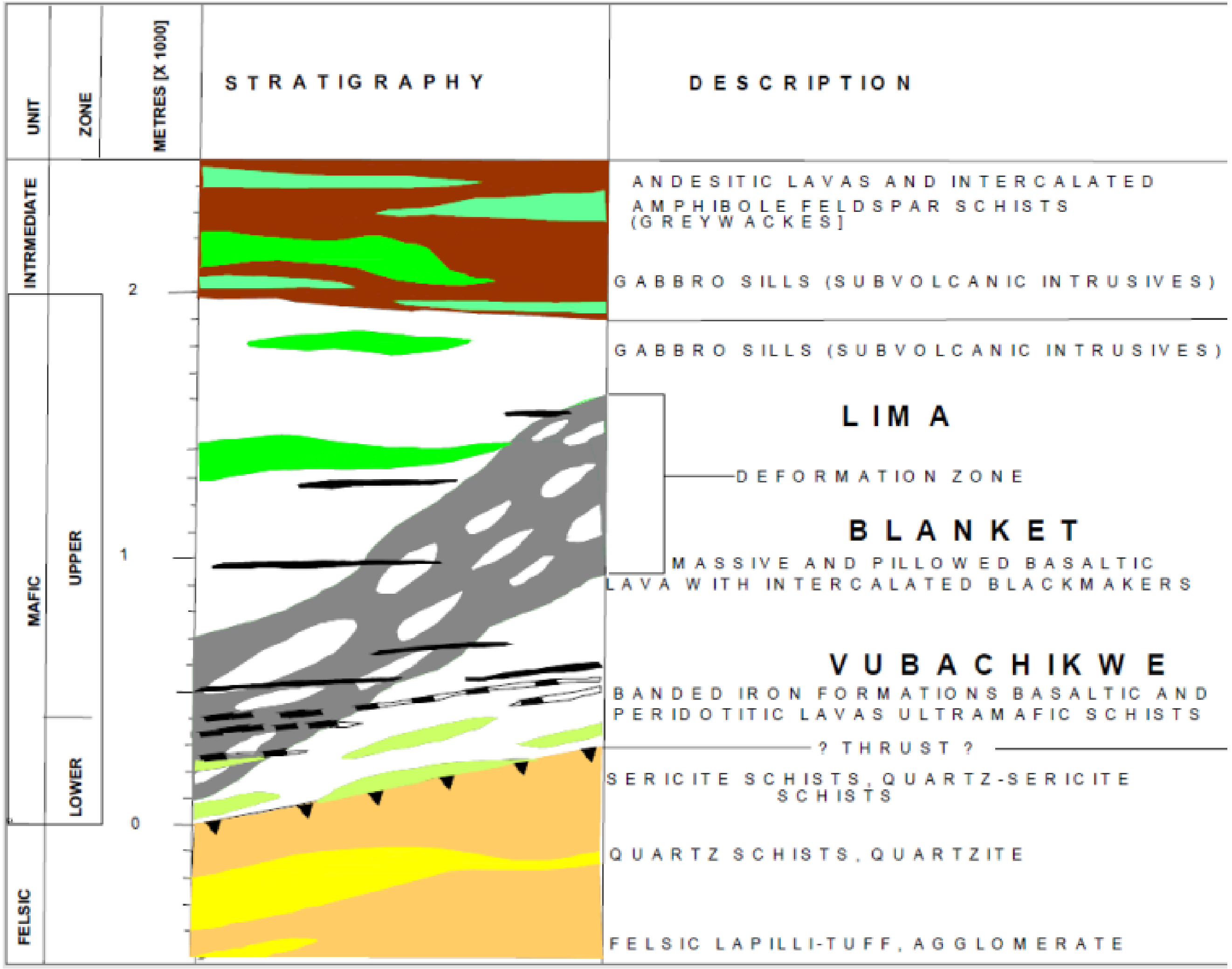
Vumbachikwe-Blanket at ca. 800 m depth vs 1 200 km at Chakari Mine.

Chilimanzi granites (2620 Ma: Chagondah et al., 2023).

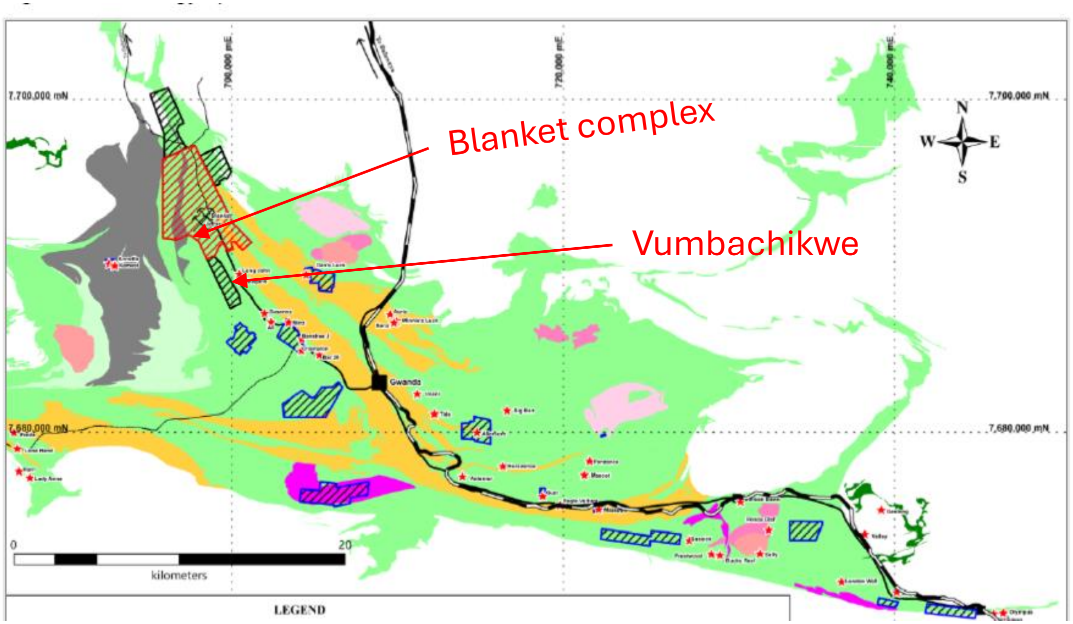
Gold production in different lithologies:



Stratigraphy of the Northwestern Mining Camp (NWMC): Gwanda belt



(Tyndale-Biscoe. 1940; Wright, 1977; Fuchter, 1990)



3 major lithological units:

- ✓ Greenstone group, interbedded with a Quartz Schist group & unconformably overlain by Greywacke group.

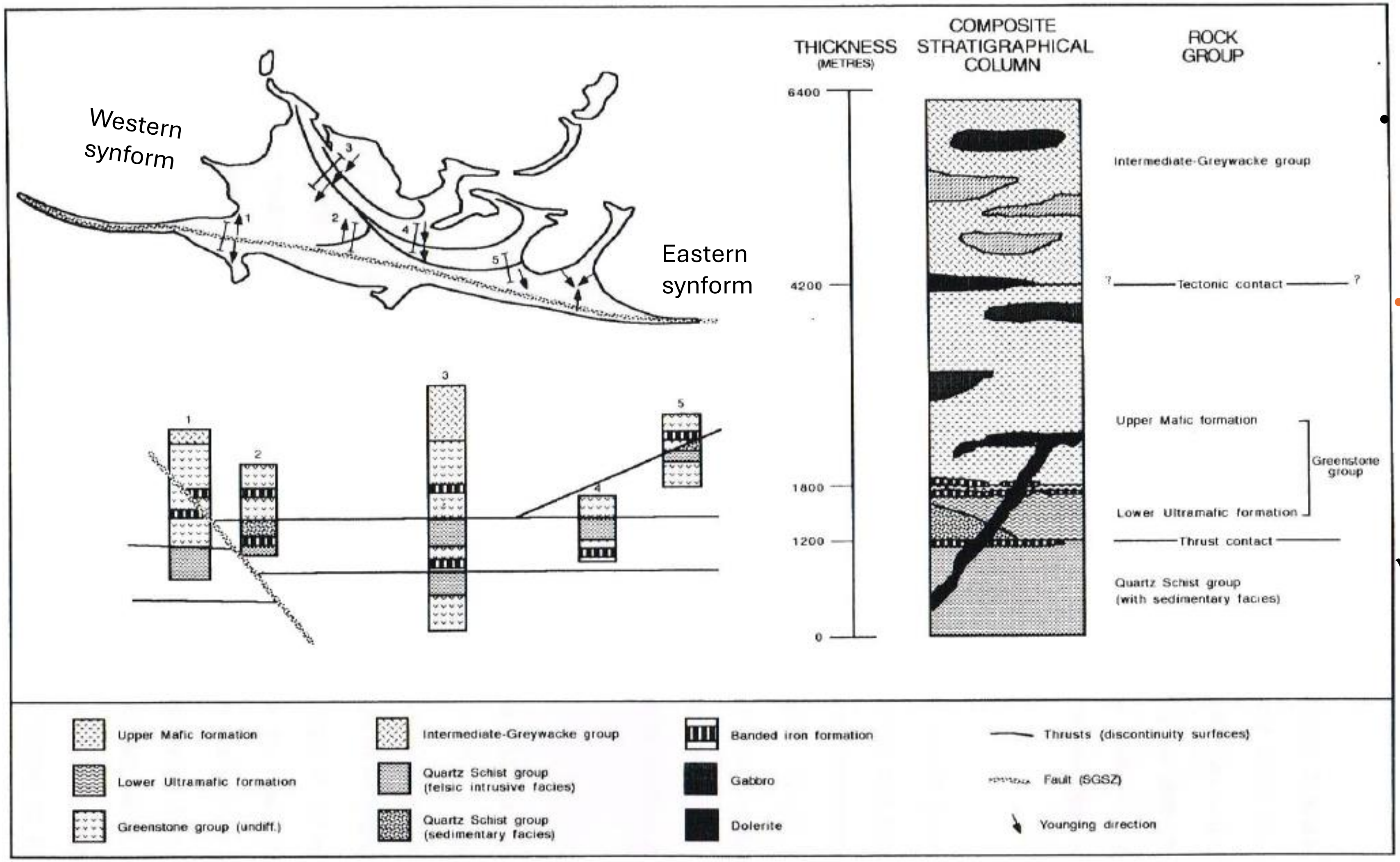
- ✓ Greenstone Group:
- • Upper mafic Fm: pillowed & massive tholeiitic lavas & agglomerates.
- • Lower ultramafic Fm: komatiitic lavas

Studies in various Archaean greenstone belts have distinguished two types of carbonate rocks:

1) carbonates concentrated in large faults and shear zones ("conduit carbonate"), (dolomite & magnesite) and
2) widely distributed "regional halo" carbonate, (calcite, ankerite, siderite) (Groves et al., 1988; Nakamura & Kato, 2004).

Deformation & Metamorphism

Stratigraphy & stratigraphical evidence of thrusting in the Gwanda belt



(Tyndale-Biscoe, 1940; Wright, 1977; Fuchter, 1990)

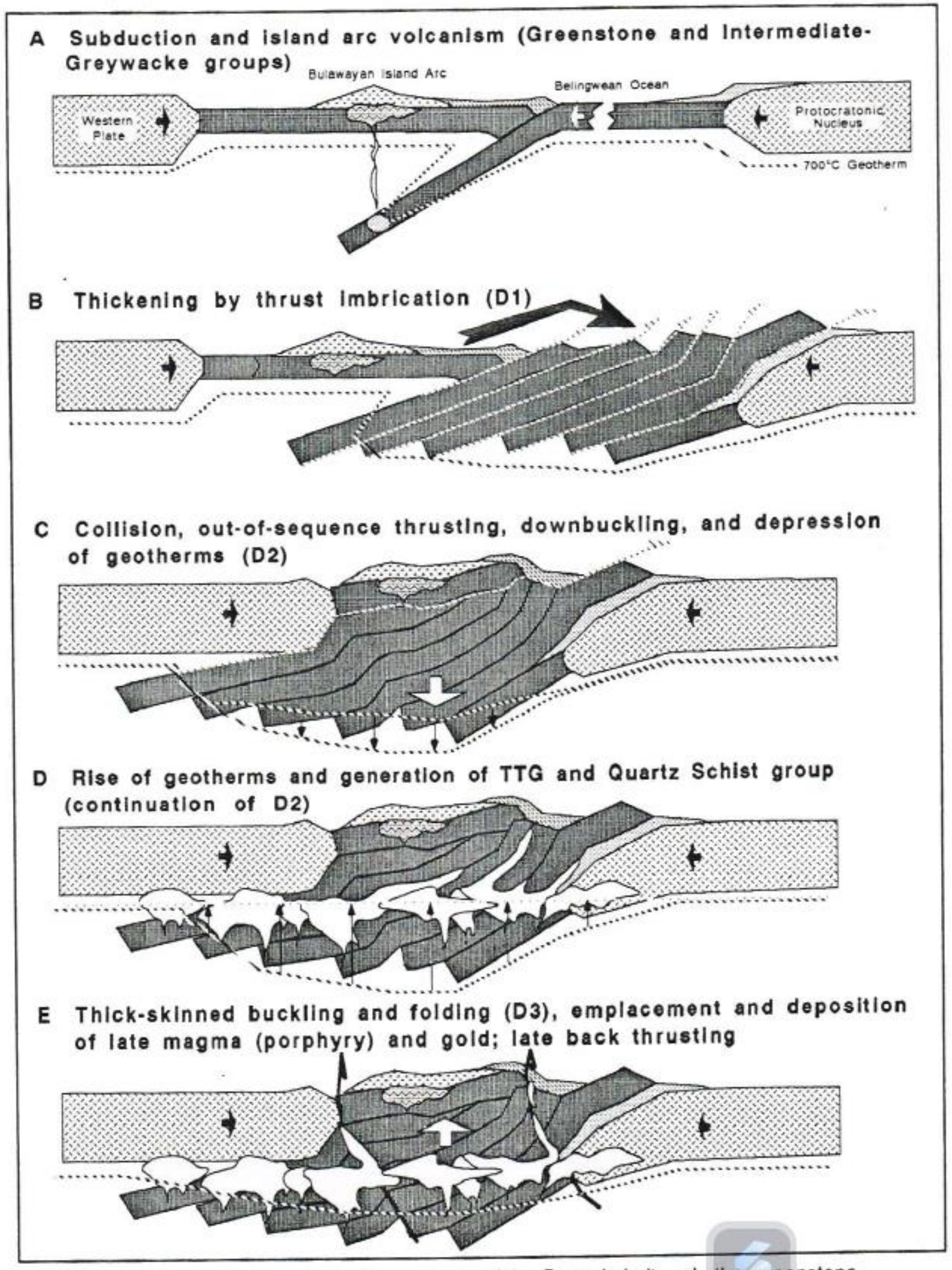
Deformation

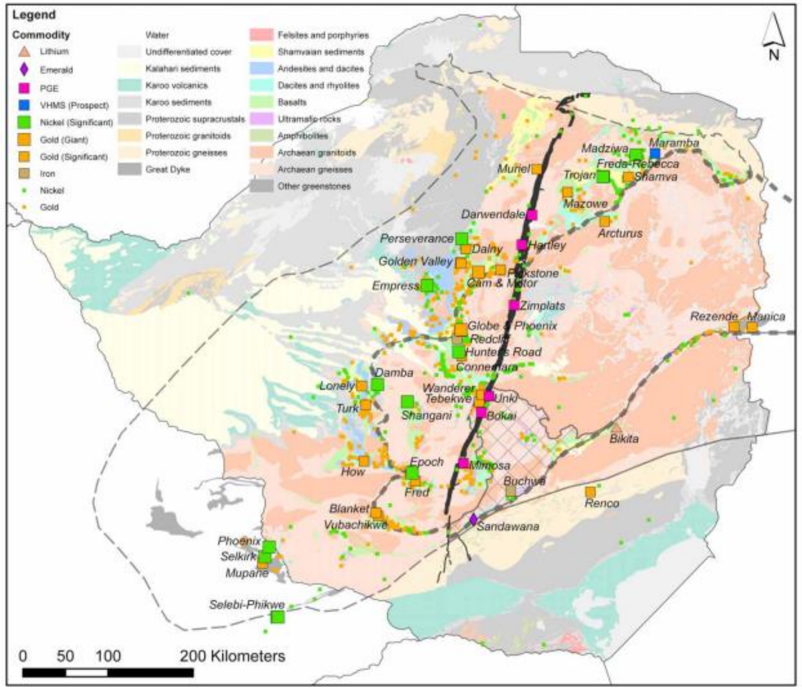
- Interbedding of Greenstone & Quartz Schist groups: is a result of thrust imbrication (Wright, 1977; Fuchter, 1990).
- Stratigraphic repetition: supracrustals now represent a series of stacked thrust slices.

Metamorphism

- ✓ The GGB experienced greenschist to lower amphibolite metamorphic facies conditions, (Saager et al., 1987; Futcher, 1990).
- ✓ Metamorphic grade increases from the central part of the GGB to NW (Bar 20, through to Vumbachikwe to Blanket Complex).
- ✓ This trend of better amenability reflects an increase in the grain size of gold & sulfides from southeast.

Geodynamic Setting (Fuchter, 1990)

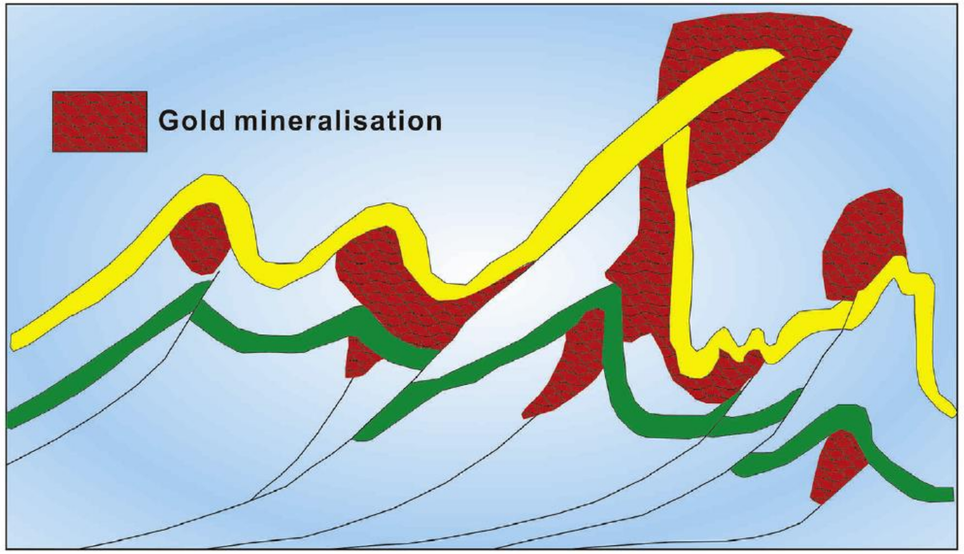




Carbonatization: deep (lithospheric mantle or magma-derived) sources introduced during tectonic activity across the belt.

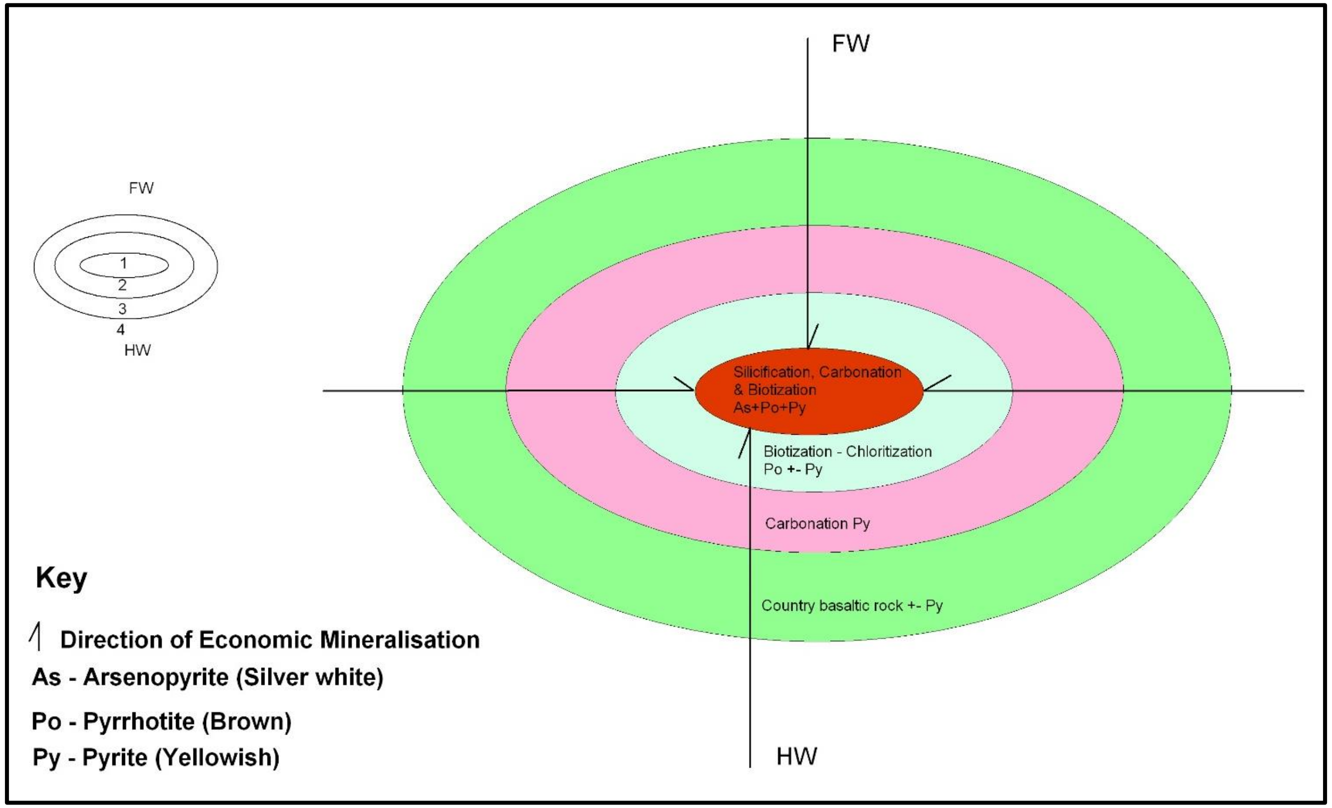
Lamprophyre dykes reported in the belt (Tyndale-Biscoe, 1940; Fuchter, 1990) = lithospheric mantle sourced.

Felsic porphyry intrusions = lower crust sourced.



(Groves et al., 2018)

Alteration & Mineralization in the GGB



Mineralization centre/ore body vectoring.

1. Core/ore zone: final stages of fluid flow: silicification & precipitation of gold-bearing sulphides from CO2-H2O-K-S-As-Au bearing fluid (Fuchter, 1990). Carbonate: siderite.

2. Biotization: variable width around the ore zone. a late (post-foliation) alteration halo close to the vein.

3. Chlorite halo: envelopes the biotite zone (relatively unaltered).

4. Country rock (relatively unaltered).

- ✓ Field observations indicate that more deformed areas containing the largest amount of carbonate are also the most foliated.

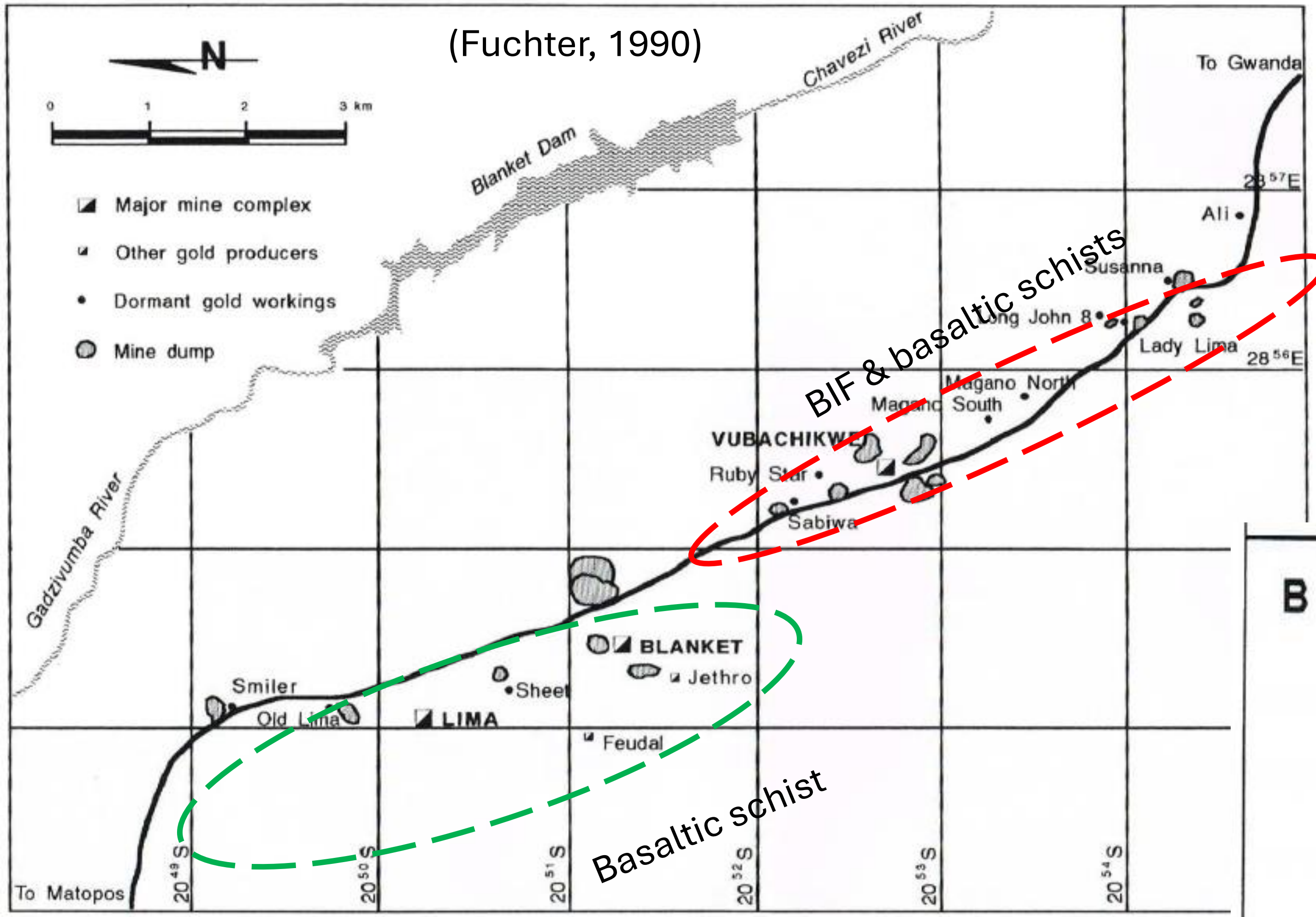
- ✓ Progressive carbonate alteration: broader carbonate alteration halo & superimposed silicification.

- ✓ There is a positive feed-back between deformation (foliation) and carbonatization, with the progressive addition of carbonate.

- ➢ The Murchison Greenstone Belt (Kaapvaal Craton, SA), contains abundant carbonatized metavolcanic rocks & orogenic Sb-Au deposits hosted in carbonate-bearing schists (Agangi et al., 2024).

- ➢ A deep origin of carbon has been proposed in the Neoarchean Au deposits of the Yilgarn Craton of W. Australia and Murchison-Thabazimbi lineament (prominent tectonic feature) Antimony line in the Kaapvaal Craton (e.g., Groves et al., 1988; Agangi et al., 2024).

Deformation & location of major gold mines in the NWMC

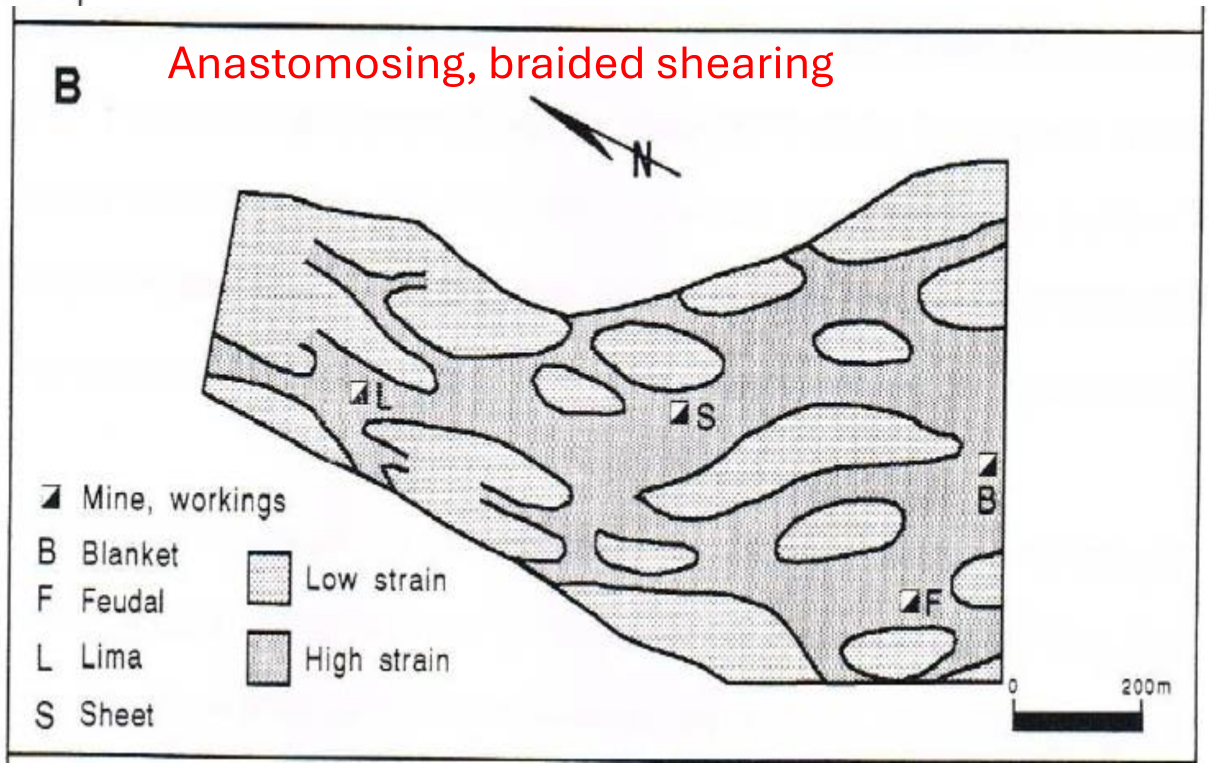


In the Bar-20, Vumba & Lima areas: As-bearing BIF, constituting the so-called Gwanda arsenic line.

Metallogenic model of ore in BIF, attracted two models: Syn-sedimentary (Fripp, 1974; Saager et al., 1987) and epigenetic (Tyndale-Biscoe ,1940; Phillips et al., 1984; Master et al., 1989).

NWDZ: Northwest Deformation Zone

- Basaltic schist: with lozenge-shaped domains of weakly foliated rocks surrounded by deformed & schistose rocks.
  - NWDZ: an anastomosing, braided, ductile deformation zone; 2km wide & 18km long.
  - NWDZ is a result of D2 deformation, associated with the collision of Western plate with the Sebakwe proto-cratonic nucleus.



Mineralization

- ✓ Ore zones are characterized by quartz-carbonate veins, thus affirming the importance of CO2-rich fluid flow for mineralization during deformation & metamorphism.
- ✓ The GGB hosts significant Au mineralization, particularly in the NWMC, with accessory Ag.
- ✓ Main sulphide minerals: arsenopyrite, pyrite, pyrrhotite, chalcopyrite-galena.
- ✓ Gwanda As line: Vumbachikwe to Lima: attests to dominance of arsenopyrite mineralization.
- ✓ In the Murchison belt: regionally, Au-Ag (+/- Cu-Pb) mineralization is markedly enriched in metamorphosed & altered rocks relative to least metamorphosed & altered areas (e.g., Agangi et al., 2024).

3 mineralization types

1. Fracture fill type:

- Ore shoots occur as quartz-carbonate veins (QV).
- Variable grade, generally high grade…free Au common.
- Occurs at high crustal levels: Blanket Quartz Reef and BIF-hosted (Vumbachikwe ore bodies).

2. Quartz-Cc-sulphide mineralized shear zones

- ✓ Associated with anastomosing shear zones: Eroica, black cat
- ✓ Quartz-carbonate veins & sulphide impregnations in shear zones.

3. Replacement type:

- Replacement of iron silicates, oxides, or carbonates by sulphides.
- Generally low-to high grade, high tonnage ore bodies: AR Main & South.
- Quartz-carbonate veins also occur in places.

BIFs: mixed facies: alternating silica-rich layers and Fe-rich layers that are typically composed of Fe-oxides (hematite & magnetite), Fe-rich carbonates (siderite & ankerite) and sulphide facies.

Review Findings

- Au mineralization in the GGB largely conforms with hallmark signatures of major Precambrian orogenic gold deposits documented in different cratons.
- Similarly to giant Archaean orogenic gold deposits, Au mineralization in the GGB is spatially associated with major crustal structures: D1 thrust zones.
- Progressive carbonation mechanically weakened the metabasaltic rocks & enhanced fluid-flow.
- There is a positive relationship between degree of deformation and alteration (carbonatization, silicification, chloritization & sericitization).
- Ore zones are characterized by quartz-carbonate veins, thus affirming the importance of CO_2-rich fluid flow for mineralization during deformation & metamorphism.
- Late Archean reactivation of the crustal-scale thrust zones, was associated with Au-Ag mineralization in D2 & D3 structures.
- Ore-localizing was focused into dilatant structures: fractures & high order shears zones.
- Preferential Au-enrichment in Fe-rich metabasalts & BIFs suggest that the rocks have either allowed enhanced fluid flow or acted as effective traps for sulphide deposition.
- The GGB show presence of lamprophyres dykes (deep sources –lithospheric mantle) external from the volcano-sedimentary succession (Groves et al., 2018) and
- felsic porphyry intrusions (lower crust-metamorphic) introduced during tectonic activity across the belt
- These structures were the main sources for CO_2-rich gold mineralizing fluids.

Implications to exploration

- ✓ Literature review to understand modern concepts on genesis of orogenic gold deposits worldwide.
- ✓ Traditional geological mapping: to decern field relationships (rock & alteration assemblages, rock attitude).
- ✓ Remote sensing: regional and local scale deformation structures (e.g., crustal scale thrust & shear zones, folds, etc.,).
- ✓ Exploration geochemistry- pathfinders (there is a strong positive correlation for Au-As, Au-Ag, Au-Sb, and As-Sb values in ores across the Gwanda belt.
- ✓ Positive feed-back between deformation (foliation) and carbonatization, with the progressive addition of carbonate.
- ✓ Positive feed-back between alteration (carbonatization, silicification, chloritization) and Au-Ag mineralization.
- ✓ Alteration seems play a crucial role at local scale mapping: good indicators.
- ✓ In the GGB, gold mineralization is associated with Fe-rich metabasaltic (tholeiitic) host rocks basalts and BIFs.
- ✓ Lamprophyre dykes and felsic porphyry intrusions (lack Au mineralization) are indicative of lithospheric mantle and lower crustal sourcing of hydrothermal fluids around area of interest, shows you are exploring in prospective area.

Future Studies

- ✓ There has been limited research on Zimbabwe geology after year 2000.
- ✓ Therefore, Zim hasn't benefited from technological advances which are being employed in other countries to better understand and advance new geological concepts.
- ✓ The world-class Zim Craton offers a natural laboratory & an excellent platform for study.

Research opportunities in the Gwanda belt and across various mineral commodities in the country include:

- ❖ Geochronological framework of the GGB: using modern dating techniques; robust SHRIMP isotopic ages.
- ❖ Carbon isotope studies to constrain the sources of mineralizing fluids: deep origin, such as the mantle or the lower crust (e.g., Des Marais et al., 1992; Good and de Wit, 1997; Deines, 2002).
- ❖ Fluid inclusion (Fis) studies on gold-bearing veins: (e.g., CO2-rich fluid inclusions) (e.g., Aibai et al., 2023).
- ❖ Laser based techniques: mineral chemistry studies.
- ❖ Sulphur isotope geochemistry on sulphides: to contribute on resolving the syn-genetic vs epigenetic genesis of gold in BIFs.

Articles for consideration:

Ore Geology Reviews
Volume 18, Issues 1–2, April 2001, Pages 1-75

Orogenic gold and geologic time: a global synthesis

R.J Goldfarb [a], D.I Groves [b], S Gardoll [b]

Geoscience Frontiers 9 (2018) 1163–1177
HOSTED BY
Contents lists available at ScienceDirect
China University of Geosciences (Beijing)
Geoscience Frontiers
journal homepage: www.elsevier.com/locate/gsf

Focus Paper

Structural geometry of orogenic gold deposits: Implications for exploration of world-class and giant deposits

David I. Groves [a,b], M. Santosh [b,c,d,*], Richard J. Goldfarb [b], Liang Zhang [b]

Ore Geology Reviews
Volume 163, December 2023, 105766

Nature, origin, and evolution of carbon-rich fluids in orogenic gold deposits: Insights from fluid inclusion and C-H-O isotope studies of the Tokuzbay gold deposit, Chinese Altai

Abulimiti Aibai [a b c d], Xi Chen [e], Yanshuang Wu [a b c d], Xiaohua Deng [f], Fengyun Hao [g], Nuo Li [a b c d], Wenjiao Xiao [a b c d], Yanjing Chen [a d]

Chemical Geology
Available online 9 October 2024, 122442
In Press, Journal Pre-proof What's this?

The use of combined C–Mg isotope compositions of carbonates from orogenic Sb–Au deposits as a tracer of fluid interaction with sea-floor altered crust

Andrea Agangi [a b], Axel Hofmann [b], Takuya Echigo [a], Robert Bolhar [e], Daisuke Araoka [d], Vincent Mashoene [c], Lucia T. Ndhlovu [c], Ryohei Takahashi [a], Pearlyn C. Manalo [a]

Thank You