UNIVERSITY OF JOHANNESBURG

IRP BuCoMO
Building Continents - From Mantle to Ore

NRF National Research Foundation

The Geological Society of Zimbabwe

Insights into the deformation and gold mineralisation of the Mwanesi Greenstone Belt, central Zimbabwe Craton

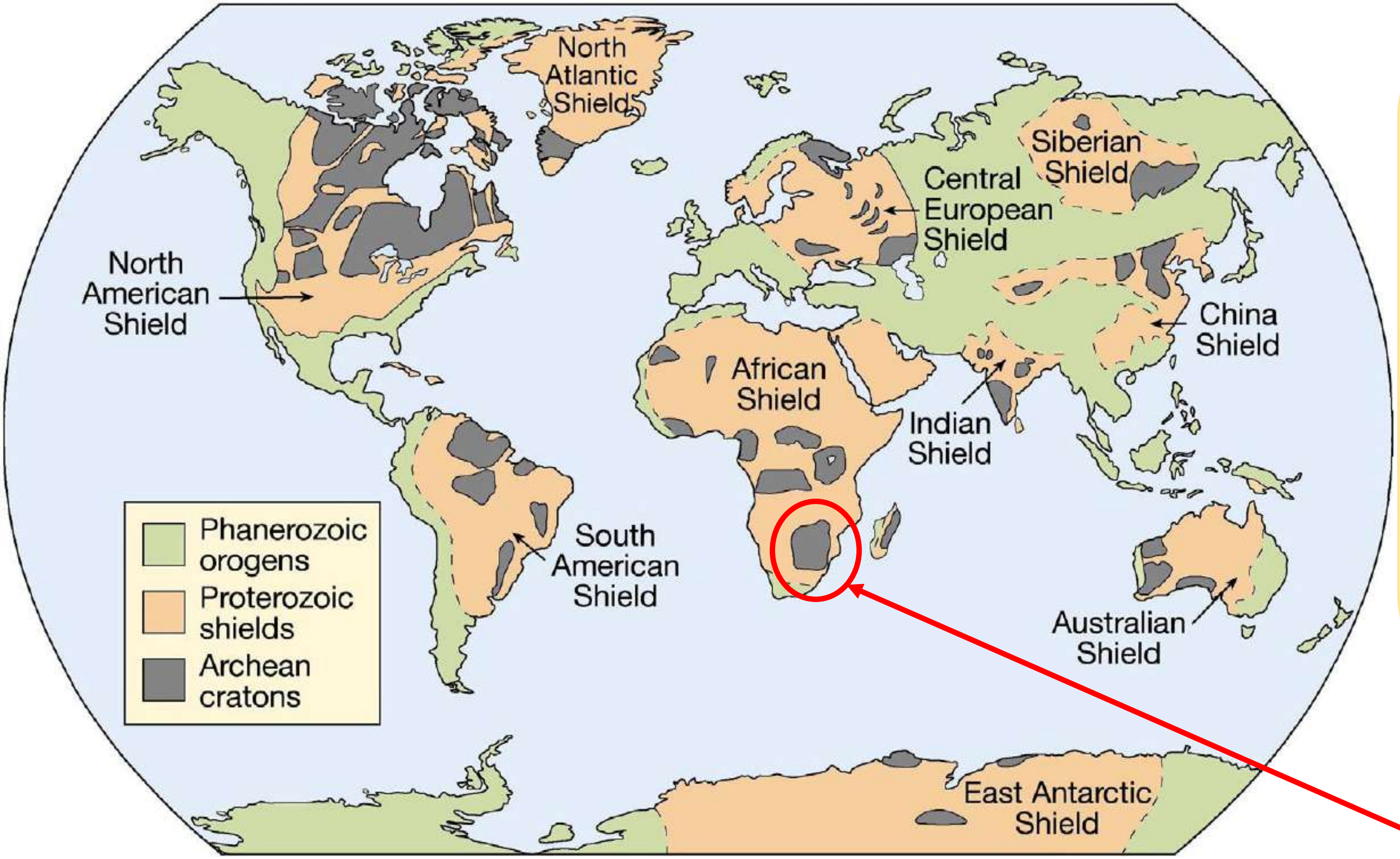
Master Student:	Brian Mapingere
Supervisor:	Prof. Jérémie Lehmann
Co-Supervisor:	Prof. K.S. (Fanus) Viljoen

Outline

- Introduction – Observations about Archaean greenstone belts in general
- Geological setting of the Mwanesi greenstone belt (MGB)
- Preliminary results from our fieldwork in the MGB
  - Tectonostratigraphy of the MGB
  - Deformation of the MGB
  - Gold mineralisation and mining in the MGB
  - Unknown facts about the MGB and the way forward
  - Summary

Folded BIF, MGB

Introduction - Some observations about greenstone belts



Furnes *et al*. (2013)

- Common in Archaean cratons
- Age range from 3600 – 2500 Ma
- Variably deformed and adjacent to granites and gneisses
- Varied structuring, conditions of accretion and stabilisation

(Anhaeusser, 2014)

Zimbabwe and Kapvaal cratons

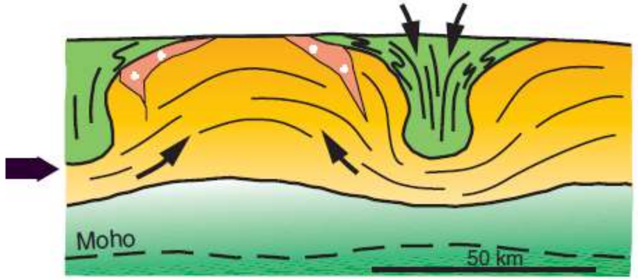
Introduction Cnt'd

- The sequences are affected by deformation during and after deposition
- Associated with a widespread deformation, metamorphism, metasomatism and mineralisation (Anhaeusser, 2014)
- Tectonic evolution of Archaean greenstone belts is still debatable (e.g. Cawood et al. 2018; Gapais, 2018; Brown *et al*. 2020)
- Archaean greenstone belts host most known orogenic gold deposits worldwide (Groves and Foster, 1991)
- Source of gold mineralising fluids remains controversial (Goldfarb and Groves, 2015; Groves *et al*. 2019a, 2019b)

Models of evolution of Archaean greenstone belts

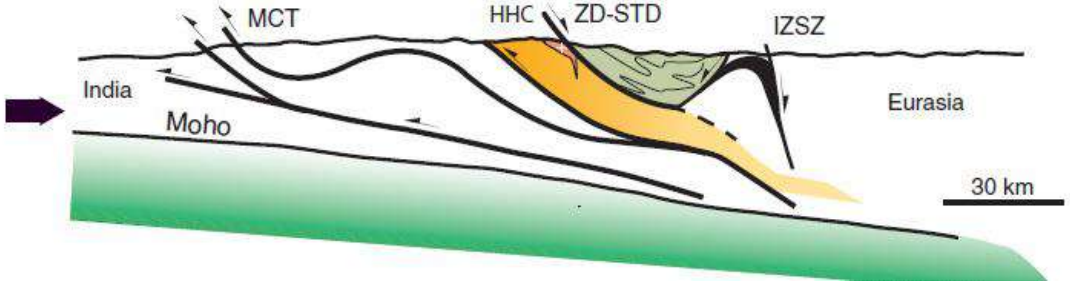
Vertical Tectonics

Gravity-driven deformations
vertical motions involving sagduction of heavy greenstones and rising of light underlying partially melted crust



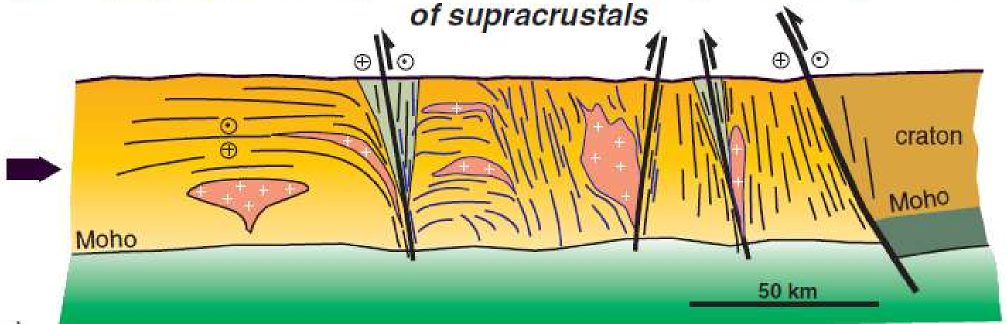
Modern-type Tectonics

Convergence tectonics between stiff plates
crustal-scale thrusts
and exhumation of high pressure rocks along detachments



Pop-down Tectonics

Convergence tectonics of hot and buoyant lithosphere
horizontal longitudinal flow combined with vertical tectonics and burial of supracrustals



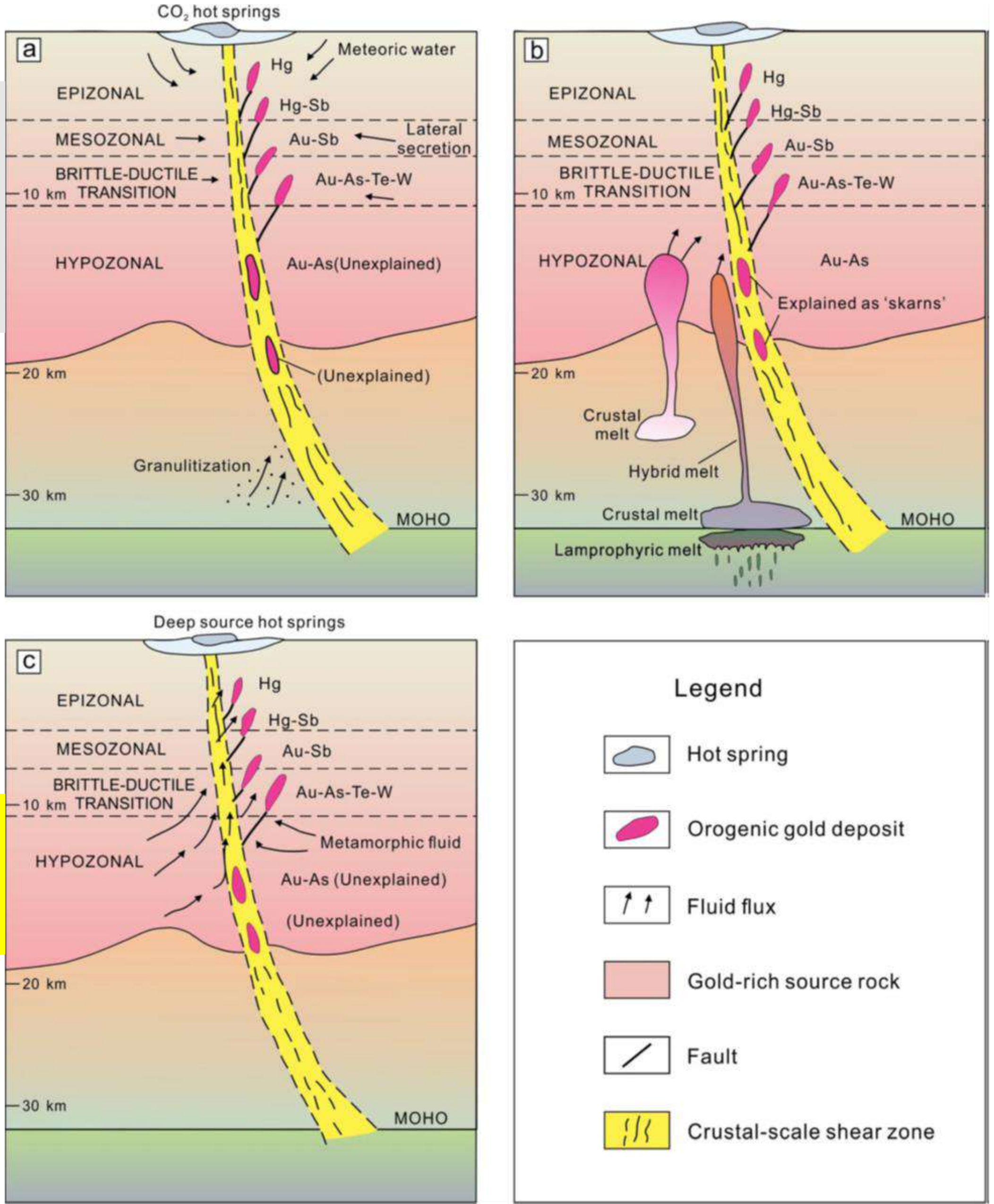
With all these models that have been suggested so far, no model seems universal in explaining the varied evolution of these Archaean terrains!

Schematic diagrams of tectonic models are from Gapais (2018) and references therein.

Ore-fluid source models for orogenic gold deposits

Shallow crustal meteoric or metamorphic models and granulitization Models (invalid?)

Magmatic-hydrothermal models (non-unifying)



Generally accepted supracrustal metamorphic models

Schematic diagrams of ore-fluid source models for orogenic deposits are from Groves *et al*. (2019a) and (2019b), adapted from Groves and Santosh (2016).

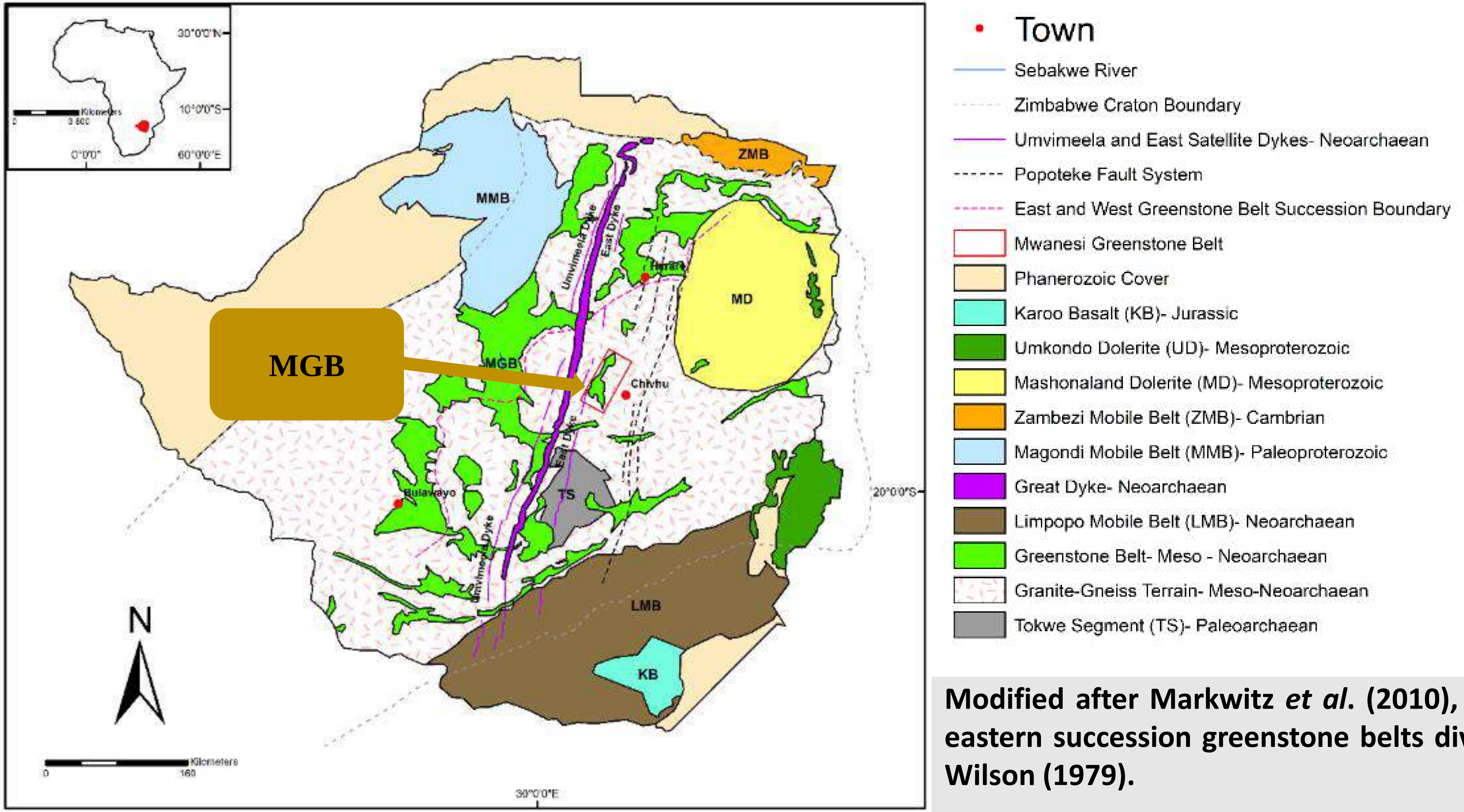
We address the following questions by studying the MGB

1. The tectonic evolution of Archaean greenstone belts
2. Ore-fluid source models for orogenic gold deposits
3. The timing of gold mineralisation in orogenic gold deposits

Why the MGB?

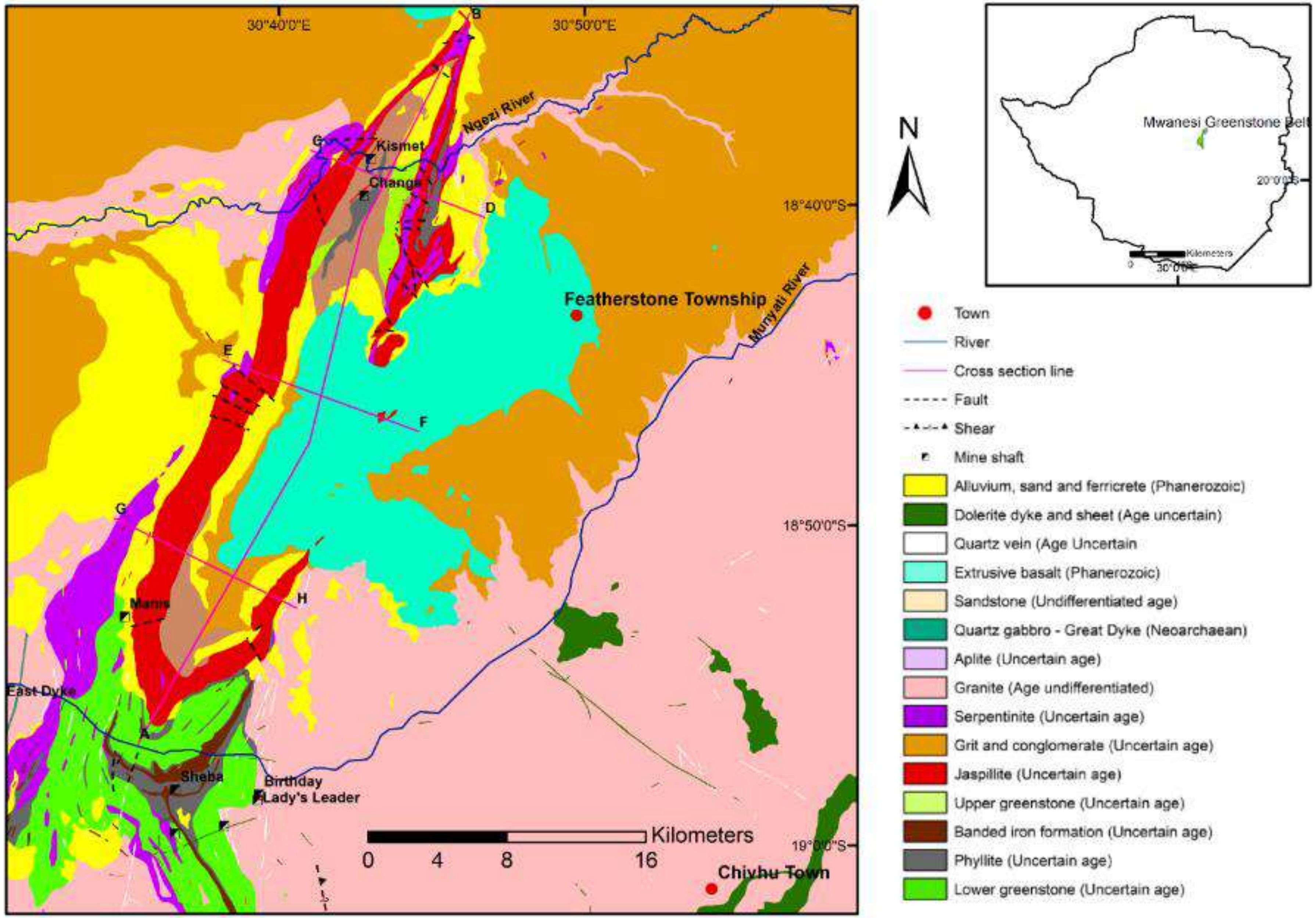
- One of the least studied greenstone belts in Zimbabwe
- Low gold endowment in the greenstone belt compared to other greenstone belts in the Zimbabwe Craton.

Regional Geology

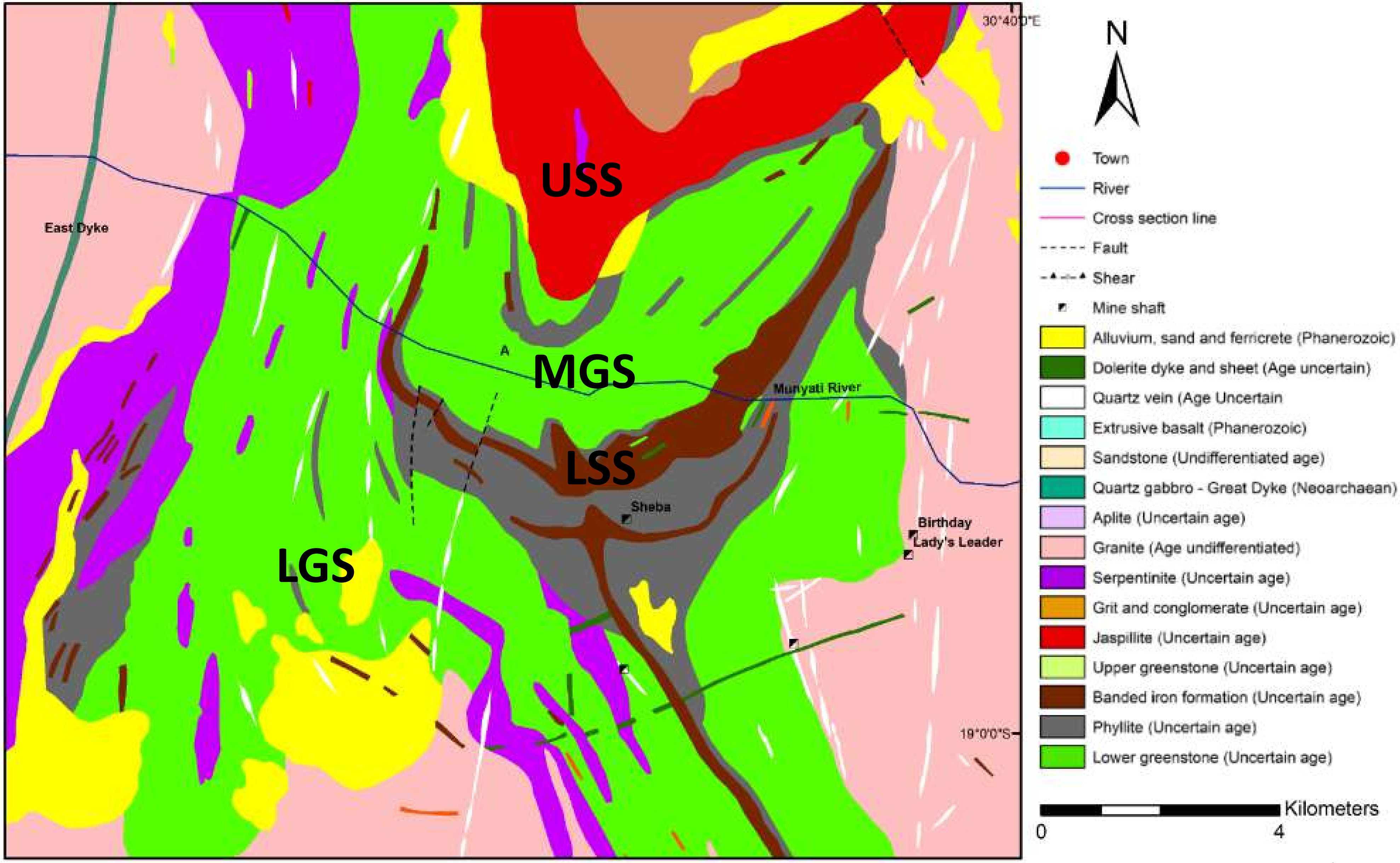


Modified after Markwitz *et al*. (2010), Western and eastern succession greenstone belts division is after Wilson (1979).

Local Geology



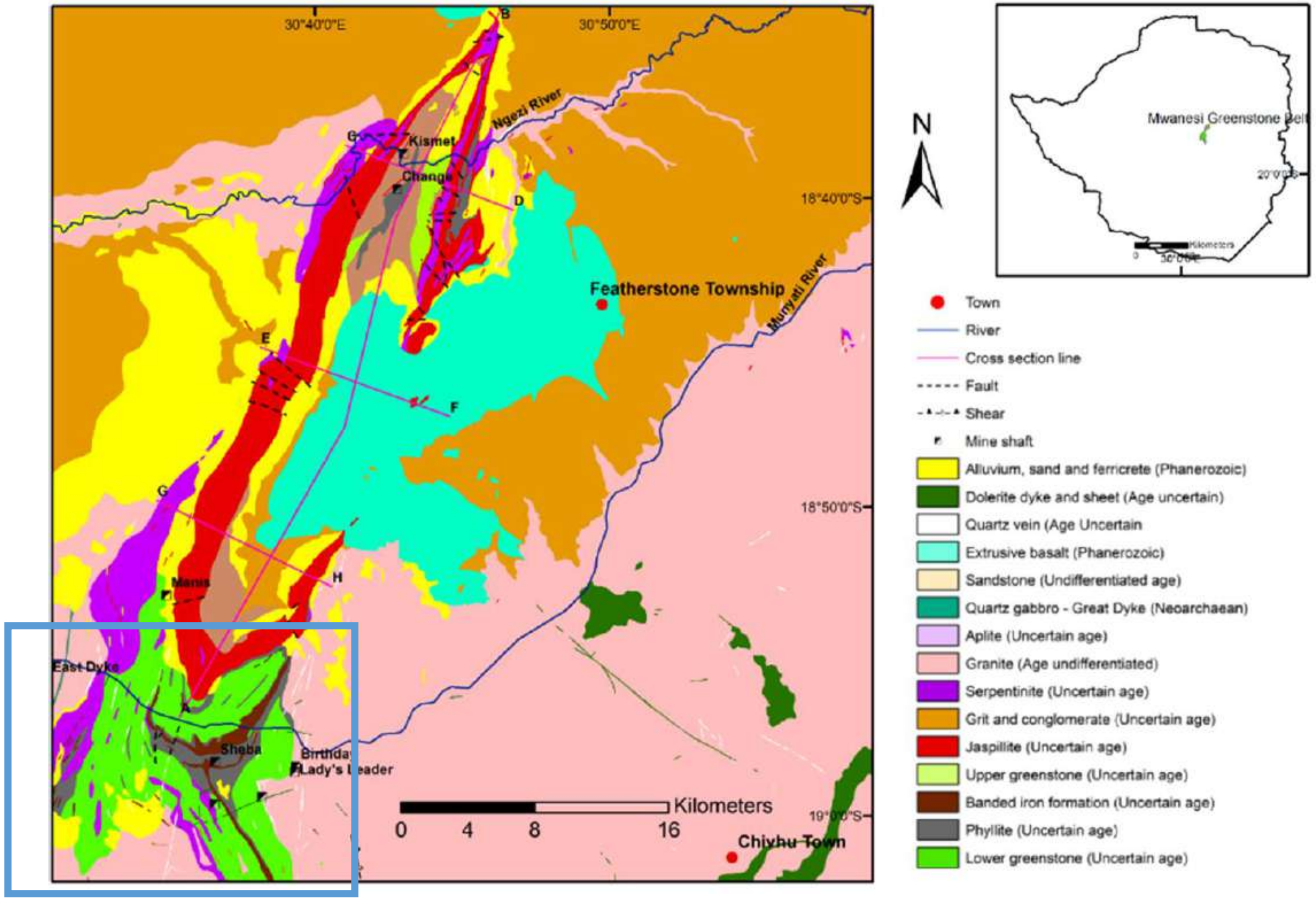
Modified after Worst (1962)

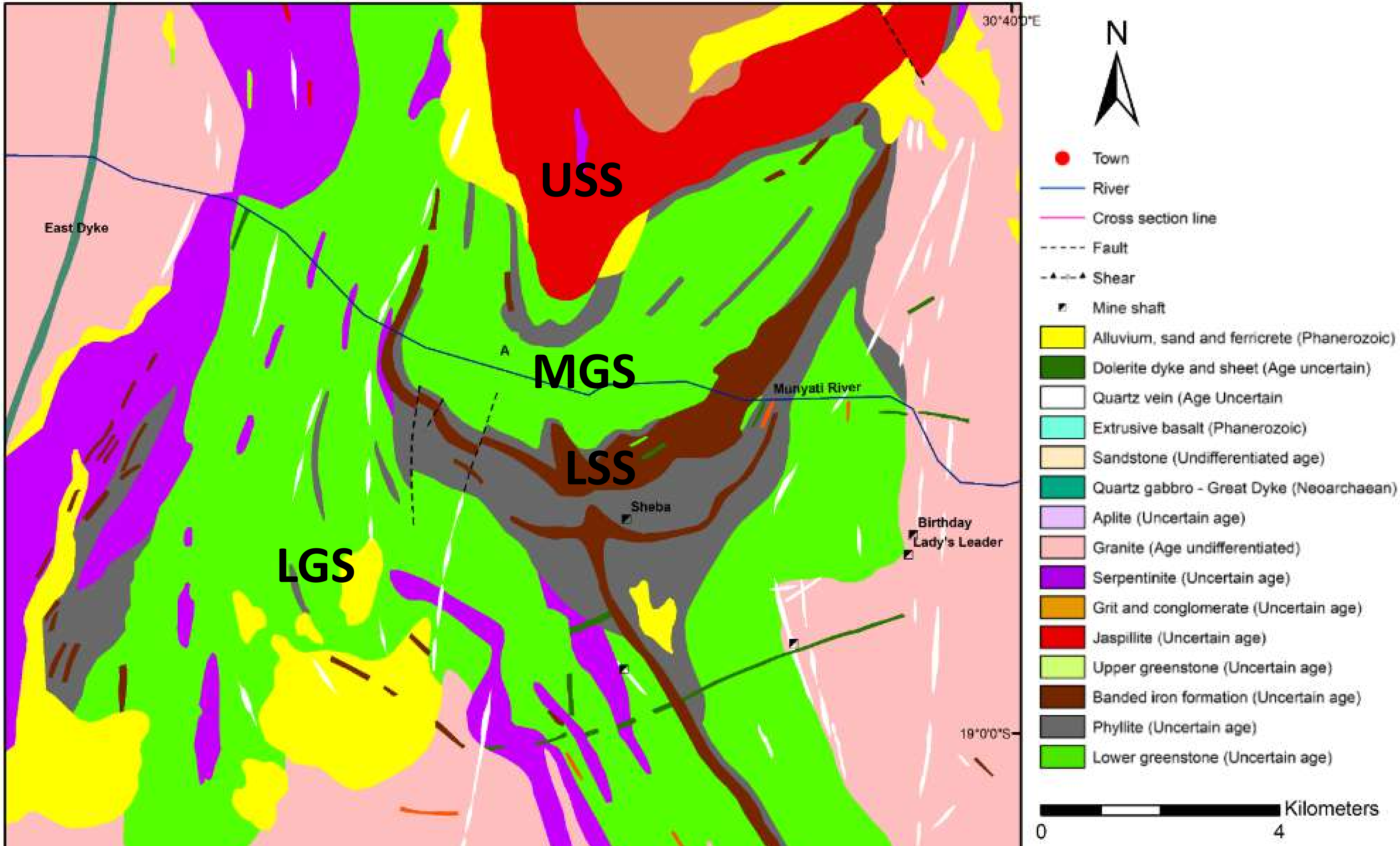


Modified after Worst (1962)

USS	Upper Sedimentary Series
MGS	Medium Greenstone Series
LSD	Lower Sedimentary Series
LGS	Lower Greenstone Series

Preliminary results from the fieldwork conducted in the southern part of the MGB





USS	Upper Sedimentary Series
MGS	Medium Greenstone Series
LSD	Lower Sedimentary Series
LGS	Lower Greenstone Series

Modified after Worst (1962)

Tectonostratigraphy of the MGB

Lower Greenstone Series

- Characterised by basaltic lavas (locally pillowed), volcanic breccia
- Intrusive mafic rocks present
- Intercalated with phyllite
- Probably subaqueous origin


Pillow with fractures filled by quartz


Deformed pillows


Intrusive mafic rock

Phyllite with quartz veins


Volcanic breccia

Clast with amygdales

Tectonostratigraphy of the MGB

Lower and Upper Sedimentary series

- Folded BIF
- Phyllite in some places

Folded BIF

Phyllite outcrop

Tectonostratigraphy of the MGB

Middle Greenstone Series

- Characterised by essentially basaltic lavas, pillowed in some places
- Pillows deformed
- Younging direction not very clear

Basalt

Pillow basalt

Tectonostratigraphy of the MGB

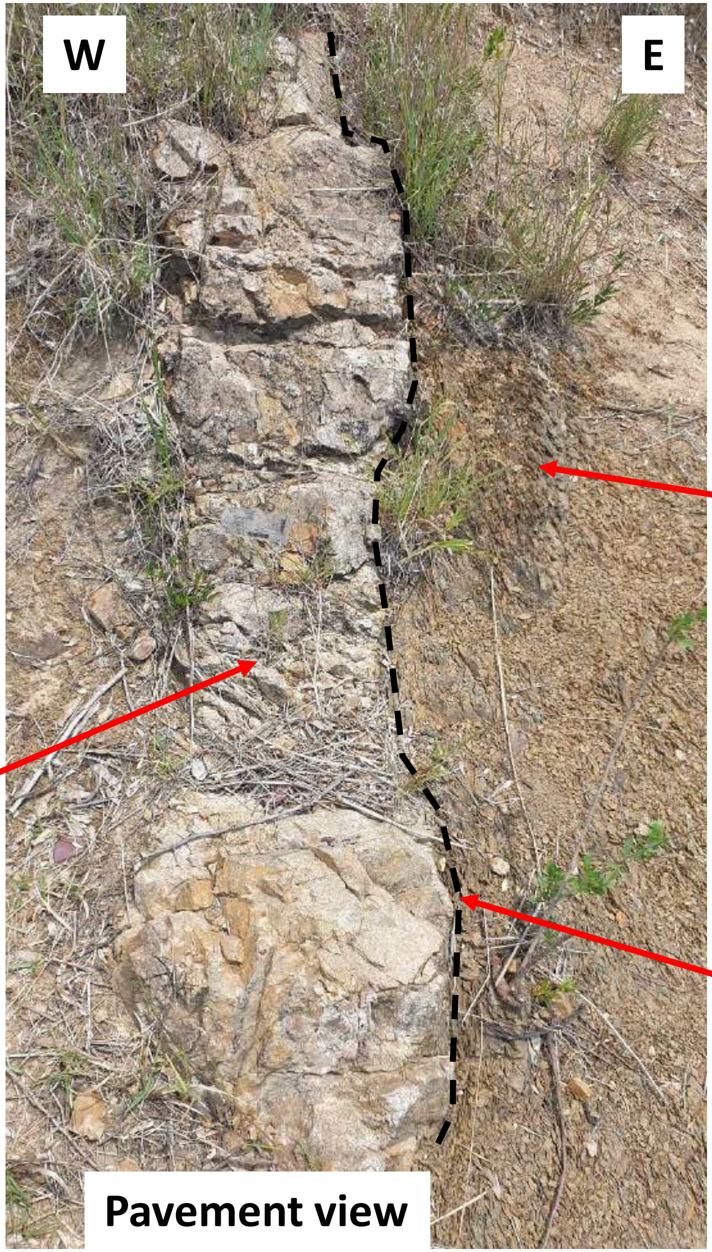
Adjacent gneissic granites

- Gneissic porphyritic to medium grained granites (a)
- Gneissic leuco-granites intercalated with grey gneisses (b)
- Ultramylonite grading eastwards into protomylonite (c) away from the core of the shear zone
- Granites become less deformed E of the greenstone belt

Tectonostratigraphy of the S MGB

Adjacent gneissic granites

- Adjacent granites younger than the greenstone
- Granites intrusive into the greenstone



Foliated greenstone meta-volcanic rock

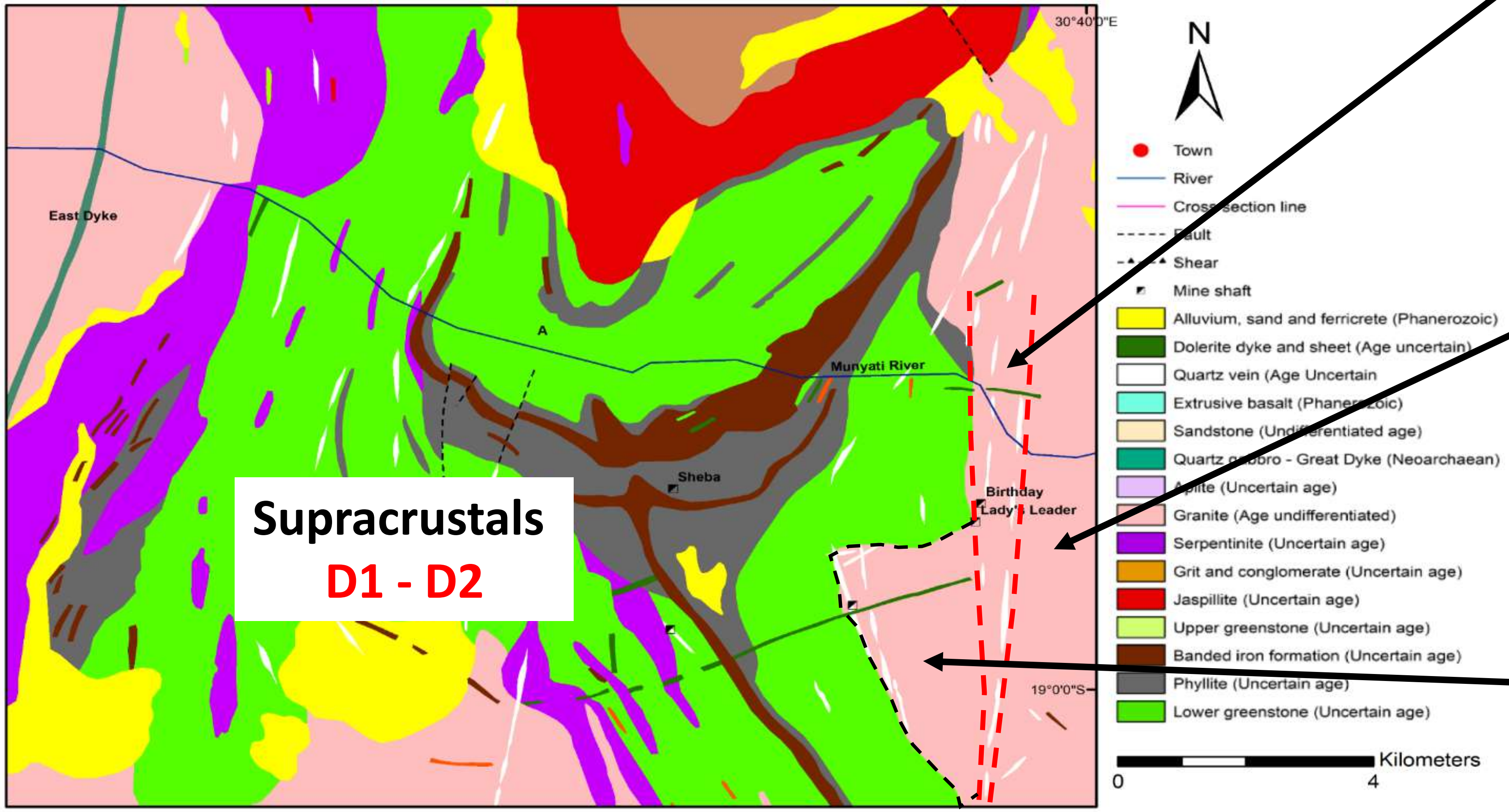
Granite dyke intruding into the greenstone

Granite dyke-greenstone contact

Deformation of the MGB

Deformation domains in the MGB

- The deformation events (D1, D2) in the separate domains are treated as localized events

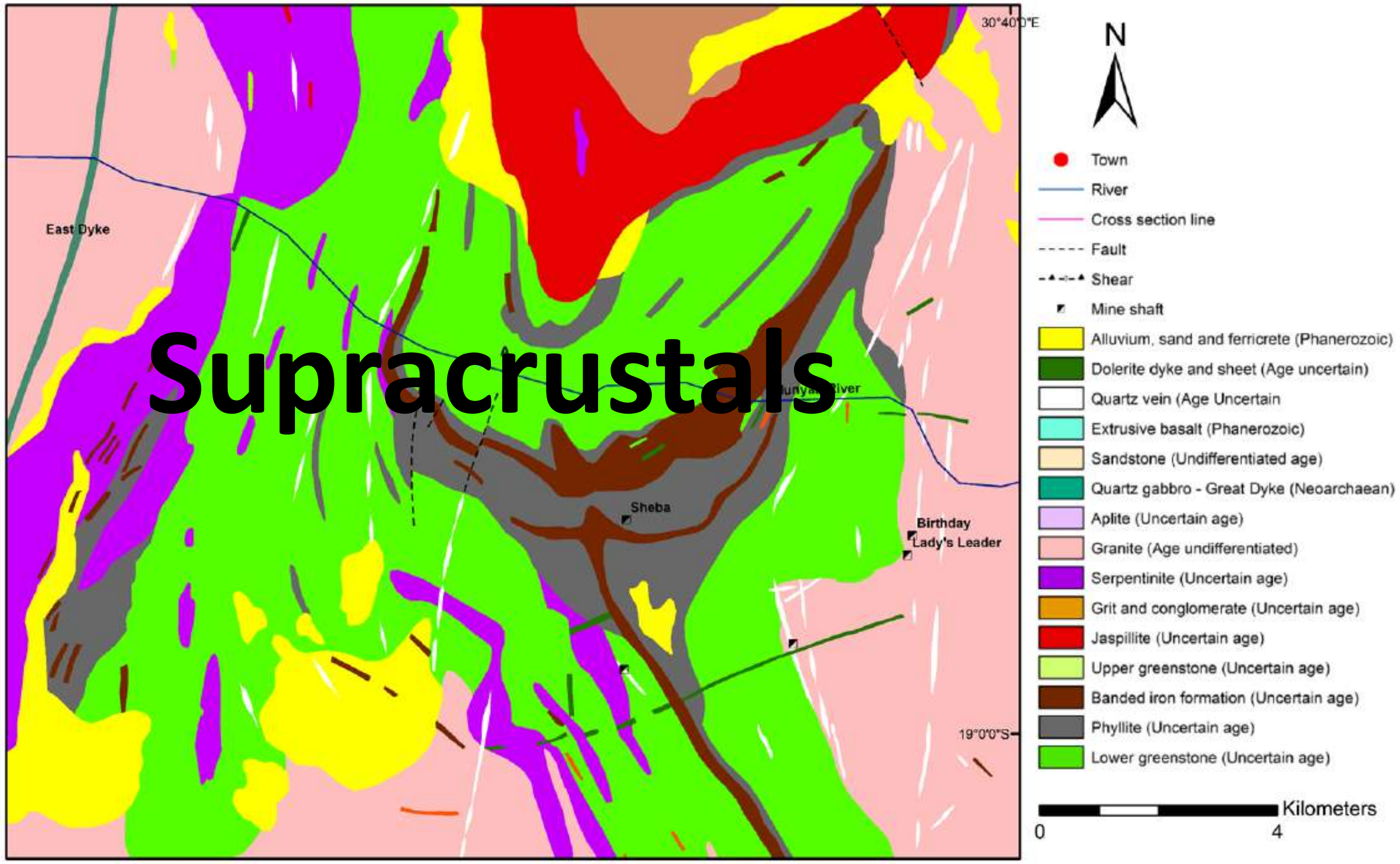


Shear zone
D1 – D2

Gneissic granites E of the shear zone
D1 – D2

Gneissic granites W of the shear zone
D1 – D2

Deformation in the Supracrustals

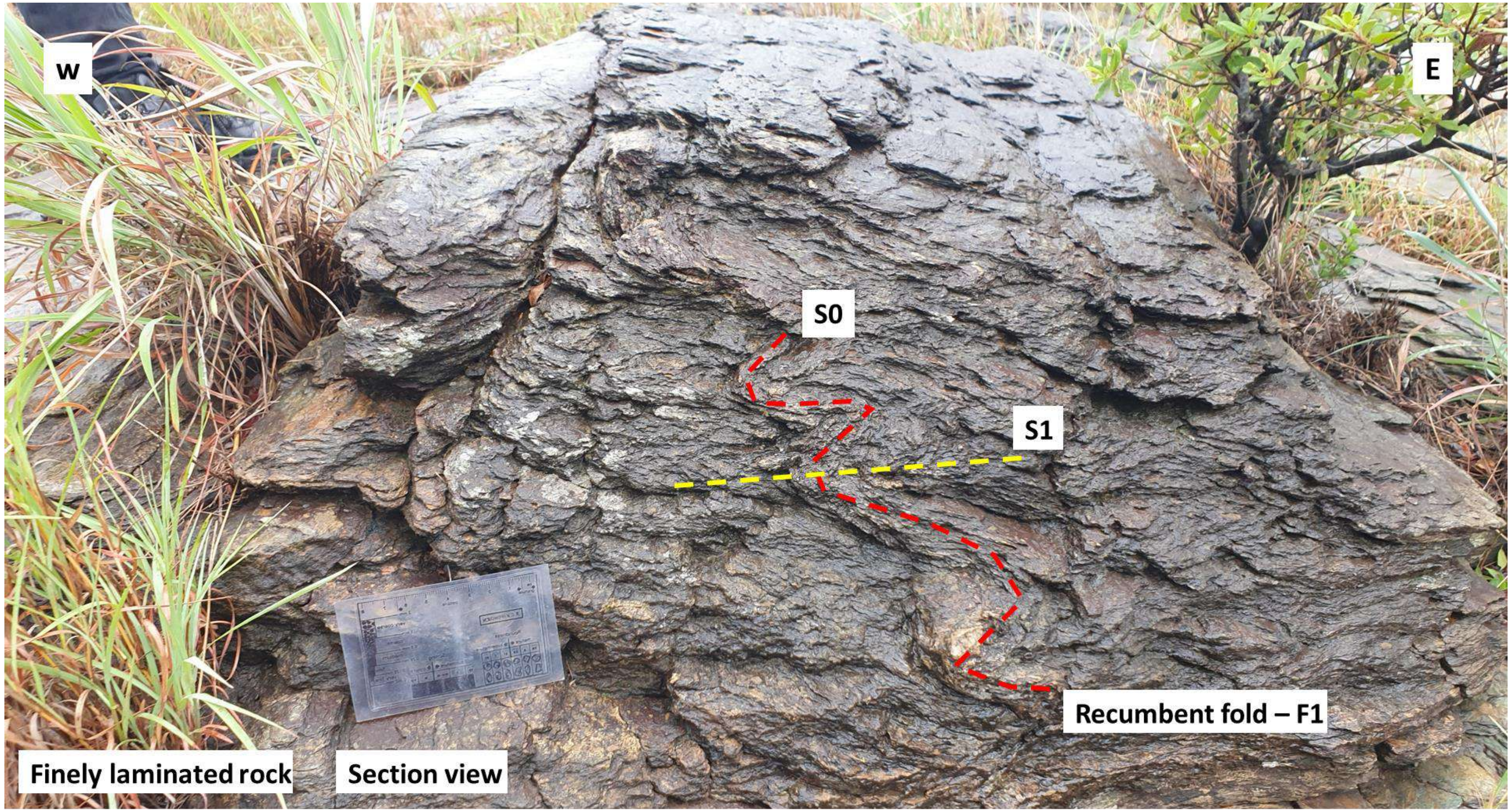


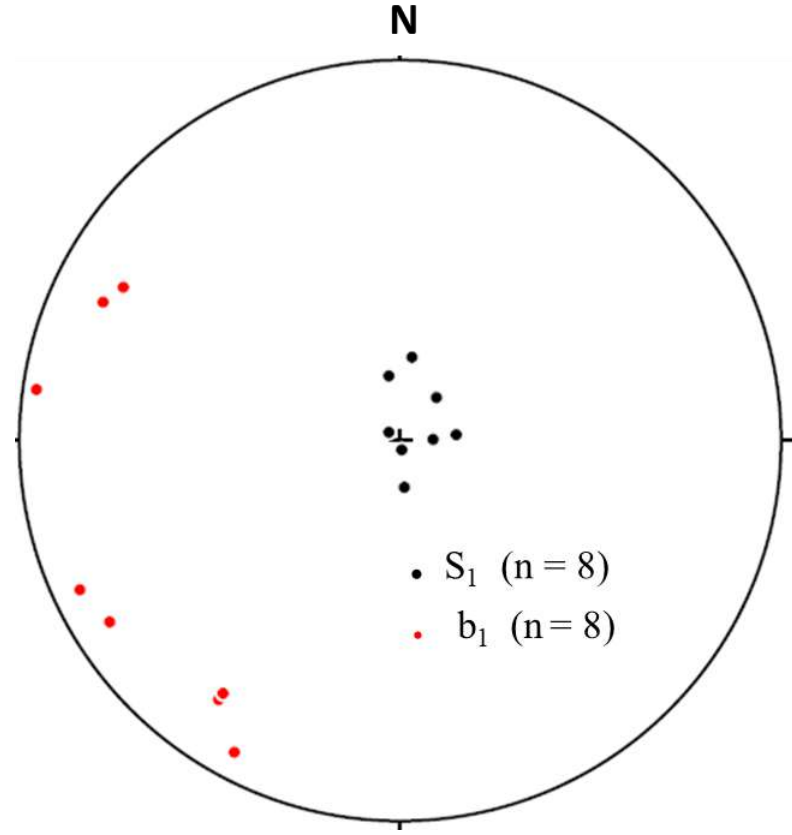
2 deformation phases observed

1. D1 – formation of axial planar cleavage associated with recumbent folding.
2. D2 – folding of axial planar cleavage of recumbent folds forming a new axial planar cleavage.

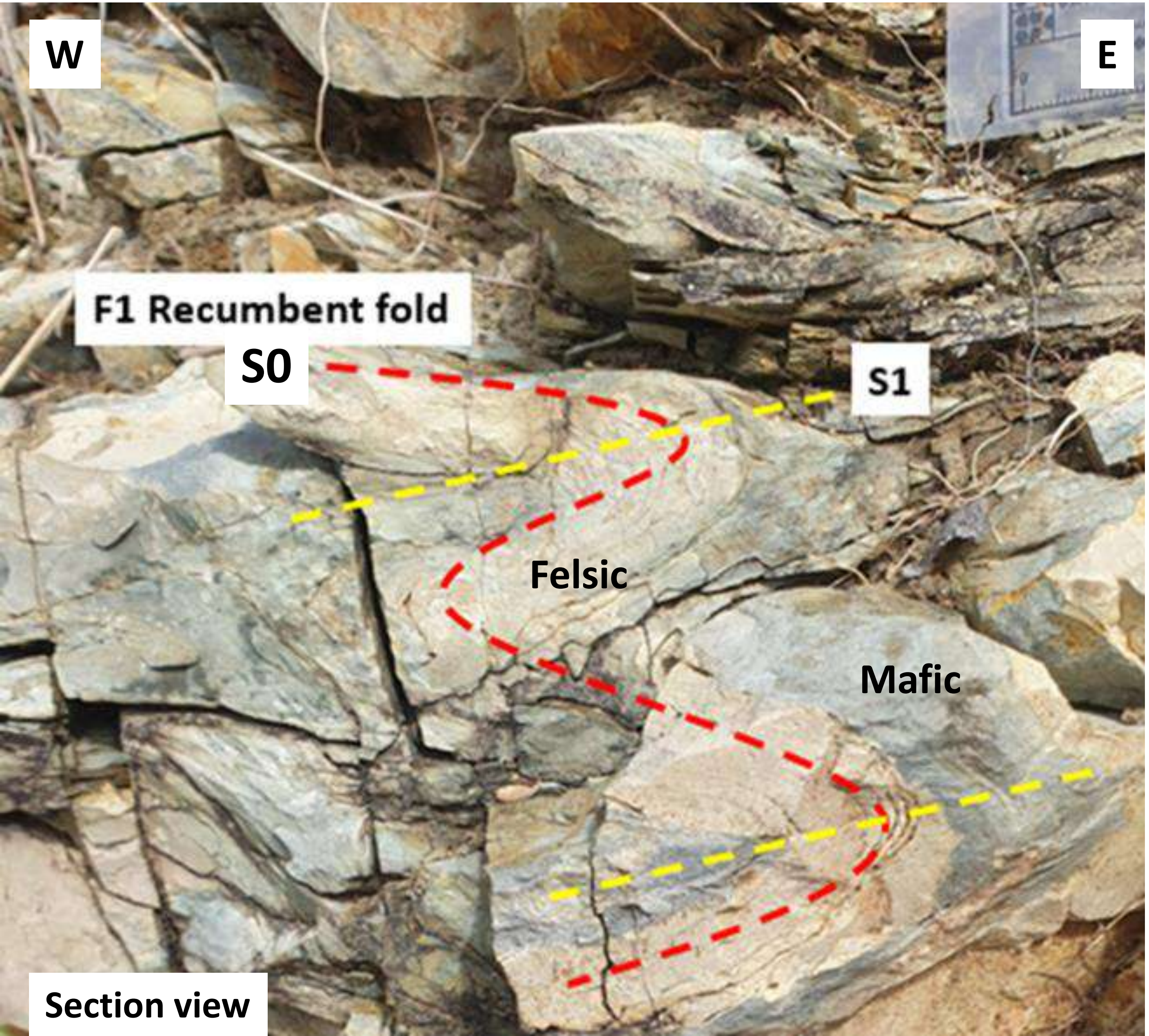
Supracrustals – D 1 event

- Recumbent folding - F1
- Shallow SW to NW dipping S1 – axial planar cleavage
- Fold axis plunging between SW & NW





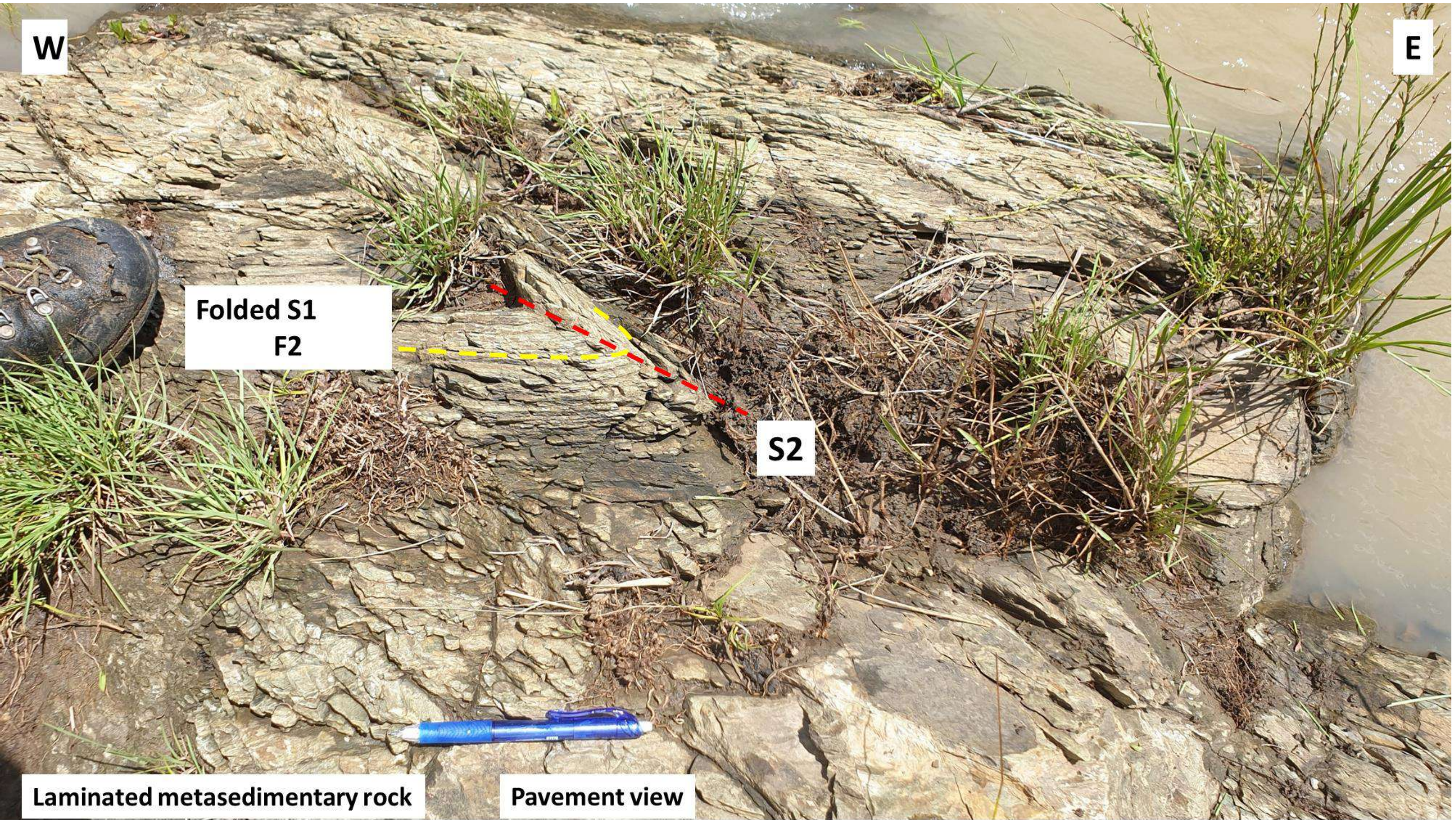
Supracrustals – D 1 event

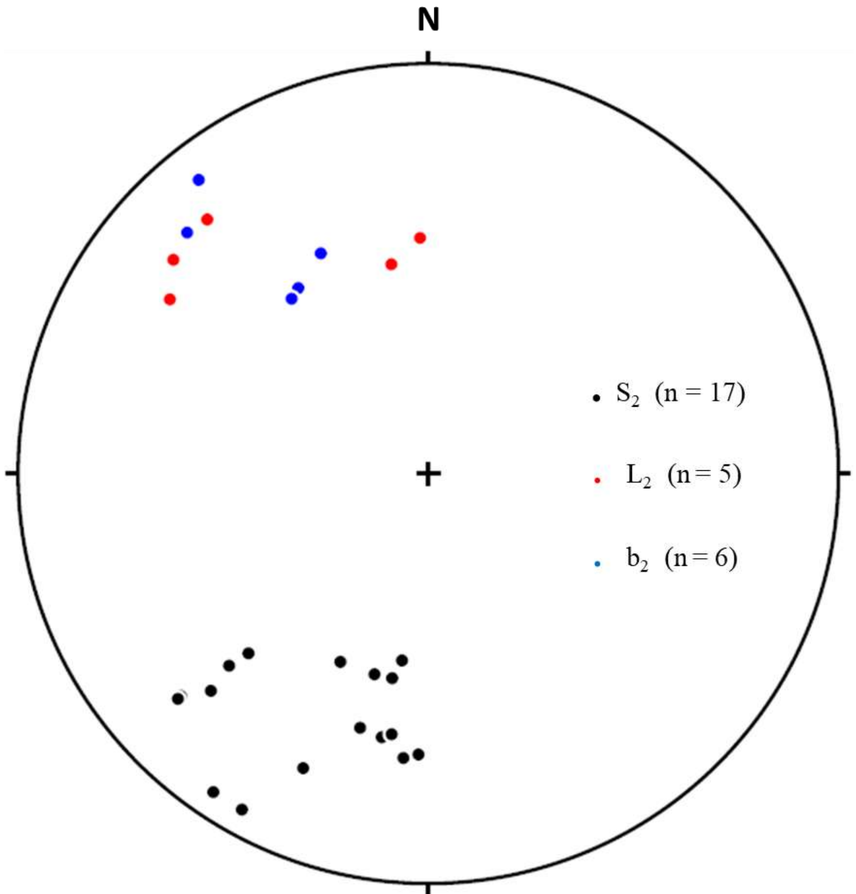


- Greenstone rock with mafic and felsic layers
- Folded S0
- Axial planar cleavage S2

Supracrustals – D 2 event

- Folded S1 (F2) forming NE to NNE dipping S2- axial planar cleavage
- Fold axis plunging NNW
- Lineation plunging generally to the NW





D 1 and D2 in the Supracrustals

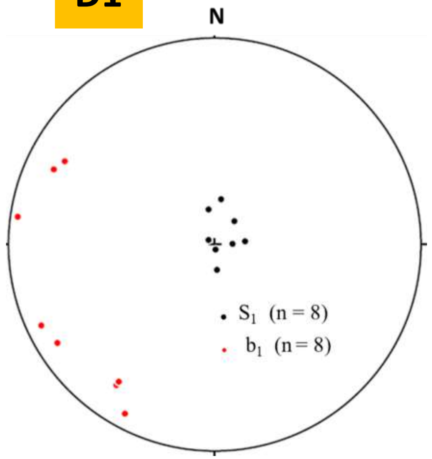
D1

- Formation of shallow SW to NW dipping axial planar cleavage (S1) associated with recumbent folding
- Shortening direction not yet known

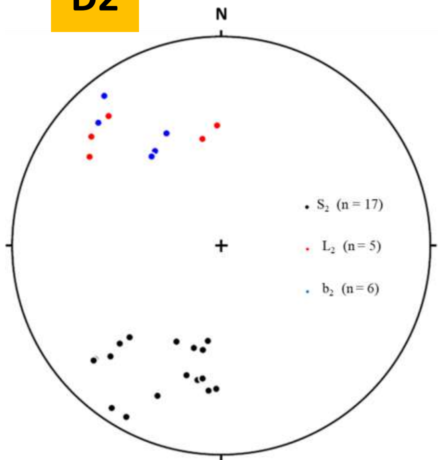
D2

- Folding of the earlier formed axial planar cleavage (S1) forming a new NE to NNE dipping axial planar cleavage (S2)
- Associated with broad NNE – SSW shortening

D1

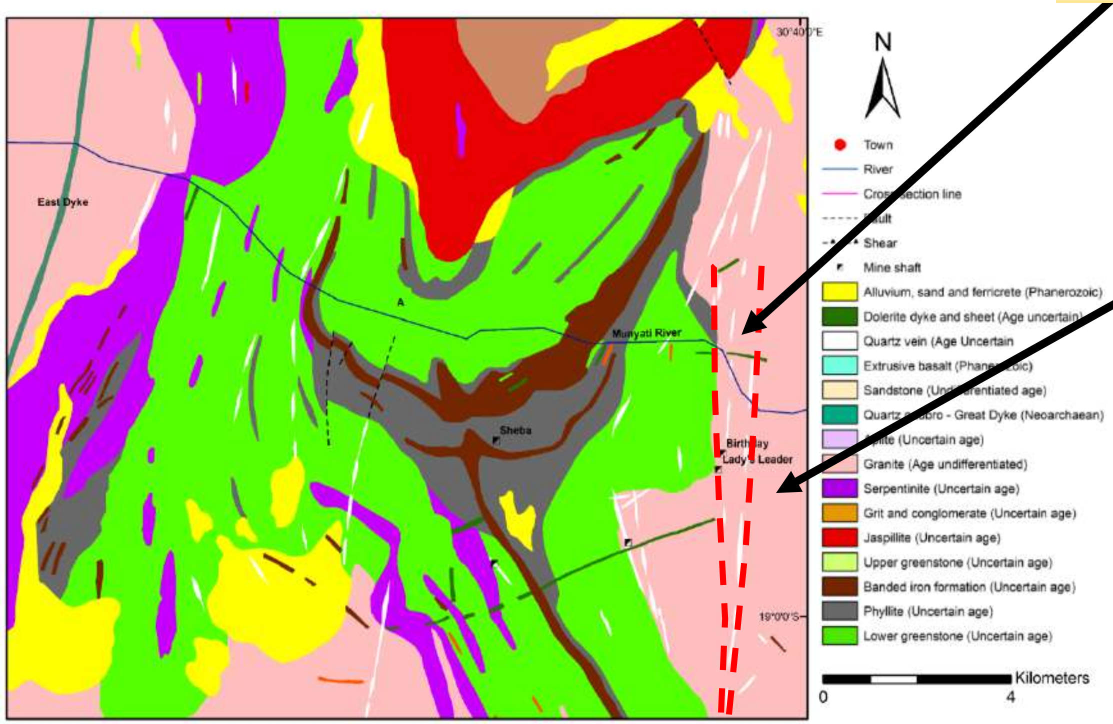


D2



Deformation in the gneissic granite E of the shear zone

Shear zone



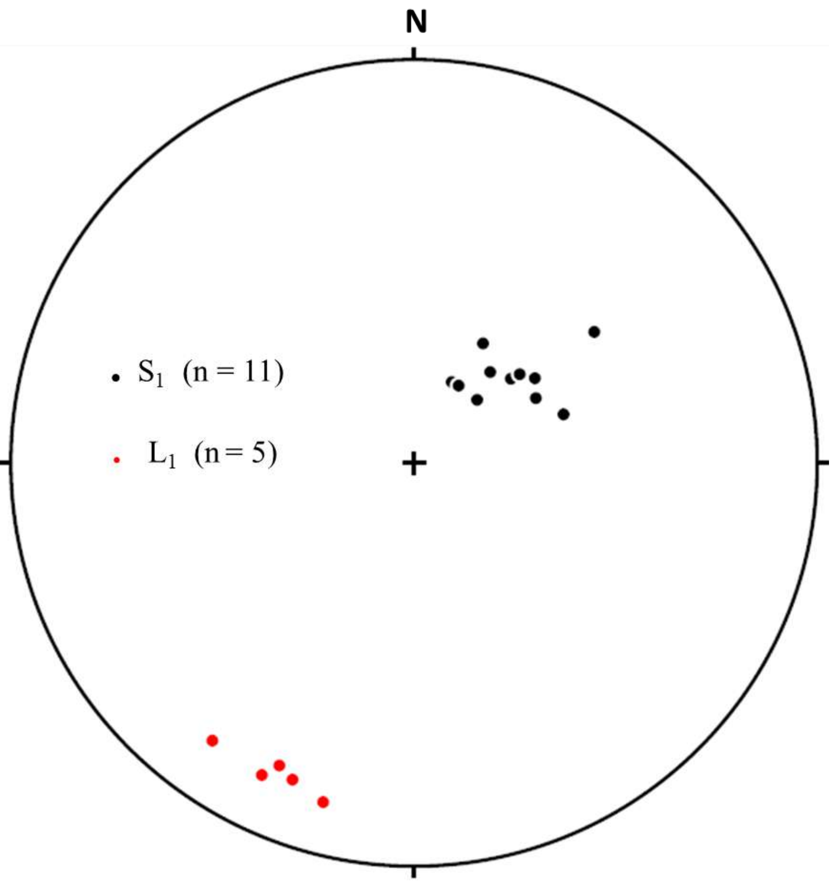
Gneissic granites E of the shear zone
D1 – D2

Deformation phases

1. D1 – gneissic foliation (S1) formation
2. S1 overprinted by new gneissic foliation - S2

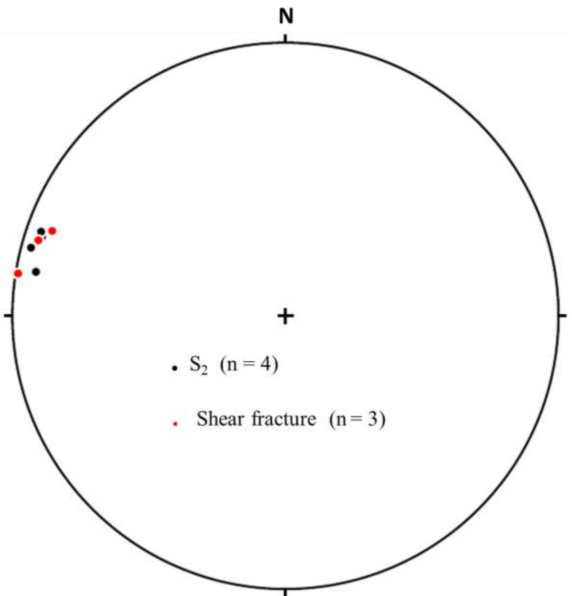
Gneissic granite E of the shear zone – D 1 event

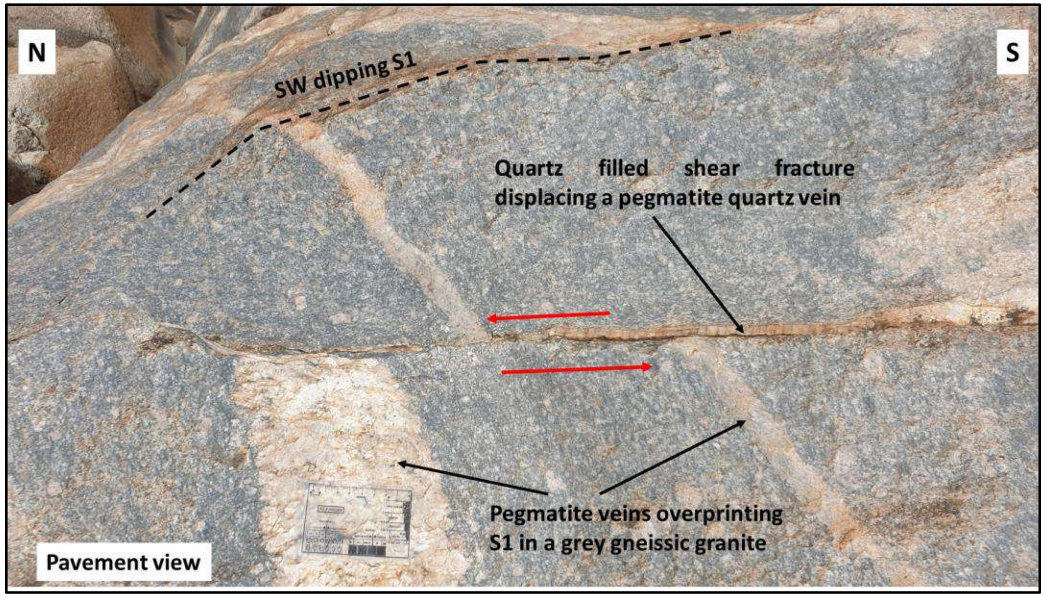
- Shallow SW dipping gneissic foliation - S1
- SSW plunging L1, not developed everywhere.

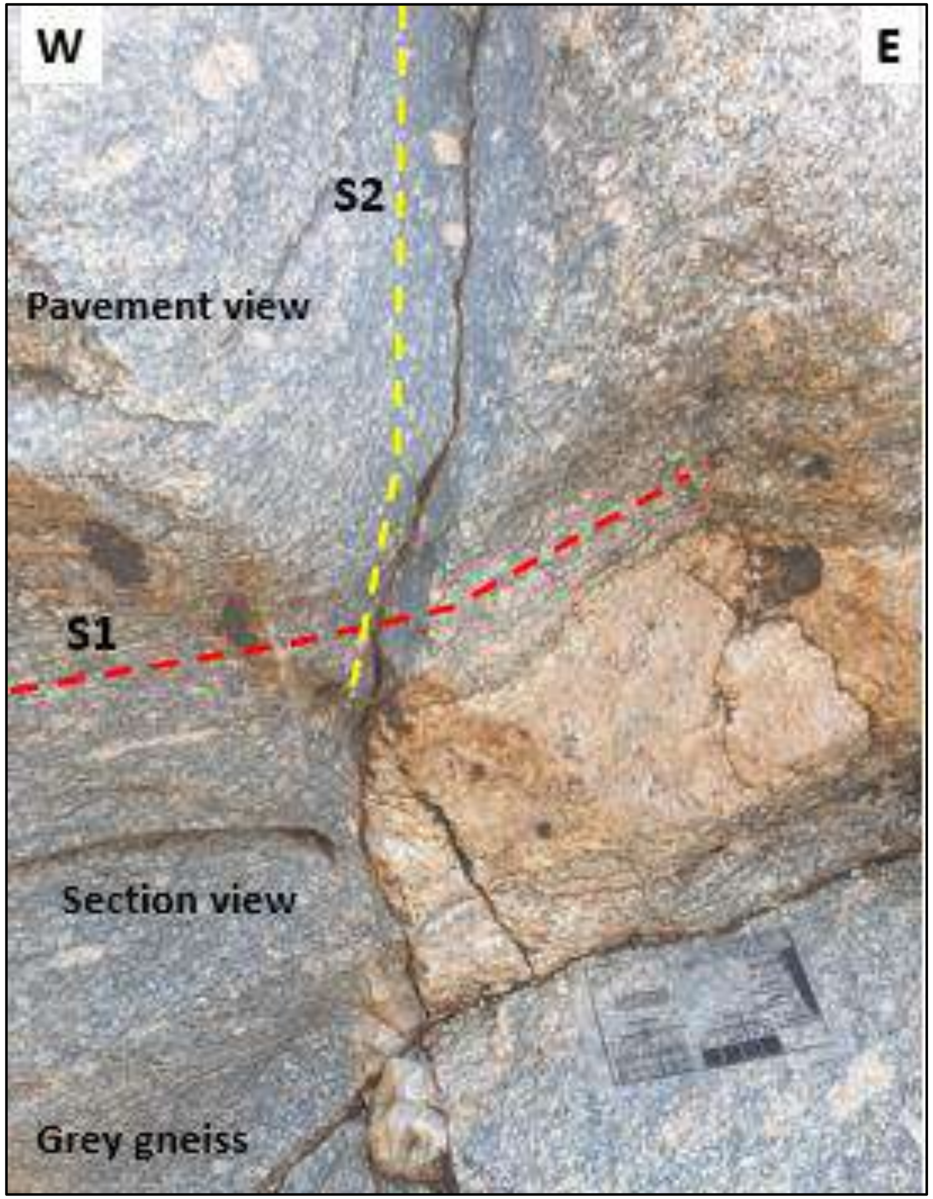


Gneissic granite E of the shear zone – D 2 event

- ESE steeply dipping (> 80º) gneissic foliation (S2) associated with sinistral shear fractures
- Shear fractures filled by quartz
- Pegmatite veins overprinting S1







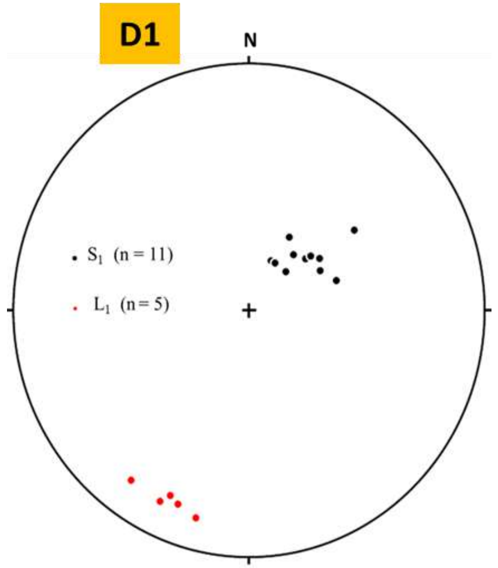
D1 and D2 - Gneissic granite E of the shear zone

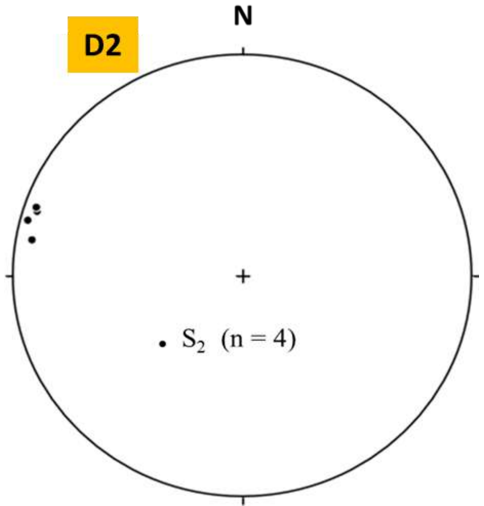
D1

- shallow SW dipping gneissic foliation S1,
- SSW plunging L1

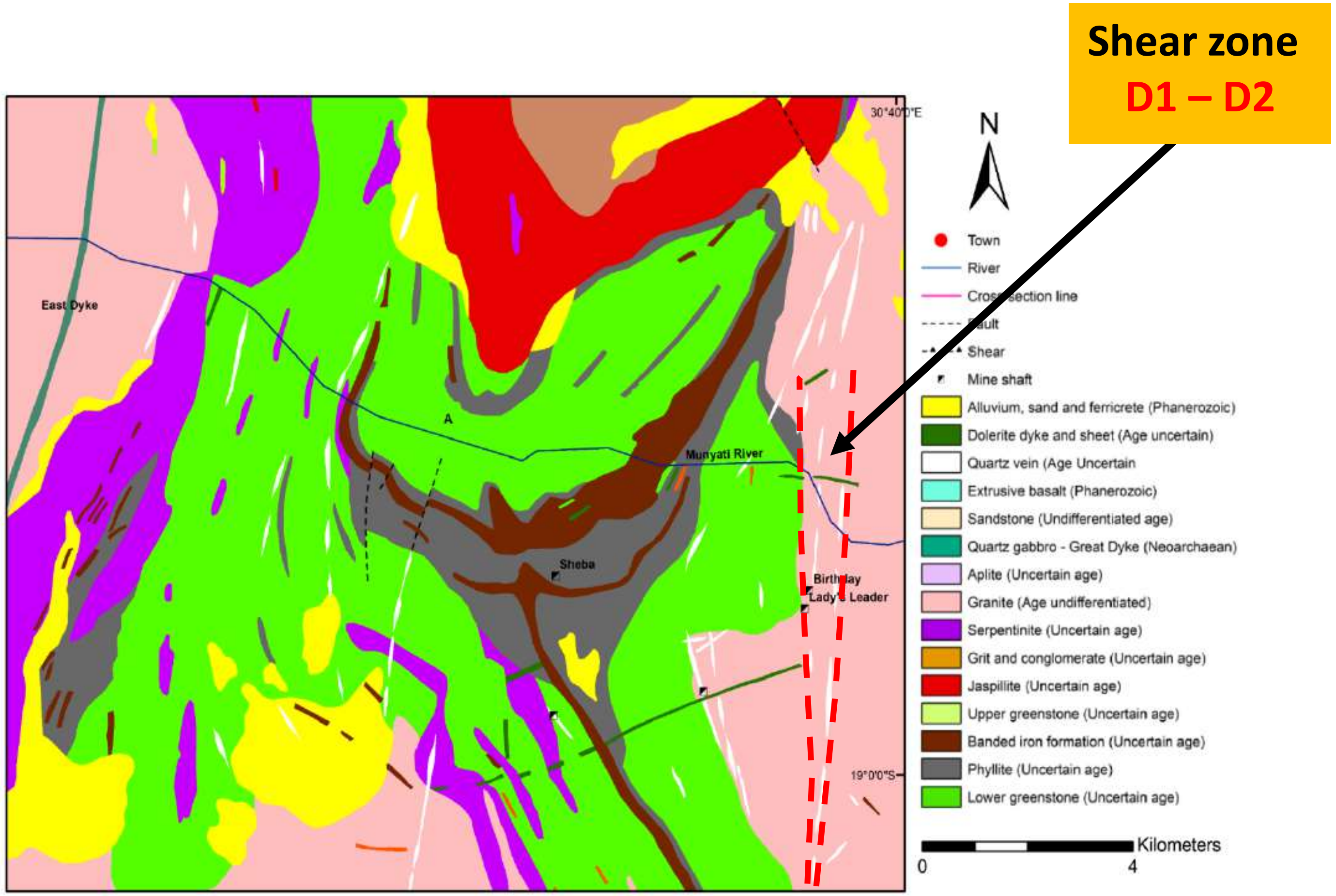
D2

- ESE steeply dipping gneissic foliation S2 overprinting S1
- Associated with shear fractures with apparent dextral shear sense
- Associated with NNW – SSE shortening





Deformation in the shear zone



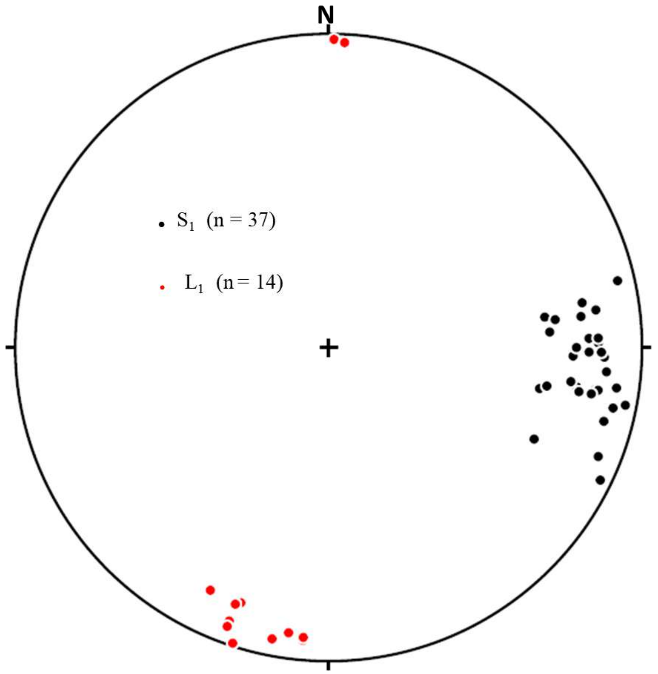
- A major structure in the south eastern margin of the belt,
- NNE - SSW striking
- Maximum width approximately 1 km
- Gradual change from ultramylonite to protomylonite, W-E

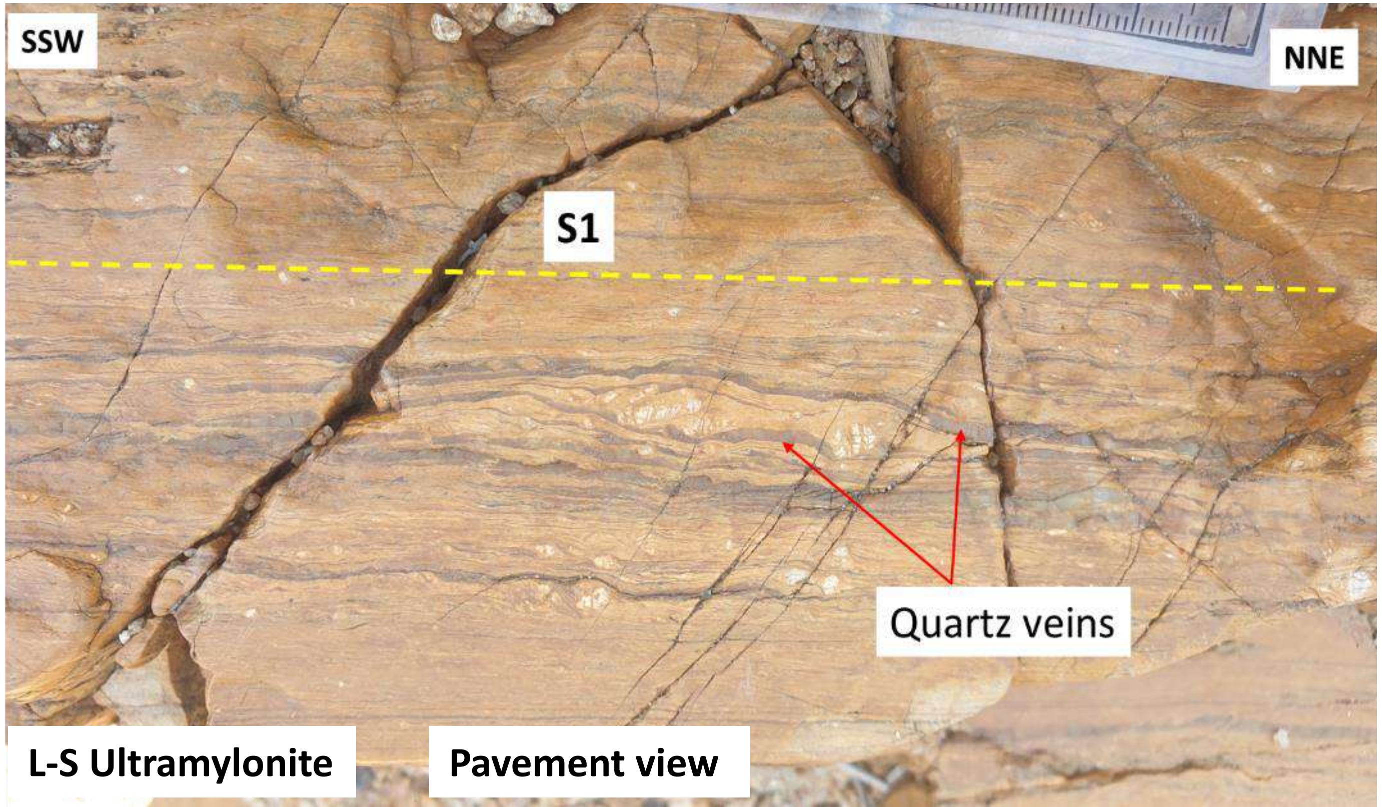
2 deformation phases observed

1. D1 - mylonite foliation (S1) formation and shear folding of S1
2. D2 - shear fractures overprinting S1

Shear zone – D1 event

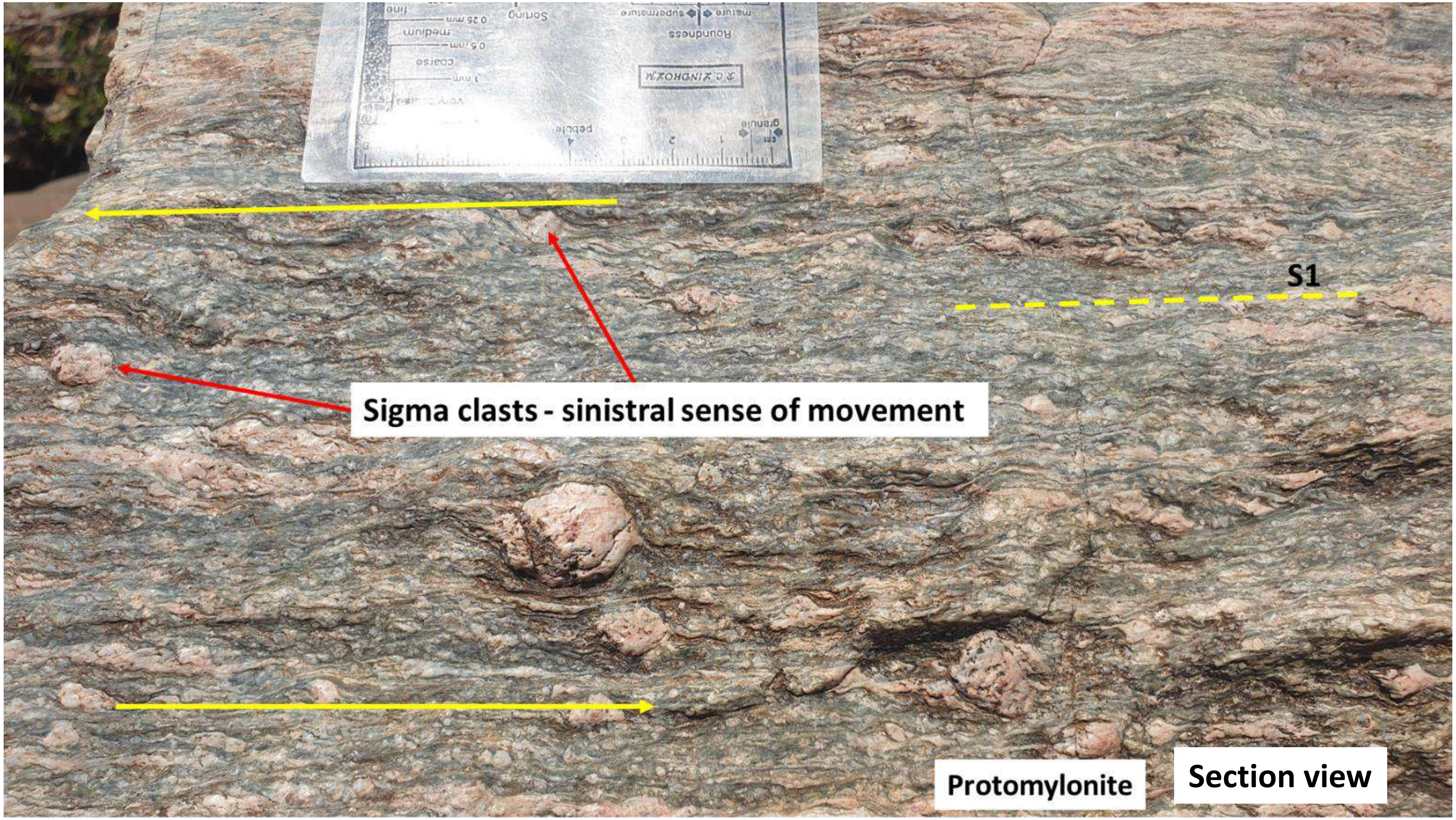
- N-S to NNE-SSW striking, generally steep (> 60º) mylonite foliation – S1
- SSW and NNE plunging mineral lineation
- S-L tectonite
- Pre-tectonic smoky quartz veins compatible with mylonite foliation orientation



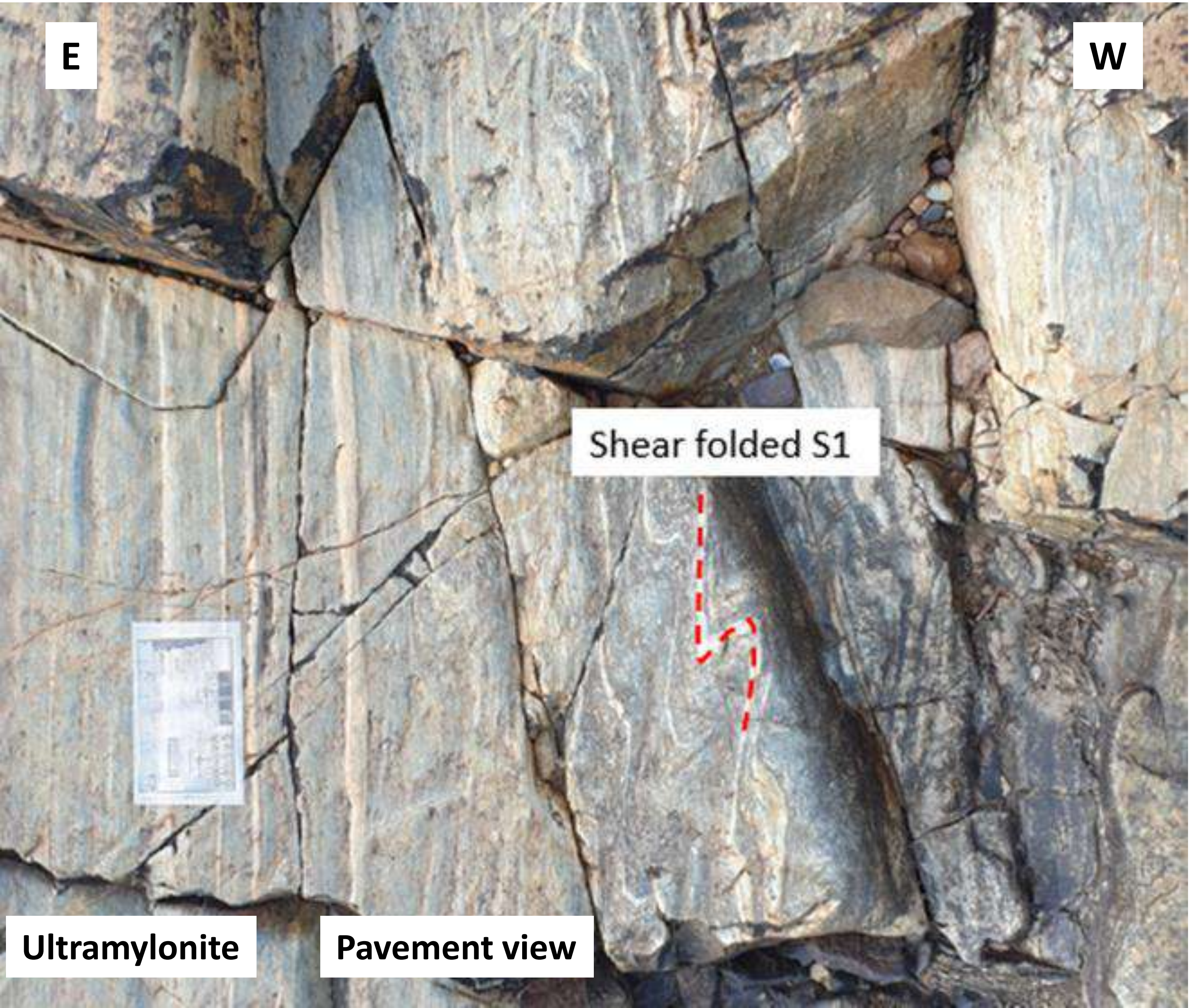


Shear zone – D1 event

- Associated with sinistral sense of movement

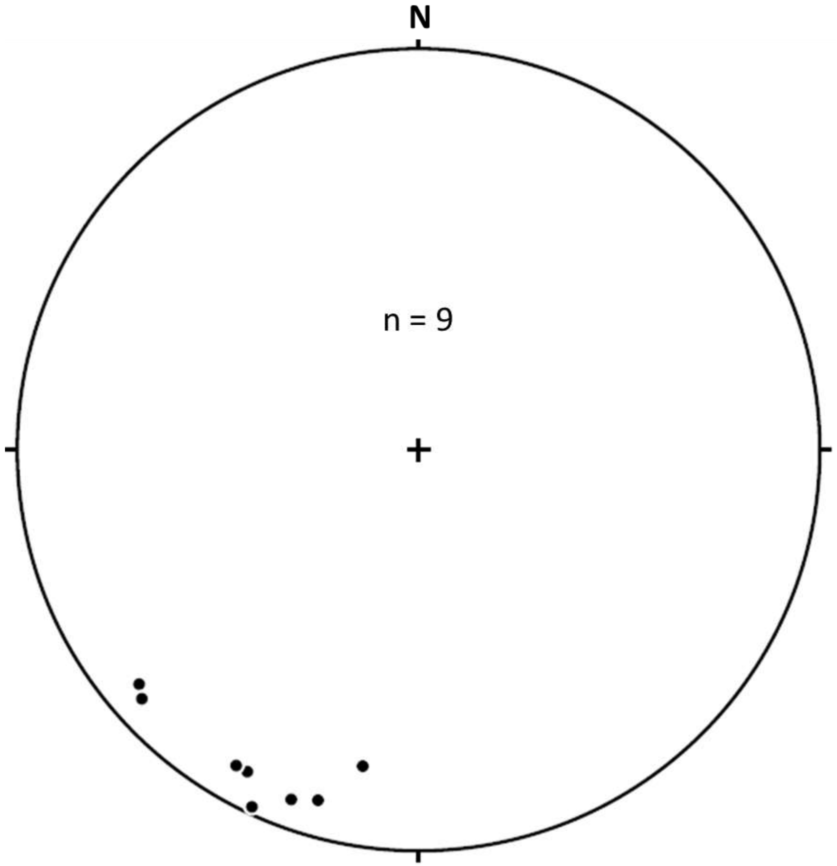


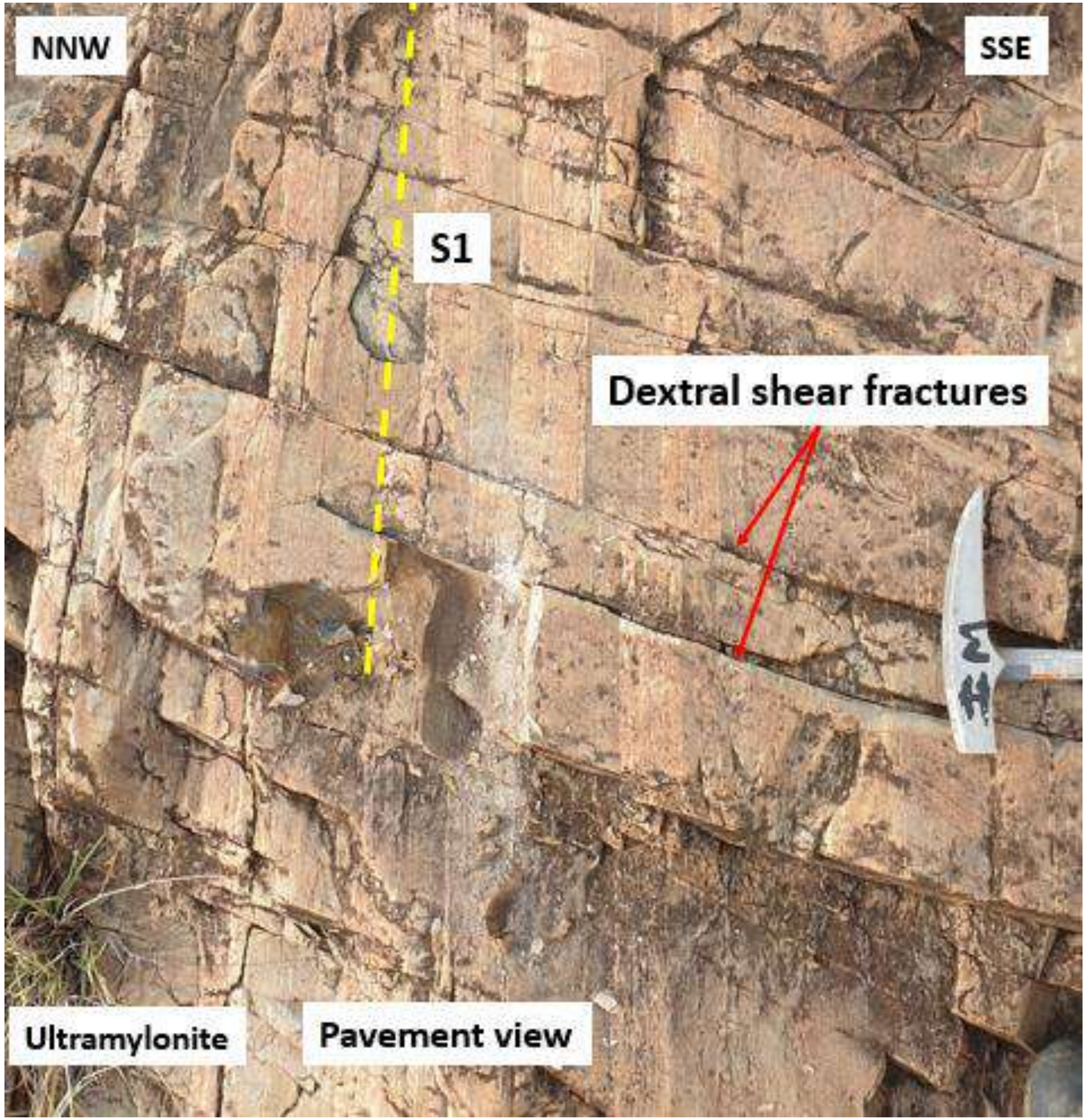
Folding of S1 in the Shear zone – D1 event



Shear zone – D2 event

- Steep (> 60º) NNE dipping shear fractures overprinting S1
- Apparent dextral sense of movement





D1 and D2 – Shear zone

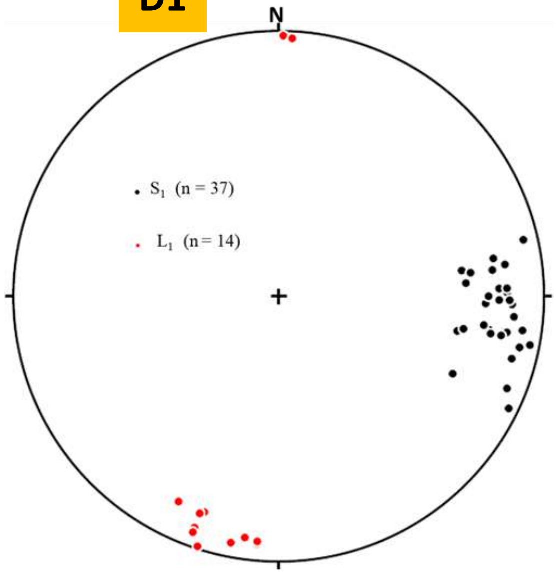
D1

- N-S, NNE-SSE striking, steep mylonite foliation, sinistral sense shear sense
- Ductile deformation
- Compatible with between E-W & NNW-SSE shortening

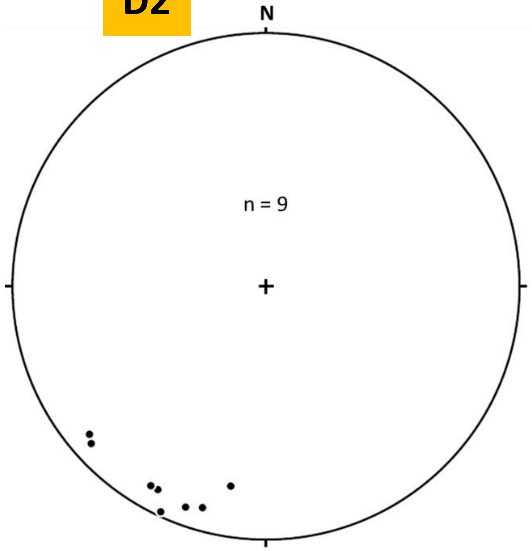
D2

- NNE steeply dipping shear fractures, with apparent dextral shear sense
- Associated with broad NW-SE shortening
- Exhumation between D1 & D2 or high strain rate deformation

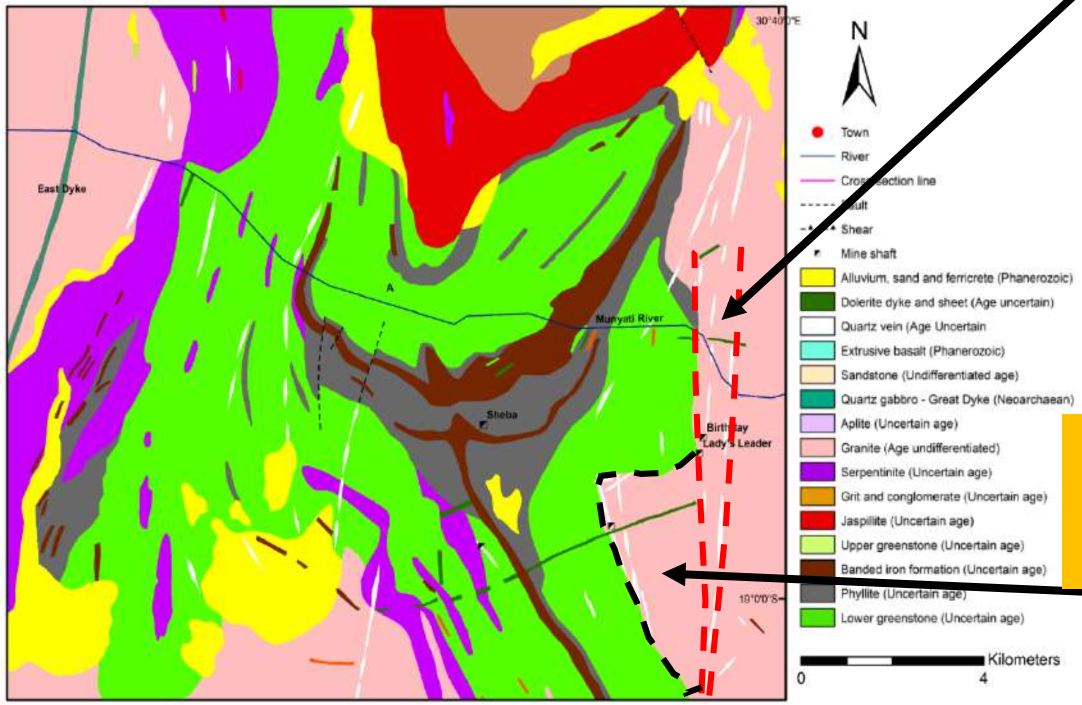
D1



D2



Deformation in the gneissic granite W of the shear zone



Shear zone
D1 – D2

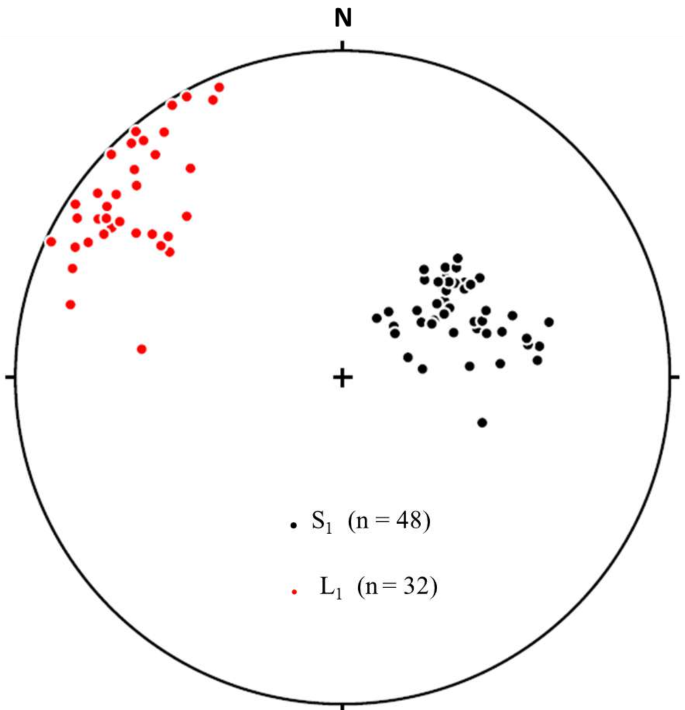
Gneissic granites W of the shear zone
D1 – D2

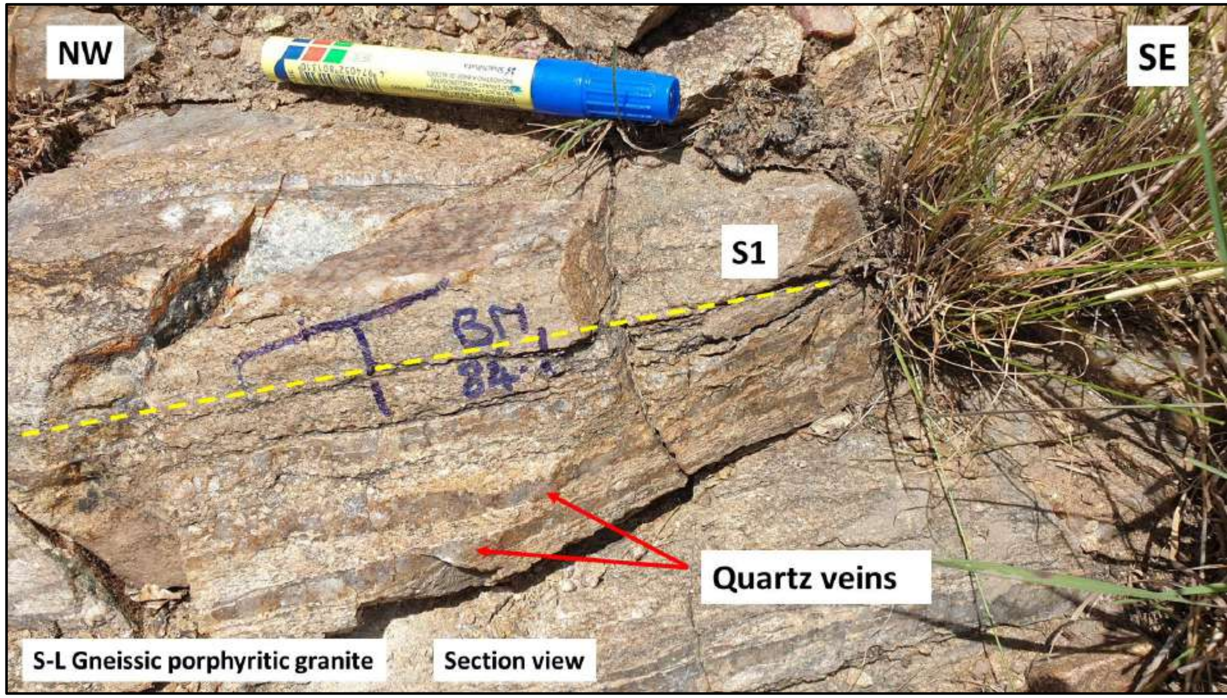
Deformation phases observed

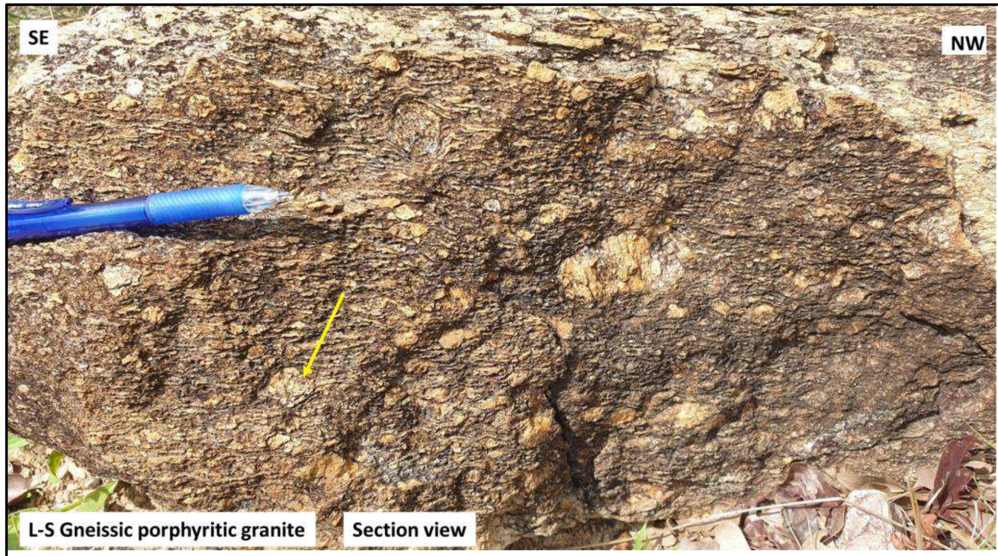
1. D1 – gneissic foliation formation
2. D2 – axial planar cleavage formation

Gneissic granite W of the shear zone – D 1 event

- Shallow SW to WSW dipping gneissic foliation
- NW to NNW plunging stretching lineation
- S-L and L-S tectonites in some places
- Associated with top to NW shearing
- Pre-tectonic quartz veins compatible with gneissic foliation

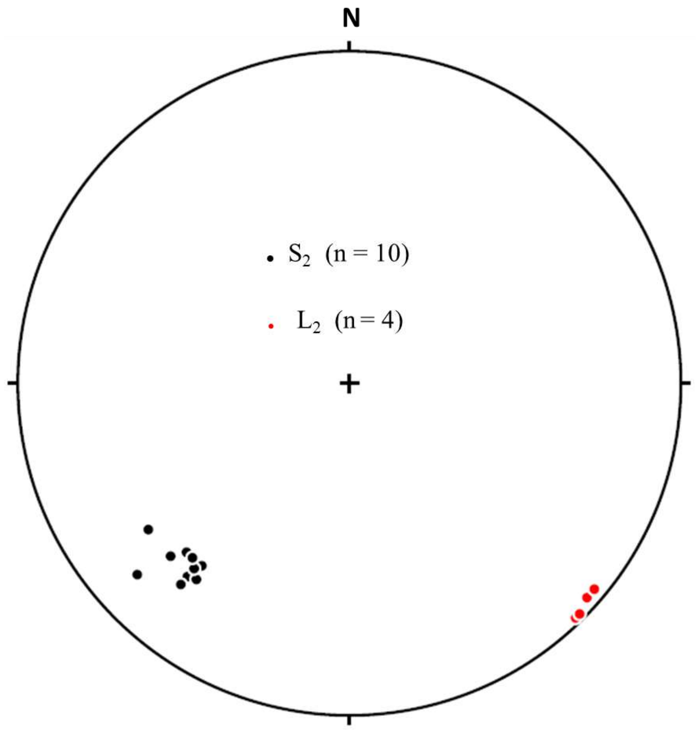


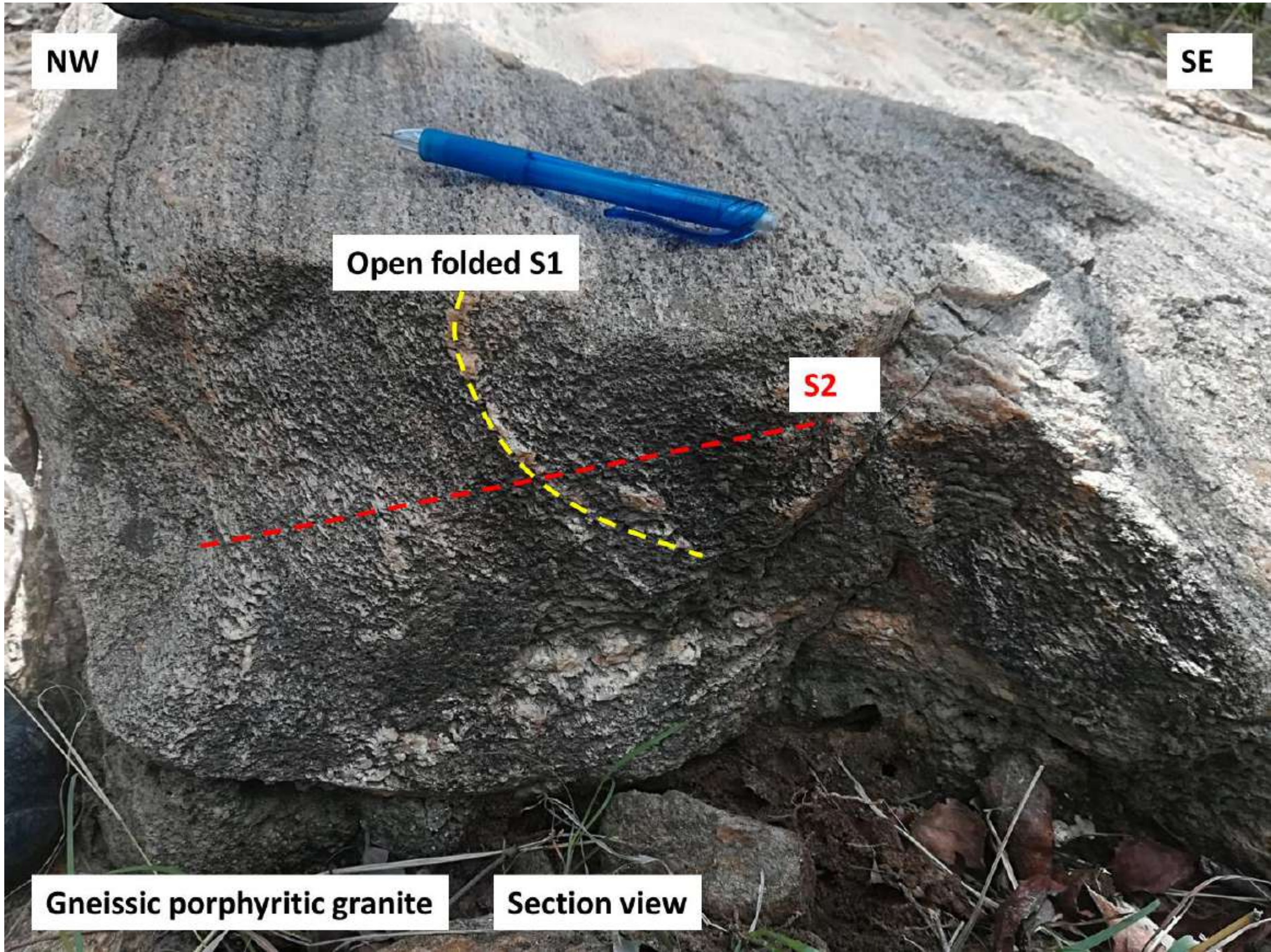




Gneissic granite W of the shear zone – D 2 event

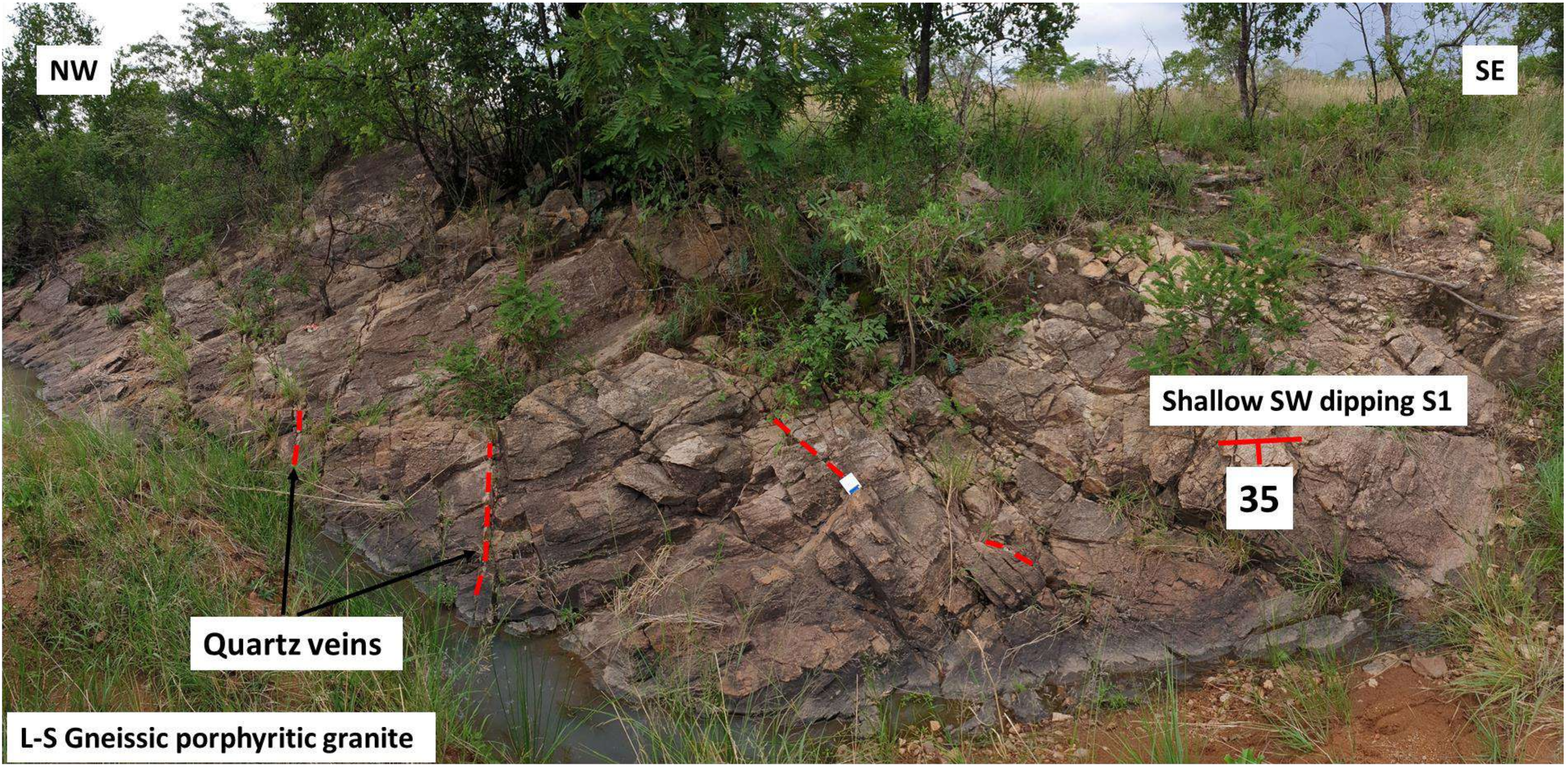
- Folding of S1
- Associated with NNE dipping axial planar cleavage - S2
- SE plunging L2
- L2 intersection lineation between S1 and S2

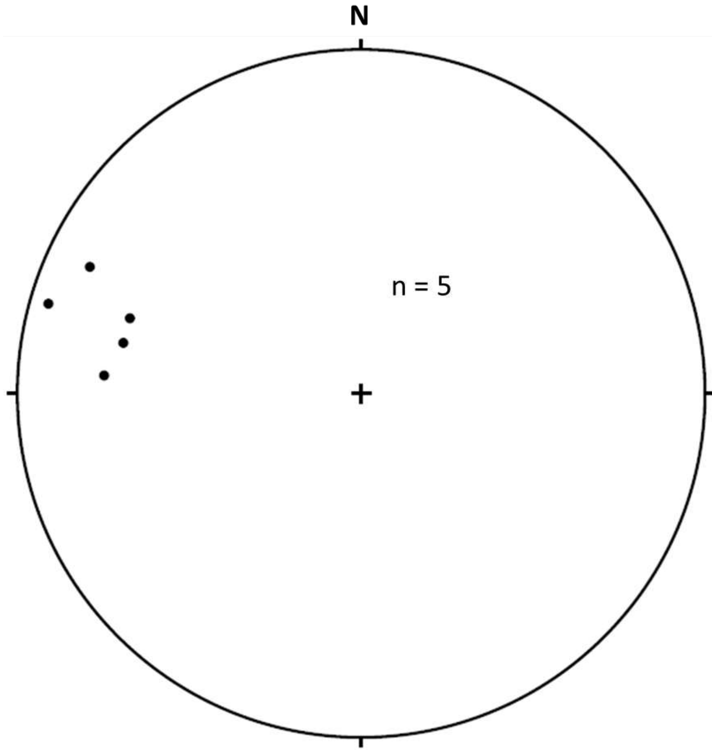




Gneissic granite W of the shear zone – D 2 event

- Quartz veins overprinting S1
- Generally, ESE dipping, steep(> 60º) .





D1 and D2 - Gneissic granite W of the shear zone

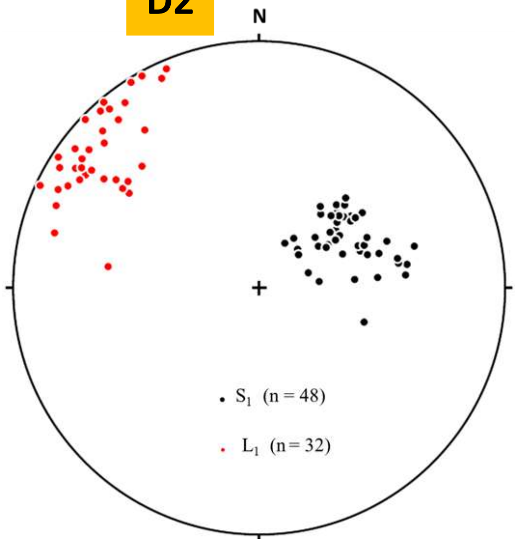
D1

- shallow SW to WSW dipping gneissic foliation S1,
- NW plunging L1,
- Top to NW shearing

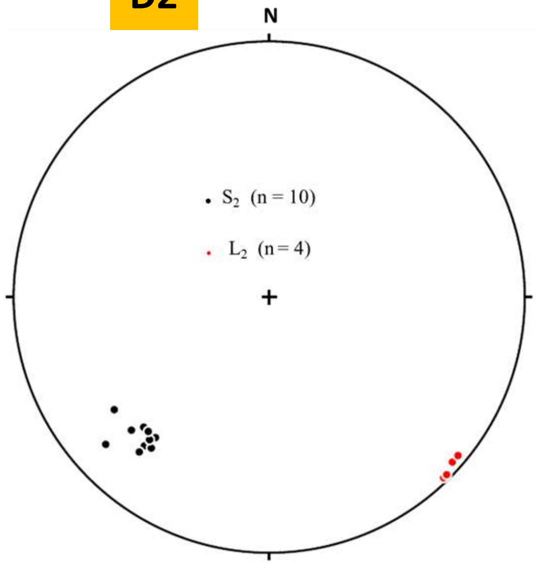
D2

- Open folding of S1 forming NNE dipping axial planar cleavage S2
- Quartz veins overprinting S1
- Associated with NE-SW shortening

D2



D2

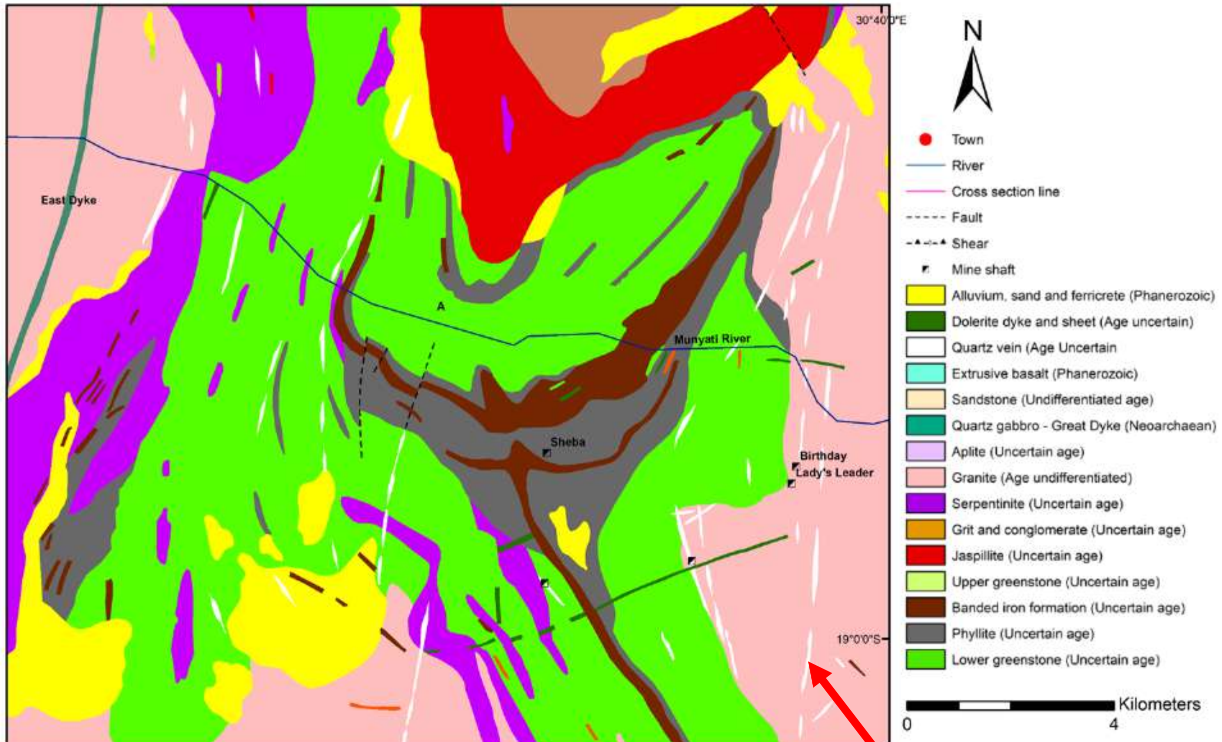


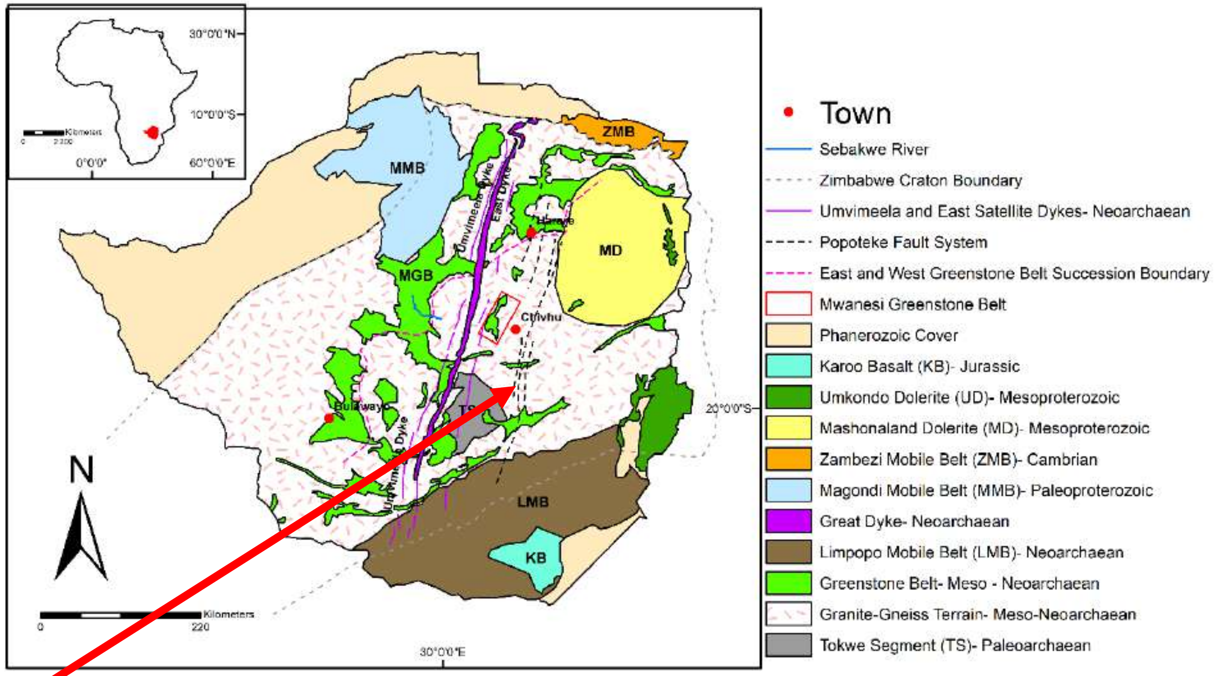
Summary of deformation events

Deformation domain	Deformation event	
	D1	D2
Supracrustals	Formation of recumbent folds Shallow SW to NW axial planar cleavage Shortening direction not yet known	Upright folds NE to NNE dipping axial planar cleavage NNE-SSW shortening
Gneissic granites E of shear zone	Formation of gneissic foliation SSW plunging lineation	Steep ESW dipping gneissic foliation NNW-SSE shortening
Shear zone	Formation of W to WNW dipping mylonite foliation Sinistral sense of shear SSW & NNE plunging lineation Between E-W & NNW-SSE shortening Ductile deformation	Steep NE dipping shear fractures With apparent dextral shear sense Broad NW-SE shortening Brittle deformation Exhumation between D1 and D2 or high strain rate deformation
Gneissic granites W of shear zone	Formation of gneissic foliation NW plunging lineation Top to NW shearing	Open folding of S1 NNE axial planar cleavage SE plunging intersection lineation NE-SW shortening

- Correlation of deformation events between different domains difficult at this point
- Geochronologic evidence, microstructural and metamorphic characteristics not yet available

Gold mineralisation in the MGB – Southern part



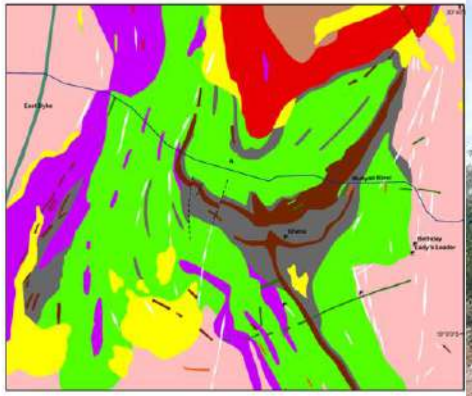


NNE-SSW striking quartz veins are related to the Popoteke fault system.

(Campbell and Pitfield, 1994).

Does it mean the timing of gold mineralisation in the NNE–SSW striking quartz veins is at least 2.57 Ga or younger?

Current mining in the MGB

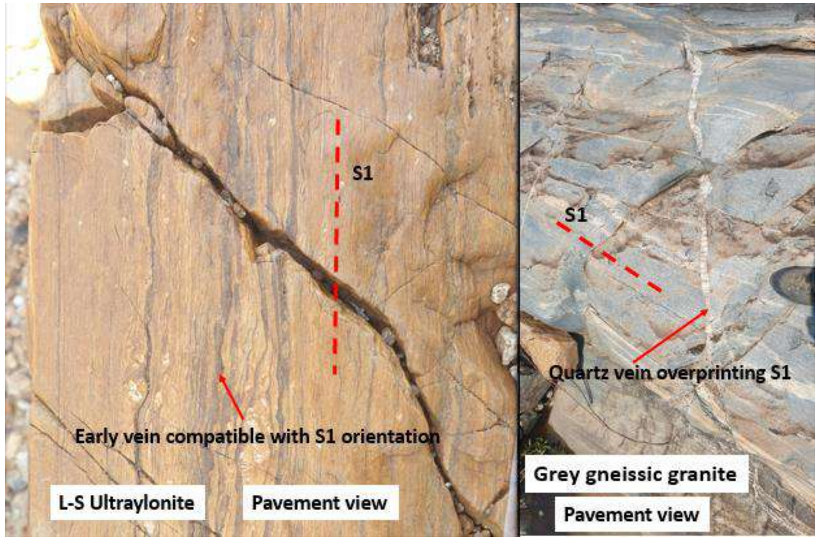


Classification of quartz veins in the MGB

- Classification of based on the size of the veins

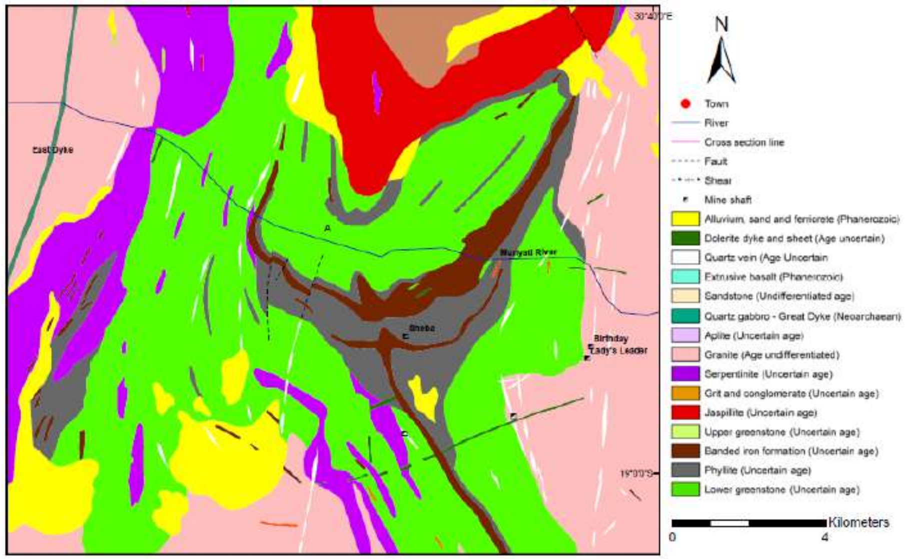
1st Class

- Small veins, < 1 m in thickness
- Developed in all deformation domains
- early veins, predate earlier formed fabrics
- Veins overprinting earlier formed fabrics
- Less abundant



2nd class

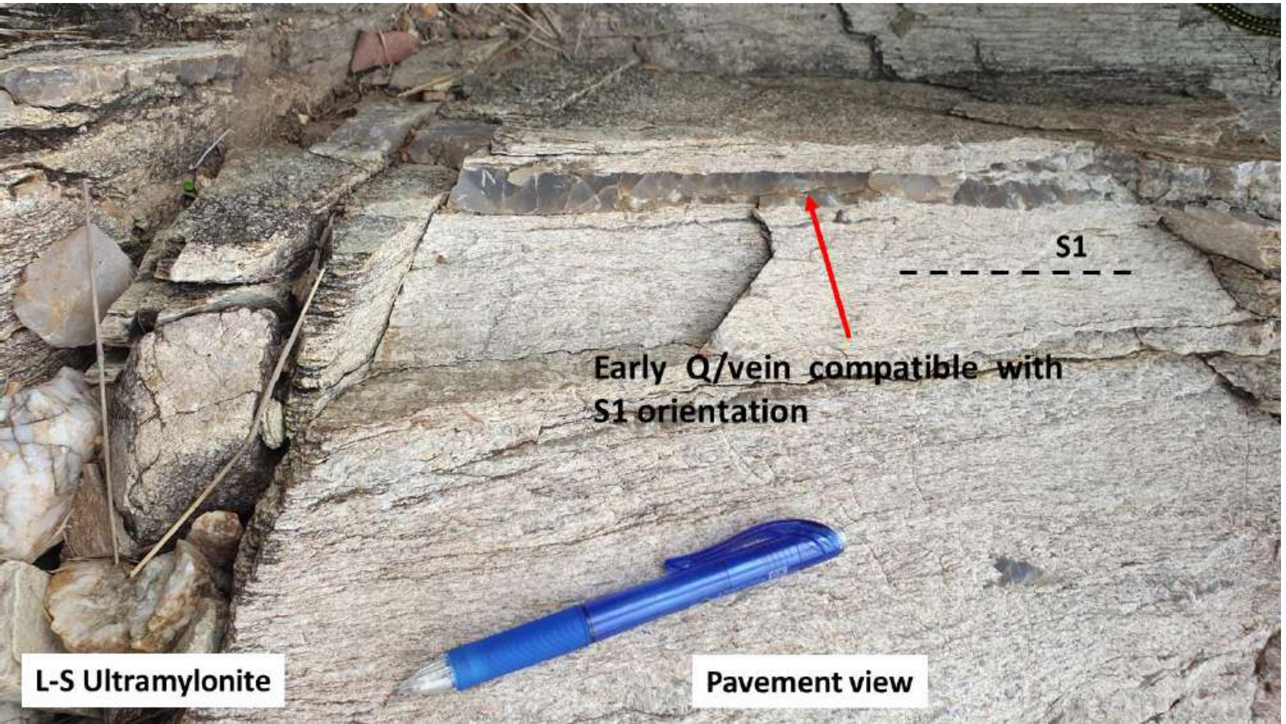
- Generally large veins, 1-50 m in thickness.
- Most of the veins striking NNE-SSW and NNW-SSE, steeply dipping
- Some are generally E-W striking, steeply dipping to the N/S
- More abundant



Generations of quartz veins in the MGB

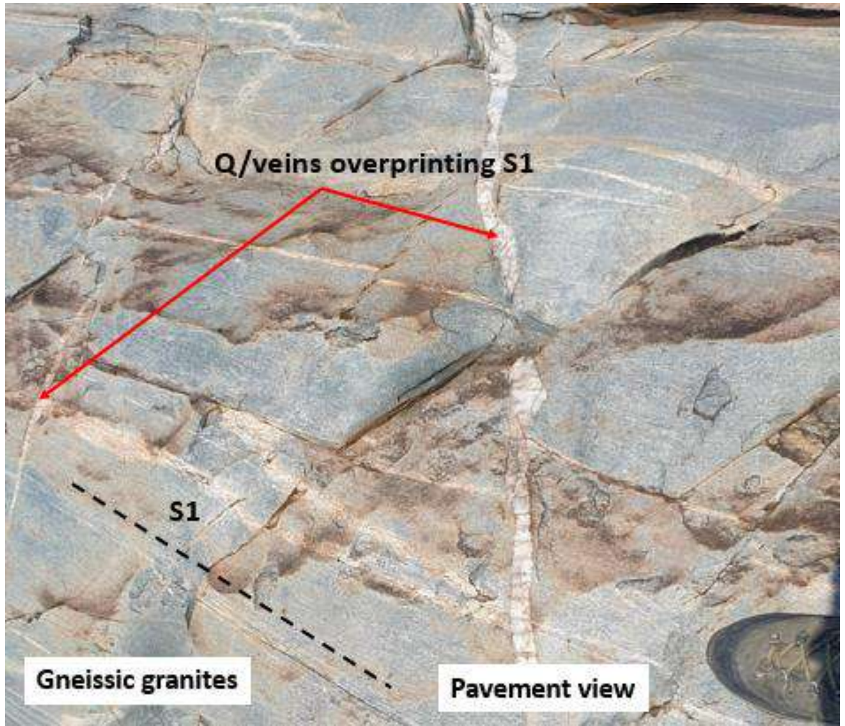
1st Generation

- Early veins, predating S1 in their respective deformation domains
- They form part of the 1st class of veins



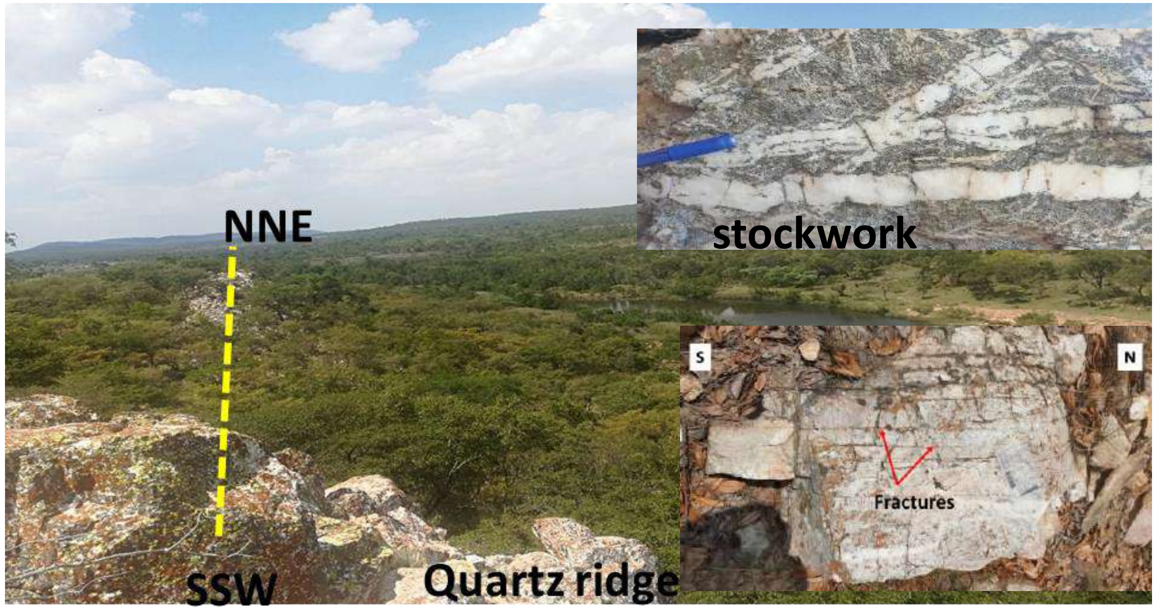
2nd Generation

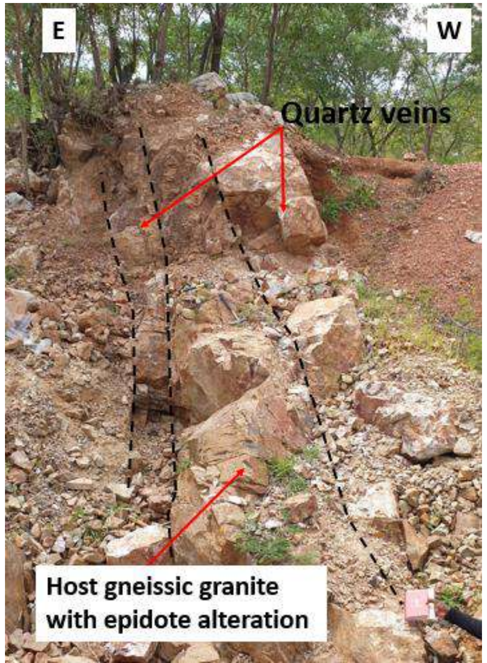
- Veins overprinting S1 in all the deformation domains
- They also form part of the 1st class of veins

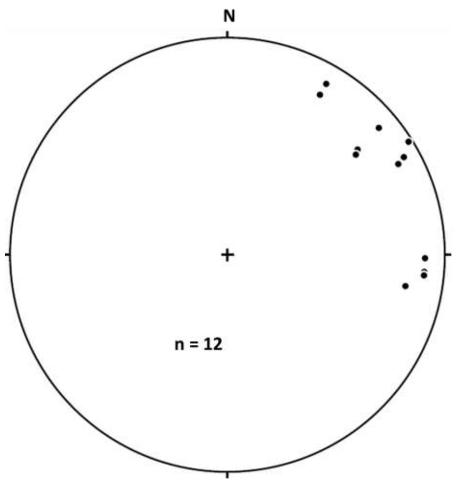


Generations of quartz veins in the MGB

- **3rd Generation**
- Consists of the 2nd class of veins overprinting S1 and S2 in all deformation domains
- Forming huge ridges, topographic highs
- Stockwork in some places –high fluid pressure
- Steep W dipping fractures
- Epidote alteration in the wall rocks.
- Fault fill veins and mode 1 filled fractures
- Veins associated with between NNW-SSE & NNE-SSW shortening
- Syn-D3







What we don’t understand about the MGB

- Age of the greenstone,
- Absolute timing of major deformation events and gold mineralisation,
- The tectonic event associated with the formation of the doubly plunging syncline,
- The origin and tectonic significance of recumbent folding in the supracrustals,
- The source of the mineralising fluids,
- Low gold endowment in the MGB
- Tectonic evolution of the MGB.

So what's next?

Summary

- Polyphase deformation in the MGB
- Four deformation domains recognized in the MGB, with different overprinting relations
- At least two localized deformation phases (D1 & D2) recorded in each domain
- D3 recorded in all deformation domains, characterized by between NNW-SSW & NNE-SSW shortening
- Three generations of quartz veins recognized in the MGB
- The 3rd generations associated with gold mineralisation, but not all veins in this generation are mineralized!

What is the way forward?

- Interpretation of structural datasets,
- Geochronology work on the supracrustals and the adjacent granites and gneisses,
- Constraining the absolute timing of deformation events and mineralisation,
- Fluid inclusion and sulphide trace element studies,
- Suggest a tectonic model for the evolution of the MGB.

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