Deportment of gold in historical Witwatersrand tailings: implications for full value realisation, environmental stewardship, and geometallurgy

Steven Chingwaru, Bjorn von der Heyden and Margreth Tadie

Geometallurgy Conference 2025

NRF National Research Foundation

ARM African Rainbow Minerals GeoMetallurgy Research Chair

cimera DSTI-NRF Centre of Excellence for Integrated Mineral and Energy Resource Analysis

Stellenbosch University Iyunivesithi Universiteit

Introduction: Witwatersrand Au tailings

- Witwatersrand represents the world's largest gold field having produced in excess of 53 000 t of native gold.

- Gold in the paleo- quartz pebble conglomerate 'reefs' of the Witwatersrand were discovered between 1884 and 1886.

- Historical mining activity has also resulted in ~270 tailings dumps, comprising over 6 billion tons of material with a surface expression of 400 km^2.

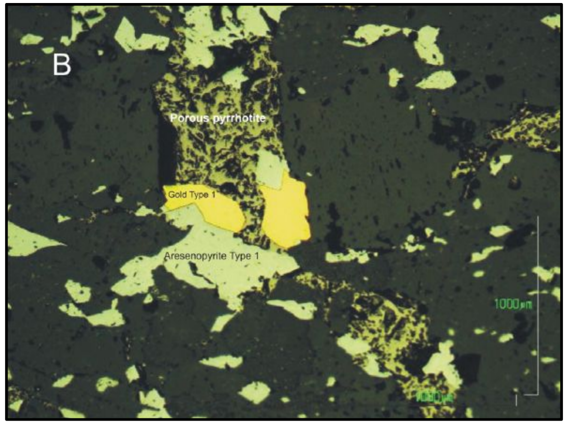
- Because of historical beneficiation inefficiencies, tailings represent an important secondary mining resource.

Image sources: R. du Toit

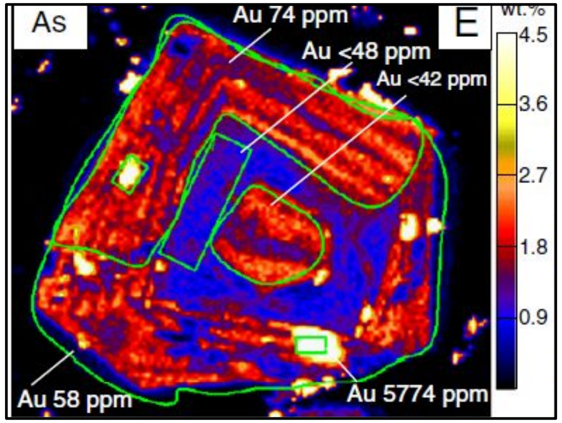
Information sources: sahistory.org.za; Liefferink and Liefferink, 2014

ARM GeoMetallurgy Research Chair
African Rainbow Minerals

Introduction: Witwatersrand Au tailings



- *Native gold*
- *Free-milling gold*
- *Free gold*



- *Invisible gold*
- *Lattice-bound gold*
- *Solid-solution gold*
- *Refractory gold*

Image sources Agangi et al. 2014; Altigano et al. 2016

- Witwatersrand represents the world's largest gold field having produced in excess of 53 000 t of native gold.
- Because of historical beneficiation inefficiencies, tailings represent an important secondary mining resource that are very valuable for RSA economy..

Historical mining
(estimated 95% efficiency)

53000 t native gold

2700 t unrecovered gold, speciation unknown

Secondary mining
(30-50% efficiency)

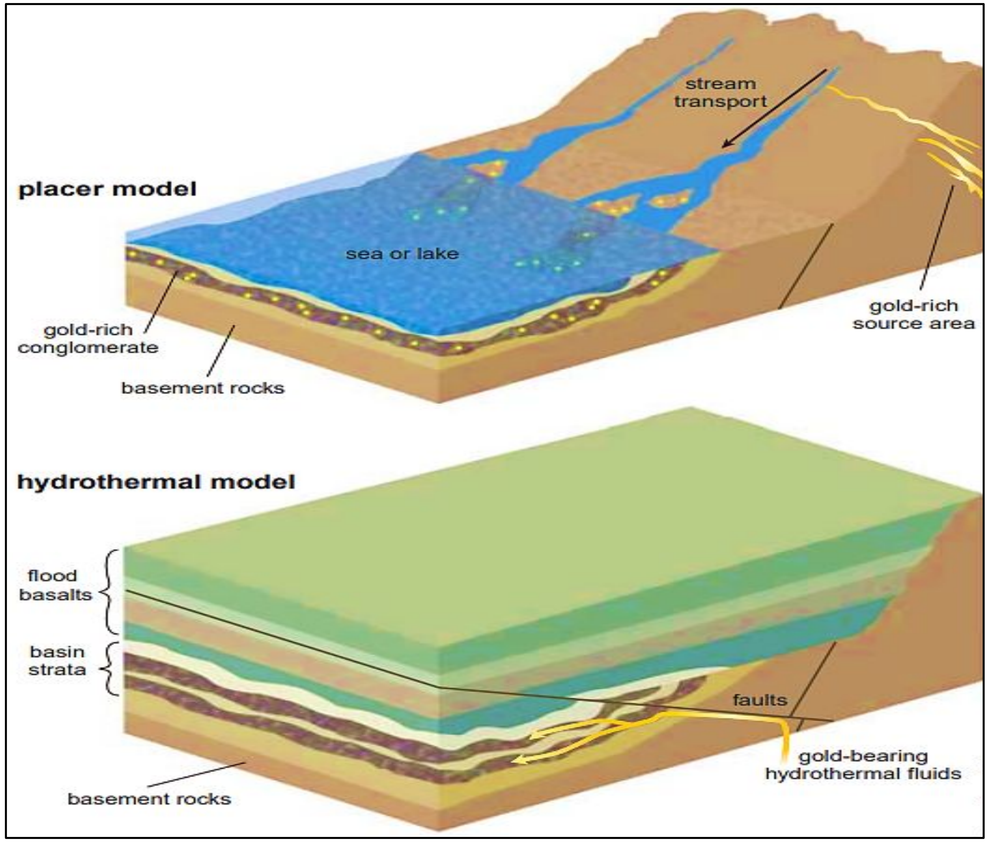
Additional native gold recovered

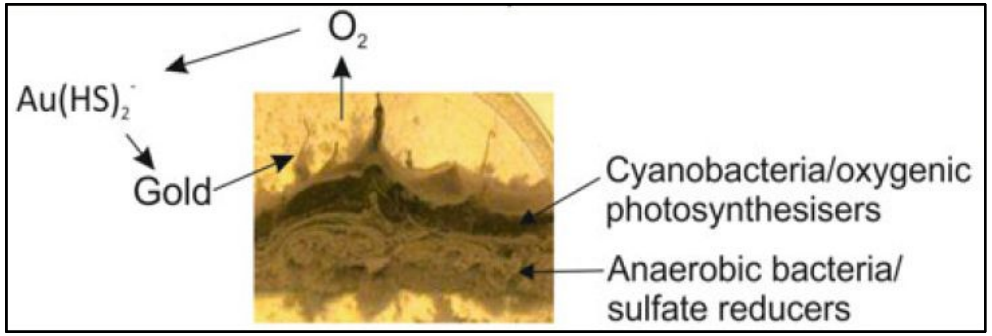
1325 – 1855 t unrecovered gold in tailings, speciation unknown

ARM GeoMetallurgy Research Chair
African Rainbow Minerals

Genetic models for Wits Au and pyrite

- Historically a contentious and polarized debate
- Main arguments centered around a placer model vs a hydrothermal model for genesis of the Witwatersrand goldfields.
- Compromise reached with the so-called 'modified paleoplacer' model.
- Recent works have reignited debate on specifically the highly auriferous Carbon Leader reef, suggesting either a biological genesis or derivation from hydrocarbon fluids.

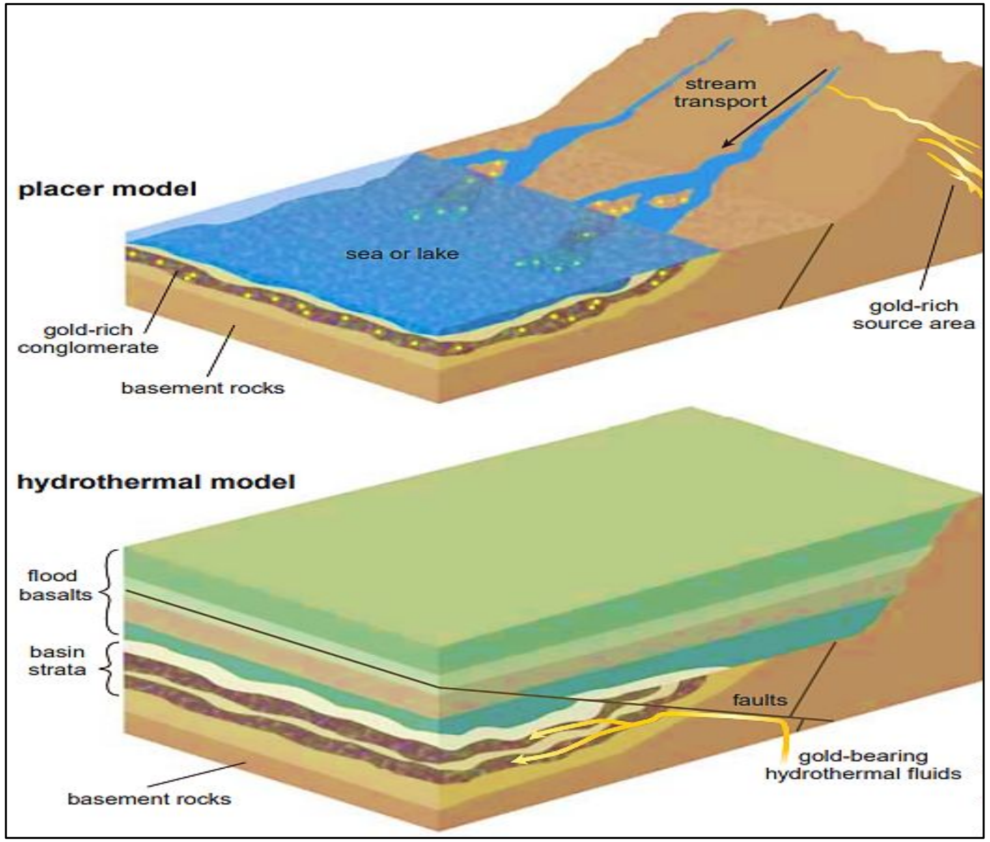


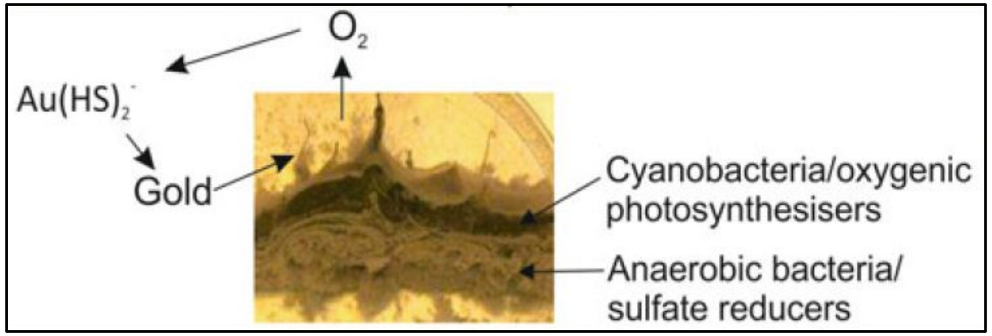


Figures after Kirk et al. 2003; Frimmel, 2018

Genetic models for Wits Au and pyrite

- Historically a contentious and polarized debate
- Main arguments centered around a **placer model** vs a hydrothermal model for genesis of the Witwatersrand goldfields.
- Compromise reached with the so-called 'modified **paleoplacer**' model.
- Recent works have reignited debate on specifically the highly auriferous Carbon Leader reef, suggesting either a biological genesis or derivation from hydrocarbon fluids.





Figures after Kirk et al. 2003; Frimmel, 2018

Study area: Historical tailings dumps

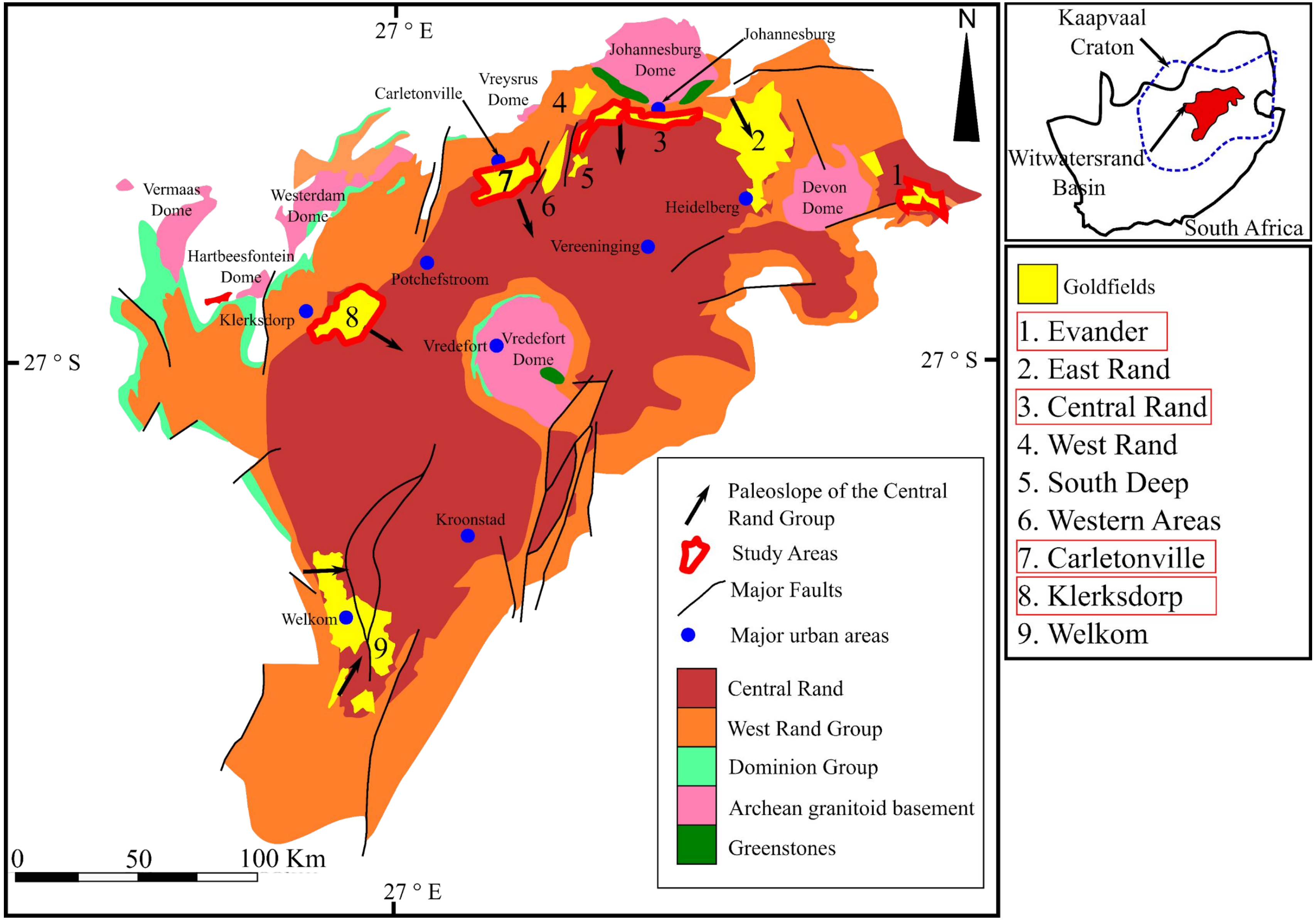


Image adapted from Frimmel et al. 2005

- 150 kg samples collected from four tailings dumps from four different gold fields.
- Homogenisation and splitting resulted in replicate samples of 1 kg for further pre-concentration and characterization.

Methodology: Pre-concentration and testing

Stellenbosch University Iyunivesithi Universiteit

Sample preparation to composite samples

Slimes removal

Slimes (<<hydraulic equivalence)

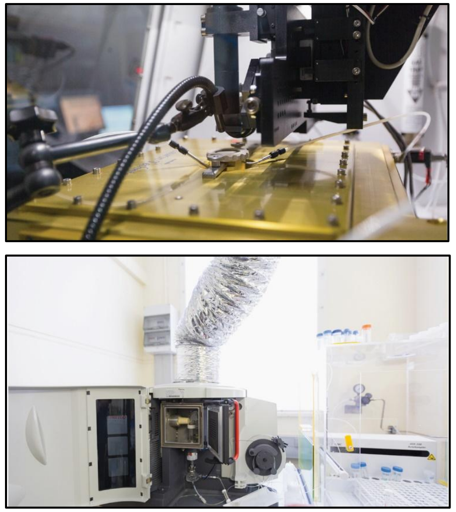
Density separation

Heavy mineral fraction (> 2,95 g/cm^3)

Light fraction (< 2,95 g/cm^3)

QEMSCAN/SEM

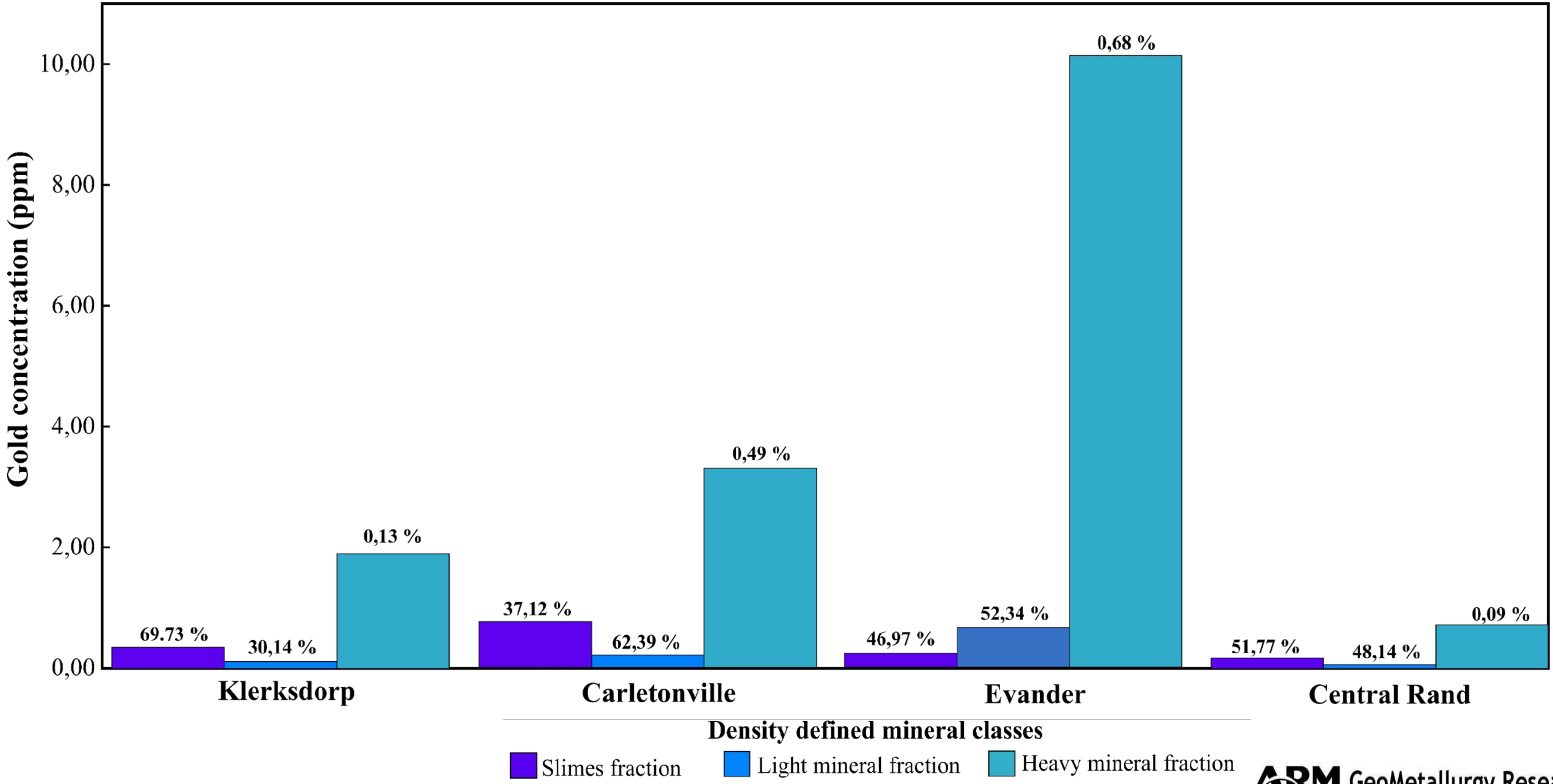
LA ICP-MS



Aqua regia digestion + ICP-MS

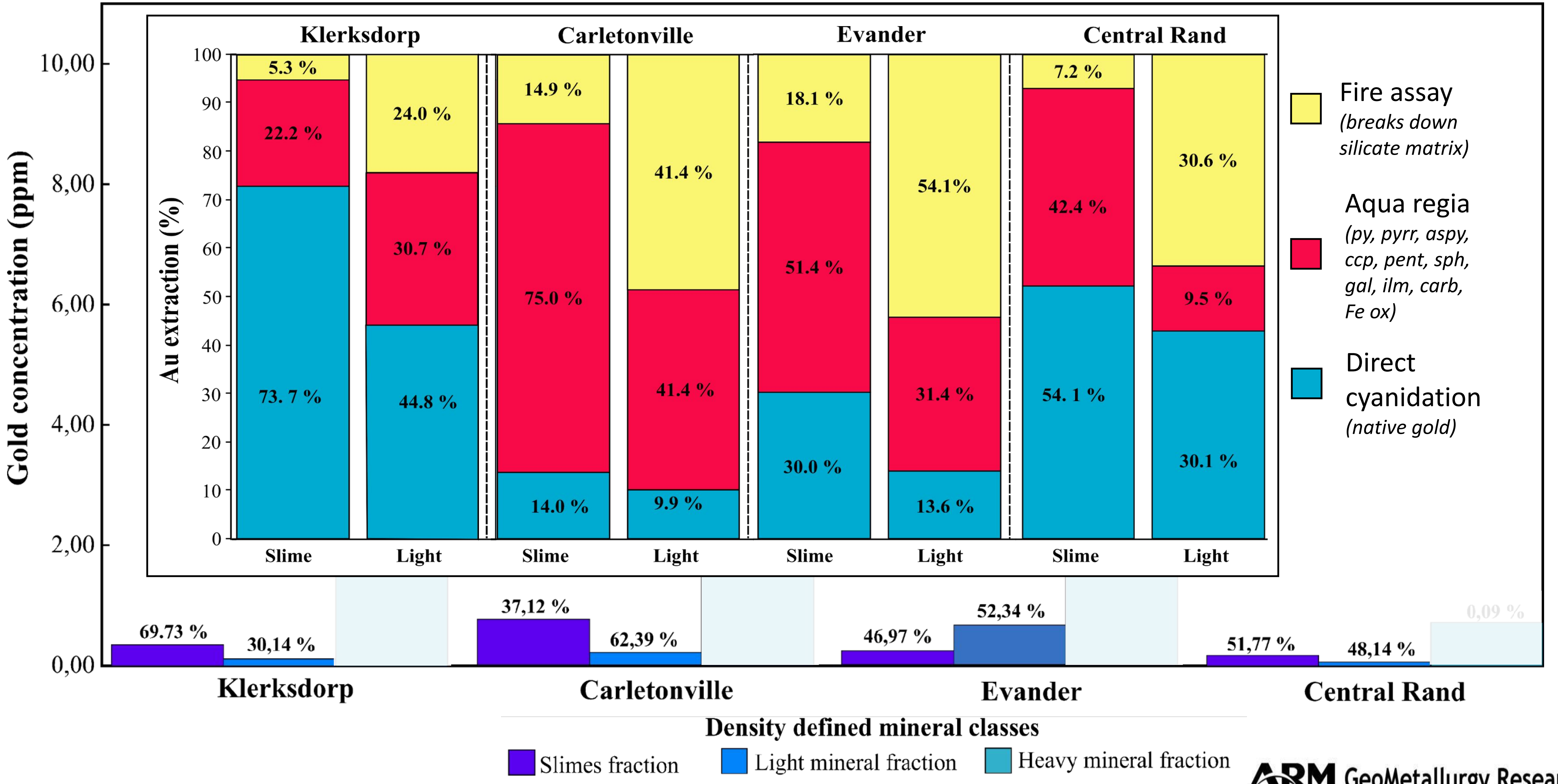
Optical Microscopy

Results: Operational deportment



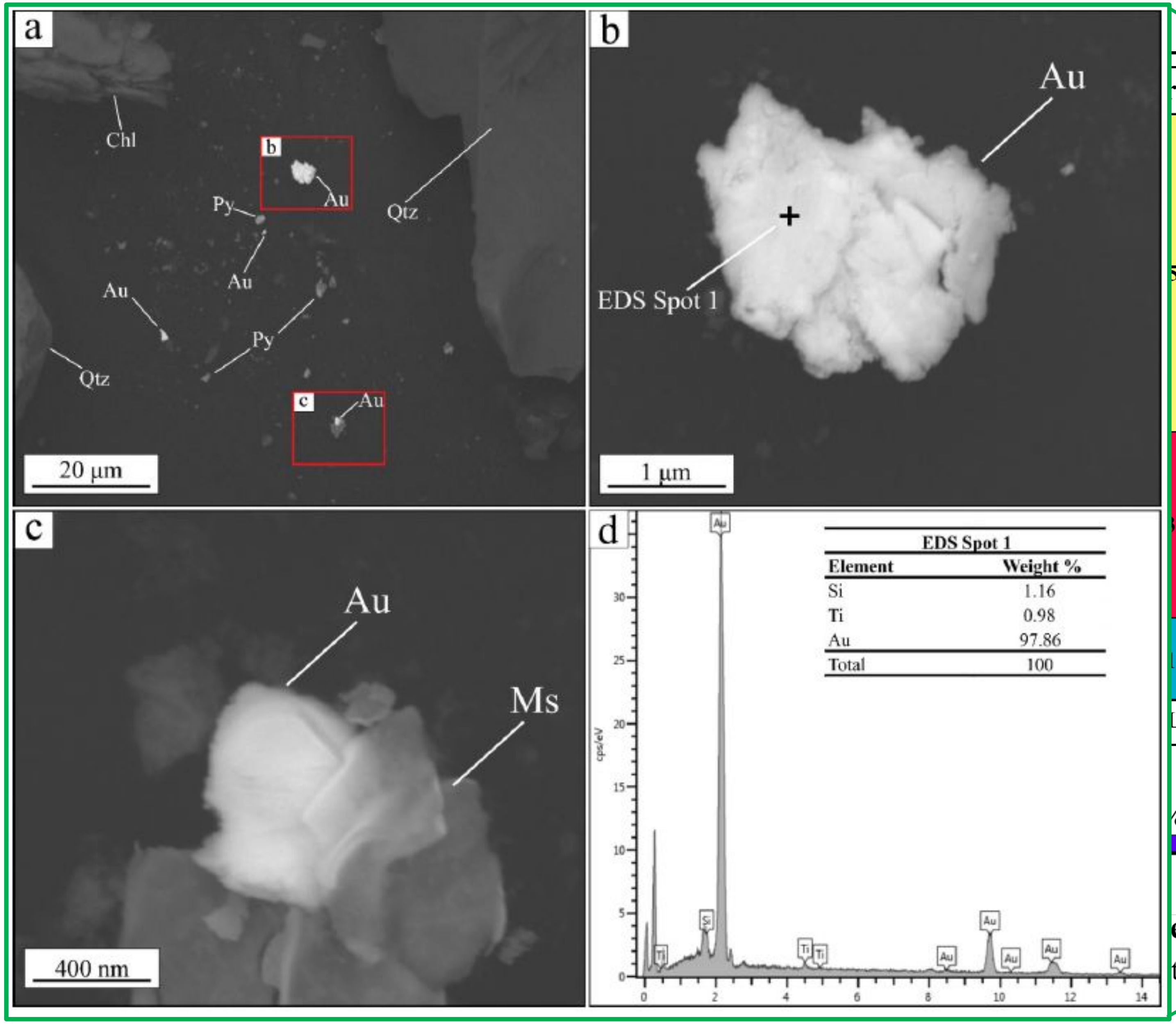
ARM GeoMetallurgy Research Chair
African Rainbow Minerals

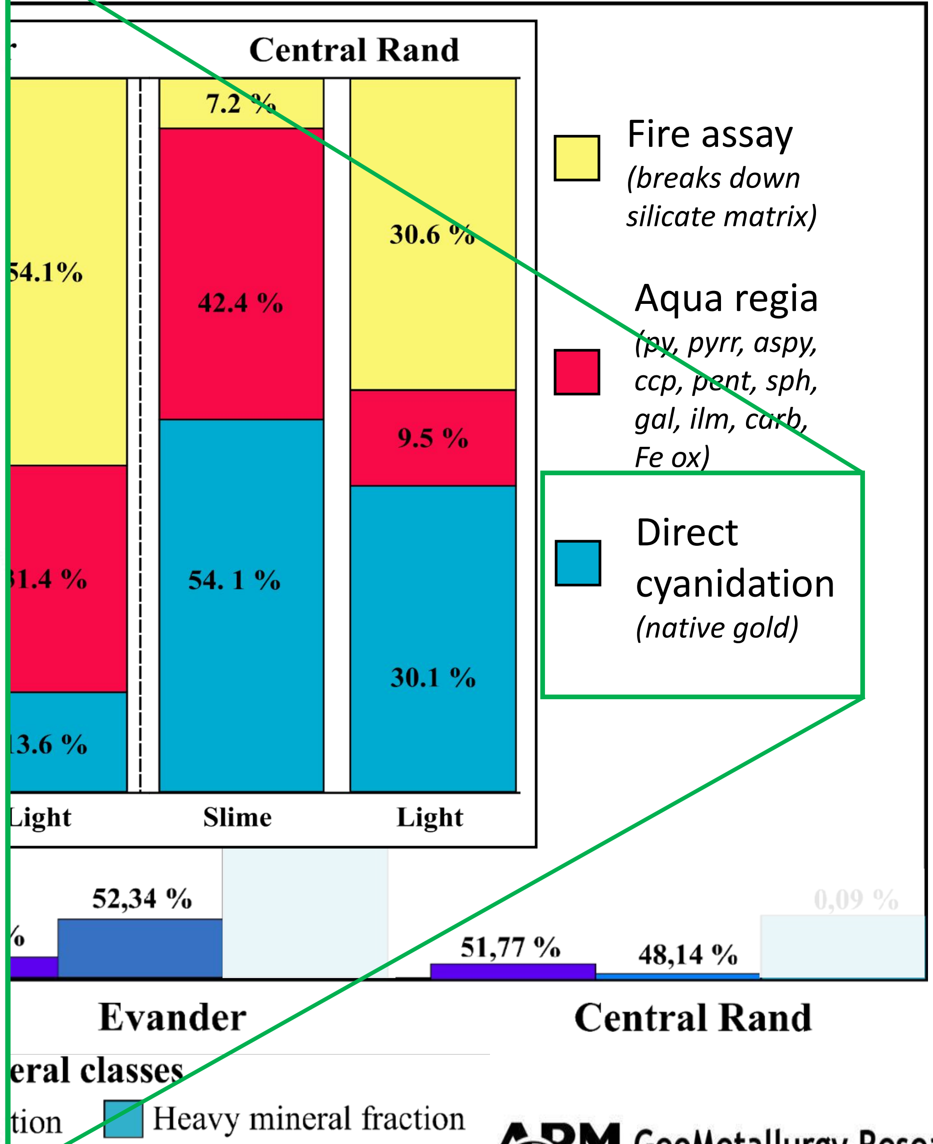
Results: Operational deportment



ARM GeoMetallurgy Research Chair
African Rainbow Minerals

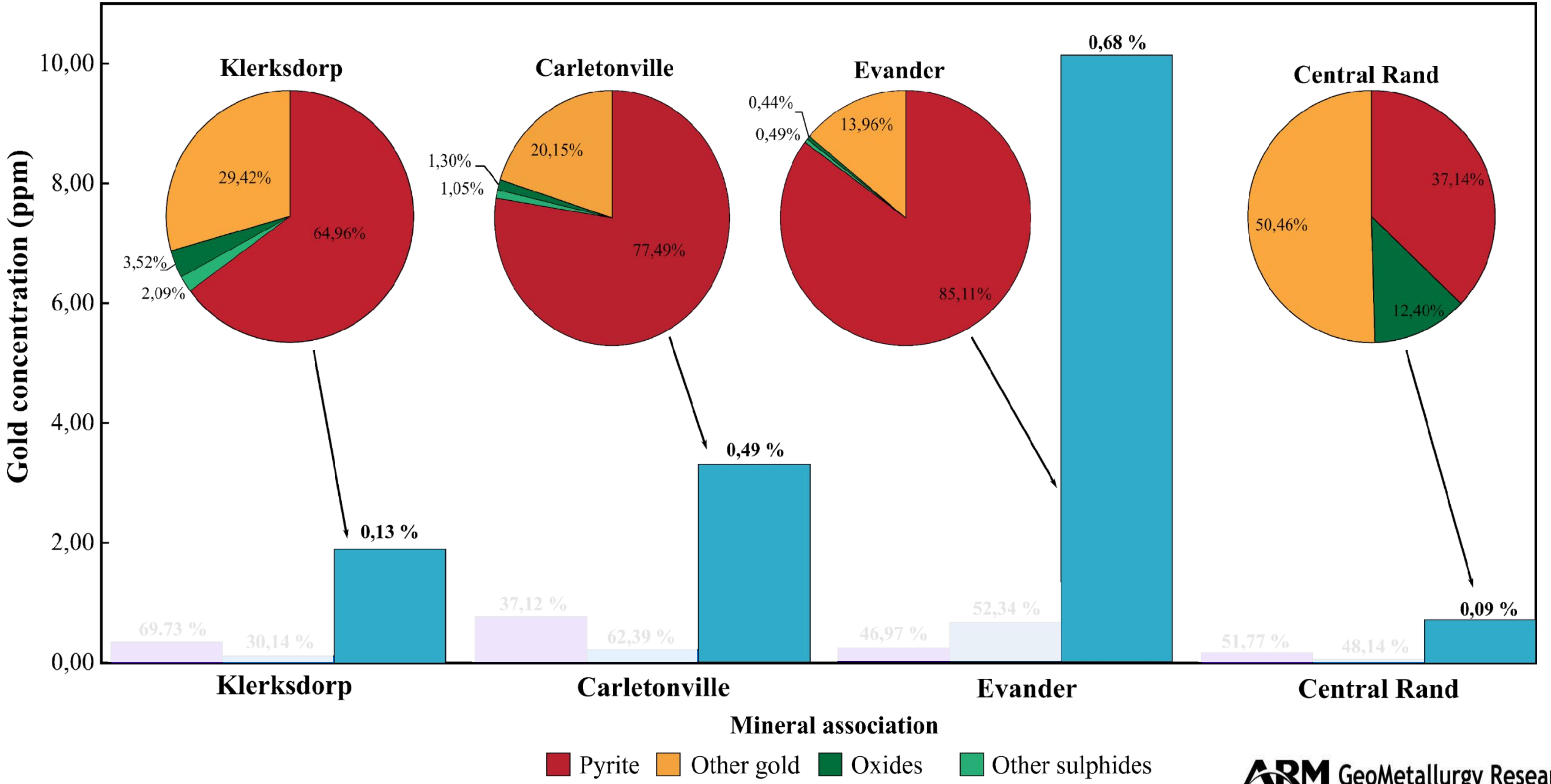
Results: Operational deportment





ARM GeoMetallurgy Research Chair
African Rainbow Minerals

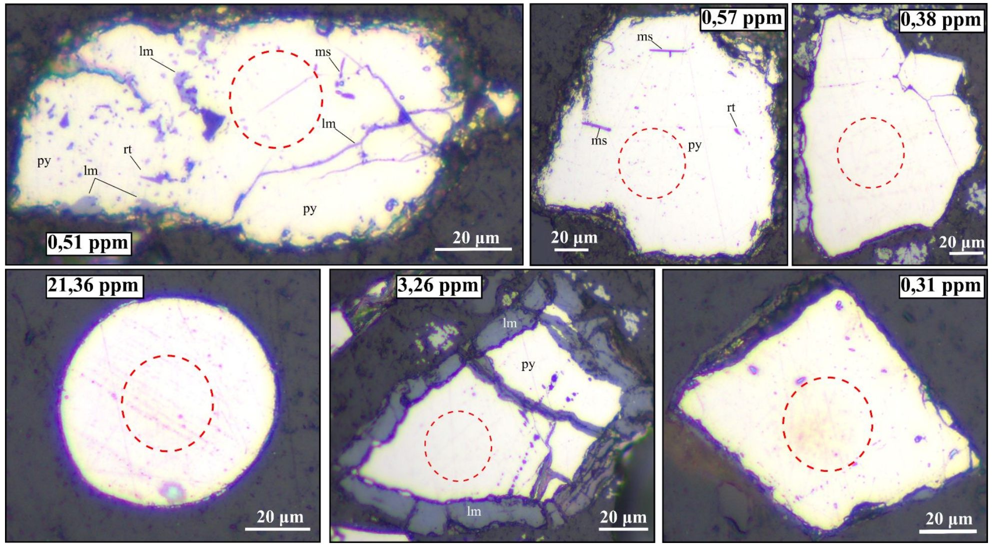
Results: Mineralogical deportment



ARM GeoMetallurgy Research Chair
African Rainbow Minerals

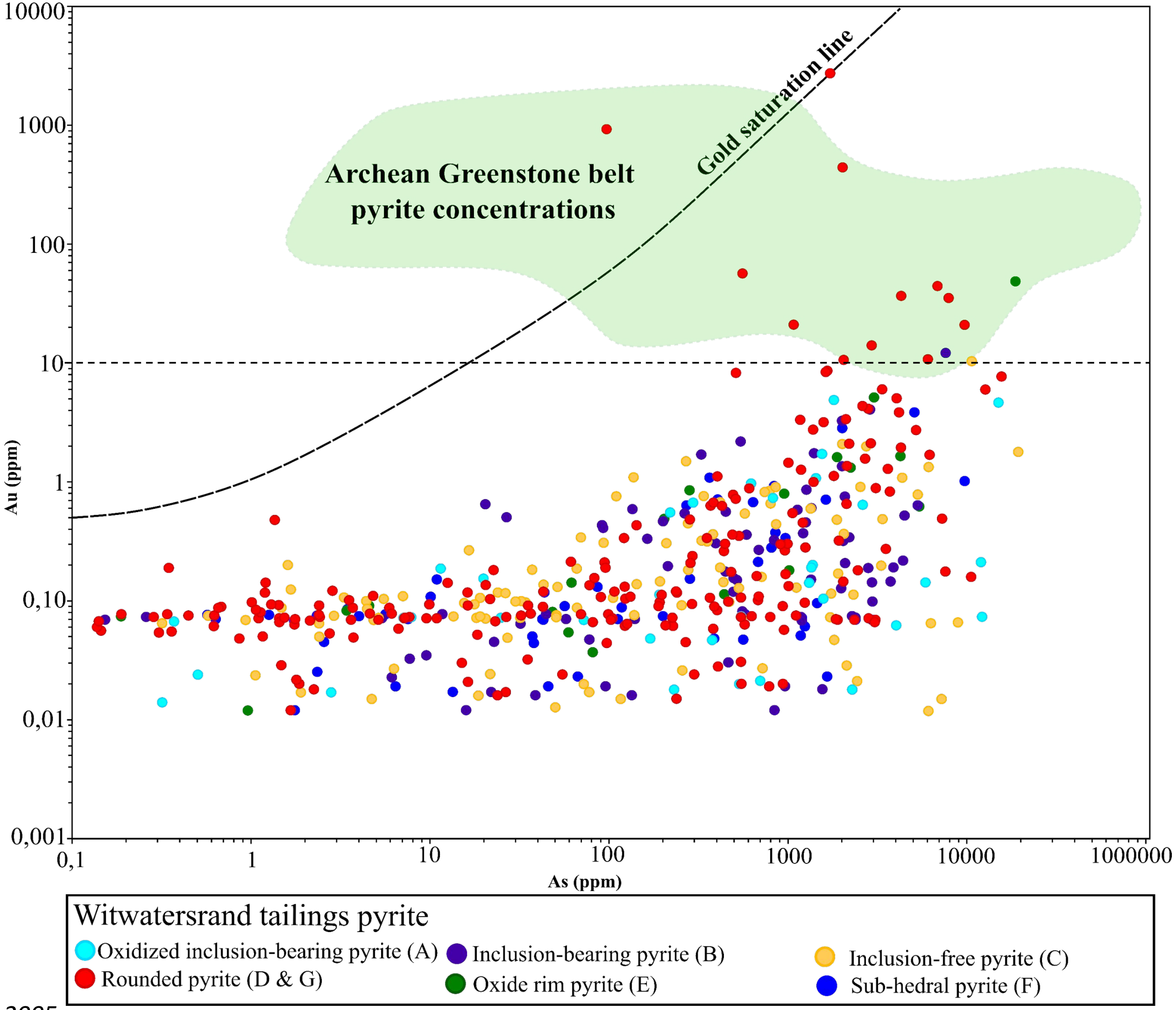
Tailings pyrite textures and chemistry

Stellenbosch
UNIVERSITY
IYUNIVESITHI
UNIVERSITEIT



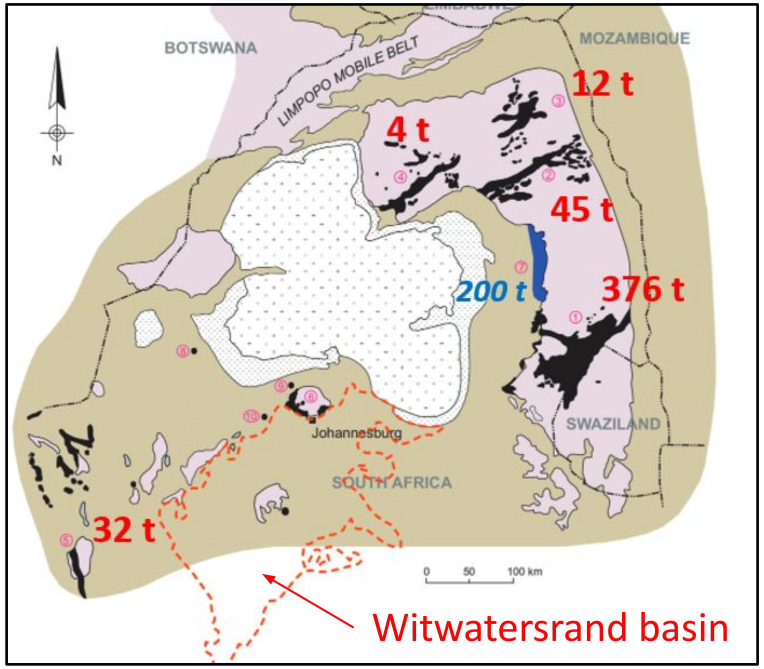
Chingwaru et al. 2023

- Pyrite types coarsely classified according to macroscopic textures.
- Rounded pyrite types have the highest Au tenors.

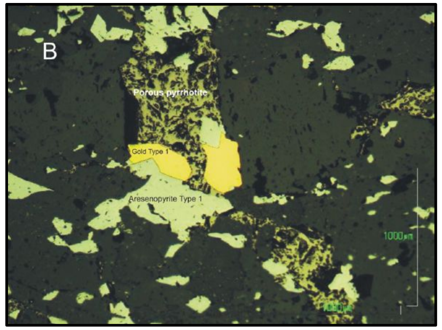


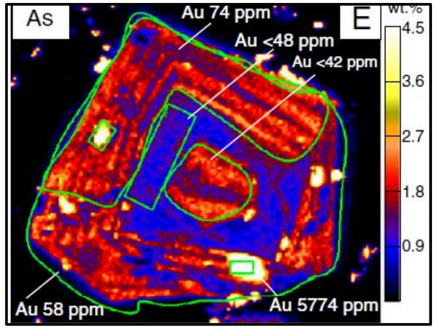
Au vs As diagram after Reich et al. 2005

Geological implications

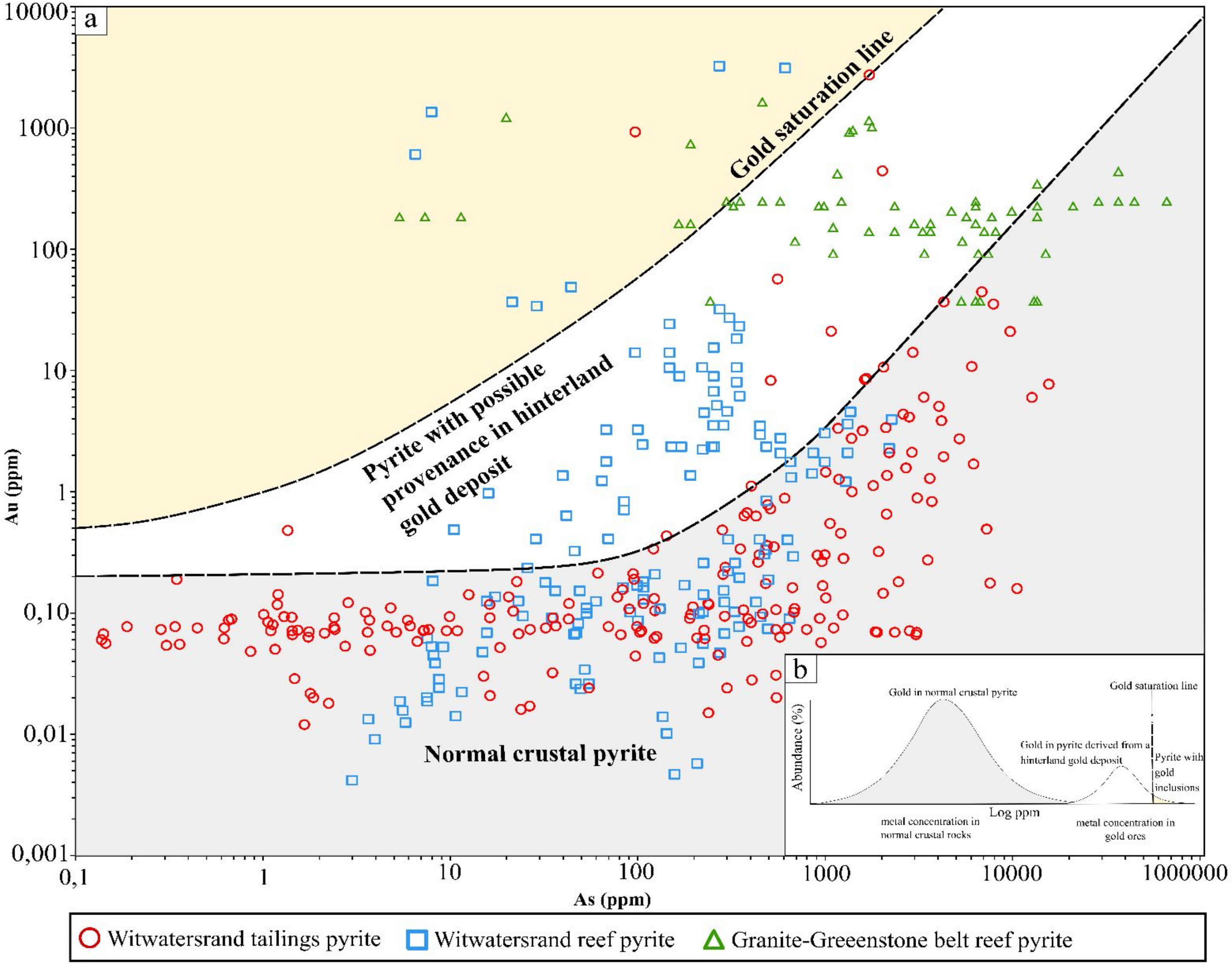


Modified from Pearton and Viljoen, 2017





Examples of Barberton Au: image sources Agangi et al. 2014; Altigano et al. 2016

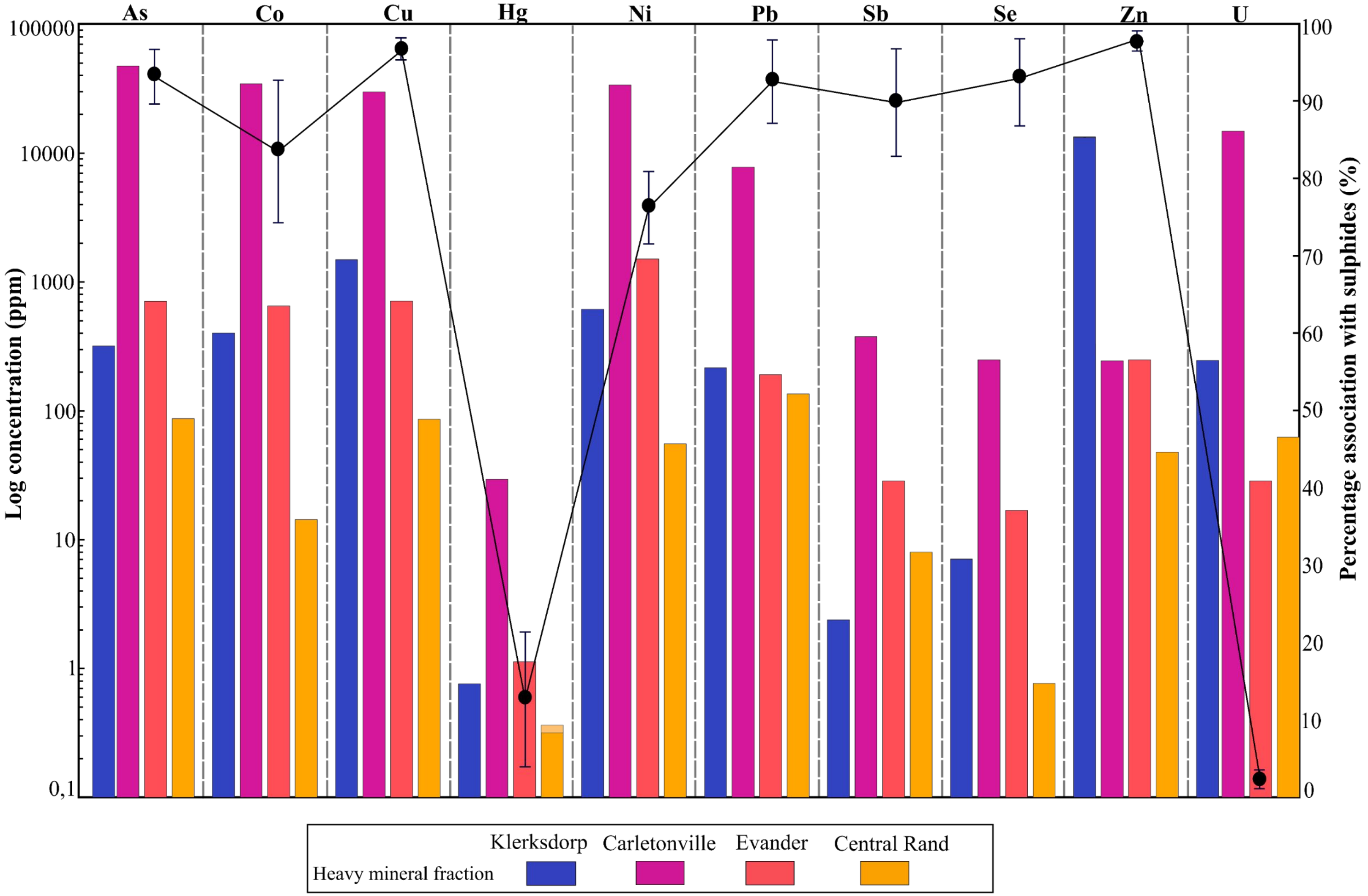


Environmental implications

- ~420 tons of Au recoverable from pyrite fraction by targeted reprocessing (e.g., *froth flotation, pre-oxidative processing and gold leaching*)

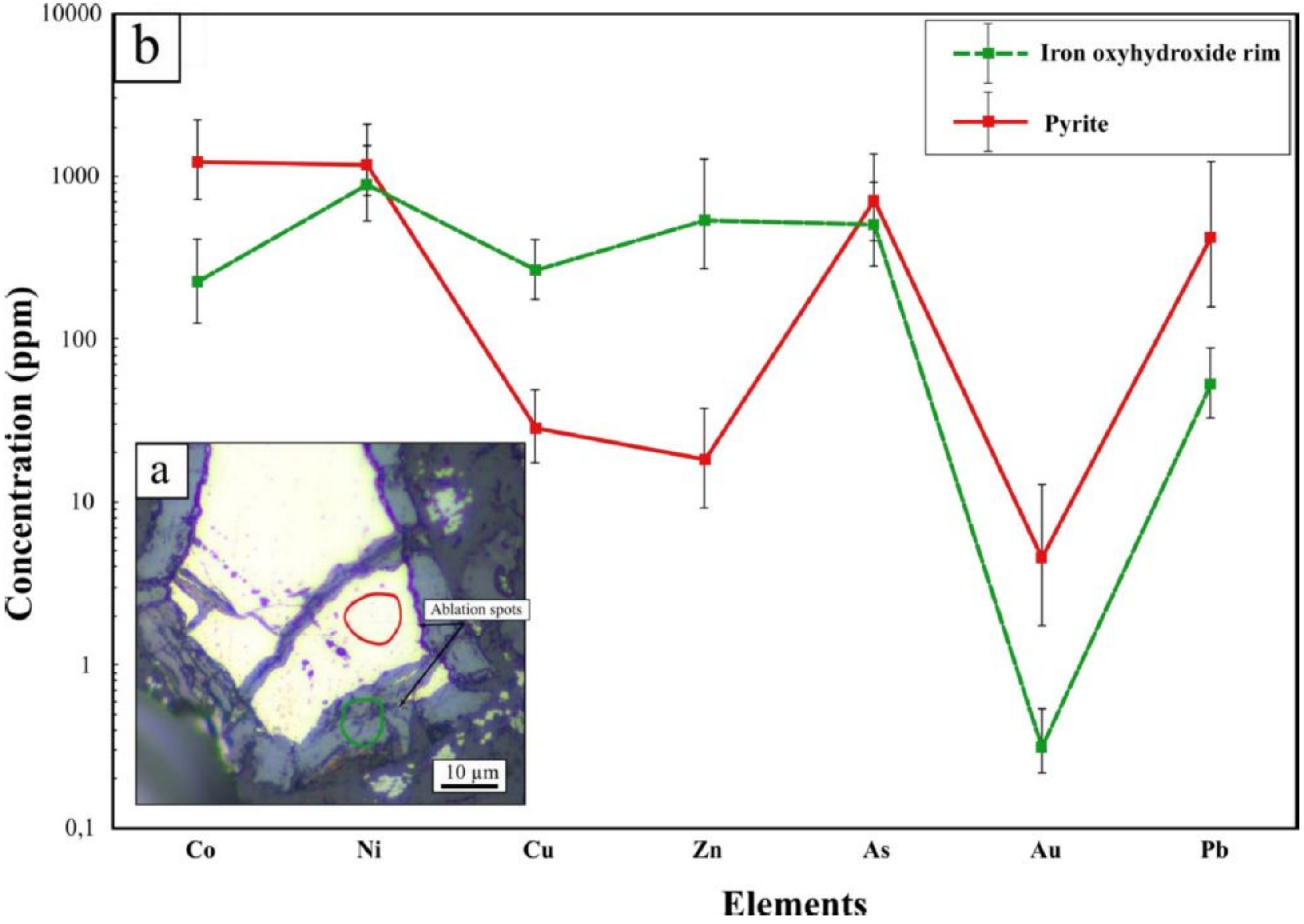
- Tailings dumps represent the major point sources for pollution from mining in the Witwatersrand.

- A targeted sulphide re-mining strategy holds additional ESG value and for recovery of sweetener metals.



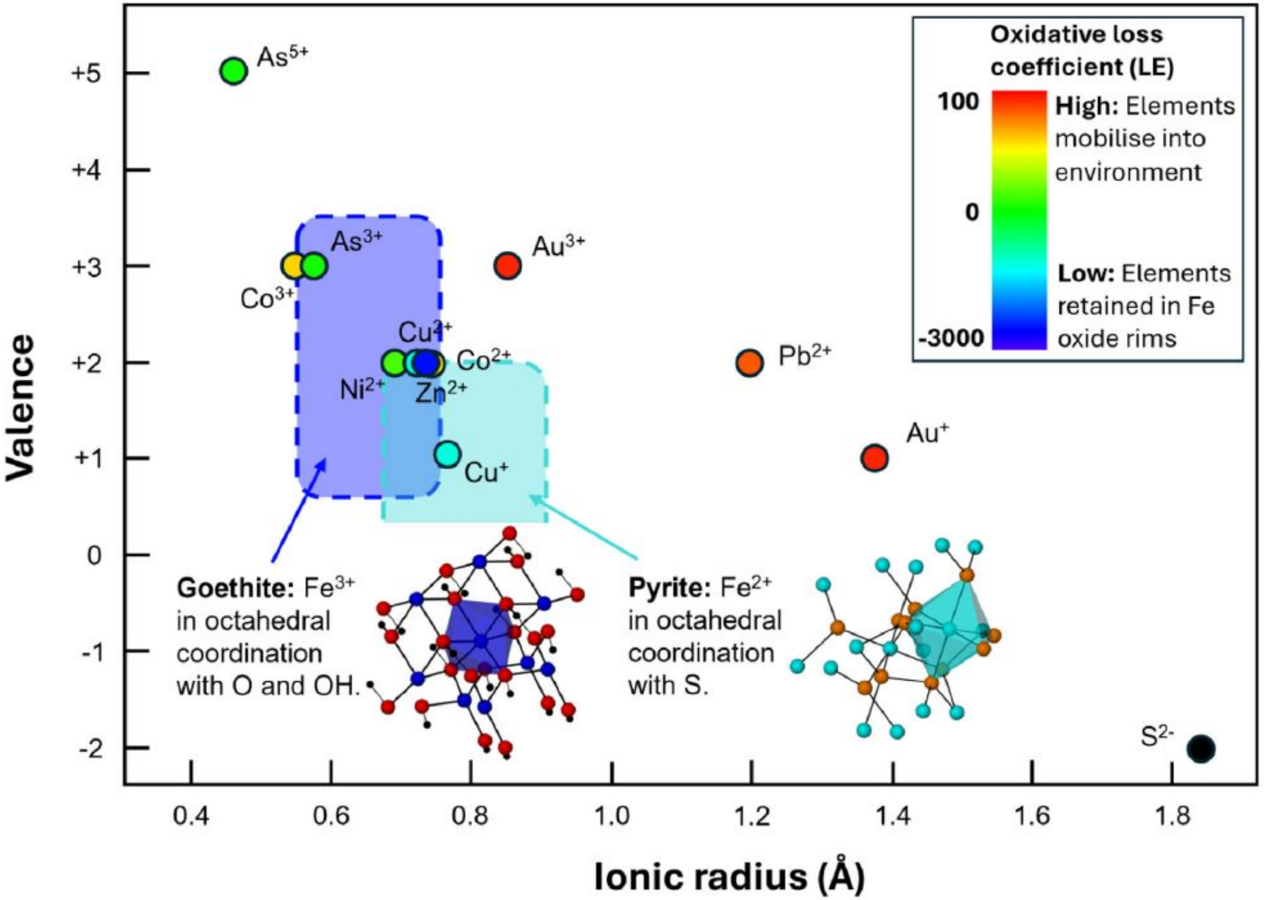
Environmental implications

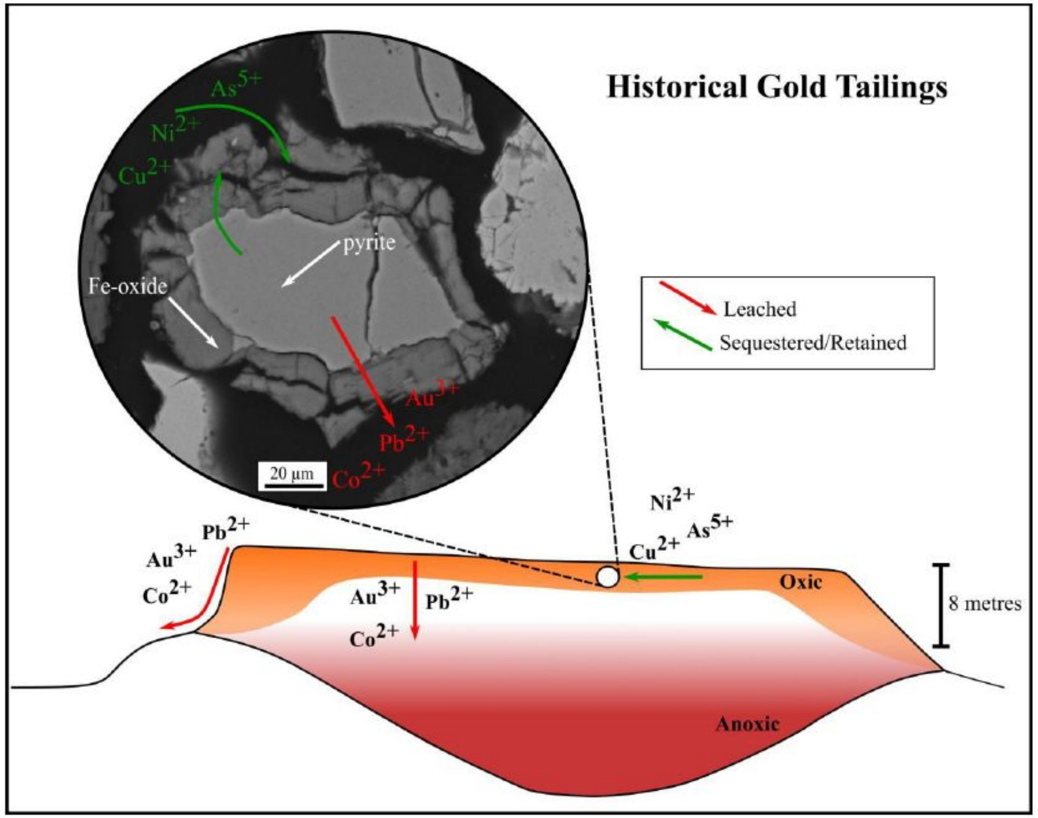
- What is the current fate of these contaminants given the 140 year mining history?
- Samples from Klerksdorp goldfield have well developed oxidation rims, allowing LA-ICP-MS analysis of the trace element deportment between sulphides and gossan.
- 110 complementary laser spots collected for pyrite and adjacent FeOOH rims.



Environmental implications

- Oxidation rims represent a transient repository for deleterious element fluxes (Cu, Ni, As), whereas others will mobilise into the local/distal environment.
- Understanding contaminant fate and mobility is not simply related to the sulphide stability, but also the stability of the gossan rims and the reversibility of surface sorption reactions.
- Strong environmental stewardship case for removing all sulphides during tailings reprocessing.





Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT
ARM GeoMetallurgy Research Chair
African Rainbow Minerals

Thank you
Enkosi
Dankie

Stellenbosch
UNIVERSITY
IYUNIVESITHI
UNIVERSITEIT

ARM African Rainbow Minerals GeoMetallurgy Research Chair

Sponsors

NRF National Research Foundation

cimera DSI-NRF Centre of Excellence for Integrated Mineral and Energy Resource Analysis

Laboratories

CAF Central Analytical Facilities STELLENBOSCH UNIVERSITY

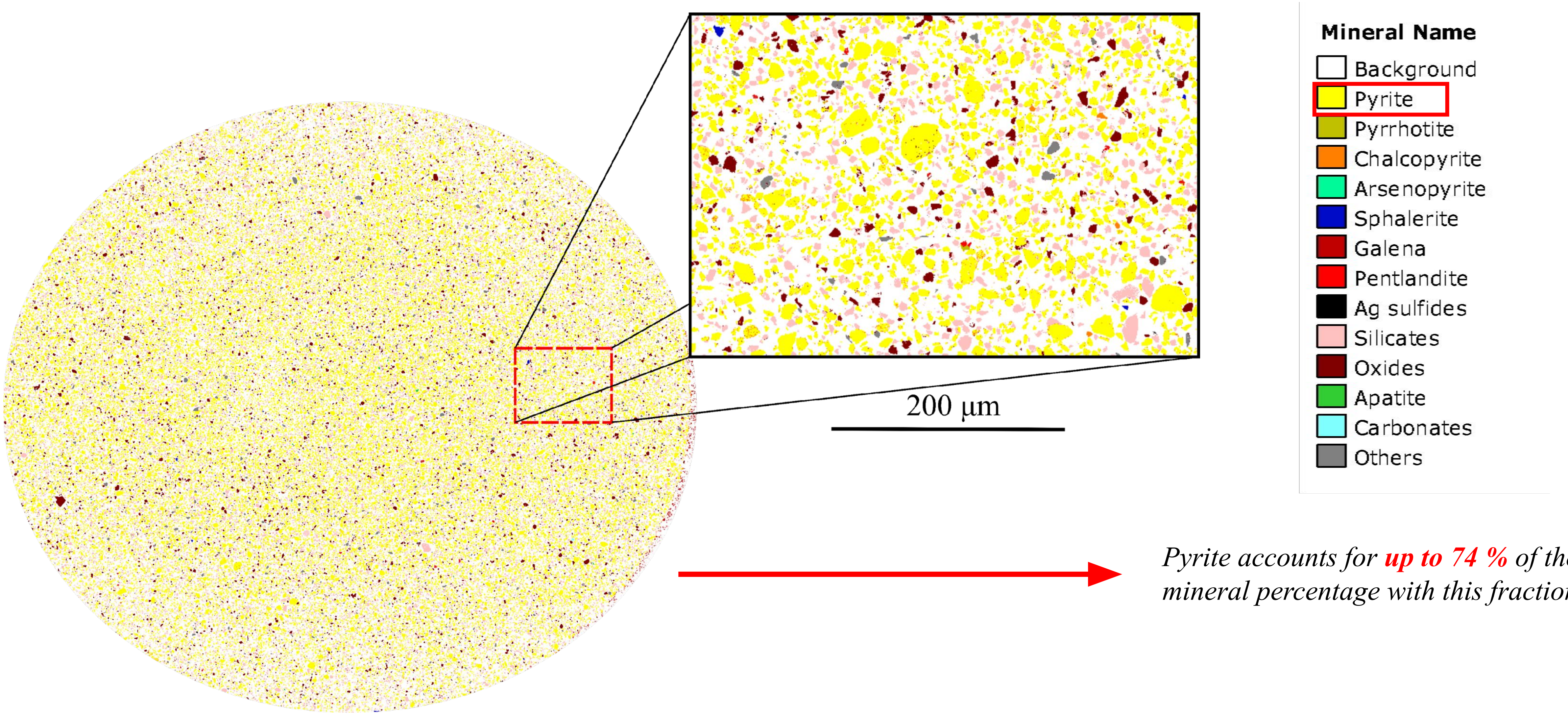
CMR CENTRE FOR MINERALS RESEARCH

Mining houses

DRDGOLD LIMITED

PAN AFRICAN RESOURCES

Heavy fraction mineralogy



Pyrite accounts for ***up to 74 %*** *of the total mineral percentage with this fraction.*

One of the detailed mineralogical pixel map of the heavy mineral fraction generated by QEMSCAN

Implications

Study contributes to :

- A greenstone belt orogenic gold mineralization source for provenance of Witwatersrand gold.
- A paragenetic relationship between gold and pyrite/arsenopyrite in greenstone belts.
- The detrital sulphides behaved as stable heavy minerals during sedimentation under the reducing Archean conditions.

Results also implies:

- Exploration potential for an accumulation of detrital auriferous pyrite (~5 g.cm^{-3}) in alternative (discrete) sedimentary settings.
- This ‘invisible’ gold is known to be inaccessible may thus be a significant contributor to the 50-70% recovery inefficiencies.
- Targeting the sulphide fraction during tailings reprocessing (e.g., *by froth flotation, pre-oxidative processing and gold leaching*) would recover this invisible gold fraction along with other heavy metals that may be of economic interest or environmental concern.
- This will further alleviate the growing ramifications of AMD and effluents with deleterious elements in the Witwatersrand mining regionc