GEOCONGRESS 2023
11-13 JANUARY

Stellenbosch University Iyunivesithi Universiteit

The next 125 years of Earth Sciences

GSSA Geological Society of South Africa

ABSTRACTS

GEOCONGRESS 2023 ABSTRACT VOLUME
STELLENBOSCH UNIVERSITY

The Geology Department and the Geological Society of South Africa staged a very successful and well attended Geocongress in January, 2023. The abstracts of the conference were made available on the conference app to all attendees, with a commitment to make them publicly available in a digital format after the conference. This document comprises the abstracts of oral presentations and posters accepted for the conference, and is a record of the proceedings and is lodged on the GSSA website, www.gssa.org.za. It is open access and may be cited as https://doi.org/10.25131/ZYMV7244, a Geological Society of South Africa digital publication. It is organized in alphabetical order of the first author surname, with the page number of the abstract indicated next to the name. There is some good science in this volume, and the Organizing Committee believes it will retain its scientific value well into the future.

The conference theme "**The next 125 years of earth sciences**" was originally envisaged for the 2020 iteration of this event, in recognition of the mutual age of both the Geological Society of South Africa and the Department of Earth Sciences at Stellenbosch University. Albeit that both are now 127 years old, the gist of the theme remains pertinent. That is, how can we as a community of earth science practitioners ensure that we remain relevant, progressive and future looking, particularly as the needs of society continue to evolve? Perhaps the answer lies embedded in a meeting such as this one, in which we have tried to be as inclusive as possible encompassing a broad range of industry professionals, scientists, governmental employees, academics and most importantly, the future talent represented by the >130 student delegates. Moreover, the conference's inclusivity and diversity is further evidenced by the wide range of different sub-disciplines represented, from molecular-level biogeochemistry through to macroscale planetary geology; and by the mix of local and international delegates attending both in-person and via our online hybrid offerings. This underpinning of moving towards a future marked by inclusivity and togetherness resonates deeply with the South African principle of Ubuntu which, for our international delegates, translates loosely to *"I am what I am because of who we all are."*

Sincerely,
Bjorn von der Heyden and Craig Smith

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20 years of U-series dating carbonates from South Africa: the good, the bad and the ugly.

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Over two decades of technical and application-based advances to the speleothem U-Pb chronometer have cemented this method at the forefront of landscape reconstruction, palaeoclimatology, and palaeoanthropology. Yet still this chronometer remains a challenging analytical exercise, more-so as the technique becomes routinely applied to carbonates with less-than-ideal U/Pb ratios. We investigate the Cradle U-Pb data set (3 to 1 Ma), consisting of 35 U-Pb ages and 291 individual matched U and Pb analyses. We use the U and Pb data, thin section petrography and laser ablation trace element transects to investigate factors controlling the age quality. U concentration has little to no effect on age quality, while the lower Pb concentration, the better. There is no apparent relationship between U concentration and residual 234U/238U, suggesting U concentration patterns are controlled by 238U, not 234U. We divide the 35 U-Pb ages into three categories defined by the % error on the U–Pb age (the good, the bad and the ugly). The 'good' ages are produced by: a large number of points (10 plus) defining their isochrons, radiogenic 206Pb/204Pb ratios, with a few very radiogenic points defining the line of the isochron, U concentrations of ~1 ppm and well-preserved trace element signals. 'Bad' ages are caused by deficit in one of these factors but may be redeemed with additional analysis to better define the line of isochron and constrain initial 234U/238U. The 'ugly' ages are attributable to low levels of radiogenic Pb, a low spread of isochron and high Pb concentrations, possibly from detrital material. We show what a completely recrystallized flowstone looks like, where the original trace element signals are obliterated, and it is impossible to resolve a U–Pb age. The thin section petrography reveals all flowstones have undergone heavy diagenesis, with the dominant fabric observed consisting of mosaic calcite with relic aragonite. However, we argue that the preservation of trace element signals, in particular the abrupt, sympathetic step-like variation is Sr, U and in some cases Ba and Mg, indicate that this diagenesis is conservative. We identify a mixture of crystal and fluid dominated trace element patterns, both of which are ultimately related to flow dynamics, in turn related to changes in external hydroclimate. This hints at the potential to extract valuable palaeoclimate records out of these old, U–Pb dated flowstones, which would be interesting given their association with early human evolution sites in South Africa.

200 Ma of melting and deformation of the Archaean crust: the Northern margin of the Kaapvaal craton

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A key element in unravelling the vexed issue of the tectonic regime of the Archaean Earth revolves around the thermal state of the crust, that controls its rheology and therefore its reaction to stresses and the strain patterns developed.

In the northern margin of the Kaapvaal craton (Limpopo Province, South Africa), structures are dominated by ubiquitous vertical foliations and horizontal lineations, reflecting transpression but lacking evidence for the archetypical dome-and-keel pattern (Chauvet et al., this meeting). Field observations reveal that the deformation occurred during melting under upper amphibolite to granulite facies conditions.

We dated a range of syn-deformation anatectic pockets, from small scale leucosomes to larger dykes and 100m-scale plutons of anatectic granites. Their age ranges over 200 Ma, from ca. 2900 to 2700 Ma, with little geographic control. Some of the granitic bodies show evidence of post-emplacement remelting, demonstrating a succession of several melting events in the same place.

Collectively, these observations suggest that the crust stayed hot, or was repeatedly heated for a long period of time, with slow deformation throughout the period, but without marked exhumation or burial. This situation is not consistent with what one would expect from a modern orogenic system, or even a succession of orogenic phases - but are also inconsistent with rapid gravity exhumation of lower or middle crust. This suggests that the artificial opposition between 'horizontal tectonics' and 'vertical tectonics' in the Archaean should be reconsidered and replaced by efforts to actually describe the Archaean strain patterns rather than attempting to apply a priori models.

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3D modelling of cupriferous basic bodies (Koperberg Suite) from the Narrap Mine, Okiep Copper District – constraints on emplacement controls and orebody geometries.

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Copper mineralization in the Okiep Copper District (OCD) in Namaqualand is associated with stubby and irregularly shaped dyke-, sill-, or plug-like mafic intrusives, so-called 'basic bodies' (anorthosite, diorite, norite and hypersthenite). The basic bodies intrude into a flat-lying sequence of granite gneisses and intercalated metasediments, but are often localized along narrow, easterly-trending zones of subvertical foliation development, locally referred to as 'steep structures' (Lombaard et al., 1986). The discontinuous geometries of basic bodies and the fact that only a small percentage of the more mafic end members contain economic-grade mineralization make them notoriously difficult to explore and delineate. Exploration, thus, requires a better understanding of the emplacement controls and mechanisms of basic bodies.

Here we present the results of a structural and 3D modelling study into the geometry and controls of Koperberg Suite intrusions from the previously mined Narrap Mine in the OCD. Data for this project is based on surface mapping and altogether 454 surface and underground boreholes.

The Narrap mine workings are centred around a cluster of steeply-dipping, easterly-trending diorites and norites that are intrusive into a steep structure. Notably, earlier dioritic intrusions are often flanked by later copper-mineralized norites. The main cluster of basic bodies describes a steeply-plunging, carrot-shaped geometry that tapers towards the base of the competent Khurisberg Subgroup metasediments. The central cluster flares out to the west into a sub-horizontal branch in the structurally higher gneisses.

This pattern of a steep plug rooted in or below the Khurisberg Subgroup branching out in overlying gneisses is also manifested at other mines in the OCD such as the old East and West Okiep Mines or the major Carolsuberg Mine (e.g., Lombaard et al., 1986). These geometries highlight the role of (1) wall-rock anisotropies (steep foliation and lithological contacts) as favourable sites for magma emplacement, and (2) rheological contrasts of wall rocks (inflation through wall-rock deformation in gneiss units versus dyke constriction in quartzitic metasediments) for the emplacement of the basic bodies. The modelling also shows that subsequent intrusions of more mafic and mineralized end-members of the basic bodies (norites) preferentially exploit anisotropies (contacts) created by preceding phases of the Koperberg Suite (diorites) against country-rock gneisses.

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A 300 ka terrestrial record from the Kalkkop impact crater, South Africa: initial palaeoenvironmental interpretations

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Background: The Kalkkop impact crater, located in the contemporary Nama-Karoo desert biome of South Africa, hosted a lake in the past.

Methodology: Drill depth reached 89 m, before contact with Breccia occurred, achieving ~80% sediment recoverability. A basal sample of the original core was dated to the beginning of MIS 7 (~250 ± 50 ka) using U–Th, while a near surface sample at 32 cm revealed an age of 18 ka using radiocarbon dating. An extraordinary find in the southern African context. The core is dominated by fine laminations, with some massive deposits. The grey scale index, performed at a one-millimeter resolution, revealed several cycles within the data potentially alluding to major climatic shifts. The core was subsampled at an approximately 16 cm resolution and subjected to a host of analyses, including spectrophotometry, magnetic susceptibility, CNS elemental analysis, and grain size analysis.

Key Results: The core can be subdivided in three major and statistically significant sedimentary units, as based on the spectral data, namely Z1: 7938 – 8735, Z2: 1881 – 7904, Z3: 0 – 1866cm. The I-band index, which isolates the [660, 670 nm] reflectance trough values as produced by Chlorophyll-a and its diagenetic products, revealed low, high, and moderate periods of primary productivity, respectively. Carbonate content is generally highest in Z3 and exhibits a weak correlation with parameter L* (Black/White).

Conclusions: Future research will focus on diatom and trace elemental analyses but primarily on a more detailed U-Th chronology, annual layer counting and the generation of a detailed age model. The implications of this new palaeoclimate archive presented here, plus its future age model, are significant given the sites close proximity to the rich archaeological record of early modern human behaviour on the adjacent southern Cape coast.

A 5-km-thick magma column in the Main Zone of the Bushveld Complex

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For over a century, the classic paradigm of volcanology and igneous petrology has been premised upon the existence of magma chambers, filled by crystal-free melt, forming 'big tanks'. Such magma chambers gradually lose heat and crystallize from all margins inwards and occasionally supply overlying volcanoes with magma that erupts onto the Earth's surface. This founding concept has been recently challenged on the basis of observations and evidence from various disciplines(1). There are, however, some observations from magmatic complexes that conflict with this emerging paradigm. Here we present one well-constrained example from the Bushveld Complex, indicating that its magma chamber appears to have contained, during one stage of its evolution, an enormous volume of resident melt that slowly crystallized from the base upwards to produce a continuous sequence of chemically stratified cumulate rocks(2). In the south-eastern part of the complex, the magmatic layering of the Main Zone continuously drapes across a ~4-km-high sloping step in the chamber floor. Such deposition of magmatic layering implies that the resident melt column was thicker than the stepped relief of the chamber floor. Prolonged internal differentiation within this thick magma column is further supported by evolutionary trends in crystallization sequence and mineral compositions through the sequence. The resident melt column in the Bushveld chamber during the formation of the Main Zone is estimated at >5-km in thickness and >380,000 km3 in volume(2). This volume is several orders of magnitude larger than the largest ignimbrite/tuff super-eruptions in Earth's history (e.g., Bishop tuff – 600 km3 and Youngest Toba eruption – up to 13,200 km3) and is only comparable to estimates of some of Earth's large igneous provinces, such as the Karoo (367,000 km3) and Afar (350,000 km3). This suggests that super-large, entirely molten, and long-lived magma chambers occur, at least occasionally, in the geological history of our planet. Therefore, the classical view of magma chambers as 'big magma tanks' remains a viable research concept for some of Earth's magmatic provinces.

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A Community of Practice to develop high-level skills in petroleum geoscience

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Background

The South African government launched Operation Phakisa in 2014 to fast track the implementation of solutions on critical development issues, such as unemployment and wealth creation. The oceans were identified as a significant opportunity, and the Oceans Economy Lab was established under the management of the South African International Maritime Institute (SAIMI). Offshore oil and gas exploration was identified as a key area. Geophysics, geology, petrophysics and reservoir engineering were identified as core disciplines with a significant capacity deficit. It was decided that the best course of action was to establish Research Chairs in the relevant disciplines. The NRF issued two calls (in 2017 and 2018) to establish a DST-NRF-SAIMI Chair in Petroleum Geoscience, but failed to attract fundable applications. Total announced the significant Brulpadda deep-water gas condensate discovery in February 2019. Shortly thereafter, the NRF, DSI and SAIMI initiated a process to establish a Community of Practice (CoP) to develop local academic expertise.

Methodology

A CoP is an instrument that the DSI and NRF uses to leverage the expertise of research chairs and centres of excellence to address matters of urgent socio-economic importance; in this case, the standard of teaching and research in petroleum geoscience. The overall goal is to ensure that South Africa draws maximum benefit from a local oil and gas industry. The CoP started to operate in March 2020. Its work plan was severely impacted by the Covid outbreak and had to be adapted. Nevertheless, good progress has been made. The CoP Steering Committee comprises representatives from government, industry and academia. The core academic members are the historically-disadvantaged coastal universities that have programmes in petroleum geoscience or reservoir engineering (Cape Peninsula University of Technology, Fort Hare, Nelson Mandela and Western Cape) as well as the University of the Witwatersrand, which co-hosts of the Centre of Excellence in Mineral and Energy Resource Analysis (CIMERA), the Reflection Seismic Research Centre, and offers an MSc in Petroleum Engineering.

Key results

Each university has identified members of staff that will expand their expertise and professional and scientific networks by participating in conferences and workshops and short-term placements in petroleum companies and leading research institutes. There are currently eight academics enrolled in the scheme. Seven have PhDs, and one has submitted his thesis. They are teaching under- and postgraduate courses in petroleum geoscience, supervising more than 20 postgraduate students and postdoctoral fellows, and publishing articles in international refereed journals.

A comparative assessment of rare earth elements in borehole cores from the Ermelo & Witbank Coalfields, South Africa

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Internationally, there has been an increase in the demand for critical elements such as uranium, germanium and rare earth elements with the advent of the fourth industrial revolution and green energy economies. According to Haque et al. (2014), the major uses of rare earth elements, including yttrium and scandium, are in the renewable energy industry, specifically in the manufacturing of wind turbines, batteries and electric cars. Currently, China has 36.7% of the world's known REY+Sc and is responsible for 70.6% of the total global production. This increases pressure on China to supply the commodity and heightens geopolitical supply risks. Hence, a need to get alternative sources for these elements. Numerous authors have investigated the potential of exploiting REY+Sc from coal and coal by-products, including Hower et al. (2020) who discovered 2000ppm REY+Sc from a coal deposit in eastern Kentucky. There is a knowledge gap concerning the potential for South African coal deposits to be alternative hosts to REY+Sc.

This project aims to determine the concentration of REY+Sc in the coal seams and adjacent sediments, as extracted from borehole cores from the Witbank and Ermelo Coalfields (Mpumalanga Province South Africa). The analyses included coal petrography; chemical analyses (proximate analysis); mineral analyses (XRD and XRF); and the elemental association through sequential leaching before ICP-MS analysis.

The results indicate that both sets of samples are medium rank C bituminous, high in ash, and low total Sulphur. The roof, floor and coal samples have a high concentration of quartz and kaolinite, microcline and smectite. There is an enrichment in light -REE La and Ce in both coalfields, and Nd, Dy, and Yb mainly in Witbank Coalfield. There is a peak in the REY+Sc concentration in the carbonate-associated fraction for both coalfields, and the Witbank samples have an additional peak in the silicate fraction. The overall coal REY +Sc values are lower than upper continental crust values for the Ermelo samples, but values are higher for Witbank samples. This implies that the coal samples would need to be ashed to increase the concentration of REY+Sc by at least three times.

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A feasibility study of dating calcrete from pans using combined (U,Th)-He and U/Th dating

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Archaeological sites in open air semi-arid environments such as pans in the Karoo are commonly dated using radiocarbon and optically stimulated luminescence (OSL) dating methods. Radiocarbon has an upper dating limit of 50 ka and OSL is generally considered limited to 150 ka [1]. However, reliable OSL ages up to 353 ka have been determined in the Rising Star cave [2]. Open air archaeological sites in the Karoo often have calcrete layers associated with the artefacts, and dating the calcrete with U/Th or (U,Th)-He dating techniques would extend the possibilities of dating these sites to 0.5 Ma and possibly beyond. Here we tested the combined U/Th and (U,Th)-He dating method developed for dating low-temperature and pedogenic carbonate and oxide precipitates [3, 4] on calcrete from three pans in the Karoo. Five calcrete samples from the Alexandersfontein, Morgenzon and Deel Pans yielded apparent (U,Th)-He ages ranging from 0.3 Ma to 14 Ma, while U/Th disequilibrium points to ages less than 200 ka. The apparent (U,Th)-He ages point to excess He of a much older component in the calcretes, probably hosted in Fe-Mn oxides-hydroxides and clay minerals observed. If it is assumed that the U/Th in this old component is at or near secular equilibrium, then ages of the calcrete can be estimated by subtracting equilibrium amounts of 238U, 234U and 230Th from the U/Th data, based on the measured 232Th/238U ratio of the bulk calcrete, and an assumed ratio for the old component. With several samples from the same layer analyzed, the assumed ratio can be optimized to yield a uniform U/Th age in an isochron-type approach. Three of the pan samples gave a combined age of 134 ± 4 ka in this way, which is not in conflict with published constraints, showing that this approach in dating calcretes holds promise.

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A Methodology for Sustainable Data in the Geosciences

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Background

'Sustainable Data' is able to be maintained at a certain level. This data can be upheld and defended.

Methodology

A system of methods, principles and rules should regulate your data's life cycle. It is a plan of attack that can be followed as a set of procedures and practices to provide quality assurance.

Key Results

Data will be durable if it is reliable and robust. Accurate data is reproducible. Precise data is unbiased. Relevant data will be material to a particular geoscientific subdiscipline.

Main conclusions

Bearing the end in mind, the data that is recorded must be observed and measured according to a defined Data Standard. This is a definition that can be improved continuously under a code of practice to introduce transparency and accountability. The suggested approach will inform geoscientific knowledge and encourage data integrity within the professional subdisciplines.

A Mineralogical Study of Phosphate Mineralization in the Nkombwa Hill Carbonatite

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This study focuses on the phosphate mineralogy of the phosphate containing minerals of Nkombwa Hill carbonatite in Zambia east of town of Isoka. The purpose of his study is to understand the mineralogical characteristics of the phosphate minerals with the aim of contributing towards identifying optimal mining and beneficiation techniques to produce phosphate as by-product from the Nkombwa Hill carbonatite complex. This was achieved by a detailed petrographic and mineralogical examination.

The carbonatite contains various phosphate mineral species: apatite, isokite and monazite. Isokite is the most abundant phosphate mineral along with variable apatite content, with monazite occurring in trace amounts. Two phosphate ore types are recognized based on the relative abundances of apatite and isokite: apatite only ore, and apatite-isokite ore. Monazite is restricted to the apatite-isokite ore type.

The apatite is a strontian fluorapatite variety, and the isokite is the magnesium containing phosphate and the monazite is strontian and REE containing. The associated gangue minerals are mainly carbonates that are ankerite and dolomite, and other minerals occurring in trace amounts, which includes barite, pyrochlore, phlogopite, magnetite, quartz, and fluorite. The strontium contained within the phosphate minerals does not pose any threat to the quality of fertilizers. However, the magnesium in isokite poses threat under given circumstances of no known technologies for processing.

There are textural differences between isokite and apatite. Apatite occurs as either coarse, well-developed prismatic crystals in apatite only ores, and as anhedral crystals, clusters and medium-to- coarse, elongate crystals in apatite-isokite ores. Isokite mostly occurs as small fibrous spherulites, less frequently as larger radiating aggregates of acicular crystal, and on rather rare occasion as veins within apatite.

Currently, there is no viable beneficiation process to produce conventional fertilizers from the magnesian phosphate mineral isokite: for this reason, despite exploration efforts over more than 50 years, the phosphate resource at Nkombwa Hill remain undeveloped. The least part of the phosphate ore at Nkombwa contains a significant amount of apatite. The isokite component of the ore has markedly different crystal form to the apatites: generally elongate needles with high length: breadth ratios that contrast with the more study, prismatic apatite crystals. During pulverizing, the isokite is likely to produce very fine-grained crush (“slime”) relative to the apatites. This feature, along with subtle density differences between these minerals, offers the possibility of producing an apatite concentrate from the Nkombwa ores that could be processed into fertilizer by conventional methods.

A new GNSS (GPS) velocity field for South Africa based on the TrigNet network: Implications for strain rate and seismic hazard

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South Africa is generally considered to be a stable continental region, falling within the San plate. Despite this, the instrumental, historical and paleoseismic records all demonstrate that significant earthquakes have occurred in the past. In areas of exceptional geomorphological preservation there is evidence for repeated rupture on the structures, suggesting that interseismic strain is constantly accumulating on them. Placing bounds on the rate of this strain accumulation can help inform probabilistic seismic hazard estimates within the region and could help guide the identification of other potentially active faults systems where the potential for geomorphological preservation is more limited.

South Africa is covered by a network of permanent, continuously operating GNSS receivers (TrigNet) administered by the Department of Agriculture, Land Reform and Rural Development through the Chief Directorate of National Geospatial Information (NGI). In this study we process these GNSS data series in order to constrain the long-term strain rate across the region. The network began with two sites in 2000 and has grown to 65 permanently-running sites. Such a study was last performed 10 years ago when significantly fewer sites and shorter time series were available, and the resulting large uncertainties limit the application of the results for seismic hazard analysis. In addition to the local constraints on long-term strain rates, these datasets may help to determine the sense of shear associated with the San-Nubia plate boundary within the Okavango region. Recent studies have come to opposite conclusions on this within the last few years, and a dense, well-constrained velocity field throughout the San Plate could help to precisely quantify the rotation between these two areas in order to resolve this issue. Given the long time series currently available, quantification of low strain-rates should be possible.

We precisely process daily observations with 30 seconds intervals of TrigNet station data in a loosely constrained solution. The processing network includes 17 IGS (International GNSS Service) sites in and around South Africa to connect TrigNet to a global reference frame. We perform quality control of each site regarding satellite visibility and environmental effects. Later we combine daily results and refer the processed network to global reference and regional reference frames. Finally we apply a Kalman Filter to realistically study the noise levels of individual sites and temporal correlations of observations, and conduct a realistic estimate of uncertainties. This is crucial in understanding rotation and deformation in a stable region with low strain rates.

A new look at the Metallogeny of the Benue Trough, Nigeria

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The Benue Trough is an intra-continental rift filled with Cretaceous sediments, extending 600km northeast from the Niger Delta. Sinistral wrenching and rifting are responsible for the development of numerous pull-apart basins with bounding structures providing favourable fluid conduits. Pb-Zn-Ba-F mineralisation occurs along the axis of the trough in three discrete sub-basins. These sub-basins are dominated by intercalations of sandstones, shales, minor limestones, subordinate intrusives and local Albian volcanics, that were disrupted by Santonian tectonism with associated mineralisation. Barytes deposits overwhelmingly favour sandstone host rocks with a few in the neighbouring basement along the southern flank. While this stratabound control is ubiquitous, mineralisation occupies hydrothermal (brecciated) fracture fillings Fluorite occurs locally in Middle-Upper Benue Pb-Zn deposits, especially proximal to granitic basement while siderite >quartz dominates the gangue. Generally, clusters of economic barytes-dominant veins are spatially separate from significant Pb-Zn±F dominant centres.

Mineralisation is closely associated with major NE-SW trending anticlinal folds and orthogonal faults which are products of Santonian buckling and N-S to NW-SE compressive episodes. Vein arrays appear to fit into a Riedel shear pattern in which faults disposed symmetrically or sub-parallel to the direction of shortening, in an arc <15° east to 25° west of north, could be regarded as antithetic R’ fractures coupled with instances of P’ shears and T cracks. Where the principal deformation zone is aligned closer to 045°-055°, these antithetic shears lie more commonly NW-SE. The major veins orientated ±050° and ±120° probably occupy R and P shears respectively. These structures locally mimic breaks or NNW-oriented magnetic highs with vein clusters occurring at their intersection with ENE to NE-trending magnetic lineaments.

Limited initial vein-marginal silicification is frequently followed by dominant siderite, locally giving rise to prominent gossans, with Fe-Pb-Zn±Cu sulphides, followed by late quartz >>carbonate infill.

It is inferred that re-circulating connate brines leached metals from basal arkosic sandstones and were expelled through the sedimentary pile and mineralised favourable structures during episodic tensional release. Fluid inclusion homogenization temperatures can be bracketed between 89°C and 254°C and typically carry 16-22wt% NaCl. We postulate that barytes-dominated veins may reflect local fluid mixing triggering $BaSO_4$ precipitation while destabilization of HS^- complexes or sulphur saturation in more reducing shales may account for the local dominance of Pb-Zn-Fe-Cu sulphides.

We posit a mineral systems approach, requiring compilation of all occurrences to understand the interaction of redox boundaries with structural architecture, possibly leading to discovery of additional speculative stratiform mineralization.

A quantitative geochemical assessment of old slimes tailings from two South African kimberlite diamond mines: implications on the development and standardization of a procedure for mineral-carbonation resource estimation

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Kimberlite tailings are the potential feedstock to sequester CO2 via mineral carbonation technology. This has necessitated defining and classifying the country's kimberlite tailings for future mineral carbonation technology implementation. Moreover, before the technology implementation phase, a nationwide mineral carbonation resource estimation of kimberlite tailings would have to be conducted. Traditionally, resource estimations are conducted on natural deposits with residual economic value using country-specific codes (i.e., JORC or SAMREC) [1]. So, to apply resource estimation on kimberlite tailings, a prototype estimation protocol would need to be developed by adopting some elements of existing estimation procedures while developing new ones.

Kimberlite waste resources in South Africa are geochemically and mineralogically heterogeneous. Therefore, developing a prototype estimation procedure required using at least two case study mines that represent some of this variability and using classical and novel characterisation methods to achieve broad but not exhaustive comparative analyses.

This paper seeks to geochemically quantify and characterise the historical kimberlite tailings from Cullinan and Finsch diamond mines. The objective of this study is twofold: (1) to develop a standard prototype procedure for classifying and categorising the tailings deposit into a practical and beneficial mineral carbonation resource and (2) to facilitate the conversion of the old slime's tailings deposit either to an inferred or indicated mineral carbonation resource estimation using the South African Code for Reporting of Exploration Results, Mineral Resources and Mineral Reserves (SAMREC) as a resource estimation framework.

In both mines, samples were collected from the old slimes dam. The preliminary qualitative XRD results revealed that both tailings contain significant quantities of talc and phlogopite, which are highly suitable target minerals for ex-situ mineral carbonation. This was verified by the significant MgO and CaO content in XRF. Particle size analysis indicates that Cullinan has high clay-sized and low sand-sized fractions relative to Finsch. Based on the enhanced weathering potential (Epot) equation, the potential sequestration capacities at Cullinan and Finsch estimated using the tailings geochemistry are 335.383 and 226,314 KgCO_2/t respectively. Upon completion of the study, the volumes for Cullinan (~317.6 tons) and Finsch (~35 390.3 tons) estimated using Digital Elevation Models (DEM) combined with pending results from other analytical tools will be used to facilitate the tailings conversion into a mineral carbonation resource estimation model.

Keywords: Tailings, SAMRAC, Sequestration

Reference

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A Reappraisal of the Geology of the Vaalputs Facility, Namaqualand, South Africa: Monitoring Implications

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Background

The Vaalputs facility located 100 km SE of Springbok, in the Northern Cape is the IAEA- certified site for the disposal of low-level radioactive waste emanating from South African nuclear programs and power generation at Koeberg in the Western Cape. The waste is stored in metal or concrete drums buried in trenches excavated in the clay-bearing greywacke of the Tertiary Vaalputs Formation. For operational requirements, the geology of the site has been the focus of numerous investigations, especially of the first two, ~7 m deep trenches excavated in the late 1980s. According to these studies, the site characteristics are adequate for the disposal of short-lived radioactive waste, though some near-surface, thrust-like structural features were identified that required further investigation.

Methodology

Follow up work included stratigraphic drilling to a depth of 1000 m, geomorphological and remote sensing mapping of the Vaalputs basin and its environs, and detailed logging of seven new trenches up to 8 m deep. Additional mineralogical work included X-ray tomography, Optically Stimulated Luminescence (OSL) dating, isotopic dating and the deployment of a seismic network.

Key results

Our new investigations demonstrate that the near-surface (~3.5 m thick) regolith profile exposed in the trenches is pervasively dissected by compressive, easterly verging shear fractures that do not penetrate the unweathered Vaalputs Formation below. The limited percentage of swelling clays in the sediments, and the laterally persistent orientation of the shear fractures and related compressive structures do not support a pedogenic origin, e.g., like the slickensides of the vertisols. The preferred explanation is that they represent stress relief structures triggered by the seismogenic reactivation, between ~60 ka and ~75 ka, of the Santab fault zone (8 km to the east) along a ~22 km long, up to ~10 m scarp.

Main Conclusions

As the fault is seismically quiet, its reactivation within the 300 years of statutory site supervision is most unlikely, yet its ongoing seismic monitoring is advisable especially for a license to store nuclear spent fuel in a Centralized Interim Storage Facility (CISF) for South Africa.

A reconstruction of Oligo-Miocene vegetation based on the palynology of core material from Langebaanweg, South Africa

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The Cape Floristic Region (CFR) hosts a diverse range of plant species that are characteristic of a Mediterranean-type climate established in the Neogene. The Elandsfontyn Formation at Langebaanweg (LBW) reveals the evolutionary history of fynbos vegetation, the exact timing of which is still uncertain. Pollen, spores and dinoflagellate cysts recovered from the previously analysed Core BH2 – preserving Elandsfontyn Formation deposits – are identified to conduct a palaeoenvironmental reconstruction of LBW. A standard palynological procedure was applied to process the sediments and produce 76 samples which were analysed using light microscopy. A total of 104 palynomorph taxa including pollen, spores and dinoflagellate cysts were recorded to accomplish the palaeo-reconstruction of LBW and statistically analysed to create clusters of palynomorph indicators, which may be associated with certain climatic parameters.

Palynological and statistical results confirm the existence of a subtropical-tropical forest dominated by Podocarpaceae (yellowwood trees), palms, climbers and ferns, pointing to wet conditions caused by summer rainfall. The possible existence of Araucariaceae – a typical Gondwana element currently extinct in Africa – is documented in this study but requires confirmation from SEM studies. Wetlands comprising Sparganiaceae (reeds), Restionaceae (restios), Cyperaceae (sedges) and Poaceae (grasses) were common, pointing to a high water table. Mangrove tree pollen were rarely recorded, possibly implying that mangrove swamps might have been confined to the coastline. Patches of proto-fynbos presumably provided an understorey component of the subtropical forests and co-fluctuated with the forest elements. A considerable marine influence was imposed on the terrestrial environment, inferred by three marine transgressions in the Apteodinium spiridoides zone (18.96–18.24 m) and a fourth and final transgression in the Operculodinium centrocarpum zone (16.865–13.4 m). These fluctuations are likely linked to global late Oligocene sea level changes. Dinoflagellate cysts belonging to Apteodinium spiridoides, Opeculodinium centrocarpum, Spiniferites mirabilis were abundant and occurred with other marine indicators, such as benthic microforaminiferal test linings and algal cysts. Savanna woodlands with Alchornea (Psilatricolporites quenua), Combretaceae (bush willows) and Peregrinipollis nigericus (Brachystegia – miombo tree) gradually replaced the subtropical forests, possibly due to more arid conditions and enhanced seasonality.

The presence of pollen types Mutisiapollis viteauensis and Tubuliflodites antipodica, as well as dinoflagellate cysts of Apteodinium spiridoides, Chiropteridium lobospinosum and Cordosphaeridium minimum infer a late Oligocene (early Chattian) to early Miocene (early Burdigalian) age for the Elandsfontyn Formation at LBW.

A volcanic-plutonic contribution to magmatic ore formation in Large Igneous Provinces

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A cogenetic relationship between plutonic and volcanic magmas is inferred for many Large Igneous Provinces (LIP) including those that have the greatest endowment of Ni, Cu and platinum group elements as in the Siberian LIP (Naldrett et al., 1995) and the Bushveld LIP (Kinnaird, 2010). Most of the models suppose basalt generation by mantle melting with periodic melt influxes into staging chambers or mush zones that may be stored in the crust as layered mafic-ultramafic intrusions. In addition, magma may stream through the chamber or escape separately to form volcanic flows and ash covers. The entire volume of magmas within the plumbing system is thought to be crucial for the degree of ore productivity of its plutonic component. This model is generally accepted for the Norilsk ore region of the Siberian LIP but this connection has not been quantitatively investigated for the Bushveld LIP although recent studies suggest that the extent of Rooiberg basaltic volcanism (Nazari-Dehkordi & Robb, 2022), that introduced the earliest magmas from the mantle to the surface, seems to have been underestimated.

This is supported by new textural, mineralogical, whole-rock geochemical and Sr-Nd-Hf isotope data on a contact-metamorphosed basaltic sequence overlying the Upper Zone of the Rustenburg Layered Suite in the Southern Marginal Zone of the Limpopo Belt. Our interpretation of the buried metabasalts as an analogue of the lower unit of the Rooiberg Group, Dullstroom volcanics, favors the extension of known Rooiberg volcanism to the entire Bushveld basin (Kruger, 2005). Basaltic rocks of the Bushveld LIP show broadly similar geochemical signatures to closely contemporaneous plutonic rocks indicating derivation from a common mantle source through a plumbing system of staging chambers or mush zones where primary magmas underwent fractional crystallisation, contamination and hybridisation via mixing to mingling. The greater volume of metal-depleted basaltic liquid that escaped the crustal plumbing system and left behind a crystal cargo helps reconcile the mismatch between the volume of the giant Cr and PGE resources in the Bushveld Complex and the insufficient solubility of the metals in mantle-derived magmas.

Addressing the geotourism potential of South Africa's game parks and nature reserves

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Background

The South African National Tourism Sector Strategy (NTSS) has been actively focussed on growing domestic tourism for a sustainable tourism economy since 2012. This is underpinned by the principle of government, private sector and community partnerships. The GSSA together with its branches and divisions forms a specialist community. The National Heritage and Cultural Tourism Strategy of March 2012 officially introduced "Geological Evidence" as a typology after the Department of National Tourism embarked on two years of workshops and comparisons with frameworks from Ireland, Australia, Sweden and Europe.

However, South Africa's geoheritage is under-marketed and under-represented by global comparisons. This is particularly apparent in our game parks and reserves, where there is no systematic and consistent approach to the display and description of geosites or training and multi-skilling of field guides.

Methodology

This situation is being addressed through a partnership between the Field Guide Association of South Africa (FGASA) and various interest groups, including the GSSA. Key aspects of this multi-year project, which kicked off in 2018 are the development of field guide training and assessment material; the establishment of a geological guiding training academy; the development of appropriately accredited qualifications (through FGASA, CATHSSETA and the GSSA); and the development of an App to support guiding and tourism activities.
Initially privately funded, it is expected that this project will become financially sustainable through training and accreditation fees, and through further private support.

Key Results

A pilot project has been completed on the Kariega Game Reserve in the Eastern Cape. A comprehensive geological guide has been completed, and geosites and geotrails have been identified and are being incorporated in the App.
Descriptions of the sites and trails are informal and geared for public interest by including links to external information and relevant websites.

The geological training material is in progress and will require a coordinated effort to complete.
The project team has been collaborating with a software developer to develop a GIS based software prototype called GeoXplor which integrates the game parks and nature reserves with the 1:1,000,000 CGS geological map.

Conclusions

This paper will demonstrate progress on the project to date, and will serve as a call to action for passionate geologists on the ground to get involved.

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Advanced analyses of Palaeoarchaean microbial mats: insights into the palaeoecology and taphonomy of Earth's earliest photosynthetic ecosystems

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Fossilised traces of photosynthetic organisms have an almost 3.5-billion-year record, the most ancient examples being silicified microbial mats and stromatolites of Palaeoarchaean age; the southern African record of Archaean palaeontology is particularly rich (Hickman-Lewis and Westall, 2021, South African Journal of Geology). Establishing the palaeoecologies of these fossilised ecosystems is a key step toward constraining the origins, distribution and early evolution of photosynthetic metabolisms. Using a range of high-resolution, high-sensitivity techniques – including SEM-EDX, laser ablation ICP-MS, Raman spectroscopy, FTIR microspectroscopy, and laboratory and synchrotron X-ray tomography – we have studied a number of the most ancient fossilised photosynthetic ecosystems, focusing on key horizons from the Barberton greenstone belt, South Africa. Correlating these advances analytical approaches has yielded insights into the communities responsible for the formation of ancient microbial mats and the mechanisms by which they were preserved.

Using laser ablation ICP-MS, we have demonstrated systematic differences in the rare earth elements plus yttrium compositions of microbial mat-bearing horizons versus fossil-deficient horizons, showing that mats developed during periods of enhanced continental inputs, when nutrient delivery was presumably highest (Hickman-Lewis et al., 2020, Precambrian Research). Applying micro-tomography, we have achieved sub-micrometre voxel resolutions and shown the preservation of numerous micromorphologies diagnostic of biogenic growth processes, including 3D non-isopachous laminae, grain trapping, fenestrae, and oriented fabric elements (Hickman-Lewis et al., 2019, Geosciences). Highly complementary organic compositional information given by Raman and Fourier Transform infra-red (FTIR) spectroscopy shows that remnant kerogen in mats is syngenetic and includes diverse organic materials. FTIR detections of aromatic C–C, aliphatic C–H, carboxylic COOH and other organic groups denotes the former presence of EPS-rich microbial mat communities that underwent extremely rapid and resilient preservation and entombment by silica. Quantifying the CH3/CH2 ratio of these carbonaceous materials has enabled the distinction between mats dominated by Bacteria and those dominated by Archaea (Hickman-Lewis et al., 2020, Palaeontology). Finally, in situ carbon isotope studies have enabled us to propose anoxygenic photoautotrophy as the dominant metabolic pathway within, although minor contributions from other pathways may explain hotspots of more negative carbon isotope fractionation.

The results of our multi-technique, high-resolution approach to Archaean microbial mat palaeobiology demonstrate that advanced analysis has the potential to establish the validity of biogeochemical signatures in deep time and decode systematic variations with environmental fluctuations. Such correlated multi-disciplinary approaches make it possible to consider the Archaean biosphere on a biome scale, addressing major questions in Earth–Life co-evolution.

Advances made in geothermal energy in South Africa

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The South African government published the Integrated Resource Plan of 2019, where the government outlined plans to increase the use of renewable energy. South Africa's renewable energy currently contributing to the energy grid is biomass, solar, hydro and wind. The Integrated Resource Plan of 2019 fails to explore or add geothermal energy as an additional alternate source of energy1.

Geothermal energy usage worldwide increased by 27% from 2015 to 2020 for installed capacity. Countries such as the USA, Indonesia, Philippines, Turkey and Kenya have the most installed geothermal power generation2.

The current research focuses on updated physical and new hydrochemical properties of South African geothermal waters to increase the understanding and knowledge of such waters as a potential source of geothermal energy. The analyses of samples from 41 sites involve physical property measurements, cation and anion and stable isotopes. This data will assist in modelling the potential geothermal reservoir characteristics using solute-based chemistry in the geothermal waters (geothermometry) to ascertain the temperature and depth from which such waters originate. The temperature range gives insight into the potential reservoirs in terms of enthalpy range. To have a comprehensive insight into the geothermal waters, updating or adding information on geological settings, hydrogeology, seismic activity, and socio-economic aspects is necessary to delineate sites for potential energy generation.

The hydrochemical data classifies the geothermal waters into four types: Na-Cl, Na-HCO3, Mg-HCO3 and mixed. In addition, utilising the chemistry with heat flow data of the geothermal waters to predict the depth of the source of the geothermal waters is possible. The data suggest that low enthalpy geothermal reservoirs are located at depths ranging from 1-3 km from the surface. We propose that these models be proven with additional geophysical modelling and exploration drilling.

Alkaline magmatism, palaeoclimatic evolution and supergene REE mineralisation in south western Africa

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The southwestern coast of Africa contains multiple intrusions of late Mesozoic and Cenozoic age alkaline and carbonate igneous rocks. This is mirrored in both time and place along the Brazilian coast suggesting a strong causative relationship in their intrusion mechanisms. Many of these Brazilian examples are deeply weathered and host significant economic deposits of Nb, P and REE, whereas this appears not to be the case in Africa.

Geochronology shows intrusion was largely during three periods of intense activity including 130 - 125 Ma, 80 - 68 Ma and then again intermittently throughout the Eocene from 56 Ma until 35 Ma. In this largely arid or hyper arid region of the African continent, thick, often lateritised, saprolite cover is preserved clear evidence that significant paleo weathering took place post intrusion. Recent investigations show that significant supergene REE enrichment may be present occuring within the regolith of a number of these intrusions.

Climate, together with the substrate being weathered, defines the regolith type, and the paleoclimate can therefore be recognised by the characteristic regolith and landform types preserved. Pervasive weathering of regionally exposed lithologies, including Mesoproterozoic gneisses and Neoproterozoic sedimentary country rocks, can be noted to have occurred prior eruption of the 46 Ma Klinghardt phonolites (Marsh et al, 2018). This weathering has been ascribed to the late Cretaceous and resulted in the formation of the so called 'Bo-alterite' (Pickford, 2016). Both the 55 Ma Zandkopsdrift REE deposit near Garies and Kieshohe REE deposit in the Sperrgebiet have been shown to have significant thicknesses of REE enriched laterite preserved. This contribution integrates published paleoclimate studies and onshore geological observations of these intrusions in an attempt to relate the identified supergene REE occurrences to the significant depths of weathering which are preserved. Supergene enrichment in REE is was most likely to have occurred during the PETM.

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Ambient Noise Surface Wave Tomography to determine granitic basement contact in northern Tasmania

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Ambient Noise Surface Wave Tomography (ANSWT) is an environmentally low-impact, low-cost method to image the sub-surface, in contrast to expensive active seismics often used in oil and gas exploration. A regional array of geophones covering several square kms in northern Tasmania reveal near-ideal ambient seismic conditions for imaging using the method of Bensen et al[1] to extract surface wave dispersion measurements. To estimate the shear wave velocity as a function of depth, an improved neighbourhood algorithm as described by Wathelet et al. [2] was used to invert the dispersion curves.

The resulting 3D seismic model reveals the granitic basement contact at around 500 m depth with strong undulations in places. Comparison with available borehole data, indicates that the model can distinguish hornfelsed sedimentary rocks from slower host sedimentary rocks, offering insights on potential hydrothermal pathways and mineralisation.

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An emerging 3T's (tin-tantalum-tungsten) metallogenic province in the Uis district of central Namibia – geological and metallogenic framework

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Pegmatites intrude both granitic and metasedimentary lithologies of the Damara Orogen, Namibia. The Uis mining licence (ML 134) in central Namibia falls entirely within the Uis swarm and contains Sn-Nb-Ta type pegmatites. Highly Sn- and Ta-mineralised pegmatites appear to be restricted to the metasedimentary host rocks whereas, intragranitic pegmatites display abundant columbite-group minerals (CGM). Mineralised pegmatites have a generally north-easterly to easterly strike, and dip between 30° and 70° towards the northwest, intruding porphyroblastic biotite schists (known as 'knottenschiefer') of the Amis River Formation, Zerrisene Group. Pegmatite emplacement is controlled by sinistral, S-shaped en-echelon fractures or sigmoidal structures associated with north-northeast – south-southwest striking half-graben faults. Tungsten-tin mineralization is also known in the district, in particular at the historical workings of Brandberg West, and the region shows promise as an emerging critical metals province of note.

The Uis pegmatites are granitic in composition and are primarily homogeneous intrusions that do not appear to contain any distinct mineral zonation. The primary mineralogical composition is quartz, feldspar and muscovite, with accessory apatite, ilmenite, magnetite, beryl, cassiterite, columbite-group minerals (CGM) and tapiolite. The highest grades of mineralisation are associated with greisens and albitised aplitic units. In addition to the known Sn and Ta mineralisation Li-minerals have also been identified in the form of lepidolite, petalite and cookeite. The metasedimentary host lithology of the Uis pegmatites is primarily a quartz muscovite schist, likely a greywacke protolith. The schist lithology hosting the Uis pegmatites experienced multiple phases of deformation resulting in folding and faulting prior to the emplacement of the pegmatites. The areas appear to have been relatively stable post- pegmatite emplacement, as little faulting and no folding of the pegmatites has been observed.

The Uis pegmatites have yielded a U-Pb zircon age of 520 Ma. Recent U-Pb dating of the Uis cassiterite provides an identical age of 519.8±1.6 Ma.

Analysis of hydrological parameters in the Central Karoo: Implications for flooding in Beaufort West.

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To overcome the problem of water scarcity in a semi-arid part of South Africa, where surface water is easily lost to evaporation, Beaufort West has turned to groundwater as a crucial source of fresh water. Thus, proper management of their groundwater resources is vital to ensure the protection and preservation of this precious resource for future generations. Although fluctuations have occurred over the years, groundwater levels in the area have progressively dropped due to this increase in abstraction within the wellfields to supply the town with water for domestic use. However, within the past decade, three major flooding events have occurred in the area, causing surface and groundwater levels to increase: with groundwater levels North-East of Beaufort West recovering tremendously during the 2019 event. Despite there being a general increase in the overall water levels, the hydrological parameters and thus the recharge associated with each event vary significantly. In this study, we present 12 years of historical data on rainfall, evaporation, surface water, and groundwater levels for the wellfields within the immediate vicinity of Beaufort West, South Africa. To better understand the relationships among the various hydrological parameters acting in the area, statistical trend analyses were done on the historical data for each of the flooding events. Insights gained from this study highlight the importance of understanding antecedent soil moisture content and its impact on flooding, and ultimately groundwater recharge in the Central Karoo.

Ancient mantle plume contamination and preconditioning of PGE wealth in the Bushveld Large Igneous Province

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The source/s and tectonic setting of the 2.06 Ga Bushveld Large Igneous Province (BLIP), one of the largest Precambrian LIPs, has long been questioned, along with the genesis of its precious metal endowment. The compositions and relative contributions of asthenospheric and sub-continental lithospheric mantle and crust, especially for metal endowment, are controversial. Understanding magmatic sources of the BLIP also provides a view of Precambrian mantle dynamics and the genesis of Precambrian LIPs. Using an approach combining zircon Hf isotopes and multiple S isotopes, together with Monte Carlo mixing models, our geochemical data show that the BLIP was indeed derived from a primitive, chondritic plume source. Simulations further suggest that two, compositionally-distinct lithospheric mantle reservoirs are required to match some observed BLIP compositions and may have provided the precious metal source for the province. Hf and S compositions require an eclogitic lithospheric mantle source as well as a second lithospheric mantle source, derived from Neoarchean plume-derived underplating. We rule out the possibility that ubiquitous non-zero Δ33S of the BLIP can only be derived from crustal contamination or the eclogitic lithospheric mantle. The presence of recycled Hadean/Archean surface material is also required in the BLIP's asthenospheric mantle source, suggesting that recycling of primitive surface material into mantle plume-sources was already operating during the Archean.

Application of Raman spectroscopy for studying shocked zircon from terrestrial impactites

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Conditions during an impact process can reach hundreds of GPa and thousands of degrees Celsius in a few seconds. A highly resistant mineral, zircon is capable of preserving information about impact processes up to 80 GPa. The radiation damage degree (metamictization) at the moment of impact and the annealing history are of particular importance when studying shocked zircons [1]. Raman spectroscopy method is one of the most powerful tools to measure metamictization [2]. Wherein zircons from impactites are typically studied using electron backscatter diffraction (EBSD) in a scanning electron microscope (SEM), and only a relatively small number of studies are based on Raman spectroscopy [3]. Current work is aimed to study shocked zircon by Raman spectroscopy and highlight recent achievements in applications of Raman spectroscopy for investigating shocked zircon from terrestrial impactites.

The zircon grains from impactites of Vredeford (Sour Africa) and Kara (Urals, Russia) impact structures with different deformation textures were studied on Horiba LabSpec HR800 Raman spectrometer and SEM Tescan MIRA LMS equipped with Oxford Nordlys Nano EBSD. The zircon grains with growth zoning, planar deformation bands, microtwins, granular structure and reidite were studied. In the case of nano-sized phase mixtures, the EBSD method showed smoothed low quality Kikuchi patterns, which created problems in detection of polymorph phases. In contrast, Raman spectra contained components of even nano-sized mixed phases. Raman bandwidth B1g (1008 cm-1) showed wide range of radiation damage degree in shocked zircons (from mildly to strongly metamict). To interpret the reasons for metamictization the radiation dose was calculated [4]. It was found that Raman band ratio of B1g/Eg and degree of metamictization maps combined could be used as signature of shock deformation features in zircon [5]. The main disadvantage of the Raman method is the low spatial resolution in comparison with EBSD and low sensitivity to the orientation of the crystal lattice. Raman spectroscopy is concluded to be most effective when applied to examining degree of damage, as well as identifying phases and misorientation in shocked zircon.

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Applying phase equilibria modelling to modern petrological problems: assumptions, pitfalls and what we can do about them

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Phase equilibria modelling techniques are increasingly being adapted to petrological studies as evidenced by the increase in citation of the term “pseudosection” from less than 1000 citations in 2007 to more than 4000 citations in 2021 (Scopus online database). At the same time phase equilibria modelling techniques are being applied to novel problems beyond the original design of the tool’s first intentions for example to model open system processes via iterative calculations as performed in Rcrust(1). This expansion of the usage of phase equilibria techniques requires careful knowledge of the assumptions required to use these tools and the pitfalls these assumptions may bring. These include the caveats of thermodynamic datasets and activity composition models, oxygen fugacity and iron valence, fluid state and water activity, extent of equilibrium/disequilibrium and the interpretation of results from phase equilibria in order to solve petrological problems. In this work we bring together a number of published case studies to highlight the different ways in which modern petrological problems can be overcome with the appropriate adaptation of phase equilibria modelling tools.

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Are the Early Proterozoic Ongeluk LIP volcanism and the Makganyene glaciation -- continental or marine deposition on the Kaapvaal Craton, South Africa?

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Basaltic andesites of the 2.426 Ga Ongeluk Formation (Gumsley et al., 2017; Humbert et al., 2019) extruded paraconformably to disconformably on the Makganyene Formation glacials of the Early Proterozoic Snowball Earth.

The Magkanyene - Ongeluk boundary was examined in a series of field sections. Lowermost Ongeluk beds are often tuffs with rare slump structures and intercalated thin lava flows with amygdaloidal tops, deposited on tillite-filled paleo-topography. Thin amygdaloidal pahoe-hoe lava flows and flow breccias occur above this contact. Massive flows further above are mainly microcrystalline, dark grey to greenish, with well-preserved primary igneous textures. Towards the top, rare, locally developed pillow-lavas with intercalated sedimentary lenses, neptunian sediment dikes, and sediment trickling down between the pillows from above lenses, occur. Related hyaloclastites are graded to non-graded, altered by palagonite and epidote, with matrix of zeolites and chlorite. Lava tubes filled with calcite and quartz or jasper were observed.

Altermann and Hälbich (1991), described an unconformity between the Makganyene and the Ongeluk formations, however, overestimated its regional importance and size. Moore et al. (2001), found conformable relationship between the Ongeluk and Magkanyene. Le Heron et al., 2022, interpreted the Magkanyene tillites as deposits in ice-sheet grounding zone wedges, with some reworking of the diamictites by mass flow processes in marine shelf environment; such wedges however, could equally be lacustrine (Dietrich and Hoffmann, 2022).

Outcrops and a drill core starting in the Ongeluk, through the Magkanyene into underlying Koegas Subgroup, demonstrate that Ongeluk volcanics are indeed locally conformable on the Magkanene glacials, where these are thinly bedded and fine grained. In other places an unconformity can be followed hundreds of meters along outcrops exposing a paleotopography developed on the Magkanyene tillites. Occasional sub-vertical pipe amygdales in basal lava flows, rising from the unconformity surface, sub-vertical columnar jointing, and ropy lava flow tops, all in relatively close lateral and vertical association to pillow lavas and hyaloclastites, imply rapidly changing most probably terrestrial to lacustrine depositional environments with a relatively short time interval terminating the Snowball Earth before the onset of volcanism in this succession. In places the Magkanyene Formation is not outcropping at all with the Ongeluk basaltic andesites deposited directly on the Koegas Subgroup rocks.

Are the Ventersdorp Supergroup and Marydale Group coeval?

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Volcanic and sedimentary packages of the Ventersdorp and Marydale Supergroups overlie Archaean granite basement at the southwestern margin of the Kaapvaal Craton. The Doornberg and Brakbosch Faults are major tectonostratigraphic boundaries, across which the stratigraphy, tectonic fabric and metamorphic imprint changes.

Outcrops at T'kuip represent the last undisputable Ventersdorp Supergroup sequence in the area. The basal conglomerate and mafic tuff unit, locally called the Ongers River formation, unconformably overlies the 2905±7Ma Maritzdam Kaapvaal basement Granite. The tuffs contain a diversity of xenocrystic zircon with a range of ages, grouped at 2921±11 (n=38), and 2877±5Ma (n=13), all older than the <2799±9Ma base of the Ventersdorp Supergroup. However, two grains were dated at 2781 ± 19 (5 points) and 2729±13Ma (5 points). They are also regarded as xenocrysts, but represent maximum ages for the Ongers River formation, which places it within the Platberg Group. The local Kuip formation, comprising pophyritic rhyolites, disconformably overlies the Ongers River formation. Its U/Pb zircon date of 2716±8Ma confirms its correlation with the 2720±2Ma Makwassie Formation, which occurs at many localities across the craton.

South of the Doornberg Fault, 2907±4Ma Welgevonden Granite predominates, showing the continuity of basement granites across the fault. However, small plutons of the 2721±6Ma Steenkop Granite Gneiss represent intrusive Makwassie Formation equivalents! Small exposures of quartz porphyries with blue quartz on farm Zoutpekel proved to have the same age (2718±5Ma) and geochemistry as the Makwassie (2720±2Ma).

The Soetvlei Arkose, lowermost Marydale Group unit, overlies Welgevonden Granite with an undefined field relationship. Stratigraphic duplications and the relationship between stratigraphic dip and metamorphic gradient show that the Marydale Group is a thrust complex, possibly with inverted stratigraphy. Three Soetvlei arkose samples have rather disparate zircon Pb-Pb age histograms, with youngest major peaks at 2850 and 2910 and oldest grain at 3500 Ma! However, in one sample, two near-concordant grains give a Pb-Pb age of 2731±14Ma and together with five discordant points yield a discordia upper intercept age of 2733±16Ma! This shows that the Marydale Group was being deposited at the same time as the Platberg Group, Ventersdorp Supergroup! Zircon Hf isotope data shows no difference between Ventersdorp Platberg (e.g. Makwassie rhyolite), Zoutpekel porphyry and the 2.7 Ga Marydale Soetvlei arkose detrital grain. The tectonically overlying units of the Marydale Group are not yet precisely dated: Perdeput metabasites (2950±180Ma Sm/Nd isochron) and Modderfontein BIF (2990±120Ma Pb-Pb), but could be coeval with parts of the Ventersdorp Supergroup.

Assessing the U-Pb AND Sm-Nd Isotope composition of vermilion monazite: A 2.67 Ga reference material to investigate Archean crustal processes

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Recent advances in LA-ICP-MS U-Th-Pb geochronology allow acquisition of U-Pb data at: 1) high spatial resolution (> 10 µm), with precision and reproducibility better than 3% on individual $^{206}Pb/^{238}U$ and $^{208}Pb/^{232}Th$ spot ages; and 2) relatively fast throughput and low cost compared to other microanalytical techniques, such as SHRIMP or ID-TIMS. Of the few well-characterized monazite reference materials available (e.g., Itambé, Diamantina, TS-Mnz, 44069, Thompson Mine, Managountry, Steenkampskraal/ Namaqualand, Iveland), there is currently no homogenous Archean monazite available for LA-ICP-MS U-Pb geochronology. In this study, we have investigated Vermilion monazite, from the ~2.7 Ga Vermilion Granitic Complex, (Minnesota, USA), as a potential reference material for U-Pb geochronology, using a high-precision ID-TIMS and high-spatial resolution techniques (LA-(SF/MC)-ICP-MS and SHRIMP). The major and trace element composition (EPMA; LA-(SF/Q)-ICP-MS) and the Sm-Nd isotope composition (LA-MC-ICP-MS) of Vermilion monazite was also characterised. Vermilion monazite is relatively compositionally homogeneous in BSE images. It is classified as a monazite-(Ce) and shows uniform, relatively LREE-enriched chondrite-normalised REE patterns (Eu/Eu* = 0.074-0.085), with little compositional variation in intra- and inter-grain scales. The ID-TIMS results show U contents varying from 177 to 1470 ppm, Th contents from 12899 to 108867 ppm, and Th/U from 66.3 to 75.5. Vermilion monazite yields slightly (-0.6%-1.8%) discordant ID-TIMS U-Pb isotope data with a weighted mean $^{207}Pb^*/^{206}Pb^*$ age of 2667.5 ± 1.2 Ma (2s, n = 7, MSWD = 5.0). High-spatial resolution data from SHRIMP and LA-(SF/Q/MC)-ICP-MS are in agreement with the high precision ID-TIMS age, and Vermilion monazite used as a primary calibrant reproduced the age of a range of other reference materials via LA-SF/MC-ICP-MS within -1.13%- 1.64%. Sm-Nd LA-MC-ICP-MS results returned an average $^{147}Sm/^{144}Nd$ ratio of 0.0854 ± 0.0027 (3.1 %RSD, 2SD, n = 108), with relatively small variation in the individual fragments. We obtained a homogeneous average $^{143}Nd/^{144}Nd$ ratio of 0.51068 ± 0.00004 (0.01 %RSD, 2SD, n = 108). The initial epilson Nd (εNdi) varied from -0.8 ± 0.5 (2s) to 0.6 ± 0.4 (2s). The reproducibility of our results showed that Vermilion monazite can be used as primary reference material for U-Pb geochronology and may be suitable as secondary reference material for Sm-Nd isotopic tracing. The Archean age of Vermilion monazite will facilitate investigation of Archean crustal evolution processes by combining matrix-matched U-Pb geochronology and Sm-Nd isotopic tracing. It also broadens the prospect of studying ancient metamorphic events and to trace the source of hydrothermal mineralization.

Assimilation of siliceous and carbonaceous xenoliths in the Upper Critical Zone of the northern limb, Bushveld Complex: Implication for hybridization reactions

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One of the most critical processes related to the formation of magmatic sulphide and chromite ore deposits is the chemical transformation of mafic magmas 1,2. One possible such process involves assimilation of siliceous1 and carbonaceous wall rocks. In this study, we characterised the effect of localized assimilation and magma hybridization of quartzite , shale, and dolomite xenoliths on Upper Critical Zone magmas in the northern limb of the Bushveld Complex.

Quartzite xenoliths comprise equant quartz grains with clayey cement. Towards contacts with pyroxenite, quartz grains exhibit interlocking clusters at triple junction and can contain inclusions of sulphides and phlogopite. Mineralized lenses of sulphides may occur along the contact (transgressing 0.5 mm into the quartzite). The quartzite's major and trace element compositions are variable. The shale hornfels contains up to 85 vol% plagioclase , with minor phlogopite, orthopyroxene, spinel and sulphides, with variable textural relationships. Some samples contain mineralization of ~0.2 mm-thick lenses of sulphide and spinel along the contact with pyroxenite. The spinel species are heterogeneous in composition, including magnetite, chromite, picotite, and hercynite. Bulk-rock compositions of the hornfels are also variable. The mineralogy of some dolomite-influenced samples indicates a transition from a pyroxenite assemblage (pl+opx inclusions) to a pegmatoidal wehrlite (cpx+ol+spinel±sulphides). Major element compositions of the wehrlite samples indicate a dolomitic protolith, showing high MgO (15.1-30.8 wt.%), CaO (3.9-36.7wt.%) and relatively low SiO2, (13.7-44.8 wt.%). In comparison, the pyroxenites contain orthopyroxene (~60 vol.%) and plagioclase (~40 vol.%) predominantly, and accessory phlogopite, spinel, and sulphides. Bulk-rock compositions are also quite variable (46-58 wt.% SiO2, 11-33 wt.% Fe2O3, 863-3600 ppm Cr, 48-2041 ppm Cu, and 241-7760 ppm Ni). Petrographic and chemical evidence of these rocks point to heterogneous mixing of xenoliths and magma. The complete transformation of the dolomite (to a wehrlite) and shale (to an anorthosite) xenoliths is indicative of complex hybridization processes. Furthermore, assimilation-fractional crystallization (AFC) modelling calculations for the shale and dolomite show good agreement with observed mineral assemblages.

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Augrabies Fold Nappe: Stratigraphic Insights into the Grünau Terrane

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The Augrabies Fold Nappe (AF-N) is situated within the Grünau Terrane (GT) of the Mesoproterozoic Namaqua Province on the western flank of the Archaean Kaapvaal Craton [2], that consists of 8 major tectono-stratigraphic terranes juxtaposed during the 1.2-1.0 Ga Namaquan Orogeny [3].

Voluminous sheets of silicic magma intruded the terranes along inter/ intra-terrane thrust zones during the Namaqua Orogeny; regional metamorphic zonation (amphibolite-granulite/migmatite facies) is ascribed to voluminous felsic magmas providing the advective heat transfer for the P-Tevolution [3]; with peak met. assembl. for the GT (Gordonia Subprovince, RSA) equilibrating at 800-850°C, 4.0-4.5 kb [1].

The NW-SE Grünau Terrane, stretches over more than 1000km across RSA and NAM and overthrusts from the NE, the 2.1-1.8 Ga Pofadder Terrane. The terrane hosts a number of macro-megascopic scale sheath folds [4, 8] and includes the allochthonous Augrabies sheath fold nappe (AF-N) with outcrop dimensions of 60 × 20 km.

The stratigraphy surrounding the AF-N consists of supracrustal sequences stacked between sheet granitic gneisses (1095-1200Ma; [4]). The plutonites consist of intrusive sheet granites and neosomes of large-scale anatectic melts. The Oranjekom Complex - a layered met. anorthosite-gabbro suite (1095± 6 Ma [6]) is the youngest intrusive. Associated with the AF-N are four more sheet granites (1155-1168Ma [4]) and a volcano-clastic sequence (Koekoekop Formation [9]). The Eendoorn gneiss - oldest granite; emplacement age of 1198±7 Ma; coincides with the first macro- scale anatectic melting (1204-1197Ma) in the Blouputs Fm [7]. The Witwater gneiss (1123±6 Ma [5]) is interpreted to be a neosome of large-scale partial melting in the Blouputs Fm.

The sheath fold complexes formed under ductile deformation conditions during intraterrane thrusting at ~ 1155 Ma.

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B isotope evidence for subduction input to arc magmatic sources: a case study of lavas from Paniri, Northern Chile

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Boron (B) is an ideal geochemical tracer for the hydration of the overlying mantle wedge at subduction zones (e.g., 1,2). The boron isotope composition of magmas, expressed with the standard notation δ11B = ((11B/10B(sample)/11B/10B(reference))-1) x 100, is useful in detecting and quantifying the exchange process between the slab and the mantle due to boron showing strong affinity for silicate melts and aqueous fluids and is not significantly affected by mineral fractionation (e.g., 1, 2). The mountain building process witnessed today at the Andes is a good modern example of oceanic-continental convergence setting, providing a modern-day analogue that can be used to interpret older convergence-buildingmountain belts around the world.

This study presents new whole-rock boron isotope data from all 7 eruptive units (~1.390±0.290 Ma to 150±6 ka) of Paniri volcano (22°03'34"S, 68°13'42"W), a Pleistocene age stratovolcano forming part of the San Pedro-Linzor Volcanic Chain (SPLVC) in the Central Andes. The 87Sr/86Sr ratios of the volcanoes within the SPLVC range from 0.7055 to 0.7094, which is attributed to variable degrees of contamination of the parental magma during its ascent through the thick continental crust (3,4). Though 87Sr/86Sr ratios at Paniri are relatively low (0.7066 to 0.7079) compared to other volcanoes within the SPLVC, except for the less evolved San Pedro and La Poruña volcanoes (0.7055 to 0.7066), they still suggest some degree of crustal contamination.

Our results (n = 7) show relatively low δ11B (-6.11‰ to +0.23‰) values when compared to mantle derived magmas affected by fluids released by the subducting altered oceanic crust (0‰ to 18‰, e.g.1). The relatively low δ11B values at Paniri are consistent with observations, e.g. (1), suggesting that such negative δ11B values require a magma source that is depleted in 11B such as the mantle (MORB, δ11B = -7.1±0.9‰) or the Central Andean basement (δ11B = -8.9‰) (e.g., 5). Given that the Sr isotopes from Paniri lavas are thought to reflect significant degrees of crustal contamination (3,4), the low δ11B values are more likely to be derived from local low-δ11B continental crust.

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Basin Analysis of the Molteno-Indwe Coalfield in the Eastern Cape Province, South Africa

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Sedimentary basins are not only known to host most of the energy resources such as oil, gas, coal, and geothermal hot water, but also significant mineral and water resources that are critical for human consumption. Therefore, it is vital to conduct technical and scientific research on the formation and evolution of the basins over geological time, including quantities, qualities, and spatial distributions of these energy, mineral, and water resources.

The horseshoe-shaped Molteno-Indwe Coalfield, one of Southern Africa's sedimentary basins, is located in the north of the Eastern Cape Province and spans an area of around 4,400 km2. It covers an area from the towns of Maletswai to Burgersdorp, James Calata, Molteno, and Sterkstroom in the southwest; then east-west from Dordrecht, lndwe, the Guba area, and Cala; and north-eastwards toward Elliot, Gubenxa, Engcobo, and Maclear.

The Molteno-Indwe Coalfield is known for its long history of coal mining activity. Coal mining commenced in 1864 at Cyphergat near the town of Molteno, and by 1877, several mines were in operation near the town of Indwe. Coal from the Molteno-Indwe Basin was exploited to supply energy to the then-discovered Kimberley diamond fields.

Thirteen vertical cores that were drilled within the Molteno-Indwe Coalfield were logged in detail and scanned by a hyperspectral scanner at the Council for Geoscience National Core Library located in Donkerhoek. All the cores were obtained from an intensive drilling program in the coalfield between 1984 and 1986.

The depositional environments, sedimentary facies, and provenance of the Molteno-Indwe Coalfield are studied using a basin analysis approach. This study aims to utilise a wide variety of geoscience datasets such as geological, geochemical, topographical, and geophysical data to evaluate the economic potential of the basin. Furthermore, As a consequence, preliminary results on geological data such as sedimentary facies, grain size, main contacts/boundaries, and types thereof (sharp, erosive, and gradational) from field core observations and hyperspectral scanner results will be presented.

Key words: Molteno-Indwe basin, basin analysis, sedimentary facies, hyperspectral scanner

Boron isotope composition of eruptive lava units and their implications: a case study of lavas from Toconce, Northern Chile

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It has been well established that arc magmas are good transporters of elements from subducted oceanic slab in subduction zones back to the overlying crust. Boron (B) behaves as a highly incompatible and mobile trace element in most metamorphic and magmatic systems. Because of this, B is a good geochemical tracer and δ11B has been identified as very sensitive indicators of subducting slab contribution in arc magmatic sources (e.g., 1, 2).

New boron isotope data from the 5 eruptive units of Toconce volcano (22°11'17''S, 68°04'43''W) are presented. Toconce, a late Pleistocene-Holocene age stratovolcano, forms part of the San Pedro-Linzor Volcanic Chain (SPLVC) in the Central Andes. Crustal contamination is evident in volcanoes that fall within the SPLVC, with significantly higher 87Sr/86Sr values (0.7055-0.7094) with respect to mantle-derived melts (i.e., 87Sr/86Sr = 0.703) (3; 4). We also present new (with the existing) 87Sr/86Sr values at Toconce, and they range from 0,7073 to 0.7089 and has the highest 87Sr/86Sr values in the volcanic chain showing significant crustal assimilation.

δ11B results show values varying between -11.16‰ and -5.06‰. Within the eruptive units (Lava Turi, Pieneta and Toconce) there is a consistent variation in the δ11B and 87Sr/86Sr values. The distal samples in respective eruptive units have the lowest δ11B and higher 87Sr/86Sr values and the more proximal samples have the higher δ11B and lower 87Sr/86Sr values. This suggest that as these magmas ascend through the thick Andean crust (~65 km, e.g., Beck et al. 1996) the initial pulses preferentially assimilate the easily/first fusible crustal material, the major reservoir for B in the crust, as these initial eruptive products reflect the δ11B values of basement granitoids and metasediments (δ11B -11 ‰ to -5 ‰, Kasseman et al., 2000). With continued magmatic activity, the magma B compositions gradually shift to a more subducting slab δ11B signature, with higher δ11B composition, as the easily/first fusible crustal material is locally depleted. This process repeats with each new cycle of magmatic activity, but each successive eruptive units starts with relatively less of the easily/first fusible crustal material available for assimilation and therefore the distal samples of each unit have progressively heavier (i.e. higher) δ11B values.

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Broadband Seismic Study of the Permian Basin, W Texas/SE New Mexico, USA

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The formation of cratonic (or "continental") basins is not easily explained by plate tectonic theory. Cratonic/continental basins rest on stable continental crust, are characterized by long periods of slow subsidence and are not obviously explained by extension or compression, yet many are coeval with the breakup of the Gondwanan-Laurentian supercontinent and the set of rifts that accompanied its fragmentation. Many of the sag basins in North Africa initiated during the Cambrian in settings that were similar to those of North American basins. Of the latter, the Illinois, Michigan, Oklahoma-Anadarko, Tobosa-Permian, and Williston Basins all formed at about the same time and have similar subsidence histories. Today's Permian Basin evolved from the Tobosa Basin, a broad sag that persisted for about 200 Myr, after which is was transformed by two compressional events during of Pennsylvanian time and then strong subsidence in the Permian to form the modern Permian Basin.

The Permian Basin, one of the world's most commercially-significant basins, has recently been the site of dense deployments of broadband seismic stations, so an investigation of the crust and mantle beneath that region is timely, and may inform studies of basins elsewhere. We conducted complementary tomography and receiver function analyses to determine the structure of the lower crust and uppermost mantle beneath the Permian Basin region. While isostasy is generally responsible for relief and subsidence, isostatic responses may have multiple causes. For example, the underlying crust may be unusually thin or dense, perhaps because it is mafic, or because of dense eclogitic lower crust, perhaps forming an eclogitic drip, or the lithospheric mantle may be unusually dense. Receiver functions do not reveal a shallow or "double" Moho, which can be the case if eclogite is present, beneath the Delaware subbasin but they do reveal high Vp/Vs ratios in the crystalline basement, which are characteristic of mafic material. Seismic travel time tomography reveals a fast P-velocity anomaly in the lower crust, which is also consistent with mafic material. Together these results provide evidence for the existence of a "Delaware Aulacogen", which has been proposed to have resulted from the Gondwana/Laurentia collision. However, other processes could have created the velocity anomaly, and the presence of an aulacogen would likely not explain the formation of other cratonic/continental basins. We will discuss other possibilities and describe a strategy for acquiring the data and performing the modeling needed to unravel the evolutionary history of the Permian Basin.

Ca. 2580-2574 Ma mafic magmatism in Zimbabwe and Kaapvaal: implication for amalgamation along the Limpopo Belt

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The timing of the amalgamation of the Zimbabwe and Kaapvaal cratons in southern Africa along the Limpopo Belt has long been debated. Arguments for this timing range from the Neoarchean through to the Paleoproterozoic. Most arguments are interpreted through metamorphic events and deformational history within the Limpopo Belt itself and usually suggest a Neoarchean origin for amalgamation, e.g., [1]. However, studies utilising the large igneous province (LIP) barcode approach suggest a minimum amalgamation age in the Paleoproterozoic, based on matches between the Mashonaland Sill Province (LIP) and the 1.9-1.8 Ga LIP events within Kaapvaal (i.e., the Black Range dykes, Waterberg sills, Soutpansberg sills and Soutpansberg lavas [2]. However, paleomagnetic studies of these same mafic magmatic units between Zimbabwe and Kaapvaal have been used to argue for an even later amalgamation [3]. Here we present new U-Pb ID-TIMS crystallisation ages of ca. 2574-2580 Ma for an ENE-trending mafic dyke and a so-called mafic sill on the south-eastern margin of the Kaapvaal Craton, in northern KwaZulu-Natal. These units cut across a ca. 2646 Ma NNE-trending mafic dyke, likely unrelated to the ca. 2556-2664 Ma White Mfolozi Dyke Swarm in the region [4]. These ca. 2574-2580 Ma ages are coeval with the ca. 2574-2579 Ma Great Dyke of the Zimbabwe Craton, however, as well as its related Umvimeela and East satellite dykes, offering a new oldest age match of mafic units between these two cratons that is more consistent with their Neoarchean assembly. Nevertheless, using further petrographic, geochemical, paleomagnetic and rock magnetic studies on these mafic intrusions, we present arguments for and against a late Neoproterozoic amalgamation of the Archean nucleus of the Kalahari Craton.

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Cape Town's fossil beaches aid in reconstructing Pliocene shoreline dynamics

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Gravelly sediment layers in fossil beaches around the Cape Peninsula and False Bay in South Africa are assumed to be Pliocene in age and are essential for reconstructing the ancient sedimentary dynamics along the shoreline in the greater Cape Town region. The cobble- to boulder-size clasts that dominate these fossil beaches point to a genesis that is likely linked to the erosion of local rocky shores during Pliocene hurricanes and "super storms". This mode of formation seems similar to the Pliocene fossil beaches located at different elevations around the world (aka 'the Pliocene sea-level paradox'). Although mapped for c. 100 years, to date, no modern sedimentological study has been conducted on Cape Town fossil beaches. Clast characteristics (e.g., clast size, sorting, roundness, composition) of the gravelly layers had been quantified in the field and by the processing of field image using ImageJ software. Our results, thus far, show that the fossil beaches are dominated by cobble-sized orthoquartzite (Peninsula Formation) clasts that are rounded, clast-supported and display a variety of percussion marks. The gravel size decreases from east to west, and the maximum clast size of 3.21 cm is recorded at Kogel Bay in False Bay. To ascertain the age, provenance and placer potential of these fossil beaches, the microfossil and heavy mineral contents of the finer-grained units (i.e., extremely rare, sandy matrix between cobbles) are being targeted for further analyses. Overall, this ongoing project, via its combined sedimentological, stratigraphical, and petrographical approach, hopes to achieve a meaningful comparison with other Pliocene boulder beds globally, and ultimately refine the Pleistocene marine dynamics of the Cape Town region and beyond.

Carbon and oxygen isotope composition of the Salpeterkop Carbonatite Complex, Sutherland, Northern Cape

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The Salpeterkop carbonatite is a Late Cretaceous (75 – 75 Ma; Malarkey et al., 2019; de Wit, 2022) volcanic and subvolcanic complex consisting of carbonatite, melilitite and ultramafic lamprophyre and trachyte. Unlike other southern African carbonatite complexes, it is only slightly eroded and therefore preserves significant sequences of original volcanic features. Previous geochemical investigations on this complex have included the petrology, whole rock and trace element analysis of the carbonatites and associated igneous rocks, but little is known about their stable isotope composition. This study presents an investigation into the carbon and oxygen isotope geochemistry of 18 carbonatites, 3 lamprophyres and 6 olivine melilitites samples from the Salpeterkop complex. The carbonate rocks have δ13CPDB values in the range -10.0 to +2.6‰ whereas their δ18OSMOW values are between +13 to +27.2‰. There is a positive correlation between the δ13C and δ18O values (r2 = 0.5). The silicate data are consistent with the magmas being unaffected by crustal assimilation, with the δ18O values for the fresh separated olivine, phlogopite and pyroxene minerals ranging from +5.32 to +6.03‰, typical of mantle derived rocks. It is suggested that the range in Salpeterkop carbonatite δ18O values is due to low temperature alteration by surface water. If δ18O value of the alteration of -5.69‰ (average present-day Sutherland groundwater, Adams et al., 2000) and a temperature of 25 °C is assumed, low – temperature calcite would have had a δ18O value of +26.90‰. Because surface carbonates in the region generally have low δ13C values (Potts et al., 2009), it is challenging to explain the positive correlation between δ18O and δ13C values. Crater lake carbonates have high δ18O and δ13C values that range from 0 to +2‰ (Mthembi et al., 2016). As such, it is proposed that the range in δ18O values and the correlation between the δ18O and δ13C is due to the analysed carbonates being mixtures of magmatic and low – temperature carbonate, with the latter being derived from downward seepage from an overlying crater lake.

Carbon and Uranium in the Witwatersrand – the Impact of One Upon the Other

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Background

The Archean metasedimentary Witwatersrand Supergroup is renowned as the world's largest gold deposit found to date (McCarthy, 2006). Along with gold, parts of the Supergroup host economic and sub-economic deposits of uranium (McCarthy, 2006). Most of the uranium and at least 40% of the gold co-occur with carbonaceous matter (England et al., 2001). Part of the ongoing discussion on the nature and origin of the mineralization in the Witwatersrand is centred on the uranium and carbonaceous matter (Frimmel et al., 2005; Fuchs et al., 2016; Burron et al., 2018; Frimmel and Nwaila, 2019; Nwaila et al., 2021). Integral to this discussion is the relationship between carbon and uranium and the effect of one upon the other.

Uranium occurs principally within uraninite which is found as rounded to subrounded grains and subangular fragments. It frequently, but not always, occurs with the solid carbonaceous matter. The carbonaceous matter appears in various forms viz. dispersed ovoid grains ("flyspeck carbon"), vein-like material and massive (up to 5cm thick). Almost all varieties contain a uraniferous (uraninite/brannerite) phase. For the flyspeck and massive types, these are typically angular fragments whilst the vein-like carbonaceous matter cross cuts and fragments sub-rounded detrital grains of uraninite. The rounded grains of uraninite are likely of detrital origin whilst the smaller fragments formed from uranium were remobilized or introduced into the system by liquid hydrocarbons and hydrothermal fluids (Fuchs et al.; 2016). Several authors have suggested that the hydrocarbons were polymerized (and solidified) by the radioactive decay of the uranium (Hoefs and Schidlowski, 1967; Smits, 1984; Barnicoat et al., 1997; Gray et al., 1998; Parnell, 1999; England et al., 2001; England et al., 2002; Drennan and Robb, 2006).

The decay of naturally occurring radionuclides occurs through the emission of either an alpha or a beta particle. The interaction of these particles with liquid hydrocarbons may cause the polymerization of the hydrocarbon molecules (Charlesby, 1960). The ability to polymerise a liquid hydrocarbon phase depends upon the penetration depth, energy, and flux of the alpha and beta particles.

Methodology and Results

Woods (2016) demonstrated experimentally that carbon nanostructures could be grown in the presence of uranium. He however noted that the role of uranium in the formation of carbon nanostructures has only been hypothesised. This presentation discusses experimental and simulation studies to determine if the amount and distribution of uranium in the Witwatersrand Supergroup reefs was able to polymerise liquid hydrocarbons.

Catalogue of South African mine tailings for geochemical carbon dioxide removal purposes

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The South African mining industry has a unique opportunity to become a global leader in devising strategies that focus on geochemical carbon dioxide removal (CDR) using mine tailings and simultaneously using methods for producing alkalinity and mineral carbonation. Specifically, this is attributed to the vast amounts of targeted mafic-ultramafic tailings produced from the Diamond, PGM, chrome, nickel, phosphate, copper, talc, and magnesite mines. There is a possibility that this strategy will provide South Africa with alternative options to offset emissions and reduce its emissions targets.

A tailings catalogue has been produced to highlight the overall national CDR potential by calling attention to site opportunities for pilot schemes and emphasizing the need for continual assessment of tailings production volumes as industrial interest increases. Using bulk geochemistry and shrinking core models, it was calculated that South Africa has a 2-3.1 MtCO_2 removal capacity potential from annual tailings, or 11-16 Mt CDR for the tailings produced between 2017 and 2021. It is highly possible that the CDR capacity could be higher if the tonnage of tailings from mines with limited public information, abandoned site stockpiles, and other similarly reactive industrial by-product materials are considered.

South Africa's diamond operations are estimated to possess the highest geochemical CDR capacities, along with metal commodity sites Phalaborwa, Nkomati, and Mogalakwena. The future holds many opportunities for academia, industry, and policymakers to review and update the geochemical CDR potential of targetable mine sites, and for other countries to catalogue their own tailings stockpiles and geochemical CDR potentials for future Mt-scale opportunities.

Cavity Identification and Risk Mitigation in Kumba Iron Ore Mines

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The Kumba Iron Ore mines are situated in a geologically and structurally-complex, karstic environment that has historically produced numerous cavities. These cavities are typically less than 5m in diameter and do not pose a major threat to personnel or equipment. On the odd occasion however, cavities larger than 5m in diameter have been intersected and pose a major threat to safety, equipment and production. Incidents have occurred in other parts of the world where man and machine have been swallowed by the sudden opening of a cavity near surface which have resulted in deaths and loss of equipment. A wide range of lithologies with differing mechanical properties exist in the area. The presence of underground water and seepage from surface processes coupled with numerous geological structures, increases the potential formation of cavities.

Cavities tend to form in softer or weaker rocks, typically associated with structural weaknesses such as faults or joints, where the material is continually dissolved or eroded away by various processes that creates voids in the rock. At Sishen Mine for example, cavities tend to form (but not exclusively) in the basal dolomites that get dissolved by acidic water that seeps through the ground. Other cavities are typically associated with geological structures (such as faults) that creates a zone of preferential weathering and erosion over time, causing the structure to open up and create a structural cavity.

The presence of cavities in the mine poses a significant threat to the health and safety of people working in the pit, as well as creating the potential for equipment to incur major damage. It is imperative to detect any cavities, or at the very least highlight high-risk areas, as early as reasonably possible (ideally well before mining in the area takes place) to prevent any harm to people or damage to equipment from subsidence-related incidents.

The aim of this project is thus to identify potential high-risk areas within geological block models with respect to cavity presence or significant structural weaknesses before any mining activities take place. Hazard maps will then be created that highlight the high and low-risk areas respectively of each mining block in a given area and bench level. This project focuses on how the high-risk areas are identified and the processes for detecting cavities and mitigating the risk they pose well ahead of time.

Characterisation of exhausts during artisanal/micro-scale Portland cement clinker production: their potential use in mineral carbon sequestration

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Current industrial production of Portland clinker, the main constituent of Portland cement, emits carbon dioxide, carbon monoxide, sulphur dioxide, oxygen, nitrogen, water vapour, and argon. For each tonne of clinker, 1.8 tonnes of gas is expelled. The related volumes are 15 m3 at 300°C, and 23 m3 at 600°C, while the accompanying heat is 1.3 GJ and 2 GJ, also at the same respective temperatures. Some of the energy could be utilized in the capture of the emitted gases.

An ongoing project has designed a clinker kiln, customised for use at an artisanal or micro-scale. In order to minimise the input of greenhouse and acid rain gases during its use, ways of capturing ways of capturing the carbon dioxide were reviewed. The indirect aqueous mineral carbonation technique, with pH reversal using NH4HSO4 and NH3.H2O, was selected. Per tonne of clinker, if the extraction tank is heated up to 140°C, the heat required is 600 MJ. It is 727 MJ for the carbonation tank.

For the artisanal/micro-scale kiln, the heat contained in the emissions was estimated, with the view to using it for carbon capture and sequestration. Firstly, an idealized estimation using local raw materials and coal fuel was carried out. This showed that for a tonne of clinker, the emitted CO2, SO2, and moisture totals 5 800 kg, while the heat energy would be 2.2 GJ and 5.1 GJ at 300°C and 600°C, respectively. Secondly, measurements from, and calculations based on a clinkering cycle, using a prototype of the artisanal/micro-scale kiln, showed that emission of 11530 kg per tonne of clinker. This potentially carries a total of 4.3 GJ at 300^{o}C and 10.1 GJ at 600^{o}C.

A three-phase, NH3-based, pH-swing carbon-capture and sequestration approach would require 600 MJ, when the gas emission temperature is 300^{o}C, but this value is 727 MJ, if the emission temperature is 600^{o}. These are required to heat up the extraction and sequestration solutions to 140^{o}C. There is, therefore, potential for utilization of the heat contained in the emissions to partly drive the carbon capture and sequestration at the artisanal/micro-scale clinkering set up envisaged in this series of studies. This is in sharp contrast to the current practice of allowing the emissions and the heat they contain to go to loss, while also contributing greenhouse gas to the earth's atmosphere.

Characterisation of the sedimentology and CO2 storage potential of the A-E1 well, offshore Orange Basin, South Africa

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Carbon dioxide capture and storage (CCS) represents a fundamental approach in a suite of technologies needed to mitigate global climate change through the reduction of anthropogenic CO2 emissions. South Africa, like many countries worldwide, is heavily reliant on fossil fuels for energy supply, with about 90% of primary energy derived from either coal, oil or gas. South Africa hosts three offshore sedimentary basins which have potential for industrial-scale (>1 million tons) CO2 storage. A country-wide assessment indicated a total storage capacity potential of approximately 150 Gt, of which 98% occurred within Jurassic and Cretaceous offshore sedimentary basins. The Orange Basin on the country's west coast covers an area of 145 000 km2 to the 2000 m isobath and hosts a proposed theoretical storage capacity of up to 60 000 Mt, making it the largest and most promising CO2 repository in South Africa. Furthermore the existence of known hydrocarbon accumulations within the basin indicate suitable trapping and reservoir mechanisms for CO2 storage.

The current study, which forms part of a joint MSc project at the University of KwaZulu-Natal and the Council for Geoscience, aims to define the CO2 prospectivity of a region of the northern Orange Basin through sedimentological and sequence stratigraphic interpretations. Within offshore frontier sedimentary basins, legacy data represent important tools for basin-scale interpretations and to this effect the study utilised legacy well data from the A-E1 well to provide evidence of reservoir/seal pairs with potential characteristics that will allow for CO2 injection and storage.

The A-E1 well was drilled to a depth of 4775.5 m on the continental shelf approximately 400 km north-northwest of Saldanha Bay. Seven seismic units (A-G) are delineated. Detailed seismo-sedimentary analysis has resolved multiple sequence boundaries through a combination of gamma ray log interpretation, seismic bounding surface identification, and available biostratigraphic data. Units A and B represent the syn-rift succession whilst the overlying units (C-G) were deposited during passive margin development. Potential reservoir targets for CO2 storage within the A-E1 well are represented by laterally extensive shelf-bound shallow-marine-sheet and deltaic sandstone packages within the passive margin sequence, whilst continental sediments including fluvial to lacustrine sandstones are defined within the syn-rift sequence.

Keywords: CCS, CO2 Storage, Just Transition, Orange Basin, Well logs

Characterising clarity enhancements in coloured gemstones using X-ray micro-computed tomography

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The multibillion-dollar coloured gemstone industry requires improved quality control regarding clarity enhancements and consumer demand for ethically-sourced gemstones has incentivised industry investment in origin-tracking methods [1]. Any routine quality control or tracking technique must first be demonstrably non-destructive, time- and cost-effective. In recent years non-medical X-ray micro-computed tomography (µCT) scanning facilities have proliferated while analysis costs have decreased - making the technique more accessible for gemstone assessments. The X-ray µCT scans provide unique 3D spatial information due to the differential X-ray attenuation of fractures, fracture filling, and natural inclusions. X-ray µCT scanning has previously been applied to calculate the volumetric proportion of the filling material within clarity-enhanced gemstones [2]. This study investigates the creation of unique 3D digital files from the surface and internal features of gemstones to allow for a routine, complementary, and non-destructive method for fingerprinting gemstones. An assortment of fracture-filled ruby, oiled emerald, and polymer-impregnated jadeite gemstones were selected for this study. The presence of filler material and inclusions was identified using standard gemmological techniques and verified with X-ray µCT imaging. Fingerprinting files were created from both surface and internal features of gemstones from X-ray µCT image data obtained under variable conditions at different facilities, scanning resolutions, and scanning durations. These files were compared visually and using surface deviation to assess if true positive identifications could be made, the success of the latter method was dependent on optimised image overlay. Fracture filling material and inclusions denser than the host gemstone have greater X-ray attenuation and greyscale contrast compared to organic fillers and inclusions with lower densities than the host. The scans with denser inclusions displayed more accurate surface rendering and therefore more successful µCT fingerprinting results. X-ray µCT has great potential as an efficient, non-destructive technique to create digital twins of gemstones using both gemstone and high-density inclusion surface files. This information can potentially be stored in databases and shared with gem labs, retailers, and customers to permit the cross-referencing and tracking of valuable gems throughout the mine to market cycle.

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Characterization and regional correlation of Pan-African strains in the Western Saldania Belt, South Africa.

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The Western Saldania belt represents the southernmost extension of Pan-African belts that formed during oblique convergence between South American crustal blocks and the Kalahari craton. The evolutionary paths and overall sinistral transpressional strains during convergence and eventual collision are well documented for the northern Kaoko and Gariep belts, but poor outcrop and the deceptive monotony of rocks have prevented a similarly detailed outline for the Saldania belt.

This study aims to integrate and semi-quantitively describe strains across large parts of the Western Saldania belt. Numerous coastal outcrops and interior exposures have been surveyed utilizing detailed drone imagery. The imagery forms the base for mapping and subsequent correlation of detailed local and regional structures. Regional maps or reports from areas no longer accessible due to urban development provide historical data, complementing field data. Both datasets are combined into an ArcGIS database.

On a regional scale, a structurally lower, polyphase deformed domain recording bedding transposition and low-angle foliation development (Swartland complex) is overlain by a folded, metaturbiditic sequence with single foliation development (Malmesbury Group) (Kisters and Belcher, 2018). The regional structural pattern is dominated by the NW-trending, sinistral strike-slip Colenso Fault Zone (CFZ), developed as an ±8 km wide anastomosing fault zone, (mylonites, low-T cataclasites and quartz-veined breccias) in the Cape Granite Suite, but poorly exposed in the Malmesbury Group. North- to WNW-trending folds, largely parallel to the CFZ, dominate throughout the Malmesbury Group. The folds are upright- to SW verging, with highly variable interlimb angles. Domains of upright, tight-to isoclinal folding alternate with zones of open-to gentle folding on a scale of several hundred meters. The development of a NW-trending, transecting cleavage in folds agrees with folding during sinistral transpression (Rowe et al., 2010) and small-scale faulting and quartz-vein formation in folds indicate hinge-parallel stretching during folding.

Results are consistent with deformation during strike-slip partitioned sinistral transpression. The regional compilation of structural data is the first of its kind for the Saldania belt and is expected to contribute to the understanding of the Western Saldania Belt, but also emplacement controls of the Cape Granite Suite.

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Characterizing Late Triassic Molteno Coals in Taung, Lesotho

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Background

The Late Triassic coals of the Molteno Formation are exposed in Taung, southwestern part of Lesotho. Stratigraphically, these are the only known coal resources in the country, but their economic potential is not well documented. Therefore, the purpose of this study is to investigate this coal's economic and environmental characteristics, which are crucial for exploiting it in a sustainable way to benefit Lesotho.

Methodology

A geological map is used to target and collect a total of 12 coal samples from outcrops and all samples are prepared for analysis. Proximate and ultimate analytical methods are used to characterize and predict utilization of this coal while observing best coal International Standards. Sulphur has a negative impact on the environment due to its ability to form acid rain; hence, its determination methods are also included in the analysis. Moreover, maceral groups are evaluated through petrographic analysis which reveals the coal rank via vitrinite reflectance method, an important economic parameter for coal utilization. Mineral assemblages from majors to trace elements are also investigated through various techniques such XRF and ICP- MS while TIMA is used to determine mineral phases like clay minerals. All instruments used are from accredited institutions of commercial and research origin, with high data quality standards.

Key results

Preliminary results from proximate and ultimate analysis indicate three samples collected at proximity to each other to have calorific values ranging from 7.6 to 13.41 MJ/kg with ash content averaging below 60 % while Sulphur content is 0.66% on average. Petrographic results show Liptinite as a major maceral group with one sample having liptinite as high as 44.8 vol%, of mainly cutinite, which is unusual because most Gondwana coals are generally poor in liptinite. Furthermore, this sample indicates the highest random vitrinite reflectance value of 0.6 vol% and therefore was considered to represent a Medium Rank C bituminous coal. The rest of the samples are not considered as coal based all these analytical results. Concentrations of rare earth elements are above crustal averages and therefore can be considered as a source for this critical elements. Overall, sampling results indicate some potential of an economic coal seam for which gravity and magnetic surveys are being employed to select drilling targets.

Main Conclusions

In conclusion, the positive coal analysis results encourage sampling at depth through core drilling which will provide good samples for further evaluation to determine its economic and environmental viability.

Characterizing Phytoplankton Communities: A Southern Ocean Case Study of Environmental Coupling and Consequences in a Climate Change Context

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Phytoplankton inhabit the upper sunlit waters of the ocean surface, at the interface between the ocean and atmosphere. Their primary process is photosynthesis, facilitated by pigment-protein complexes which harvest light (Falkowski and Raven, 2013). The combination of these photosynthetic and photo-protective pigments can act as a fingerprint for specific groups. The chemo-taxonomic analysis of these pigments can be used to estimate the composition of phytoplankton groups (Mackey, Mackey, Higgins and Wright, 1996).

In the context of climate change, one can view our global oceans as carbon sinks, attributed in part to the phytoplankton (Reinfelder, 2011). Varying communities have diverse biological function; therefore, shifts in the community affects the role phytoplankton play in the global climate. In the Southern Ocean, data for these community profiles are sparse both spatially and seasonally (biased towards summer). The work presented here addresses the seasonal knowledge gap of Southern Ocean phytoplankton community structure using data from a winter 2017 expedition in the Indian sector and both a winter and spring expedition in 2019 in the Atlantic sector. Samples were collected for pigment analysis as well as other environmental parameters from the surface water between Cape Town and the Antarctic sea-ice onboard the polar research vessel, SA Agulhas II.

This research explores the variation in phytoplankton community composition across these three datasets, determining the extent to which group-specific prevalence can be attributed to environmental observations. This assessment factors up to 9 phytoplankton groups and 4 environmental variables in quantitative canonical-correlation analysis (CCA).

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Climatic control on the 2.9 Ga gold mega-event

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First large-scale concentration of gold took place at around 2.9 Ga in the form of fluvial placers. Endogenous gold concentrations, such as porphyry and epithermal as well as or orogenic deposits only start to play a significant role from c. 2.75 Ga onwards after plate tectonics had begun to shape the Earth's crust. The 2.9 Ga gold mega-event has been explained by a higher Au run-off from Mesoarchaean land surface promoted by deep chemical weathering under a reducing acidic atmosphere and trapping of Au dissolved in river water by microbial colonies. Remnants of microbially fixed gold are preserved in kerogen layers in the lower Central Rand Group of the Mesoarchaean Witwatersrand Basin. Poor preservation potential of these delicate structures led to widespread sedimentary reworking, release of minute gold particles from the eroded microbial mats, thus forming highly auriferous conglomerates, mainly between 2.9 and 2.8 Ga. While this hypothesis neatly solves the source-problem for detrital Witwatersrand gold, it does not explain the conspicuous absence of similar gold deposits in strata >2.9 Ga. Little evidence exists for fundamental changes in biology or atmospheric composition across the 2.9 Ga boundary. Here the suggestion is presented that climate served as first-order control on the leaching rate of Au from the granitoid-greenstone-dominated Archaean land surface. Cold conditions are indicated for the period 2.96-2.91 Ga by the occurrence of diamictite in the West Rand Group and its stratigraphic equivalents. In the various goldfields across the Witwatersrand Basin, glaciogenic diamictite has been identified in up to three stratigraphic positions, where it is closely associated with shallow marine ferruginous shale and locally iron formation, overlain by littoral sandstone, analogous to glacial and post-glacial deposits known from Palaeo- and Neoproterozoic successions elsewhere. Moreover, the abundance of detrital feldspar and correspondingly low indices of chemical weathering document cold climate. In contrast, the dominant sandstones and auriferous conglomerates in the 2.90-2.79 Ga Central Rand Group are conspicuously devoid of feldspar and yield generally high chemical indices of alteration, especially below erosional unconformities. All in all, geological, petrological and geochemical evidence speaks for a major climatic shift at around 2.90 Ga to warm/humid conditions that facilitated leaching of Au from the hinterland, thus triggering the first major concentration of gold in Earth's history.

Comparing the provenance of the Main Karoo succession to those of Karoo-aged equivalent units in India: new insights from U-Pb detrital zircon ages of the Gondwanan successions of the Bokaro and Jharia coal basins.

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The sedimentary successions of the Main Karoo Basin, South Africa, has been the subject of numerous studies in recent years and several inquests regarding the provenance of its formations have been undertaken. The similarities between the stratigraphy of the Karoo Supergroup as preserved in the Main Karoo Basin and Karoo-aged (Carboniferous to Jurassic) successions on neighboring continental fragments of Gondwana have also long been recognized and investigated to varying degrees. The Gondwana successions of the Bokaro and Jharia basins in India represent two such erosional relicts. Although the stratigraphy these two basins have been described in the past, their age of deposition is relatively poorly constrained and their correlation to the Main Karoo succession has received less attention compared to some of the other Karoo-aged erosional relics, despite the remarkable similarities regarding the stratigraphy of the basins. A detrital zircon U-Pb LA-ICP-QMS provenance study was therefore undertaken on samples from the Gondwana successions preserved in the Bokaro and Jharia basins to better constrain the age of deposition of these units, investigate the provenance of the sediment and determine whether the strata were deposited in isolated syndepositional graben basins, in the overall context of the geology of India or formed part of a wider regional depositional system. The findings of this provenance study were also compared to U-Pb provenance data available on the Karoo Supergroup, as preserved in the Main Karoo Basin.

Unlike the lower Karoo Supergroup, the age equivalent units of the Bokaro and Jharia basins in India do not show any input of detritus form the events related to the Gondwanide orogeny, inferring the absence of Paleozoic aged source areas in the vicinity of these basins. Youngest detrital zircon age fractions (Cambrian) older than the proposed age of deposition of the sediments reflect the age of the youngest source area and hence the age of the stratigraphic units could not be better constrained. Newly obtained youngest detrital zircon ages also did not lead to a more stringent correlation between the strata of the Bokaro and Jharia basins and the Main Karoo Basin. Zircon age fractions range from early Neoarchean to earliest Cambrian and source regions in India and Antarctica have been proposed. Similarities between these zircon ages and those of Karoo-aged Mahanadi and Panhita-Godavari basins in India have also been identified, implying that fault-bound Gondwana basins in central east India formed part of a much wider regional depositional system.

Considering Karoo Magmatism

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I approach the Jurassic Karoo Large Igneous Province looking from the outside in, that is, from the perspective of experience predominately in basalts and related differentiated rocks of the deep ocean floor and ocean islands. For both Karoo and the ocean floor, huge data sets now exist and the literature for both is extensive. To get at mantle sources in a continental setting, the effects of silicic contamination must be considered. This I do by comparison with Iceland, where andesites and dacites are abundant, and evidence for magma mixing between basalt and such differentiates is well documented in the field. Karoo dolerites geochemically are much the same, with important effects on rare-earth concentrations and ratios, Nb, and the radiogenic isotopes of Sr and Nd: "enrichment" indicates silicic contamination, not deep mantle sources. Most of the Karoo Basin, however, was never, unlike Iceland, part of a spreading ridge system. Along ridges, and at large islands such as Hawaii, narrow zones of magma injection along strongly parallel dike injection systems were established by a characteristic regional stress pattern, and which compelled magma mixing. The same pattern is seen as sheeted dike complexes in ophiolites and is necessary for the formation of the magnetic stripes seen over 60% of the planetary surface. Instead, at Karoo, the broad distribution and wide range of directions of dikes and cuspate dolerite sills that intruded a wide and thick sedimentary sequence most nearly resemble that recently discovered using modern oceanographic seismic techniques along the thickly sedimented continental margin of the South China Sea, a Pacific marginal basin e.g., 1. This is related to the Neogene-to-present arrangement of subducting plates. At Karoo, no mantle plume was involved, and portions of the sub-continental lithospheric mantle were unroofed as the southern Indian Ocean opened. This mainly refractory ultramafic material is now present beneath the Marion Rise and the Southwest Indian Ridge2, locally giving rise to volcanic islands, but mainly resulting in shallow axial elevation and production of thin crust. Basalts there are isotopically depleted (MORB-like, with sub-continental mantle sources3, like those of least contaminated Karoo dolerites.

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Consistency of geological, structural, and geochronological data in constraining the dynamic evolution of the Arabian Nubian Shield of the East African Orogen.

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The Arabian–Nubian Shield (ANS) is the northern part of the East African Orogen (EAO) extending from southern Israel to Southern Kenya where it is wedged against the Southern part of the EAO - Eastern Granulite–Cabo Delgado Nappe Complex [2]. The EAO is one of the major and world´s largest Neoproterozoic to Cambrian orogenic complex (e.g., [1], [2], [3]).

The ANS is comprised of mostly juvenile low- to medium-grade rock assemblages of the Arabian Nubian Shield (ANS), while its southern part is constituted of high-grade metamorphic rocks of the older Paleoproterozoic crust traditionally referred to as the Mozambique Belt (MB) ([4],[2]).

This work reviews the geodynamic evolution of the ANS considering the geological, geochronological, and structural data generated in the last 3 decades from the various portions of the ANS. The consistency of geochronological data constrains well the age of formation of the ANS crust in and adjacent to the Mozambique Ocean within 880 to 620 Ma; followed by various stages of crustal uplift, post-orogenic extension, and several late-to post-tectonic and post-orogenic/collisional granitoids ([4],[5], [6], [2]).

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Constraining the P-T-t evolution of the crust by modelling processes of partial melting, magma formation and emplacement: new insights provided by combining compositionally variable phase equilibria in Rcrust with accessory phase saturation and trace element partitioning

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Background

The formation and chemical differentiation of the crust relies on processes that transfer chemical components from one portion of the Earth to another. Most notable of these in a crustal context are the metamorphism, devolatisation and partial melting of the crust, magma segregation, possible phase entrainment at the site of melting or during transport through the crust and finally fractional crystallisation and assimilation at emplacement. In order to model systems undergoing compositional change the Rcrust phase equilibria modelling tool has been developed which uses a unique path dependent algorithm to allow compositional change throughout the modelling process [1,2].

Methodology

New insights have been gained on the conditions and timing of magmatic processes in the crust by combining this thermodynamically constrained modelling of major phases with saturation calculations for accessory phases of apatite and monazite. These accessory phases, though small in proportion, host an abundance of trace elements and can provide important information on conditions during crystallisation from melt. Current thermodynamic databases and activity-composition models cannot account for the large array of trace elements as chemical components in modelled systems. Instead, phase saturation is calculated by assuming that all components that exceed that which can be accommodated in melt must form new phases, and through iterative calculations in Rcrust, appropriate chemical subsystems are apportioned. Finally, activity distribution coefficients are used to partition trace elements between melt and the stable phases.

Key Results

The results firstly highlight the importance of major element components that also contribute to accessory phase formation such as calcium in apatite (which can accommodate a non-trivial quantity of the available calcium) and the resultant effect on phase equilibria of major phases. It is shown that the chemical effect of considering trace amounts of calcium apportioned into apatite is equivalent in the case study to a 30 °C change. Secondly it is shown that accessory phase modelling and their trace element compositions can be compared to natural data to provide constraints on the formation and crystallisation of crustal magmas, when combined with major phase modelling.

Main conclusions drawn from these results

This provides a novel approach for approximating trace element distribution among thermodynamically constrained phases with thermodynamically unconstrained accessory phases, apatite and monazite. This has important implications on geothermobarometry and thermochronology in the crust.

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Constraints on the genesis of the orbicular rocks and sulphide mineralization in the Koperberg Suite, Namaqualand Metamorphic Complex, South Africa.

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The 1020-1060 Ma Koperberg Suite (KS) in South Africa was emplaced during a localized ductile event that formed the E-W trending steep structures controlling regional Cu-mineralization. The KS rocks contain zones with orbicular textures, thought to form by either magmatic, metasomatic or metamorphic processes. There is no consensus or single mechanism explaining the genesis of these textures both globally and in the KS. Some orbicular zones are also associated with Cu sulphide mineralization, suggesting a possible link between orbicule formation and metallogenesis. This study documents a selection of orbicular localities from the KS to understand their genesis using petrography, in-situ mineral chemistry and isotopic data. Five different orbicule localities are described including Orbicule Koppie (OK), Jubilee Pit (JP), Henderson North (HN), Henderson South (HS) and Hoogskraal Lease (HL).

Orbicules occur in spectrum of lithologies of the KS, ranging from granite to diorite. The orbicules are characterized by coarse-grained (2-6 mm), felsic cores composed of feldspars, biotite and quartz. Sharp contacts mark the transition from cores to the fine-gained (0.2-1 mm) shells. Alternating, fine-grained mafic and felsic shells exhibit polygonal textures. HS and HL orbicules are characterized by radiating textures that are restricted to orbicular shells. Sharp boundaries mark the transition from core to shells and coarse-grained matrices, all of which contain similar mineral assemblages. Some of the orbicule localities contain deformed orbicules trending parallel to steep structures. Plagioclase in the HN (An47-65) and HS (An52-62) orbicules are more calcic than plagioclase at HL (An35-52) and OK (An41-57). Biotite in the HN (¯(“x”) = Mg#77) and the OK (¯(“x”) = Mg#75) orbicules are more magnesian than those at HS (¯(“x”)=Mg#62) and HL (¯(“x”)= Mg#68) orbicules. Plagioclase in the HN orbicules are characterized by elevated initial 87Sr/86Sr ratios (ISr) (0.709675 to 0.723517) relative to other orbicule localities (0.705608 - 0.724905).

Formation of these orbicules has been attributed to metasomatic processes. However, a variety of textural and geochemical constraints rules out a metasomatic origin. These include chemical similarity between orbicules and the magmatic matrices, as well as a variety of synmagmatic textures. This, along with isotopic data, indicate that distinct pulses of orbicule-forming magmas make up the KS, where variable amounts of magma mixing, mingling and assimilation occurred. These differentiation processes possibly took place during magma ascent and emplacement, possibly triggering the ideal conditions for orbicule and sulphide formation.

Continental mafic LIPs: hot or wet?

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Large igneous provinces (LIPs) are subdivided to mafic and silicic, oceanic and continental. This presentation deals with continental mafic LIPs. Adjectives mafic and continental imply mantle-derived and thick lithosphere, respectively. The latter means that under the lithosphere the melting should be suppressed by high pressure. At normal mantle geotherm, irrespective of peridotitic or eclogitic lithology, no melting can occur at pressure above 4 GPa that corresponds to depth of below ~130 km. The majority of continental lithosphere has greater thickness including some regions that experienced voluminous LIP magmatism. Usually, that fact is used to accept abnormally high temperature of melting such as due to decompression of a plume originated at hotter core-mantle boundary. However, even plumes that 300 degrees hotter compared to normal mantle geotherm cannot produce melts at depth of ~160-230 km depending on the plume composition (peridotitic or eclogitic). To explain voluminous melting, hot plume models are usually complemented by models of lithospheric thinning or destruction for allowing magma generation at shallower depth. The negative effect of pressure can be overcome by enrichment of the melting source by volatile components, primarily CO_2 and H_2O, which lowers melting temperature. Available petrological and geochemical data suggest that CO_2 is important for generation of alkaline silica undersaturated melts that are at subordinate amount within continental mafic LIPs. Predominant types of rocks within such LIPs are so-called low-Ti and high-Ti subalkaline and normal alkaline basalts. Low-Ti basalts are characterized by geochemical signatures that resemble those of calk-alkaline basalts of subduction settings whose origin is at mantle wedge enriched by H_2O from subducting slabs and by H_2O-fluid soluble elements. This geochemical evidence is not straightforward, however, and 'subduction-like' geochemical indexes are considered by many scholars as evidence of crustal contamination of dry mantle-derived melts. Analysis of melt inclusions in early crystallizing minerals of basalts such as olivine may solve the dry-versus-wet conundrum. One of the problem is that such an analysis requires melt inclusion homogenization at high temperature that may lead to loss of H_2O from the inclusions. To prevent this, a temperature homogenization is conducted at an elevated pressure. Such homogenization experiments showed high H_2O content in olivine-hosted melt inclusions of low-Ti basalts of Snake River plane, associated Columbia River Plateau and high-Ti meimechites of Siberian Traps. This is explained by the deep water cycle model in which subducting slabs stagnate in the mantle transition zone and propagate far under continents.

Controls of fluid flow and mineralization at the Twin Hills gold prospects in the Central Zone of the Damara Belt, Namibia

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The Twin Hills gold prospects in the Central Zone of the Damara Belt in Namibia combine to a large (>12 km strike length), orogenic disseminated, low-grade mineralized system. This study describes the controls of the mineralization and fluid flow that determined economic-grade mineralization in high-grade metamorphic turbidites at Twin Hills. The interpretation is based on limited surface mapping, structural and lithological data, mainly from ~14 km of orientated core, combined with petrographic work and gold assays. Wall-rocks are subvertical, tightly folded and transposed, amphibolite-facies metaturbidites (cordierite-biotite metapelites and quartz-biotite metapsammites) that form the subvertical limb of a regional-scale synclinal structure. Sulphides and associated gold mineralization are either finely dispersed in the matrix of the rocks or take the form of networks of quartz-sulphide (pyrrhotite>arsenopyrite>>pyrite) veinlets. The location, geometries and deformation of the mineralized vein networks suggest their formation during flexural-slip folding and the progressive transposition of the metaturbidites into the regional, ENE trending steep foliation. The more competent metapsammites promoted fracturing while ductile strain during flexural-slip was localized into the schistose metapelites. As a result, economic-grade mineralization is best developed in well-bedded, compositionally heterogeneous parts of the metaturbidites that experienced pronounced strain partitioning. Metapelite-dominated packages, in contrast, show mainly disseminated sulphide mineralization, fewer and variably transposed vein networks and only sub-economic gold grades. The similar timing of disseminated and vein-type mineralization suggests that pervasive fluid flow was channelized within the lithologically heterogeneous packages that provided fracture permeabilities and hydraulic gradients for more focused fluid flow. Higher gold grades correspond to subtle (5-15°) deflections of bedding and the regional foliation that may relate to dilational jog geometries. On a prospect-scale, the position of economic-grade gold mineralization corresponds to the inflection and change of the vergence of regional-scale first-order folds. The style of mineralization shares similarities with other turbidite-hosted orogenic gold deposits. Differences and the disseminated style of mineralization can be explained by the relatively early, syn-tectonic (D2) timing of fluid flow and the amphibolite-facies grade and ductility of wall rocks that prevented the formation of larger, brittle, high-permeability structures. In very poorly exposed terrains, structural information of this nature can only be extracted from a detailed drilling program with structurally orientated core.

Coupled Sm-Nd, Lu-Hf and 142Nd isotope systematics of the 3.25 Ga Stolzburg Complex, Kaapvaal Craton

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Whole rock Sm-Nd, Lu-Hf and 142Nd isotopic data are presented for various rock types of the Stolzburg Complex, a prominent and well-preserved ultramafic-mafic layered complex north of the Barberton Greenstone Belt, to elucidate aspects of petrogenesis, magma source composition and geodynamic setting. Trace element geochemistry is consistent with a mantle source that underwent moderately large degrees of melting above the garnet stability field. The Sm-Nd and Lu-Hf data yield well-defined isochrons corresponding to apparent ages of 3367±62 Ma (n=12, MSWD=1.5) and 3396±36 Ma (n=11, MSWD=2.1), respectively. Initial Hf (+3.3 to 5.7) and Nd (+0.9 to +1.7) isotopic compositions indicate derivation from depleted to chondritic mantle sources. Isochron ages and a regressed initial Hf isotopic composition of +4.0±0.9 (at 3.4 Ga) disagree with an established emplacement U-Pb age of 3.25 Ga and epsilon Hf values for zircon of 0 to +3. The coherence in isochron ages and variability of initial Hf and Nd isotopic composition is adequately explained by reworking of mafic-ultramafic (oceanic?) crust with a composition not distinguishable from newly formed (intrusive) magmas, explaining the overall similarity in whole rock compositions across all lithologies. A subset of samples was also analyzed for 142Nd isotopic compositions and results reported as mu142Nd (-2.3±2.2 to 1.7±2.1) are indistinguishable from the modern terrestrial value. Therefore, 142Nd-enriched or depleted mantle reservoirs had not remained isolated from convective homogenization in the asthenosphere, or the volume of mantle underlying the layered complex could not resolve mantle heterogeneity. The Stolzburg Complex was most likely emplaced on the ancient seafloor; Ca-metasomatism – a fingerprint of hydrothermal alteration on the seafloor, is recorded in the form of rodingites.

Cr-distribution patterns in Bushveld magnetitite: a primary magmatic or secondary feature?

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A great amount of debate exists regarding on how faithfully fossilized layer intrusions record magmatic activity, or by how much have they been modified by subsequent processes. While many have attempted to explain igneous layering in a purely magmatic framework, others have suggested that modification by fluids played an important role. Recently, this controversial issue has also reared its head in dealing with the origin of magnetitite layers of the Bushveld Complex. Two geochemical features complicate their petrogenesis: a rapid depletion in Cr contents upwards that differs from that predicted by fractional crystallization, and Cr-rich dome-shaped structures that decorate the bases of magnetitite layers. To explain the former, previous investigators have invoked primary magmatic processes (1, 2), such as periodic magmatic recharge (2), that can cause a deviation in the Cr-depletion curve compared to pure fractional crystallization. The Cr-rich domes have been interpreted as the sites of incipient nucleation and growth of magnetitite on the underlying anorthosite. However, these interpretations have recently been challenged, with a recent study (3) proposing that a reaction with Cr-rich liquids migrating upwards from below may be responsible.

To test these conflicting views, we have examined: a large basaltic xenolith situated directly underneath a magnetitite layer at the Magnet Heights locality that would have served as a barrier to migrating fluids coming from below; cumulus magnetite in the anorthosite underneath a magnetitite layer that should be enriched in Cr if a Cr-rich liquid passed on through; small-scale protrusions of magnetite into the anorthosite that should be dramatically enriched in Cr if they reacted with a Cr-rich fluid. However, using a combination of methods involving portable XRF and EPMA, we find no evidence for a relative Cr enrichment or depletion of the magnetitite sitting on top or adjacent to the xenolith, cumulus magnetite in the underlying anorthosite is much poorer in Cr compared to the overlying magnetitite, and small-scale protrusions contain low Cr concentrations, even those located directly below Cr-rich domes. We thus argue that Cr-rich fluids are not responsible for the geochemical features of Bushveld magnetitites, and models involving Cr-rich fluids (3) should, for the time being, be considered false unless direct evidence for their existence can be provided by future research.

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Crystallization and segregation of carbonated silicate melt in kimberlitic melt inclusions from the Monastery kimberlite

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Ilmenite megacrysts from the Monastery kimberlite contain up to 7 mm-sized melt inclusions (MIs) consisting of abundant calcite and Mg-rich silicate matrix (SM). Minor phases include secondary ilmenite, perovskite, spinel, kassite/cafetite, phlogopite, garnet, monticellite, apatite, corundum and serpentine.

100-1000 µm thick zones along the margin of MIs contain most of the K2O and TiO2 of the MI bulk composition. Ti-Fe-rich skeletal spinel and 20-60 µm small phlogopite flakes form randomly oriented grains. Perovskite (CaTiO3) commonly forms epitaxial crystals on the hosting ilmenite megacryst. ~100-200 µm sized zoned aggregates contain cafetite (CaTi2O5�H2O) or kassite (CaTi2O4(OH)2) cores surrounded by thin calcite zones. Subhedral Ca-Ti-Fe garnet forms the outer rim of these aggregates. In other samples, Ca-rich olivine may be present instead of garnet.

The interior of melt inclusions is occupied by variable proportions of calcite and SM. Raman spectroscopy indicates that the SM commonly contains sub-SEM scale serpentine but glass is preserved in some samples. We interpret that the SM formed from the quenching of residual melt.

The texture of the calcite and SM in the interior of MIs varies depending on their relative abundance. In calcite-rich MIs, calcite forms large coherent domains that occupy most of the inclusions. Within the less abundant SM, small calcite domains form an emulsion-type pattern in which the calcite ranges in size between less than <5 µm to >50 µm. Coherent domains of calcite-free SM does not exceed ~100 µm in size. This pattern is consistent with carbonate-silicate melt segregation achieved by nucleation and growth of carbonate droplets. By contrast, in MIs containing low proportions of calcite, the SM forms large coherent domains separated from equally coherent calcite domains. In one sample, ROM264, calcite and the SM are separated by a ~300-500 µm thick zone of highly interconnected meander patterns formed by Fe-Mg-rich silicate and carbonate "spaghetti"-shaped structures. The textures and compositions in this zone are indicative of spinodal segregation.

Neither textures consistent with nucleation and growth nor those consistent with spinodal decomposition contain Ti-rich or K-rich phases. This suggests that the crystallisation of Ca-Ti-K phases along the inclusion margin preceded the segregation of carbonate and silicate melt. Textures indicating carbonate-silicate melt segregation have significant implications for the evolution of kimberlite magma.

Cyanobacteria-dominated microbialites >120 Myr before the Great Oxygenation Event

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The Great Oxygenation Event (GOE) was an unprecedented geobiological revolution in deep time (~2.4–2.3 Ga) and the driver of subsequent geosphere–biosphere interactions. Its timing is widely believed to reflect the rise to dominance of oxygenic photosynthesisers, primarily cyanobacteria, in shallow-water ecosystems. Our understanding of the GOE is complicated by poor preservation of the ancient geological record and an absence of biomarkers diagnostic of the rise of oxygenic photosynthesis; furthermore, the earliest unambiguous cyanobacterial cellular fossils are only 2 Gyr old.

Here, we present high-resolution, organic–inorganic geochemistry evidencing a cyanobacteria-dominated microbialite assemblage >120 million years before the main GOE in the 2.52 Ga Gamohaan Formation, South Africa. Rare earth elements plus yttrium (REE+Y) geochemistry show that these microbialites formed under a micro-oxic manganese-bearing marine water column. Textural and microstructures observations suggest that their constituent organic materials were mineralised extremely rapidly during growth, and have not undergone substantial post-depositional alteration. They comprise organic materials with an aliphatic fraction dominated by long, unbranched fatty acid-like membrane lipid residues, consistent with bacterial origins, carbon isotope fractionations diagnostic of oxygenic photosynthesis using Form I Rubisco, and nitrogen isotope fractionations potentially denoting aerobic nitrification–denitrification. EPR and Raman geothermometry using the organic fraction of these microbialites clearly establish the syngeneity of the mat laminations with the host rock, indicating that the organic geochemical signatures within arose from the primary biological community. The Gamohaan microbialites thus present the oldest fossil evidence for cyanobacteria-dominated microbialites, and adds weight to the argument that cyanobacteria were the architects of Palaeoproterozoic atmospheric oxygenation, though lived in anoxic conditions during their earliest history. At 2.52 Ga, the Gamohaan microbialites postdate the estimated evolution of oxygenic photosynthesis by ~400 Myr and precede global atmospheric oxygenation by at least 120 Myr.

Finally, using correlated SEM-EDX, Raman and FTIR mapping, we demonstrate the specific co-occurrence of ferroan dolomite with microbial mat laminations, indicating that dolomite nucleated syndepositionally within microbial ecosystems, providing the oldest evidence for microbial dolomite formation, and showing that microbes have played a role in forming this enigmatic phase since at least the terminal Archaean.

Dating autocrysts, xenocrysts and detrital zircons in the Ventersdorp Supergroup in Kimberley diamond mines

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Ventersdorp Supergroup rocks exposed in Kimberley mines can be assigned to the Platberg and Pniel groups. The sedimentary Kameeldoorns Formation and volcanic Goedgenoeg and Makwassie formations were investigated.

The gneissic basement includes amphibolite dated at 2959 ± 10 Ma, a 2874 ± 24 Ma granodiorite and 2903 ± 23 Ma tonalite. Metamorphic monazite is 2856 ± 21 Ma.

In Kameeldoorns conglomerate the youngest detrital zircons are 2901 ± 24 Ma, corresponding to the youngest zircons in the Ventersdorp Contact Reef in the Witwatersrand goldfields.

In magmatic rocks, comagmatic zircon autocrysts may be distinguished from xenocrysts (older grains derived from the source or country rocks) using cathodoluminescent images. Other criteria can be 207Pb/206Pb age histograms and unmixing algorithms, Lu-Hf isotopes, Th/U ratios (if Th is measured) and stratigraphic context relative to other dated samples.

The basal dacitic ash-flow tuffs in rocks assigned to the Goedgenoeg Formation yield an age of 2781 ± 5 Ma, based on all 51 points. This seems to be autocrystic, reflecting extrusion. Higher in the Goedgenoeg Formation, the extrusive age is 2717 ± 15 Ma and xenocryst groups aged 2872 ± 11 Ma and 2851 ± 36 Ma were found.

The overlying Makwassie Formation quartz porphyries give zircon autocryst ages of 2729 ± 10 and 2725 ± 3 Ma, which agree with the established 2722 ± 2 Ma age of the Makwassie (ref1). Xenocrysts were dated at 2874 ± 16 Ma.

Lu-Hf zircon data for Ventersdorp Supergroup volcanic, xenocrystic and detrital samples are consistent with derivation from an enriched mantle source which developed beneath the Kaapvaal Craton between 3.5 and 3.1 Ga (ref2).

The Makwassie and Goedgenoeg Formations are almost coeval within errors. The older age found at the base of the Goedgenoeg might represent an older stratigraphic unit. It corresponds geochemically to the Goedgenoeg, but has slightly higher Hf isotope ratios. The main xenocryst groups were probably derived from the basement granitoids.

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Dating very small impact craters on Earth: Morasko strewn field, Poland

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Precise and accurate dating of impact craters allows the correlation of impact structure formation with other geological events, is crucial to determine the impact flux on Earth, and helps to better understand the overall geological history. The aim of this paper is to: 1) date Morasko strewn field based on 14C of charcoals within its proximal ejecta blanket (similarly to Kaali [1] and Ilumetsa [2]); 2) provide recommendations on how to determine age of other small and recent (<50 ka) impact craters on Earth.

Morasko is a strewn field consisting of ~7 craters [3]. The largest crater is ~100 m in diameter and 30 m deep. It is located on a slope of a glacio-tectonically modified moraine of the last glaciation. Target consists of up to a couple of meters of glacial/fluvioglacial sand, up to a couple of meters of glacial till [3], underlaid by glacio-tectonically affected Neogene clays at depths from 0 m up to a couple of meters. The age of the crater is estimated to be between 3 and 5 ka [4, 5].

We performed ten 14C measurements at the Vienna Environmental Research Accelerator laboratory at the University of Vienna (Austria) and calibrated using OxCal. Samples were selected from two types of locations of proximal ejecta blanket: 1) seven were from a trench, 2) three from hand-drill cores. Out of the samples within trench, three were taken from charcoals intermixed within ejecta, and four samples were located within the well preserved paleosoil underlaying ejecta.

The combined age of the charcoals from paleosoil in trench is between 5230 and 5060 cal BP (4556+/-17 14C-age BP). The combined age of the charcoals from the ejecta in the trench are ~half a millennium younger: 4570-4420 cal BP (4035 +/- 20 14C-age BP). We suggest that the latter is the age of the Morasko impact event. The ages of charcoals collected from drill cores are problematic: one is consistent with the age of the impact, while two point to much younger events, probably wildfires and were intermixed within the drilling material during sampling. This shows that hand-drills should not be used to sample for charcoals when dating very small and recent impact craters.

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Dealing with Disruptions – impact on Geoscience Education

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Disruptions have always been a part of tertiary education in South Africa. Pre-1994, disruptions were principally political in nature, with boycotts and sit-ins being a popular form of resistance, but classes went ahead and teaching and learning continued. Post-1994, certain universities faced disruptions cause by geopolitical difference and xenophobia where academics and students alike took to the streets causing lecture halls to stand empty for a few hours at a time, but again, lectures were caught up and teaching and learning progressed. More recently, Universities were challenged with #FeesMustFall (2015–2017), closing lecture halls altogether and forcing face-to-face teaching to shift rapidly towards a form of "blended learning". Such "blended learning" was more about managing protests and not about pedagogical innovations (Czerniewicz, 2020; Hodges et al., 2020). The onset of the COVID-19 pandemic presented very different challenges where both educators and students were forced into isolation because of social distancing, and long-term online engagement became a necessity. Institutions resorted to a temporary shift of instructional delivery (Hodges et al., 2020), referred to as Emergency Remote Teaching and/or Learning (ERT/L). During ERT/L only the most essential content was taught, leaving out sections of content, creating serious quality assurance issues. This was compounded by many students (and even some staff) suffering from a lack of resources and technologies to participate in ERT/L. Geoscience subject areas most severely compromised by ERL/T include optical mineralogy, petrology, field mapping, applied geology and skills development.

The Centre for Global Development estimates that there is a 22-28% chance of another COVID-19 magnitude outbreak within the next 10 years, increasing to a 47-57% chance in the next 25 years. It is therefore not a case of if, but when, the next disruption will occur. Geoscience educators should begin planning now so that pedagogically suitable materials and assessment tools are readily available which will promote interactive, whole brain learning. This necessitates detailed research into what did and did not work previously, as well as research into how best to teach complex geoscientific knowledge and skills under pandemic conditions. In short, Geoscience Education needs to become a recognized research area in South Africa, as it is elsewhere in the world. Curriculum reform is essential and new approaches to teaching and learning Geoscience must be implemented.

Deep drilling in the Bushveld Complex: The BVDP Project

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The Bushveld Drilling Project (BVDP) has been approved for generous support by the International Continental Scientific Drilling Program (ICDP), and drilling is due to commence in March/April, 2023. The main components of the project are: (1) a single continuous borehole of ~3000 m in length, envisaged to start at approximately the boundary between the Upper and Lower Critical zones and extending into the floor beneath the Rustenburg Layered Suite (RLS) in the Clapham Trough area of the Eastern Bushveld Complex, (2) downhole geophysical measurements, including density, magnetic susceptibility, electrical conductivity and a vertical seismic profile, and (3) sampling of deep fluids and gases for physical and biological measurements. The new drilling set to take place in the Eastern Limb will complement core that has been donated to the project, providing a near continuous section through the RLS, all the way from above the Upper Zone and into the floor of the intrusion. In addition, the project intends to provide a drillcore of ~500 m length in the Northern Limb to cover the gap in currently available sampling of the unusual troctolite horizon in the Main Zone. The continuous 3000 m borehole, complemented by donated core, is designed to represent a reference stratigraphic section of the entire RLS, as well as the Roof granitoids for present studies as well as for decades of future research. Science objectives include, but are not limited to: magma chamber processes, origin of layering, crust-mantle interactions, origin of Bushveld granitoids, origin of ore deposits, correlation with other stratigraphic boreholes, and nature and origin of deep crustal fluids/gases. We are also planning substantial outreach activities to residents in the local communities. After initial characterization of the drillcores (logging, photography, scanning) all information gathered will be made available online to the worldwide geoscience community. Subsequently, a steering committee will consider requests for samples from the worldwide community. Several research projects utilising the donated core material (housed at the Council for Geoscience and the University of the Free State) are already underway, both nationally and internationally.

Deep structure and neotectonics of southern Africa revealed AfricaArray seismograph networks

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Background

AfricaArray is a pan-African initiative that promotes linked research and training programmes to build professional geosciences capacity in support of the mineral, petroleum, geohazard and environmental sectors. It was launched in 2004 by the University of the Witwatersrand, Council for Geoscience and Penn State University (USA). In association with many African and international partners, AfricaArray has developed a 'backbone' network of 51 permanent geophysical observatories (broadband seismometers, GPS stations and weather stations) in 19 countries and deployed more than 100 broadband seismometers in temporary arrays in Botswana, Cameroon, Madagascar, Malawi, Mozambique, Namibia, South Africa, Tanzania, Uganda and Zambia. The stations provide data that illuminates the structure and dynamics of the continent; aid the search for oil, gas, metals and minerals; and help to forecast natural hazards such as earthquakes and volcanic eruptions.

Methodology

Many investigations of the structure of the crust and mantle have been conducted using techniques such body and surface wave tomography, waveform modelling, shear-wave-splitting and the joint inversion of receiver functions and surface waves. In many cases, the AfricaArray broadband seismograms are augmented by data recorded by other agencies, as well as other types of data such as gravity, magnetics, magnetotellurics and reflection seismics.

Key results

Tomographic images reveal the seismic structure of the subcontinent as deep as the mantle transition zone, revealing the boundaries between major tectonic provinces. Regions that have been studied include the Kaapvaal craton, the East African Rift System, and the island of Madagascar. Geodynamic questions that have been addressed include the cause of the region of elevated topography (the African Superswell) and the connection (if any) to the Superplume, the origin of mantle anisotropy, and evidence for secular variations in crust-forming processes.

The hazard posed by earthquakes has been addressed through seismotectonic studies in East and southern Africa, seismic hazard assessments in the DR Congo and along the East African Rift, and investigations of the risk posed by mining-induced earthquakes.

Conclusions

AfricaArray's deployment of broadband seismograph networks and coupled research and training programmes have led to substantial advances in knowledge of the structure and evolution of the African continent, and to the development of geoscience researchers and practitioners.

Deformation/melting of the Archaean crust: new insights from the Northern Kaapvaal and Barberton Granite Greenstone belt areas, South Africa.

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The tectonic style of the Archaean Earth still remains a controversial subject and the debate is polarised between actualistic (plate tectonics) models, and a wide variety of alternative models, which have in common their opposition to modern plate tectonics and their conception of a drastically different mechanical and thermic behaviour of ancient crust. However, the debate is largely focused on geochemical arguments, or conclusions from numerical geodynamic models, and the actual strain patterns of the crust are rarely described

We studied two emblematic domains, the Barberton Granite-greenstone terrain and the Northern Kaapvaal domain (Limpopo Province), both in South Africa in which combined field and structural studies demonstrate the importance of melting/magmatism in association to Archaean deformation. Whereas the Barberton terrain displays the archetypical dome-and-keel pattern, the Northern Kaapvaal, in contrast, features regular vertical foliations associated with intense anatectic deformation. Despite their apparently contrasting map patterns, common characters are present in both:

- Both domains exhibit several tectonic events (different in both regions) lacking features typically found within classical collisional domains. In each case, the events cover a 200-300 Ma time range, evidencing long-lived deformation.
- Deformation rate is weak within both domains certainly because of the association with magmatism and/or melting. The Northern Kaapvaal domain exhibits structures strongly associated and/or controlled by in situ melting. At Barberton, rigid basement domains are separated by zones of magmatic injection rather than classical tectonic contacts.
- Drastic mechanical changes are observed through time in both regions. This is particularly evident in the Northern Kaapvaal that, despite it corresponds to deeper structural levels, shows brittle deformation associated to the latest anatectic events.

We propose that the features of both regions are understood in the context of the deformation of hot and buoyant crust subjected to external strain, and thus can be characteristics of the deformation model of an Archean continental crust.

Deposition of the Palaeoproterozoic Hotazel BIF-Mn Formation in a stratified oceanic basin during a highly transitional period in Earth's history.

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The 2.4Ga Hotazel Formation is a cyclically interlayered sequence of banded iron formation (BIF) and manganese-rich sedimentary rock at the uppermost part of the Neoarchaean-Palaeoproterozoic Transvaal Supergroup in South Africa. It represents an unusual stratigraphic association in the context of the origin of BIF and the evolution of oxygen and life in the early Earth and hence bears special relevance to the environmental conditions and processes characterizing the period leading up to the Great Oxidation Event (GOE) at ca. 2.3Ga. The mineral assemblages that characterize the Hotazel rocks are dominated by carbonate, silicate and oxide minerals which are traditionally interpreted as predominantly diagenetic in origin, particularly the carbonates. By contrast, primary mineral assemblages are inferred to have been dominated by ferric oxyhydroxides and tetravalent manganese oxides which show no preservation in the rocks and consequently hinder reconstruction of environmental conditions during sedimentation.

Here, we revisit the Hotazel succession with focus on its bulk-rock and carbonate-specific mineralogical, geochemical and stable isotope (C, Fe) composition, by applying for the first time a high-resolution stratigraphic approach to sampling and analysis. Our main aim is to constrain as far as possible the precursor mineralogy to the Fe- and Mn-rich facies in the Hotazel strata in order to unravel the redox conditions behind the massive cyclic deposition of Fe and Mn at the onset of the GOE.

Our carbonate-specific results question traditional diagenetic models for the development of the carbonate fraction of the rocks and instead place the origin of much of the present mineralogy to water-column processes in a stratified basin characterized by successive redox pathways with changing water depth. These pathways exploited a series of thermodynamically predictable electron acceptors for organic carbon recycling which include – probably for the first time in Earth history – aqueous Mn(III) and O2 as electron acceptors for the oxidation of both Fe(II) and organic carbon. The emergence of Mn(III) was also critical for the development of a Mn redox shuttle which led to effective water-column stratification between aqueous Mn and Fe in the depositional basin.

We conclude that the first-ever oxidation of Mn(II) to Mn(III) as recorded in the Hotazel Formation, must be a fundamentally diagnostic step in the redox evolution of the oceans and atmosphere in the lead-up to the GOE.

Depositional Environments of the A And B Seams, Ermelo Coalfield: An Organic Geochemistry, Palynology and Petrology Investigation

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The depositional environment of South African coal deposits has been studied extensively, generally using traditional analytical methods and occasionally, palynology and detailed coal petrography. Organic geochemistry studies, such as biomarker geochemistry and stable isotopes, have been limited despite their usefulness in understanding depositional environments. The overall aim of the study is to investigate the formation of inertinite macerals in Ermelo and Waterberg coals with consideration of depositional environments using geochemical techniques, to further understand the developmental pathways of inertinite, the dominant maceral group in South African coals. The study makes use of the following analytical techniques: stable isotopes (δ13C and δ15N), biomarkers, palynology, in addition to organic petrography, proximate and ultimate analyses. Sixteen (16) Ermelo coal samples (A and B Seams, South Africa) were sampled from a drill core based on changes in lithotypes. Organic petrology, palynology, and biomarker geochemistry analyses. The petrographic data shows bituminous coals with high mineral content, dominated by inertodetrinite. Bisaccate and bisaccate-striate pollen are the dominant palynomorphs. Overall biomarker patterns are comparable for all samples, thus indicating a similar coal origin. Pristane/phytane ratios indicate an oxic depositional environment, which is corroborated by the abundance of inertinite in the coals. Input by terrestrial plants is also suggested by the n-alkane parameters; steranes and diterpenes were absent. Water level fluctuations were also determined based on the biomarker parameters, supported by the changing maceral composition through the sequence. Stable isotope data showed a warming climate during the formation of the Ermelo coal deposit, as well as charring of organic matter resulting in inertinite formation. Furthermore, carbon isotopic data indicates changing water levels, specifically, the positive shifts which terminate each seam (and/or parting thereof), probably related to flooding. The data from the Ermelo Coalfield will be compared to biomarker and stable isotopic data for the Waterberg coals. The study contributes the first stratigraphically constrained biomarker and stable isotopic data for the Ermelo and Waterberg coalfields.

Keywords: Palaeo-depositional environment, Palynology, Biomarkers, Stable Isotopes, Inertodetrinite, Ermelo Coalfield, Waterberg Coalfield.

Developing a Mine Waste Atlas for the Northern Cape Province, South Africa

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The Northern Cape province played an important role in the South African economy since the 19th century through copper mining. The legacy of past mining practices includes numerous derelict and abandoned mines including open shafts, tailings dumps, pits and mine infrastructure scattered across the Namaqualand region (Cornellissen, 2019). Currently it is primarily mined for iron, copper-lead-zinc, manganese, diamonds, but the province has vast mining prospects for the future given that it hosts more than half of the critical metals/materials needed to be mined to achieve low-carbon alternatives to fossil fuel-based technologies. Another area of interest to the mining industry has been the Witwatersrand basin which is the world's largest known gold deposit and has been subject to extensive mining over the past one hundred years and generated over 6 billion tons of waste material in the form of tailings that are scattered across densely populated areas in Johannesburg. Despite the gold industry's contribution to the economy, it is also a key example of the negative impacts waste has on the surrounding environment and communities (Sibanda and Broadhurst, 2018). In alignment with striving towards the United Nation's Sustainable Development Goals, it is imperative that potential mining boom areas like the Northern Cape consider managing mine waste soon to avoid waste crises like the one associated with the Witwatersrand deposit. Therefore, this research focuses on the development of a mine waste atlas using spatial analysis techniques coupled with deep learning tools available in ArcGIS Pro which consumes models that have been trained to detect specific features in third-party deep learning framework, such as TensorFlow, CNTK, PyTorch and output features or class maps. This will be used to assess the current mine waste conditions in the province based on the following characteristics: location, area size (height above ground, size of the footprint), elevation, vegetation cover, erosion status and visible tailings spills onto neighbouring areas. This can be incorporated with settlement information (roads, bridges, housing, and agriculture), administrative boundaries and hydrology. The identification of possible pathways connecting pollution sources to the human population through rivers, irrigation, aquifers or windblown dust will also be investigated. This research will assist in creating a basis upon which further investigations can rely on to prevent and mitigate the negative effects mine waste poses to the environment and surrounding communities, as well as act as means of monitoring to aid compliance and safety in mining regions across the country.

Development of the Barberton Greenstone Belt (BGB): an alternative to plume and subduction models

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Insights into the origin of Archaean greenstone belts can be gained from their comparatively less-studied ultramafic-mafic layered complexes. In the Barberton Greenstone Belt (BGB), at least 27 such complexes are spatially associated with the supracrustal succession[1]. We constrain the origin of the Barberton Greenstone Belt (BGB) using new trace element data from one of the layered bodies, the Stolzburg Complex (SC)[2], together with published data from the Pioneer Complex and Komati Formation.

The chondritic Al_2O_3/TiO_2 ~ 22 and Nb/Ta ~ 17 as well as the low (La/Yb)[illegible] ratio of 1.5 suggest that the SC parental magma was not affected by crustal contamination, indicating development in an oceanic setting. Besides its light REEs enrichment, the source of the SC parental magma is shown to have been similar to the Primitive Mantle (PM) model composition. The flat heavy REEs pattern and chondritic Zr/Y and Al_2O_3/TiO_2 ratios displayed by the SC rocks suggest that the parental magma was generated through partial melting of a mantle source with no garnet in the restite. The Al-undepleted SC parental magma is envisaged to have formed through high degree partial melting of an undepleted/ or unfractionated mantle source, where garnet was completely consumed. The negative Nb-Ta anomaly exhibited by the SC rocks is attributed to either fractionation by an unknown high-pressure phase retained in the restite during partial melting or segregation of these elements from the silicate melt phase by an exsolved metallic liquid phase.

The geochemical aspects of the SC (and associated rocks of the BGB) are inconsistent with an origin similar to that in Phanerozoic geodynamic settings. An alternative setting is proposed, where the SC parental magma is envisaged to have formed as an impact melt. Accordingly, the development of the Barberton Greenstone Belt is ascribed to bolide impact events in the early Earth. It follows that cratonic roots and TTG suites too owe their origins to bolide impact settings and not endogenic processes as proposed in previously published studies.

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Diamond growth and resorption morphologies observed in situ using 3D X-ray tomography of diamondiferous eclogite xenoliths

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Diamonds, recovered as xenocrysts from kimberlites, predominantly form as metasomatic phases in the sub-continental lithospheric mantle (SCLM). Cathodoluminescence studies of euhedral diamonds reveal tree-ring like growth and resorption textures in diamonds, indicating complex histories in the mantle. Furthermore, en route to the surface diamonds are unstable in the host kimberlite and can become highly resorbed losing up to 50% of their original weight. Discriminating mantle vs. kimberlite resorption events, however, is challenging due to the rarity and the difficulty in making thin sections of diamondiferous rocks. Here we use X-ray computed tomography to create 3D models of exceptionally rare diamondiferous mantle xenoliths (n=14) from the Newlands and Excelsior Group II kimberlites (aka Kaapvaal lamproite). This allows us to look through the silicate phases of the host rock and observe the morphology and spatial relationship of diamonds in situ.

Diamond abundances range within the xenolith suite from single diamonds to samples with >50 diamonds. Both euhedral and resorbed diamonds are observed. Euhedral diamonds are all step-faced octahedra whereas flat-faced octahedra are notably absent. Step-faced octahedral diamonds are the result of growth events with multiple nucleation centres and different growth modes producing aggregated clusters (e.g., Fedortchouk et al., 2022). Diamonds in the xenoliths are commonly aligned forming distinct diamond-rich veins representing channelised fluid flow and diamond growth related to infiltrating metasomatic fluids. Octahedra exposed at the edges of the xenoliths generally do not show signs of significant resorption indicating that kimberlite-related resorption is not affecting these diamonds. In contrast, several samples have a diamond population characterised by rounded highly resorbed morphologies, indicating significant resorption in situ within the mantle rather than en route to the surface. Several samples have multiple populations of diamonds with both euhedral and resorbed morphologies observed implying complex growth and resorption on a small-scale. Thus, in situ observations clearly show multiple diamond growth and resorption events occurring on a cm scale indicating complex growth histories during their residence in the SCLM and formation during multiple metasomatic events.

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Diamonds delivered to the Atlantic Coast: are 3 billion carats still valid?

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In the early 1900s diamonds were discovered along the Atlantic coast of southern Africa in a range of Cainozoic sedimentary deposits. Ever since different theories have been were proposed about its source, such as offshore volcanoes, diamondiferous kimberlites in Namaqualand, Pre-Mesozoic sinks such as the Ventersdorp, Nama and Cape Supergroups and the Dwyka Group or a combination thereof. However, the most geologically accepted and now well-established explanation is that the diamonds were derived from Cretaceous primary sources on the Kaapvaal Craton. Released from the kimberlites through erosion, the diamonds reached the Atlantic Coast via a diverse transport system dominated by the palaeo- and recent Orange/Vaal drainage network. Since breakup these rivers have experienced significant reorganisation with the Orange River delivering diamonds to the Atlantic Coast at different positions along the coastal tract. In the early 1970s the first attempt was made to quantify the amount of diamonds that were eroded from inland kimberlites since their emplacement. An estimate of 3 Bcts became the baseline figure. Later this was adjusted to well over 1.5 Bcts to allow for the loss of many poor-quality diamonds that were destroyed during river transport.

Advances in kimberlite geology laid the foundation of a more complete kimberlite model, and new geochemical and geochronological techniques identified two main groups of Mesozoic kimberlites, each with different age ranges and erosion histories. Although diamonds supplied by pre-Karoo kimberlites of Cambrian, Mesoproterozoic and possibly even Archaean age, is an additional complication, most of the Atlantic Coast diamonds are believed to have been released from Mesozoic kimberlites. Using a combination of new techniques, the geomorphology and erosion rates of southern Africa are better appreciated to develop a more robust kimberlite erosion model. These techniques include 1) detailed analysis of crustal xenoliths in kimberlites to assess lost stratigraphy, 2) low-temperature thermochronometry techniques (apatite fission track and apatite (U-Th)/He)) to estimate levels of cooling/denudation and 3) accurately defined post-Gondwana offshore successions identified during the oil and gas exploration. This indicates that the initial estimates of 3 Bcts released by the primary sources in the cratonic hinterland is considered too high by at least one third. Diamonds therefore delivered to the Atlantic Coast would be even less taking into account diamond loss during river transport.

Dinosaur Body Size Evolution across the Triassic-Jurassic Boundary: Insights from South Africa's Elliot Formation

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The End-Triassic mass Extinction event (ETE) took place c. 201 Ma ago and was triggered by the breakup of the supercontinent Pangaea (1). The Elliot Formation in South Africa's main Karoo Basin is one of the few continental strata with a rich vertebrate fossil record that spans the ETE (2). Currently, the ETE is hypothesized to lie between the litho- and biostratigraphically distinct lower Elliot (lEF) and upper Elliot (uEF) formations (2). Ecosystems upheavals from mass extinction events like the ETE may be captured by ecological proxies such as animal body size, e.g., the "Lilliput effect" where extinctions select for smaller body sizes (3). To examine these effects, we investigated the body-size distribution of dinosaurs across the Elliot Formation by assembling a skeletal measurement of 373 vertebrate specimens (114 from the lEF, 253 from the uEF) from 20 genera. We also collated metadata on geographic occurrences, osteological representation and Taphonomic properties. We inferred masses of individual specimens using skeletal scaling methods, assessed geographic fossil collection biases using spatial autocorrelation metrics, and tested for taphonomic biases. Body-size distribution is generally similar across the Elliot Formation, with more small-bodied than large-bodied taxa being present throughout. However, lEF faunas have lower body-size maxima (notably the ~ 500 kg bipedal Massospondylus carinatus) and maxima (the 12-tonne quadruped Ledumahadi mafube) are present. Dinosaur collections in the Elliot Formation are spatially autocorrelated, with some clustering of localities that bear fossils of similar body mass. Our results find no support for a "Lilliput effect" in sauropodomorphs after the ETE, suggesting either that sauropodomorphs were unaffected by it or rebounded rapidly. They also counter anecdotal statements in the literature suggesting that lEF taxa are larger than the uEF taxa, and that preservational style reflects temporal changes in palaeoenvironments.

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Downwelling dense mantle residues generates mid-ocean-ridge hotspots and magma-rich continental breakup: Application to the Karoo large igneous province

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The geodynamic origin of melting anomalies found at the surface, often referred to as "hotspots," is classically attributed to mantle plume processes. The distribution of hotspots along mid-ocean-ridge spreading systems around the globe, however, questions the universal validity of this concept. Here, the preferential association of hotspots with slow- to intermediate-spreading centres and not fast-spreading centres, an observation contrary to the expected effect of ridge suction forces on upwelling mantle plumes, is explained by a new mechanism for producing melting anomalies at shallow (< ~3 GPa) depths. By combining the effects of both chemical and thermal density changes during partial melting of the mantle (using appropriate latent heat and depth-dependent thermal expansivity parameters), we find that mantle residues experience an overall instantaneous increase in density when melting occurs at < ~3 GPa. This controversial finding is due to thermal contraction of material during melting, which outweighs the chemical buoyancy due to melting at shallow pressures (where thermal expansivities are highest). These dense mantle residues are likely to locally sink beneath spreading centres if ridge suction forces are modest, thus driving an increase in the flow of fertile mantle through the melting window and increasing magmatic production. This leads us to question our understanding of sub–spreading centre dynamics, where we now suggest a portion of locally inverted mantle flow results in hotspots. Such inverted flow presents an alternative mechanism to the upwelling of hot mantle plumes for the generation of excess melt at near-ridge hotspots and the genesis of large igneous provinces during continental breakup, i.e., dense downwelling of mantle residue locally increasing the flow of fertile mantle through the melting window. Near-ridge hotspots and large igneous provinces, therefore, may not require the elevated temperatures commonly invoked to account for excess melting. We model the development of the Karoo magma-rich margin using geodynamic numerical models and find a close resemblance of the modelled volcanic crustal thicknesses produced to observations from magma-rich margins.

Dynamics of mantle melting at LIPs

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A feature of many LIPs is the early emplacement of volcanic traps, usually made of sub-horizontal mafic lava flows emplaced via fissure volcanism (dyking) in the upper levels of oceanic or continental lithosphere. Typically, flows and dykes range in thickness from 1 to 10 m. Both total volumes and magma production rates are commonly large – hundreds of thousands of km3 and 1 km3/y. In most cases (e.g. Afar, Deccan, NAIP – the North Atlantic Igneous Province), no significant tectonic activation is coeval with trap-emplacement apart from dilatation through dyking and localized crustal extension related to central volcanoes. The regional ⍰ stretching factor coeval with trap-emplacement is thus close to 1. This makes the cause of trap-related sub-lithospheric mantle melting enigmatic.

A combination of geological observations, physics and numerical modelling may help solve this issue without the need of a conceptual model. In the NAIP most of the Paleocene traps were fed by tholeiitic and alkaline magma that was erupted from dykes. Most (if not all) of those dykes were injected laterally from large localized systems of gabbroic magma chambers in the continental crust. Those chambers were the roots of large central volcanoes underlain by complex networks of gabbroic cone-sheets and differentiated felsic/acidic intrusions forming ring-dykes or small plutonic bodies. The locations of those past igneous centers is easy to map using gravity and magnetic charts. Some, but not all, are clearly located along inherited lithospheric discontinuities.

A major conclusion from this observation is that sub-lithospheric melting during trap emplacement is (1) not homogeneous, and (2) partly controlled by lithospheric structural inheritance. In addition, the spacing between the igneous centers away from discontinuities increases linearly with lithosphere thickness. This observation, and the geochemistry of lavas, strongly suggest that igneous centers were fed by sub-adiabatic melting at the top of small-scale Rayleigh-Bernard instabilities developing at the lithosphere-asthenosphere transition. Modelling shows that T- and P-dependent mantle viscosity naturally encourages such small-scale convection regardless of the geodynamical context. This robust suggestion of inhomogeneous melting of sub-lithospheric mantle to account for volcanic traps also applies when LIP-lithosphere breaks up and volcanic passive margins form.

The puzzle of the origin of LIPs could be reduced to one simple question: what are the factors, apart from a progressive or sudden heat increase, that can accelerate the small-scale convection below plates?

Early Jurassic Rainbow Nation: diverse bipedal and quadrupedal theropod and ornithischian dinosaur trackways (Makhosi, Lesotho)

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The Triassic – Jurassic records a crucial period in Earth's history, marked by devastating end-Triassic mass extinction events and a post-extinction recovery of palaeoecosystems which gave rise to the dominance of dinosaurs throughout the Mesozoic. The Upper Triassic – Lower Jurassic upper Stormberg Group (main Karoo Basin), which preserves a plethora of dinosaur body and trace fossils, is one of a few extensive continental deposits that can offer insights into this vital time in dinosaur history. Historically, the trace fossil record was neglected and grossly understudied, but a recent rejuvenation in ichnological research has shown that fossil tracks can contribute to our understanding of Gondwanadian palaeodiversity, palaeoecology and evolutionary trends.

Here, we describe in detail for the first time, a diverse Early Jurassic dinosaur track assemblage near Makhosi, Roma (Lesotho) briefly mentioned in a short report[1]. Over 30 true tracks, some still partially infilled with casts, are preserved on a ripple-marked, desiccated and bioturbated palaeosurface in the upper Elliot Formation. The tracks preserve varying degrees of anatomical fidelity and can be divided into two distinct morphotypes. Morphotype I tracks are elongate and have slender toes which taper to sharp claws and can be attributed to theropod trackmakers. These tracks are solely preserved as pes (foot) impressions, indicating that the trackmakers utilised bipedal locomotory styles. Morphotype I tracks have a maximum length of 46 cm, making them some of the largest theropod tracks preserved in southern Africa. Morphotype II tracks are wider than long, have robust, rounded toes with a wide splay, and can be attributed to ornithischian trackmakers. These tracks are preserved either as pes impressions or as manus-pes (hand-foot) pairs, indicating that the ornithischian trackmakers used a combination of bipedal and quadrupedal locomotory styles.

The findings at Makhosi support that, following the end-Triassic mass extinction events, there was an increase in dinosaur diversity and body size in Gondwana, which is congruent with global observations. Furthermore, Morphotype II tracks preserve insights into ornithischian pes morphology and locomotory styles, which is especially significant considering the sparse record of ornithischian traces from the Early Jurassic of southern Africa.

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Early Pleistocene habitat change at Collection Area 13 in the northeastern Turkana Basin, Kenya

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The lithological sequence of the northeastern Turkana Basin, in northern Kenya, known as the Koobi Fora Formation, represents an extensive Plio-Pleistocene volcanoclastic sequence associated with an abundant fossil faunal assemblage. The volcanic ash horizons in this sequence provide a chronostratigraphic framework for contextualising biological and behavioural human evolution. However, these investigations may be limited due to the lithologically diverse sequences and spatially limited outcrop, even in instances where the sequence is constrained by stratigraphically adjacent ashes. In some instances, the combination of good preservation with extensive outcrop (both vertically and laterally) can provide an opportunity to conduct detailed investigations; this is the case in the collection Area 13, a collecting area that has produced early Homo fossils, including very early Homo erectus (KNM-ER 2598 fossil). Through extensive mapping, lithological descriptions, petrographic descriptions and faunal studies, we propose a new sedimentary facies analysis for this area. We report a hetereolithic lithological succession across the area, representing sub-environments associated with a near lake-shore setting, as well as deltaic lobes being fed by E-SE flowing rivers. To the eastern region of the collection area, sub-aerial deposits occur, which include an ox-box lake habituated by siliceous freshwater megascleres sponges. To the west, we find a subaqueous setting, with fine sediments interlaminated with poorly developed bioclastic sandstones. We propose NW-SE trending a palaeo-shoreline which outlines the extent of the hominin and their interaction with this environment. Finally, we combine all our observations into a sequence stratigraphic analysis of contemporary deposits [using the KBS tuff (1.87 Ma) as a boundary surface] across the sub-basin, which reveals the final stages of a lake transgression in which these hominins and associated fauna lived in. This geological study provides a rare window in hominin habitat palaeo-reconstruction by placing it in a high spatio-temporal context that has previously been limited.

Earth's oldest (>3,6 Ga) high-grade BIF-hosted iron ore deposit, Aridongri Mine, Bastar Craton, India

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High-grade iron ore deposits (>60 wt% of Fe) occur mainly in Precambrian banded iron formations (BIFs). The enrichment of BIF with Fe-oxides at the expense of silica is the predominant ore forming process; it is due to hydrothermal or supergene alteration - or a combination of both. The supergene and supergene-modified hydrothermal deposits are all composed of hematite and all indications are that they formed post GOE in association with lateritic weathering profiles. In contrast, high-grade BIF-hosted hydrothermal deposits are structurally controlled pinching out upwards in BIF host rocks with hematite and/or magnetite ores present.

Here we report on a rather unique hydrothermal high-grade BIF-hosted magnetite ore body, with a resource of 15 million tons averaging 61 wt % Fe, hosted by BIF and exploited at the Aridongri Iron Ore Mine near Dalli-Rajhara on the Archean Bastar Craton of central India. It is unique in the sense that our investigations indicated it to be at least late Eoarchean in age making it the World's oldest known iron ore deposit. Furthermore the iron formation host rock, that must be older, has experienced only low-grade metamorphism and probably represents the best-preserved example of Eoarchean iron formation in the world.

The deposit is situated in an enclave of steeply westward dipping oxide facies BIF and quartz-muscovite schist, some 8,5 km long along strike and 1,4 km wide, surrounded by 3.6 Ga TTG gneisses and true granites in the core of the Bastar Craton. The ore body is intruded by easterly and northerly trending granite dykes comprising two age populations. The older generation, containing xenoliths of magnetite ore, is pink in colour and yields well defined SHRIMP and ICDP U-Pb zircon ages of ~3,6 Ga. The younger generation is light grey in colour and yields U-Pb zircon ages around 2,7 Ga. The entire succession is crosscut by a younger, northwest-southeast trending Paleoproterozoic diabase dyke swarm.

At depth, in the open pit of the mine, the ore is composed of coarse grained magnetite that has been partly transformed to martite closer to surface. Adjacent to the younger 2,7 Ga granite dykes retrograde metamorphism led to the development of large specularite euhedra in the magnetite ore. Next to a prominent younger diabase dyke highly schistose specularitic ore is developed. Identification of this ore deposit as being Eoarchean in age opens up the exploration potential for similar deposits in very early Archean BIF successions.

Emplacement dynamics of impact melt dikes: evidence from the Lesutoskraal Pavement, Vredefort, South Africa, derived from high-resolution unmanned aerial vehicle orthophotography

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Hypervelocity impacts of large meteorites with rocky planetary bodies generate voluminous melt sheets, which feed impact melt dikes in the underlying crust, such as the granophyre dikes of the Vredefort Impact Structure (South Africa). The granophyre dikes extend for several kilometers but are only a few meters wide. Impact melt dikes are emplaced over 105 years after the impact [1], when the melt sheet is above the liquidus and flows into fractures below the crater floor. Such fractures open progressively, and the Vredefort granophyre dikes have been shown to form in at least two phases: 1) an older intermediate composition, and 2) a younger mafic composition [1]. The emplacement dynamics are not well constrained, although it is known that the primary crystallization took place over a narrow temperature range, from 1150°C to 1000°C [2]. Furthermore, the melt entrained clasts from adjacent crustal material as the melt was rapidly and turbulently emplaced [3]. At the Daskop Granophyre Dike, clasts are preferentially grouped along the southern margin.

Here, we present an analysis of the Lesutoskraal Granophyre Dike "pavement", which is a polished exposure of ca. 20 x 5 meters. The contacts with the host granite are preserved on both margins. We generated a high resolution orthophotograph at 0.412 millimeter/pixel, to enable mapping of 1933 clasts and 127 fractures. Clasts are preferentially located along the dike's northern margin, with long axes parallel to the dike's margins. Fractures are classified into two populations: 1) large, central fractures oriented parallel to dike margins, and 2) smaller sub-parallel fractures oriented perpendicular to dike margins. Cooling joints at the host rock contact are clearly expressed.

The results show the preferential clustering of clasts, consistent with the turbulent flow model [3]. Cooling of the melt caused fractures to preferentially occur in the central portion of the dike which enabled and directed younger melt emplacement. The high resolution orthophotography presented here showcases a valuable methodology to use unmanned aerial vehicles to map features spatially expressed across areas as small as several millimeters.

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Energy Transition and Southern Africa's potential in raw material supply chains

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South Africa's mining economy has been underpinned by major global markets such as gold (financial), coal (energy), PGMs (automotive), iron-manganese-chromium (steel and alloys), and various others. Since 2000, one of the key trends for large-scale raw material demand has been the growth of China's steel industry and the associated raw materials, in which South Africa has played a major role.

The latest global trends are switching the focus from our carbon economy to the transition of energy sources, with regard to meeting climate-related emission goals. One of the major raw material impactors within this narrative has been electric vehicles (EVs). EVs require a completely new basket of raw materials compared to conventional internal combustion engine (ICE) vehicles, not only for their onboard technology (light-weighting, batteries, e-motors, etc.) but also for the energy grid infrastructure that is required to support the transition of the automotive network to a non-carbon-fuel energy source.

Several of the raw materials required for energy transition technologies to meet their targets have a relatively low demand base and a ramp-up in supply is required to meet demand (e.g. lithium, rare earths), while others have well-established demand sectors where supply chains will compete for better margins (e.g. nickel and manganese). China is once again setting the pace for raw material demand, this time to produce energy transition technologies critical for the developed world to meet its climate targets.

Outside of China, supply risk (criticality) to support energy transition technologies is at the top of government agendas and strategic alliances are being formed to secure sustainable and ethically sourced supply chains. Canada and Australia as resource-rich nations are already ahead in developing critical mineral strategies, looking to capitalise on growing investments in new-energy technologies and their raw material supply chains. With opportunities from all major economies looking to secure supply, what role can Southern Africa play?

Establishing an effective Powder X-Ray Diffraction technique for accurate quantitative characterisation of complex multi-phase industrial rocks: Implications of Mineral Carbonation in kimberlite tailings and beyond

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Abstract:

Kimberlites have relatively higher carbon sequestration potential since they comprise accessible phyllosilicate minerals that are highly reactive with atmospheric CO2 [1]. To conduct a thorough valuation of these kimberlite clay minerals' carbon sequestration potential and the extent of their reactivity, on an industrial level, requires they be thoroughly characterised. X-Ray Diffraction (XRD) provides a diffraction pattern and relative intensities because of the specific structural manifestations (at an atomic level) of the constituent crystals. Materials with grains of preferred orientation result in weak wavelength detection. In contrast, amorphous materials produce indistinguishable X-ray diffractions [2]. Hence, these materials are displayed as broad background peaks in the diffractogram, with no precise crystallographic information.

This study is conducted on six blue ground kimberlite samples collected from Cullinan Diamond Mine with two main aspects of sample preparation. (1) Evaluating different sample mounting procedures to determine which one promotes random orientation for effective XRD/Rietveld refinement analysis and (2) preparation of artificial kimberlite samples against which all quantitative analyses conducted on the natural samples will be compared. Hitherto, each sample preliminary XRF and standard qualitative XRD results denote the predominance of smectite and serpentine. Due to isomorphic substitution, the former possesses water absorption tendencies resulting in polytypism. Conversely, serpentine experiences turbostratic disorder, hence the preferred orientation.

The results from these pre-analyses will inform the preparation of artificial samples for each natural kimberlite sample. Pawley/internal standard method, a modified Rietveld refinement method, uses a fitting approach independent of diffraction patterns of ideal structures and is suggested by recent research [3] to have a high capability of enhancing the characterisation of clay minerals.

Conducting the XRD and modified Rietveld method should yield a negligible difference between the observed and calculated reflection intensities at all locations of the produced XRD pattern (R-value).

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Estimating Water Storage Change using GRACE satellite data and Machine Learning in Western Cape-South Africa

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1. The Western Cape is predicted to be most at-risk due to climate change driven by increasing temperatures. This vulnerability is exacerbated by high levels of poverty and a strong dependence on subsistence farming as well as rapid urbanization and the growth of informal settlements lacking basic infrastructure. It is clear that groundwater resources will play an important role in South Africa's future to understand change in groundwater level.

2. We will use global hydrology models (GLDAS) in conjunction with GRACE satellite gravity data to understand the terrestrial water storage (TWS) in the study area. The GLDAS model uses satellite and ground data for hydrological analysis and water resources modelling. These models compute surface and subsurface runoff, groundwater recharge, and river discharge and storage variations. We will use GLDAS model version 2.2 which includes atmospheric, precipitation and radiation fields, and starts from February 2003.

The latest released version of GRACE satellite data, namely CSR GRACE/GRACE-FO RL06 v02 mascon solution, will be downloaded from the Centre for Space Research at the University of Texas.

3. Changes in groundwater storage (GRACE-derived ΔGWS) will in turn be computed from the terrestrial water change (ΔTWS) after deducting contributions that arise from other terrestrial water stores including soil moisture storage (ΔSMS) and surface water storage (ΔSWS).

4. Water storage predictions will be checked against existing ground data. This data, in the form of depth to groundwater level measurements, will be extracted from the South African National Department of Water and Sanitation 2021.

5. The Terrestrial Water Storage (TWS) derived from the GRACE data will provide an integrated measure of the hydrological cycle relevant for monitoring and predicting hydrological events and making informed long-term water management decisions.

6. The calculate groundwater storage measurements will be integrated with machine learning to predict future groundwater level changes during the uncertainty of climate change. The gradient boosting decision tree (GBDT) models will be used to predict groundwater level changes. The approach will integrate numerous available satellite-based data, land surface models, and hydrogeological datasets to train, calibrate and test the GBDT model. The model will be used to predict monthly groundwater level, at 10km resolution in the aquifers of interest in the Western Cape. The approach will demonstrate the applicability of machine learning to generate local groundwater information to improve groundwater management.

Evaluation of machine learning algorithms for the classification of lithologies using geophysical logs

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With the availability of abundant large datasets, several machine learning-base methods have been widely adopted to assist geoscientists in efficient evaluation and interpretation of large datasets with the aim of improving the accuracy of lithologies identification and scientific results required for accurate objective decision-making structures. The aim of this research is to evaluate optimized machine learning-base methods for the automatic classification of lithologies based on the stratigraphic unit at the Formation level for the purpose of correlating the in-situ quartzites and mapping possible radioactive zones within the mining horizon. The area of study is the Moab Khotsong gold mine at the Klerksdorp gold field. The geological structure of Moab Khotsong is complex with series of faults and intrusives crosscutting meta-sedimentary (quartzite and siltstone) and igneous (basalt) rocks.

We used grid search and 10-fold cross-validations methods to obtain the optimal parameter sets for each supervised model to avoid overfitting and mitigate misclassification error. analyzed features and labelled datasets are multivariate downhole geophysical and geological logs from DSeis project boreholes at Moab Khotsong gold mine. The input log datasets were randomly splitted into a training and testing sets that made up 80% and 20% of the original datasets, respectively. The training set was used to build the models, while the testing set was used to evaluate and cross-validate the models. Supervised (support vector machine, random forest and gradient boosting decision trees) and unsupervised (k-means clustering) machine learning classification methods were utilized in our analysis. The classification performance of each model was validated using F1 scores and confusion matrix.

The results show that random forest and support vector machine classifiers produce highest effective lithologies classification performance in less computational time with F1 and accuracy scores over 0.80 in borehole A and 0.70 in borehole B during model testing and cross-validation. The results demonstrate that the logging features Vp, density and natural gamma-ray are the strongest contributors to lithologies classification. The outcome proposes that the quartzites at different stratigraphic positions in each borehole are similar and they are correlated across the DSeis boreholes.

This study illustrate that machine learning-base methods can help improve the work of data analysis in geosciences with accurate and automated outputs related to lithostratigraphic classification, correlation and indication of radioactive zones in gold deposits. Also, prospect of further mineral exploration can be improved by interpreting this study outputs with other geoscience data (e.g., geochemical datasets) using machine learning-base methods.

Evidence for temporal shifts in basaltic magma compositions in the Karoo dolerites, and the implications for the role of cumulus processes

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The magmatic phase at the termination of the development of the Karoo Basin, associated with continental break-up in the Jurassic, is characterized by an extensive and basin-wide episode of sill-emplacement. Chilled margins, as well as transects across selected sill intersections, were collected from sills intruding the Beaufort Group sedimentary rocks, roughly in the middle of Karoo stratigraphy. The sills intruding this stratigraphy in the central Karoo Basin are distinguished by the occurrence of relatively rare stacked saucer-shaped geometries. The sampled intersections are across the ascending limbs of the saucers, and have been interpreted1 as potentially representing composite sills, hosting both early-emplaced melts and later backwashed differentiates from the distal saucers.

The sampled chilled margins show phenocryst populations consistent with multiply-saturated melts, including plagioclase, clinopyroxene, and orthopyroxene. No olivine is preserved, although altered amorphous grains are present. The average major element composition of the chills corresponds to a quartz-normative leucogabbroic assemblage, and (therefore) Fo-absent. In phase diagrams, the compositions are plagioclase-first compositions. However, in the interiors of the thicker sills in this study, and in other deeper (basal Beaufort to Ecca-hosted) thicker sills elsewhere in the Eastern Cape (such as the Mt Ayliff intrusion) olivine is a prominent mineral phase. The olivine in the interiors of thicker sills is associated with elevated whole-rock MgO contents, and has been interpreted as representing accumulation of early olivines by density settling. Textural evidence suggests that the olivines have preceded plagioclase crystallization, but do not indicate cumulus processes. A localized texturally heterogeneous layered sequence which might suggest cumulus processes is interpreted as an autolith, and is spatially associated with a large (m-scale) country rock xenolith. Models involving early emplacement of a plagioclase-first gabbroic assemblage, followed by a backwashed residual differentiate, or the creation of a vertical pressure gradient across the sill to account for internal geochemical variations, are rejected, and a model involving a magma source changing from early evolved to a later, more primitive magma, is proposed.

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Evidence of localized hydromagmatic control on PGE distribution in the Merensky Reef, Bushveld Complex, South Africa

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The Merensky Reef has historically been treated as one of the classic natural examples for the evaluation of platinum group element (PGE) mineralization in layered mafic intrusions. However, in this context, it has been increasingly revealed a relatively complex system that was almost certainly open at virtually all stages of its evolution, rendering its interpretation much less straightforward than was initially perceived. In this study (1), the PGE ore mineralization zones and the intervening variably pegmatoidal rocks were sampled across wide-reef sections (>10 m), allowing for effectively high spatial resolution evaluation of PGE distribution across the reef.

Two sections from the Eland Mine in the western Bushveld have been compared, one with a bottom chromitite layer but no top one, and no texturally prominent pegmatoid, and the other section with no distinct chromitite layers, but a distinct pegmatoid underlying the top mineralized contact. Both sections are underlain and overlain by anorthositic rocks. The top and bottom contacts of each reef section show distinctly elevated PGE contents, as expected, although the enrichment factor associated with the chromitite layer is significantly higher than at the other three contacts. The mineralized contacts are enriched specifically in PPGE (the Pt-PGE) and in Au and Cu, as expected. Both the hangingwall and footwall rocks are depleted in IPGE (the Ir-PGE), but with the footwall rocks also exhibiting PPGE depletion. The PGE mineralization itself is dominated by equant PGE-sulphides (mainly as braggite) in the bottom contact mineralization, whereas at the top contact and in the intervening rocks, PGE-bismuthotellurides (e.g., merenskyite, moncheite), antimonides (e.g., stumpflite) and arsenides (e.g., sperrylite) are more prominent. Galena is also present throughout. These lower temperature PGE phases are also typically inequant, and are associated with small veinlets with hydrous greenschist facies silicate assemblages, plus quartz and chalcopyrite. Alteration of primary PGE-sulphides to rims of IPGE-non-sulphides is evident. Simple models of PGE distribution controlled by any one vertical process (gravity settling downwards, or fluid migration upwards) are rejected (although not dismissed). A model is developed in which the reef sensu lato was emplaced as a sill into an existing (semi-) crystalline pile, and PGE distribution subsequently driven by a combination of fluid-scavenging of PGE from around the contacts and reprecipitation at the contact horizons, and upwards fluid-facilitated PGE scavenging from the footwall.

Reference

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Evidence of reactive melt flow in the petrogenesis of the platiniferous Merensky Reef

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Fossilised layered mafic-ultramafic intrusions of the Proterozoic-Archean age are the main repositories of platinum-group elements (PGE) in the Earth's crust. The petrogenesis of the platiniferous Merensky Reef pegmatoids of the Bushveld Complex remains elusive. We present new petrological, major element mineral chemistry and in situ plagioclase 87Sr/86Sr isotopic data for the Merensky pegmatoids and its overlying "normal" pyroxenites from four drill cores spanning 10 km at Royal Bafokeng mine in the Western Bushveld. We use these data to show that the Merensky Reef was formed by reactive melt flow in a crystal mush.

There is evidence of dynamic recrystallisation (e.g., peritectic textures, orthopyroxene neoblasts and rotated orthopyroxene megacrysts) in the pegmatoidal pyroxenites of the Merensky Reef. Peritectic reactions are evident from resorbed olivine inclusions in orthopyroxene megacrysts and compositional peaks near the megacryst cores that define the reaction zones. The orthopyroxene neoblasts have compositions similar to the rims of the adjacent orthopyroxene megacrysts and typically exhibit minor reverse zoning. These, along with the orientation of clinopyroxene exsolution lamellae in the orthopyroxene megacrysts toward the neoblasts, are consistent with dynamic recrystallisation caused by melt flow.

There are regional (km-scale) variations in the major element and $^{87}Sr/^{86}Sr$ compositions of the mineral phases in the Merensky Reef. Orthopyroxene Mg# increases from northeast to southwest in the pegmatoids (i.e., away from the inferred magma feeder), whereas the Mg# of orthopyroxene remains constant in the hangingwall pyroxenites. An contents (mol %) of interstitial plagioclase are highly variable (35-85 mol % An) in the northeastern Merensky pegmatoids. This is consistent with inter- and intra-grain $^{87}Sr/^{86}Sr$ heterogeneity ($^{87}Sr/^{86}Sr$2.06Ga = 0.7070-0.7080). However, the range in plagioclase An content is much smaller (70-73%) in the southwestern pegmatoids and the range of $^{87}Sr/^{86}Sr$ heterogeneity is 0.001 lower ($^{87}Sr/^{86}Sr$ 2.06Ga = 0.7060-0.7070). Interstitial plagioclase of the Merensky hangingwall pyroxenite also shows strong inter- and intra-grain heterogeneity ($^{87}Sr/^{86}Sr$ 2.06Ga = 0.7063-0.7079) as well as along strike variations ($^{87}Sr/^{86}Sr$ 2.06Ga = 0.7072-0.7066).

Our detailed textural observations and regional chemical variations are consistent with the rejuvenation of the crystal mush by reactive melt flow. Reactive melt flow was channelized in proximity to the inferred feeder and was porous distally to the inferred feeder. This mode of magma emplacement in the Merensky Reef may have important implications for the origin of its PGE enrichment.

Evolution of an Early Jurassic desert system: erg dynamics and geochronology of the Clarens Formation, Karoo Supergroup, southern Africa

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The Lower Jurassic Clarens Formation represents the youngest sedimentary succession of the Stormberg Group in the Karoo Supergroup of southern Africa. The unit is dominated by thick to very thick beds of massive and very large to large-scale cross-bedded sandstones, which were interpreted as deposits of aeolian origin with intermittent wet conditions throughout. Its Early Jurassic age is deduced from the biostratigraphy and geochronology of the underlying Elliot Formation, and radioisotopic ages of the overlying Drakensberg Group. Despite extensive work on the sedimentary facies, a detailed understanding of small to large-scale processes still remain elusive, while a systematic regional geochronological framework has not yet been conducted. Utilising field-based facies analysis and U-Pb isotopic age dating of detrital zircons, this study confirms the dominance of massive and aeolian dune deposits and establishes a broad chronostratigraphic framework for the Clarens Formation. The spatiotemporal distribution of the facies can be explained by a typical zoned-erg depositional model controlled by short- and long-term drivers, where short-term water table fluctuations controlled the spatial expression of the lateral facies distribution, whereas vertical facies changes are attributable to erg expansion/ contraction dynamics through time. Maximum depositional ages suggest a Late Sinemurian age for the lower zone, an Early Pliensbachian age for the middle zone and a Late Pliensbachian age for the upper zone. This trend is particularly prevalent in the south of the basin, where these signals are incorporated into each zone, respectively, and towards the north and northeast, they appear in the subsequent younger zone, which may demonstrate that sediment was primarily supplied from the south and southwest towards the north and northeast. The reported facies distributions and geochronology therefore confirm the validity of the zonation of the Clarens Formation, which is consistent with climatic trends reported from the Tethyan margin of Gondwana during the Sinemurian and Pliensbachian. The results thus suggests that the temporal facies changes in the Clarens Formation in southern Gondwana resulted from global climatic fluctuations in the Early Jurassic.

Exceptional scarp preservation in SW Namibia reveals geological controls on large magnitude intraplate seismicity in southern Africa

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Namibia (and SW Africa in general) is considered a stable continental region (SCR) with a limited history of significant earthquakes. There are only a few instrumentally recorded >5 Mw events in the country and only one important palaeoseismic feature, the Hebron Fault, has been studied in detail. Here, we describe four previously unrecognised neotectonic fault scarps in southwest Namibia. These relatively straight, simple but segmented structures are 16–80 km long and have measured vertical separations of 0.7–10.2 m. We estimate that each is capable of producing earthquakes of Mw 6.4 or greater, an order of magnitude larger than anything instrumentally recorded in Namibia. Our results indicate that large earthquakes can and have occurred in the region despite limited cumulative displacement and there is strong evidence that some of these scarps were formed by repeated earthquakes. Comparison with aeromagnetic and geological maps reveal that the normal faults reactivate major crustal weaknesses that are orientated North-South and Northwest-Southeast, and perpendicular to the local gravitational potential energy gradient. The presence of these structures suggests that the maximum expected earthquake magnitude of the region, Mmax, is an order of magnitude greater than the largest recorded earthquake (5.4 Mw). These structures highlight the necessity of incorporating information from fault studies into probabilistic seismic hazard assessments in this region, in a similar way to other SCRs. The fact that such major structures have gone hitherto unrecorded suggests significant further research is needed to characterise these sources of hazard. The apparent cluster of large magnitude neotectonic earthquakes in the area may be related to the exceptional preservation potential of scarps rather than indicating an area of comparatively rapid deformation. If this interpretation is correct, then these scarps represent an important indication of the potential seismic hazard across the region, and the occurrence of infrequent large-magnitude seismicity on similar structures should be considered throughout southwestern Africa.

Exchange of dissolved Pb between Indian and Atlantic oceans: Role of Agulhas Current and atmospheric Pb input from South Africa

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The atmospheric emissions from continents determine lead (Pb) distribution in the global ocean. Being surrounded by coal-dependent developing nations, the Indian Ocean receives more anthropogenic Pb compared to the South Atlantic. In this study, using a temporal dataset of dissolved lead (dPb) from the subtropical oceans surrounding South Africa, we examine the exchange of dPb between the Indian and Atlantic Oceans quantitatively. Within the South Atlantic sector, the southeast Cape Basin shows an elevated surface dPb concentration (21-30 pmol kg-1) due to an additional supply from the Indian Ocean via the Agulhas Current (AC). We estimated up to 90% of the measured dPb in the Cape Basin was delivered through the AC. The contribution of Agulhas water in the South Atlantic increases from winter to summer, thus varying the dPb fluxes seasonally. In the Cape Basin, the temporal change in dPb in the AC-derived upper water was consistent with the change in atmospheric Pb emissions from South Africa. Together with the distribution and sources of Pb in aerosols, these details suggest that South African-origin atmospheric Pb contributes significantly to the Pb inventory of the Agulhas water, which is then transported to the South Atlantic and regulates the Cape Basin's dPb signature. This study emphasizes the importance of monitoring Pb emissions from Southern Africa to predict the delivery of dPb to the South Atlantic.

Exploring the Dinosaur Cave: palaeoecological implications of unique footprints in the Lower Jurassic Clarens Formation of the Maloti-Drakensberg

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Vertebrate tracks are considered rich archives of palaeoenvironmental and palaeoecological information, yet palaeontological attention in southern Africa has primarily focused on the vertebrate body fossils. This is despite the fact that the first fossil footprints ever reported in Sub-Saharan Africa were described as early as 1885 from the Lower Jurassic Clarens Formation at Morija in Lesotho. A cliff-forming sandstone-dominated succession across southern Africa, the Clarens Formation was deposited in the prevailing southern Gondwanan aeolian system from c. 195 to 183 Ma ago. The Formation preserves a diverse faunal record, including remains of sauropodomorphs, ornithischians and crocodylomorphs, but is still considered body fossil scarce. In contrast, fossil footprints are more abundantly preserved in the Clarens strata but are characterized by a low ichnodiversity, almost exclusively dominated by theropod tracks. Herein, we report the findings of a unique and diverse dinosaur track site from the Clarens Formation in the scenic Maloti-Drakensberg mountains of KwaZulu-Natal in eastern South Africa. The footprints are preserved as true tracks on sandstone blocks that are shielded from weathering in a rock shelter, aptly named 'Dinosaur Cave'. Over 60 tracks, comprising several trackways, were identified and assigned to five distinct morphotypes attributable to theropod, sauropodomorph and quadrupedal ornithischian trackmakers. Additionally, footprints of a large biped (track length ~39 cm) are tentatively assigned to a new ichnogenus and provisionally attributed to a large ornithischian, currently not represented in the skeletal record of the upper Karoo Supergroup in southern Africa. Although this new ichnogenus shares resemblance to other large ornithischian tracks from the Lower–Middle Jurassic of China and Poland, it lacks manus impressions and is much larger in comparison. Ultimately, the Dinosaur Cave footprint site not only presents a diverse dinosaur-dominated ecosystem but also provides new insight into the palaeogeographical and palaeoecological distribution and evolution of bipedal ornithischians in the Early Jurassic of southern Gondwana.

Extraction of metals from native plant species at Klein Letaba gold mine tailings, Limpopo Province, South Africa

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Background

This study focused on the Klein Letaba Tailings Dam which was the largest gold producer in the Giyani Greenstone Belt with an estimated yield of about 3 tons of gold. It revealed an abundance of metals such as Pb, Zn, Cu, As, Ni, Mn, Cr and Cd. The main focus of the study was to investigate the potential of metal extraction from native plant species growing on the mine tailings storage facility which could not be extracted by the mine using physical-chemical techniques.

Methodology

Fieldwork involved mapping of the plants (combretum imberbe, cynodon dactylon and sporobolus africanus) distributed on the storage facility and collection of both plants and tailings samples growing on the mine tailings. A total of 80 samples were randomly collected seasonally (summer and winter). The samples were analysed for metal concentration using inductively coupled plasma-optical emissions spectrometry (ICP-OES).

Key results

Klein Letaba gold mine tailings were found to be highly contaminated with metals such as nickel, lead, chromium, arsenic and zinc. Using the statistical analysis, the concentrations of nickel (Ni), lead (Pb), arsenic (As), chromium (Cr), zinc (Zn) and copper (Cu) were found to be high, with a maximum of 2049.3 ppm, 1885.7 ppm, 1275.7 ppm, 1271.3 ppm, 695.2 ppm and 139.8 ppm respectively. The minimum concentrations for the above-mentioned metals were as follows 458.1 ppm, 81.5 ppm, 98 ppm, 74.4 ppm, 27.8 ppm and 21.9 ppm respectively. The soil around the study area was contaminated with metals from the tailings. Combretum imberbe, Cynodon dactylon and Sporobolus africanus accumulated high concentrations of metals in the roots then followed by the leaf and stem. Lead (Pb) and chromium (Cr) were high in the roots, followed by the stem and the leaf.

Main conclusions

The expected outcome was to identify suitable plants that have the potential to extract metals from contaminated sites due to the abandoned storage facility which could not be recovered by the mine using physical and chemical techniques. This is an environmentally friendly remediation strategy for metal extraction and stabilisation of the gold mine tailings using native plants. Therefore, this remediation strategy will not only be applied in the studied site but can also be applied to other similar studies.

Facial variations of precious metal grade and tenor in the Waterberg Project ore-bearing units and their significance for models of ore formation

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The Waterberg Project magmatic sequence rests unconformably on granite-gneiss of the Southern Marginal Zone of the Limpopo Belt north of the Hout River Shear Zone. The succession is composed of basal Marginal pyroxenite sills, the Ultramafic Sequence (UmS), the Troctolite–Gabbronorite-Anorthosite sequence (TGA) and the Upper Zone. Platinum-group element (PGE)-Au-Cu and Ni sulphide mineralisation within the succession is confined to both the UmS and the upper portion of the TGA (the T Zone). This mineralisation is associated with blebby and disseminated chalcopyrite, pentlandite and pyrrhotite. Within the UmS, the mineralised interval varies from 3 to 100 m in thickness with grades occurring in both the lower feldspathic pyroxenite (FP) and the upper feldspathic harzburgite (FH). As for the T Zone, the highest-grade mineralisation is within the lower subzone (T2) gabbronorite, transgressing up-dip from west to east and along strike from SW to NE into the Lower Pegmatoidal Anorthosite (LPA).

The specific PGE to Au proportions, the associations with troctolite and leucogabbroic rocks as well as settings in the Main and Upper zone lithologies make Waterberg mineralization unique to the Bushveld Complex. On a base of 23 drillhole dataset, a 3D geological model was generated with PGE sulphide tenor and Cu/Pd spatial variations used to understand the ways of magma emplacement that likely control the distribution of magmatic facies and metal supplies in the ore-bearing units. Overall, no upward reduction in PGE tenor (PGE content in 100% sulphide) is revealed through the UmS. Instead, tenors are lower at the base of the UmS increasing upwards to higher values towards the top, implying that multiple UmS magma influxes were already rich in PGE-bearing sulphides when entering the resident magma chamber. Both the lateral PGE tenor and Cu/Pd variations favour a westerly/SW feeder zone for the UmS magma influxes. Some variability in both tenors and Cu/Pd trends within the T Zone favours a westerly/SW feeder zone with higher tenors in both T2 and the LPA. Unlike the UmS, there are higher levels of lateral anti-correlations between PGE and Au tenors implying that the anomalously high Au abundances observed within the T Zone were derived from a distinct source.

Fault-slip analysis of slickensides in a historical quarry supports post-impact crustal relaxation model for the Vredefort Impact Structure

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Deformation at deep crustal levels of large meteorite impact structures on rocky planetary bodies is poorly understood. Specifically, long-term crustal relaxation associated to impact-induced crustal thinning has limited supporting evidence, especially from observable structural geological features. Large meteorite impact structures on Earth are affected by post-impact processes which can obscure observation, such as burial by younger sediments at the 65 Ma Chicxulub impact structure (Mexico), tectonic deformation at the 1.85 Ga Sudbury Impact Structure (Canada), and significant erosion the 2.02 Ga Vredefort Impact Structure (South Africa), the latter also largely covered by grasslands.

The long-term crustal relaxation model purports that the upper crust will extend horizontally in response to progressive uplift which occurs over at least 103-104 years [1]. To test this model, available structural data can be interrogated to discern whether the principal orientations of extension and shortening are consistent between local areas and the regional model.

Here we present a fault-slip inversion using a population of slickensides measured in a small quarry in the central eastern portion of the Vredefort Impact Structure. Slickensides are found on both quarry granites (n=157) as well pseudotachylites (n=24), an in-situ melt from the impact. The total population of slickensides (n=181) as well as the two subsets underwent 6 fault-slip inversions, making use of both paleostress and strain inversion techniques. The inversions yielded NW-SE extension and vertical shortening of the exposed quarry rocks. A closer spread of inversion orientations was yielded from the inversion of slickensides from the pseudotachylite population compared to the granite and total populations.

Our principal strain orientations are consistent with an uplifting crust and horizontally extending upper crust, notably with respect to where the slickensides were measured in the Vredefort Impact Structure. The spread of principal strain orientations yielded from the inversions of the pseudotachylite population is age-constrained to after the pseudotachylite was emplaced which may relate to its smaller population size or suggest that the Vredefort Impact Structure was not deformed by other deformation processes.

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First high precision U/Pb age dates from the Cenomanian - Turonian of Central Utah: Implications for dating the Cenomanian-Turonian Boundary and development of the Greenhorn Seaway.

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Background

Early Late Cretaceous sediments of the Western Interior Basin of North America documents several cycles of volcanism, the peak transgression of the Greenhorn Cyclothem and higher atmospheric CO2 levels, which resulted in the Oceanic Anoxic Event 2 and a related progressive marine-based extinction corresponding with the Cenomanian-Turonian boundary. Historically, the resulting biostratigraphical and/or lithological features have been used to derive relative-age dates for major geological events during this time, with absolute age dating being supplemented recently to increase stratigraphic resolution.

Method

Two ash falls were sampled from the Northern Last Chance Desert, south of the Wasatch Plateau, Central Utah. The first ash fall, identified as tonstein TT1, is emplaced within the Naturita Sandstone and the second ash, TT4a, forms the underlying bentonitic layer of the TT4 doublet, within the Tununk Shale. A blended laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), chemical abrasion thermal ionisation mass spectrometry (CA-TIMS) and δ13C isotopic analysis was utilized for this study.

Key Results

Zircons recovered from these ashes produced a depositional age (DA) for the middle Naturita Sandstone (TT1) of 94.6 Ma ±0.027 and 94.01 Ma ±0.017 for the Tununk Shale (TT4a).

Main conclusions drawn from these results.

These results, the first U/Pb dates for this area, contribute to local stratigraphic resolution by associating TT1 with mollusc genera representative of the Sciponoceras gracile/ Euomphaloceras septemseriatum biozone (Cenomanian age) [1,2,3] and constraining TT4a to the Watinoceras coloradoense biozone by the proximity of key Turonian-aged ammonites within the Tununk Shale [1,2,4,].

The results also provide improvement in intra and interbasinal correlation, a marginally older, more constrained temporal range for the C-T boundary and details the local Greenhorn Seaway development.

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Fluid induced formation of coronal multilayers of titanite,scapolite, garnet and amphibole within the amphibolite to granulite faciestransition: A petrological, geochemical and mass-balance approach

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In this study we focus on garnet corona textures formed around coronal multilayers in high-grade amphibolite to granulite facies meta- gabbroic anorthosites from south central Tanzania. Coronas form due to drastic changes in P-T conditions leading to instability of a given mineral assemblage and, consequently, to a change in the mineral paragenesis for a certain bulk rock composition. The main motivation from this study are the garnet corona textures, which grew around cornal multilayers of titanite, scapolite and amphibole under amphibolite to granulite facies conditions. Generally, a metastable magmatic core inside the corona, or either the coronal multlayers, is seperated from the surrounding rock forming minerals in the matrix. In contrast to previous investigations, we record in this study in a first stage the formation of isolatedgarnet nucleides during prograde isothermal compression, followed by a drop of isobaric heating and finally in a second stage the completion of the garnet coronas took place during isobaric cooling after reaching peak metamorphic conditions. The garnet corona forming reaction was triggered by an internal fluid flux released by the breakdown of a S and Cl bearing scapolite corona during prograde metamorphism. Three types of garnet coronas could be identified; (i) garnet corona around metastable magmatic ilmenite rimmed by a titanite corona, followed by a plagioclase and clinopyroxene/amphibole bearing “symplectite”, which is a product of the breakdown reaction of the former scapolite corona at low aH2O. (ii) garnet corona around original plagioclase and clinopyroxene, and (iii) garnet corona around metastable magmatic chalcopyrite, hematite and pyrite surrounded by a scapolite corona. Peak metamorphic conditions at ~800°C and ~12.8 kbar have been documented for the suggested “clockwise”P-T path. To get evidence of the main rock forming mineral reactions during high-grade granulite facies metamorphism, LaserICPMS analyes have been carried out on all rock forming minerals (LREE, HFSE andHREE), which confirms the existence of the suggested mineral reactions. A mass balance approach shows that the garnet coronas are formed to ~75% by theconsumption of minerals inside the garnet corona and consequently ~25% of thenecessary mass flux was delivered by minerals in the matrix.

Formation of continental crust during Bushveld magmatism

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High magnesium felsites erupted at the onset of Bushveld magmatism have compositions similar to continental crust (1). Covariations among Ti, Zr, Y, Lu and Hf show that the high magnesium felsites are coherently related to B1, B2 and B3 sills emplaced before the Rustenberg Layered Suite and establish amphibole fractionation as the control of the coherent relations. The boninitic B1 sills are amphibole free but compositionally similar preBushveld sills are amphibole rich (2,3). Basaltic B2 and B3 sills have REE patterns that indicate, respectively, clinopyroxene and orthopyroxene control. The protolith is a hybrid diapir of peridotite and pyroxenite that stalled at the base of the crust. B1 magma is a melt of hydrated peridotite. B2 and B3 magmas are cumulates from pyroxenitic magma which fractionated to produce the high magnesium felsites. Plumes do not melt pre-existing continental crust (1) instead, continental crust is the magmatic product of hybrid plumes.

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From grains to tracks: the role of substrate on the anatomical fidelity of dinosaur tracks (upper Stormberg Group, southern Africa).

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Footprints result from the interaction between the animal's foot and the sediment conditions in which the footprints are formed. For example, differences in sediment grain size (e.g., mud vs coarse-grained sand) and water content often cause dramatic variations in track morphology from high to extremely low anatomical fidelity. The upper Stormberg Group of the main Karoo Basin in South Africa and Lesotho is rich in Triassic–Jurassic dinosaur footprints, and the highly variable abundance and anatomical fidelity of the footprints between and within ichnosites are well documented. To evaluate the role of substrate on fossil footprints' anatomical fidelity in the upper Stormberg Group, we examined the petrographic properties (e.g., grain size, grain roundness, composition) of the host sedimentary rocks to complement the established macro-sedimentary observations and assessed the microbially induced sedimentary structures (MISS) preserved at selected ichnosites. Our petrographic analysis shows that from the Upper Triassic lower Elliot to the Lower Jurassic Clarens Formation the: (1) maximum and average grain size decreases; (2) grain roundness increases; (3) morphological quality increases (i.e., footprints have higher anatomical fidelity in substrates with finer, more rounded grains). In addition, ichnosites with MISS tend to preserve footprints in greater abundance as well as with higher anatomical fidelity. This is likely due to MISS binding and biostabilizing the sediment, aiding the consolidation of registered footprints thus positively influencing their anatomical fidelity, registration and preservation potential. The association of diverse MISS also increases up stratigraphy, playing a role in the observed anatomical fidelity preservation trends. Our observations suggest that finer grained, better rounded sands, coupled with cohesive substrates influenced by microbial activity, provide an ideal environment for footprint registration and preservation.

Garnet and pyroxene megacrysts, and their primary melt inclusions, from the Orapa and Letlhakane mines, Botswana.

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A total of 23 megacrysts of garnet (15), clinopyroxene (5) and orthopyroxene (3) were collected from the Old Recovery Tailings at Orapa mine. Orthopyroxenes are clear brownish-green enstatites (mg# 89-90) cut by serpentine-calcite veins along which the opx reacts to cpx and olivine. Melt pools are rare to absent, but in one case a larger melt pool contains euhedral phlogopite, spinels and a corroded olivine crystal in a serpentine matrix. Clinopyroxenes are chromian diopsides with 1.8-2.5 wt% Na2O. They are also veined and partly deformed into subgrains. Along the veins and subgrain boundaries, cpx acquires a porous texture, with cpx-II being lower in jadeite and higher in diopside component. The veins are filled with serpentine and locally calcite and carry small euhedral crystals of Mg-Al-chromite. One Cpx megacryst is intergown with large olivine. Others carry small inclusions of primary phlogopite or amoeboidal olivine, indicating that both minerals were part of the megacryst assemblage. Melt pools are dominated by calcite and cryptocrystalline serpentine in variable proportions and may also contain phlogopite and Mg-Al-chromite.

Garnet megacrysts are sufficient in number to allow a classification into two groups with different chemical trends: a Cr-poor group with a trend of Fe-Ti enrichment and a higher-Cr group. Ilmenite can occur as a primary inclusion in the first group, phlogopite, biotite and spinel in the second group. One garnet shows considerable chemical zonation. All megacrysts are extensively veined and most of them contain pools of former melt. Their content ranges from assemblages similar to the ones found in the pyroxene megacrysts (serpentine and subordinate calcite, often with euhedral spinel and phlogopite) to almost fully crystallized polymineralic assemblages comprised of olivine, orthopyroxene, clinopyroxene and amphibole in addition to spinel and biotite. Olivine, when present, is the first mineral to crystallize together with spinel, followed by orthopyroxene which partly resorbs the olivine, clinopyroxene and slightly sodic amphibole. All minerals are unusually Al-rich as a result of re-equilibration with garnet. Most spinels are strongly zoned, from Cr-rich cores to more aluminous rims. Decrepitation textures of the former melt pools, with outward-tapering veins, and the relatively coarse grain size of the polymineralic assemblage in the pools are taken as evidence that the pools are inclusions of primary megacryst magma that partly or largely crystallized before decrepitating when mobilized by kimberlite magmatism.

GCRF Mine Dust and Health Network: trans-disciplinary solutions for the emissions and impacts of mine dust.

Johanna RC von Holdt

The mining industry has the potential to be, and often is, a significant contributor to the economies of developing countries around the world. However, the activities associated with this industry often have significant impacts on the surrounding environment and local people. The extraction, transportation and downstream utilisation and processing of mineral resources have significant impacts on air quality, particularly in resource rich developing countries, such as those in southern Africa (i.e., South Africa, Namibia, Botswana, Zimbabwe, Zambia, and Mozambique). Mining-host and mining-affected communities are potentially exposed to increased air pollution resulting in more severe health outcomes due to the dispersion of particulate matter and gaseous emissions from mining operations and associated downstream activities. The impact on natural ecosystems can also be significant with soils, vegetation (including crops) and water resources negatively affected by emissions resulting in further indirect effects on communities. The extensive semi-arid to arid regions of southern Africa exacerbates particulate emissions and makes this region particularly vulnerable to the effects of climate change which may increase dust emission from drier mining operations and natural surfaces. Mining and associated activities can also have significant consequences for the well-being and socio-economic development of communities, often thousands of kms from the actual mine site. The diverse impacts of atmospheric emissions from mining and related industries are generally not well quantified and understood, or in some instances, simply lack the will and incentives to bring about improvements. To effect change requires an inter-disciplinary, multi-stakeholder approach due to the complexities involved. Our aim is to improve the socio-economic well-being, health, and environment of mining-affected communities. Achieving this aim necessitates investigations of the health and environmental effects, mitigation and rehabilitation, the influence of governance and legislation, the way we monitor and measure air pollution, the impact of emissions on socio-economic development and climate change considerations.

Generation of the Phalaborwa Complex, South Africa from Long-lived, High- δ18O Mantle?

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The 2060±2Ma Phalaborwa Complex is a pipe-like ultramafic to carbonatite series of intrusions. These produced a main pipe of pyroxenite, carbonatite and foskorite (olivine-apatite-magnetite-calcite) and many smaller syenite plugs around the pipe. The complex is the oldest known carbonatite in southern Africa and the only one known to host economic copper deposits. No detailed multi-mineral O- or H-isotope study has yet been published.

The range in δ18O values for all rock types in the Phalaborwa Complex is 2.24 to 18.3‰, but 90% of pyroxene and apatite have values within a 1.5‰ range. The δD values for Phalaborwa phlogopite range from -112 to -66‰. The δ18O values of baddeleyite (2.99±0.13‰, n=2), olivine (6.12±0.08‰, n=2), diopside (7.37±0.40‰, n=24), magnetite (3.46±0.75‰, n=8), apatite (6.37±0.57‰, n=14) and aegirine (6.39±0.65‰, n=10) are thought to be magmatic, with most plots of δ18O vs. δ18O for different mineral pairs being consistent with equilibrium at high temperatures. Alkali feldspar (9.30±1.15‰, n=10) and micas (8.56±3.16‰, n=24) have more variable δ18O values and have probably undergone subsolidus exchange/alteration.

Magma δ18O values estimated from constituent minerals for pyroxenites (~7.3-8.3‰), foskorite (~5-9.5‰) and carbonatite (~7.5-10.5‰) are generally higher than normal mantle magmas. The δ18O value of syenite magma estimated from aegirine was ~8.9-10.2‰, and in equilibrium with whole-rock δ18O values. The phlogopite δD values are consistent with typical mantle magma water δD. Despite evidence for fluid-rock interaction in the carbonatite-foskorite rocks, carbonatite δ13C-δ18O range overlaps with the unaltered, primary igneous carbonatite field (Deines, 1989) (δ18O 8.13 to 11.62‰, δ13C -3.67 to -5.60‰).

Local basement rocks have average bulk δ18O values of 8.6±0.7‰ (n=14). This is too low to be a realistic contaminant capable of raising the δ18O values in the mafic rocks, since approximately 66-72% contamination would be required. The estimated δ18O values of Phalaborwa magmas are similar to those of the RLS of the Bushveld Complex (2060-2055 Ma) and Karoo picrites (183 Ma), and hence consistent with an extensive and long-lived high-δ18O mantle source beneath southern Africa. The higher δ18O values in the syenites are consistent with an origin by partial melting of metasomatized country rock.

Geochemical and geochronological analysis of post-impact hydrothermal alteration in the Morokweng Impact Structure, South Africa.

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The ~70 km diameter Morokweng impact structure (MIS) represents the eroded remnant of the original 146 Ma crater that was buried at some time in the Late Cretaceous or Cenozoic beneath sediments of the Kalahari Group. The M4 drillcore located at a radial distance of ~15-18 km from the centre of the MIS, intersected 100 m of Kalahari Group sediments and 268 m of shocked and highly fractured Archaean granitoid gneisses and younger dolerites that were affected by post-impact hydrothermal alteration and veining. Rare garnet-epidote-feldspar-chlorite assemblages found in vugs suggest relatively high-T hydrothermal alteration, but lower-T zeolite-clay-haematite alteration is most pervasive. The upper parts of the core are marked by significant abundance of calcite crystals grown in fractures, vesicles, and mm -thick veins, some in close association with plagioclase, epidote, or quartz. Calcite and clay mineral trace element and stable and radiogenic isotope geochemistry are used to establish the physicochemical conditions of hydrothermal alteration within the MIS, including the source(s) of fluid.

LA-ICP-MS trace element systematics of four calcite-plagioclase veins suggest a hydrothermal fluid source, based on: Weak LREE enrichment over HREE when shale-normalised, negative Ce anomalies indicating oxidised conditions and enriched Eu relative to neighbouring REE, the latter suggesting breakdown of plagioclase caused by fluid transport and enriched Y due to complexation with CO_3^(-2) at hydrothermal conditions. Thus, the precipitate occurred under oxidizing conditions involving meteoric and/or basinal fluids underlying the MIS. LA-ICPMS preliminary K-Ar ages for smectite-illite range from 50.16 ± 2.24 Ma, 57.41 ± 7.14 (119 m), 59.45 ± 7.74 Ma (216 m), 68.88 ± 48.87 Ma (121.8 m) to 105.80 ± 4.43 Ma (214.40 m), whereas U-Pb calcite ages of 13.95 ± 4.32 Ma (143 m), 18.57 ± 0.55 Ma (144.09 m), 35.3 ± 119.6 Ma (131.90 m) to 74.07 ± 3.94 Ma (114 m). Combined geochemical and geochronological data of carbonates and clays suggest resetting of the original impact hydrothermal assemblages or formation of a younger generation of veins prior to or during the late Cretaceous Kalahari Group deposition.

Geochemical evaluation and correlation of the Dart and Hrdlička borehole cores from the Taung Skull Site

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The Taung Skull site is the locality where the Australopithecus africanus type specimen, commonly referred to as the Taung Child, was found in 1924 at the Buxton-Norlim Limeworks (BNL), near the town of Taung [1]. Yet, a century after the discovery of the Taung Child fossils the deposits at the site and the fossils are still to be radiometrically dated [1, 2]. The deposits at this site are 10s of meters in thickness and 100s of meters in lateral extension, and mainly comprised of the white and highly porous Thabaseek tufa interbedded with the massive, pink-coloured deposit (PCS), which is pedogenic pink calcrete [1]. These interbedded deposits indicate multiple episodes of tufa precipitation and calcrete accretion and can be seen clearly in two boreholes cores drilled in 2012. The Dart core is ca. 13 m long and was obtained from the Dart Pinnacle whereas the Hrdlička core is ca. 52 m long and was obtained from the Hrdlička Pinnacle [2]. The Taung Child skull is alleged to have come from the PCS near the Dart Pinnacle [1, 2]. In this study we used high-resolution sampling of the core (10 cm intervals) for major and trace element geochemistry obtained using inductively coupled plasma optical emission spectroscopy (ICP-OES) and inductively coupled plasma mass spectroscopy (ICP-MS), respectively. The results are intended for the geochemical correlation of the two drill cores and better understanding of the depositional environment of each unit. The cyclicity between humid and arid periods is being assessed using the Mg/Ca and Sr/Ca ratios of the carbonate-only dissolution [3]. The rare earth elements (REEs) are being used to assess the aeolian vs fluvial input for the non-carbonate material throughout the cores [3]. These results will assist a better approach for radiometrically dating the deposits.

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Geochemical insights into the formation of the Rooiberg Group, Bushveld Large Igneous Province, South Africa

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The Rooiberg Group is one of the largest intracratonic volcanic successions in the world and a rare example of a prominent volcanic event comprising both mafic and felsic volcanics. Representing the earliest magmatic activity associated with the Bushveld Large Igneous Province (LIP), the Rooiberg Group comprises four formations including, in ascending stratigraphic order, the Dullstroom, Damwal, Kwaggasnek and Schrikkloof formations. The Dullstroom Formation is composed of a differentiated suite ranging from low-Ti and high-Ti basalts to rhyolite, whereas the three upper formations are composed principally of rhyolite. The mafic-ultramafic rocks of the Rustenburg Layered Suite (RLS) physically divide the Dullstroom Formation into a lower portion beneath the RLS consisting mainly of basalts with minor felsic volcanics, and an upper portion above the RLS dominated by dacite and rhyolite.

A new whole-rock dataset of major and trace element compositions combined with the available literature for the Rooiberg Group indicate that the low-Ti and high-Ti basalts, together with dacite-rhyolites of the Dullstroom Formation, collectively represent advanced degrees of partial melting of a mafic lower crustal source. The Dullstroom basalts share chondrite-normalised rare earth element and primitive-mantle trace element patterns that are comparable with, but slightly more pronounced, than those of the Mg-rich magma referred to as the B1 parental magma of the Lower Zone and lower Critical Zone of the RLS, the latter composed mainly of pyroxenite, norite and peridotite. These commonalities militate in favour of a common source for the Dullstroom basalts and the parental magma of the B1 intrusives. In contrast, the silica-rich Damwal, Kwaggasnek and Schrikkloof formations of the Rooiberg Group are the products of a fractionally crystallised melt derived from a different source rock to that for the Dullstroom suite, likely of intermediate composition. This study also suggests that the low-Ti and high-Ti basalts of the Dullstroom Formation were derived from a common source, and that variations in their Ti contents are due to the crystallisation of phenocrystic euhedral magnetite-ilmenite from the high-Ti basalts, whereas the anhedral Ti-poor magnetite of the low-Ti basalts precipitated from a slurry dominated by interstitial liquid.

Geochemical Vectors towards Magmatic Nickel Sulphide Mineralisation in the Kunene Complex

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Magmatic Ni-Cu-Co-PGE sulphide deposits hosted in basaltic intrusions are an important contributor to global nickel resources and more discoveries are needed to meet current and future demands of nickel. However, magmatic nickel sulphide deposits are relatively small in size (1.5-20 km^2) and lack indicative alteration haloes, which makes their exploration challenging. The 1.33 Ga Voisey's Bay intrusion is part of the 1.36-1.28 Ga Nain Plutonic Suite (NPS) and is a world-class example of a magmatic nickel sulphide deposit. The 1.50-1.36 Ga Kunene AMCG Complex (KC) of Angola and Namibia shares many similarities (e.g., geological setting) with the NPS and has the potential to host similar magmatic nickel sulphide deposits. In this study, we characterise the petrology and geochemistry of basaltic intrusions at the southwest margin of the KC to assess their metallogenic potential.

Field and petrographical observations, and whole-rock major oxide data of the basaltic intrusions show that they are dominantly composed of mafic-ultramafic cumulate lithologies including olivine gabbros, gabbronorites, leucotroctolites, troctolites, pyroxenites, lherzolites and dunites. The cumulate textures, along with a magmatic foliation, glomeroporphyritic textures, and resorbed olivines are all consistent with turbulent magma flow in a conduit environment. There is also evidence of brecciation, crustal xenoliths and orthopyroxene reaction rims around olivine suggesting the intrusions were structurally controlled and interacted with their country rocks. Magma-crust interaction is supported by high Th/Nb and La/Sm which is consistent with the assimilation of Paleoproterozoic and Archaean basement rocks. In situ olivine compositions (Fo_{54-82} and NiO up to 0.27 wt%) and pyroxene compositions ($Mg\#_{57-89}$ and Cr_2O_3 up to 0.87 wt%) are consistent with their crystallisation from primitive magmas. The intrusions have low Cu/Zr compared to the primitive mantle suggesting there was sulphide liquid segregation from the magmas and possibly the removal of chalcophile and siderophile metals. This is supported by the evidence of localised sulphide mineralisation in the intrusions.

Our observations suggest that the KC basaltic intrusions represent suitable environments for the exploration of nickel sulphide mineralisation as geochemical proxies suggest there may have been segregation of sulphide liquids early in the crystallisation sequence. The southwest margin of the KC, which includes the Oncócua intrusion, is particularly prospective due to structural controls on emplacement and its intersection with the sulphur-bearing basement rocks (e.g., Schist-Quartzite-Amphibolite-Marble±Metapelite Complex). Similar targets should be sought in this region, along with the covered eastern margin of the KC, in the search for high-metal tenor nickel sulphide deposits.

Geochemical-mineralogical characterization of a granulite-facies migmatite and its leucosome and melanosome fractions (Namaqua Metamorphic Province, South Africa)

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Migmatites are a common occurrence in granulite-facies terrains. Due to the mobility of the melt at or near peak P-T conditions, the origin of the melt (in situ, close by, distant) now represented by the leucosome fraction may be problematic to ascertain, particularly if metamorphism was syn-deformational. Furthermore, any in situ melt volume may have been modified due to partial melt loss.

A migmatite occurrence in the granulite zone of the Bushmanland Domain of the Namaqua Metamorphic Province of southern Africa shows an S-L structural arrangement of aligned elongate leucosome patches within a melanocratic matrix at a scale that allows to physically separate the two fractions for further major and trace element analysis. The melanosome is characterized by the abundance of cordierite, biotite and sillimanite, while the quartzo-feldspathic leucosome contains a substantial amount of garnet. The presence of hercynite + quartz in both fractions confirms the high grade of metamorphism, as well as low pressures.

The geochemical-mineralogical study carried out reveals an anatectic process that resulted in leucosome compositions which are less siliceous, and which have a higher maficity, compared to the melanosomes. Although the leucosome proportion is high (between 40 and 60 vol%), there is very little local interconnectivity between adjacent leucosome patches, with no clear evidence for either larger-scale melt accumulation, or for melt escape channels along or across the rocks' structural anisotropy. Geochemical evidence indeed points to anatexis without significant melt loss, whereby the resultant leucosome and melanosome segregations combine in the bulk rock to a composition that corresponds to a pre-anatectic metapelitic protolith. The leucosomes show no evidence for the involvement of externally derived melts. While cross-cutting melt veins do occur locally, they have a chemical signature distinctly different from the concordant leucosomes.

Garnet plays a critical role for the major and trace element distribution between leucosome and melanosome, as it is concentrated in the former, lowering the Si content relative to the bulk rock and increasing FeO, MnO, Sc and HREE. The high proportion of peritectic garnet within the newly formed melt would also have increased its density markedly. In conjunction with the unusual, constrictional deformation-related distribution of non-interconnected leucosomes in the migmatites, the low density contrast between magma and a largely solid melanosome may well have impeded effective melt loss from the source rock, despite the high melt proportion.

Geochemistry and metal fertility of the peripheral intrusions along the SW Kunene Anorthosite Complex of Angola and Namibia

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Several ultramafic to mafic intrusive bodies are located adjacent to the southern and western margins of the Mesoproterozoic Kunene Complex (KC) of Angola and Namibia (1500 – 1370 Ma). These intrusions are generally small (few km2), range in composition from dunite to anorthosite, and may be Ni-Cu-(PGE) mineralised. Similarities exist with the world-class Ni-Cu-Co sulfide deposit of Voisey's Bay in the Nain anorthosite suite, Canada.

Previous ages obtained on some satellite intrusions did not clarify whether the peripheral intrusions are coeval to the KC, but exploration drilling shows that the KC discordantly cross cuts Ombuku North, with a non-chilled intrusive contact, therefore, the KC is a later intrusion.

We measured five LA-ICPMS U-Pb zircon and apatite ages on four intrusions. At Ohamaremba we obtained a concordant date of 1407 ± 5 Ma, interpreted as crystallisation age, with two xenocrystic zircons at 1755 ± 6 Ma and 1723 ± 6 Ma. At Otjijanjasemo, two xenocrystic zircons dated 1762 ± 8 Ma. At Ombuku North, an in-situ concordant zircon age of 1353 ± 4 is interpreted as the intrusion maximum age. Zircons of ca. 1.74 Ga display typical xenocryst characteristics. The in-situ U-Pb ages obtained from Oncocua apatite provided an age at 1350 – 1450 Ma. The new data suggest that at least some of the intrusions are coeval to the KC.

A geochemical investigation on ca. 3400 assays on a range of elements (including S, Ni, Cu, Co, Pt, Pd, and Au) was performed on seven peripheral intrusions. The major elements define a fractionation trend from ultramafic to anorthosite lithologies. Chalcophile and siderophile elements concentrate primarily in ultramafic lithologies, specifically pyroxenite, harzburgite, and serpentinite, often at the contacts with more fractionated rocks. The highest Ni-Cu-Co metal tenors are at Ombuku North, associated with blebby to net-textured pyrrhotite, chalcopyrite and pentlandite. Massive sulfide mineralisation at Ongoro, Oheuwa, and Onyokohe has low base and precious metal tenors.

Ombuku North shows relative PGE enrichment and low Cu/Pd, therefore, it is inferred that the intrusion experienced minor sulfide fractionation before emplacement. The intense alteration (serpentinisation) might have favoured hydrothermal remobilisation of base and precious metals, contributing to metal enrichment at Ombuku North. However, more analytical work on isotopes and trace elements on whole rock and sulfides is required to validate this hypothesis.

The mafic/ultramafic satellite intrusions to the Kunene Complex, based on geochronology and geochemistry, represent an excellent target for base and precious metal exploration.

Geodynamic evolution of the Giyani Greenstone Belt and its implication to gold mineralisation in the region

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The Council for Geoscience has embarked on an integrated and multidisciplinary geoscientific research in the Giyani Greenstone Belt (GGB) and surrounds. The objective of the project is to support economic growth, address water security and promote environmental stewardship through an integrated approach that covers multi-discipline tasks (i.e. detail geological mapping, soil geochemical mapping, geophysical investigations, geotechnical, groundwater and environmental studies). This data is also targeted toward understanding the geodynamic evolution of Archean environments and how these affected various mineralising systems.

The GGB is situated along the boundary between the Kaapvaal Craton and the Southern Marginal Zone of the Limpopo Metamorphic Belt. It comprises largely of tonalite-trondhjemite-granodiorite rocks, metavolcanic and metasedimentary rocks and various Archaean-Paleoproterozoic granitoids. The belt formed one of the first continental fragments on earth and key component in the development of the Kaapvaal Craton.

Six 1:50 000 geological maps covering the entire GGB and the surroundings were produced. A Magnetotelluric (MT) survey focusing on deep crustal features (>15km) was conducted in the central part of the GGB along a profile of about 30 km oriented NW-SE. This included the delineation of deep crustal shear zones and subsidiary structural zones. Integration of MT and historical geological datasets on deep geological structures confirmed that these subsurface structures hold potential for structurally controlled gold mineralisation in the area. This is corroborated by the results of the Induced polarization Survey in one of the generated mineral targets. Soil geochemistry delineated previously unmapped sequences in the region. Follow up geochemical studies of the generated mineral anomalies confirm some of the promising anomalies.

The results of this study are now being used to define a new tectono-stratigraphy of the GGB. This will include targeted isotope geochemistry and geochronology to determine the precise formation and evolution pathway of the GGB.

Keyword: Mapping, Archaean, Integrated geoscientific mapping, Magnetotelluric survey, Geochemistry

Geologic framework and first results from ICDP BASE drilling in the Moodies Group (~3.22 Ga), Barberton Greenstone Belt, South Africa

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Units of the up to 3.7 km-thick Moodies Group (~3.22 Ga) in the Barberton Greenstone Belt, South Africa and Eswatini, comprise some of the oldest well-preserved sedimentary strata on Earth, deposited within only a few million years in prodeltaic to alluvial settings, with a dominance of tidal deltas and coastal plains. They consist of polymict conglomerates, widespread quartzose, lithic and arkosic sandstones, siltstones, shales, and rare BIFs and jaspilites, all interbedded with dacitic air-fall tuffs and several lavas. Moodies strata preserve abundant sedimentary structures and represent a very-high-resolution record of Paleoarchean surface processes. Microbial mats, early diagenetic vadose-alteration zones and tidal rhythmites are locally common. Moodies strata provide a unique opportunity to investigate the conditions under which early bacterial life spread and thrived in coastal-zone and terrestrial settings on Earth.

The ICDP Barberton Archean Surface Environments (BASE) Project drilled November 2021 to July 2022 eight inclined boreholes of 280 to 497 m length each through steeply inclined or overturned Moodies Group strata. The unweathered and continuous core record was complemented by sampling in three several-km-long tunnels and by detailed surface mapping. Two to three rigs operated concurrently, delivering twenty to sixty m of high-quality core daily. This core was processed in a large, publicly accessible hall adjacent to the museum in downtown Barberton. An exhibition provided background explanations for visitors and related this fundamental-geoscience research project to the geology of the Barberton-Makhonjwa Mountains World Heritage Site. The archive half of the core, nearly 3 km total, remained in South Africa, the working half is curated at the ICDP core repository in Berlin, Germany.

We show preliminary cross sections, overall core photographs and representative lithologic descriptions from the eight boreholes.

Geological revision of the middle Cretaceous Mussentuchit Member, Cedar Mountain Formation, Central Utah (USA)

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Intensified work on the volcaniclastic-rich sediments of the fossil-bearing Mussentuchit Member (Mbr) (uppermost Cedar Mountain Formation, Utah) has provided critical insights into chronostratigraphic and paleoenvironmental, which have remained cryptic (1,2, 3,4). Thus, we sampled newly identified ash bed units along with facies analysis and architectural reconstruction on exposed Mussentuchit Mbr outcrops south of Emery, Central Utah. Ongoing fieldwork resulted in the discovery of multiple stratigraphically separable syndepositional ash falls. Here we present novel U-Pb geochronology by coupling high-precision LA-ICP-MS and CA-TIMS on 4 four (4) syndepositional dacitic ash beds ranging in age from 99.53 ± 0.026 Ma (MAZ1) to 98.93 ± 0.054 Ma, and the resulting sub-million-year temporal framework (5).

Additionally, sediment emplacement occurred on the landward portion of a paralic depocenter, influenced by distal alluvial and proximal coastal systems, analogous to the modern coastal plain of French Guiana (6). However, this landward paralic depocenter was not uniform through time. Sedimentological evidence indicates landscape modification was ongoing, influenced by an altered base level (high groundwater table, long water residency in sediments, sifts in paleosol types, heavier to lighter δ18O, and distinct shifts in (ε) relative humidity; common in coastal settings). Based on the above data, we correlate the Mussentuchit Mbr to the transgression of 3.1; with sediments emplaced between the upper Mesa Rica Sandstone and Romeroville Sandstones (7) of the south and central Western Interior Basin. To the north, the Mussentuchit Mbr. was emplaced just after the Albian Wayan Formation (101.0 Ma; 8), being more correlative to the upper Blackleaf Formation (10,11). Altogether, our results strengthened linkages in the central Western Interior Seaway and formulated novel linkages across early-Cenomanian North America.

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Geology of the early Late Cretaceous Moreno Hill Formation, Zuni Basin, New Mexico

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Background

The Turonian–Coniacian Stages of the early Late Cretaceous were typified by ongoing plate tectonics, orogenies, prevalent volcanism, as well as global warming during the Cretaceous Thermal Maximum (KTM) after which exceptionally high seas receded, opening up eco-space along coastal margins. However, many of these terrestrial ecosystems remain understudied, with surmised/tenuous linkages between supposedly coeval depo-centres. One of these sedimentary archives, the Moreno Hill Formation (Zuni Basin, New Mexico), offers a crucial glimpse into landscape evolution during this time of biological turnover and explosive radiation. Albeit previously described and subdivided into three members, we provide previously lacking spatiotemporal, palaeoenvironmental, and stratigraphic context which has hitherto limited geohistorical interpretations for this unit and its endemic dinosaurian palaeoassemblage.

Methodology and key results

We dated sampled detrital zircons via LA-ICP-MS and CA-TIMS to determine the provenance, maximum depositional age (MDA), and emplacement history of the Moreno Hill. Our results show that deposition occurred in two phases, newly suggesting a revised subdivision into two members instead of three. A 90.9 Ma MDA was determined for the lower member and an 88.6 Ma MDA for the upper member, with middle member ages indicating sediment reworking. Furthermore, shifting provenance between the lower and upper members was linked to effects of the migrating forebulge of the Western Interior Basin of North America, which slowly cut off and diverted westerly-lying fluvial feeder systems.

Subsequent sedimentary facies analysis confirmed that the Moreno Hill was a proximal paralic to distal floodplain to the Gallup Delta. Palaeoenvironmental development over time was also linked to landscape-level effects of the migrating forebulge coupled with ongoing cooling and aridification following the KTM, and to smaller transgressive-regressive phases which interrupted the overall regression of the Western Interior Seaway.

Whilst these results also supported subdivision into only lower and upper members, local geologic linkages remained hindered by stratigraphic uncertainties. These were resolved by combining our revised chronometry within a progradational geomorphologic model, which included sedimentary and supporting structural data. This provided novel stratigraphic context for several key field sites, and redefined seaward linkages to the Gallup Delta (e.g. Crevasse Canyon Formation). Building thereon, several geo- and biological ties to analogous ecosystems (e.g. Ferron Sandstone, Utah) and fossil assemblages from around the world (e.g. Bissekty Formation, Uzbekistan) were either strengthened or newly established.

Main conclusions drawn from these results

Together, our results suggest that climate change drove landscape and biological evolution during the Cretaceous Period.

Geomorphological Analysis Of The Kruger-Malale Fault Scarp: Implications For Seismic Hazard In Limpopo, S.Africa?

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South Africa is a stable continental region (SCR), where significant earthquakes are infrequent. A typical recurrence interval for major earthquakes on a fault in such regions could be on the order of 10-100ka, or even longer, due to slow interseismic strain accumulation. Thus, less than a handful of earthquakes with magnitude greater than 6 have been recorded in South Africa over the last two centuries. These include the 1809 MW6.3 Milnerton earthquake, the 1912 ML6.2 Koffiefontein earthquake, the 1932 MW6.3 St Lucia earthquake and the 1969 MW6.3 Ceres earthquake. 200 years of seismicity are not likely to reflect the full earthquake cycle in SCR regions. Furthermore, in other SCRs, larger earthquakes have occurred, such as the 2001 MW7.9 Bhuj earthquake in India, and the 2017 MW6.5 Moiyabana earthquake in Botswana. It is important to understand how common such events are, and whether they could occur within South Africa.

One way of addressing this is to map and investigate the faults which show geomorphological signs of neotectonic activity. One such fault is the focus of this study. The Bosbokpoort normal fault is located in the Limpopo Mobile Belt (LMB) near the Mozambique-South Africa-Zimbabwe border. References to unpublished reports and personal communications in previous studies suggest that the fault displays 10m of displacement of Quaternary sediments. To map the aforementioned fault, we apply stereophotogrammetry to aerial photographs from the directorate of National Geo-Spatial Information (NGI). This allowed the construction of a dense point cloud of elevation data in the AgiSoft Metashape. The point cloud was rasterized in ArcGIS to create a Digital Surface Model (DSM) from which elevation profiles were extracted. The DSM and the elevation profiles were used to map the section of the fault displaying evidence of recent displacement and were used to calculate the vertical displacement of the scarp using MATLAB codes, respectively.

The scarp was found to be 53km long with 13m average slip where it displaces Quaternary sediments. This amounts to the slip-length ratio of 2.4x10-4 which is significantly higher than that found in most single event scarps. This may suggest that the scarp formed in multiple events. Scenarios of at least 2-7 events were considered; each event had a magnitude of at least MW7. This implies that events similar to the M7 Machaze earthquake, which occurred close to the eastern boundary of the Zimbabwe Craton, may occur on its southern boundary as well, the LMB.

Geomorphology, sedimentology and preliminary radioisotopic age constraints of ?Middle Pleistocene termitaria near Calitzdorp, South Africa

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Termites are keystone organisms, capable of modifying the physical structure of the landscape and recycling important soil nutrients. Their soft bodies are not commonly preserved in the fossil record and often the only evidence of their existence are their intricate nest structures. In Calitzdorp, Western Cape, eight interconnected fossil termite nests (termitaria) are described, which may represent a new ichnogenus and potentially records the presence of a termite species that is now locally extinct. The sediments that host the termitaria have not been previously studied in detail, nor dated, and therefore the termitaria lack geological constraints. In this on-going research, we describe the geomorphological and sedimentological contexts of the fossil termitaria and provide preliminary uranium-series radioisotopic age constraints on their construction. By building a digital elevation model (DEM) using an aerial photograph database and undertaking field investigations, we show that the termitaria are situated on an alluvial terrace along the Gamka River within calcified gravel-rich palaeo-soils. The fluvial terrace and associated deposits are exposed elsewhere in the vicinity, which aids future prospecting efforts. Both the alluvial host sediments and the termitaria themselves are strongly affected by secondary pedogenic carbonate precipitation that solidifies the nest structures, enhancing their preservation. A geochemical pre-screening procedure was followed using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to identify high U/Th carbonate layers suitable for uranium-series dating. Subsequently, selected layers were hand-drilled and dated using solution multi-collector inductively coupled mass spectrometry (MC-ICP-MS). Preliminary results indicate that the carbonates formed in the Middle Pleistocene (Chibanian), around 320 ka, which provide a tentative minimum age constraint for the construction of the nests and carbonate precipitation. This research exemplifies the usefulness of multi-disciplinary methods when studying the largely overlooked Quaternary geology and ichnology of the Western Cape.

Geoscience Education in a South African Science Centre

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Informal educational settings such as science centres play an important role in science education around the world. Science centres are known to have a positive influence on promoting visitors' curiosity, interests, and knowledge of science because visitors can interact with real objects and engage with exhibits in a relaxed informal environment, watch science shows, or consult websites. In addition to such informal-type education, learning in science centres can also be non-formal through organized, systematic, educational activities such as workshops.

The South African Human Science Research Council has identified science centres in South Africa as the dominant spaces for science awareness promotion in the country. The task of science centres is to develop programs, workshops and undertake outreach programs, which focus on creating awareness and teaching science and technology also in disadvantaged regions, such as rural areas and townships.

The Science and Technology Education Centre at the University of KwaZulu-Natal (STEC@UKZN is one of these science centres and a place of hands-on science learning with an emphasis on Geoscience education. Over the years, STEC@UKZN has developed numerous low-cost geoscience-related activities, and educational materials. Incorporated in the Science Centre is the Geology Education Museum with displays on the rich geological heritage of South Africa. The Science Centre also houses geoscience-related simulations and 3-D models of geological and mining environments designed and built by students.

Education takes place both inside and outside of the science centre. In the in-house environment the visitors engage with the geoscience exhibits, posters and models. They can also visit a natural glacial pavement that happens to be exposed on the University campus, or take part in a science show on volcanoes. Outside the science centre we engage learners, teachers and the public in busking activities, exhibits, posters and science shows. Professionals, the public and students are usually the ones visiting our Geology of KZN website. We deliver workshops mainly to visiting school groups, e.g. on geological related disaster and fossils for junior and senior grade preparatory school learners and for example a plate tectonic and crystallography workshop for high school learners. As part of our outreach we also present workshops and talks for learners, teachers and the public during science festivals or when we are visiting schools.

Giant impacts and geological cycles

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The earth experienced two major degassing events (1) associated with giant impacts at 25 and 100 million years after the start of the solar system (2). The first impact is associated with initial formation of the core, the second with formation of the moon and further growth of the core. Controls on the position of the core-mantle boundary are unclear; here I propose that dehydration of the high pressure polymorph of aluminium oxide hydroxide, δ-AlOOH,(3) determines the position of this boundary. After the first giant impact δ-AlOOH forms through reaction between iron hydride, ferric iron and aluminous bridgmanite. Because δ-AlOOH has a lower density than iron hydride, it rises from the core, dehydrating at the core-mantle boundary and initiating hydrous melting (4) of the silicate mantle. After the second giant impact δ-AlOOH survives in those portions of the mantle now recognised as thousand kilometre scale iron-rich large low shear-wave velocity provinces (5) and hundred kilometre scale structures such as the Perm anomaly (6). Global melting events currently related to supercontinent formation may instead be related to major episodes of hydrous magmatism initiated by the ascent of δ-AlOOH from these structures. The million year time scale for the growth of hotspots (7) may similarly be related to intermittent flux of hydrous melt from the core-mantle boundary.

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Gold deposits top-down

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The all-time world gold production surpassed 200,000 tonnes or 6000 Moz in late 2021 —obviously an estimate only. Those 200,00 tonnes have come from many countries, and the larger land areas such as USA, Russia, Australia and Canada have produced considerable gold. Stand-out producers considering their size include Ghana and Zimbabwe. However, by any measure, South Africa reigns supreme surpassing 50,000 t—as an illustration, this production would fill the Stellies Geology courtyard to a height of 10 m.

One estimate is that over 200,000 mostly small and historic deposits have produced gold. The classification of these deposits can be bottom-up giving many different names for different local styles and geographic regions, with the result being a plethora of overlapping and unhelpful terms: the overlap ensures that debates will follow. A different approach is to look for similarities along with any fundamental differences.

Five characteristics are found amongst most gold deposits; i.e. deposits occur in gold provinces, ores represent three orders-of-magnitude enrichment of gold above crustal gold abundance, ore formation is epigenetic and hence after its host rocks, and deposits are either without economic base metals and have low salinity fluids, or produce economic base metals especially copper and have highly saline ore fluids. The former gold-only deposits dominate production. This top-down approach to primary gold geology generated three scientific breakthroughs around 1980 and their uptake occurred rapidly within the Western Australian industry. In the Barberton goldfield the same breakthroughs were incorporated into exploration and mining practices essentially over a weekend in 1982 reflecting the strong knowledge base of the team involved. Both regions have subsequently benefitted from geological excellence.

Virtually all primary gold deposits have been in metamorphic environments at some stage, and likely during their formation (elevated T and P with or without igneous activity). It follows therefore, that like structural geology skills, metamorphic skills are critical before one can be involved in the geology discussions and debates that lead to optimal exploration and mining strategies. Today, metamorphic skills extend beyond T-P to include an appreciation that aqueous fluids can and do move through solid rock, and the mechanisms that allow this to happen during a gold-forming event. The VCR sample from Kloof mine in the Stellies Geology foyer illustrates the paradox of a metamorphosed and altered rock yet with negligible porosity and low strain.

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Gondwana break-up related magmatism in the Falkland Islands

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Jurassic dykes (178-182 Ma) are widespread across the Falkland Islands and four distinct suites of intrusions are recognized. NW-SE oriented dykes have εNd_{182} in the range -6 to -11 and $^{87}Sr/^{86}Sr182$ >0.710 and therefore require an old lithospheric component in their source. Major element variations show that these intrusions were probably derived from a pyroxenite-rich source. A suite of basaltic-andesites and andesites exhibit major and trace element compositions like those of Ferrar dolerites, but they have εNd_{182} c. 0 and $^{87}Sr/^{86}Sr182$ <0.7055 showing that they were derived from a less isotopically enriched source than the Ferrar dolerites. Basalt intrusions with $^{87}Sr/^{86}Sr182$ c. 0.7035 and εNd_{182} c. +4, and low Th/Ta and La/Ta ratios (c. 1 and c. 15 respectively) escaped interaction with the lithosphere, and represent syn-break-up, asthenosphere-derived magmas emplaced at the initiation of oceanic spreading. There is no evidence to suggest that mantle potential temperatures were more than 1450°C in the Falkland Islands, leading to the possibility that melting occurred by decompression of mantle that had undergone internal heating whilst isolated beneath Gondwana for 100s of Ma.

Granite emplacement mechanisms of the Pan-African Peninsula Granite, Saldania Belt, Sea Point contact, Cape Town, South Africa

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The Sea Point contact, Cape Town, South Africa, exposes the intrusive contact between the Malmesbury Group metasedimentary rocks of the Pan-African Saldania Belt and the S-type Peninsula Granite of the Cape Granite Suite (CGS). The main contact zone is marked by sheets of compositionally variable "hybrid" granites that intruded immediately prior to the dominant voluminous coarse-grained porphyritic granite, concordant to the country rock structure. The various hybrid granites were primarily emplaced as incrementally assembled, repeated pulses of inclined granitic sheets approximately normal to, or at high angles to the regional NE-SW D1 shortening of the Malmesbury fore-arc during the 560-550 Ma Saldanian orogeny. The emplacement mechanisms used by the Peninsula Granite, and the relationship between these and the pre-existing structure in the Malmesbury Group needs to be investigated.

The pre-existing planar anisotropies (bedding planes and foliations) in the country rock provided preferential pathways for magma emplacement and propagation during deformation. The pressure difference between an opening fracture and the surrounding rock plays the key role in determining magma input into the fracture. Magma rise is driven by buoyancy and density differences between the magma and surrounding rock. The density contrast between the melt and host rocks results in a difference in the lithostatic pressure (Plith) in the wall rocks compared with the pressure in the melt-filled inclined fracture (Pmelt) causing the Pmelt at the tip of the fracture to exceed the sum of Plith and tensile strength of the host rock (T0). This enables the melt to part the bedding and foliation planes of the host rock. At the tail of the fracture, Pmelt < Plith and so Plith will close the melt-filled fracture. Field and petrographic evidence suggest a late syn- to post-tectonic timing for granite emplacement relative to the main D1 deformation phase and a degree of ductile flow of the host material to accommodate granite emplacement due to highly viscous magma flow.

Granitic intrusion involved a feedback mechanism whereby tensional stresses opened up space which allowed magma to intrude, which subsequently pushed aside the country rock to make space for itself particularly as the intrusive pulses became more voluminous. Heating of the country rock during magma pulse intrusion resulted in the country rock behaving plastically, thus facilitating magma through-flow. Magma stoping is considered to have been a secondary emplacement process.

Granite-hosted uranium deposits (GHUD): Towards a process-based model with insights from Namibia

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Process-based mineral deposit models aided by a mineral systems approach are gradually replacing older more descriptive ore deposit models. Recent versions for uranium mineral systems by Skirrow et al.,1 and the IAEA2 are significant but perhaps do not contain the detailed information recently available. This presentation highlights a greater degree of detail and focuses on some of the constraints provided by studies of Namibian granite-hosted uranium deposits.

Uranium is essentially an incompatible element in magmatic systems and so its concentration in granitic rocks is largely a result of critical factors in processes which include initial anatexis, melt extraction, magma transport, fractionation, and saturation of uranium in the melt to a point where uranium minerals crystallize. Subsequent, hydrothermal redistribution can be instrumental in forming an economic deposit and contributing to profitable concentrations.

It is well established that most GHUD are associated with granites of a peraluminous composition, are crustally derived and are associated with collisional orogens albeit typically post-kinematic. This suggests a ground-preparation phase that is critical in the initial magma generation. What is more contentious is the nature of the source rocks, the amount and cause of post-kinematic anatexis and details of subsequent fractionation. Geochemical data from deposits in Namibia help to constrain the magmatic processes and are similar for all deposits which extend over an area of 1500 km2.

It may be possible to extend a model for GHUD to other temporally-equivalent granite associated deposits such as LCT pegmatites and Sn-W deposits. However, these are typically different magma-types and so the associate may be process-based rather than genetic.

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Groundmass mineralogy and olivine composition correlations in Sierra Leone kimberlites provide constraints on craton-specific melt-lithosphere interactions

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The Man Craton, West Africa hosts two clusters in Sierra Leone namely Koidu and Tongo, which are of particular interest in this study. Both clusters consist of NE-SW trending dikes and eruptive pipes. This study uses olivine, phlogopite, and spinel compositions in combination with detailed petrography to classify and delineate the petrogenetic history of these kimberlites.

Both the Koidu and Tongo rocks share characteristics with cratonic lamproites, for example their highly micaceous nature, with groundmass phlogopite abundances ranging from 36–65 vol.% (normalized to olivine-free). The kimberlites of the two clusters are predominantly macrocrystic and have a groundmass composed of phlogopite, spinel, perovskite, and apatite, set in a base of serpentine and carbonate. The compositions of phlogopite and spinel are similar between the Koidu and Tongo samples and display an evolutionary trend comparable with those occurring in worldwide kimberlites.

Complex zoning occurs in the olivine macrocrysts and microcrysts, with distinct cores, internal zones, and rims observed in both Koidu and Tongo samples. The olivine core compositions range in Mg# from 81 to 95 and are interpreted to be derived from the disaggregation of lithospheric mantle xenoliths and proto-kimberlite related megacrysts. The olivine rim compositions from the three dikes within the Tongo cluster have similar compositions, whereas a range in rim compositions (Mg# 87-89) is observed in the different locations within the Koidu cluster. These rim compositions are interpreted as the product of primary magmatic crystallization. Further, a strong positive correlation is displayed between average Koidu olivine rim compositions and average olivine core compositions, consistent with the trend observed in worldwide kimberlites. This indicates a strong control by melt lithosphere interaction on melt compositions.

Previously, the abundance of groundmass phlogopite (± oxide minerals) negatively correlated with the Mg# of olivine rims. However, the Koidu and Tongo kimberlites are very phlogopite-rich and, given their high olivine Mg#, fall outside of the worldwide kimberlite array. The Koidu and Tongo kimberlites have the same olivine compositions and phlogopite abundances as some cratonic lamproites, which leads us to suggest that they represent a unique style of highly micaceous kimberlite magmatism. This style of kimberlite magmatism has not been reported in other cratonic regions and is genetically linked to the assimilation of K_2O-rich, metasomatic mantle lithologies. We further suggest that the K_2O content of ascending parent magmas from worldwide kimberlites and cratonic lamproites may be related to the assimilation of craton-specific metasomatic lithologies in the SCLM.

Groundwater resources assessment for Siloam Village, Nzhelele River Catchment

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This study was aimed at assessing quantity and quality of groundwater resources for Siloam Village. Groundwater resource assessment is essential in planning and allocation of groundwater resources. The groundwater balance equation was used to estimate the groundwater storage changes in order to determine available groundwater resources due to lack of groundwater yield data. Groundwater abstractions for both public and private boreholes were monitored from July to October 2011 and daily groundwater abstractions from the aquifer were determined. The physical water quality parameters (pH, Electrical Conductivity (EC) and turbidity) were measured from May-October 2011.Due to low rainfall and high evaporation, groundwater recharge on many occasions was found to be zero, resulting in negative changes in groundwater storage. The pH values for the boreholes ranged from 7.03 to 9.07, which falls within the Department of Water Affairs (DWA) recommended guideline for domestic use expect for the spring. The EC of Project, Spring, Mugagadeli, and Community sites falls within the range of 0-70 mS/m which is the DWA target water quality guideline. However, many boreholes had a marked salty taste which is likely to cause corrosion of pipes and appliances. Turbidity of Siloam household boreholes, community borehole and spring ranged from 0.2 NTU-12.5NTU, which was above the acceptable DWA standard of 5NTU. In private boreholes there were high abstractions during summer as compared to winter seasons, yet in a community borehole, high abstraction was during winter as compared to summer.

Hematite ages from high-grade iron formation-hosted iron ores and associated lithologies of the Northern Cape Province of South Africa: Implications for ore formation

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The Northern Cape Province is the economically most important region for high-grade iron ore in South Africa [1]. The iron ores are hosted within the Paleoproterozoic Transvaal and Keis Supergroups, occurring in iron formations in the former and in the basal shales and conglomerates of the Gamagara Formation in the latter [1]. The formation of these ores has been explained either exclusively or by a combination of supergene, hydrothermal and endoclastic reworking processes [1].

Advances in the age dating of hematite utilizing the combined (U-Th)/Ne and (U/Th)Ne technique [2] provide an opportunity to better understand the formation of the high-grade iron ores in the Northern Cape Province. Samples were taken across the region and include material from the: northern Maremane Dome; southern Maremane Dome; Wolhaarkop Dome; Kalahari Manganese Field (KMF); and Griqualand West region. Sampled rock types included iron-formation hosted laminated, massive and brecciated ores and altered iron formation from multiple units in the Transvaal Supergroup as well as conglomeratic ore and hematite-rich sandstone from the Gamagara Formation.

Three main hematite (U-Th)/Ne age populations occur: ~2100-1800 Ma; ~1700-1400 Ma; and ~1200-1000 Ma. Hematite (U-Th)/He ages were more variable and were always either similar or younger than their respective hematite (U-Th)/Ne ages.

The oldest hematite (U-Th)/Ne age population overlap with the age of the pre-Gamagara unconformity (~2.2-2 Ga) [1; 3; [4] as well the lower Olifantshoek Group of the Keis Supergroup [5]. The hematite in this age population is interpreted to have formed by supergene enrichment below the pre-Gamagara unconformity and clastic reworking and deposition above the unconformity of these supergene ores [1]. The middle age population has no overlap with any known major geological events in the region and could be an age reset related to sediment burial. The youngest age population corresponds well to the age of the Kheis-Namaqua orogeny [5]. This implies that there was either further ore formation or significant hematite age resetting occurring due to orogeny-driven hydrothermal fluids utilizing the pre-Gamagara unconformity as a flow channel. This late-stage event appears more commonly towards the south and southwest of the Maremane Dome and in the KMF.

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Heterogeneous mantle sources in the Umkondo continental flood basalt province

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Continental flood basalt provinces are the fossilised remnants of huge volumes (>1 Mkm3) of basaltic magma emplaced on and in the Earth's crust in a short duration (1-5 Myr). The sources of continental flood basalt provinces are debated with contributions of sublithospheric mantle and continental mantle proposed. There are at least four major basaltic provinces preserved in Southern Africa and the most well-studied is the Jurassic Karoo province. In this study, we investigated the magma sources of the poorly studied Mesoproterozoic (1.1 Ga) Umkondo province using new high-precision trace element and radiogenic (Sr-Nd-Hf) isotope data. The Umkondo province dominantly comprises doleritic-gabbroic sill complexes emplaced in Paleoproterozoic sedimentary successions and basement Archean granites. Umkondo sills are mostly low-Ti (<1.5% TiO2) sub-alkaline tholeiitic basalts with high Ce/Yb compared to Karoo basalts. Sm/Yb indicates that the Umkondo basalts are derived from shallow mantle sources (spinel lherzolites at 40-50 km depth) and PRIMELT models suggest that the primary magmas were komatiitic in composition (~18% MgO). Zn/Fe shows that the mantle sources were comprised of both peridotite and pyroxenite lithologies. An assimilation fractional crystallization array is apparent in the Sr-Nd-Hf isotope data for the Umkondo province with crustal contamination of mid- to lower-crustal Archean granites. The Vredefort sills show the most mantle-like isotopic compositions with evidence of enriched mantle sources (initial 87Sr/86Sr of ~0.705, εNd of ~0, εHf of ~0). Slight decoupling in Nd-Hf isotopes may be explained by magma interaction with the continental lithospheric mantle. Our new data show that the Umkondo province is derived from the partial melting of heterogeneous sublithospheric mantle. These findings imply that mantle plume-driven magmatism in the Mesoproterozoic was analogous to Karoo magmatism in the Jurassic.

High δ18O values in the Karoo LIP mafic rocks are unrelated to incompatible element and radiogenic isotope enrichment.

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High δ18O values in Karoo LIP mafic magmas have been ascribed to the presence of previously subducted material in the mantle source (Harris et al., 2015) and some authors have suggested that enrichment of 18-O, HFSE, and radiogenic isotopes resulted from transfer from a descending slab of oceanic crust (e.g. Heinonen et al., 2018). The Mashikiri nephelinites (MN) represent both the earliest, and most incompatible element-enriched magmas of the Karoo LIP. Their Zr/Nb ratios of ~1.8 are distinct from most Karoo LIP mafic rocks, which have Zr/Nb ~17. Low εNd (-6 to -22) and initial 87Sr/86Sr ratios of 0.7046 to 0.7073 have previously been explained as due to their derivation from ancient metasomatized mantle lithosphere by low degrees of partial melting (Bristow, 1984). Olivine and pyroxene phenocrysts from the MN have δ18O values that range from 5.30 to 5.96‰, and 5.50 to 6.61‰, respectively, that are consistent with high-temperature oxygen isotope equilibrium. Crystallization was from magmas having δ18O values that vary from 6.0 to 6.6‰, up to 1‰ higher than expected in magmas derived from a MORB-like mantle. The δ18O values show no correlation with εNd, MgO, Na2O, or incompatible trace elements and this is consistent with the processes that enriched the magma in 18O being unrelated to the mantle metasomatism.

Explanations for the variation in MN δ18O values are limited to crustal contamination, and derivation from a high δ18O mantle. Crustal contamination cannot explain high δ18O values because of the lack of correlation between δ18O value and indications of contamination such as Zr/Nb, SiO2, and Pb. Because O is a major element, any increase in δ18O value requires addition of a significant proportion of higher δ18O material. A mixed eclogite-peridotite source with high-δ18O could have developed by emplacement of a substantial component of oceanic lithosphere into the cratonic keel during Archaean subduction, and this almost certainly happened prior to metasomatism. Subsequent veining must have variably infiltrated the mantle including the high-δ18O component prior to the eruption of lavas to allow extremely negative εNd values to develop.

High-precision baddeleyite geochronology of the layered Zebra Lobe of the Kunene Complex (Namibia)

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Massif-type anorthosites are plagioclase-dominant plutons that are temporally restricted to the Proterozoic. These batholithic intrusions are constructed over prolonged periods of time (≥100 Myr). Certain domains within massif-type anorthosites are characterised by lithological and mineral layering, but the timescales of layer formation with respect to overall batholith emplacement are uncertain. The Zebra Lobe is a layered domain within the Kunene Complex, which is the largest massif-type anorthosite on Earth. As such, the Zebra Lobe provides an opportunity for understanding the nature and timescales involved in the crystallisation of these layered plagioclase-rich magmatic systems. The layers in the Zebra Lobe are defined by mineral and geochemical variation, forming rhythmic km-scale ridge and valley topography. Ridge lithologies are mainly composed of unmetasomatised, olivine-dominant anorthosites, while the valley lithologies are variably metasomatised and dominated by pyroxene-bearing anorthosites with variable but minor modal olivine. In this study, we present the first high-precision ID-TIMS U-Pb baddeleyite ages to better constrain the crystallisation timescales of the Zebra Lobe and its layering. The samples collected for this study represent lithologies along and across strike within the Zebra Lobe. The location and morphology of the baddeleyite grains were assessed using an automated mineralogy application (TIMA). Baddeleyite, which is intermittently rimmed by euhedral polycrystalline zircon, occurs in cumulate phase interstices, associated with late-stage Fe-Ti oxides. The presence of zircon rims indicates late-stage increased silica activity in these magmatic systems, suggesting possible operative, fractional crystallisation, metasomatic fluidisation, and crustal contamination processes that promoted silica saturation. Crustal contamination is also advocated to by the presence of ubiquitous zircon inheritance yielding single grain 207Pb/206Pb dates of up to 1973.1 ± 3.0 Ma. The preliminary baddeleyite data show at least two age and compositional groups. Baddeleyites from two samples of pyroxene-dominant, metasomatised valley anorthosites in an effective stratigraphic distance of 5.26 km and separated by at least three ridges of unmetasomatised, olivine-dominant anorthosites, yielded weighted mean 207Pb/206Pb dates of 1377.3 ± 0.34 Ma and 1376.94 ± 0.88 Ma. A sample of olivine-dominant ridge anorthosite contains baddeleyites yielding weighted mean 207Pb/206Pb dates of 1368.88 ± 0.60 Ma. These dates are the best proxy so far for the crystallisation age of the different layers of anorthosites and provide the first high-precision constraints on the formation of the Zebra Lobe between 1377-1368 Ma.

Holocene paleoecology of a wetland along Gerhard Minnebron River, North West Province, South Africa
-Tracking climate change and anthropogenic activities

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Background:

The north-western part of South Africa is currently understudied in terms of Holocene palaeoecology, climate change and the impact pastoralists and farmers had on the landscape. Extensive peatlands, ideal archives for proxies like pollen analysis in combination with sediment analysis which can reveal long-term changes in high resolution, exist along the Mooi River and its tributaries. The regional geology consisting of dolostones with interlayering chert bands of the Transvaal Supergroup results in a landscape with karstic springs like Gerard Minnebron River where 5 sediment cores revealed a peat thickness of >6 m. A 1.50 m long core is currently under investigation.

Methodology:

Using multiple proxies (pollen, diatoms, microscopic charcoal remnants and sediment grain size as well as pXRF) it is possible to infer past environmental conditions and changes.

Results/Discussion:

The waterlogged core is organic-rich, mostly clayey with gravel layers. The bottom of the core was lost during the drilling process. The diatoms were unfortunately, due to the alkaline nature of the wetland sediments, only preserved in the top centimetres. Preservation of pollen and spores as well as fungal remains were satisfying and charcoal fragments were abundant in the upper 100 cm, reflecting a grass-dominated open landscape with a high abundancy of Asteraceae (daisy family) and chenopods whereas tree pollen were rare but include acacias and Combretaceae (bush willow). Chenopods and Carduus (thistle) as well as pine pollen show more recent anthropogenic activities in connection to the European colonization. A higher water table at the top of the profile is indicated by the prevalence of Phragmites (reeds) over Cyperaceae (sedges). Due to a lack of radiocarbon dates, currently the impact of livestock management and farming activities -as indicated in other late Holocene sites in north-western South Africa- is uncertain.

Conclusion:

The palynological and sediment analytical results show a great potential for Holocene palaeoecological studies in the region.

How are Silicic Volcanic and Plutonic Systems Related?

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Silicic volcanic and plutonic rocks (SiO2 > 66 wt%) are generally viewed as being either compositional equivalents or complementary to each other. However, consideration of the geological, geophysical and chemical evidence suggests that silicic volcanic and plutonic rocks are not generally direct compositional equivalents. Also, volumetric and compositional relationships between the two groups suggest that silicic plutonic rocks are not generally cumulate mushes left behind after withdrawal of eruptible magma fractions. Reservoirs from which large-volumes of rhyolite have erupted should, in theory, contain residual, unevacuated magma fractions. However, the fine-grained and generally porphyritic rhyolites do not have the same compositions as the large volumes of silicic magmas that solidify to form batholiths. From these data we conclude that important genetic differences may exist in the modes of formation and evolution of silicic magmas that become rhyolites and those that become coarse-grained granitic rocks.

How the remains of unicellular organisms are giving us insight into Neogene to modern changes in southern African coastal and marine environments

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The Southern Ocean plays a crucial role in the heat transfer and chemical budgets in the global ocean circulation model. This, in turn, has an effect on global climate, and can contribute to global warming or cooling. Within coastal and marine sediments, fossil remains of unicellular organisms give us insight into how the oceans and climate have evolved over time. Their evolution, extinctions and geochemistry aid in understanding these changes.

Faunal analyses, trace element geochemistry and isotope geochemistry ($\delta^{18}O$, $\delta^{13}C$, εNd) were performed on foraminifera and sediments from the western margin and south coast of South Africa to determine how marine environments have been impacted by natural glacial-interglacial cycles, as well as recent anthropogenic influences on the environment in a coastal region.

A faunal turnover in these organisms during the Miocene-Pliocene transition indicated a change in sea levels and cooling of the oceans during a time when the Benguela Upwelling System initiated. During the Pleistocene, certain assemblages were also associated with the lowering of sea levels. Neodymium isotopes (εNd) and $\delta^{13}C$ in fossil foraminifera revealed that oxygenation decreased during Pleistocene glacial periods when ocean circulation also changed. Trace element geochemistry of the remains of these organisms also showed sea surface temperatures fluctuating between glacial-interglacial terminations, with SST increasing during glacial terminations.

These organisms are not only reliable indicators for palaeoenvironments, but are also indicative of modern environments. Analyses into fossil and modern organisms in coastal areas on the south coast of South Africa revealed how polluted areas cause decreasing diversity of these organisms and that changes in microhabitats have a negative effect on these organisms. Our results also indicate how the sediments and substrate have an effect on the species compositions on a wide scale, from the continental slope to coastal environments, where certain species become more abundant in certain substrate environments or in sediments where certain grain sizes dominate. For example, species such as Epistominella exigua, Oridorsalis umbonatus, Melonis spp., Pullenia bulloides and Hansenisca soldanii become more abundant in areas and in time periods when the grain size of the sediments become finer. These organisms are therefore proven to be reliable indicators of geologic, environmental and oceanographic change over deep time, and in modern environments around southern Africa.

How to obtain community buy-in during research drilling: ICDP BASE Project, Moodies Group, Barberton Greenstone Belt

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The ICDP Barberton Archean Surface Environments (BASE) Project, managed by DSI-NRF CIMERA, drilled eight research cores in the Moodies Group of the Barberton Greenstone Belt to investigate the conditions under which the 3.2 Ga terrestrial and shallow-marine strata of the Moodies Group formed. Because most of the drill sites were located in the Barberton Makhonjwa Mountains World Heritage Site (BMM WHS), significant societal engagement formed an essential component of the project from its very beginning, with the aim of obtaining public support and advancing science and tourism.

EOP (Education Outreach and Publicity) activities took place in all four project phases: During Phase 1 (2017 - 2020), governmental and local communities were consulted and briefed on the concept and objectives. During Phase 2 (Mar. - Oct. 2021), landowners, local community leaders and governmental agencies, including BMM WHS Management, Nature Reserves, Environmental Agencies, Water Affairs, SAHRA, and local community leaders were informed in detail; media releases spread the news. Persistent lobbying of regional government by local stakeholders, led by the local tourism manager, secured an ideal location for the project work, a former industrial hall in the centre of Barberton, which we utilized for geological displays, core processing, and storage. Phase 3 (Nov. 2021 – Jul. 2022), the drilling campaign, saw daily close coordination of visits, briefings, interviews, guided tours etc. between the on-site geoscience team, drillers, local tourism marketing officer, local businesses and media. Much of the success during this peak phase resulted from our ability to efficiently combine (1) teaching by museum-type information displays, (2) observing real-time and hands-on core processing, and (3) visiting an active drill site. Individuals and groups of scientists, school learners, university students, local community leaders, tourists, heritage and nature interest groups, as well as government officials in the tourism and education sectors visited the project during this phase. We spread the word on radio interviews, TV appearances and through social media platforms. Phase 4 (Aug. 2022 - present) saw the construction and completion of a permanent new display room in the Barberton Museum, dedicated to geological education and showcasing results of research initiated by BASE.

Overall, the success of BASE EOP activities suggests that this approach could serve as a best-practice example for similar geoscience projects.

Hydrogeochemical characterisation of groundwater quality in Ndlambe coastline: Implication for saltwater intrusion

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In coastal arid and semi-arid regions, where 13% of the world's population dwells, groundwater is one of the essential sources of urban, agricultural, and industrial supply. The peculiarities of coastal aquifers influence the sustainability of groundwater, which may impede growth in certain places if effective water management is not implemented [1]. For a community to have access to a potable and sustainable water supply, a comprehensive examination of hydrochemical processes, groundwater quality and quantity is essential [2].

The hydrochemical characteristics of groundwater in the research area are the outcome of hydrogeochemical processes and spatial-temporal distribution. The hydrogeological parameters of the research area were explored by collecting groundwater samples (within 10 kilometres of the coastline), measuring critical parameters in-situ, analysing acquired samples in the laboratory, and analyzing multivariate and spatial data. Using graphic approaches, the key components influencing groundwater systems were determined (Piper diagram and Gibbs plot). The Hydrochemical Facies Evolution (HFE-D) was utilized to investigate the hydrogeochemical changes in groundwater undergoing salinization–refreshing phases in coastal aquifers. The hydrochemical facies evolution diagram (HFED) revealed that the majority of samples fell along the mixing line, indicating the mixing of seawater and fresh water, but some samples fell in the intrusion phase. In addition, the geographic information system was employed to detect the hydrochemical characteristics and spatial distribution of groundwater.

Following the regional flow direction, it was established that the salinity of groundwater increased from northeast to south-west. In addition to salinisation, the upstream and intermediate groundwater was also nitrate-contaminated. Calculations of ionic ratios and seawater percentage revealed that seawater intrusion is predominant in the area under study. Results revealed that groundwater is mostly saline in the coastline.

The primary findings are that seawater intrusion is found in the vicinity of the wells closest to the coast. The Gibbs plot illustrates that rock-water interaction processes regulate the chemistry of groundwater in the studied area. the chemical features of groundwater are regulated by natural geochemical processes and, to a lesser extent, by human activities.

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Hydrogeological characterisation of the coastal aquifer in Gqeberha, Eastern Cape, South Africa

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The increasing demand for water and decrease of its supply due to the drought conditions in South Africa has forced municipal authorities to impose multiple water restrictions. Groundwater has therefore become a viable and cheaper alternative source of freshwater in Gqeberha, Eastern Cape, South Africa. This might have major implications for groundwater abstraction in the region. In this study, a hydrogeological characterisation of the coastal aquifer in the region was conducted using both aquifer, hydrogeological and geophysical parameters. The Audio-Magnetotelluric method and Ghyben-Herzberg relation for the saltwater interface approximation were used to properly assess the impacts of the increased groundwater abstraction in the area. Aquifer parameters were also analysed in order to determine sustainable pumping rates for the Summerstrand suburb. This was done due to the aforementioned suburb having more than one thousand well points. Although previous investigations and studies suggest that high percentages of groundwater level can be found in the Table Mountain and Algoa Groups, geophysical analysis from this study suggests that the aquifer can be greatly impacted, with high risks of saltwater intrusion in various areas, in the near future if no sustainable groundwater management strategies are practised. This is evident in the Coastal Sand aquifer and Table Mountain Group sandstones. It is therefore recommended that the city adapts multiple managed aquifer recharge strategies to ensure the aquifer in the region is not degraded or exhausted.

Hydrogeology under siege

Dr Roger Parsons[1]
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A need to better quantify groundwater resources emerged in the 1950s, much of which was dealt with by the Groundwater Division within the Geological Survey of the Department of Mines. This function moved to the Department of Water Affairs in 1977 when the Department subdivided their Division of Hydrological Research into three units, one of which was the Directorate of Geohydrology. A year later the Ground Water Division of the Geological Society of Southern Africa was formed, and has since operated almost independently of the parent body.

These developments clearly recognized that the study of groundwater was founded in the science of geology, but needed its own skills. Efforts to have hydrogeology recognized as a separate field of practice by SACNSP failed and hydrogeologists are recognized either as Earth Scientists or Geological Scientist. Codes of Conduct are relied on to ensure appropriate education and training for those working in this field, but a current court case involving a geologist who sites boreholes demonstrates that this approach does not work.

The state of the groundwater professions is also hampered by the inability of DWS to process and issue water use licenses (in part due to their lack of hydrological skills), the need to license all groundwater use within 500 m of a wetland, by further regulations requiring agreement from a Water Services Authority before using groundwater in their areas of jurisdiction, the enforcement of the SANS 241 drinking water standard which fails to take account of the quality of groundwater consumed in much of the western part of the country and the general absence of vocational training opportunities for recent graduates to gain practical experience.

The clear definition of what is a hydrogeologist and who may practice as one in the government section, the private sector or as an academic would be a useful first step in improving the situation. Re-establishment of the Directorate in Geohydrology – dismantled with the implementation of the National Water Act (Act No. 36 of 1998) – to develop the nations hydrogeological expertise, as it did previously. This should be accompanied by a revision of all hydrogeologically-related standards and the establishment of extension services to those municipalities reliant on groundwater for their water supply. Finally, any state funded project that entails (or should entail) a groundwater component should be subject to an independent audit at both the design and implementation stage, and regularly thereafter.

ICDP drilling into the upper fringe of the aftershock zone of the 2014 Orkney M5.5 earthquake that ruptured an almost entire depth range of the West Rand Group

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Background

The 2014 Orkney M5.5 earthquake is one of the best-documented moderate-magnitude earthquakes owing to seismometers densely installed in the Moab Khotsong gold mine, a strong-motion seismic network by the Council for Geoscience, and information from exploration drilling, 2D and 3D reflection seismic surveys and mining. The aftershock distribution revealed that the rupture had a strike length of ~7 km and depth extent of ~3.5 to ~7 km, corresponding to the depth extent of West Rand Group (WRG) strata. The seismogenic zone was thus accessible to drilling from mine workings .

Methodology

The drill rig was installed in WRG below the gold-bearing strata of the Central Rand Group (CRG). Rocks of the Ventersdorp, Transvaal and Karoo supergroups lie above the CRG. Many intrusive rocks cut these formations, such as dyke/sill complexes related to the Ventersdorp and Karoo large igneous provinces, the Bushveld Complex, and other magmatic events. Three NQ holes were drilled from 2.9 km (95 level, Moab Khotsong mine) to 3.4 km depth. Continuous core with minimal drilling-associated damage was recovered from the collar to the upper fringe of the aftershock zone (UFAZ) of the earthquake.

Results

In total, about 1.6 km of core samples from Roodepoort, Crown, Babrosco formations and various ultramafic/mafic sills and dykes were drilled, logged and curated. Furthermore, damaged and strongly-altered materials were recovered from the UFAZ. This is the first time that the UFAZ of a moderate magnitude tectonic earthquake in metamorphic hard-rock formation has been drilled. The geomicrobiology team found hypersaline brine (salt concentrations sevenfold greater than seawater) at the intersection of a mafic dyke and sill. Furthermore, hypersaline brine with unique isotopic characteristics was recovered from deeply-buried Archean host rock. These datasets are unique in seismology, geology, and geomicrobiology, initiating a discussion on the role of metamorphism and alteration in ultramafic, mafic, and felsic hard-rock formations and associated subsurface fracture fluids as they influence the deep biosphere.

Conclusions

In our presentation we will review the major outcomes of the DSeis project; according to the MoU between the ICDP and the research consortium, the core and related logging information will be made public once the ICDP primary documentation has been produced. Although our progress was delayed by COVID19, we hope this unique dataset will benefit the South African Earth Science community.

ICDP and many associated co-mingled funds, mainly from Japan, the US, Germany, South Africa, Switzerland, and other countries, have supported this project.

ICDP-DSeis project to drill into the aftershock cloud of the 2014 Orkney earthquake

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Background

Inspired by the occurrence of the 2014 Orkney earthquake (M5.5) that ruptured almost the entire thickness of the West Rand Group, scientists from 8 countries (including Japan, South Africa and USA) submitted a proposal to the ICDP to drill holes into the aftershock cloud of the Orkney earthquake beneath Moab Khotsong mine and the seismogenic zones around the mining front in Cooke 4 mine. The main objectives of this DSeis project are to better understand the underlying physics of earthquake generation and geological structures that control seismicity, and to explore the deep biosphere. Here we discuss the drilling targeting the Orkney earthquake aftershock cloud.

Methodology

An underground laboratory was developed on 95 level of Moab Khotsong mine to drill holes. The intersected formations included Roodepoort, Crown, and Babrosco with the complex of ultramafic/mafic sills and dike. Hole A (817 m) did not reach the aftershock cloud due to deflection, but intersected a hypersaline water reservoir in which geomicrobial activity is expected. A packer system was installed to enable sampling of the hypersaline water and temporal variations in temperature and pressure to be monitored. Hole B (700 m) intersected the aftershock cloud at ~610m from the collar. Fractured rocks probably related to the aftershock cloud were recovered, but the samples of the highly-fractured fault zone were lost. Hole C (96 m) was branched from Hole B 544m from the collar to collect samples of the fault zone using a triple-tube core barrel.

Results

In-hole logging was carried out in Holes A and B. Non-destructive core logging was performed at the Kochi Core Center in Japan on core samples around the hypersaline water reservoir (Hole A) and aftershock cloud (Holes B and C). Stress measurements and frictional tests were also performed on core samples. Mineralogical and metamorphic analyses suggested that the geological structure hosting the Orkney earthquake is an altered lamprophyre dyke that is rich in talc, biotite and amphibole.

Conclusion

ICDP-DSeis project in Moab Khotsong mine is the first drilling project in the world to reach an active seismogenic zone. Therefore, it is invaluable site to study seismogenic processes. The hypersaline water provides opportunities to explore the deep terrestrial biosphere, and to consider the possibility of extraterrestrial life. By conducting seismological and geobiological studies at the same site, we can evaluate the impact of an interaction between seismicity and microbial activity on alteration and metamorphism of rocks.

Iceland and the C-block model

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Iceland and the Greenland-Iceland-Faroes Ridge (GIFR) constitute enigmatic features in the North-Atlantic realm. The GIFR crust is up to six time thicker than the usual oceanic crust worldwide with a maximum under Iceland. The GIFR and Iceland are usually interpreted as, respectively, a hot-spot track and an active hot-spot underlying the NE-Atlantic oceanic accretion axis since Chron 24 (Eocene). However, such an interpretation fails to explain some first-order crustal characteristics such like as thick, riftward-dipping wedges of volcanic lava flows in the GIFR upper crust. These correspond to so-called SDRS (Seaward-Dipping Reflectors Sequences) in seismic reflection studies.

From the Eocene to Present SDRS dipping towards present-day Iceland conjointly developed from E-Greenland to W-Iceland (transverse Ridge) and, more discontinuously, from the Faroe Islands to E-Iceland (the Greenland-Iceland and Faroes-Iceland transverse ridges, respectively). SDRS are distinctive features of volcanic passive margins (VPMs), not of slow-spreading oceanic ridges. Two types are recognized in deep seismic reflection lines. Inner-SDRS, thick and fault-bounded, lie at the proximal and necking part of margins. Seaward, outer-SDRS, thinner and prograding seaward, form on the top of a sub-horizontal discontinuity. Enigmatic sub-horizontal or gently-dipping, flat-lying flows or volcano-sediments overlie deep buried basement (FLF-type crust) and also exist at some VPMs seaward of outer- or inner-SDRs and continentward, clearly identified oceanic crust.

The dominant view is that Inner-SDRS are related to syn-magmatic continental crust thinning and stretching. The meaning of outer-SDRS and FLF is more controversial. Recent high-resolution seismic analysis in the aborted Laxmi Basin (W of India) and along the S-Atlantic VPMs showed that both outer-SDRS and FLF could convincingly be interpreted as emplaced on top of passively exhumed continental lower crust. In addition, thermo-mechanical modelling shows that the initial steps of conjugate VPM-formation isolates a central continental block (a “C-Block”) which constitutes the common footwall area of the continentward-dipping faults bounding the earliest inner-SDRS wedges. The C-Block is progressively buried and tectonized as the breakup system develops. This pattern is exactly what is observed in the Laxmi basin. It is also what we suggest for the GIFR. In this view Iceland is then simply the remnant of such a C-Block located between lava-covered (i.e. outer-SDRs and FLF) exhumed (and intruded) lower continental crust from the NAM and EUR lithospheres.

Iceland: mantle plume or microcontinent? A zircon study

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In recent years, unexpected continental crust in areas presumed to be purely oceanic in nature has been discovered, indicated by the presence of Paleozoic zircons in rock samples. Notable examples include the Rio Grande Rise, Mauritius, and potentially also the Comoros islands, which have all previously been interpreted as mantle plume edifices. Iceland is also often interpreted as a hotspot of mantle plume origin, however the presence of a deep seated consistent thermal anomaly with depth has long been challenged, with implications for the wider regional geodynamic evolution.

Previous reports of Mesozoic and Paleozoic zircons from Iceland may allude to the presence of continental material at depth, although these are sometimes suggested to be the result of contamination. Nonetheless, geochemical evidence from erupted material at Öræfajökull may indicate a continental contribution to melts beneath SE Iceland, and the nearby Jan Mayen microcontinent readily demonstrates the ability of continental material to make its way to the ocean interior, coincident with hotspot volcanism. Furthermore, continental material in the NE Atlantic Ocean is perhaps more common than previously thought, with recent work suggesting that substantial components of the Greenland-Iceland-Faeroes region may be continental in nature.

Here, we test the hypothesis that the basaltic upper crust of Iceland is underlain by older continental crust. To do this, we have undertaken extensive, targeted sampling of Icelandic rocks and sediments using robust collection approaches to eliminate the possibility of contamination. Over a 3-week period in summer 2022, we collected samples from across the entirety of Iceland. We sampled both intrusive and extrusive rocks with a wide range of ages (both felsic and mafic, but with an emphasis on felsic rocks), as well as river sediments from above 250 m elevation (to avoid potential contamination from Greenland glacial debris). Zircons will be separated from these samples using contamination-safe approaches, and then U-Pb and Hf isotopic age analysis will be completed. The results from this preliminary study will be used to guide further sampling in summer 2023, allowing evaluation of the competing hypothesises for the origin of Iceland.

Improved gold regressions for mineral resource definition data

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Background
The Platreef orebody, currently being mined at Anglo American Platinum's Mogalakwena Mine, is situated in the northern limb of the Bushveld Igneous Complex in South Africa. The Platreef orebody is underlain by two different footwall assemblages namely a crystalline Archaean granitoid basement in the northern regions, and a partially metamorphosed Transvaal Supergroup sedimentary succession towards the south. The emplacement of the Platreef magmas was associated with thermal and geochemically reactive interactions with the underlying footwall lithologies. These reactions led to the hydrothermal remobilisation of sulphide mineralisation which resulted in different gold against palladium correlations along strike of the orebody. Samples obtained from the orebody are sent to an internal laboratory for platinum group element base metal, oxide, density, and gold analysis. The analysis is performed by means of a lead collection method with an optical emission spectroscopy finish. The optical emission spectroscopy analysis is not suitable for gold detection at low gold grades and as a result the gold results are predicted using a regression equation with palladium as the regressor.

Methodology
This study focused on investigating the accuracy of the regressed gold results and to improve the current gold regression formula. Exploration borehole core assay data and a statistical software package were used to model the revised equations.

Key Results
The regression equation used to predict the gold content in the Platreef orebody was revised for increased accuracy of reporting.

Main conclusion drawn from these results
The revised equations honour the spatial differences between the gold and palladium relationships in different regions of the mine.

In situ dating and thermometry in zircon from Archean high-K magmatism in the Barberton Greenstone Belt, South Africa

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In situ dating and thermometry in zircon were applied to magmatic zoned grains from a quartz-monzonite of the Boesmanskop Alkaline Complex in the South of the Barberton Greenstone Belt, South Africa. Geothermometers considering the Ti-in-zircon[1 2] are useful to investigate the temperature interval of crystallization, as well as constrain initial magma temperatures[3]. The alkaline magma with unknown volatile content and scarce calibration of relevant phase activity-composition models inhibit its temperature constraint, in this regard Ti-in-zircon is a suitable alternative. In situ U-Pb and zircon trace elements analysis was carried out by La-ICP-MS at the CAF laboratory from Stellenbosch University. Ti-in-Zircon geothermometer[2], follows the equation: log(Tizircon)= (6.01±0.03) - (5080±30)/T(K). The systematics of Ti substitution into zircon are controlled by aSiO2 and aTiO2 in the melt, leading to the equation: log(Tizircon)= (5.711±0.072) - (4800±86)/T(K)-log(aSiO2)+log(aTiO2) [4]. The primary zircon grains present two well-defined clusters of Ti from 26.5 to 28.7 and 11.4 to 14.5 ppm, without core/rim variation. These Ti contents yielded crystallization apparent temperatures between 913 ±4°C and 820 ±10°C for quartz-monzonite (considering values of aSiO2 = 1.0 and aTiO2 = 0.6 established to felsic magmas [4]). It may represent a discontinuous crystallization (917 to 810 °C) or a contribution of different Ti-bearing components with distinct solidus temperatures. Moreover, U-Pb analysis in the same zircon grains yielded $^{206}Pb/^{207}Pb$ ages of 3067 ±26 Ma to 3157 ±22 Ma and a concordant age of 3115 ±15 Ma (MSWD= 6.8). Thus, combined thermometry and geochronology indicate coeval crystallization of heterogeneous zircon grains during the extensive ~ 3.1 Ga high-K magmatism at the Barberton Greenstone Belt.

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Inherited structural control on large stable continental region (SCR) earthquakes: comparison of active fault scarps with mapping from aeromagnetic data in Botswana and Namibia

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Despite being considered a stable continental region (SCR), geomorphological evidence is growing for the existence of recent, large (greater than Mw 7.0) earthquakes in southern Africa. Recognition of these active fault scarps makes a significant contribution to the small catalogue of SCR earthquakes, whose origins are the subject of intense research and debate. Plate boundary zone earthquakes occur in relatively narrow areas of strain localisation and high strain rate; they are frequent enough for empirical relationships, such as slip to length ratio, to be reasonably robust. In contrast, SCR earthquakes occur in areas where strain rates are low and driving stresses are less clear; it has been suggested that they obey different scaling laws. The occurrence of these earthquakes is also significant for seismic hazard, since they may dramatically alter estimates of Mmax. Understanding the locations of these infrequent but potentially damaging earthquakes is therefore important in terms of contributing to our knowledge of SCR seismicity and also to our understanding of local and regional seismic hazard.

Here, we focus on a detailed study of fault scarp locations in Botswana and Namibia in the context of local and regional geological structures, using locations mapped from high-resolution DEMs and satellite imagery superimposed on aeromagnetic data. Interpretation of the aeromagnetic data reveals that, in many cases, geologically recent earthquakes occur on pre-existing structures in orientations that dominate the magnetic fabric of the regions. In some cases, active fault scarps terminate against major inherited structures, demonstrating an additional geological control on active faulting. In one case, measurement of a slip vector in recently faulted calcretised sediment demonstrates oblique slip, providing tantalising evidence for slip along structures that are imperfectly oriented for the ambient driving stress field, emphasising the first-order control of geological inheritance in these low-strain-rate regions. Attempts to understand the driving stresses behind such earthquakes are currently ongoing and it seems that in these regions, the locations of SCR earthquakes are controlled by an interplay between the regional stress field and the presence of heavily deformed, inherited zones of weakness which can be identified and mapped from the surface geology and from aeromagnetic data.

Further interpretation of aeromagnetic data allows us to extend our mapping to recognise families of similarly oriented structures along-strike of currently active fault segments, targeting searches for geomorphological evidence of recent activity and representing potential sources of future seismic hazard.

Insights into an ancient world: palaeoclimate and palaeo-ecology of lake-bearing basal Clarens Formation strata near Thabana Morena, Lesotho

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Background:

The Lower Jurassic Clarens Formation records dramatic climatic fluctuations within the main Karoo Basin from dry to wet desert systems[1]. These fossiliferous aeolian-lacustrine-fluvial deposits are key for unravelling the ancient Early Jurassic environment of southwestern Gondwana and understanding the recovering palaeoecology after the end-Triassic mass extinction event.

Methodology:

Here, we assess lake deposits from the basal-most Clarens Formation near Thabana Morena, western Lesotho. Integrating macro-sedimentological observations with X-ray diffraction and X-ray fluorescence analytical techniques, we reconstruct and refine the local palaeoenvironment and palaeoclimate. Additionally, we also describe in detail, for the first time, two casts of tridactyl dinosaur footprints collected from Thabana Morena and housed at the Morija Museum and Archives (accession number: BM G.059).

Key results:

At Thabana Morena, large-scale aeolian cross-bedded, fine-grained sandstones are preserved both under- and overlying 6.8 m of grey-green silt and sandy lacustrine deposits. This suggests that dry to wet to dry climatic phases existed during the deposition of the 16.6 m thick and old Clarens strata at the study site. Major element composition of the fine-grained sediments, via the use of chemical alteration indices, show that deposition in the lake occurred under prevalent dry climatic conditions. In addition, these described Eurbontes tracks are large (track length: 29.6 m) and may be attributed to Dracovenator, a southern African theropod.

Main conclusions drawn from the results:

Our sedimentological, geochemical and palaeontological evidence from Thabana Morena is in agreement with recent studies that illustrates that the basal Clarens Formation was deposited in wet desert conditions capable of supporting diverse life forms[2]. And despite these overall dry conditions, Early Jurassic life continued to thrive at Thabana Morena, shown by the presence of fossil 'conchostracans' (bivalved branchiopod crustaceans), wood, vertebrate bones and dinosaur tracks within these Lower Jurassic strata[3].

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In-situ trace element characterisation of Fe(-Ti)-oxides of the peripheral intrusions of the Kunene Complex, Angola and Namibia

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The Kunene Complex is a Mesoproterozoic massif-type anorthosite complex situated in southern Angola and northern Namibia. This study focuses on some of the Ni-Cu-mineralised mafic/ultramafic intrusions peripheral to the Kunene Complex, investigating their economic potential through the trace element characterisation of magnetite. In recent years, magnetite has shown to be a useful petrogenetic indicator as it crystallises as an accessory mineral in various environments (e.g., magmatic, hydrothermal, and sedimentary). The behaviour of elements partitioning into magnetite is directly controlled by the crystallisation environment. When segregating with sulfides, magnetite can be used as a record of sulfide fractional crystallisation and magma enrichment. Constraining the degree of fractionation of the sulfide liquid gives an indication of how fertile the intrusions were and, therefore, it provides constraints on the potential economic interest.

Magnetite grains from seven different intrusions were analysed through electron microprobe (EPMA) and laser ablation - inductively coupled plasma - mass spectrometry (LA-ICP-MS). By combining the geochemistry with texture and mineral associations, magnetite has been differentiated into type 1: magnetite associated with sulfides with the highest lithophile element content (Cr, Ti, Al, Mn, Sc, Nb, Ga, Ge, Ta, Hf, W, and Zn). Type 2: magnetite associated with silicates and enriched in chalcophile elements. Type 3: magnetite replacing Cr-spinel with high Cr content. Type 4: hydrothermal magnetite replacing sulfides with high Ni, Co, but also high Cu (4300 ppm) and Pd (max 48 ppb), while Pt is below the detection limit. Type 5: hydrothermal magnetite crystallising as microveinlets, enriched in Ni/Cr, due to Ni solubility, and depleted in Ti, Al, Zr, Hf, Nb, Ta, and Sc. The magmatic magnetite crystallised from a sulfide liquid (type 1) is HFSE-depleted compared to Norilsk-Talnakh and Voisey's Bay, mainly due to ilmenite crystallisation. Discriminatory diagrams show that most of the type 1 magnetite crystallised form a relatively primitive monosulfide solid solution (MSS). The hydrothermal magnetite replacing the sulfides at Ombuku North (type 4) has high concentrations of chalcophiles, especially Cu and Pd, and occurs in highly altered serpentinites. Geochemical assays indicate that these rocks retain the highest Ni-Cu tenor, suggesting metal remobilisation and enrichment due to hydrothermal fluid circulation (300-550°C). Our results show that the highly altered ultramafic rocks can be considered a target for possible Ni-Cu-(PGE) mineralisation.

Investigating passive mineral carbonation in kimberlite tailings from Cullinan Diamond Mine, South Africa

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The exposure of the kimberlite tailings to the Earth's surface conditions results in silicate weathering in which CO_2 is fixed in secondary carbonate minerals. It is a well-recognized pathway for storing CO_2 in diamond mine sites [1-2]. Since this is not the intended outcome of the tailings storage facilities, carbonation occurs passively without human mediation and at zero cost to the mine [2]. Therefore, to combat climate change by mitigating carbon emissions, kimberlite tailings may represent the optimal environment to pursue mineral carbonation.

This study investigates how kimberlite tailings from Cullinan Diamond Mine respond to the Earth's surface conditions and if CO_2 is sequestered during the spontaneous reactions between the tailings and the atmosphere. A case study on Diavik Diamond Mine, Canada [1], serves as the baseline such that the main objectives include: (1) detailed characterization of the tailings; (2) verifying the occurrence of carbon mineralization by identifying the various secondary carbonate minerals and; (3) utilizing stable carbon and oxygen isotopes and radiocarbon analyses to verify the sources of carbon and the driving geochemical processes.

Various samples, including kimberlite, precipitates of secondary minerals and; pore and discharge water, were collected at the old and new slimes tailings dam. Preliminary XRF results indicated that the kimberlite tailings contain significant quantities of CaO and MgO. XRD detected various secondary minerals including carbonates in the mineral precipitates sampled in the new slimes tailings dam, and stable isotope results verified the atmosphere as one of the possible sources of CO_2. In addition, the geochemical results of the water samples indicated that the water is saline, has high pH (9.97-10.6) and is highly concentrated in SO_4, Na, Cl, Mg, K, and Ca. The dominant secondary carbonates detected by XRD include Na (trona) and Ca (calcite) carbonates; which is consistent with the results of water samples; however; no secondary magnesium carbonates were detected despite the high concentrations of Mg.

Cullinan is one of the best sites to implement mineral carbonation, since the mine has produced over a billion tonnes of tailings in the past century [3]. Therefore, the mine site can potentially offset more than its greenhouse gas emissions if passive mineral carbonation is enhanced.

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Investigation into the mineralogy and metallurgical performances of various UG2 ore-types from Hossy shaft of Sibanye-Stillwater Marikana Platinum Operation, Bushveld Complex, South Africa.

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A variety of Upper Group 2 Chromitite (UG2) ore types are recognized at the Hossy shaft these include; feldspathatic-pegmatoidal-pyroxenite, IRUP, transitional, pothole-edge, and pothole facies'. These differences pertain to the thickness of the layer, mineralogical composition, the vertical distribution of the platinum group elements, base metal sulphides, and platinum group minerals, and association with late postmagmatic such as faults, potholes, and iron-rich ultramafic replacement pegmatites (IRUP). Consequently, this project investigated the mineralogical composition and metallurgical performances i.e. milling and flotation responses of such facies-types, with a view to understanding how these features particularly IRUP affect the metallurgical behavior of the UG2 during processing. This was achieved through running a series of laboratory-scaled metallurgical tests work (both milling and flotation tests) as well as performing quantitative and qualitative mineralogical analyses using the Mineral Liberation Analyser (MLA).

IRUP-rich alteration layers on the UG2 horizons are frequently observed as conformable sheets below the reef bottom contact, where replacement of the immediate footwall (plagioclase-rich-pegmatoidal pyroxenite) unit occurs. This has resulted in the introduction of iron, titanium, vanadium, and calcium which causes the formation of phases such as titaniferous, magnetite, and ilmenite; and alteration of primary silicate minerals such as orthopyroxene and plagioclase which form low-temperature hydrous minerals e.g. amphibole, talc, and serpentine. The milling-test results show that pothole-edge and pothole facies requires the least time (25 minutes) to achieve 75 weight percentage passing 75 microns sieve compared to IRUP and transitional facies (26); and feldspathatic-pegmatoidal-pyroxenite facies (34). In addition, flotation-test results have illustrated that these ore-types follow different flotation behavioral trends, for example, the higher cumulative mass pull was recorded for transitional facies-type relative to others. However, the averagely IRUP facies-type shows relatively higher water recoveries.

Investigation of the ore mineralisation styles and alteration zones of Messina copper deposits

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Messina Copper is a unique copper deposit with its distinct style of mineralisation and alteration. The deposits were emplaced within in the granulite metamorphic facies of the Central Zone of the Limpopo Mobile Belt1,2. The mineralisation and associated pervasive alteration of the wall rock are thought to be of post-Karoo age. Three types of ores can be distinguished; brecciated, disseminated replacement, and vein/fissure type ore1,2,. The sulphides and alteration paragenesis define the characteristic concentric zoning: pyrite and sericitisation in the outer zone; an increase of chalcopyrite and bornite concomitant with albitisation and chloritisation towards the center; chalcocite, native copper, and associated epidote, zoisite, and quartz in the inner zone1,2. Two models were proposed for the origin of Messina deposit; a magmatic – hydrothermal plumbing system1 and meteoric water circulation process2. No consensus has yet been reached regarding copper mineralisation.

To investigate the relationship between ore, alteration and the gangue minerals, Tescan Integrated Mineral Analyser (TIMA) was employed specifically to identify and assess secondary minerals and trace elements associated with copper sulphides. These minerals allow comparison with other known copper deposits. Unlike typical copper deposits, Messina is characterised by reverse mineralisation and alteration. That is, the low temperature minerals are found at the core of the ore body, whereas the high temperature minerals occur in the outer parts of the body associated with subsequent chemical evolution within structural traps. Thus, the core represents the last phase of mineralisation. In addition, most of the body is not exposed at the surface, but rather buried below the surface1. Petrographic observations reveal that mineralisation zoning is from pyrite and/or molybdenite (though rare) in the outer part, to chalcopyrite – bornite, and bornite – chalcocite. These Cu-sulphides are associated with iron oxides (magnetite, hematite, and specularite). Alteration minerals are closely associated with copper sulphides and suggest that the mineralising fluids also caused alteration once they were depleted in S and Cu. In this sense mineralisation occurred by means of elemental replacement and redistribution and thus appears to be analogous to the process that form pegmatites deposit1.

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Invisible gold in the Archean detrital sulphides of the Witwatersrand tailings dumps: A large and under-exploited gold resource

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The Witwatersrand Basin is the world's largest gold province hosting over 53 000 tons of native gold predominantly in quartz pebble conglomerates. The Witwatersrand gold tailings dumps are subjected to secondary mining operations which involve traditional extraction techniques (further comminution and cyanide leaching) that lead to 30-50 % recovery of gold missed by the historical beneficiation. This leaves a projected 1325-1855 tons of refractory gold together with an estimated 30 million tons of sulphide material which reports to the discard stream after secondary mining. The mineralogical deportment of this remaining or refractory gold is not well constrained. The study is a dedicated gold deportment and ore characterization of 200 kg composite Witwatersrand tailings material from the Klerksdorp, Evander, Central Rand and Carletonville Goldfields. The tailings material is subjected to a modified preconcentration to define density fractions. The analysis involves optical microscopy, X-ray powder diffraction, quantitative evaluation of materials by scanning electron microscope, fire assay, aqua regia digestion, inductively coupled plasma mass spectrometry and laser ablation inductively coupled plasma mass spectrometry. Results from the analyses indicate that about 0,89 to 10,5 ppm of gold is distributed in the heavy mineral concentrates which are predominantly made up of sulphides (35,12 - 68,93 %), oxides (8,59 - 20,12 %). Detailed in situ analyses suggest the gold in the concentrate fraction is 'invisible-' or 'solid-solution' gold hosted predominantly in pyrite and arsenian pyrites, Au grades range from 0,01- 2730 ppm (up to 14 % of total gold in the tailings). Given that the Witwatersrand Goldfield is historically a native gold deposit, identification of invisible gold in detrital pyrites (stable under Archean surface conditions) represents a potentially under-exploited resource (up to 420 tons) which explains a portion of the refractory nature of the gold remaining after secondary mining. The implications of these findings for the economics or tailings remaining and for the genesis of the Witwatersrand goldfields will be discussed.

Is Iceland a Continental LIP?

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A popular explanation for Iceland is a deep-mantle plume. The strongest advocates of this model are typically geophysicists practicing mantle tomography and geochemists. Geologists with detailed knowledge of the local geology often are the most critical, citing observations including the distribution of volcanics in time and space and unexplained "coincidences" with major regional structures. An alternative explanation for Iceland that can holistically explain essentially all the observations without recourse to special pleading is that Icelandic lavas overlie a ribbon-like microcontinent that spans almost all the NE Atlantic Ocean.

North of present-day Iceland, the Atlantic Ocean formed at ~ 52 Ma by breakup of Laurasia along the ~ 400 Ma Caledonian suture. South of present-day Iceland the new spreading axis split the Greenland craton. At the boundary between these two geological provinces the land persisted above sea level, stretched as the ocean widened, and a transverse band of high topography persisted. This high-standing band, the Greenland-Iceland-Faroe (GIF) Ridge, remained subaerial for ~ 35 Myr before partly foundering beneath sea level. Now, the 450-km-wide landmass of Iceland is the only remaining remnant above sea level.

The GIF Ridge has been persistently tectonically unstable, deforming diffusely and featuring laterally migrating rift zones, complex transfer zones, and a 40-km-thick crust that cannot be explained as oceanic crust or mantle. The GIF Ridge decouples the regions to its north and south and these have contrasting developmental histories.

These, and other hitherto-unexplained observations, are naturally accounted for if the GIF Ridge is lava-capped, highly extended continental crust spanning the ocean. This model has radical implications for the structure and evolution of the NE Atlantic. The anomalously thick crust beneath the GIF Ridge is then largely continental and not entirely formed by melt production amplified by high temperatures at an otherwise normal spreading plate boundary. This new theory can explain why very high temperatures are not observed and why the colossal 40-km thickness of the crust cannot be explained as melt. Simply put, there are no such high temperatures and there is little, if any, excess melt thickness compared with the spreading ridge offshore. If correct, the lavas exposed in Iceland comprise a continental LIP and have intriguing implications for both continental and oceanic magmatism and geochemistry.

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Kimberlite and HIMU paradoxes: megacrysts provide the link

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Recent isotopic studies of kimberlites (e.g., Giuliani et al., 2021 PNAS; Nakanishi et al., 2021 PNAS) have suggested that these are derived from mildly depleted sources that are distinct from the upper mantle source of MORB and also distinct from extreme OIB end-members (e.g., HIMU, EM), but similar to deep mantle reservoirs that may mix with plumes during their nucleation or ascent. Additionally, recent studies of oceanic volcanism and mineral chemistry of HIMU-type ocean island basalts (e.g., Homrighausen et al., 2018 Earth-Science Reviews; 2020 Science Advances; Weiss et al., 2016 Nature) have provided evidence that (1) the HIMU end-member is far more widespread as a source component of intraplate volcanism than previously recognised and (2) the HIMU mantle end-member (characterised by high 206Pb/204Pb, intermediate 143Nd/144Nd and low 87Sr/86Sr and 176Hf/177Hf) appears to be better explained as being derived from carbonatite-metasomatised continental lithospheric mantle (possibly entrained into mantle circulation after detachment from continent) rather than from ancient subducted oceanic crust.

We present major & trace element and Sr-Nd-Pb-Hf isotope data for kimberlite megacrysts that provides evidence for an intimate relationship between the HIMU end-member and kimberlite sources. Clinopyroxene megacrysts from six southern African Cretaceous kimberlites (with ages of 114-75 Ma) span a range of compositions from mild EM1 to those similar to PREMA/FOZO to strong HIMU signatures (e.g., with 206Pb/204Pb ratios as high as 20.8). From each locality, the most primitive megacrysts (Cr-poor, with lowest Ca/(Ca+Mg) ratios) have the strongest HIMU affinity, and more evolved megacrysts formed at lower crystallization temperatures have progressively less HIMU like compositions, with megacrysts from the off-craton Gibeon and Pofadder kimberlites showing the greatest isotopic variation. The data are consistent with the megacrysts representing the products of mixing of melts of HIMU-type (or in one case, PREMA-type) sources with metasomatised continental lithosphere similar to phlogopite peridotite and MARID (e.g., Fitzpayne et al., 2020 Lithos).

The presence of strong HIMU isotopic signatures in primitive megacrysts from kimberlites present across southern Africa and emplaced over 40 Myr poses issues with deriving kimberlites primarily from a depleted PREMA-like deep mantle reservoir, and also with deriving HIMU from deeply recycled carbonatite-metasomatised lithosphere. We present trace element and isotopic modeling evidence that is consistent with primary kimberlite melts originating from a deep PREMA-like isotopic reservoir but also (at least in southern Africa) undergoing melt-rock interaction with a carbonatite-metasomatised basal lithospheric layer having a strong HIMU isotopic affinity.

Kimberlitic olivines from pipes in the Orapa, Jwaneng and Tsabong clusters in Botswana, and what they reveal about the evolution of kimberlite magmas

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Olivines in samples of coherent kimberlite from BK9 (Damtshaa mine) and AK22 in the Orapa cluster, DK2 (Jwaneng mine) and pipe 008 in the Jwaneng cluster and from pipe 0079 in the Tsabong cluster were investigated with regard to mineral composition and zoning patters, deformation, grain shape and grain size. The purpose was to evaluate the relevance of these properties for the interpretation of olivine and understand the early magma evolution.

The percentage of olivines with undulous extinction or subgrain development is low, as is the number of polycrystalline aggregates (“dunite” nodules). Brittle fracturing is common in olivines from DK2 but is a late emplacement-related phenomenon. Large grain sizes (2-10 mm) can be found over the entire range of mg# but are least common at intermediate compositions. Euhedral grains are almost absent in the samples from BK9 and AK22, rare in DK2, more common in Jw008 and dominant in the T0079 samples.

Olivine compositions follow the common pattern of core composition variation from high mg# and NiO to moderate or low NiO at low mg#, while rim compositions follow a trend from high to low NiO at intermediate and constant or slightly decreasing mg#. This pattern is interpreted traditionally as the result of incorporation of xenocrystic olivine into the kimberlite magma, where the rim overgrowth occurs. A more detailed investigation of zoning patterns and profiles reveals that some of the olivines “overshoot”, i.e. Mg-rich cores develop an intermediate zone that is more Fe-rich than the rim, or (more rarely) vice versa. Even some cores that already lie in the range of the rim composition, rarely develop an intermediate zone that is more magnesian, or even more ferrous, before the rim grows. Infiltration of a very Fe-rich magma is recorded in some fragments of Mg-rich olivine.

We interpret these zoning patterns as evidence that a number of magmas in different states of differentiation exist in the kimberlite source region, which are reconnected by the disruptive processes that trigger kimberlite eruption. Phenocrystic and antecrystic to xenocrystic (wall material) olivines of these magma reservoirs are exposed to magmas of different composition for a short time before magma mixing is complete and provides for a uniform rim growth, which is characterized by buffered Fe-Mg and sulfide extraction.

Lamprophyre differentiation within a radiating dyke and cone sheet complex around a Frederikshåbs Isblink carbonatite (SW Greenland)

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Much like along the southern west coast of Africa, several Cretaceous and Neoproterozoic lamprophyre-kimberlite-carbonatite clusters outcrop around the Labrador Sea and typically within terrane block centers of the Archean North Atlantic Craton. The carbonaceous nature of such lamprophyres and kimberlites and close spatial and temporal association with carbonatites, argue for an intimate petrogenetic relationship that has been known for some time. While both lamprophyres and kimberlites were likely generated at relatively shallower and greater depths, respectively, and very low degrees of volatile-rich partial melting of a carbonated mantle, it is less clear how more independent carbonatites form from these.

In southern West Greenland, a combined radiating dyke swarm and proximal cone sheet swarm pattern converges onto a distinct positive aeromagnetic anomaly (typical for carbonatite centers) that is currently located below the retreating edge of a Frederikshåbs Isblink glacier. Bulk major oxide chemistry from surrounding tabular intrusions reveals two suites with roughly parallel incompatible element patterns, consistent with both suites being co-genetic. The more primitive suite, with overall lower incompatible element concentrations, can be further subdivided into distinct high- and low Mg damtjernite groups, which in three cases correspond to more porphyritic and aphyric dyke cores and margins, respectively. The more evolved suite defines consistently linear element variation trends between more phonolitic nephelinite and carbonatitic endmembers, where intermediate samples have varying interstitial proportions of analcitic and carbonatitic components.

From the above results, it is proposed that damtjernitic dyke cores accumulated mafic phenocrysts and analcitic ocelli, through in situ flow segregation from more differentiated margins. The more or less anaclitic to carbonatitic suite emerged as differentiation allowed interstitial and likely immiscible analcite- and carbonate-dominated rest melts to somehow segregate into varying proportions. It is further predicted that inside the central magma chamber that all dykes and sheets of both suites were injected from, more voluminous carbonatites were more efficiently generated through analogue differentiation processes, including a combination of ultra-rapid fractional crystallization within low-viscosity melts, as well as immiscible segregations into a least dense anaclitic top and only a slightly denser carbonatitic base of a stratiform chamber. Since sodium is trapped inside a separate anaclitic phase, results do not conform to any experimentally determined immiscibility field, yet the Frederikshåbs Isblink complex nevertheless appears capable of producing calcic ± magnesian and ferroan carbonatites regardless of that.

Late Archean microbial ecosystems of the 2.52 Ga Gamohaan Formation: new insights from drill core AHL-4

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The late Archean Campbellrand–Malmani carbonate platform (CMCP) records geochemical evidence of a marine water column that was stratified with respect to oxygen, prior to the Great Oxidation Event (GOE) at c. 2.42–2.33 Ga. A recent drill core (AHL-4), transecting the shallow marine platform environment of the Kogelbeen Formation and slope to basinal Gamohaan Formation, recovered a well-preserved microbial archive from across this interval. The microbial carbonates were investigated to decipher biogeochemical cycling preceding the GOE.

The microbialites were characterized using light microscopy and laser Raman spectroscopy, concentrating on their organic microfabrics and associated sulphides. In-situ S-isotope measurements by SIMS are reported from primary sulphide grains along with bulk S-isotope analyses. Carbonate associated sulphate data (CAS) are also reported from a stromatolite of the shelf margin, contorted microbial mat of the slope, and deeper water organic-rich carbonates bearing pyrite concretions.

Large positive mass-independent S-isotope (MIF-S) fractionations are preserved in sulphide grains of the Gamohaan and Kogelbeen formations (max Δ33S = 12.6‰) confirming the operation of photolytic reactions in an anoxic late-Archean atmosphere. Small, early pyrites in fenestrate microbialites record an atmospheric signature (average δ34S = 7.6‰, Δ33S = 8.5‰, Δ36S = −7.6‰) reflecting the preservation of atmospherically derived elemental S particles. Contorted microbial mat layers exhibit large mass-dependent fractionations, with δ34S of up to 30.6‰ that plot off the Archean reference array, suggesting oxygenated seawater on the shelf-slope. Pyrite concretions in organic-rich deeper water carbonates show S-isotope values (average δ34S = 3.1‰, Δ33S = −0.2‰, Δ36S = 2.5‰) recording microbial reduction of seawater sulphate. The CAS data show positive Δ33S values up to 8.49‰ and positive δ34S values that do not reflect estimated late-Archean seawater sulphate.

The sulphide data are interpreted within the framework of depositional models proposed for the CMCP. The carbonates of the shelf margin and lagoon are depleted in organic carbon and pyrite, consistent with oxidative recycling of organic matter in an aerobic, shallow water environment. In comparison, the much darker and more organic-rich slope carbonates of the Gamohaan Formation record mixing of atmospheric and oceanic sulphur, with evidence of microbial sulphate reduction in the deepest samples. The CAS data are interpreted to record the early oxidation of sulphides carrying positive Δ33S by shallow oxygenated water in the upper diagenetic zone that moved through the sediment and was then incorporated during early digenesis into the platform carbonates.

Life and land engulfed in the late Early Jurassic Karoo lavas of southern Gondwana

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The rock record from the late Early Jurassic in southern Africa encompasses the history of voluminous continental flood basalt outpourings associated with the magmatic events in the Karoo-Ferrar Large Igneous Province in southern and eastern Gondwana. This multiphase magmatism produced one of Earth's largest continental flood basalt successions volumetrically, and is assumed to have been a main driving mechanism in late Early Jurassic global environmental perturbations, including mass extinctions and changes in climate. In southern Africa, these Lower Jurassic flood basalts are interbedded with fossiliferous sedimentary rocks, which in turn host the last signs of 'Karoo life' in the form of fossil plants, invertebrates and vertebrates, including the trackways of crocodylomorph, hopping mammals and the ultimate Karoo dinosaurs. These Karoo sandstone interbeds in the continental lava flows narrate the local palaeoecological history during a globally significant late Early Jurassic inferno. More specifically, this study explains how a complex freshwater palaeo-habitat prevailed – albeit temporarily – in this extremely stressful environment, which was unlike any modern volcanic system. The sedimentology and palaeontology of the interbeds archived depositional and biotic processes in running water as well as in and around shallow, up to ~10-m-deep freshwater lakes and ponds in the late Early Jurassic. The evidence from ichnology, stratigraphy and sedimentology collectively points to seasonally wet, warm temperate climatic conditions during the early phases of Karoo volcanism. Moreover, the evidence in the rocks also suggests that this dynamic, massive and multiphase igneous event trigged shifting habitats that likely facilitated the migration of the ultimate Karoo biota towards the north and west, away from the main Karoo land of fire, just before Gondwana started to disassemble. This refinement of the environmental dynamics in southern Gondwana presented herein lays the groundwork for future high-resolution volcanological, geochronological and chemostratigraphical studies aimed at the nuanced understanding of the global and local environmental effect of the Karoo–Ferrar and other large igneous provinces.

LIFE OF COAL- FROM COAL TO FLY ASH: Monitoring the variations in mineralogy, petrography, and geochemistry during coal combustion

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During coal combustion for electricity generation, there is the formation of clinker and large volumes of coal utilization by-products (CUP), such as coal fly ash (CFA). The physical and chemical characteristic of CFA depends on the qualities of the parent coal, coal particle size, burning method, and type of ash collector.

In Mpumalanga more than 36.7 million tons of CFA are produced annually, only 5% of CFA is used and recycled, and the rest 95% is stored in the landfill, ash dams, or ponds (Akinyemi et al., 2012). The inorganic elements in coal impact the environment, human health, and the economy therefore monitoring the variations in petrography, mineralogy, and geochemistry will aid in better understanding the life of this electricity-generating source.

This project aims to characterise the textural/petrographical, mineralogical and geochemical characteristics of five samples collected from the Secunda Sasol power plant (Mpumlanga, South Africa). The samples represent the different stages of the life of coal during the coal burning process: from the coal sample to clinker and three kinds of CFA: coarse CFA, fresh CFA, and weathered CFA. The samples were analysed for: 1) petrography and mineralogy, using microscopy, X-ray diffraction (XRD) 2) major and trace elements compositions, using X-Ray Fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry (ICPMS).

The physical changes from a consolidated black rock to unconsolidated clay-like fragments gave a glimpse into the variations in petrography, mineralogy, and geochemistry from coal, clinker, and CFAs. Petrography shows that the slightly foliated coal lost its fabric and was dominated by larger subhedral crystals in the clinker and CFAs. The domineering presence of kaolinite in coal surrendered when it came to clinker and CFAs, as they were dominated by quartz and mullite. The clinker and CFAs showed enrichment (2x) of major and trace elements when compared to coal. Coal's enrichment in SiO2, Al2O3, classified it as a CaO-rich coal. There was increase in elemental concentration of heavy metals (such as V, Cr, Ni, Cu, Zn,) in clinker and CFAs in contrast to coal.

Although, coal properties are crucial, the burning method, and type of ash collector as just as important in the variations observed. Maybe altering the burning method and type of ash collector would yield to different results.

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Lithium in Africa - where is it coming from and where is it going to?

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International agreements to limit climate change to less than a 2°C temperature increase, requires a global transition to clean renewable energy sources including an electrification of the transport sector. According to the World Bank (2020)1, society will need a 488% increase in lithium by 2050 to meet its needs for the transition to green energy and over the last 10 years there has been an increase from 27 to 71% of the total world lithium production being used for Li-ion batteries. The major source of lithium is from salars in South America, although production from pegmatites is still a significant source and is preferred to that from salars, due to a higher purity of the refined material.

In Africa, lithium production from pegmatites has occurred for more than 50 years, notably from Bikita, but most of this has been for ceramics production. Many other lithium-bearing pegmatites occur throughout Africa, notably Manono Kitololo in DRC, Arcadia and Zulu in Zimbabwe, Goulamina in Mali, Rubikon and Helikon in Namibia with many smaller pegmatites either being re-assessed for lithium in tailings or being brought into production especially in Zimbabwe. Spodumene and petalite are favoured due to the relative ease of processing whereas the most widely occurring lithium mineral – lepidolite - has not been mined extensively because of the difficulties of lithium extraction. Lepidico, an Australian company that owns the Rubikon-Helikon pegmatite deposits in Namibia plans to build a plant in Abu Dhabi to process lithium mica, while in Zimbabwe a Chinese consortium is investing $2.83 billion for an integrated battery-metals park to produce nickel sulphate and lithium salts by 2025.

Currently China controls more than half of the world's lithium processing and refining and has 75% of the lithium-ion battery megafactories in the world. It is also the world's largest lithium consumer as home production is comparatively low. Chinese companies are ensuring lithium supplies by investing in a number of the African pegmatite deposits including Bikita, Zulu and Arcadia as clearly Africa can make a significant contribution to the increased needs for lithium.

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Lithological and structural controls of gold mineralization of the MEM2 deposit in the Murchison Greenstone Belt, South Africa

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The major gold and antimony deposits of the Murchison Greenstone Belt (MGB) in South Africa are aligned along the Antimony Line, a subvertical, brittle-ductile shear-zone corridor that can be traced for some 13 km along its easterly strike in the central parts of the MGB. Mafic and ultramafic lavas and minor intercalated metasediments dissected by the Antimony Line have been locally overprinted by a pervasive silicification, carbonatization and sericitization, which is associated with the gold and antimony mineralization.

This study reports the results of detailed mapping, sampling and 3D modelling of the MEM2 deposit along the eastern extents of the Antimony Line. The study further integrates detailed petrographic work aimed at identifying the paragenesis of disseminated gold mineralization revealed by deposit-scale structural and lithological 3D modelling. Present results suggest gold mineralization to be controlled by subtle lithological variations. Disseminated gold mineralization is primarily associated with pyrite and arsenopyrite that is mainly concentrated in quartz-carbonate schists (former metasediments) that are enveloped by talc-chlorite schists (former mafic volcanics) and spatially closely associated late-tectonic mafic dykes. The relative rheological contrasts between weaker talc-chlorite schists (ductile) enveloping more rigid quartz-carbonate schists (brittle-ductile) resulted in a pronounced strain partitioning within the layered sequence. Gold-sulphide mineralization largely confined to the brittle-ductile quartz-carbonate schists suggests that fracture permeabilities in the more rigid domains preferentially controlled fluid flow and mineralization.

On a broader scale, the MEM2 deposit spatially coincides with the deflection of the regional and deposit-hosting ENE-WSW trending schistosity along a massively-developed fuchsite-quartz-carbonate plug to the immediate north. The kinematics and 3D geometry of this structural setting is the subject of further field mapping and 3D modelling.

Overall, the MEM2 deposit serves as a case study into the styles and controls of gold mineralization along the Antimony Line, integrating relevant observations from a regional-, mine- and microscopic-scale, to effectively guide exploration.

Lithological characterization of the shallow Platreef contact-style mineralization

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Along with the Flatreef reef-style deposit in uncontaminated magmatic rocks, Cu-Ni-PGE (platinum group element) mineralization also occurs at the base of the Platreef Unit within a thick succession of mafic-ultramafic rocks highly contaminated by the footwall material. On Turfspruit and Macalacaskop, this marginal style mineralization is hosted in rocks of variable textures and characterized by specific mineralogy affected by the interaction of the Platreef magma with shales and dolomites of the Duitschland Formation. The distribution of PGE at the basal contact is irregular and discontinuous that majorly resulted from assimilation of heterogeneous country rocks and have direct implications for ore processing.

The mineralogical characteristics of shallow Platreef marginal style mineralization were studied to determine the ore variability and predict flotation performance. Qualitative X-ray diffraction was used to determine the bulk modal mineralogy while the Mineral Liberation Analyzer was used to search for platinum-group minerals (PGM). Concentrations of Pt, Pd, Rh and Au (4PGE) were determined using ICP-OES. SMC Test was used to investigate the hardness and the energy required to break the rocks. Based on the five drill cores assessed, the three major rock types in the shallow Platreef deposit are norite, feldspathic pyroxenite, and feldspathic harzburgite with subordinate para-peridotite (hybrid peridotite), serpentinite, hornfels, calc-silicates and granites. Three representative samples with relatively low 4PGE grade were selected for geometallurgical testing: feldspathic harzburgite with 1.86 ppm 4PGE, norite with 0.85 ppm 4PGE and feldspathic pyroxenite with 0.50 4PGE. In terms of the bulk modal composition, feldspathic harzburgite comprises serpentine as a dominant mineral (15-30 wt. %) followed by olivine, plagioclase and clinopyroxene occurring in minor amounts (5-15 wt. %). In feldspathic pyroxenite, predominant orthopyroxene (30-50 wt. %), followed by plagioclase and clinopyroxene (5-15 wt. %) whereas norite is composed of major plagioclase (30-50 wt. %) and orthopyroxene (15-30 wt. %). In all three samples, base metal sulphides, quartz, talc, tremolite and mica are present at trace concentrations. The identified PGM species include michenerite (PdBiTe) sperrylite (PtAs2) and sobolevskite (PdBi). The Drop-weight index (DWi) from the SMC test, characterized all three rocks as hard. These first results of our ongoing study provided the background information that will be used to predict the response behaviour of this ore during processing.

Lithostructural Mapping of Neoproterozoic Basement Complex Terrane of Wawa Area, Western Nigeria: Implications for Epizonal-Orogenic Gold Potential

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The western Neoproterozoic basement terrane of Nigeria is distinguishable from its eastern counterpart due to its gold potential. Gold deposits have been reported in several areas within the western Nigeria basement complex and they are believed to have formed during the orogenic events that plagued the region of Africa about 500–700 million years ago. The study area is a southern extension of the Zuru Schist belt, one of western Nigeria's most understudied schist belts. Artisanal mining activities confirm the presence of gold mineralization in the area. This research applied geophysical datasets to map lithologies and structures within the area to assess its potential for epizonal-orogenic gold deposits. Aeromagnetic data were used for structural mapping while aeroradiometric data were employed for lithological mapping, coupled with field investigations. Structural mapping using aeromagnetic data revealed the existence of regional NNE–SSW-trending lineaments, as extensions of the Anka–Zuru–Bin Yauri fault system reported previously, and it showed as well the presence of a regional shear zone in the western part of the area. Lithological mapping using aeroradiometric data showed the presence of amphibolite and amphibole schists in the area together with granite gneiss, older granites, migmatites and migmatitic gneiss, quartz veins, and mica schist. Field investigations revealed that gold deposits in the area are mostly associated with quartz veins within amphibolite/amphibole schist and granite gneisses, which occur close to the regional lineaments. The occurrence of gold mineralization in close association with regional lineaments and rock types similar to those reported in other orogenic gold provinces worldwide indicates that the study area has high potential for epizonal-orogenic gold deposits. A geochemical investigation is recommended to further probe the findings of this study. It is concluded that lithostructural mapping within western Nigeria is crucial to the recognition of potential for orogenic gold deposits in the Neoproterozoic basement complex terrane of the area.

Magma supply and storage at Paniri volcano, northern Chile

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Paniri (22°03’S; 68°14’W) is a Pleistocene stratovolcano that forms part of the San Pedro-Linzor Volcanic Chain (SPLVC) and is spatially related to the areal extent of the Altiplano-Puna Magma Body, a region of partially molten material in the upper crust within the Altiplano-Puna Volcanic Complex, Central Andes. Basaltic-andesite to rhyolite lava and pyroclastic flows were erupted from Paniri between 1.4 Ma to 150 ka during seven major eruptive events. These rocks contain dominantly plagioclase, orthopyroxene and clinopyroxene with variable amounts of olivine, amphibole, biotite, and quartz as minor phases. Previous studies have constrained the geochemical composition and ages of different erupted products from Paniri and other SPLVC volcanoes, however the crystallization and storage history of the parental magmas are still not well constrained in the Central Andes.

Here we present P-T estimates and hence depth(s) of magma storage for different Paniri eruptions. For this, we employ clinopyroxene-melt and two-pyroxene thermobarometry using representative lava samples from each unit of Paniri, from oldest to youngest, Los Gordos, Las Lenguas, Las Negras, Viscachas, Laguna and Llareta. Our data yield a temperature range between 951 to 1028 °C and pressures between 272 to 441 MPa, equivalent to a main pyroxene crystallization interval between 9 and 15 km depth.

Our pressure and temperature estimates point to a systematic change of magma plumbing through time, indicating a shift from deeper to shallow crystallization levels during the evolution of the magmatic plumbing system at Paniri. The older (>400 ka) dacitic lavas (~63 wt.% SiO_2) show the deepest pyroxene crystallization at ~15 km depth. The 400-170 ka period, on the other hand, began with the eruption of more mafic lavas (~56 wt.% SiO_2), followed by dacitic to almost rhyolitic volcanism (up to 70 wt.% SiO_2). Pyroxene from these rocks record slightly shallower storage conditions, with crystallization peaks between 12 and 13 km depth. The youngest activity at Paniri (<170 ka), in turn, is mainly comprised of dacitic lava flows (~64 wt.% SiO_2) and contain clinopyroxene that record crystallization at <9 km depth. These temporal variations may be associated with mafic magma recharge at depth, which is indicated by low-silica volcanism at ca. 400 ka. This recharge event would have modified the magma properties (i.e., composition, density, viscosity) of the melts residing within the plumbing system and possibly facilitated potential upward migration of magma to shallower levels beneath Paniri.

Major and trace element geochemistry of olivine in the 2.06 Ga carbonatite-phoscorite Phalaborwa Complex.

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The Phalaborwa Complex (PC), being one of the world's largest sources of copper, also provides a well exposed igneous suite of rocks, including silicates and carbonatites. Aspects of petrogenesis, including mantle source compositions, and metasomatic processes, remain poorly constrained. Since olivine as an early crystallizing phase, can be linked to parental melt composition(s) and melting processes, in-situ olivine geochemistry of the PC may provide potential means to address these debated topics. Here, In-situ olivine trace and major element analysis coupled with oxygen isotopic compositions obtained from phoscorite, pyroxenite, transgressive and banded carbonate (the four primary rock types of the Loolekop intrusion) is used to elucidate the mantle source composition(s) of the PC. Using geochemical methods, such as SEM-EDS, EMPA, LA-ICP-MS as well as SIMS, a comprehensive in-situ geochemical dataset for olivine of the Phalaborwa Complex has been obtained.

Detailed petrographic examination indicates olivine modal abundances of ~36, ~20 and ~5 vol% in phoscorite, banded carbonatite and transgressive carbonatite, respectively. Associated accessory minerals such as phlogopite and apatite, veinlets and inclusions of sulphides, Ti-Fe oxides, carbonate material and apatite, alteration minerals, and serpentinized infilled fractures in olivine grains provide evidence of fluid-rock interactions. Reversed pleochroic primary and, secondary phlogopite in carbonatite veinlets give insights into metasomatic processes of the PC. Spongy and disintegrated olivine grains found in the transgressive carbonatites confirm fluid interaction and can be attributed to post magmatic hydrothermal alteration or metasomatic modification.

The vol% of olivine decreases significantly in younger rock types confirming a decrease in silica content of the primitive melt. Back-scattered electron and phase mapping augment petrographic interpretation for all rock types of the Loolekop intrusion and document homogeneity as well as minor to no intra-sample zoning. This suggests extreme interdiffusion and slow crystallization of olivine grains from the melt, resulting in compositional uniformity. Ni concentrations range from 280-320 ppm, with phoscorite having the highest concentration. Forsterite contents in olivine range for each rock type from Fo80-84 and, Fo84-89 to, Fo94-99 for phoscorite, banded carbonatite and transgressive carbonatite, respectively. This, coupled with trace element compositions (Ti/Ca), confirm a mantle origin with co-magmatic formation of the various lithologies of the PC resulting from mixing of magma batches.

Mapping features potentially related to glacio – volcanic activity in Utopia Planitia, Mars

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Utopia Planitia is one of the major depressions in Northern plains, which are filled with Hesperian and Amazonian fluvial/lacustrine and periglacial sediments (1). The basin floor is covered with structures related to water presence like channels, polygons, thumbprint terrain or buried impact craters (2). The origin of some of the observed structures is still not identified and might have been related to the endogenetic origin.

The study area is located in NW of Utopia, it covers over 32 km² of area. All features in the selected area were mapped and presented as a map. Here we show distribution and properties of a previously not mapped feature with an unknown origin present: low elevation mounds. We mapped 131 low elevation mounds. Their diameter ranges between 1 km to 7,3 km and have height from 5 to 65 m. Morphologically low elevation mounds can be divided into 3 types. Type 1 - Fractured mounds with distinct crack at the top of mound; Type 2 - Cratered mounds, with summit covered with sub-circular features; Type 3 - Smooth mounds, which do not show any particular features on their surface. The summits are covered with dark material.

Low elevation mounds resemble pingos or mud volcanoes. Compared to other martian pingos, low elevation mounds have significantly higher diameter, but show similar fractured features (3). The low elevation mounds show similar range of sizes to mud volcanoes. The summits of low elevation mounds are characterized by subcircular orifices, which are similar to those found on some of the martian mud volcanoes examples (4). Those features are most probably pingos.

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Metamorphism of the Stolzburg Block, Barberton Granitoid Greenstone Terrain: Implications for the evolution of the Archaean continental crust

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The Stolzburg Block in the Barberton Granitoid Greenstone Terrain (BGGT), South Africa, is one of the best-preserved sections of the Archaean middle crust. It comprises Paleoarchaean tonalite-trondhjemite-granodiorite (TTG) plutons and amphibolite-facies supracrustal rocks. The pressure-temperature (P-T) estimates for the mafic lithologies are in the range of ca. 7-10 kbar and 550-700 °C [e.g. 1], while until now no metamorphic conditions have been obtained for the TTG rocks due to their biotite-quartz-plagioclase assemblage that is unresponsive to metamorphic change in the relevant P-T range. Despite these limitations, some geodynamic models have proposed distinct P-T conditions for the two lithologies [e.g. 2]. In this contribution, the validity of these models is assessed by obtaining temperature estimates for the granitoids. We present estimates of metamorphic temperatures for the TTG rocks in the form of Ti-in-zircon and Zr-in-titanite temperatures, complementing the published P-T estimates for the associated greenstones, along with trace-element data for apatite, titanite and zircon grains as well as Sr isotope data for whole-rock and apatite samples. Temperature estimates from metamorphic titanite and zircon grains indicate that metamorphism of the TTG rocks occurred at up to 700 °C, in agreement with the conditions reported for the associated mafic lithologies. Apatite grains show a preservation of primary, igneous REE and Sr isotopic compositions, while their U-Pb isotope systematics have been partially reset in three distinct metamorphic events. There is no correlation between the apparent age of an apatite zone and its trace-element and Sr isotopic composition. The preservation of igneous signatures in apatite despite heating to up to 700 °C implies that the duration of peak metamorphism was relatively short (< ~200 kyr). The results of this study argue against some of the proposed geodynamic models for the assembly of the Stolzburg Block and the BGGT implying a long-lasting high-temperature event. Our study indicates that the felsic Archaean crust preserved in the Stolzburg Block was relatively cool and stable and that metamorphic processes were short-lived.

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Microbially induced sedimentary structures in Archean clastic lithologies and their modern counterparts

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Microbially induced sedimentary structures are microbialites that occur in clastic deposits, both modern and fossil (Noffke et al., 2022). The earliest examples have been detected in the Dresser Formation of the Pilbara Craton in Western Australia (Noffke et al., 2013). However, also the Barberton Greenstone Belt, and the Pongola and Witwatersrand Supergroups, South Africa, and the Nama Group, Namibia, include many examples that were detected in marine shelf, lagoonal, tidal and fluvial sedimentary rocks (Noffke, 2010). Such structures do not resemble stromatolites but have planar morphologies. Example structures are multidirectional ripple marks, polygonal oscillation cracks, wrinkle structures, mat chips and roll-ups. Textures, visible in thin-section, include oriented grains, microsequences, and many more.

Such structures do not only provide evidence for early life on Earth, but also allow insight into paleoecology and paleoenvironment. The Pongola Supergroup includes an entire series of microbial structures recording a climate change from tropical to subtropical-semi-arid to moderate. Storm frequencies and intensities are recorded as well as current directions and tidal patterns. Stratigraphic profiles in the Nama Group, the Witwatersrand Brixton Formation, and others document that ancient microbial mat systems established with transgressions during sea level rises.

The interpretation of microbially induced sedimentary structures of Archean ages is facilitated by studies that monitor the formation of such structures in modern environments. Such comparison allowed the identification of facies zones and their physical characteristics that host specific microbial structures. Indeed, a paleoenvironmental reconstruction or stratigraphic analysis based on microbial structures has a very high resolution.

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Microfossil detections in the Palaeoarchaean Barberton Greenstone Belt

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Given the great age of the 3.5-3.3 Ga Palaeoarchaean sedimentary formations of the Barberton Greenstone Belt, it is popular to underline the importance of one's own investigations as being innovative and state of the art, while suggesting at the same time that previous studies were either wrong or outmoded. Identification of the traces of ancient life forms (biosignatures) is a case in point. While optical microscope studies of purported microbial filamentous fossils from the Barberton Greenstone Belt [1] have recently been corroborated by a combination of different, sophisticated techniques including in situ synchrotron radiation and ToF-SIMs [2], similar investigations of in situ microbial biofilms have been unjustly denigrated as being modern contamination (i.e. lack of syngeneity).

Reliable identification of microbial biosignatures is best supported by use of a variety of techniques that document morphological details, the structure and composition of organic molecules associated with the morphological structures, as well as other accessory information related to microbial metabolism or life style, including evidence for bio-mediated processes, for example precipitation of a mineral phase (e.g. carbonate, iron minerals), formation of a biostructure or interaction with the immediate environment (e.g. stromatolites, MISS) [3,4].

Here, we present a combination of optical microscope, scanning and transmission electron microscope observations, together with Raman spectroscopy and µ-XANES analyses that clearly document the biogenicity and syngeneity of a 3.33 Ga stack of microbial biofilms formed on the surface of periodically-exposed near-shore, volcanic sediments [5,6]. What we underline here is the importance of rational understanding of microbial biofilms and their preservation based on knowledge of biofilm formation in analogue modern environments and the simulated fossilisation of microorganisms that inform interpretation of potential biogenic signatures, especially those in the oldest, well-preserved sediments on Earth.

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Microseismicity associated with the Hebron Fault scarp, a major neotectonic earthquake rupture in SW Namibia

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The Hebron Fault scarp lies within southwestern Namibia, a stable continental region. This 45 km long scarp with an average height of 5.5 m resulted from normal reactivation of the Nam Shear Zone and is expressed prominently in Quaternary sediments and Proterozoic basement. In Quaternary sediments, the scarp is well preserved in places due to the calcretisation of alluvial gravels. Where the scarp crosses uncemented, more recent surfaces, it is diffuse but remains mostly visible. Fault scaling relationships suggest the scarp formed in 2–5 events of Mw ~7 on the upper limit of previously studied normal faults in stable continental regions. Interestingly, geomorphological analyses only found evidence for a single event suggesting that the scarp could have formed in a single unusually large event.

In common with other major paleoseismic fault scarps in South Africa and Namibia, the International Seismological Centre earthquake catalogue contains few earthquakes located in the immediate vicinity of the Hebron Fault. This apparent mismatch between the density of small earthquakes in the recent instrumental record and the location of large earthquakes recorded in the landscape poses important questions about how to identify areas of future hazard. In order to investigate the possibility that low-magnitude seismicity below the detection threshold of the regional catalogue may cluster around such structures we installed a network of 23 4.5Hz three component geophones around the Hebron fault scarp.

Earthquakes were identified using a STA/LTA coincidence trigger and P and S wave arrivals were manually picked. After inverting for a one dimensional velocity model, more than 130 earthquakes were located near the Hebron Fault. The majority of earthquakes occur at depths from 10–15 km to a maximum depth of 20 km. A regression through the hypocentres results in a plane with a strike of 136° and a dip of 58° to the south-west. Observed earthquakes at the Hebron Fault may either represent a long-lived aftershock sequence or a form of background seismicity associated with the fault. Our results suggest that the densification of station coverage and targeted local geophone deployments could greatly assist in identifying active faults in the region. Earthquakes could also help to locate the causative faults of historical earthquakes in areas where geomorphological preservation is poor. The possibility that these events represent an extremely long-lived aftershock sequence has important implications for the interpretation of seismic clusters within the region and should be investigated further.

Mineralogical and geochemical characterization of the Gamsberg zinc deposit

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Controversy still surrounds the genetic model of the Aggeneys-Gamsberg Pb-Zn-Cu-Ag deposit. For the Gamsberg zinc deposit, Stalder et al. (2004) proposed a differentiation of the depositional basin into oxygen deficient basin facies hosting sulphide ore and oxygenated shelf facies which are composed of manganiferous iron formations, based on non-opaque minerals that are closely associated with the ore. However, HÖhn et al. (2020;2021) used Cu isotopes to argue that the Aggeneys-Gamsberg ore district experienced deep oxidation of the primary sulphides between the Okiepean and Klondikean orogenic events, changing into a nonsulphide deposit. During the Klondikean orogeny, re-sulphidation of the ore occurred and formed the current sulphide ore bodies.

This study presents a detailed mineralogical study of sulphide minerals at the Gamsberg zinc deposit using QEMSCAN, EPMA and LA-ICP-MS data to reveal characteristics of, and relationships between sulphide minerals as well as implications on the genetic model.

There are at least five types of pyrite recorded in the basal pelitic ore of the Gamsberg zinc deposit: anhedral inclusion-rich pyrite and pyrite cores as well as disseminated pyrite microcrystals (Py1), inclusion-free, subhedral to euhedral pyrite (Py2), granoblastic pyrite (Py3), mottled pyrite-sphalerite (Py4), and pyrite in durchbewegung textures (Py5). Pyrite1 is richer in lattice bound trace elements Co, Ni, Se and As whereas its Py3 rims are poor in these elements. Pyrite4 contains the highest Co and Ni, and the lowest As of all pyrite types.

These observations indicate that there are at least five phases of pyrite formation in the pyrite-dominated metapelitic ore: syngenetic to diagenetic Py1, hydrothermal Py2, prograde to peak metamorphic Py3, retrograde metamorphic Py4, and brittle deformation Py5. In the better-preserved pyrite-dominated ore of the north ore body, Py1, 2 and 3 co-exist with sphalerite that shows diffusion zoning associated with re-equilibration during retrograde metamorphism. At the south and west ore bodies, pyrrhotite forms at the expense of pyrite. This pyrite-to-pyrrhotite co-exists with sphalerite of two contrasting compositions, one of hingher Fe and Mn and the other of higher Zn and Hg. The pyrite-dominated ore is undeveloped at the overturned east ore body, and sphalerite there contains the highest MnS mole % along with alabandite inclusions. The pyrite-dominated ores' pyrite and sphalerite textures and trace elements are comparable to other SEDEX deposits that have experienced regional metamorphism above upper greenschist facies. Despite metamorphic overprinting, the sulphide minerals reveal some important parts of the deposits history.

Mineralogy of Secondary Copper Minerals Forming on Sulphide Slag from the Okiep area, Northern Cape

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The mode of formation of secondary minerals on ageing slag dumps, particularly those which introduce levels of toxicity into the environment, was investigated using applied mineralogy techniques.

Slag samples were taken from two historical copper smelting sites in the OKiep area (1,2). The first site is close to Jubilee Copper Mine, where slag was produced in a blast furnace until 1930. Samples of granulated converter slag were also taken from the concrete apron at Nababeep, where smelting operations ceased in 2007.

Samples were examined and analysed using light microscopy, and SEM-EDS at the Universities of Cape Town and Stellenbosch. Selected samples were also analysed by XRD, XRF, LECO and ICP-MS to provide additional information.

Although the two primary slags have comparable composition and produce similar secondary minerals, textural differences were noted both on a large and a microscopic scale.

The use of low-vacuum SEM on secondary samples proved especially helpful as traditional treatment often results in material being lost, damaged and/or misidentified. Drawbacks included skewing of EDS results due to topography, but electron imaging provided crystallographic information.

A bewildering variety of copper- and copper-iron sulphates were recorded. The identification of doubly terminated antlerite ((Cu3SO4(OH)4)) is interesting as it is relatively uncommon and prefers arid areas. Curved crystals of developing brochantite ((Cu4SO4(OH6)) probably reflect seasonal periods of deposition and dissolution. The similarity between brochantite formation on Nababeep slag and slag from Argent Mine in Gauteng (3) is informative and shows transport of copper sulphate from weathering matte to the site of deposition. Partially altered matte gives insight into the source of the copper-rich fluids and confirms that the residua in an undisturbed setting are hydrated iron oxides. Which copper sulphate forms may sound irrelevant, but each sulphate possesses a different solubility, and this will affect ease of leaching into the environment.

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Mode of Occurrence and Origin of Iron Ore deposit: A case study of Ga-Nchabeleng Area, Limpopo Province, South Africa

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Background

The study area falls within the Sekhukhune District Municipality in Limpopo province. It is situated near the contact between the Bushveld Igneous Complex and the Transvaal Group sedimentary rocks. The aim of the study was to establish the mode of occurrence and origin of iron ore deposits at Ga-Nchabeleng area.

Methodology

The outcrops of the iron ore cover mainly the four hills with the host rocks forming mainly contacts between the iron ore. The geological mapping was conducted along traverses drawn across the general strike of the lithology. Iron ore and host rock samples were collected at an exposed area within and around four hills. Ore sampling was done following the trend of the ore deposits. Collected rock and iron samples were physically and geochemically characterised and X-ray fluorescence spectrometry method was used for selected samples for geochemical characterisation.

Key Results

Petrographic and ore microscopy was used for mineralogy, textural and grain size analysis. Petrographic study revealed the present of feldspar in the gabbronorite, and high concentration of oxides mineral and Ore microscopy revealed the more oxides minerals. The oxides minerals were identified as hematite at low content and magnetite at high content.

Main Conclusions

The study concluded that the iron ore is hosted by intermediate to felsic igneous rocks which were found to be gabbronorite and the magnetite ore formed stringers zones that were randomly oriented veins associated with fractional crystallization of the layered complexes. The magnetite ore within the study area was of good grade with average value above 50% and rich in V, Cr, Ni, Zn and Co.

Keywords:

Iron ore, Bushveld Igneous Complex, Rustenburg Layered Suit, Ga-Nchabeleng, Mode of occurrence

Monitoring seismic sources and volcanic processes in the near field and the anticipation of tectonic events in Costa Rica

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The Costa Rica Volcanological and Seismological Observatory, at the National University (OVSICORI-UNA), operates a very dense and countrywide geodynamic control network of over 100 stations, with broadband seismic sensors, strong motion instruments and/or cGNSS receivers. In addition to this regional network, it maintains seismic, geochemical, and geodetic instrumentation at 9 active volcanoes.

Although Costa Rica, in Central America, is a small country - only half the size of Malawi - it is exposed to the interaction of 4 tectonic plates generating seismicity and volcanism associated with 5 plate boundaries. As a result of these active tectonics, OVSICORI-UNA locates around 1000 earthquakes per month, and the population of Costa Rica feels around 150 earthquakes per year.

Four peninsulas sit over the seismogenic zone of large subduction earthquakes allowing the recording of deformation in the near field and the anticipation of large earthquakes. I'll be presenting the successful case of anticipation of the Nicoya 2012 Mw=7.6 earthquake.

Real time monitoring of active volcanoes allows OVSICORI-UNA to provide immediate information to civil defense authorities and volcano park rangers. Since all volcanoes in Costa Rica are national parks, with permanent tourist visitation, providing prompt and truthful information is indispensable to save lives.

There is an interest from researchers at OVSICORI-UNA to share our experience and learn from other observatories. Therefore, this African Geological Congress represents an excellent opportunity to interact with African colleagues, specially from those countries along the African Rift Valley, and begin an academic exchange that could lead to mobilization of personnel through internships and sharing of data for joint research.

Mortar texture and magma dynamics in the massif-type anorthosites of the Kunene Complex, Angola

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Background

A characteristic feature of Proterozoic massif-type anorthosites is 'mortar texture'—plagioclase primocrysts surrounded by mantles of finer-grained plagioclase neoblasts, where the expulsion of Fe–Ti oxide inclusions from the plagioclase primocrysts during recrystallization gives the rock a distinctive bleached appearance. The apparent lack of comparable recrystallization in mafic interstitial phases in these rocks has led some authors to suggest that these textures were produced by mechanical abrasion during flow of a crystal-rich magma, for example during ascent and emplacement. However, these interpretations were largely based on qualitative observations or relied on methods that can be significantly improved on today. Previous research has shown that the formation of massif-type anorthosites requires ascent of plagioclase flotation mushes from Moho levels, so these are necessarily crystal-rich systems, yet many questions remain concerning the nature of these mushes and their mode of emplacement. Therefore, a study of mortar textures has the potential to shed light on some fundamental aspects of anorthosite petrogenesis.

Results and preliminary conclusions

We used electron backscatter diffraction (EBSD) to conduct a detailed, quantitative microstructural study of mortar textures in the Kunene Complex (KC) of Angola—the largest Proterozoic massif-type anorthosite complex in the world. In the KC, mortar textured anorthosite commonly occurs as intensely laminated, kilometre-scale, dominantly NE-trending belts. Our EBSD results show that the fabrics (crystal preferred orientations) in these rocks show a strong inherited magmatic component. However, the interstitial mafic phases in these rocks are also deformed, and although deformation likely started under melt-present conditions, the majority of the recrystallization that defines the mortar texture took place under subsolidus conditions, by dislocation creep. Our study suggests that the deformation that produces mortar textures in massif-type anorthosites cannot be due entirely to internal stresses caused by the emplacement of the anorthosite itself, as has previously been suggested, but is a response to external tectonic forces. This then raises the question of whether it is the nature of pre-existing magmatic fabrics or the rheological properties of plagioclase-dominated rocks that makes mortar textures ubiquitous in massif-type anorthosites complexes.

Multiple mantle components for lavas of the Tuli basin, Karoo LIP

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The Tuli basin in Zimbabwe and Botswana is one of the largest and best-preserved remnants of rift-related sequences associated with the Karoo Large Igneous Province (LIP) of southern Africa. Early Jurassic tholeiitic high-Ti picrites and basalts mostly represent the continental LIP volcanism in Tuli, but lower-volume alkaline rocks are also found in the volcanic sequence. Here we present new whole-rock major and trace element and Sr-Nd-Pb isotope data for the alkaline volcanic rocks from the Tuli basin. We have identified three distinctly different groups of alkaline rocks: 1) nephelinites (K_2O/Na_2O < 0.5), 2) potassic (K_2O/Na_2O = 0.5 to 2), and 3) ultrapotassic rocks (K_2O/Na_2O > 2). Nephelinites are characterised by an incompatible trace element enrichment, positive Nb-Ta anomalies, and radiogenic $^{87}Sr/^{86}Sr_i$ (0.705 – 0.707) and low εNdi values (-7.0 to -6.7) and Pb isotope ratios ($^{208}Pb/^{204}Pb$ = 37.83 – 38.07; $^{207}Pb/^{204}Pb$ = 15.49 – 15.52; $^{206}Pb/^{204}Pb$ = 17.55 – 17.61); potassic rocks by high concentrations of incompatible trace elements, positive Nb-Ta anomalies, radiogenic $^{87}Sr/^{86}Sr_i$ (0.705 – 0.706), unradiogenic εNdi (-8.3 to -4.5) and highly radiogenic Pb isotope ratios ($^{208}Pb/^{204}Pb$ = 38.89 – 39.54; $^{207}Pb/^{204}Pb$ = 15.59 – 15.65; $^{206}Pb/^{204}Pb$ = 17.75 – 18.31); and ultrapotassic rocks by a very pronounced positive K anomaly, negative Nb-Ta anomalies and BSE-like Sr, Nd and Pb isotope ratios ($^{87}Sr/^{86}Sr_i$ = 0.704 – 0.705; εNdi = -1.7 – -1.1; $^{208}Pb/^{204}Pb$ = 38.10 – 38.20; $^{207}Pb/^{204}Pb$ = 15.51 – 15.55; $^{206}Pb/^{204}Pb$ = 17.60 – 17.78. We show that each alkaline rock type represents a distinct source component, thus the mantle source is interpreted to be heterogeneous beneath the Tuli basin. These source components resemble the more geographically dominant SCLM signature, but also support varied metasomatic inputs that are likely related to subduction-driven processes that affected the base of the SCLM prior to the Karoo magmatism.

Multiple sulphur isotope signature of the Uitloop mafic/ultramafic and footwall lithologies, northern limb of the Bushveld Complex

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We present an integrated study of sulphide mineralogy and multiple S isotope composition of the Lower Zone and Platreef as well as footwall rocks from the Zebediela Project on the Uitloop 3KS farm. The Uitloop mafic/ultramafic and footwall rocks are richly endowed in base-metal sulphides (BMS); the sulphide content is highly variable and generally increases towards the footwall contact. The BMS mainly consist of pyrrhotite, pentlandite, and chalcopyrite, which occur in mafic/ultramafic rocks as disseminated and blebby aggregates and in the footwall as widespread blebby to net-textured mineralization and less common massive veins. There is evidence of sulphide melt fractionation in both the footwall and mafic/ultramafic samples, where the sulphide blebs consist of a pyrrhotite core with exsolved and granular pentlandite, whereas chalcopyrite is generally confined to their rims. The sulphides are commonly associated with platinum-group minerals (PGMs) and tend to be replaced by secondary sulphides (e.g., pyrite, chalcocite, millerite and violarite) and violarite-rich silicates. The main sulphide assemblages observed in the studied samples are Po – Pn– Ccp ± Py and Po – Py – Ccp ± Mil ± Cc. Multiple S isotope compositions have been used to constrain the source of S and the timing of S addition in the Bushveld mineralised zone and deposits. The main BMS in the Uitloop footwall and ultramafic rocks from 10 drill-cores were analysed for multiple S-isotope composition. The δ34S values range between –6.3 ‰ and +15.2 ‰ for the Duitschland Formation, –0.4 ‰ and –0.7 ‰ for the Penge Formation, and +2.1 ‰ to +7.1 ‰ for the Malmani Group. The Δ33S values for these rocks range from –0.26 ‰ to 4.15 ‰. Pristine Platreef magmatic rocks show near-zero Δ33S values and δ34S values of 0 ‰ to +2 ‰, whereas the Uitloop Platreef contaminated rocks show a wide range of δ34S values between –0.8 ‰ and +12.1 ‰ as well as Δ33S values ranging from –1.8 ‰ to +0.13 ‰. Lower Zone sulphides yielded similar δ34S and Δ33S values between – 0.3 ‰ to +12.8 ‰ and – 0.2 ‰ to +0.35 ‰ respectively. This sulphur isotopic composition of the Platreef and Lower Zone is indicative of the incorporation of Archaean surface-derived material into the magma, suggesting magma and country rock interactions in the magmatic chamber.

Nature and origin of the Jwaneng kimberlite (pipe-8) from the NW margin of the Kaapvaal Craton, Botswana

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The Jwaneng kimberlite located on the northwest margin of the Kaapvaal Craton, southern Botswana is diamondiferous and Mesozoic in age (235 Ma). Its formation has been linked to the dispersal of Gondwana from the Pangaea supercontinent overlying the African large low shear-wave velocity province. The Jwaneng kimberlite is famous for being the richest diamond in the world and producing large quality diamonds with (e.g., the third largest diamond worldwide 1093 carats was discovered in June 2021). Therefore, most research has been diamond focused leaving a relative dearth of information about the kimberlite itself. Here, we provide a detailed petrographic study of the Jwaneng kimberlite, along with whole-rock geochemical data, in-situ mineral major and minor element data and preliminary Sr-Nd-Hf isotope analyses of the Jwaneng kimberlite pipe-8. Petrographically, the Jwaneng kimberlite consists of olivine, phlogopite and garnet set in a groundmass of olivine, serpentine, spinel, perovskite, Mn-ilmenite, carbonate, and minor phlogopite which suggests a strong affinity to Group-I type. The whole-rock data also indicates that major element concentrations have a strong affinity to Group-I kimberlites, whereas the trace element data is more compatible with Group-II type and this may suggest that the source of the kimberlite had a metasomatised component incorporated into it as a result of alteration processes (e.g., carbonatization and deuteric alteration). However, this does not necessarily mean that this a true Group-II kimberlite type. The kimberlite pipe displays high concentrations of Pb, K, Ba, LREE and low Nb, suggestive of a strong affinity to Group-II type and possibly sourced from a deep metasomatized continental mantle lithosphere. The Jwaneng Th/Nb, Ba/Nb, La/Nb ratios are slightly elevated, and plot well within the Group-II kimberlite field compared to other kimberlites from Southern Africa.

Based on major and trace element ratio partitioning data, we suggest that the primitive kimberlitic melt was initiated as a partial melt (~1%) of deep metasomatized SCLM at pressures > 6 GPa equivalent to depths ≥150-230 km. The in-situ major element data of olivine/spinel/phlogopite gave important insights to the overlapping compositions between Group-I and Group-II kimberlites on the and the preliminary Sr-Nd-Hf isotope data displays concentrations that have a strong affinity to Group-II kimberlites. Considering the petrographical mineralogical and whole rock data, we propose that Jwaneng is possibly a Group-I or transitional kimberlite type with a strong affinity to Group-I kimberlites (also supported by preliminary Sr-Nd-Hf isotope data).

Network-based biostratigraphy for the late Permian-mid Triassic Beaufort Group (Karoo Supergroup) in South Africa enhances biozone applicability and stratigraphic correlation

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The Permo-Triassic vertebrate assemblage zones (AZs) of South Africa's Karoo Basin are a standard for local and global correlations. However, temporal, geographical and methodological limitations challenge the reliability of the Karoo AZ framework. We analyze a unique fossil dataset comprising 1408 occurrences of 115 species grouped into 19 stratigraphic bin intervals from the Cistecephalus, Daptocephalus, Lystrosaurus declivis, and Cynognathus AZs. Using network science tools we compare six frameworks: Broom, Rubidge, Viglietti, Member, Formation, including a framework suggesting diachroneity of the Daptocephalus/Lystrosaurus AZ boundary (Gastaldo). Our results demonstrate that historical frameworks (Broom, Rubidge) still identify meaningful AZs, and can be useful in corroborating frameworks that identify more unique Karoo Basin AZs. None support the Cistecephalus AZ, and it likely comprises two discrete communities. The Lystrosaurus declivis AZ is traced across all frameworks, despite many shared species with the underlying Daptocephalus AZ, suggesting the extinction event across this interval is not a statistical or methodological artifact. A community shift at the upper Katberg to lower Burgersdorp formations may indicate a depositional hiatus which has important implications for regional correlations, and Mesozoic ecosystem evolution. The Gastaldo model still identifies a Daptocephalus and Lystrosaurus AZ community shift, does not significantly improve recent AZ models (Viglietti), and highlights important issues with some AZ studies. Localized bed-scale lithostratigraphy (sandstone datums), and singleton fossils cannot be used to reject the patterns shown by hundreds of fossils, and regional chronostratigraphic markers (i.e., subaerial unconformities, index fossils) of the Karoo foreland basin. Meter-level occurrence data also suggest that 20-50 m sampling intervals capture Karoo AZs. This unifies the use of meter-level placements of singleton fossils to delineate biozone boundaries, and improves Karoo AZ applicability for correlations across southern and eastern Africa, and globally.

New insights into the Platreef at Sandsloot: Magmatic stratigraphy and Ni-Cu-PGE distribution

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The northern limb of the Bushveld Complex, South Africa, is widely regarded as one of the world's largest resources of platinum-group elements (PGEs)[1]. These PGEs, as well as significant amounts of base metals (Ni, Cu, Co), are critical for many modern technologies. As a result, it is becoming increasingly important to re-visit our understanding of these deposits, particularly as brown-field exploration at sites such as Sandsloot, continue to illustrate the complexities present in the Bushveld Complex.

The Platreef forms the major PGE-Ni-Cu-Co deposit, and is part of a complex package of Critical Zone (CZ) rocks in the northern limb which have been mined at the Sandsloot by Anglo American since 1993. The Platreef differs to the wider Bushveld in that high grade PGE mineralization is spread over a much greater thicknesses compared to the Merensky Reef of the eastern and western limbs, as well as significantly higher base metal contents, and a higher Pd/Pt ratio[2]. The Platreef also differs as it lies north of the Thabazimbi-Murchison lineament, and rests directly on the metasedimentary Transvaal Supergroup, and accompanying footwall structures. These structures are likely to have had a significant impact on the emplacement and magmatic pathways of the northern limb magmas and resultant stratigraphy. Additionally, footwall contamination is known to have created significant variation in Platreef mineralogy and geochemistry along strike[3].

In this study, the petrology and bulk geochemistry of samples from Sandsloot are examined, with the aim of establishing the primary magmatic stratigraphy of the newly discovered deep Platreef, down-dip of the Sandsloot open-pit. The Platreef is thought to have formed from discrete magmatic units, each with their own grades, geochemistries and thicknesses[4], and several packages are identified at Sandsloot, which correlate both along strike and up-dip to varying degrees. Significant PGE and base metal mineralisation are observed in some, but not all of these packages. Contamination from the underlying Malmani Dolomite is evident in both the geochemical signatures and enigmatic hybrid textures of the Platreef rocks. Variations in unit thicknesses and stratigraphy are proposed to be controlled by the footwall architecture, in particular the Dolomite Tongue, the source of the individual CZ magmatic packages and the intrusion of Main Zone magmas post Platreef emplacement.

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New petrological and geochemical insights into the mantle sources and origin of the Marginal Zone of the Bushveld Complex

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Background

The Marginal Zone is a suite of crustal xenolith-bearing noritic rocks that occurs at the base of the Rustenburg Layered Suite (RLS) of the Bushveld Complex and as sills in the Transvaal Supergroup. The Marginal Zone has been postulated to represent the parental magmas of the RLS.

Methodology

This study resampled the Marginal Zone in the Eastern Limb of the RLS to conduct a new petrographical and geochemical study and to provide fresh insights into its origin.

Key results

The Marginal Zone has been divided into three chemical groups known as B1, B2, and B3. The B1 group (15.7 wt.% MgO; 55.3 wt.% SiO2) consists of spinifex-textured orthopyroxenites with interstitial comb-textured plagioclase. The B2 (51.6 wt.% SiO2; 5.5-14 wt.% MgO) and B3 (4.4 wt.% MgO; 50-53.2 wt.% SiO2) groups consist of medium-grained gabbros with similar intergranular textures, although the B3 group contains more biotite and clinopyroxene. Primitive mantle-normalised multi-element spider show prominent positive Pb anomalies and smaller positive U, Nd, Eu, and Tb anomalies. The positive Eu anomaly is most pronounced on the B3 group. Additionally, the B2 and B3 groups have positive Ba anomalies that are absent on the B1 group. There are also negative Zr, Hf, Ta, Nb, P, Ti, and Yb anomalies. The Marginal Zone overall shows L/HREE-enrichment, but with Ce/Ybn decreasing from B1 (8.6) to B2 (6.5) and to B3 (4.3). The Marginal Zone has low Sm/Ybn (0.4-0.8), TiO2/Yb (0.7-1.7), and Nb/Ybn (0.2-0.8).

Main Conclusion

The low Sm/Ybn, TiO2/Yb, and Nb/Ybn .suggests its parent magmas were derived by the partial melting of a shallow lherzolitic mantle source. However, the weak Eu anomaly on the B1 and the B2 group could indicate the melting of a mantle with a spinel lhezolite composition. The pronounced positive anomaly on the B3 group could indicate the melting of a mantle with a plagioclase lherzolite composition. We suggest that the Marginal Zone rocks are not representative of the parent magmas to the overlying cumulates of the RLS. Instead, the parent magmas to the Marginal Zone appear to represent crustally contaminated residual melts derived from the underlying magmatic plumbing system to the RLS.

No LIP Service to Mantle Plumes

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Large Igneous Provinces vary considerably. For example, the "big four" southern Africa LIPs, the Umkondo, Bushveld, Ventersdorp and Karoo, are very different despite having formed in the same general geological region. It thus makes sense to explore different theories for them, instead of assuming the same cause and proposing ad hoc, untestable special factors to explain their differences. That approach introduces confusion, well-illustrated by the diversity of suggested source compositions, depths and processes. These include crust, SCLM, re-enriched or not, asthenosphere, and deep plumes with or without heterogeneities.

The assumption of plumes regardless of observations leads to a dead end. LIPs generally fit the model poorly and it does not help to attribute every observation and its inverse to plumes. If vast volumes of homogeneous tholeiite are explained by plumes, it is perverse to attribute also to them diverse petrologies via "heterogeneous domains". Likewise, if plumes are considered capable of pancaking beneath the ancient cratonic lithosphere, producing widespread uplift and volcanism, they cannot then be claimed to erupt through narrow conduits and avoid heating ancient diamond-bearing lithosphere. The Ventersdorp basalts erupted over ~100 Myr – much longer than claimed for plumes. The Karoo is associated with continental breakup but plumes cannot split continents and constant repetition of this claim does not make it true. A sub-lithospheric source does not equate to a deep plume. The claimed centers of the big four in a similar region is an argument against plumes, not for them. That region is the confluence of three continental rifts and unlikely to be a coincidence.

There is a need to return to basics and carefully assess the structural settings of these LIPs. Although basaltic magmas may flow considerable distances from their feeders, the concept of localized "centers" for LIP-sized volcanic provinces thousands of kilometers across is unrealistic. We need to accept that geochemistry has very little power to reveal the depth of origin of materials. No geochemistry requires a core-mantle-boundary source. Claims that "most people believe" in plumes is not a scientific argument. In many publications, all mention of plumes could be eliminated without significant loss of content. It is absurd to ignore the role of the lithosphere. We need to critically examine our assumptions, ask what is required by our observations, what is the simplest way of explaining them, and what is the best way to test this.

Observations from a previously unmapped block of granite: fieldwork by first principals

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Background:

The Saldania belt is a structurally complex fore-arc region representing multiple stages of deformation, sedimentation and plutonism (1). Intrusions of the Cape Granite Suite associated with the deformation Saldania Belt are considered syn- late- and post-tectonic (1). Although the geology of South Africa has been mapped extensively at several scales, many regions were mapped decades ago. Our geological understanding has improved since and areas have been found to have been mapped incorrectly (2). Where the regional structural geology is incorrectly mapped and construction and development take place, serious consequences can transpire (3).

Methodology:

Geotechnical and subsequent geophysical investigations undertaken in the central portion of the Tygerberg Terrane have revealed the presence of a previously unmapped block of granite surrounded by sediments of the Malmesbury Group.

Key Results:

Soils observed in trial pits comprised angular quartz grains with relict foliation structures indicative of a residual material of igneous origin. Interpretations of electrical resistivity tomography data, collected perpendicular to the strike of the Colenso fault, revealed that pinnacles and core stones of weathered granite are ubiquitous across the traverse.

Main conclusions drawn from these results:

These findings highlight a need to validate existing geological maps, for example along the Colenso fault by means of detailed investigative works, such as trial pitting and drilling, and geophysical surveys. Detailed characterisation of previously unmapped/incorrectly mapped lithologies is an important step in understanding the nuances of syn-tectonism of granite emplacement along the Colenso Fault, and detailing geo-structural features relevant to development in South Africa.

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Observed mechanisms leading to capacity loss in the Gariep Dam in the Orange River of South Africa due to global change

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This study recorded the water capacity loss in dams through sedimentation, using remotely sensed means. This research was especially driven by the COVID19 epidemic, causing restrictions of movement of people, and an inability to do maintenance on water infrastructure. The focus fell on the Gariep Dam in the Orange River of South Africa. Recent satellite imagery and archived mapped information was used in the evaluation process. Special emphasis was placed on the recent regional extreme condition. The image database consisted of the publicly available Sentinel, Landsat and Google resources, made available through ARCMAP. All observations were tested through a field visit. The focus of the investigation was to observe temporal changes, especially water colour, sediment occurrence and dam size, and the land use or vegetation change in the upper Orange catchment. The results could indicate sediment origin, water colour changes over time, and showed sedimentation patterns in the Gariep, normally associated with delta formation. The findings concluded that mechanisms controlling sedimentation in large dams need to be revised, as the observed condition for sedimentation questions the conventional thinking. This study further raised concerns especially related to sediment build-up occurring deeper into the dam, getting closer to the water abstraction points like Oviston recently indicated as a problem.

Origin of eclogitic corundum xenocrysts from the Kareevlei Kaapvaal lamproite

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Mantle-derived eclogites found in kimberlites are generally interpreted to have originated from subducted, metamorphosed Archean oceanic crust. The presence of aluminous phases in eclogites, e.g., corundum, is rare and hints at either plagioclase-rich gabbroic or clay-rich sedimentary components. The strongest evidence for crustal protoliths to mantle eclogites is the deviation of δ18O from the typical mantle composition of 5.5 ± 0.4‰ (Mattey et al. 1994). Here we present LA-ICP-MS trace element data and oxygen isotopes for a suite of corundum xenocrysts from the Kareevlei Kaapvaal lamproite (formerly Group II kimberlite) to constrain the origin of a high aluminium oceanic crust protolith.

From a suite of ~30 corundum xenocrysts recovered so far, 10 were selected for detailed analyses in this study; we have also recovered two corundum-bearing eclogite xenoliths (not analyzed yet). The corundum xenocrysts have a range in colour from deep purple, similar to the famous G10 garnets, to pink-purple to distinctly pink. The purple corundum have elevated Ti (500-1100 ppm) and Mg (600-980 ppm) relative to the pink xenocrysts. The pink xenocrysts are also characterised by elevated Cr contents, up to 6000 ppm, relative to the purple (<3000 ppm). The Cr/Ga and Fe/Ti values are high (10-100) and consistent with derivation from metamorphic protoliths.

The δ18O values of the corundum xenocrysts range from 2.94 – 4.81‰, and are within the range of δ18O values reported by Radu et al. (2019) for corundums from two Roberts Victor eclogites. The purple corundums have a restricted range of 3.24-3.45 ‰ compared to the pink (2.94-4.81‰). Radu et al. (2019) established that the δ18O values of corundum were within error of those of garnet in the same rock; this means that the Kareevlei corundums are lower than the 'normal' range expected for mantle-derived phases. This range in δ18O is interpreted to reflect that of the protolith(s), and was probably caused by water-rock exchange at relatively high temperature. This is consistent with an origin from recycled oceanic crust. High-temperature alteration typically occurs within cumulate gabbroic rocks, in ophiolite sequences. Thus, the presence of highly aluminous phases like corundum with low δ18O values is consistent with the recycling of hydrothermally altered plagioclase-rich gabbros and not clay-rich sediments, which typically have high δ18O values.

Origin of fluids responsible for the Orange River Pegmatite Belt; Namaqua-Natal Metamorphic Province

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The Orange River Pegmatite Belt (ORPB) forms a continuous, ~450km-long E-W oriented belt intruding the Namaqua sector of the Proterozoic Namaqua-Natal Metamorphic Province (NNMP) in the Lower Orange River region of southwestern Africa. The geochemical character of the pegmatites of the ORPB varies along strike with the western pegmatites dominated by Li-Cs-Ta (LCT)-type, whereas the eastern part of the belt is mostly Nb-Y-F (NYF)-type. Regional U-Pb geochronology has revealed that the ORPB was emplaced over a ~75 Ma period (1040 to 965 Ma), synchronous with (and outlasting) the strike-slip shear event at the end of the Mesoproterozoic Namaqua orogeny. Pegmatites intruded along the evolving discrete NW-trending, subvertical shear zones (e.g. Pofadder Shear Zone) and along older Namaqua tectonic domain boundaries reactivated by the transcurrent shearing. Sm-Nd isotope analyses of pegmatites correlate with the rocks of the hosting tectonic domain/s of the NNMP, suggesting a localised source for the pegmatites but a regional and coeval melting process.

Preliminary results indicate the LCT pegmatites in the western ORPB hosted in the Paleoproterozoic rocks of the Richtersveld Magmatic Arc have a narrow range of quartz $\delta^{18}O$ values between 6.9‰ and 9.4‰ (mean = 8.8‰) whereas quartz $\delta^{18}O$ values from LCT pegmatites in the far eastern section of the Kakamas Domain range from 10.9‰ and 14.6‰ (mean = 12.5‰). The Δqtz-fsp for all LCT pegmatites in this study range between -2.5‰ and 6.9‰. However, only 9/16 samples have Δqtz-fsp between 0.3 and 1.53‰, and thus consistent with equilibrium under closed system conditions. whereas Pegmatites outside this range were probably affected by fluid-rock interaction at high-T $\Delta > 1,53$ or low-T $\Delta < 0.3$, the latter presumably post-emplacement. NYF pegmatites within the Kakamas domain (eastern ORPB) have a larger range of quartz $\delta^{18}O$ values, between 9.9‰ and 12.2‰ (mean = 11.3‰), possibly reflecting the mixed metamorphic rock assemblage of the Kakamas domain. The Δqtz-fsp for all the NYF pegmatites range in from 2.3 to 5.1‰ indicating disequilibrium and interaction with external fluid at high-T during crystallisation and/or emplacement.

These findings support the interpretations of the Sm-Nd isotope geochemistry on the ORPB that the pegmatites show a regional zonation with respect to both radiogenic and, from this study, stable isotope composition, which is interpreted to reflect fluid source characteristics inherited from the melting of local host rocks that resulted in the widespread pegmatite emplacement at ~1.0 Ga.

Our Coal Addiction

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Mankind has used coal for more than 6 000 years. Once it was found to produce a higher, more consistent heat than either wood or charcoal, its use increased wherever it was found. Coal has been used for carving ornaments; smelting and forging metals; domestic and industrial heating; steam and electricity generation; manufacturing cement, bricks and tiles; producing chemicals and their many derived products; making paints and fertilizers; producing gas and petrochemicals; and for domestic and international trade. The global distribution of coal led to the development of economies heavily dependent on its extraction. Some, such as England and Germany, no longer mine significant amounts of coal and have transitioned to other sources of energy to support their economies. Others, such as China, Indonesia, Australia and South Africa, still rely on coal to both power their countries and their economies.

In many ways, modern economies have been built on coal: the invention of the coal-burning steam engine by James Watt in 1775 powered the Industrial Revolution, allowing countries to move away from cottage industries and agriculture-based economies to ones based on factories, large-scale industries and increasingly mechanized manufacture. Transport benefited too, with the invention of the steam locomotive by Richard Trevithick and George Stephenson and Robert Fulton's paddle steamer, not to mention commercial steam-driven shipping. The Industrial Revolution increased wealth and distributed it more widely, leading to the rise of the middle class
The often-atrocious working conditions lead to the birth of the trade union movement, an important social development that could be said to be a byproduct of coal.

However, the negative effects of burning coal are impacting on humanity and indeed, the planet, in alarming ways. As early as 1306, a ban on the use of coal was proclaimed - by King Edward I of England - due to the public outcry regarding the pollution and impact on health the coal used by blacksmiths and other artisans was having. In 1895, Svante Arrhenius, a Swedish scientist, published a paper suggesting a link between atmospheric CO2 and temperature. In 1912, an article in Popular Mechanics warned that the combustion of coal created a global blanket of CO2, affecting the climate.

How then do we move away from burning coal and transition to a cleaner, greener future? How does South Africa utilize its not insignificant coal resources, without compromising our energy security, our economy and our desperately needed social development?

Oxygen isotope variations in kimberlite megacrysts from the Monastery kimberlite

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Megacrysts are large (>1cm) crystals found within kimberlites and crystallize from proto-kimberlite melts intruding into the base of the subcontinental lithospheric mantle (SCLM). Proto-kimberlite melts have been shown to evolve through closed or open system processes by fractional crystallisation and/or melt-SCLM interactions. Deviations from mantle-like $\delta^{18}O$ (5.0-5.5‰) in mantle-derived melts are rare. However, the $\delta^{18}O$ of mantle-derived magmas may vary if recycled crust is incorporated either during ascent or in the magma source. We present laser fluorination $\delta^{18}O$ data for a well-characterized suite of megacrysts from the Monastery kimberlite, South Africa, to assess the degree of open system behaviour and to constrain potential sources and effects of melt-SCLM interactions on the $\delta^{18}O$ values of mantle-derived magmas.

The $\delta^{18}O$ of primitive Fe-poor olivines (Fo_{83-88}) is restricted to the normal mantle range of 5.05-5.42‰ and show no correlation with Mg# or Ni content, whereas the $\delta^{18}O$ of the Fe-rich olivines (Fo_{78-83}) range from 4.53-4.94‰ and show positive correlations with Mg# and Ni content. Moore et al. (1992) identified three ilmenite groups. Group I ilmenites (Cr- and Mg-poor, part of the Cr-poor megacryst suite) range from 3.88-4.35‰, Group II ilmenites (Cr-rich, but relatively Mg-poor) range from 2.74-4.46‰ and Group III ilmenites (both Cr- and Mg-rich) range from 2.93-4.05‰. The $\delta^{18}O$ of Group I ilmenites show a positive correlation with Cr#, while the $\delta^{18}O$ of Group II and III ilmenites show no correlation with Cr#. The main silicate megacrysts ("MST"; garnet, clinopyroxene and orthopyroxene) range from 5.10-5.78‰ and show no correlation with any major element. We determined $\delta^{18}O$ ranges for phlogopite and zircon to be 4.25-5.73‰ and 4.07-5.09‰, respectively.

The positive correlation between $\delta^{18}O$ and Mg# in the Fe-rich olivines, in addition to the lack of correlation between $\delta^{18}O$ and Mg# in the Fe-poor olivines, suggest that the megacryst parent melt evolved within an open system. Similarly, the $\delta^{18}O$ fluctuations among the three ilmenite groups further suggests that the megacryst parent melt evolved within an open system with two distinct changes in $\delta^{18}O$ during evolution. We propose that the decrease in $\delta^{18}O$ can be explained by stages of assimilation including a low-$\delta^{18}O$, Cr- and Nb-rich SCLM component followed by assimilation of a slightly higher-$\delta^{18}O$, Mg-rich, Cr- and Nb-poor SCLM component.

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Paleoarchean Buffalo River komatiites: Progressive melting of a single large mantle plume beneath the growing Kaapvaal craton

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Komatiites are a significant component of Archean mantle-derived volcanism and early crustal development, which enable us to track the thermal nature and evolution of the Archean mantle including its plume and ambient components. The Paleoarchean Buffalo River Greenstone Belt located on the southeastern margin of the Kaapvaal craton, consists of komatiites and basalts exposed within three discontinuous inliers. Using field and geochemical data from this previously undocumented portion of the Kaapvaal craton, we constrain the nature and composition of the mantle source for this komatiite-basalt system.

Distinctively different geochemical signatures allow for the classification of the volcanic rocks of the Buffalo River into three main types: (1) Spinifex textured lava flows represent Al-depleted komatiites, with subchondritic Al2O3/TiO2 ratios (5-12) and enrichment of LREE over HREE (Gd/YbN = 0.9-2); (2) Al-undepleted komatiites that have chondritic Al2O3/TiO2 (17-24) and flat REE patterns (Gd/YbN = 0.9-1.1); (3) A rare Al-enriched komatiite type that display suprachondritic Al2O3/TiO2 ratios of >25, LREE depletion and HREE enrichment (Gd/YbN = 0.2-0.6). The Al-depleted and Al-undepleted komatiites from Buffalo River are comparable to archetypal komatiites from the 3.48 Ga Komati and 3.26 Ga Weltevreden formations of the Barberton Supergroup respectively, whereas the Al-enriched komatiites resemble the 3.33 Ga Commondale komatiites on the southeastern Kaapvaal craton.

We use a previous model determined for the Barberton komatiites to explain the co-existence of the three major types of komatiites present in this volcanic succession. Their association requires that each komatiite melt type escaped from an upwelling mantle source at different pressure but similarly hot temperature conditions.

We find that Al-depleted komatiites have low initial whole-rock 187Os/188Os values, which suggests an origin from a primitive mantle reservoir during the Paleoarchean. Additional highly siderophile element (HSE) data of the spinifex textured Al-depleted komatiites from Buffalo River are within the range of typical HSE concentrations of Barberton-type komatiites. Such concentrations are consistent with an origin from the deepest upper mantle with high melt retention in an upwelling plume source as previously demonstrated for the Barberton komatiites. Progressive melting of such an upwelling mantle source, to the point of garnet/majorite exhaustion, may explain the Al-undepleted and Al-enriched komatiites found in the Buffalo River. The presence of all three major komatiite types within a single volcanic succession may be linked to deep critical melting of a single large mantle plume that probably was associated with formation and growth of the Kaapvaal ‘continent’ at around 3.5 Ga.

Paleomagnetic results from the Mesoarchean Nsuze flood basalts

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The Pongola Supergroup is one of the world's oldest and best preserved supracratonic successions. It contains some of the oldest known continental flood basalts as well as the oldest glacial deposits on Earth. Its pristine nature should make it ideal for paleomagnetic study, but so far only discrepant remanence directions have been reported [1, 2]. Here results of a comprehensive paleomagnetic study of the ~2.99 – 2.96 Ga Nsuze Group are presented.

Two high-stability remanence directions were identified. The first is south and down and similar to that described by 2. We, however, assigned it an age of 2654 ± 2 Ma based on a positive baked contact test. A second high-stability component is west and down (similar to that reported by 1). It is more tightly grouped after application of tilt-corrections. At Piet Retief/Amsterdam it achieves best grouping at ~60% unfolding. The precise timing of the folding is unknown, although it must post-date emplacement of the ~2.87 Ga Thole Complex which is folded within the syncline [3]. Hofmann, Kröner [4] associated folding with the emplacement of the Nhlangano gneiss at ~2.72 Ga. Oour remanence can thus be constrained between ~2.87 Ga and ~2.72 Ga.

Paleomagnetic results do not constrain the paleogeography of the Kaapvaal Craton during extrusion of the Nsuze Group lavas at ~2.99 Ga. Instead, it provides constraints at ~2.87-2.79 Ga and ~2.65 Ga. As such, we constrain the craton's paleolatitude to ~45° at the end of Central Rand Group deposition before the craton made a polar crossing.

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Partial melting in the mantle: The importance of peritectic crystal entrainment for the formation of layered mafic intrusions and chromite seams.

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Background

The high average chromium (Cr) content of layered mafic intrusions such as the Rustenburg Layered Suite, South Africa, is irreconcilable with the low solubility of Cr in the broadly basaltic-andesitic magmas suggested as parental to the suite, thus requiring a much greater volume of magma than currently considered to have been involved in the formation of the complex(1). This 'Cr-paradox'(2) highlights the need for an alternative model for the transport of Cr from the mantle source to the final crustal emplacement level.

Methodology

This study used a thermodynamic modelling approach to investigate the details of the melting reactions which occur in a garnet peridotite during adiabatic decompression from 30-15 kbar (H2O & CO2 free) with incremental magma extraction.

Key results

The results show that orthopyroxene and clinopyroxene are produced as peritectic products of the partial melting reactions in specific portions of the magma decompression paths, and these peritectic pyroxenes contain significant amounts of Cr2O3 (up to 1.52 wt.%). As the peritectic crystals nucleate at the sites of melt production, entrainment of these crystals to the magma is highly probable. In a second step, during magma ascent, entrained peritectic pyroxene reacts with melt to form olivine and Cr-spinel crystals. The emplacement of the resulting high temperature crystal slurry into the crustal magma chamber will thus see the immediate formation of chromitite layers, which separate from olivine and melt due to differences in density.

Main conclusions drawn from these results

The results demonstrate how peritectic pyroxene has a much higher capability than any viable melt for transporting Cr from the mantle source to the crustal magma chamber, where gravity settling can generate chromitite as well as silicate layering along with a relatively small amount of evolved liquid, producing an igneous stratigraphy that broadly matches what is observed in the Lower and Critical Zones of the Rustenburg Layered Suite(1,2). We thus overcome the volumetric problems associated with the Cr-paradox through a simple alternative for the formation of chromitite and silicate layering in layered mafic intrusions as a consequence of Cr-rich peritectic crystal entrainment to mantle magmas.

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Patagonia: Gondwana's "Dark Passenger"? Tectonocyclic-induced extinction events in South Africa during the Devonian

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The similarity of sedimentary packages in West Gondwanan Palaeozoic-aged depocentres has long been recognised. At least two first-order geodynamic episodes occurred in West Gondwana (Ordovician-earliest Carboniferous and middle Carboniferous-Late Jurassic). The timing of these events suggests a common allocyclic proxy which may be linked to tectonic events along the respective Famatinian and Patagonian margins of Gondwana. During the Devonian virtually all West Gondwanan depocentres experienced renewed subsidence and marine incursions likely beginning during the Pragian. Faunally, this transgression is associated with the replacement of Silurian-Lochkovian Afro-South American faunas by cool-water Pragian-Eifelian Malvinoxhosan biotas. At least 4-5 2nd order regional transgressions of decaying intensity are recorded in South Africa and South America with maximum flooding surfaces during the early Emsian, late Emsian, early Eifelian, late Eifelian and mid Givetian. These transgressions are associated with a gradual decline in diversity culminating in the extinction of the Malvinoxhosan biota during the late Eifelian with only warm-water taxa persisting from the mid-Givetian onwards. Environmentally, no appreciable change is evident with this extinction.

Recent intensive analysis of detrital zircons from the Bokkeveld Group have revealed the presence of at least four sources of detritus into the Cape Basin during the Devonian. These include proximal Neoproterozoic-Cambrian Pan-African Belt and post Pan-African Cambro-Ordovician basins, and distal Cambro-Ordovician Famatinian Belt and Silurian-Devonian aged Patagonian massifs. Curiously, zircons from Famatinian and Patagonian sources become increasingly younger and more frequent up the succession. A partitioning of zircon populations is also observed in the Bokkeveld Group when sequence stratigraphy is considered. Famatinian and Patagonian derived zircons often dominate in deposits laid down during transgressions in the early Emsian, late Emsian-early Eifelian, early Eifelian, late Eifelian and mid Givetian. Strong deep-water geostrophic currents are thought to have brought these zircons into the basin. In regressive deposits the converse condition is evident and Pan-African and post-Pan-African sources predominate. Time-sliced palaeogeographic reconstructions of the Cape Basin during the Devonian further show reorganisation of basin morphology, notably shifts in palaeoshoreline orientation, associated with changes in sea-level suggesting far-field lithospheric flexure for both observations.

The sum of evidence suggests that the convergence of Patagonia with Gondwana both affected tectonics, palaeogeography and allocyclicity in the Cape Basin (and associated West Gondwana depocentres). Such changes in tectonics and palaeogeography are extended to suggest that the convergence of Patagonia might have also broken-down allopatric barriers to speciation, such as circumpolar currents, causing the decline of cool-water specialist Malvinoxhosan biotas.

Petrogenesis of megacrysts from Liberian kimberlites and the structure of the West African cratonic lithosphere

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Kimberlites worldwide often contain large (1cm – 13 cm) chemically homogeneous single mineral crystals and crystal intergrowth called megacrysts (Boyd and Nixon, 1973).

However, there is still uncertainty regarding their origin and relationship to kimberlite magmatism.

This study presents the first extensive in-situ major and trace element and Sr isotopic results for 265 garnet, clinopyroxene, orthopyroxene and ilmenite megacrysts from the West African craton, where megacrysts occur in abundance within Liberian Camp Alpha kimberlites, in order to provide insight into the dominant processes responsible for elemental and isotopic variations of megacrysts.

The megacryst suite is of the Cr-poor variety with minerals showing a wide range of compositions and exhibiting tight, well-defined trends on major element diagrams as well as incompatible and rare earth element abundances similar to those previously reported for Cr-poor megacrysts. Such chemical trends generally indicate that the grains crystalized from a fractionating liquid. The more evolved minerals (garnet and ilmenite with lower Mg# as well as clinopyrones with high Ca#) display enrichment in incompatible trace elements relative to the less evolved minerals. Clinopyroxene single mineral thermobarometry indicates that the megacrysts equilibrated at temperatures of 946 to 1444 °C and pressures of 4.3 to 6.2 GPa along the 38 mW/m2 geotherm. Their intersection with the mantle adiabat corresponds to cratonic thickness of 195±10 km in agreement with the 200 km thickness of the West African Craton derived from global shear wave modelling. These conditions indicate that megacrysts originate from the base of the lithosphere within the lithosphere-asthenosphere boundary. Melt compositions in equilibrium with garnet and clinopyroxene calculated using recent high-pressure mineral-carbonated melt partition coefficients are close to trace element equilibrium and have trace element compositions similar to the host kimberlite. This indicates co-crystallisation of megacrysts, which has an influence on the chemical variations observed. It also suggests crystallization from primitive melts with kimberlite-like trace element compositions. We propose a model for the origin of West African megacrysts in which megacrysts grow by fractional crystallization from a large body of Cr-Mg-Ti rich silicate-carbonate protokimberlite melts at the base of the lithosphere. This initially occurs at high melt/rock ratio and progresses to low melt/rock ratio such that the more evolved, low temperature megacrysts indicate show metasomatic interaction with the surrounding lithosphere.

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Petrogenesis of the apatite-enriched layers in the uppermost Upper Zone, Northern Limb, Bushveld Complex: Insights from in situ LA-ICP-MS trace element and O isotopes in apatite

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Current interpretations propose that the apatite-enriched layers formed from immiscible liquids, while the role of trapped liquid in the formation of the rocks near the top of the Bushveld Complex is also emphasized. In addition, available field, chemical and isotopic data appears to indicate that the Bushveld Complex has been operating as an open-system magma chamber that grew incrementally via numerous magma replenishment events. However, in contrast with this popular belief, the complex also shows the crystallization sequence that is broadly consistent with the internal differentiation of a single parental melt under closed-system condition. This study uses apatite to improve our understanding of the magmatic processes in the uppermost UZ. Apatite can incorporate a wide spectrum of elements (e.g., F, Cl, S, rare earth elements, Th, U, P, Sr, Pb, Mn), which can be used to trace the evolution paths of magmas and constrain magmatic processes in mafic layered intrusions. LA-ICP-MS analyses (University of Stellenbosch) and δ18O determinations (Potsdam) on apatite grains are used to obtain, respectively, the δ18O content and wide spectrum of trace elements of apatites from the most differentiated part of the Upper Zone. New in-situ trace element data obtained on apatite from two apatite-enriched layers in the uppermost UZ demonstrate an increase in LREE with increasing crystallization from 2665 ppm in the lower apatite layer to 3450 ppm in the upper apatite layer. This progressive increase of REE content in residual melt implies that the system was open, with further input of REE-rich Fe-Ti-P magmas. By contrast, this systematic increase in REE is accompanied by a slight decrease of the δ18O (6.62–6.23‰, respectively), with stratigraphic height showing a constrained δ18O pattern that did not vary much in the course of apatite crystallization. Such a change rules out the closed-system fractional crystallization model, while a common genetic origin for the apatite-enriched layers is suggested. This data is interpreted to support extensive fractional crystallization under open system conditions.

Petrographic and geochemical evidence of calc-silicate xenolith – magma interaction in the western Bushveld Complex, South Africa

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Underground workings at Rowland Shaft, Lonmin Platinum, near Marikana have exposed a large (>7 x 5 m) calc-silicate xenolith in mottled anorthosite ~20 m below the UG 1 chromitite of the upper Critical Zone. The xenolith displays a monticellite + forsterite + spinel metamorphic assemblage, indicating Tmax conditions of between 975 and 1125 °C at P = 0.6–1.6 kbar and XCO_2 ~ 1. Variations in the modal proportions of these phases in the xenolith are interpreted as relict sedimentary layering, which dips steeply west, approximately orthogonal to the magmatic layering.

The xenolith is flanked by an ~25 cm wide magmatic skarn zone that contains several small cm- to dm-scale calc-silicate fragments that display the same peak metamorphic assemblage as the main xenolith, as well as a dm-scale chromitite stringer and mm- to dm-scale stringer-like masses of uvarovitic garnet. The skarn is mineralogically and compositionally zoned in relation to the main xenolith and the individual calc-silicate fragments. It comprises a ≤10 cm monomineralic clinopyroxenite layer proximal to the xenolith that is dominated by an unusual, zoned, aluminian-ferrian diopside (high Ca, Al, Fe3+). The clinopyroxenite grades outwards into a pseudo-ophitic plagioclase-clinopyroxene texture involving similar aluminian-ferrian diopside and anorthitic plagioclase (An_{99}), with the clinopyroxene locally hosting wollastonite inclusions and the plagioclase enclosing fine-grained calcite and diopside. This, in turn, grades distally into a more conventional igneous-textured gabbro. The contact between the gabbro and the anorthosite could not be sampled, however, the matrix of the chromitite stringer is dominated by plagioclase. In the skarn zone, chromite grains are enclosed in uvarovitic garnet that grades outwards into grossular, which also occurs as fine rims replacing clinopyroxene and calcite in the pseudo-ophitic texture. These features are consistent with crystallisation of a magmatic skarn contaminated by a strongly calcic xenolith component under elevated fO_2. Limited development of grossular-vesuvianite symplectite at the clinopyroxenite-gabbro interface indicates that fluids evolved to more hydrous compositions under subsolidus conditions (T < 750 °C; XCO_2 < 0.1).

The steep bedding orientation in the xenolith, the presence of the chromitite stringer and uvarovite-spinel aggregates, and evidence of plastic shear strain in the xenolith and skarn suggest that the xenolith underwent density-driven foundering within the RLS magma from an initial location above the UG 1 chromitite layer and that parts of the intervening magmatic stratigraphy were mechanically disrupted and became entrained in the skarn envelope, whereupon they experienced variable chemical contamination by the devolatilising xenolith.

Petrographic and hyperspectral analysis of post-impact hydrothermal alteration in the M4 core from the Morokweng impact structure, South Africa

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The 368 m long M4 drill core into the Morokweng Impact Structure (MIS), situated in North West Province, intersects a suite of Neoarchaean granitoid gneisses, metadolerite and dolerite that are strongly shocked, fractured and cataclased, and which are cut by pseudotachylite and suevitic breccia dykes. Additionally, the rocks have been affected by hydrothermal alteration particularly in the impact breccias and along fractures. Hydrothermal mineral assemblages are dominated by zeolites, smectites, haematite and chlorite, but also include calcite, feldspar, garnet, epidote and sulfides. In order to understand the type, distribution and the extent of the post-impact hydrothermal alteration in the MIS, this study integrates transmitted and reflected light petrography with the hyperspectral imaging technique, Tescan Integrated Mineral Analysis (TIMA), and EPMA to determine, in more detail, the assemblages and micro-textures generated by the hydrothermal alteration. TIMA elemental maps are used to distinguish between the extremely fine-grained zeolite and clay mineral assemblages. The hyperspectral and TIMA results reveal that alteration is more widespread in suevite, pseudotachylite, and cataclastic fault breccias, but the gneisses and dolerites also contain alteration assemblages in fractures and vugs. Hyperspectral results provide evidence for the spatial distribution of veins and hydrous minerals in the core; whilst veins are mostly restricted to the upper parts of the core, alteration is found throughout, and mineralogy varies mainly in response to host rock composition. This suggests relative low rock:fluid ratios, consistent with a terrestrial crater.

TIMA analyses revealed that the secondary mineral assemblage includes Fe-Mg smectites, Ca-Na-zeolites, feldspars, calcite, and minor quartz, Fe-oxides and hydroxides, sulfates, and sulfides, which can be stable down to $T < 100$ °C. In rare cases, higher-T minerals such as garnet, epidote, feldspar and chlorite are observed in vugs, particularly towards the bottom of the core, and indicate a post-impact $T \geq 300$ °C. This may imply that the M4 core experienced a variable post-impact hydrothermal alteration geotherm; however, low-T minerals at shallower levels may have overprinted higher-T assemblages during the same or later events.

The hydrothermal mineral assemblages and textures in the M4 core are very similar to those described from the 1.3 km M0077A core through the peak ring of the marine Chicxulub impact crater, where a combination of shock heat, uplift of originally mid-crustal rocks and the impact melt sheet overlying the crater basement drove convective fluid circulation.

Petrographic, textural, and novel geochemical analysis of deep-seated cumulates: Discerning the petrogenesis of the earth's crust

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Background:

The bimodal composition of the Earth's crust, with basaltic oceanic crust and andesitic continental crust, differentiates it from other terrestrial planets. Likewise, the iron-depleting calc-alkaline series and iron-enriching tholeiitic series observed in the continental and oceanic crust, respectively, represent ubiquitous magmatic differentiation trends on Earth. The origin of these calc-alkaline signatures remains controversial because most studies utilise volcanic and shallow plutonic rocks, which have experienced significant intracrustal differentiation, to explain the duality in compositions of the Earth's continental crust. By studying deep crustal cumulate rocks that formed before significant intracrustal differentiation processes may have taken place, this study provides a bottom-up view of the composition of the magmas transiting MASH zones in crust forming environments and how these deep processes may influence the composition and evolution of the crust.

Methodology:

Petrographic and textural analyses were conducted using a BX41 petrographic microscope and a BX63 full-section imaging system, able to scan entire thin sections in plane and cross-polarized light. TIMA was used to quantify mineralogical data, produce elemental maps, and conduct phase searches. For major and trace element data, whole-rock XRF and ICP-MS analyses were conducted for major and trace element data respectively. Ti isotope data was generated by whole-rock Ti isotope analysis which includes digestion followed by column chromatography and then MC-ICPMS.

Key results:

TIMA results suggest that most cumulates are mafic to ultramafic in composition with distinct hetaradcumulus to harrisitic cumulus textures. On the alkali-FeO*-MgO diagram, island arc (A=0.2-9, F=15-54, M= 38-84) and MOR cumulates (A=11-21, F=30-98, M=20-54) plot into the tholeiitic field and continental arc (A=0.2-50, F=16-65, M=18-84) and continental hotspot (A=5-25, F=40-57, M=22-46) cumulates plot into the calc-alkaline field. MOR cumulates display the highest δ49/47Ti range (-1.147 to +0.2989‰), followed by island arc cumulates (-0.6084 to +0.0115‰), then continental arc cumulates (-0.0449 to +0.0972‰), and finally continental hotspot cumulates (-0.0432 to 0.0926‰).

Main conclusion:

Consistent depletion in highly incompatible mobile LILEs and complementary depletion in Ti-Nb-Ta anomalies in continental arc and continental hotspot cumulates proves that crustal contamination played a key role in the evolution of the Earth's continental crust. The large Mg # range (33.75-90.56), and variable δ49/47Ti values, serve as evidence of crystal fractionation taking place during magmatic differentiation and playing a pivotal role in shaping the signatures observed in the continental crust.

Petrography, geochemistry and age of the intrusive units of the Leinster deposit, Northern Cape Province, South Africa

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The Leinster Deposit is one of the five erosional relics of the Kalahari Manganese Field (KMF) which is the world's largest, land-based source of economically viable Mn. The KMF is associated with the Hotazel Formation and is characterized by three Mn ore horizons interlayered with four superior-type Fe formations. Unlike some of the other Mn deposits in the KMF, the Leinster deposit is characterized as a low-grade Mn deposit with the normal stratigraphic succession heavily disrupted by dykes and sills referred to as "bostonites" due to their red discoloration (Kleyenstüber, 1985). Given the extent to which these intrusions have affected the normal stratigraphic succession in the vicinity of the Leinster Deposit, it is essential that they be adequately investigated and classified, as no detailed study of the intrusions of the Leinster Deposit has been done before.

A petrographical and geochemical study on 29 drill core samples of the intrusions associated with the Leinster Deposit was conducted to properly characterize, classify and relate them to the other intrusions of the KMF. SEM-EDS, XRD, TIMA, and optical microscopy aided in determining the mineralogy and petrography. XRF and ICP-MS were utilized to determine the whole-rock geochemistry.

The samples were also investigated for the presence of minerals suitable for geochronology (e.g., zircon, baddeleyite, titanite, apatite) to aid in constraining the age of these intrusions, by using heavy mineral extraction techniques, but no suitable datable phases were found. Titanite was identified in thin section using TIMA and will be dated soon.

The intrusions consist mainly of plagioclase, clinopyroxene and chlorite, with trace amounts of quartz, ilmenite, pumpellyite and titanite. Geochemical analysis classifies them as tholeiitic basalts to basaltic andesite. The rare earth element chondrite-normalized data show LREE enrichment over HREE, with a weak negative Eu anomaly. Primitive mantle-normalized trace element data show positive U and Pb anomalies, and negative Nb, Sr, and Ce anomalies. The intrusions of the Leinster deposit are therefore better classified as dolerites. Previous studies on the intrusions of the Main Kalahari Manganese and Avontuur deposits of the KMF also found them to be tholeiitic basalts to andesitic basalts. Similar positive anomalies for Pb and U, and negative Eu anomalies are seen in intrusions across all three deposits, thus suggesting that the intrusions of the KMF are co-magmatic.

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Petrological characterization of three coal seams of the Imaloto basin, South-Western Madagascar

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The Imaloto Basin is a fault-bounded coal bearing sub-basin of the Morondava Basin in South Western Madagascar. Twelve coal samples were collected from three economic coal seams (Main Seam, Upper Seam and Top Seam) of the basin and analyzed for detailed chemical, petrological, and mineralogical characteristics. The Main Seam has the best qualities in terms of calorific value (CV), ash and fixed carbon (FC) contents compared to the other two seams. The average CV across the basin is 18.64 MJ/Kg. The average CV in the Main Seam is 22.83 MJ/Kg, in the Upper Seam is 18.06 MJ/Kg and in the Top Seam is 13.85 MJ/Kg. The average weight % of ash and total Sulphur (TS) across the basin are 36.78% and 1.93% espectively.

The Imaloto coals are moderately high ash (Main Seam) to high ash (Upper and Top seams) coals. Vitrinite reflectance measurements placed the coals between the Sub-Bituminous Low Rank A to Bituminous Medium Rank D coal categories according to the ISO/FDIS 11760 (2018) Coal Classification scheme. Petrographic analysis revealed abundance of inertinite macerals in the Main Seam (55.4 vol. %) and the Upper Seam (54.0 vol. %), with lower amounts in the Top Seam (33.9 vol.%). This is typical of Gondwana coals, which are generally inertinite-rich. Vitrinite macerals are more abundant in the Upper Seam and Top Seam samples compared to Main Seam samples, with an upward increase in abundance. Similar study on the petrography of the Songwe-Kiwira Coalfields of the Permian coal basins in Tanzania also found that seams developed in the lower parts of the basin have the highest inertinite contents, while seams that occur in the upper sections contain more vitrinite macerals. Common coal minerals such as silicates (clay and quartz), carbonates and sulphides (especially pyrite) were observed under the petrographic microscope in the Imaloto coal samples. Results of XRD showed similar proportions of these mineral components in the samples.

The Imaloto coals could be used as fuel for power generation plants, supplying nearby towns and villages with electricity. The coals might also be used in place of wood. In the rural areas of Madagascar, wood is widely utilized in brick kilns. Charcoal is still the primary source of energy for cooking in most households of the rural regions of the country.

The findings of this study would be of fundamental aid for future exploration, mine design and exploitation, and to coal marketers and users.

Petrological, geochemical and geochronological constraints on the Kameel Complex, Northern Cape, South Africa: implications for the Hartley Large Igneous Province

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The Kameel Complex (KC) is a mafic intrusion located in the western part of the Kalahari Craton, South Africa. It occurs within the Paleoproterozoic Keis Supergroup rocks overlying the Transvaal Supergroup in the Griqualand West area. The KC, which has never been studied before, is completely covered by Cenozoic Kalahari sediments and is only known from drill core.

The KC can be subdivided from the base to top into a Lower Zone (LZ) and Upper Zone (UZ). The LZ is made up of gabbros composed of plagioclase and clinopyroxene, while the UZ is mostly magnetite gabbros and is composed of plagioclase, clinopyroxene and Fe-Ti oxides. Geochemically, the KC rocks become more evolved upward and follow a tholeiitic differentiation trend with enrichment of Fe and Ti upward. There is an enrichment in light REE relative to heavy REE and negative Nb, Ta and Ti anomalies (for the gabbros) and positive Zr and Ti anomalies (for the magnetite gabbros). The most plausible parental magma is a tholeiitic liquid that was emplaced at shallow depth.

New 39Ar/40Ar step-heating biotite ages obtained for the KC reveal ages ranging from 1901 ± 11 Ma to 1950 ± 12 Ma. The younger 1901 ± 11 Ma age is affected by alteration and interpreted as a minimum crystallization age. The older 1950 ± 12 Ma age, obtained from primary biotite, is interpreted as a cooling age. Our ages overlap within error with the existing U-Pb zircon ages of ca.1.9 Ga for the Hartley Formation, placing the KC into the context of the Hartley Large Igneous Province. The KC may constitute the bulk of the 1.9 Ga Hartley magmatism, which was so far only recognized from lavas and dykes. Further dating with the U-Pb technique on apatite and ongoing paleomagnetic investigation will refine our results.

Petrology and geochemistry of the K-richterite- and leucite-bearing Kareevlei Kaapvaal lamproite

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The Kareevlei diamond mine is the first of its kind on leucite-bearing Kaapvaal lamproite. It is situated ~130 km northwest of Kimberley, South Africa, close to other well-known Cretaceous-aged Kaapvaal lamproites (aka orangeites) in the southwestern part of the Kaapvaal craton. Kaapvaal lamproites commonly comprise a wide variation in mineralogical composition. To further assist in understanding.

the petrogenesis of these lamproites, we present the petrography, with phlogopite, diopside, and K-richterite mineral compositions, and bulk-rock geochemistry of thirteen hypabyssal samples. These lamproites comprise completely altered olivine macrocrysts (3 – 11 vol.%) set in a groundmass of olivine microcrysts (3 – 19 vol.%), phlogopite (32 – 58 vol.%), diopside (12 – 36 vol.%), leucite (0 – 27 vol.%), K-richterite (0 – 25 vol.%), and interstitial material containing carbonate and clay minerals. Two distinct mineralogical varieties are observed based on the presence/absence of leucite and K-richterite: (1) leucite-richterite and (2) phlogopite-diopside lamproites.

Phlogopite laths in these varieties show two distinct core populations characterized by high- (Cr2O3 = 0.89 – 1.97 wt.%) and low-Cr2O3 concentrations (Cr2O3 = 0.04 – 0.68 wt.%) mantled by TiO2 and FeO-rich rims. High Cr2O3 cores are interpreted as xenocrysts from phlogopite peridotite xenoliths whereas low Cr2O3 cores resemble MARID xenolith phlogopite and are also interpreted as xenocrystic. Phlogopite rims have compositions similar to typical Kaapvaal lamproites and represent direct crystallisation by the parent magma. Two distinct mineralogical varieties have distinct incompatible trace element concentrations with the leucite-richterite samples being depleted in LREEs (LREE/Chondrite: La = 656 – 828; Ce = 518 – 597; Nd = 234 – 261) compared to phlogopite-diopside samples (LREE/Chondrite: La = 1125 – 1391; Ce = 817 – 1029; Nd = 333 – 415). However, mineralogical types have similar 87Sr/86Sri and 143Nd/144Ndi ratios ranging from 0.7071 – 0.7073 and 0.5118 – 0.5119, respectively.

Sr-Nd isotopes suggest that both lamproite varieties are derived from a similar mantle source within the sub-continental lithospheric mantle. In contrast, the difference in incompatible trace element concentrations indicates variable degrees of partial melting in the source/evolution of the magma through fractional crystallisation. Olivine macrocrysts occur in low abundances compared to typical macrocrystic Kaapvaal lamproites (i.e., 25 vol.%), indicating loss through fractionation and consistent with a fractional crystallisation control on the evolution of the lamproites, however, fractionation cannot account for the differences in incompatible trace element ratios between mineralogical varieties, favouring variable degrees of partial melting as an important process as well.

Petrology and Geochronology of Sapphirine-bearing granulites from the Limpopo Complex in eastern Botswana: Implications for Paleoproterozoic long-lived high-pressure/ultrahigh-temperature metamorphism and rapid exhumation

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The Limpopo Complex in Southern Africa is a classic example of Neoarchean collisional orogens with a Paleoproterozoic thermal overprint. We report new petrological, pressure–temperature (P–T), and geochronological data of sapphirine-bearing Mg–Al-rich and pelitic granulites from a metasupracrustal unit (the Beit Bridge Complex (BBC)) in the eastern part of Botswana to constrain its P–T–time evolution. Textural observations and phase equilibria modeling of the peak mineral assemblage of Mg–Al-rich granulites (K-feldspar + orthopyroxene [Al2O3 up to 8.8 wt.%] + sillimanite + quartz + rutile + biotite + inferred melt) in the NCKFMASHTO system recorded a peak metamorphic condition of >930°C and >10.3 kbar. A pelitic granulite recorded consistent P–T conditions of 960°C–980°C and >10.3 kbar, indicating high-pressure (HP) and ultrahigh-temperature (UHT) metamorphism for the BBC in Botswana. Post-peak retrograde conditions were obtained based on the stability of sapphirine + cordierite symplectite assemblage in the Mg–Al-rich rocks (820°C–860°C and 6.4–7.0 kbar) and orthopyroxene + cordierite symplectite assemblage in the pelitic granulite (830°C–930°C and 4.3–5.8 kbar), indicating near-isothermal decompression after the peak HP–UHT metamorphism along a clockwise P–T path. Similar HP–UHT metamorphism followed by a near-isothermal decompression along a clockwise P–T path was reported from different regions of the BBC in South Africa and Zimbabwe (P >14 kbar and ~1000°C based on the stability fields of magnesian staurolite and sapphirine + quartz assemblage), although the peak P–T condition is slightly lower in Botswana. Monazite grains with patchy zoning show isochron ages of 2115 ± 77 Ma for Th-poor domains, and 2058 ± 40 Ma and 2033 ± 34 Ma for Th-rich domains. Similar ages were obtained from zircon U–Pb geochronology as 2141 ± 24 Ma and 2010 ± 19 Ma (Th/U = 0.05–0.26). REE and Y contents of the monazites indicate that the older ages from higher Y monazites (2.1 Ga) correspond to the prograde metamorphic event, whereas the younger ages (2.0 Ga) indicate the near-peak high-grade event. The P–T conditions and zircon/monazite ages suggest Paleoproterozoic long-lived metamorphism associated with intracontinental transpressional tectonics related to Paleoproterozoic orogenic events around the united Zimbabwe-Kaapvaal Craton.

Keywords: Paleoproterozoic, Beit Bridge Complex, Sapphirine-bearing Mg-Al-rich rock, High-pressure and ultrahigh-temperature granulite, Phase equilibria modeling

Platinum group element and base metal sulfide variation in the Critical Zone at Sandsloot, Northern Limb of the Bushveld Complex: beyond the traditional mining horizon

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The extraction of new resources of PGE, Cu, Ni and Co is critical to satisfy increased demand driven by the energy transition. Developing genetic models for ore deposits aids in the generation of exploration targets, whilst understanding the geometallurgy of individual deposits is paramount to efficient processing of ores. The Northern Limb of the Bushveld Complex is renowned as one of the Earth's largest resources of the PGEs, as well as containing important resources of Cu, Ni and Co. The Critical Zone of the limb hosts the world-class Platreef PGE-Ni-Cu-(Co) deposit, which thickens and increases in grade down-dip [1], reaching >10 g/t (4E) over several meters in places. In the Sandsloot area of the Northern Limb, recent exploration and re-evaluation of the down-dip Critical Zone has identified multiple high-grade PGE-rich zones on the scale of 10s of meters, as well as thick base metal sulfide (BMS)-rich zones up to several hundred meters below. To date, these down-dip zones at Sandsloot have received no detailed mineralogical studies, thus characterising the geometallurgy of the ores has important implications for processing, in addition to aiding in understanding why there are distinct differences in the metal budget of the two zones.

The upper PGE-rich zone has around 1-2 vol % sulfides, with a typical assemblage of pyrrhotite-pentlandite-chalcopyrite (average proportion of 50/35/15 %). The most common PGM are Pt-Fe alloys, Pt-Pd-Pb alloys, Pt-Pd bismuthotellurides, Ru sulfides and Pt arsenides. High tenor Pd and Rh bearing sulfides have also been identified by Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICP-MS) analysis. In contrast, the lower BMS-rich zone contains semi-massive to massive sulfides, which are much lower tenor, being comprised dominantly of pyrrhotite, with lesser pentlandite and minor chalcopyrite. Relative to the PGE-rich zone this zone contains much lower PGE grades, and notably an IPGE dominant PGM assemblage of Ir arsenides, Ir-(Pt,Rh,Rh) arsenosulfides and Ru sulfides (62%), with lesser Pt arsenides (18%), Pt-Pd bismuthotellurides (9%) and Pd-Pd alloys (4%).

In this ongoing study we will characterise the PGM and BMS variation throughout these zones, both down-hole and down-dip, integrating this with lithological and alteration variation established from hyperspectral and mineralogical analysis. This will aid in establishing the relative controls, magmatic (fractionation), syn-magmatic (contamination) and hydrothermal, which control the metal budget and geometallurgy of both the PGE-rich and BMS-rich ores at Sandsloot.

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Platinum Group Elements (PGEs) and associated sulfide mineralisation in mafic-ultramafic units belonging to the Tantalite Valley Complex (TVC)

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Magmatic sulphide deposits are important producers of base-, semi-, and precious metals for the world. As such, the formation of an immiscible sulphide melt within mafic-ultramafic magmas and its concentration of base-, semi-, and precious metals has long been the subject of investigation for many researchers and explorationists alike. This study investigates the Tantalite Valley Complex, a mafic-ultramafic igneous intrusion found in Southern Namibia in the Richtersveld Subprovince of the Namaqua-Natal Metamorphic Complex. The study focuses on the formation of sulphides within mafic – ultramafic layers and their potential to host valuable metals (namely PGEs). This study investigates the source of sulphur in the magmatic system using multiple sulphur isotope analysis and whole rock sulphur/selenium ratios. As well as, determining the fractionation and diffusion of precious metals between different sulphide phases through LA-ICP-MS. Scanning Electron Microscopy reveals the compositions and associations of discrete precious metal bearing minerals. X-Ray Computed Tomography investigates the distribution of discrete precious metal bearing phases and sulphides within a well mineralized pyroxenite sample and visualizes the distributions and proportions of these phases.

δ34S values obtained from multiple sulphur isotope analysis of sulphides fall between the range -0.63 and 2.08 ‰, largely within the accepted mantle range of 0,1 ± 2 ‰ (Lesher, 2017). Whole rock sulphur/selenium ratios plot near mantle values of between 2850 and 4350 (Eckstrand and Hulbert, 1987). These analyses reveal the origin of the sulphur in the system to be derived from the mantle with little to no crustal contamination. Sulphide saturation is believed to have occurred due to high degrees of crystal fractionation and the sulphide melt to have concentrated in more ultramafic layers within the complex, particularly a pyroxenite layer. Precious metals exist in both solid solution and discrete precious metal bearing minerals found closely associated with the sulphide phases. Discrete mineral phases include Hessite (Ag2Te), Electrum (gold-silver alloy), Merenskyite (Pt,Pd)(Te,Bi)2 and Paolovite (Pd2Sn). Findings indicate the complex is a potential host to PGE mineralization, a factor having never been the subject of study till now.

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Plio-Pleistocene Palaeoceanography of the Western Continental Shelf of Southern Africa under the influence of the Benguela upwelling system

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The oceanography and sedimentation of the western margin of southern Africa is influenced by the highly productive Benguela Upwelling System (BUS), which initiated in the late Miocene (> 5.3 million years ago). The Pliocene period (5.3 – 2.6 Ma) can be regarded as the best reference to modern climate as global atmospheric CO2 levels were similar and the climate was warmer, while the Pleistocene (2.6 – 0.01 Ma) was colder. This study assesses how this climate transition during the Plio-Pleistocene affected the oceanography and palaeoenvironments under the BUS along the western shelf of southern Africa and its relation to the development of a highly productive system. Sediments and microfossil foraminifera from vibracores offshore Namibia and western South Africa (199 – 400 m) were analysed using faunal analyses, foraminiferal biostratigraphy, and strontium isotope stratigraphy. The dating methods used provided conflicting results for various components. For example, in one unit, phosphorite was dated to 1.0 – 5.5 Ma, but indicator species yielded a younger age in the Pleistocene to Holocene (< 2.4 Ma). This indicates reworking of sediment. The temporal inconsistencies and reworking of sediment is proposed to have been induced by increasing sea level amplitude fluctuations during the Pleistocene under an intensified BUS and subsequent palaeoenvironmental changes during the Plio-Pleistocene, which include: 1) the intensification of upwelling and organic matter delivery from the late Miocene to the Pleistocene; 2) the gradual decrease of sea level and shallowing of depositional environments and; 3) a shift in benthic environmental conditions from oligotrophic to eutrophic. This is evident from the progressive decrease in Uvigerina spp. abundances and infaunal taxa during the Pleistocene along the western margin of southern Africa. Through these results, this study contributed to a greater understanding in the relationship between productivity, sediment deposition, and the BUS.

Potential Kunene-related mafic dyke swarms

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Two conflicting perceptions concern a Kunene Igneous Complex (KIC), including the World's largest known massif anorthosite. While >60 myrs of recorded mafic magmatism is more consistent with a subduction zone setting [1], [2] also position the KIC next to a 1385 Ma LIP-center, within a trans-Nuna/Columbia rift. We aim at testing these contradicting plate tectonic settings with data on a >400 km-wide swarm of mafic dykes, showing a definite ESE-trend towards the KIC, but only for <200 km WNW before getting truncated by the Atlantic Ocean. Dykes were locally deformed and amphibolitized by a Pan-African orogenesis along a nearby Kaoko belt, are cut by Umkondo dykes and cross-cut granitic plutons (i.e., bracketed within <1.8-1.1 Ga). The swarm includes both N- and E-MORB dykes, where one E-MORB dyke has a baddeleyite U-Pb age of 1385 ± 5 Ma [3], linking it directly to the KIC. Furthermore, some E-MORB dykes are particularly REE and P_2O_5-rich, resembling rare nelsonites inside the KIC.

Assuming all dykes relate to the KIC, their bimodal signatures require derivation from both more depleted and ambient mantle sources, together with only moderate differentiation. While di-rich E-MORB dykes are consistent with magma equilibration at ~9 kbar, N-MORB dykes more likely equilibrated at shallower depths. Asthenospheric to moderate arc signatures are inconclusive in discriminating between the aforementioned contradicting settings, since asthenospheric melts may get overprinted by lithosphere and back-arc rift magmas are often less arc-like. Within [2]'s Nuna/Columbia reconstruction, ~1385 Ma E-MORB dykes could have been injected from a huge magma chamber below an initially intact continental crust (a classic source for massif anorthosites), while subsequent extensive rifting allowed ascending depleted mantle in generating subsequent N-MORB dykes. In detail, extrapolation of Kunene dykes within [2]'s reconstruction even allows these to have become involved in a breakup between Kalahari and São Francisco craton blocks, explaining difficulties in finding Kunene dykes extending into Brazil. Conversely, the formulated petrogenetic model adequately fits a back-arc setting, which better accommodates prolonged magmatism, suit Mesoproterozoic anorthosite-charnockite-mangerite-granite (ACMG) complexes and incorporate both margin-parallel and -perpendicular swarms. While most of the above will be addressed in the presentation, paleomagnetic results of these dykes are also underway and may further refine paleogeographic models for this Congo sector during Nuna/Columbia breakup.

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Preliminary petrophysical (porosity) and geochemical (XRF major element oxide) caprock results from two boreholes within the site vicinity of the proposed South African pilot carbon injection site, Leandra, Mpumalanga

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Anthropogenic carbon dioxide (CO2) emissions, largely from the combustion of hydrocarbon-based fossil fuels, contribute significantly to the acceleration of global warming. Carbon capture and storage (CCS) is widely considered important to support the reduction of CO2 emissions, thereby mitigating climate change. CCS can only be considered successful following the assurance that the injected CO2 has been fully confined. A critical component of containment is the sealing efficiency of sequences (caprocks) overlying the potential storage reservoir. The petrophysical properties of these caprocks act as a barrier, preventing the dissipative loss of CO2. This study forms part of a larger investigation associated with the South African pilot site that has been identified near Leandra in the Mpumalanga Province, South Africa. Detailed borehole logging, helium expansion, X-Ray Fluorescence (major element oxides), and hyperspectral borehole scanning was done on two boreholes (2068 and 2188) within the site vicinity. These analyses were undertaken in an initial attempt to characterise the suitability of Ventersdorp Supergroup lavas to act a caprock to CO2 storage. Initial results, including porosities of 1.17 % (borehole 2068) and 1.3 % (borehole 2188), and a large subaerial extent, are encouraging. These initial analyses will be supplemented by further investigations that include permeability, X-Ray tomography, Scanning Electron Microscopy, conventional microscopy, X-Ray Diffraction, and XRF trace elemental analyses.

Keywords:

Caprock, Seal, Carbon sequestration and storage, porosity

Preliminary results on the tectonic evolution of the Zebra Lobe, Kunene Complex (Namibia) using structural geology and geophysics

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The Kunene Complex (KC), an 18 000 km2 Mesoproterozoic massif-type anorthosite extending from SW Angola to NW Namibia, is one of the largest in the world yet the least studied. At the periphery of the complex are mafic-ultramafic bodies documented to contain Ni-Cu-PGE mineralization (Maier et al., 2013). Three different structural components are observed in the KC and their formation and evolution is controversial. The two domains within the Angolan part are NNE-trending. Instead, the southern component in Namibia (i.e., the Zebra Lobe, ZL) is characterized by an ENE-trending domal structure. We combine structural data with processed aeromagnetic data to constrain the architecture and tectonic evolution of the ZL.

Four deformation phases are observed. The upper amphibolite facies D1 forms a steep NE-striking gneissic foliation and stromatic layering in basement rocks (i.e., Epupa Metamorphic Complex, EMC). D2 consists of high temperature (HT) subsolidus steep N-S-striking gneissic foliation in KC anorthosites, with a steeply plunging pyroxene and hornblende lineation. The parallelism of subsolidus S2 and the magmatic foliation in KC anorthosites may suggest a syntectonic emplacement of the KC during an E-W shortening event. D3 formed ENE-WSW-striking HT subsolidus fabrics and a network of anastomosing shear zones compatible with NNW-SSE shortening. D3 overprints pre-existing structures in the anorthosites by deflection along shear planes associated with top to the NW kinematics. We interpret the ZL as a regional D3 inclined fold plunging to the SW, associated with a steeply SSE-dipping axial planar cleavage. A later D4 event, formed a steep NW-striking cleavage at greenschist facies observed in the EMC, KC and the Nosib Group of the Damara Supergroup. D4 probably formed during the Pan-African Orogeny and is associated with NW-striking fault planes that mark the southern ZL-EMC tectonic contacts. Geophysical maps highlight faults along the ZL-EMC contacts and within the ZL. Strong positive magnetic anomalies along the margins of the ZL coincide with locations of peripheral mafic-ultramafic intrusions. The ZL is characterized by alternating high – low magnetic responses attributed to the alternating white-dark anorthosites that make up the ZL.

This study confirms that the ZL acquired its architecture during an NNW-SSE shortening event (D3), possibly during Kibaran tectonism. This deformation event reworked earlier D2 fabrics, which are concordant with the NNE trend of the KC in southern Angola. A localized D3 event in the ZL accounts for the orientation difference between the NNE-trending Angolan and ENE-trending Namibian components of the KC.

Proximal impact ejecta from the Vredefort impact structure: Implications for Proterozoic stratigraphy

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The ca. 300 km diameter, 2020 Ma [1,2] Vredefort structure is the largest impact structure on Earth [2]. The only preserved ejecta derived from the Vredefort event was found in Greenland [3] and Russia [4], and it is believed that erosion removed the proximal ejecta [5]. However, the basal portion of the Gamagara Formation preserves breccias that are age constrained by the lavas of the Ongeluk Formation (2222±13 Ma; [6]) and the Hartley Basalt Formation (1928±4; [7]) thus being in the age range for the Vredefort event. Modeling of impact ejecta predicts ca. 100 m thickness of Vredefort ejecta at the sampled distance (~500 km; [8]), similar to the thickness of the Doornfontein Member of the Gamagara Fm [9]. In this study, samples from numerous field sites and drill cores above the Pre-Gamagara Unconformity were petrographically analyzed to test if it is ejecta.

The studied samples are poorly sorted polymict breccias, with very angular clasts of BIF, carbonate, chert, and quartz, although the rocks have been substantially affected by iron enrichment, replacing many of the original minerals with hematite and chlorite. The hematite-replaced fragments preserve textures, demonstrating plastic deformation of individual clasts. Shocked minerals are present within these breccias, including planar fractures in quartz and recrystallized granular zircon grains. At the top of the Doornfontein Member, bedded accretionary lapilli with lithic cores and concentric rims are present; these were previously described as pisoliths [10]. Previous models of formation of the Doornfontein Member do not adequately explain the observations made in this study, and therefore, we reinterpret it to represent the Vredefort impact ejecta. Therefore, the Doornfontein breccia represents a time-stratigraphic horizon that was deposited at the precise time of the Vredefort event and is the oldest known terrestrial proximal ejecta blanket.

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P-T-t-D record of the contact metamorphic aureole of the Kunene Complex in Angola

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The Kunene Complex (KC) is the largest massif-type anorthosite complex on the planet (Rey-Moral et al., 2022). It is located in southern Angola and northern Namibia, at the present-day southwestern margin of the Congo Craton. The emplacement and tectonic setting of Proterozoic massif-type anorthosites (including the KC) remains a debate among geoscientists (Ashwal & Bybee, 2017). Massif-type anorthosites crystallize at multiple levels in the crust; however, anorthosites do not contain the ideal mineral assemblages for thermobarometric calculations. Studies of the country rocks may be able to solve the problem, even though other challenges must be considered, such as a lack of exposed contacts, and a complex pre-and post-anorthosite emplacement history that needs to be separated.

We conducted a detailed pressure–temperature–time–deformation (P-T-t-D) study on a suite of supracrustal rocks close to the northwestern margin of the KC in Angola. Our study includes geological and structural mapping, petrographic and geochemical analysis, thermobarometric calculations, microstructural analysis and dating of uranium- and potassium-bearing minerals. By examining the pressure and temperature conditions of the country rocks, the time related to the metamorphic changes, and the deformation events that occurred pre-and post-emplacement, we can obtain several lines of evidence that will help us to understand the emplacement conditions of the KC.

Rock types observed in the study area are represented by an amphibolitic unit, a migmatitic unit (with minor amphibolite, schists, and chert) and granitoids (porphyritic granite and diorite), which present a variable spatial record of metamorphism. Three tectonometamorphic events are represented in the area, with the oldest deformation event D1 represented by a steep E-W-striking, low-to-high-grade metamorphic foliation, which was folded by D2, resulting in a steep N-S-striking medium-to-high-grade metamorphic foliation. D2 was folded by a D3 event, resulting in a shallow medium-to-high-grade metamorphic foliation and associated with diatexites. U-Pb zircon and monazite ages from metapelitic country rocks record evolution of the KC northwestern contact aureole in the interval 1790-1350 Ma.

Our preliminary structural and thermobarometric results question existing geological interpretations for the area and provide new constraints on the deformation events and conditions experienced before and during KC emplacement.

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Putting the Paleaoarchaean Noisy Formation on the map, Barberton greenstone belt, South Africa

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A major c. 200m thick felsic volcaniclastic unit has been identified in the upper Onverwacht Group in the Barberton Greenstone Belt (BGB). The provenance, sedimentology, depositional setting, stratigraphic position and status as a separate formation has been a matter of contentious debate. Workers in the northern part of the belt place this felsic volcaniclastic unit with dacitic intrusions in the uppermost Hooggenoeg Formation as a conformable H6 unit. Those working in the south, have referred to it as a separate tectono-stratigraphic complex, namely the 'Noisy Complex', which unconformably overlies the metabasalts of the 'Hooggenoeg Complex'.

Drill core observations indicate a number of coarse-grained polymictitic conglomerate beds are present consisting predominantly of rounded to subangular dacitic and rhyolitic clasts, although in the field rare banded gneiss clasts are also observed. The matrix in these polymictitic conglomerates are sand-sized grains, with no mud observed. Using bulk rock compositions, calculation of a chemical index of alteration indicates values of between 50 and 60. A 15cm thick chert horizon, namely the regionally exposed H5c chert, is found also in the drill core. Multiple sulphur isotope analyses of pyrite extracted from the metasediments record a strong Mass-Independent Fractionation (MIF) signal of up to +2 per mil. Two main detrital 207Pb/206Pb zircon age populations are identified at c. 3.553 to 3.527 Ga (ε(Hf) values from +3.5 to – 5.7) and 3.472 to 3.418 Ga (ε(Hf) from +7.5 to -2.8).

This study proposes a new formation in the upper Onverwacht Group of the BGB, namely the felsic volcaniclastic c. 3.432 Ga Noisy Formation. This formation is separate and conformable with the underlying H5c chert and pillow metabasalts of the Hooggenoeg Formation. No evidence for a major erosional unconformity can be found, hence no major tectonic uplift of oceanic lithosphere can be argued for. The term Noisy 'Formation' is preferred to Noisy 'Complex' as the latter tectono-stratigraphy term implies modern-style plate tectonics at c. 3.432 Ga. The coarse-grained beds are not diamictites or tillites, but rather polymictitic conglomerates and sandstones. The rocks are still relatively fresh and were likely storm-related debris flows, proximal to a felsic volcanic centre. Given the proposed juvenile nature of the BGB, some exotic detritus was most likely derived from recycled crust of the Ancient Gneiss Complex as recorded by the negative ε(Hf) values of detrital zircons. The Noisy Formation was deposited in a cold, shallow marine-subaerial environment under reduced atmospheric conditions.

QEMSCAN Results for Shergottite NWA7397: implications for use is mapping the mineralogy of martian meteorites

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Martian meteorites are currently our only existing samples from Mars. They are divided into two primary types, the shergottites and the nakhlite-chassignite types. The shergottites are by far the most abundant and are all basaltic in composition. Shergottites are further divided based on their texture into three sub-groups: 1) olivine-phyric, 2) basaltic, and 3) poikilitic. The poikilitic shergottites are mineralogically the most complex comprising multiple generations of both olivine and pyroxene and characterised by the presence of coarse-grained (>1cm) compositionally zoned pyroxene oikocrysts containing abundant olivine and chromite chadacrysts. These oikocrysts are set in a groundmass dominated by olivine and pyroxene with less common maskelynite (shocked plagioclase), Fe-Ti oxides, phosphates (merrillite and apatite), and sulphides. Here we use Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN) to accurately map the mineralogy of a poikilitic shergottite, Northwest Africa (NWA) 7397, to constrain its petrogenesis and to evaluate the use of QEMSCAN in mapping the mineralogy of martian meteorites.

Within, the sample, olivine makes up ~37 vol.% of the sample and is subhedral in shape where observed as chadacrysts and euhedral in shape in the interstitial groundmass. Within the poikilitic areas, the olivine chadacrysts are more Mg-rich as inclusions in the pyroxene oikocrysts compared to the surrounding groundmass. The non-poikilitic areas show olivine grains with compositional zoning through most grains. Within the pyroxene oikocrysts, we find orthopyroxene primarily as cores surrounded by pigeonite and rimmed by augite. There is slightly less pyroxene present in the sample than there is olivine. The phosphates within the sample tend to appear more elongated in appearance. Merrillite and apatite show similar chemical properties with apatite tending to have F and Cl in its composition and merrillite having neither of those. Apatite and merrillite also show variations in their CaO content. The use of the QEMSCAN has greatly aided us in the mineralogical mapping of NWA7397. We will continue to work with the data to further refine what we have and combine it with other data we will acquire in the future.

Quaternary fossil termite nests as proxies for palaeovegetation (Calitzdorp, South Africa)

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Background:

Fossil termite nests (termitaria) are commonly preferentially overprinted by calcium carbonate precipitates and preserved as hardy, calcretised material[1]. A typical process for pedogenic carbonate precipitation is the downward migration of saturated carbonate solutions from the upper soil levels[2]. Consequently, the precipitates may be used to infer palaeoenvironmental conditions at the time of formation[3]. In South Africa, carbonates from fossil mounds inferred to have been made by termite activity, have successfully been studied to determine palaeovegetation and palaeoclimate trends using carbon (C) and oxygen (O) stable isotope ratios[4], respectively.

Methods:

Here, we evaluate the δ13C values of two calcretised, Quaternary termitaria preserved in a well-developed soil profile near Calitzdorp, South Africa.

Results:

The fossil nests comprise 27 wt.% of carbonate minerals, specifically calcite and dolomite. The carbonate horizons, which can be identified macroscopically as cream-coloured layers amongst beige-coloured sands, have δ13C values ranging between -3.45‰ and -0.69‰ , based on 33 samples for the two termitaria.

Conclusion:

This δ13C signature is comparable to calcretised termite mounds from Worcester (South Africa)[4], which are interpreted to have C4 characters, commonly associated with vegetation adapted to warmer, drier climates. Whether the C4 character observed for the Calitzdorp termitaria is related to the preferential harvesting of plants by the ancient termites or related to soil respiration rates is still under investigation.

Key words:

Quaternary, termitaria, stable isotope, C4 characters

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Rare Earth Elements in South African Coals: Concentration and mode of occurrence in density fractionated samples from the Waterberg Coalfield.

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The demand for REEs in recent years has led to increased interest and research in coal deposits being considered as an alternative source for these critical raw materials. Several countries including South Africa are looking for coal and coal by-products for the extraction of REEs. However, before extraction, one needs to understand the concentration of REE in the host rock. South Africa has extensive coal resources, but the understanding of the mode of occurrence and distribution of REEs in coal and associated sediments is limited. The recovery methods for critical elements (including REEs) include preconcentration, activation, extraction, enrichment, and purification. Density fractionation of coal is considered a preconcentration method. The study aimed to assess density-fractioned coal samples from the Waterberg Coalfield to determine the concentration and mode of occurrence of REEs and to establish whether there is a relationship between REE concentration and density fractionation. Thirty density-fractionated coal samples selected from zones 8H, 8I, 7B, 4B, and 3C were characterized using proximate analysis, petrography, X-ray diffraction (XRD), and X-ray fluorescence (XRF). The concentration of REEs was determined using ICP-MS (after microwave digestion). The mode of occurrence of REEs was determined using Pearson's correlation (indirect) and Tescan Integrated Mineral Analyzer (TIMA) (direct).

The coals are classified as medium-rank C bituminous coals. The dominant REE-bearing minerals determined include calcite, hematite/magnetite, pyrite, and kaolinite. The REEs including scandium and yttrium (REY) concentrations range from 52.51 to 400.28 ppm. Float densities 1.40 to 1.80 show a notable higher degree of differentiation (different REY enrichment in the selected horizons) of LREY compared to MREY and HREY. Density fractions F1.30 and sink 1.80 show no distinct type of REY enrichment as the differentiation degrees between the different zones differ significantly. The results suggest that there is a relationship between the concentration of LREY with float densities of 1.40 to 1.80 and therefore, preconcentration may be beneficial for these coals. Pearson's correlation identified positive correlation coefficients of REY with organic matter and mineral matter suggesting that the REY in the density fractionated coal samples have a mixed organic and inorganic affinity. The TIMA image analysis revealed that REEs in these samples have both an organic and inorganic mode of occurrence particularly associated with phosphates, silicates, aluminosilicates, iron-bearing, and sulphur-bearing minerals. The REE occurring in these coal samples may have occurred due to inputs of volcanogenic hydrothermal solutions and sediment input from the Bushveld Complex.

Raw Material Exploitation, Strategy and its Public Acceptance in Saxony-Anhalt, Germany

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The province of Saxony-Anhalt in central Germany is rich in raw materials, it offers a mining tradition and important industrial sites. Saxony-Anhalt has state-wide potential of near-surface stones and earths commodities, as well as deep-lying potash and rock salt, and of extensive lignite and natural gas resources.

The commodities are important both locally and globally as basis for transport infrastructure, industrial plants, building stock, accommodation, everyday products, communication, working and recreation, and recycling. The industrial development of the province is induced by geology as indicated by soda and potash salt production, and by important hard rock and gravel plants supplying nationwide.

Raw material enterprises enhance nature and landscape after the extraction of raw materials by complying with environmental standards. The follow-up usage of extraction sites depends on extraction technology and is area-related. Combined regional business structures are examples for the sustainable use of raw materials, based on economic, social and ecological aspects.

The approval of mining permits in the state spatial planning is in strong competition with claims for other land uses. This requires a strategy of safeguarding raw materials by the Geological Survey of Saxony-Anhalt. A Raw Materials Strategy for Saxony-Anhalt includes:

- Political commitment to the extraction of domestic raw materials
- Creation of a political and legal framework by the State
- Knowledge of raw material distribution, quality and stock by the Geological Survey;
- Compatibility of raw material extraction and environmental protection
- Communication of fact-based awareness of location based, crucial commodities to government and public
- Public awareness that the sustainable supply with domestic raw materials is a social prerequisite for industrial development and the maintenance of our country's infrastructure
- Mining approval procedures are lengthy so that companies have to secure deposits early in cooperation with authorities

The ways of securing raw material mining in Saxony-Anhalt in the short to medium term are regulated by the Spatial Planning Act and Federal Mining Act, specifying the type of approval of the mining companies under mining law.

Overall, the public acceptance of mining projects in Saxony-Anhalt is variable: For instance, the expansion of stockpile capacity for an economically important commodity such as potash salt is more accepted than greywacke quarries in mining priority areas situated next to nature conservation.

Reconceptualising the electromagnetic spectrum with regards to electric field theory as per De Broglie's wavelength formula

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The electromagnetic spectrum is often erroneously presented in isolation as a means to demonstrate the various options available to scientists for the analytical measurement (structural or chemical) of matter. De Broglie's wavelength formula ($\lambda = h/mv$) explicitly reconciles wavelength-particle duality for ALL quanta. Though it is often erroneously suggested in popular science, quanta is not restricted to the "very small" and is simply a conceptualisation of ANY discrete package of energy (mass). As per De Broglie's formula, this includes the very small (photons) AND the quite large (electrons, protons, neutrons, ions and molecules) though these are never presented as a continuum of the electromagnetic spectrum. This poster attempts to present these concepts NOT in isolation but as a somewhat continuous spectrum that should aid all scientists in rigorously formulating their procedures for precise interrogation and maximum value add in their research endeavours. By presenting, the "electric field" spectrum and the electromagnetic spectrum as a continuum, it becomes apparent that ALL analytical techniques constitute analogues of analysis that can be represented in Cartesian space with the three different axes essentially informing the analytical questions (presented as a hierarchy):

1. Which quanta do I use for analysis (sample penetration vs spatial resolution)?
2. Do I want to measure the structure or chemistry of a sample (diffraction vs dispersion)?
3. If I am measuring chemistry, do I want fast chemistry at low resolution or slow chemistry at high resolution (energy dispersive spectroscopy vs wavelength dispersive spectroscopy)?

The overarching qualifier of any given analysis, as expressed by the question of imaging vs analysis (with its multiple formulations) is also inherently implied by this reconceptualization.

Reconstructing oxygen levels in ancient seawater using cerium anomalies in carbonate rocks

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Negative cerium anomalies develop in well-oxygenated waters and are eroded below the chemocline under suboxic to anoxic conditions. Cerium anomalies can be preserved in carbonate rocks and survive diagenesis and even dolomitisation. They therefore represent a promising proxy for tracking the appearance and rise of shallow marine oxygen in the geological record. Geochemical and geological evidence pinpoint the first appearance of atmospheric oxygen at the Archean–Proterozoic Boundary [1], but oxygen levels remained low throughout the Proterozoic [2]. Consistent with this, long term data compilations show that Ce anomalies were small and rare in carbonates before the mid-Palaeozoic [3,4]. The location, areal extent, and oxygen concentration of oxic waters are poorly constrained. We address this through a series of targetted studies. Firstly, a high-resolution shelf to basin transect from the Ediacaran suggests that oxygen was patchy and exerted an important control on ecosystem structure. Secondly, micro-drilling of microbial reefs does not reveal any negative Ce anomalies, suggesting that these productive environments were not sufficiently oxic to trigger Ce oxidation. Thirdly, Ce anomaly data from the Cambrian record the impact of a global expansion of anoxia on the shallow shelf.

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Regional- to Deposit-scale Structural Controls on the Emplacement of the Miduk Cu Porphyry, Kerman Porphyry Copper Belt, Urumieh-Doktar Magmatic Arc, Iran

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The Miduk Copper Porphyry (CP) is located 85 km along-strike from the world-class Sar Cheshmeh CP. It forms part of a suite of major CP deposits within the Kerman Porphyry Copper Belt (KPCB), encompassed by the Urumieh–Dokhtar Magmatic Arc. Economic mineralization at Miduk remains largely open at depth, whilst lateral exploration of analogous satellite CP systems in its vicinity, within a 5 km radius, is advancing. This contribution describes a deep, fertile CP system, contributing to the overall understanding of crustal- to meso-scale structural controls on the CP system.

A detailed mine-scale structural mapping and 3D geological modelling of the mining volume was initiated in 2017. This was performed in conjunction with an analyses of broader, regional magnetic surveys, satellite imagery and geological maps. Mine-scale mapping, producing over 12,000 structural measurements from exposed pit faces and excavations, was combined with UAV-based photogrammetry surveys, regional outcrops, drillhole data, downhole ATV surveys and macrostructural logging to produce the first fully-constrained, implicit 3D geological model of the deposit, its host structures, country rocks, alteration zones and joint domains.

The 3D model depicts predominantly syn-mineralization brittle deformation, dominated by persistent, NNE-SSW trending, sinistral strike-slip faults (D1b) that mutually cross-cut conjugate NW-SE and NE-SW strike-slip faults (D1a). The geometry and kinematics of D1b is analogous with R', and D1a with R and P-shears, consistent with an overall right-lateral Riedel Shear configuration. This points towards emplacement of the host granodiorite along a subvertical extensional jog and/or (R') fault step-over.

Regionally, mine-scale D1a and D1b faults are subordinate in scale and persistence with respect to the major, right-lateral Rafsanjan and Nayband fault zone systems that confine the KPCB's northern and southern margins. This setting argues for emplacement of the Miduk CP system and "feeder" magma bodies in a relatively low-strain, Inter Fault Zone (IFZ), characterized by overall gentle, km-scale, F1 (D1) folding. It is hypothesized that the IFZ and F2 anticlines were preferential structural settings for the emplacement and preservation of feeder magma bodies, whilst extensional jogs and/or fault stepovers at the more local to mine-scale provided focussed dilational zones for sub-vertical dykes/pipes and associated magmatic-hydrothermal mineralization. The lack of persistence in (D1) faults, associated with extensional jogs and/or step-overs, creates a relatively closed mineralization system, thereby promoting the generation of an economically-viable CP system.

Reprocessing of legacy seismic profile for shale gas exploration in the Karoo Basin (South Africa)

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Reflection seismic method has proven to be one of the major contributors to mineral exploration and mine planning because of its ability to image targets at great depths. South Africa has collected and stored an extensive number of reflection seismic profiles for mineral exploration in the past 50 years. The Karoo basin has been initially estimated to provide significant shale gas energy reserves of 450 tcf, however, this estimate has been reduced to a different level after considering the effect of the dolerite networks in the subsurface (Scheiber-Enslin et al., 2021; De Wit, M., Tinker, J. [2004]; Decker, J. E., and J. Marot. [2012]).

Considering the potential of the area for shale gas exploration, this research reprocesses a legacy reflection seismic profile, acquired in the south western section of the basin, using today's processing tools to map the subsurface structure of the study area. The reprocessing is essential because it has been demonstrated in the literature that this allows a significant improvement in imaging quality and signal-to-noise ratio (Manzi et al., 2019).

The data are reprocessed using the conventional seismic processing approach. The steps include pre-stack processing steps such as field geometry setup, gain applications, first-break picking, noise attenuation, deconvolution and velocity analysis. Post-stack processes such as seismic migration and and f-x deconvolution are applied to generate high resolution maps of the subsurface. All processing are done carefully to balance the signal to noise ratio.

The main aim of the project was to reprocess the legacy seismic profile with improved quality so that subsurface features such as boundaries, dolerite intrusions and gas escape features in order to aid shale gas exploration in the Karoo Basin of South Africa. The results suggest that reprocessing legacy data improves imaging quality and may be important to map the subsurface structures for shale gas development in the Karoo Basin.

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Review of the Archean Ntem craton and a new petrological survey into its greenstone-granitoid terrain in the Republic of Congo

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The Ntem craton/block, forms the north-western corner of a Greater Congo Craton. It stretches across most of Gabon, Cameroun and Republic of Congo. In Congo, it is subdivided into the northern Ivindo and Kelle-Mbomo basements and a southern Chaillu Massif1,2.

Our petrographical and bulk rock geochemical survey on 18 greenstones, 21 TTG and 5 granite samples from across the northern Ivindo and Kelle-Mbomo to southern Chaillu basement outcrops, reveals that most amphibolites to mafic granulites in the greenstones were likely depleted (N-MORB) arc magmas, associated with dunitic to hornblende pyroxenitic cumulates. It can only be speculated when and how such juvenile arcs got incorporated in amongst the TTGs and greenstones, after significant volumes of banded iron formations (BIFs) and volcano-clastics had also been deposited. The TTGs include local sanukitoids, which collectively share most geochemical signatures, apart from a systematic southward decrease in heavy rare earth elements (HREEs) that likely records increased pressures of formation as partial melts from a meta-gabbroic to garnet amphibolitic source. Again, it can only be speculated as to how such different depths of patrial melting may have been induced, either along one or more subducting slabs, underplatings and/or within an accreted terrane. Subsequent granites likely involved a source that had become more enriched in large ionic lithophile elements (LILEs), through the dehydration of subducting slabs but how this LILE-enrichment got incorporated into the petrogenesis of these granites remains elusive. Granulite facies peak metamorphism, affecting greenstones and TTGs at ~2.84-2.82 Ga3, was only reached in the north-western corner of the Chaillu Massif and correlates well with a granulitic, charnockitic and SW-NE trending metamorphic belt that extends into Gabon.

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Seasonality of Cadmium in the Southern Ocean

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The Southern Ocean is separated into distinct biogeochemical zones consisting of distinct water masses. Little is known of trace metal dynamics from the region for the lack of data, especially seasonal data. This study discusses distribution and cycling of the bioactive micronutrient Cadmium, between South Africa and Antarctica along the zero meridian. Samples for dissolved cadmium (DCd) were collected in Summer (2015), Spring (2019), as well as Winter (2015, 2019) from the Subtropical Zone (STZ), SubAntarctic Zone (SAZ) and the Antarctic Zone (AAZ) in the Surface Mixed Layer (SML).

The mean SML DCd concentrations showed a poleward increase, ranging from 16.057 ± 13.00 (pM) in the STZ to 557.4 ± 115.53 (pM) in the AAZ, congruent with prior studies, explained by typical oligotrophic conditions in the STZ, and the HNLC regime further south.The STZ had a mean Cd:P of 104.90 ± 67.68 (SD), where the AAZ showed the highest Cd:P, 313.1 ± 40.80 (SD). The aforementioned ratios and concentrations found here support both the influence of biological uptake, and the phytoplankton community composition playing a role in modifying the DCd concentrations.

In the STZ, physical processes seemingly controlled the seasonality of SML concentrations, and up to a depth of 1000 m in the case of the 2019 Spring. In the SAZ, dynamics were similarly seasonally variable in that physical processes and the seasonality thereof controlled the DCd dynamics in the SML, where concentrations were controlled by deep winter mixing and entrainment, related to the formation of SubAntarctic Mode Water (SAMW), and sequential sinking, followed by intense shoaling in the onset of Spring. In SubAntarctic Surface Water (SASW), the main drawdown of DCd and the seasonality thereof was diatom growth, subsequently reliant on silicate. Seasonality in the AAZ was related to the physiological responses of phytoplankton, including Summer depletion related to seasonal blooms, whereas winter showed typical accumulation and under-utilization as well as upwelling and shoaling of Upper Circumpolar Deep Water (UCDW) during 2019. 2015 showed winter biomass was overestimated, resulting from the increased production of chl-a per cell in response to the typical winter conditions (low light, high Fe). With this, intra-annual differences were also found.

Sedimentology and Taphonomy of drought afflicted tetrapods in the Early Triassic Karoo Basin, South Africa

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The End-Permian Mass Extinction Event approximately 251.9 Ma was Earth's greatest biological crisis. A global increase in mean annual temperature of at least 10oC over 10-50 kyr (a hyperthermal) likely resulted from sustained atmospheric pollution accompanying massive volcanic eruptions in northern Pangaea. Currently, there is considerable debate surrounding the rapidity of global warming and its effect on the terrestrial ecosystems of Gondwana.

The sedimentology and taphonomy of in-situ fossils from earliest Triassic strata (Induan) in the southern Karoo Basin of South Africa is presented as evidence for episodes of drought-induced mass death of the resident tetrapods. The rubified mudrocks, abundant desiccation cracks, loessic calcic palaeosols and evidence of floodplain deflation are interpreted as the result of climatic drying and loss of vegetation. Abundant skeletons are preserved in a 2m-thick tabular silty-sandstone capping a multi-storeyed low-sinuosity channel sandstone interpreted as a wide shallow channel that became progressively abandoned, with more ephemeral flow regime than in the underlying channels and subjected to intermittent flows of low-density sediment-laden floodwaters.

Stratigraphic and planimetric distribution of 170 in-situ tetrapod fossils shows several clusters of up to eight closely-spaced articulated Lystrosaurus skeletons preserved in prone and spread-eagled body position. These are interpreted as drought-stricken carcasses that collapsed and died of starvation in and alongside dried-up water sources. Two of the specimens display an unusual micritic envelope with a distinctive pustular texture interpreted as permineralised mummified skin indicative of rapid desiccation after death. Bonebeds of disarticulated bones of multiple juvenile Lystrosaurus occur in shallow depressions within the rubified mudstones. Layering of different skeletal elements suggests some hydraulic sorting but the initial aggregation was likely a behavioural response to drought.

Osteohistology of spread-eagled Lystrosaurus (L. declivis and L. murrayi species) skeletons show that they represent early juvenile stage which is in accordance with previous findings that throughout Pangaea Early Triassic Lystrosaurus died relatively young due to environmental stressors. Our results support the hyperthermal hypothesis that ~252 Mya increased continental aridity, already a consequence of the coalescence of Pangaea, was critically intensified by volcanogenic greenhouse gasses from the Siberian traps. We propose that in the aftermath of the End-Permian mass extinction event, a succession of climatic drying episodes orchestrated a series of fully-functioning terrestrial ecosystems that were markedly different to those of the pre-extinction, and likely had a profound and lasting influence on the evolution of tetrapods.

Seismic characterization and hydrocarbon potential of the deepwater sedimentary succession off the East Coast of South Africa

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The east coast of South Africa can be seen as "frontier" where exploration remains sparse and historically focused on the shelfal portion of the Durban Basin. This study assesses the hydrocarbon potential of the deep-water along the east coast focusing on the Durban Basin (DB) and Durban-Deep Basin (DDB).

The study area is ~ 75 400km2 in size and is defined by the coverage of two 2D seismic surveys. The methodology followed an integrated seismic characterization approach incorporating structural and seismic interpretation, and facies analysis to identify depositional processes and systems.

The DB (~18000km2) and DDB (~15815km2) is separated by a basement high, the South Tugela ridge (STR) (Bhattacharya & Duval, 2016). Basement faulting is abundant within the inboard DB and over the STR represented by a highly rugose basement comprising multiple grabens forming isolated depocenters. Localized reactivation of faults is observed within the Tertiary. In the DDB basement faults are less pronounced, with zones of polygonal fault systems dominating the sedimentary column. Most faults are representative of conjugate sets trending NW-SE and NE-SW. Sediments within the DB is up to 4.6sec thick, deposited by the proto-Tugela River forming fans and channels (Bhattacharya & Duval, 2016). Contouritic depositional elements are observed in the form of plastered drifts, drift mounds and sediment waves in the DB. Hybridization of these contourite deposits with channels and fans result in mixed depositional systems (MDS). The sedimentary succession in the DDB is up to 3.1secs thick and is dominated by hemi-pelagic sedimentation in the Lower Cretaceous and by contouritic processes in the Upper Cretaceous with three distinct zones of sediment waves.

Hydrocarbon potential in the DB is related to channels and fans. Isolated depocenters likely facilitated source rock development. Contouritic elements exhibit hydrocarbon prospectivity in a variety of ways either by facilitating reservoir distribution or sealing potential, while MDS act symbiotically to facilitate reservoir formation intermingled with sealing prone sediments. Play types of this nature have seen large scale discoveries in Mozambique north of the South African border. In the DDB indications of hydrocarbon reservoir potential are observed at the base of, and sporadically intermingled with sediment waves by high amplitude reflectors (HARs). These plays present exciting hydrocarbon opportunities along South Africa's east coast.

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Seismic Hazard Assessment near the Koeberg Nuclear Power Station, Western Cape, South Africa

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Ground motion associated with near-source seismic waves from shallow earthquakes can pose a serious hazard to critical infrastructure such as nuclear power stations. South Africa is an example of a stable continental region (SCR), but significant seismicity has occurred in the recorded history. Past earthquakes in South Africa have ranged from micro-seismic occurrences (i.e., ML ≤ 0), to earthquakes of a potential magnitude of 6.5 in the Milnerton area in 1809 based on historical reports. Another well-known event in the South African earthquake catalogue is the September 29th,1969 earthquake of magnitude 6.3 near Ceres-Tulbagh. The Ceres-Tulbagh earthquake and the 1809 earthquake both happened within a short distance (less than 100 kilometres) of the Koeberg Nuclear Power Station, emphasising the need to take the potential seismic hazard in this area very seriously. Previous studies have demonstrated that the source zones of historic and even prehistoric SCR earthquakes are often associated with increased microseismicity over hundreds or even thousands of years. In this study, we seek to determine whether earthquakes are identifiable on known or unknown regional structures. Such events may help identify the structure responsible for the 1809 event, which is still unclear. To achieve these aims, we deployed a temporary seismic network consisting of 18 stations across an area of 40 by 35 km near the Koeberg Nuclear Power Station. The network which provided coverage of the Colenso fault zone was also located in the vicinity of the hypothesized Milnerton fault zone, the Ceres-Tulbagh region, and the Cape Town area. Each station in the network included a 3-component high-frequency sensor coupled to a 3-channel datalogger and recorded for approximately 3 months between August and October 2021. Using machine learning, we have systematically searched for seismicity near known structures such as the Colenso fault, and although some initial detections appeared like good candidates for microseismicity the absence of these events at nearby stations makes it unlikely that these detections are real natural seismic events. The algorithm has identified a dozen quarry blasts during the period of the deployment and these have been corroborated by satellite imagery and epicentral locations. Our initial results suggest a lack of seismicity from natural sources during the duration of recording, however, more work is needed to conclusively identify these initial detections.

Seismic Tomography: Mantle Images or Mirages?

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Although seismic tomography provides the most spatially detailed and geologically relevant information available about the three-dimensional structure of the Earth's interior, this information is subject to many limitations, weaknesses, and biases. These limitations must be borne in mind when interpreting tomographic models, to avoid unsafe conclusions, for example about Earth structure beneath LIPs. Multiple independently conducted inversions of large high-quality data sets, for example from the U. S. Array component of the EarthScope initiative, provide striking illustrations of the variability of tomographic results.

Wave-speed anomalies are not temperature anomalies or anything else so simple. They depend also upon the chemical composition and phase of Earth materials, and consequently their physical/chemical interpretation is not unique. Methods for determining anisotropy, anelasticity, and density can sometimes provide valuable supplements to wave speeds in this regard.

Geographical seismic-ray coverage is seriously limited by the distributions of Earth's seismicity and seismometers. This coverage is highly uneven and strongly correlated with geological and tectonic environment. The vast majority of seismic rays originate in subduction zones, for example, while most of the Earth's oceanic areas go un-sampled. Even if coverage were perfectly unbiased, mathematical limitations (e.g. trade-offs between wave speeds and unknown earthquake locations and times) would limit the resolution of true wave speeds. Therefore, absolute wave speeds often are not accurately resolvable, and in particular, teleseismic tomography cannot detect vertical variations within the upper mantle. Moreover, unknown wave-speed structure outside model volumes can introduce significant bias into teleseism-based models. Methods exist for reducing this particular bias, but they are not often applied in practice. They should be.

Commonly used display methods often distort tomographic models (e.g. by vertical exaggeration and color saturation). Moreover, formal resolution- and confidence-assessment computations systematically underestimate the true uncertainties. Many of these effects tend to produce misleading (e.g. plume-like) artifacts (because most seismic rays are approximately vertical in the upper mantle). Apparent structures in tomographic models are therefore often artifacts of accidental features of the data such as ray bundles.

Signs of superfaulting in the Morokweng impact structure, South Africa

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The 146 Ma Morokweng impact structure (MIS) located 140 km northwest of Vryburg is completely buried beneath Late Cretaceous to Cenozoic sediments of the Kalahari Group. It is well defined by an ~70 km diameter annular magnetic anomaly, making it one of the 10 largest impact structures yet discovered on Earth. Multiple drillcores have revealed that the MIS underwent erosion by ~1-1.5 km prior to its burial, which removed the shallow crater-fill deposits. Nonetheless, 4 boreholes in the central parts of the MIS (R ≤ 15 km) have revealed that up to 800 m of impact melt remains. In contrast, the 369 m deep M4 borehole, located at R ~ 16-18 km from the estimated centre, contains only highly fractured and brecciated, shocked, Archaean granitoid gneisses and younger dolerites, which are interpreted as uplifted crater basement corresponding to the structural peak ring of the MIS.

Peak rings form in large impact craters owing to collapse of the central uplift volume, which represents the highly shocked crater basement immediately below and adjacent to the impact point. Rebound of this initially strongly compressed volume first forces material inwards and upwards, after which it collapses downwards and outwards. Whilst these displacement patterns at the gross scale appear indistinguishable from fluid flow, the reality is that the exceptional strain rates and multi-km scale translation of material over, at most, minutes, necessitates large displacements significantly in excess of those seen along tectonic faults. Such faults, in which continuous slip over seconds to tens of seconds exceeds 100 m, are known as superfaults.

Here we report on evidence from the M4 drillcore that supports contemporaneous development of cactaclasite, pseudotachylite and mixed ("suevite") breccias through continuous, large-magnitude, slip in an impact-generated fault zone. Macro- and microscopic structural relationships suggest that the fault evolved principally in a thrust mode, which has implications for both its timing during peak ring evolution and its location within the peak ring and, consequently, for the minimum size of the MIS.

Some highlights of studying the coastal and marine Cenozoic deposits of South Africa

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The coastal plain and continental shelf are one continuous geomorphic feature, separated only by relative sea level at any point in geological time. South Africa is a far-field site with respect to global ice sheets, and as such, has remained unglaciated through the Quaternary glacial-interglacial cycles. This spatial setting means that geological deposits within the range of these sea-level fluctuations may be better preserved than other regions globally that were scoured by shifting ice sheets. The vertical range of sea-level change experienced in the late Quaternary of South Africa has generally been between ~10 m above present sea level in periods of warming, and ~130 m below present sea level during times of cooling. As sea level falls in response to glacial cycles, the continental shelf is exposed as a terrestrial landscape. In the Cape, this corresponds to an area the size of the country of Ireland. The narrow shelf of the East Coast experiences more limited spatial shifts. Across the present-day continental shelf, despite the contrasts in the extent of exposure, aeolianite and cemented beach deposits have been preserved that illuminate the nature of past coastlines. In places, these have been mapped with high-resolution hydroacoustic methods and some have been sampled by scuba diving and sediment coring. These mapping and sampling methods include multibeam bathymetry, side-scan sonar, marine magnetics and shallow sub-bottom profiling. Onshore-offshore correlation and comparison has been conducted, and several ongoing and completed projects by our team have specifically focused on ancient human use of these coasts, and reconstruction of now submerged landscapes. In this talk, I demonstrate several key findings such as how we made a geological map of the Last Glacial Maximum environment 20,000 years ago on the Palaeo-Agulhas Plain of the southern Cape, a human response to rapidly rising sea level in the past, Quaternary palaeoclimate results of coring expeditions, an overview of animal and human trackways discovered on the Cape coast from our ongoing research, and thoughts on why these Pleistocene rock deposits are preserved in some places and not others.

Some lessons learned from rockburst studies

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This paper summarises lessons learned from mine seismology that may be of interest to geologists.
Fault stability: Mining associated fault slip events manifest as true earthquakes, up to local magnitude 5. We have learned exactly how to make such earthquakes. We therefore also know how to minimise such hazard. We have also learned what signs to look for to allow some spatial hazard assessment. In one particular case the stress built up around an asperity was reflected by the nature of the seismic events and a part of the mine was timeously evacuated.

Ortlepp shears: These dynamic brittle shears that evolve through intact rock proximal to mine openings, are a "trademark" of rockbursting in the Wits gold mines. Analyses of these and other mining induced deformations allowed insight into the rupturing and fracturing processes of brittle rock under high stress. Some simple truths can be stated. It is in the nature of rock to deform through shearing, since simple shear can yield large strain with no volume change. Rock is weak in tension, that is why "explosive" source mechanisms are unlikely in solid rock. The size of rock fragments resulting from brittle deformation depends on the rate of deformation – in the limit the rock is turned into a powder, referred to as rock flour.
Forensic analyses: Much like the sequence of deformation events are deciphered by structural geologists, the sequence of dynamic deformation processes in mines help to explain "what happened" and thus provide information useful for preventative methods of mining and support. Examples include slickensides superimposed on fractographic striae (showing that extension fracturing preceded slip) and the orientations of bent rock anchors (pointing to the source region of the seismic event). Recognition of seismic sources in core: A recent study lists the characteristic of those discontinuities in core that are recent, dynamic shear failures.

South African Devonian biozones identified with network analysis provide evidence for a pulsed extinction event at high latitudes

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Fossils from the Cape Supergroup are the only means of inferring relative age constraints for the Early-Middle Palaeozoic (Ordovician-Devonian) as well as correlating strata with time equivalents throughout West Gondwana. In West Gondwana Early-Middle Devonian faunas may be compartmentalised into at least three faunal complexes, namely the Silurian-Lochkovian Afro-South American fauna, the Pragian-Eifelian Malvinoxhosan fauna and the Givetian Post-Malvinoxhosan fauna. Those belonging to the Early-Middle Devonian Malvinoxhosan bioregion are notoriously difficult to use in biostratigraphic studies and are the subject of this study. These difficulties are due to their highly endemic nature as well as the bioregion having a complete lack of globally important fossils (eg conodonts, palynomorphs, ammonoids, and graptolites) for biostratigraphy. Low origination rates further complicate the recognition of potential assemblage biozones in that biozones are often marked by total ranges with no clear pattern over overlapping occurrences. A thorough reassessment of all known South African fossil material in repositories (Council for Geoscience, Iziko Museum) as well as from literature have been used to create a database of 26,000 individual records. Much of these data are associated with geographic and stratigraphic information making them ideal for biostratigraphic and biogeographic studies. Here, these data have used to improve the characterisation of the biota and their biostratigraphic ranges. This research has revealed the presence of at least seven to eight assemblage biozones housed within at least two large faunal complexes in the South African Devonian System using novel multivariate statistical methods in conjunction with network analysis (NA). Here strata-fossil relations were recorded in a presence-absence matrix and used to perform non-metric multidimensional scaling (NMDS) and cluster (CA) analyses to indicate potential groupings of strata according to their fossil content. The fossil-strata interactions were further used to create a dataset of nodes (taxa and formations) and edges (weighted taxon-formation relationships), and a NA performed. Network analysis is a relatively new method that can be performed on relational data by assuming independent pair-wise links to elucidate natural complex relational structures among data with limited bias. The relational groupings from the network analysis show strong support for the assemblage biozones recognised using NMDS and CA. Lastly, the data also reveal evidence for a pulsed extinction over a period of at least 10 Ma with changes in relative base-level being the extinction mechanism. The NA has revealed that changes in base-level deleteriously affected epifaunal organisms with higher survivorship registered among infauna.

Spatial and temporary association of Neoarchaean Sanukitoid Diorite, Trondhjemite and High-K Granite in the Francistown Granite-Greenstone Complex: Implication on the geodynamic processes in the SW margin of the Zimbabwe craton

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The Neoarchaean Francistown Granite-Greenstone Complex has an intricate geotectonic history which is still being actively debated. The complex forms an integral part of the southwestern margin of the Zimbabwe craton. Geochemical and geochronological data of the spatial associated sanukitoid diorite, trondhjemite and high-K granite suite in the Neoarchaean Francistown granite-greenstone Complex constrained their emplacement ages and genesis. The data provide insight into the magma generation processes, crust-mantle interaction and tectonic history of this Neoarchaean complex. Zircon U-Pb dating on the sanukitoid diorite, trondhjemite and high-K granite was conducted together with the petrogenetic investigations. The sanukitoid diorite, trondhjemite and high-K granite recorded the crystallization ages of 2715.9±2.5 Ma, 2714.3±2.8 and 2719.9±8.4 Ma, respectively, which indicate that they are coeval. In addition, the three rock units have arc-like geochemical features which suggests a close petrogenetic relationship amongst the units.

The geochemical characteristics of the high-K granite are consistent with derivation from incipient melting of a tonalitic source. The sanukitoid magmatism is ascribed to a metasomatized mantle source, and the trondhjemite magmatism is linked to partial melting of hornblende-bearing mafic crustal source or tonalitic source followed by crystal fractionation. Most geochemical characteristics of the high-K granite and trondhjemite are similar suggesting a common source. These geochemical characteristics are possible inherited features from the protolith. The heat source that triggered partial melting of metasomatized mantle and tonalitic partial melting is ascribed to the upwelling of the mantle after slab break off.

The spatial and temporary association of the sanukitoid diorite, trondhjemite and high-K granite in the Francistown Granite-Greenstone Complex is attributed to partial melting of a subducting slab resulting in the formation of tonalitic magma and partial melting of the overlying mantle wedge to form mafic magma which eventually produced the mafic lavas of the Tati greenstone belt and associated tonalitic granitoids, respectively. Subsequent slab break off triggered partial melting of the metasomatized mantle and partial melting of the tonalite resulting in the formation of the sanukitoid diorite and trondhjemite as well as high-K granite.

State-of-the-art analytical geochemistry facilities at Wits set the stage for exciting new research avenues

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The School of Geosciences has recently finished the installation for two new state-of-the-art mass spectrometers from Nu instruments; a Collision Cell Multi-Collector-ICPMS (NuSapphire) and a Thermal Ionisation Mass Spectrometer (NuTIMS). This new instrumentation was made possible through a NRF National Equipment Program grant (along with Wits University co-funding) and forms a powerful synergy with the Wits Isotope Geosciences Laboratory (WIGL). The WIGL is a state-of-the-art, ultra-clean metal-free laboratory designed to perform ultra-low blank chemical separation and isotope dilution to prepare samples for mass spectrometry measurements. This combination of instruments and labs does not exist elsewhere on the African continent, and will complement the existing LA-ICPMS system (Thermo Fisher Element XR coupled to an ASI/AR Resolution excimer laser) and quadrupole ICPMS (Thermo Fisher iCAP-Q). The Wits Advanced Mass Spectrometry (WASp) Lab, containing all of the School's mass spectrometers, will be a centerpiece of the new Earth Observatory - a world-class facility housing a broad array of geoanalytical instrumentation.

This new combined laboratory and mass spectrometry infrastructure allows for high-precision measurements of traditional radiogenic isotope systems such as Pb, Sr, Hf, and Nd. The addition of the collision cell to the MC-ICPMS allows for the measurement of non-traditional stable isotopes of elements such as Ca, Fe, Cu, Zn, Ti, and S, opening research avenues to African students and researchers not available anywhere else on the continent. The field of non-traditional stable isotopes is still growing rapidly and, the new facilities at Wits mean that southern African universities will be able to compete globally at the forefront of isotope geoscience.

The NuTIMS will allow for the measurement of Sr and Nd isotopic compositions at unparalleled precision on smaller sample aliquots. The NuTIMS is equipped with a 16-channel multi-collector array utilising Faraday collectors as well as a Daly collector and electron multiplier for very low concentration applications. The requisite clean lab and instrumental setup for Re-Os, U-Pb, and small aliquot Sm-Nd isotopic applications on the NuTIMS will be developed. These methods have great utility for constraining the chronology of mineral deposits, tectonic processes, deep crust and mantle evolution and Earth history events at high precision.

We encourage outside users from across southern Africa to acquire highly-precise and accurate isotope geochemistry data and to learn methods and techniques in this unique facility.

Stratigraphy, Dating and Palaeoclimatic Reconstruction of the Gondolin and Kromdraai Hominin Sites, South Africa

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Gondolin and Kromdraai are the only two Paranthropus robustus fossil bearing sites in the Cradle of Humankind that remain undated. We plan to determine a robust chronology using U-Pb dating of flowstones found interbedded with the fossil bearing sediments. This technique has been applied for more than a decade at similar sites, and reached a level of maturity where it can be applied routinely (Pickering et al, 2010; 2019). Cosmogenic nuclide exposure dating will also be used to build a more complete picture of the caves' development through time. This will enable a comparative study of fossils collected in South Africa to those in eastern Africa and see how individual palaeobiogeographies were, similarities, differences and what these effects had on the life evolution of Paranthropus in the regions.

The research will also involve mapping, determining stratigraphical sequences and depositional facies at the two sites. Creating chronological accounts of the geological history for each of the caves and their pits will aid in the confirmation of the connection between pits and reaffirm they were part of the same cave system but formed at different times. Palaeoenvironmental and palaeoclimatic investigation during Paranthropus' existence will be conducted to establish and provide an understanding of the landscape's evolution from then till now and likely factors responsible. This will be done primarily on flowstones, as these are excellent palaeoclimate archives indicating positive water balance in the cave correlating to a wet phase outside the cave.

The general hydroclimatic influenced cave morphology and stratigraphy layout recently applied to karst caves in South Africa will be tested and the new ages acquired will be assessed to determine whether they conform to the existing range found in other Cradle hominin sites (Pickering and Edwards, 2021).

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Structural and geochronological constraints on polyphase deformation in the southern Central Zone of the Damara Orogen, Namibia

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The Pan-African Damara Orogen is a trench-trench-trench triple junctions orogen that formed at 580- 470 Ma during the Gondwana Supercontinent assembly. It is generally accepted that rocks of the Damara Orogen have been deformed several times during orogenesis, however, i) the number, direction of finite strain, and kinematics of deformation events, and ii) the absolute timing of deformation are debated. This is especially so for the NE-trending Central Zone of the Damara Orogen, a tectonostratigraphic domain characterized by Paleoproterozoic basement-cored migmatite domes, along with voluminous granitic bodies.

We focus on the Namibfontein-Vergenoeg dome, an ENE-WSW-trending basement-cored migmatite dome in the southern Central Zone of the Damara Orogen. Detailed field-based structural geology reveals that the NV dome formed by the interference of three main contractional folding events. 1) E-W shortening produced upright folds with steep N-S-striking fold axial planes, S1 schistosity, and stromatic layering in migmatite. 2) NNW-SSE shortening formed moderately (and rarely steeply) NE-plunging F2 folds with steep E-W-striking axial planes, S2 schistosity, and compositional layering. Lastly, 3) NE-SW shortening, i.e., perpendicular to the structural grain of the Central Zone, produced F3 folds plunging moderately to the NE associated with moderately NE-dipping axial planar S3 schistosity. Aggregate mineral lineations of biotite ± sillimanite, cordierite, and magnetite parallel F1, F2, and F3 fold axes. Rarely, leucosome forms rods in F2 and F3 fold axes. All deformations affected both basement and cover rocks of the NV dome. Deformation fabrics formed at upper amphibolite facies conditions (~760°C, ~4.5 kbar) and rheology controls fabric intensity.

Pre-, syn-, and post-deformational leucogranite, granite, and alkali-feldspar granite bodies and veins occur across the NV dome. LA-Q-ICP-MS U-Pb monazite dating of a peraluminous granite showing S1 spaced cleavage, defined by aligned biotite laths, gives a 206Pb/238U crystallization age of 558 ± 4 Ma (ages <10% discordant) giving a maximum age for D1. Additionally, preliminary in-situ U-Pb monazite ages coupled with trace element analyses of structurally controlled leucosomes appear to support the relative chronology of deformation fabrics based on overprinting relations observed in the field. These ages show that D3 could be as young as ~500 Ma. However, further petrochronological data are needed to constrain the timing of deformation events. These data suggest that rocks of the NV dome have been deformed at least three times in a contractional setting. During this time, peraluminous granitoid emplacement and migmatization lasted for at least 60 Ma.

Structural and Lithological Overview of a Polygenetic Mélange in an Evolving Lufilian Arc Foreland Basin, Kolwezi, DRC

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The Kolwezi area of the Democratic Republic of the Congo hosts world-class stratabound Cu-(Co) and U-(±Cu-Ni-Co-Pb-Zn) mineralisation in large écaille or fragments of coherent lower Roan Group units which are hosted in regional breccias. Long-debated genetic models for the development of these types of deposit involve halokinesis or salt tectonics, and/or the development of tectonic mélanges, friction breccias, sedimentary mélanges and olistostromes. Historical and new data at K.O.V. Mine, situated in the Kolwezi "Klippe", or sub-basin, has been re-analysed and used in the construction of a fully-constrained 3D implicit model of lithologies and major structures. This data, which spans 70 years, comprises diamond and reverse-circulation drilling, new structural and lithological face mapping, downhole televiewer data and macrostructural logging. In-pit observations and the new 3D model, presented herein, provide new insight into K.O.V.'s genesis.

The Kolwezi sub-basin, characterized by K.O.V. Mine, resulted from gravity-driven mass-transport processes, concomitant with the development of a polygenetic sedimentary mélange, within a folded foreland basin during orogenesis. The final configuration of K.O.V. Mine is primarily due to: 1) structures inherited from the residence time of fragments within the hinterland of the fold-and-thrust belt; 2) lateral extension due to loading and oblate flattening strain that caused chocolate tablet geometries in coherent units, which were initially exploited by veins; 3) variable geometries, sizes and attitudes of fragments; 4) block-in-matrix fabrics; 5) soft-sediment deformation structures; 6) matrix-supported, polymictic conglomerates; 7) discordant and unconformable sedimentary relationships; 8) multiple Roches Argilo-Talqueuses (R.A.T.) sub-types and "incursions" of R.A.T. and Roan Breccia into fragments which exploited the chocolate tablet geometries; 9) variable shearing in proximity to the base of fragments; and 10) large-scale juxtaposition of fragments, the configuration of which was complicated by late-kinematic tightening of the Kolwezi sub-basin and dewatering of the pile. This was probably accompanied by further remobilization of fluids and metals. Collectively these features suggest that the Kolwezi sub-basin comprises a foreland olistostrome.

Structural and stratigraphic analysis of the T-Goob Structure, within the eastern Mesoproterozoic Aggeneys Terrane

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The terranes of the Mesoproterozoic Namaqua-Natal Province represent tectonic events associated with the two super-continents, Rodinia (1200-1000 Ma) and Columbia (2000-1800 Ma (1, 2, 3). The Aggeneys Terrane in the western part of the amphibolite-granulite Namaqua Province is comprised of supracrustal sequences and syntectonic sheet granitoids emplaced at ~1195 Ma. (2). The intensely deformed terrane can be subdivided into several high and low ductile strain zones (km-scale ductile shear zones) with the eastern part as an example of the former. A structural-stratigraphic study of ~1350 km² within the eastern Aggeneys Terrane indicated that it can be defined by four structural domains consisting of km-scale sheath folds hosting metasedimentary and metavolcanic sequences enveloped within sheet granitoids; these domains are subdivided by intra-terrane thrust sheets.

Intense ductile deformation occurred during a single long-lived progressive shear deformation event (4). The terrane is dominated by both co-planar (fabric/layering, axial planes of folds, and thrust planes) and co-linear tectonite fabrics (mineral/stretching lineations, fold axes of various phases of folding). The co-linear fabrics regionally have a shallow plunge and trend toward the northeast, subparallel to the northeast to southwest tectonic transport direction (4). The co-planar fabrics regionally have shallow to moderate dips northwards and northeastwards (4). For the eastern Aggeneys Terrane, six phases (D1-D6) were identified to form progressively (5). The D1 phase is defined by an S1 transposed shear fabric associated with the intrusion of sheet granitoids seen regionally. Inter-and intra-terrane thrusting is also associated with the D1 phase of deformation.

The D2 deformation phase consists of F2 macroscopic sheath folds and mesoscopic folds with a penetrative S2 axial planar foliation that forms the regional foliation. The D3 phase is recognised by the refolding of D2 sheath folds and at certain locations the development of an associated S3 axial planar foliation. The D4 phase is manifested by kilometre scale Z folds that fold earlier structures (6). The D5 and D6 shears can be seen throughout the study area on kilometre scale, trending east-west and northwest-southeast deforming all earlier structures.

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Structural control on gold mineralisation in the southwestern part of the Barberton Greenstone Belt (South Africa, Eswatini)

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The Barberton Greenstone Belt contains over 350 gold occurrences and has an estimated production of 342 tons of gold, mainly extracted from the Fairview, Sheba and New Consort areas. Many studies focus on these areas to understand the general formation model of the Barberton gold mineralisation, but other gold occurrences such as those of the Malolotja and Steynsdorp areas remain poorly studied. This study focuses on understanding the structural control of the gold mineralisation in the Malolotja and Steynsdorp areas and on the characterisation of their type with respect to classical gold deposits nomenclature (i.e., orogenic, intrusion-related).

The distribution of the gold-bearing event(s) within the Malolotja synform and the Steynsdorp anticline is studied using field structural geology associated with mineralogical and microstructural analysis. Three major tectonic events have been identified. The first event (D1) produced a locally preserved composite metamorphic foliation S0-S1, which is steep and E-W striking. The second event (D2) is related to large-scale folding forming the anticline-synform pair, an N-S striking axial planar cleavage S2, and the emplacement of the gold-bearing veins, in response to E-W shortening. Structural evidence in support of syn-D2 mineralised quartz veins are dynamically recrystallised mineralised quartz veins parallel to S2 cross-cutting, cross-cut by or in continuity with gently F2-folded tension gashes. A third deformation event, locally overprints the S2 cleavage, produced by NE-SW shortening, is also related to late hydrothermal quartz veins. Petrographic and SEM observations show that the mineralised veins are mainly composed of quartz, tourmaline, minor K-feldspar, and rare sulphides probably associated with gold. The presence of K-feldspar and a significant amount of tourmaline and albite in the alteration zones was observed and question the potential magmatic-hydrothermal character of the gold mineralisation in these two areas.

The proposed formation model considers the possible intervention of at least three tectonic events. The first one remains enigmatic and might be related to the inverted stratigraphy at Malolotja with Onverwacht Group rocks overlying Moodies ones. The two following deformation events are associated with quartz veins formation and intense hydrothermal alteration. The D2 event is most likely linked to the closure of the Moodies basin and formation of the orogenic belt . The role of magmatism and related body forces in the distribution of the vein systems and deformation record will be discussed in the light of possible tectonic modes in the Archean.

Structural controls of fluid flow and 3D geometry of high-grade oreshoots at Namoya Gold Mine, Kivu Region, DRC

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Background

Namoya Mine consists of several gold deposits and prospects in the south-western extent of the Twangiza-Namoya Gold Belt, situated within the Kivu-Maniema region of the Mesoproterozoic Kibaran Mobile Belt, Eastern Democratic Republic of Congo (DRC). The Namoya Mine area consists of NW-trending, steeply-dipping Mesoproterozoic tectonostratigraphic units of low grade metamorphosed, (up to) greenschist facies, meta-sedimentary and meta-volcaniclastic/volcanic units that exhibit variable strain and fabric/schistosity development within a broad "damaged" or shear zone corridor.

Methodology

Detailed structural and kinematic mapping and analysis of Namoya Mine's open pit operations was integrated with modern implicit modelling workflows and software (Leapfrog) to constrain the orebody geometries and controls in 3D space.

Key Results

On a local scale, auriferous deposits spatially coincide with the clockwise deflection or rotation within the encompassing WNW- to NW-trending, dextral shear zone corridor. On a deposit-scale, there are spatial correlations between (1) auriferous mineralized zones; (2) chlorite-sericite-carbonate±pyrite hydrothermal alteration; (3) the development of quartz, quartz-carbonate and quartz-carbonate±tourmaline veins; (4) heterogenous strain partitioning and shearing localized along contacts of contrasting/variable competency under greenschist facies metamorphic conditions and (5) prominent clockwise deflections within the host tectonostratigraphy and controlling S2 mylonitic shear foliation.

Main conclusions drawn from these results

Field observations are consistent with brittle-ductile S2 shear development and associated fluid flow centered within or along incompetent sericite schist units adjacent to relatively competent meta-volcanic units. A rheological/competency contrast facilitates strain incompatibility and heterogenous strain partitioning along these contacts during continued deformation. The clockwise rotation along these contacts and S2 shears, coupled with dextral-transpressive kinematics, result in releasing bend geometries within the host tectonostratigraphy. This created low mean stress conduits along the flexures of the releasing bends that enabled the development of linear conduits, geometrically-similar to dilational jogs, of increased permeability, preferential fluid flow and increased fluid flux during deformation and fluid pressure cycling. Individual dilational jogs exhibit moderately to well-developed steeply-plunging prolate ore shoot geometries that internally consist of interconnected parallel to sub-parallel arrays of auriferous mineralized lenses. The spatial continuity of mineralized lenses is observed to correlate with the degree of clockwise deflection of the host tectonostratigraphy.

Structural Evolution and Mineralization of the Intensely-Deformed Golegohar Iron Ore Complex – Insights from Detailed Structural Mapping and 3D Geological Modelling of Golegohar Mine 1, Sanandaj-Sirjan Zone, Iran

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The Golegohar Iron Ore Complex (GC) comprises six, generally massive, magnetite deposits within a 45 km2 area. It is one of the most significant iron ore deposits in the Middle East, with estimated ore reserves of over 1.3 Bt. The GC falls within the south-eastern margin of the Sanandaj-Sirjan Zone (SSZ), which is generally described as an overall HT-LP magmatic-metamorphic belt that overlies a suture between the north-eastwards subducting Arabian Plate and the Iranian Microcontinent and/or greater Eurasian Plate. Despite recognized mid- to upper- amphibolite facies metamorphism and intense deformation during and after formation of the GC, its genesis is highly disputed. Mineralization models range from chemical-sedimentary (modified BIF or ironstone), magmatic-hydrothermal (modified IOCG?) to paleo-skarn.

Based on detailed structural mapping and 3D geomodelling of Golegohar Mine 1, the geometry, kinematics and structural cross-cutting relationships between magnetite units (ore), associated mineralization and country rock - including micaceous schist (variable protoliths), amphibolite (meta-gabbro) and subordinate gneiss (felsic intrusive) - may be elucidated. Progressive deformation is distinguished in (relict) early-tectonic, D1, layer-parallel (co-axial, burial deformation) foliation development, progressing into syn-tectonic D2 (non-coaxial) recumbent-isoclinal folding (cm- to several hundred meter-scale) in conjunction with top-to-the-NNE thrusting of the tectonostratigraphy. Late-tectonic, D3, upright to SSW-verging closed to open folds (several hundred meters in scale to the kilometre-scale) refold D1-2 structures, whilst the entire sequence is block-faulted by an unrelated, D4, brittle normal fault system.

The preservation of (relict) brittle veins comprising Fe-Cu-sulphide + magnetite + serpentinite parageneses in amphibolite (shear-) boudins, points towards an initial hydrothermal source of ore-forming magnetite. This is consistent with deposit-scale, tectonically-interleaved boudins of 1) massive, primary magnetite with relict internal layers of Fe-Cu-sulphide, and 2) serpentine-altered amphibolite that, in parts, records advanced serpentinization to talc retrogression caused by progressive, fluid-assisted, D1-2 shearing. Intense potassic (biotite ± chlorite) alteration of schist, interlaced with phyllonite horizons, accentuated zones of extreme strain-softening that envelop amphibolite and magnetite boudins. These observations favour a hydrothermal origin of mineralization, in the form of tabular, massive magnetite bodies that were most likely emplaced along tectonized lithological contacts and/or early-tectonic D1-2 thrusts. These were subsequently subjected to progressive syn- to post-D1-2 deformation, hydrothermal alteration and regional metamorphism.

Structural geology investigation of the Red Granite Belt of the Kunene magmatic complex, Angola

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The Kunene Complex (KC) is mainly composed of anorthosites, granitoids, and gabbroic rocks of the Mesoproterozoic age. The KC is elongated in an N-S direction in Angola and ENE-WSW-trending in Namibia (Zebra Lobe) and southernmost Angola. The KC anorthosite is divided by the NNE-SSW trending Red Granite Belt (RGB) into troctolitic and noritic facies to the north and south, respectively. The RGB is 80 km long and a maximum of 3 km wide. The olivine-bearing anorthosites are not only restricted to the north of the RGB boundary but occur in layered sections within the noritic facies. Previous U-Pb dating constrains the RGB crystallisation ages between 1414-1370 Ma; troctolitic facies at 1380 Ma, and noritic facies at 1410-1400 Ma. The tectonic setting, geochronology, and deformation events suffered by the RGB are not well constrained and remain a matter of speculation. Thus, this study aims to reconstruct the tectonomagmatic history of the RGB.

The RGB geometry changes from N-S striking (SW part) to NE-SW striking (central part) and E-W striking at the NE tip. The RGB is commonly more gneissified than the surrounding anorthositic rocks. The gneissic foliation is parallel with the RGB-anorthosite contacts and magmatic plagioclase lamination in the adjacent southern anorthosites. The SW sector of the RGB, at the margin of the KC, reveals KC margin-parallel, locally-developed, steep, N-S striking shear zones carrying steep mineral and corrugation lineation in m-thick RGB granites and adjacent anorthosites suggesting weak vertical stretching under E-W shortening. Layered granites in the central part of the RGB have steep N-S striking magmatic layering overprinted by moderately to steeply dipping NE-SW striking shear bands. The NE-SW striking foliation is commonly steeply dipping to the SE and, more locally, to the NW with down-dip lineation marked by elongated feldspar and quartz. Kinematic indicators indicate ductile thrusting on both the NW and SE dipping planes. In highly deformed zones at the NE tip of the RGB, gneissic foliation and mineral lineation are folded (open to tight) with NNE-SSW to E-W axial planes, which are parallel to localised gneissosity. Therefore, it is suggested that the RGB was deformed during a progressive ductile thrusting event which transitioned spatially from E-W, NW-SE to NNW-SSE shortening in the SW, central, and NE parts of the RGB, respectively. This study also suggests that the limit between the northern olivine-bearing and southern pyroxene-bearing KC anorthosites is a km-wide tectonic boundary marked by highly sheared granitoids.

Structural setting, emplacement controls and evolution of selected pegmatites in the Orange River pegmatite belt, Namaqua Metamorphic Province, Southern Africa

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The Kakamas Domain (KD) located along the eastern portion of Namaqua Metamorphic Province has been the subject of debate. This investigation aims to model the pegmatite mineral system across the KD by use of modern GIS techniques, field mapping, structural analyses, and petrography. The KD is composed of approximately 15 known major structural lineaments. These structures are characterized by high magnetic field ratios ranging between 142-322nT and -23 to 322nT. The greatest variation in magnetic intensity is seen across the Straussheim subarea. The western extent of the Straussheim subarea is dominated by folds ranging from moderately-plunging-upright-gentle-folds to moderately-plunging-moderately-inclined-tight-folds (sheath fold) to moderately-plunging moderately-inclined-closed-folds to steeply-inclined-moderately-plunging-open-folds. The axial planes range in strike from NNW/SSE to ESE/WNW to NNE/SSW whilst the stretching lineations across the Straussheim subarea trend predominantly NE. The NE and NW dipping fabrics along the limbs of thecharacterizederised as phyllonites, blastomylonites, protomylonites, and mylonites change to a sub-vertical NE dipping fabric along the Straussheim shear zone (SSZ). In addition to the series of en echelon Straussheim pegmatites emplaced between the SSZ and BRSZ, the bulk of the pegmatites were emplaced concordant to the main high-strain fabric. In places, the relationship between the sub-vertical and moderately dipping foliations was seen as S-C fabrics. A heterogeneous mixture of meta-pelite, semi-pelite and schist, meta-psammite, dirty-calcsilicate, skarn, greenstones, amphibolite, meta-basalt, and epidosite are found west of the BRSZ. A comparison between maximum deposition age versus distance from the western boundary of the KD revealed a sawtooth curve representative of sedimentary recycling, underplating, and rear wedge exhumation. A series of geochemical tectonic discrimination diagrams revealed that granites plot within the volcanic-arc, syn-collisional, and within-plate fields. The remnant ophiolites and heterogeneity across the various facets of geoscience indicate that the KD is a suture zone. Since pegmatites were emplaced between 966,9±3,5Ma to 1042,7±5,0Ma (Maphumulo.,2020) it might have fractionated from nearby granitic magma emplaced around 1014±36Ma (Colliston et al.,2015). However, they could have also been sourced from a pressurized solute-rich magmatic volatile phase (Troch et al.,2022).

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Structure, alteration, and genesis of copper mineralisation at the Onganja Mining District, Namibia

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The Onganja Mining District is ~60 km due east of Windhoek. Although best known for the gem-quality cuprite, the district has been a source of copper for both African and European miners for several centuries.

Corporate mining began in 1904 and targeted several shallow, high-grade (2-6% Cu), low-tonnage (<10000 t) orebodies. These orebodies comprised subvertical breccias, consisting of chalcocite and chalcopyrite, associated with a N-S striking, sheeted-vein complex and subhorizontal, stratiform lenses, consisting of chalcopyrite, within the Kuiseb Schist Formation. Locally, gold and molybdenite are present but do not show a strong correlation to copper mineralisation. Gangue minerals include quartz, albite, biotite, calcite, magnetite, and hematite with minor pyrite, rutile, mushketovite, chlorite, apatite, and scapolite.

Despite the structural complexity of the Kuiseb Schists in the Southern Zone, extraction of the ore has been possible with simple mining techniques. Target generation and exploration, however, have been the controlling factor in the continuity of mining, with several exploration programs failing owing to the misidentification of targets. This is largely the consequence of the district not resembling known deposit models at the time of the exploration programs.

Recently, however, by applying an Iron Oxide-Copper-Gold (IOCG) model to the district, two orebodies were discovered. Although this approach has displayed some success, recent field observations and geochemical data suggest that an IOCG model may not be representative of the style of mineralisation. Rather, these data indicate that the albitisation is localised, the formation of magnetite or hematite is dependent on the host rock composition, and enrichment in IOCG indicator elements is the consequence of later oxidation and upgrading of the chalcopyrite ores. Current research is aimed at defining the relationship between the sulphides and the vein system through rutile geochronology. In addition, magnetite and hematite trace element analyses will be used in conjunction with whole rock classification schemes to describe the style of mineralisation at Onganja.

Subduction origins of Roberts Victor eclogites?

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Whole rock data from Roberts Victor eclogites (1, 2) show correlations of ratios among Ti, Zr, Y, Lu and Hf that are here interpreted to record amphibole crystallisation after hydrous melt rose into the stability field of amphibole at depths above 90 km. However the presence of coexisting diamond and graphite (3) firmly establishes that Roberts Victor eclogites finally crystallised at depths below 160 km. Amphibole crystallisation is therefore a feature that, like the oxygen isotope signatures (4) , is inherited from ancient crust that was subsequently transported to the deep mantle . The ubiquitous disequilibrium features in Roberts Victor eclogites (1,3,5) demonstrate that the eclogites were emplaced into the Kaapvaal craton shortly before kimberlite emplacement and likely originated in a Cretaceous hybrid plume (6) which contained the ancient crust. Hydrogen isotopes (7) present a challenge to the subduction hypothesis because they show mixing between two components with isotopically light hydrogen and provide no direct evidence for the presence of the isotopically heavy hydrogen present in seawater. The hypothesis that the ancient crust originated very early in earth's history,before the addition of the late veneer, must therefore be entertained. Transport of the ancient crust into the deep mantle may be associated with a giant impact, prior to the onset of plate tectonics and the subduction process.

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Substantial downward accumulation within a rare layered mafic Karoo intrusion (Mwenezi Complex, SE Zimbabwe)

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A layered mafic intrusion, within the northernmost part of a Mwenezi Complex [1], has been $^{40}Ar/^{39}Ar$-dated to ~178 Ma [2] and is thereby coeval with an Okavango dyke swarm [3] that propagated laterally NW [4,5] from its location at a conspicuous triple rift junction with two Karoo lava monoclines (e.g., [6]).

While [7] argued for separate magma injections, generating four different concentrically inward-dipping zones inside a saucer-shaped layered intrusion, cryptic layering is more consistent with downward accumulation during magma chamber differentiation, at least down through an upper ~2 km-thick sequence (from intrusion's center) of laminated olivine gabbro, gabbro, gabbronorite to quartz diorite ("sandwich horizon"?), through which cumulus plagioclases and augites exhibit systematic An_{79}-An_{48} (excluding presumed antecrysts up to An_{86}) and Di_{84}-Di_{54} decreases, respectively (conformed by either enstatite or olivine). However, a ~1.8 km-thick exposed lower sequence (from intrusion's chilled margin) does not mirror this upper zone but includes a less systematic assemblage of less laminated pigeonite gabbronorites, gabbronorites and olivine gabbros, exhibiting an equally erratic (replenished?) cryptic layering (An_{76}-An_{57} and Di_{79}-Di_{63}, excluding central quartz diorite shared by both zones) that does not conform to any particular accumulation direction. Nevertheless, spectacular plagioclase-capped olivine megacrysts outcrop in a fashion that conforms with symmetric inward crystallization of both upper and lower zones, forcing us to either explain how the exposed lower zone accumulated so differently upwards or re-consider the possibility for separate intrusions into the lower zone. This will hopefully be resolved at the presentation.

Still, ~2 km of downward accumulation is more than twice the thickness of Skaergaard's Upper Border series (another rare example of downward accumulation) and begs a scientific/economic important question whether the Mwenezi intrusion is just so much more voluminous than Skaergaard? It is in this context also worth noting how much more primitive Mwenezi is, yet with an exposed absence of ultramafic cumulates. A drill core down through the center of this Mwenezi intrusion should resolve most outstanding issues, all the while that our results, based on field samples, are intriguing.

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Terrestrial temperature evolution of southern Africa during the Late Pleistocene and Holocene: evidence from the Mfabeni Peatland

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The scarcity of suitable high-resolution archives, such as ancient natural lakes, that span beyond the Holocene, hinders long-term late Quaternary temperature reconstructions in southern Africa. Here we target two cores from Mfabeni Peatland, one of the few long continuous terrestrial archives in South Africa that reaches into the Pleistocene, to generate a composite temperature record spanning the last ~43 kyr. The Mfabeni Peatland has previously been proven suitable for temperature and hydrological reconstructions based on pollen and geochemical proxies. Here we use branched glycerol dialkyl glycerol tetraethers (brGDGTs) preserved in the Mfabeni peatland to derive a new quantitative air temperature record for south-east Africa, and evaluate the potential impact of hydrology on the reconstructed temperatures. Our temperature record generally follows global trends in temperature and atmospheric CO2 concentrations, but is decoupled at times. Annual air temperatures during Marine Isotope Stage (MIS) 3 were moderate (c. 20.5 °C), but dropped by c. 5 °C during the Last Glacial Maximum, reaching a minimum at c.16-15 ka. Asynchronous with local insolation, this cooling may have resulted from reduced sea surface temperatures linked to a northward shift in the Southern Hemisphere westerly winds. Concurrent with the southward retreat of the westerlies, and increasing sea surface temperatures of the Agulhas offshore, warming from minimum temperatures (c. 15.0 °C) to average Holocene temperatures (c. 20.0 °C) occurred across the deglaciation. This warming was briefly but prominently interrupted by a millennial-scale cooling event of c. 3 °C at c. 2.4 ka, concurrent with a sudden change in hydrological conditions. The average Holocene temperatures of c. 20.0 °C were similar to those reconstructed for MIS 3, but after the 2.4 ka cooling period, air temperatures in the Mfabeni peat recovered and steadily increased over the most recent c. 2 ka. In summary, our record demonstrates that eastern South Africa is highly sensitive to global drivers as well as nearby sea surface temperatures.

Testing the capability of core scan hyperspectral imaging to characterise South African coal, its functional groups and associated inorganic matter

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Coal resources are determined through exploration, which involves drilling, core logging, and sample analysis. The traditional core logging and laboratory-based analyses can be time consuming, and the accuracy of the data depend entirely on the experience of a geologist. The core-scan hyperspectral imaging (CSHI) is an automated technique that can be used in exploration projects, to improve the level of accuracy of core logging and to rapidly acquire data. The technique measures the spectral response of samples based on their reflectance properties, and the data is presented as a function of reflectance vs wavelength. The CSHI is used extensively in many commodities, but there is a limited information pertaining to benefits in coal exploration.

In this study, a borehole core from Zibulo Colliery (Witbank Coalfield, South Africa) was imaged within the visible and near-shortwave (350-2500 nm), and longwave (8000-12000 nm) infrared ranges. The coal spectra were classified within the visible and near-shortwave infrared (VN-SWIR) spectral region, as determined by low reflectance and a gradual increase of reflectance towards the SWIR region. To assess the capability of hyperspectral imaging to characterise coal and associated inorganic matter, the CSHI data was compared to X-ray diffraction (XRD) data, supported by proximate analysis and X-ray fluorescence (XRF) data. The positive slope of the coal spectra is influenced by the amount of fine-grained clay and Fe rich minerals associated with the organic matter. The CSHI characterised the coal functional groups as aliphatic, aromatic rings and oxygenated groups. However, the weak absorption features and overlapping bands with inorganic matter resulted in uncertainty in the accuracy of data interpretation. The CSHI identified kaolinite, quartz, illite, barite, gypsum, smectite, calcite, chlorite, and magnesite.

The XRD data confirmed the occurrence of quartz, kaolinite calcite, gypsum and smectite, and further identified dolomite, pyrite, microcline, muscovite, plagioclase, siderite, and alunite in the scanned core. Microcline, muscovite, and plagioclase were unidentified by CSHI, but illite was; illite forms by degradation and weathering of feldspars and muscovite.

The CSHI did not identify pyrite which is the most significant inorganic phase within South African coal seams due to pollution concerns. This study established that the CSHI can indicate the presence of organic matter within the borehole core but cannot adequately separate data on coal functional groups. The technique is a useful tool to characterise inorganic matter within borehole core, however more research is still required on certain minerals such as pyrite.

Testing the use of olivine as a diamond indicator mineral and in defining kimberlite/Kaapvaal lamproite sampling depth and craton margins

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Olivine is a dominant constituent of kimberlites and Kaapvaal lamproites (formerly Group II kimberlites), the primary sources of diamonds on the Kaapvaal craton, comprising 40-50 vol.% of the rocks. It occurs as anhedral/ rounded macrocrysts (>0.5 mm) and euhedral to subhedral microcrysts (<0.5 mm), the majority of which show sharp compositional zoning between xenocrystic cores and magmatic rims. The xenocrystic cores generally display variable compositions (e.g., Mg# = 75 - 95) corresponding to those that characterize mantle xenoliths, including granular and sheared peridotites as well as the megacryst suite[1]. Due to their abundance, olivine xenocrysts offer great potential for characterizing the subcontinental lithospheric mantle (SCLM) column traversed by kimberlites and Kaapvaal lamproites.

We present new electron microprobe (EPMA) and laser ablation (LA-ICP-MS) trace element data of olivine xenocrystic core zones sampled by two on-craton Kaapvaal lamproites (Finsch and Roberts Victor) and one on-craton kimberlite (Goedehoop). Olivine cores from Finsch and Robert Victor are predominantly Mg-rich with a Mg# range of 90.4 - 94.7, NiO restricted between 0.30 and 0.50 wt.%, MnO = 0.06-0.15 wt.%, and CaO < 0.07 wt.%. In each location, only one out of 42 and 36 grains, respectively, was found to be Fe-rich (i.e., Mg# < 89). Goedehoop olivine cores show Mg# = 83.8 - 92.8, NiO = 0.24 – 0.42 wt.%, MnO = 0.1 - 0.2 wt.%, and CaO = 0.02 – 0.14 wt.%. The concentration of temperature-dependent elements (i.e., Al, Na, V, Cr, and Ca) and Cu in olivine cores progressively increase from Roberts Victor through Finsch to Goedehoop. While the xenocrystic olivine cores from all three localities were primarily sampled from garnet peridotite lithologies, several Roberts Victor and Goedehoop olivine cores were sampled from spinel peridotites.

Preliminary results suggest that the Goedehoop, Finsch and Roberts Victor pipes predominantly sampled mantle material that equilibrated in the garnet stability field. The next step of the project involves applying the recently calibrated Al-in-olivine thermometer[2] to the olivine xenocrysts sampled from garnet peridotite lithologies to determine whether material from within the diamond stability window was sampled.

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Textural and LA-ICP-MS trace element analysis of pyrite in the Kibali gold district, DRC

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The Kibali gold district is located within the Neoarchean Moto Greenstone Belt in the northeastern portion of the Congolese Congo Craton. It is among the well-endowed gold districts in Africa, with more than 23 Moz of gold resources. Previous studies highlight that gold is mainly disseminated within the volcano-sedimentary host rock, where it is intimately associated with sulphides, of which pyrite is the most dominant type. These gold deposits have been defined as orogenic-type mineralisation, although our recent work suggests a component of overprinted paleoplacer or pre-orogenic gold mineralisation. However, despite several decades of active gold exploration and scientific research, the nature of gold in pyrite and the composition of ore-forming fluid remains poorly constrained. Optical petrography, SEM and in-situ LA-ICP-MS trace element data from 390 pyrite point analyses augmented by seven traces of elemental imaging were investigated. This was conducted at seven gold deposits (KCD, Kombokolo, Agbarabo, Gorumbwa, Tete Bakangwe, Pakaka and Kalimva). The results of careful textural microscopy analyses of 101 polished sections indicate five significant pyrite types; including py-0 (rounded), py-1 (microcrystalline sooty), py-2 (core-rim), py-3 (veinlet) and py-4 (euhedral free-inclusion). LA-ICP-MS trace element data reveal differences in the chemistry between metasediment (KCD area and Tete Bakangwe) and metavolcanic sequences (Pakaka and Kalimva). In the metasediment sequence, LA-ICP-MS spot analyses and elemental imaging of pyrite generation py-0 and py-2b show an enrichment in Au (median 1.65 and 0.56 ppm, respectively) along with the trace elements As, In, Pb, Ti, Cr, Ge, Ag, Sb, Cu, Sn, TI, W and Zn. The py-2a and py-3 generations are depleted in most of these trace elements. Nevertheless, these generations have Co/Ni ratios <1, suggesting a pre-orogenic origin. The py-2c and py-4a&b show a wide range in their trace element signatures with notable enrichments of Ni, Co, Se, and Te, and Co/Ni ratios >1 suggesting a hydrothermal process. However, in the metavolcanic sequence, py-1 is homogeneously enriched in Au (median 15.38 ppm) and trace elements (Sb, Pb, Ti, Hg, Ni, Cu, Zn, Bi, Cd, TI and Sn). The chemistry and texture of Py-1 point to a syngenetic marine sedimentation process comparable to VHMS-type. In contrast, the py-2a&b and py-4a&b exhibit a wide range of trace elements and these signatures are probably a hydrothermal origin. Thus, textural and trace element analyses of pyrite in the Kibali gold district support a model of multiple stages of gold formation, including sedimentation, metamorphism and late-stage deformation.

The Belingwe greenstone belt, Zimbabwe – some new age constraints and implications for greenstone belt evolution

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The Neoarchaean Belingwe greenstone belt of the Zimbabwe craton consists of a well-preserved succession of rocks of very low metamorphic grade and low strain. We present new age constraints for the Ngezi Group of the belt and discuss them in the light of greenstone belt evolution. We propose crustal destabilization of the Zimbabwe proto-craton as a result of global convective mantle overturn at ~2.75 Ga. This gave rise to extension of a Mesoarchaean granitoid-greenstone terrain, rapid subsidence and, initially, deposition of a transgressive cover succession (Manjeri Formation). High degrees of stretching of proto-cratonic and mantle lithosphere provided accommodation space for the emplacement of several kilometres of submarine volcanic rocks on deeply submerged granitoid-greenstone basement. Once extension and magmatism had ceased, chemical and clastic sedimentary rocks of the Cheshire Formation were deposited prior to 2.71 Ga as a result of, and subjected to, compressional deformation, and much earlier than previously assumed.

The complex nature of mantle crust interactions in Variscan post-orogenic magmatism: evidence from Mt. Aigoual dykes, Massif Central, France

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The Variscan orogeny exposed in the Massif Central of France contains a large number of occurrences of magnesian and potassic rocks (up to 6 wt% K2O) of variable composition (SiO2 = 45 – 65 wt%), locally termed ”vaugnerites” or, more globally, PCMM (post-collisional mafic magmas). Some of these rocks occur as the more mafic component of composite dykes that vary gradationally from lamprophyric to granitic and that occur in a NE-SW trending closely spaced population that intersect the NE margin of the largely granitic Aigoual pluton. The composite dykes show a wide range of SiO2 contents (53 – 73 wt%), high contents of Al2O3 (14 – 17 wt%) and K2O (4 – 7 wt%), with shoshonitic affinities as well as elevated concentrations in LILE and LREE, relative to the primitive mantle. The granitic components are moderately to strongly peraluminous, displaying seriate porphyritic textures with extreme variations in the average crystal sizes. High bulk rock and mineral Mg# and high, Cr and Ni contents clearly indicate the involvement of mantle magmas. Conversely, radiogenic whole-rock Sr-Nd-Hf isotopes and Hf isotopes of zircon delineate crustal-like isotopic signatures, giving the composite dykes a dual geochemical character. Euhedral quartz crystals from a range of different rock compositions in the composite dykes have high δ18O values (11.76 to 11.21‰) typical of crustal rocks and do not correlate with SiO2 content. The δ18O values of zircon determined by SIMS analyses at the Helmholtz Zentrum Potsdam provide insight into the origin of the dual crustal and mantle-like geochemical character of the dykes. In a population of magmatic textured zircon crystals, most analyses show crustal-like δ18O values between 8 – 9‰, However, a smaller population of overgrown core domains are characterized by mantle like isotopic signatures (~6‰). The fact that a high proportion of material in the dykes has crustal δ18O values means that mass balance considerations rule out the formation of the dykes by mixing between a mantle-derived magma from an unmetasomatised source and a crustally derived magma. The preservation of such small-scale heterogeneities, in combination with the high-K and compatible element enriched character of the dykes are interpreted to reflect the derivation of both the mafic and silicic portions of the dykes by different degrees of partial melting of a phlogopite-bearing mantle wedge source that was strongly metasomatized by sediment derived fluids or melts prior to collision.

The contribution of mineralogy to sustainability in the mine life cycle

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For millennia man has had a relationship with minerals. Minerals have fuelled the development of civilisations to the current advanced state of our society in the 21st century. However, in doing so, mining has inadvertently also created a negative legacy leading to many of the challenges we now see in society including environmental degradation, economic and social inequality, population displacement, gender-based violence, corruption, violation of human rights and increased health risks related to the interaction of the human body with mineral matter. Yet at the same time, rethinking the way mining and its associated stakeholders operate, provides the opportunity to address many of these challenges ultimately bringing together economic development, social inclusion, and environmental sustainability. It is also now realised that many of the core technical activities (and consequences thereof) related to ore deposit discovery, mining, mineral processing, metallurgy and waste management are underpinned by the mineralogical characteristics of the ore and associated waste. While this may have been self-evident to some of the pioneering geologists and engineers this concept was overlooked for several decades until its resurgence in the 1970s and 1980s coupled with the development of technologies that allowed routine quantitative investigations of the mineralogical characteristics of ores, feeds, concentrates, tailings.

This presentation considers the contribution of mineralogy to sustainability through the mine life cycle looking through the lens of the domains of process mineralogy, environmental mineralogy and medical mineralogy and their relationship to the pillars of sustainability - profit, planet and people, respectively. Using several case studies from around the world, examples will be shown as to how the application of mineralogy and the tools used for characterisation have evolved over the decades. The case studies will show case some of the efforts of the early pioneering mineralogists to some of the most recent work at the University of Cape Town where mineralogy is fully integrated into all aspects of ore and waste use and valorisation.

The Deccan Traps (India) and other flood basalts on rifted continental margins: Who needs mantle plumes?

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The mantle plume model for the Deccan Traps/Lakshadweep-Chagos Ridge/Réunion Island faces several problems. The bulk (>95%) of Deccan flood basalts are evolved (MgO 4-7 wt.%) and there is no evidence for picritic liquids or an abnormally hot mantle source. There was no province-wide, kilometer-scale prevolcanic uplift, as expected for an arriving plume and pre-Deccan (68.5 Ma) alkaline magmatism was long-term.

Models involving pre-breakup magma accumulation and tectonic activation, breakup, and post-breakup re-equilibrating, explain the observations well. The circular outcrop of the Deccan flood basalts does not indicate a spherical plume head, but is a result of several intersecting, reactivated continental rift zones, some running along Precambrian structural trends. The massive phase of tholeiite, rhyolite and trachyte magmatism at Mumbai at 62.5 Ma cannot be explained by a plume because volcanism there lasted ~9 m.y. The intense young (62.5-61 Ma) magmatism also cannot be ascribed to a "plume tail" as this tail was supposedly 1000 km further south at the time. The accuracy of Ar-Ar ages for the Lakshadweep-Chagos Ridge used to construct the "hotspot track" is questionable. This Ridge was likely a leaky oceanic transform, without systematic age progression, and is at least partly continental. The Mascarene islands are unrelated to the Deccan Traps.

Geochemical-isotopic similarities sometimes claimed between Réunion, Mauritius and Deccan lavas could arise from delaminated Indian continental mantle in the Indian Ocean asthenosphere. This is similar to what has been proposed for the Southwest Indian Ridge.

Contrary to common assumptions, continually repeated, the Deccan Traps fit the deep mantle plume model poorly. New models are needed. One is potential long-distance lateral flow of partially molten mantle and magma segregation therefrom due to horizontal pressure gradients arising from processes such as older and distant subduction. Magmas then pond beneath pre-thinned lithosphere such as rift zones, intruding the crust and reaching the surface during periodic plate-scale extension. Flood basalts may be events of rapid emptying of such magma reservoirs that were filled slowly, over millions or tens of millions of years. Long-lived, aggregated, ponded melt would have a complex history, defying simple interpretations by geochemical modelling. Similar models explain features of the North Atlantic Igneous Province and other classical flood basalt provinces on rifted continental margins such as the Indo-Madagascar, Rajmahal, Paraná and Karoo LIPs.

The effectiveness of using virtual reality materials in preparing students for geological fieldwork

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Background

During the recent worldwide lockdowns due to the COVID-19 pandemic, several institutions around the world, out of necessity replaced their customary field work with virtual field trips, using existing photographic materials gathered over many years conducting the same fieldtrip, causing the lecturers to conclude that this was a reasonable alternative as the marks scored were similar.

Several years before the pandemic hit, UWC's Applied Geology section had already embarked on the development of high-resolution virtual field tours (VFTs)to use as supplementary material in the provision of field education to our geology students, based on the geocognition concept. This was done as rising costs and increasing health and safety rules effectively forced us to keep fieldwork for students to an absolute minimum, which is unacceptable in geology education. Additionally, in this manner, students could be exposed to classical geology sites from anywhere in the country without having to travel there, as an archive of prime teaching outcrops could be built like this.

Methodology

We created the Virtual Field Tours using High Resolution Photography and constructed the tours using Pano2VR enhanced with videos and drone images. In three different projects we tested for learning gain after exposure to our VFTs by using identical pre and post VFT questionnaires. Pandemic restrictions forced us to replace our first-year introductory field trips by VFTs.

Key Results

In a final assessment testing for understanding of geological principles based on their usage of these VFTs, the assessment results for first year students showed encouraging signs of learning gains. In the second project we exposed second year students, third year students and Honours students as well as graduate geologists to the basic principles of slope stability in engineering geology. In this case we presented a lecture, followed by a questionnaire on the concepts mentioned, followed by the VFT and again the same questionnaire where we demonstrated a distinct learning gain. Finally, we used a lecture on basic characteristics of sedimentary features in turbidite deposits, enhanced by a comprehensive VFT to prepare Honours level students for a weeklong field trip. Comparing their final report with the final report of the previous year's group of students also demonstrated learning gain.

Conclusion

While we acknowledge that real-life field work can never be replaced, we have demonstrated that properly designed VFTs can be successfully used to enhance learning at real-life field work.

The first geological study of Lefika la Noka tufa deposits in the Cradle of Humankind, South Africa

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The Lefika la Noka tufa deposit is situated north of the Malapa and Gladysvale fossil sites, along the Skeerpoort River, within the Cradle of Humankind (Cradle). It has a maximum thickness of ca. 12.5 m and was deposited on top of the Timeball Hill Formation shales. Tufa can present excellent opportunities to produce high-resolution palaeoclimatic data and detect records of short-lived climatic events. Such data is crucial for the Cradle, particularly for the late Pleistocene – Holocene period, when Homo naledi and archaic Homo sapiens emerge in the fossil record. Textural, mineralogical, and geochemical studies at the micro-scale using techniques such as x-ray diffraction, x-ray fluorescence and scanning electron microscopy are currently in progress. The tufa deposits comprise seven texturally distinct facies, phytoherm framestones (bryophytic tufa and tufa cemented vertical stems), phytoherm boundstones (tufa stromatolites and thrombolites), oncoidal tufa, pisolitic tufa, and cemented rudite. Oncoids were deposited in agitated pools within waterfalls, whereas phytoherm framestones and phytoherm boundstones were deposited in a high-velocity fluvial waterfall/cascade environment, and fluvial channels contained the cemented rudite facies. Hyperspectral imaging of the drill cores showed that at a macroscale, the tufa is dominated mainly by calcite (aragonite not observed) but also contains quartz and phyllosilicates as well as mixtures of calcite-smectite, sericite-calcite, and smectite-calcite formed due to weathering of the bedrock.

The observed vertical stratigraphic changes in the tufa facies represent changes in hydrodynamics and hydrochemistry of the depositing river through time. The stratigraphy of the Lefika la Noka tufa indicates an alternating environment of deposition between fluvial waterfalls/cascades and fluvial channels with high flow velocity than is observed currently.

The Formation of Micro-Diamonds in Decompression-Cracks During the Uplift of the Kimberlite Controlled by the C:O:H Ratio in NAMS

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We show new evidence that natural micro-diamonds can be formed in decompression-cracks by C:O:H bearing volatiles during the uplift of an bimineralic eclogite. The investigated rock sample is a heterogeneous kyanite- bearing and bimineralic eclogite. Kyanite reacts out in the kyanite bearing part of the sample, but metastable relics are still present within the bimineralic part of the rock. The presence of these metastable kyanite relicts, suggest very low fH2O during the phase transition from the kyanite- bearing into the bimineralic eclogite (Sommer et al., 2017). High-spatial-resolution synchrotron based FT-IR and RAMAN spectroscopy have been used to detect C:O:H-bearing volatiles around micro-diamonds in lineage defect structures and N concentrations has been analyzed within the micro-diamonds. In micro-diamond-bearing lineage defect structures, a correlation between C:O:H-bearing volatiles can be identified whereas in micro-diamond free lineage defect structures no correlation of the different C:O:H containing volatiles was detected. We propose that the C:O:H bearing volatiles acted as a catalyst, changing in composition with changing P-T conditions in the rock during metamorphism. Nitrogen concentrations in the analyzed micro-diamonds suggest that the formation of the micro-diamonds took place shortly before the uplift of the eclogite from the Earth mantle to the surface. The conclusions from our study proves that C:O:H-bearing volatiles are indicative of the formation of micro-diamonds, which is controlled by C:O:H bearing fluids.

The genesis of hydrothermal graphite and fluorite veins in the Aukam valley, southwest Namibia – a consequence of large scale, late Neoproterozoic hydrothermal systems?

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The Aukam valley in southwestern Namibia hosts a number of high purity fluorite veins and a rare, vein hosted, amorphous graphite deposit. Mineralisation is hosted within high grade metamorphic rocks of the Mesoproterozoic age Namaqua Metamorphic Province. All these veins are situated at or very close to the overlying late Neoproterozoic Nama Group sedimentary unconformity. The graphite occurs as a massive zone of granite gneiss replacement as well as disseminated grains along a shear zone of at least 5 km length while the fluorite veins are associated with quartz and calcite and are noted for their exceptional purity. Detailed microscopy, scanning electron microscopy, fluid inclusion thermo-barometry, Raman spectroscopy, δ13C isotopic analysis and geochronological studies were carried out to study and ascertain this relationship better.

The Namaqua gneisses show a regional peak metamorphic granulite facies event and a later ductile overprint with amphibolite facies temperatures of around 570 - 600 °C and 2.8 - 3.5 kbar. Between 530 and 546 Ma, and with the unconformity already in place, the graphite, which has been dated via intergrown monazite, was precipitated. Conditions were maximum greenschist facies, as shown by graphite crystallization temperatures of around 360 - 410 °C and with associated alteration assemblage of quartz and muscovite (sericite). The δ13C isotopes values indicate a partle biogenic source for the graphite. The fluorite veins have features indicating a low metamorphic-diagenetic environment and δ13C values for calcite in these veins are similar to the regional Kuibis Subgroup graphitic limestones overlying the unconformity.

Microthermometric data indicates precipitation from a mixed fluid with two chemically contrasting end-members. These end-members are (1) F-rich brines sourced from the Namaqua basement, and (2) Ca-rich, limestone derived formation fluids from the Nama Group. Observed fluorite overgrowths on earlier precipitated quartz is likely the effect of post-mixing fluid cooling. Late-stage calcite is recognized with fluid inclusion compositions distinctly different from those observed in the fluorite and quartz. With significantly lower homogenization temperatures, these likely formed during the shutdown of the hydrothermal system.

The fluorite veins are hosted in post-Cambrian brittle structures that formed during Mesozoic opening of the South Atlantic. Deposits of massive fluorite mineralization occur on both sides of the Atlantic Ocean, and may be associated with Pangea rifting. This study demonstrates that the formation of both the fluorite and graphite mineralization is most likely related to the unconformity and not the granulite facies host rocks.

The geochemistry of Archaean granites in the Barberton region of South Africa as a guide to crustal evolution

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The Barberton region of South Africa is characterized by a broad variety of granite types that range in age from ca. 3.5 Ga to 2.7 Ga and reflect the processes involved in the formation of Archaean continental crust on the Kaapvaal Craton. These granites are subdivided into three groups, as follows:

(1) A tonalite-trondhjemite-granodiorite (TTG) suite diapirically emplaced at 3450 Ma and 3250 Ma into pre-existing metamorphosed greenstone belt material. TTG melts were derived from melting amphibolite in the lower crust, with individual plutons being emplaced at various crustal levels. The dome-and-keel geometry that characterizes the TTG-greenstone dominated crust at this time is inconsistent with a plate tectonic domain and reworking was likely controlled by gravity inversion or 'sagduction';

(2) Regionally extensive potassic batholiths (the GMS suite) were emplaced at 3110 Ma during a period of crustal thickening and melting of a TTG dominated lower crust. Subsequent to emplacement of the voluminous GMS granites, the thickened continental crust had stabilized sufficiently for large sedimentary basins (Witwatersrand, Pongola etc) to form; and

(3) Late granite plutons were emplaced along 2 distinct linear and sub-parallel arrays close to what might have been the edge of a Kaapvaal continent at 2800-2700 Ma. They are subdivided into high-Ca and low-Ca granites that resemble the I- and S-type granites of younger orogenic episodes. The high-Ca granites are consistent with derivation from older granitoids in the lower crust, whereas the low-Ca granites may have been derived by melting metasedimentary precursors in the lower-mid crust. Granites with similar characteristics are associated with subduction zones in younger terranes, although the recognition of such a feature at Barberton remains unclear.

The petrogenesis of granites in the Barberton region between 3.5 Ga and 2.7 Ga provides a record of the processes of Archaean crustal evolution. These granite-forming processes are particularly instructive to considerations regarding the onset of plate tectonics on the early Earth.

The geological period no one talks about: menstruation in the field

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A simple Google search for the phrase "period in geosciences" will likely yield reference to geological time. However, ask any woman[1] in geosciences, in either academia or industry, and they will have experienced at least one menstrual period in the field, predicted or not. Given the composition of most undergraduate classes, at least half the class are likely to be at risk of experiencing menstruation during field training, and yet, this issue remains unspoken of at best, taboo at worst. This is a global issue, with some Institutions leading the way with innovative policy and practical guidelines[2].

To get a sense of the scale of this issue in the South African setting, we ran an informal survey, during the Human Evolution Research Institute's (HERI) All Womxn Field Camp. Field camp participants all reported experiencing menstruation at some point during their field training and all expressed issues of discomfort, pain and anxiety affecting their ability to work optimally. Many indicated the inability to openly communicate with lecturers and/or demonstrators about menstruation related issues due to the surrounding stigma.

Following this discussion and referring to best practice guidelines elsewhere[2], we propose including sanitary wear in packing lists provided to students. We put together an emergency period kit to accompany every field excursion, containing a range of menstrual products, pain relief, sanitizer etc. We further recommend that bathroom breaks should be planned for and made frequent throughout all field excursion[2,3]. Finally, we advocate for open communication about this issue and hope that the emergency period kits can help facilitate this. The awkwardness and stigma that surrounds menstruation needs to be tackled head on, and we encourage all lecturers, demonstrators and PIs to actively participate in this endeavor to ensure that all geoscientists have a fair chance to engage optimally in field settings.

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The Geology and Mineralization of the Renosterkop Tin-Tungsten-Zinc Deposit Augrabies - Northern Cape

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Rhenosterkop is a significant tin, tungsten and zinc deposit largely exposed on surface and located adjacent to a tarred road on one side and the Orange River on the other. The economic potential was recognized for the first time by a Rio Tinto geologist named Dr Vaughn Armstrong in the early 1980's who discovered the deposit by means of geochemical soil sampling techniques.

The mineralization is not visible in hand specimen, and is hosted within an A-typical quartz, biotite, topaz greisen. Typical greisen deposits contain muscovite and not biotite, making Rhenosterkop unique in its mineralogy. The biotite greisen is believed to have formed by hydrothermal fluids altering the host granitic rock along thrust planes forming shallow dipping sheet-like bodies which merge to form a massive mineralized and greisenized body in the centre. The body is weather resistant compared to the surrounding granites and forms an outcropping ridge 1500 m long and 300 m wide, with a dip of 15 degrees to the east. The deposit contains 29 million tonnes at a grade of 0.124% Sn, 0.583% Zn and 0.016% WO3 with a stripping ratio of 0.27:1.

The geology of gold mineralization in the Nangodi greenstone belt, Ghana

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One of the recent gold discoveries in Ghana is the Namdini Gold Project in the northern part of the country situated within the Bole-Nangodi greenstone belt. The Bole-Nangodi greenstone belt consists of Birimian volcanic and volcaniclastic rocks (basalt to rhyolite) and immature sedimentary rocks (greywacke, shale) and is flanked on both sides by extensive granitoid complexes. Exploration in the area has led to the estimation of a 5.1 Moz ore reserve. We present petrographic analysis, whole rock major and trace element geochemistry and ore mineralogy and mineral chemistry of drill core from the Namdini Project. Gold mineralization is associated with strongly sheared, volcanic arc-type meta-andesite and meta-dacite/-rhyolite. The mineralization is restricted to shear zones characterized by carbonate-quartz veins that acted as hydrothermal fluid pathways for the precipitation of sulphides hosting the gold. Compositional zoning in sulphides is interpreted as due to the evolution of mineralizing fluids from As-poor to As-rich, forming early-stage pyrite/arsenopyrite, followed by the deposition of As-poor, late-stage pyrite. Oriented sulphides, pressure shadows and deformed veins all suggest that the mineralization was coeval to deformation of the Bole-Nangodi greenstone belt.

The good, the bad and the ugly revealed by TEM: Three types of polygranular neoblastic zircon recrystallized after shock

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Zircon is a robust refractory mineral, which usually forms singular elongated crystals with concentric or sector zoning. Polycrystalline "strawberry" zircon was first reported in the 1990s from the products of the three largest known terrestrial impact craters: Sudbury, Canada; Chicxulub, Mexico; and Vredefort, South Africa. Later on, polygranular zircons were found in many impact structures and even in Lunar breccia, and were proven to be a robust geochronometer of impact events. Initially, little was known about the formation mechanisms of such textures. It was then suggested that granular zircon could form in impactites by three distinct processes: (a) phase transition to reidite (high-pressure $ZrSiO_4$ polymorph) and its reversion back to zircon; (b) dissociation into ZrO_2 and SiO_2 phases and their subsequent back-reaction forming new zircon, (c) crystallization of amorphous zircon material [1]. Within the last five years, the dominant explanation for granular textures became the "FRIGN" ("former reidite in granular neoblastic") zircon model [2]. FRIGN zircon model agrees with (a), assuming zircon phase transformation to reidite under shock pressure and reversion to polygranular zircon after heating. This model, although viable, did not explain a variety of granular zircon textures and associated features, such as ZrO_2 inclusions, twin orientations between neoblasts, etc.

We studied multiple granular aggregates of zircon from three impact structures on three continents (Vredefort, South Africa; Araguainha, Brazil; Kara, Russia). Granular zircons were identified in thin sections using scanning electron microscopy, and the selected grains were subjected to transmission electron microscopy investigation in focussed ion beam foils. After inspecting multiple polygranular zircons at a nano-scale, we could confirm that there are at least three mechanisms for zircon recrystallization into polygranular aggregated during impact events: (a), (b), and (c), following [1]. Type (a) is associated with reidite and represents fine-crystalline areas interfingering with reidite domains. Zircon crystals are 100-200 nm in size, densely packed, and associated with nano-fractures and nano-pores. Type (b) is composed of larger grains (0.5-3 µm), isometric and elongated that are often detached from each other or have sintering necks and triple junctions. Neoblasts contain inclusions of ZrO_2 and SiO_2. Type (c) comprises grains 1-10 µm in size associated with domains of amorphous or nearly amorphous material. Mixed types are also observed. Each polygranular neoblastic zircon texture indicates unique shock conditions and cooling history, facilitating the P-T-t reconstructions of impact events.

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The impact of climate change on Zambezi River Basin: implications to water-energy-food nexus in Southern African Region

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The Zambezi River Basin is Southern Africa's largest drainage basin shared by eight countries, Zambia, Angola, Zimbabwe, Mozambique, Malawi, Botswana, Tanzania, and Namibia. Water resource plays a pivotal role in ensuring a sustainable water supply, energy, and food in countries. Hydropower from the Zambezi River Basin is the main energy source in most Southern African countries, and sustenance and commercial agricultural and fishing activities in riparian countries rely heavily on the water resource. The southern African Development Community (SADC) region benefits from hydropower generated in the Zambezi River through an established electricity power pool. At the same time, food produced is also traded among SADC member states. However, the water resource is threatened due to climate change that disturbs water flows and negatively affects water interlinked sectors. In addition, the 'Basin's sub-catchments have experienced prolonged cyclic drought periods and catastrophic events leading to increased food insecurity and intermittent energy generation. The resource is further threatened by heavy reliance on the Zambezi River Basin, prioritization of certain water-linked sectors over another, involvement of multiple countries and hence the lack of coordination in managing water resources. Apart from threats to the Zambezi River 'Basin's energy and food security, the study explores adapt- responses to climate change and equitable use of water resources.

The in situ crystallization of non-cotectic and foliated rocks on a magma chamber floor

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A common feature of many layered intrusions around the world is the presence of foliated, non-cotectic assemblages of cumulus minerals that are typically inferred to arise by processes involving hydrodynamic sorting of previously formed crystals (1). However, massive magnetitite layers from the Bushveld Complex, South Africa, reveal a perplexing contradiction. Geochemical evidence, such as a remarkably smooth upward depletion in Cr (2), has been presented for their in situ crystallization. In spite of this, magnetitite layers typically show gradational tops into magnetite anorthosite layers where the plagioclase content grades across values (10-80%) that does not match expected cotectic proportions (<10% magnetite and >90% plagioclase). Plagioclase crystals present in this gradational contact also display a well-defined foliation. Traditionally, such features are explained by the process of crystal settling, where the denser magnetite grains accumulate in excess of the expected cotectic proportions while the tabular plagioclase crystals obtain their foliation as they settle on a planar solidification front.

However, ICP-MS analysis on pure magnetite separates across such a contact reveals a smooth decrease in Cr contents from 990 to 600 ppm Cr across 13 cm. Such a regular decrease can only be produced by in situ crystallization, or the immediate, short distance settling of magnetite that would not allow the proper separation of a non-cotectic suspension of magnetite and plagioclase crystals. We propose that the solution to this problem lies within a thin (±3 mm) compositional boundary layer located atop a magnetitite layer that grows by in situ crystallization. As magnetite is extracted from the boundary layer, its density decreases, and it periodically breaks away from the solidification front in a plume-like fashion. With progressive evolution of the melt, plagioclase eventually reaches saturation within the boundary layer. However, as the boundary layer is continuously removed by convection, plagioclase cannot grow in the abundances predicted by mineral-phase equilibria. With continued evolution of the liquid, plagioclase becomes more abundant, producing the gradational contact. Crystallization within such a thin boundary layer would greatly favour lateral growth of plagioclase, thus producing the magmatic foliation. This study shows that some non-cotectic, foliated igneous rocks may in fact be produced by in situ crystallization.

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The increase of dust source points on the west coast of South Africa and their relationship to land cover and drought

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The emission, transport, and deposition of dust have shown to be an important process in South Africa, with consequences for public health and nutrient distribution [1,2]. However, the spatial and temporal distribution of dust sources in South Africa and the future development of these sources remain a topic of current research [3,4]. This study presents the dust source points on the semi-arid and arid west coast of South Africa from 2000 to 2021 using MODIS images and combines this with weather data, NDVI data, and land cover data from the SANLC dataset.

In total, 540 dust source points were detected during the 22 years of analyses, with most sources occurring in the Northern Cape Province. The dust season occurs from April to September and showed a tripling in dust source points in 2020 and 2021. The maximum wind velocity during dust events did not vary over time, which suggests the increase in dust sources comes from a change in the erodibility. The land covers of the dust sources are mainly extraction pits and quarries (23.7%), bare surfaces (22.6%), and succulent Karoo shrubland (40.5%), but the recent increase in dust sources can mainly be linked to shrubland areas. This higher emissivity could be the result of the drought that occurred from 2017 onwards, which was accompanied by a continuous decrease in NDVI. Considering the expected further decrease in precipitation on the west coast of South Africa [5], understanding the relationship between land use, vegetation cover, drought, and erodibility would be of importance. Furthermore, these results shine a light on the importance of this region as a dust source and its potential impact on ocean chemistry.

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The influence of the Nucleation Delay of Magnesian Olivine on the Crystallization of Komatiite lava flows

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To better understand what the influence of the nucleation delay of magnesian olivine (forsterite) on the cooling and crystallization of komatiites lava is, we conducted dynamic crystallization experiments on four ultra-magnesian compositions (that is 23% < MgO < 34%) belonging to the CMAS system. Compositions were superheated to 10°C above their liquidus and rapidly undercooled to sub-liquidus temperatures where they dwelled for variable timespan. Once the incubation period of olivine crystals was found, we replicated the experiments for several degree of undercooling so that Nucleation curves in Temperature-Transformation-time diagrams for each composition could be drawn up. The discovery that, under degree of undercooling that bear similarities to those deduced from komatiites, nucleation of euhedral olivine happens very quickly without much dependence on MgO content, drew us to the conclusion that crystallizing komatiites lava flows experience a second nucleation episode of euhedral olivine that could be the source of part of the cumulate layer.

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The Klipheuwel Group (Western Cape) – Pan-African aftermath or Cape prelude?

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The Klipheuwel Group is loosely used to refer to several enigmatic immature and coarse-grained siliciclastic deposits of probable Cambrian age in the Saldania Belt of the Western Cape. Some of these basins are clearly fault bounded and tilted, such as at the Klipheuwel Group type locality. Other basins are erosional relics and preserve their original subhorizontal attitude. Stratigraphically, all, if not most, of these basins are remarkably similar in their stratigraphic fill and may be subdivided into the lower rudaceous to arenaceous Magrug Formation, and an upper argillaceous succession of characteristically reddish-purple mudstone and sandstone referred to as the Populierbos Formation. Where the lower contact of the Magrug Formation is exposed, it is disconformable and strongly erosive into underlying Cape Granites or Malmesbury Group metasediments. Where exposed, the upper contact of the Kliphewuel Group with the Cape Supergroup is marked by an angular unconformity that may appear to be paraconformable to conformable in places. Sedimentologically, the fill of the Magrug Formation is alluvial in nature, chiefly characterized by well-exposed immature coarse-grained deposits that probably accumulated in an alluvial fan to braided fluvial complex marked by rapid facies changes with the Populierbos Formation perhaps representative of distal low-energy fluvial deposits. The timing and tectonogenesis of these basins are debated having thought to have formed either during the Pan-African deformational event (possibly as segregated or extensive wedge-top or fault release step-over intramontane basins), post Pan-African (as segregated rift basins during orogenic collapse) or perhaps are related to the formation of the Cape Basin (as short-lived early impactogenic or aulacogenal rift basins). This research revisits the sedimentology and detrital geochronology of these enigmatic depocentres to unravel their basin histories by improving their depositional environments and identifying pathways for detrital sources and sinks. This research will potentially help improve inter-basinal correlation and timing of hitherto unrecognised tectonostratigraphic events. Preliminary findings suggest sourcing directly from recycled Pan-African source terranes with a revised maximum depositional age of at least 510-520 Ma and might be related to late-stage magmatic activity associated with the Darling batholith and/or Klipberg Granite. A comparison of potential source areas with the overlying Cape Supergroup shows a difference in younger source areas suggesting that the two depophases are unrelated.

The Kuunga Nappe Accretionary Complex of Sverdrupfjella, western Dronning Maud Land, Antarctica

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The geology of Sverdrupfjella, western Droning Maud Land, Antarctica comprises three complexes. The ~1140Ma Jutulrora Complex consists mostly of arc-related TTG orthogneiss with evolved Sr/Nd isotopic signatures with TDm ages >2by. A 2.8Ga Archaean basement to the Jutulrora Complex exposed at Brekkerista has recently been recognised.
The Fuglefjellet Complex, structurally overlying the Jutulrora Complex, comprises supracrustal (~800-900Ma) carbonates intercalated with paragneissic quartzo-feldspathic gneisses with provenance ages of 1100 Ma with ca. 500Ma metamorphic overprints.

The Rootshorga Complex, structurally overlying the Fuglefjellet Complex, contains paragneisses with minor ~1100-1200Ma orthogneisses, intruded by granitic orthogneiss of similar age and has TDm ages <2by.

In the Rootshorga and Fuglefjellet Complexes D1 and D2 deformation verges top-to-NW with D2 also involving low angle thrust faulting with SE plunging lineations which truncate an extensional ca. 520 Ma pegmatite phase. D3 is characterised by syntectonic dilational granite sheets with extensional and compressional displacements with top-to-the SE shear. Zircon ages of the granitic sheets are 490-500Ma. In the Jutulrora Complex, rocks dip dominantly S with D1 and D2 verging to the N; D3 is characterized by ~100m scale folds with NW dipping axial planes cut by SE dipping dilational granite sheets.

Sr/Nd isotopic signatures of the ca. 500 Ma granitic sheets, which intrude all complexes have TDm ages >2 Ga and are consistent with partial melting of crust similar to the Jutulrora Complex with Archaean and Mesoproterozoic xenocrysts seen in some samples.

P-T-t studies from the Rootshorga Complex yield an ITD path with decompression from ~1.4Gpa at ~570Ma to ~0.7Gpa at ~500Ma whereas P-T-t estimates from the Jutulrora Complex are <~0.8Gpa at ~500Ma with a path consistent with crustal loading.

The Rootshorga and Fuglefjellet Complexes, containing an inverted stratigraphy geochronologically and inverted P-T conditions, are inferred to comprise a mega-nappe, emplaced during the Kuunga Orogeny ~500Ma ago, over the footwall Jutulrora Complex with the granitic veins arising from partial melting in the nappe footwall. The nappe is inferred to extend eastwards to Lutzholm Bay in the east and is correlated witth rocks of similar age and P-T characteristics, via klippen structures in N Mozambique and Sri Lanka, rocks north of the Lurio Belt in Mozambique and the Highlands Complex in Sri Lanka. Gravity data from DML, Antarctica are consistent with this interpretation, reflecting over thickened crust typical of a continent-continent collision setting in the amalgamation of N and S Gondwana.

The Lanseria palaeosol: implications for palaeoweathering and terrestrial life at ~2.6 Ga on the Kaapvaal Craton

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Archaean basement immediately below the nonconformity with the Transvaal Supergroup, along the northern margin of the Johannesburg Dome, Kaapvaal Craton, shows evidence for paleoweathering and the presence of carbonaceous matter before the deposition of the ~2.6 Ga Black Reef Formation. We used petrographic, carbon isotope, major and trace element geochemistry, total organic carbon (TOC) and Raman spectroscopy data to assess the atmospheric conditions during pedogenesis and the source of carbon along the nonconformity.

The ~25 m-thick Lanseria palaeosol records relatively constant Al/Ti values similar to the granodioritic bedrock, suggesting that the palaeosol developed in situ. The Al content and CIA values of the palaeosol progressively increase from the bedrock towards the nonconformity as Si, Na and Ca concentrations decrease. The loss of Co, Zn, Fe, Mg and retention of U, V and Cr suggest a reducing and acidic environment at least at ~2.6 Ga. The negative δ13C isotopic composition of the carbonaceous matter (−27 to −23‰) is compatible with the former presence of photosynthesizing cyanobacterial soil crusts, further supported by copper depletion and mobility of P, indicating the presence of organic acids that enhanced the chemical weathering of the bedrock. We compare the Lanseria palaeosol to palaeosols in the Schagen and Kalkkloof areas (Martini, 1994; Watanabe et al., 2000, 2004), which similarly contain organic carbonaceous matter immediately below the nonconformity, although in larger quantities, and lie beneath the Black Reef Formation. The correlation between carbonaceous matter in the Lanseria, Schagen and Kalkkloof palaeosols suggests that photosynthesizing cyanobacterial mats extensively colonised the Kaapvaal Craton at 2.6 Ga.

The Lanseria palaeosol is overprinted by diagenetic-hydrothermal K-metasomatism, silicification, regional metamorphism and deformation, which transformed the palaeosol into a quartz-sericite schist, as it presently occurs. Despite these modifications, the original record of intense paleoweathering and microbial colonisation is well preserved. Unlike most Precambrian palaeosols, the Lanseria palaeosol is well-exposed and relatively thick. It, therefore, represents a suitable and reliable reference for Archaean climatic reconstructions and early life studies.

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The limits of beneficiation of high-grade BIF hosted iron ores as deduced from geochemistry, mineralogy and mineral chemistry of ore forming hematite

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Most of the high-grade iron formation (BIF)-hosted hematite (>60% Fe) iron ores being mined in South Africa are formed within ancient karstic depressions on the Maremane Dome, Northern Cape Province [1]. Ancient supergene enrichment is thought to be the main ore forming process [2] with minor younger hydrothermal modification [3]. These ores are currently being mined at Sishen, Khumani, Beeshoek and Kolomela Mines and the mineable ore types include laminated, massive and breccia-textured ores [1]. In all these ore types hematite is the only ore-forming mineral of significance-occurring in various microtextural types.

High-grade iron ores deposits from Brazil, India and Australia are thought to have formed or significantly overprinted during extended episodes of lateritic weathering [4]. In these deposits, both goethite and hematite occur as ore-forming minerals, however goethite, in particular, has been shown to vary considerably in minor element composition [4]. This study is thus aimed to investigate, if systematic changes in chemical composition and mineral chemistry are preserved in the microtextural types of hematite that constitute high-grade iron ores of Maremane Dome through XRF, SEM, optical microscopy and EPMA analysis.

The whole rock geochemistry and petrographic analysis of the studied samples did yield no surprise to those documented in previous studies [5, 6], with ore type samples comprising almost exclusively of Fe2O3 (97-100 wt%), with minor amounts of SiO2 (0,9-2 wt%), P2O5, Al2O3, TiO2 (0,05-0,8 wt%) and whereas the altered BIF and Gamagara Formation marked by higher concentrations of SiO2 (20-60 wt%) and Al2O3 (2-10 wt%). Hematite micro-textures, including microcrystalline hematite, microplaty hematite, specularite, patchy hematite and martite. The EPMA results on microplaty hematite, patchy hematite, specularite and martite show low concentrations of SiO2, P2O5, Al2O3, TiO2, MnO (0,01-1,0wt%) on other ore types, whereas in high-grade iron ore MnO concentrations below limit of detection

Highly detrimental elements to iron ore such as Al, P and Ti are clearly incorporated into the hematite textural types that comprise the high-grade iron ores. This indicate that for mechanical beneficiation techniques to remove all these impurities, will be difficult or impossible.

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The Marion Hotspot Track Isn't

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The concept of mantle hotspots originated with the work of J. Tuzo Wilson who in 1963 hypothesized that the formation of the Hawaiian Islands was due to the slow movement of the tectonic plates across a hot region in the underlying mantle producing a linear volcanic chain or Hotspot Track, as they are known today. Morgan (1971) further proposed that hotspots are manifestations of deep mantle plumes originating in the lower mantle providing an independent fixed framework for determination plate migrations. Prominent among proposed hotspot tracks has been a track originating in Madagascar at around 90 Ma on the African Plate and ending at volcanically active Marion Island on the Antarctic Plate. To test this hypothesis, Cruise SO273 of the German Research Vessel RV Sonne undertook an International German, US, Chinese and South African Expedition to survey of the anomalously elevated seafloor terrain associated with the proposed Marion Hotspot track in March and April 2020. What was anticipated was a chain of extinct seafloor volcanos similar to those associated with the Hawaiian seamount chain. What was found was a series of ridge-parallel rifted volcanic highs formed at the SW Indian ridge over the last 30 Myr. The track had well defined magnetic anomalies with identifiable chrons on both flanks of the ridge consistent with a robustly spreading magmatic segment, indicating a relatively stable average spreading rate of 7.2 km/My to the south, and 5.9 km/My to the north over the last 30 My. In addition, a new large active volcanic seamount shoaling to 400-m was found lying on the proposed track in the northern rift mountains 50 Km from the present day ridge axis. The southern flank of this volcano exhibits ridge parallel rifting, and thus likely originated on axis at 8.5 Ma. This would make this the only documented hotspot track with an active volcano at each end — perhaps better characterized as the pushymepullyou hotspot (apologies to Hugh Lofting). In any case it is clear that the track is not a classic hotspot track, but rather a long-lived ridge melting anomaly whose geochemical characteristics likely reflect the recycling of old oceanic and continental crust and mantle to the ridge.

The Neoproterozoic Pan-African- Brasiliano Orogeny of Western Gondwana using Landsat8 OLI satellite imagery

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Background

The Pan-African orogeny is a protracted orogenic cycle, reflecting the opening, and closing of large oceans as well as the accretion and collision of crustal blocks over extensive geographical and temporal extent [1]. Some of the uncertainty related to Neoproterozoic global tectonics is dependent on understanding the geodynamic evolution of Southwest Gondwana [2]. Rift structures including the Damara Orogen, created during the break-up of Rodinia and filled with continental deposits, between about 800 and 500 Ma, were deformed and metamorphosed during Pan-African tectonic events, [3,4].

Methodology

A created collage of Landsat8 OLI (LSAT8) bands 7,6 and 3, revealed large-scale geological structures over Southern Africa. These planar view images show contrasting responses from 'broad mineralogical groups' on the earth's surface. Fold-related structures under the cover of Kalahari sands define extensions to known outcropping features of the Damara Belt. These structures were verified by airborne magnetic and gravity data, as well as from magnetotelluric traverses.

Key Results

Two SW-NE trending, almost parallel, fold structures in the Damara Belt with NE-trending fold axes are interpreted. These structures tie in with those of the southern Dom Feliciano Belt in South America when rotated back in a pre-breakup Gondwana configuration. Geochronological data, geological mapping, geophysical data, and a study on the evolution of the Dom Feliciano Belt [5] support this interpretation.

The main feature of lithospheric folds is that they strike perpendicular to the maximum stress direction of the active tectonic stresses [6]. By identifying the strike of fold structures, perpendicular to the maximum stress direction, crustal movements of a very large scale, not observable on the ground, can be interpreted.

Main conclusions drawn from these results

Where collages of satellite images covering Africa and eastern South America are brought together in pre-breakup Gondwana configuration (500Ma), clear fold structures show that compressional stress prevailed following the opening and closure of the Iapetus Ocean during the Neoproterozoic and opening of the Rheic Ocean in the Paleozoic. The results of the Pan-African Orogeny on key economic areas in Southern Africa are recognised.

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The not-so-Great Meteor Hotpot cannot explain Eastern Canada seismicity

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Although seismicity occurs across North America, some areas are more active than others, with seismicity broadly divided into plate-boundary (e.g., west coast) and intraplate (e.g., central and eastern Canada) regions. Plate-boundary seismicity is often larger in magnitude, occurs more frequently, and the geologic processes involved are better understood and constrained. Intraplate seismicity, such as in the Western Quebec Seismic Zone (WQSZ), is less-studied and more poorly understood. The WQSZ is an extensive, geologically diverse, intraplate region characterized by spatial clustering of weak to moderate recent seismicity of unclear origin. Nonetheless, earthquakes up to moment magnitude ~6 have been recorded there. This region is proximal to large urban areas including Montreal and Ottawa, and thus understanding the causes of the seismicity is important.

Previously proposed mechanisms to explain the seismicity include: 1) reactivation of pre-existing structures under the present-day stress regime, and 2) deformation along the track of the Mesozoic Great Meteor Hotspot. Proponents of the hotspot explanation point to an apparent coincidence between the band of seismicity and Mesozoic igneous centres such as the Monteregian Hills, Quebec. However, several observations do not fit this model: 1) the proposed hotspot track does not align well with the seismicity distribution according to multiple plate reconstructions, 2) elevated geothermal gradients are typically associated with 'strain softening' i.e., diffuse deformation, and not focused brittle (i.e. seismogenic) deformation, 3) the proposed hotspot passed the region >100 Myr ago and any thermal effects have long since dissipated, and 4) geochronology questions the suggested age-progressive hotspot track and instead shows a distributed network of igneous centres.

In the light of these discrepancies, we instead propose that the seismicity arises from reactivation of optimally oriented pre-existing structures under the present-day tectonic stress regime, associated with the distal mid-Atlantic ridge and possibly the convergence along the west coast. Glacial isostatic adjustment following the last glacial maximum likely contributes stress as well, and may also encourage reactivation of non-optimally oriented faults. Candidate structures for reactivation include late Precambrian to early Paleozoic Iapetan rifts and aulacogens, and Precambrian suture zones and plate boundaries forming linear zones broadly coinciding with the seismicity. These major tectonic features in the area include grabens and half-grabens of the Saint Lawrence Rift system, such as the Ottawa-Bonnechere and Timiskaming grabens which substantially pre-date the postulated hotspot. Both the Mesozoic magmatism and the current seismicity may be responses to ongoing, low-level activation of these structures.

The O-, H-, and Sr-isotope composition of Cape Town groundwater; implications for recharge and sustainability

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We have measured the hydrogen, oxygen and strontium isotope composition of over 350 borehole, wellpoint and natural spring samples, collected since 2017 from across Cape Town. On the E side of the Table Mountain Range (TMR), the δD and δ18O values range from -19.9 to 13.7‰ and -4.37 to 2.35‰, respectively. The EC range was 110 µS/cm to 58700 µS/cm (median 685 µS/cm). The δD and δ18O of groundwater samples from Hout Bay, 20 km south-west of Cape Town range from -16.5 to -6.4‰ and -3.90 to -2.14‰. Electrical conductivity of ranges from 126 µS/cm to 2370 µS/cm (median 578 µS/cm). The long-term weighted average δD and δ18O values for rainfall at UCT are -11.0 and -3.11‰, respectively whereas those for Hout Bay from March 2020 to February 2021 are -6.2 and -2.38‰ respectively. The δD and δ18O values of Hout Bay rainwater cluster around the local meteoric water line established for UCT, which is consistent with aquifers being recharged by local, present-day rainfall. East of the TMR, there is a slight altitude effect on δD and δ18O values of groundwater but a limited amount effect in the UCT rainfall record. In contrast, Hout Bay rainfall shows a strong amount effect (r = -0.92 for δD vs amount).

The relatively low EC in groundwater from all areas, and the lack of correlation between EC and isotope composition, even in the highest EC samples is not consistent with seawater infiltration. Instead, high EC in groundwater is attributed to dissolution of salt from the sandy substrate. Small but distinct differences between groundwater from adjacent areas is consistent with multiple aquifers with each lithostratigraphic unit.

The range in 87Sr/86Sr ratios for 20 groundwater samples analysed was 0.7094 to 0.7310. the low 87Sr/86Sr ratios are dominated by strontium from sea spray or shells in the substrate whereas high 87Sr/86Sr ratios reflect strontium derived from granite or Malmesbury Group bedrock. East of TMR there is no relationship between 87Sr/86Sr and δD or δ18O values whereas for Hout Bay there is a strong negative correlation between 87Sr/86Sr and δ18O (r = -0.91). This relationship probably results from a combination of the altitude and amount affects that are more pronounced in Hout Bay rainwater. Seawater Sr dominates at low altitude whereas bedrock Sr dominates higher up the mountain where δD and δ18O values are lower.

The occurrence of contrasting orthopyroxenite layers above the UG1 chromitite in the Central Sector of the eastern Bushveld Complex, South Africa

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The immediate lithology above the UG1 chromitite, previously regarded as a homogenous layer[1], is a feldspathic orthopyroxenite. Recent continuous field exposures, approximately 40km in strike length indicate that this layer consists of at least four contrasting sublayers, named from the bottom upwards, Pyroxenite 1-4 (PXT1-4). From drillcore intersections, the feldspathic orthopyroxenite attains a thickness of approximately 40m, and it is difficult to distinguish individual sublayers. Rather, the four sublayers are remarkably noticeable in field outcrops due to differential weathering. PXT1-4 have similar mineralogy (orthopyroxene, plagioclase, clinopyroxene and chromite), however, the proportions of these minerals, as well as rock textures differ, resulting in sharp lithological boundaries. Significantly, the sublayers crosscut each other, with the top layers always undercutting the bottom layers to form potholes. Furthermore, there exists a "chill" zone between PXT1 to PXT2, formed by an abrupt increase in interstitial plagioclase, accompanied by a concomitant reduction in mineral grain size. These lines of evidence indicate that the hangingwall of the UG1 in the Central Sector is not as homogenous as previously thought. The mineralogical, textural, and field relationships suggest that these sublayers formed via the replenishment of the magma chamber by a superheated melt that spread along the chamber floor as basal flows causing erosion of the pre-existing floor rocks[2]. We conclude that new observations support the existence of a progressively growing, long-lived and largely molten Bushveld magma chamber (3-4).

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The Olifants River Greenstone Belt: A newly discovered Archaean greenstone remnant in the central Kruger National Park, South Africa

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Archaean greenstone belts and their scattered remnants are known to occur in areas bordering the Kruger National Park, including the Barberton greenstone belt in the south, the Murchison greenstone belt north of Phalaborwa and the Giyani greenstone belt further northeast. Satellite imagery has revealed the presence of numerous greenstone remnants and associated granites, gneisses and migmatites, occurring as extensions into the Kruger Park.

One of these remnants, here named the Olifants River Greenstone Belt (ORGB), may represent a greenstone remnant associated with the eastern extension of the Ofcolaco-Mica-Phalaborwa group of greenstone fragments depicted on the 1:250 000 Geological Series map 2430 Pilgrim's Rest (1). Alternatively, the ORGB may represent a hitherto unrecognized greenstone remnant situated south of the Olifants River, approximately midway between Phalaborwa and the Olifants Camp in the Kruger Park.

The main mass of the greenstone remnant is represented by a well-layered and refolded succession lying between the Olifants River in the west and the Nhlaralumi River tributary in the east, a distance of approximately 4 km. The greenstone belt extends eastwards for a further 11 km and is overlain by sediments and volcanic rocks of the Karoo Supergroup.

The ORGB is believed to be in excess of ca. 3200 million years old based on previous geochronological studies undertaken in the vicinity of the Murchison greenstone belt northwest of Phalaborwa. The remnant comprises metamorphosed volcanic and associated sedimentary rocks about which virtually nothing is known at present. This is due to its extremely remote locality in the National Park and access is restricted. Limited sampling suggests the greenstone remnant consists predominantly of amphibolites, the latter intruded by granitic gneisses. The granite-greenstone terrane, including the ORGB, is intruded by a prominent northeast-trending mafic dyke swarm possibly linked to the ca.1990 Ma Black Hills dyke swarm (2).

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The Orange vs The Olifants: Questioning the stability of South Africa's landscape

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For decades, many classical landscape evolution models in South Africa have relied on large-scale, predominantly qualitative, field observations as a method of investigation (Du Toit, 1933; King, 1947; Wellington, 1955; Partridge and Maud, 1987). However, the development of the accelerator mass spectrometer (AMS) in recent decades, has allowed for innovative thinking in landscape evolution studies to quantify rates of denudation and establish timescales of landscape development. As a result, more Quaternary landscape evolution studies in South Africa have adopted the use of cosmogenic nuclides as a method of investigation (Fleming, 1999; Decker et al., 2011; Erlanger et al., 2012; Scharf et al., 2013; Bierman et al., 2014; Dirks et al., 2016; Makhubela et al., 2019), with many using 10Be in quartz-bearing rocks to do this. South Africa's landscape is considered passive (Andreoli et al., 1996; Bierman et al., 2014) with very little to none natural tectonic events and its climate spans various types as one traverses the country from east to west. Taking this into consideration, this study aims to use 10Be, a cosmogenic nuclide, to investigate the development of geographically separate parts of the South African landscape, and by doing so, contribute towards the growing database of landscape evolution rates across southern Africa. Granitic bedrock samples have been collected along the Olifants River in the Kruger National Park in the subtropical east and are compared to samples of similar composition from the Orange River near the Augrabies Falls National Park in the arid west. Both rivers have similar multi-channel morphologies (i.e. mixed bedrock-alluvial anabranching channels). A comparison of erosion rates along these otherwise similar rivers at opposite sides of the country will enable an investigation of the effects of climatic differences on erosion rates and how stable the region is. Results of this study will allow us to test previous, largely qualitative hypotheses of landscape evolution using state-of-the-art cosmogenic nuclide data analysed at the African continent's only AMS facility.

The Origin of Karoo-age Diamondiferous Lamproites in Eastern Zambia

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Mesozoic diamondiferous lamproite pipes occur along the Kapamba River within the Luangwa Valley of eastern Zambia, which is a Karoo-age precursor branch to the East African Rift System. The Luangwa Rift developed above a reactivated mega-shear zone that cuts through the Proterozoic Irumide Belt between the Congo-Tanzania-Kalahari cratons and thus it provides a rare snapshot of early-stage cratonic rift evolution. The study focused on the geochemical and thermobarometric characterization of rocks from Kapamba through techniques including XRF, EPMA and LA-ICPMS, to help better understand the tectono-magmatic processes responsible for the formation, emplacement and evolution of these lamproites in comparison to other known circum-cratonic lamproite occurrences worldwide.

The mineralogy of the fresh volcanic rocks suggests that they represent a continuum between primitive olivine lamproites and slightly more evolved olivine-leucite lamproites. However, there are some similarities to rocks from the Kaapvaal craton, the East African Rift, and a key region of the rifted North Atlantic craton. The bulk compositions of the Kapamba volcanic rocks fall within the range of 'cratonic' low silica lamproites, but there is overlap with more evolved leucite- and sanidine-bearing orangeite varieties. Modelling of the process by which most of the original leucite was transformed into analcime suggests that these lamproites and the type kamafugites located on the East African Rift System, represent melting products of similar K-metasomatized cratonic mantle domains, but their formation occurred under contrasting volatile conditions at different stages during rift development.

Temperature estimates for peridotite-derived olivine xenocrysts from the Kapamba lamproites suggest that the Luangwa Valley is an aborted cratonic rift that retained a relatively cold (≤42 mW/m2) lithospheric mantle root down to ~180 – 200 km depth during the Mesozoic. Olivine major and trace element compositions support the presence of an Archean mantle root that is progressively metasomatized toward its base.

Keywords: continental rifting; craton reactivation; ultrapotassic volcanism; anorogenic lamproite; unconventional diamond deposits.

The origin of transgressive ferrogabbro at the Kameelhoek mine, western Bushveld Complex

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The Upper Zone of the Bushveld Complex has long been known to have formed from a major influx of magma into the chamber that caused large-scale erosion of the chamber floor cumulates. The most dramatic manifestations of this process are two major gap areas (Northern and Southern) in the western Bushveld Complex. However, due to an almost complete lack of outcrops in the gap areas, petrological information could only be derived from loose boulders or drill cores (1). It was only with start of chromite mining operations at the Kameelhoelk mine that the contact has been exposed for the first time, occurring as a series of transgressive potholes filled with fine-grained ferrogabbros of the Upper Zone (UZ) as it chilled against the host orthopyroxenite of the Lower Critical Zone (LCZ) (1). It was found that the ferrogabbro within the potholes differ geochemically and petrographically fromUZ rocks within the Northern Gap, with plagioclase occurring as microphenocrysts within the chills and as radial clusters that become larger towards the centres of the potholes (1). Importantly, previous research has shown that the UZ's initial Sr isotope ratios (Sri) are ~0.7073 (T= 2060 Ma) and remains nearly constant from the top of the Pyroxenite Marker towards the top of the UZ (2, 3). Therefore, it was quite unexpected to find out that the Sri ratios from a sample collected at Kameelhoek have values of around 0.7055, similar to those of the UZ in the southeastern Bushveld Complex (0.7055) (2, 3). Our research on these transgressive potholes aims to further study this petrological and geochemical anomaly, with the main task being to conduct Sr isotope analysis and zircon dating of the ferrogabbros. We plan to determine which type of magma is parental to ferrogabbros and why their Sri ratios differ from those of 'normal' UZ rocks. The study may thus provide a better understanding of the magmatic processes occurring in the UZ during its emplacement and crystallization.

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The palaeoredox condition and structural variation of Nama Group microbialites

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Microbialites are the fossilised trace of microbial communities and have persisted since the Paleoarchean, 3.5 billion years ago (1), making microbialites some of the earliest direct evidence for life on Earth. Billions of years later, in the Ediacaran Period, microbialites became habitats for some of first animals, termed the Ediacaran Biota (2,3) Earth's atmosphere prior to the Cambrian Period was still low in oxygen (4). How did the Ediacaran Biota live within these low oxygen waters? It is possible that the waters around the microbialites were locally oxygenated by the photosynthetic microbes that created them. Here, we test this hypothesis using a suite of columnar stromatolites from the Nama Group, South Africa. We have studied the texture and mineralogy using XRD, SEM, petrography, and polished surfaces. We have also performed high resolution carbon & oxygen isotopes and rare earth element analysis from microdrilled microbial laminae to study productivity and local redox conditions.

Analysis on the microstructure indicates that the columnar laminae are micritic peloids, while the intercolumn material is largely microspar. The presence of peloids has been associated with cyanobacterial activity. Analysis on the mesostructure (1 to 10 cm scale) shows textures are similar across tens of metres. The REE data record seawater compositions and are in line with bulk rock analysis from the Nama Group. However, there are no cerium anomalies, suggesting microbial reefs were not highly oxygenated microenvironments.

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The Paleoproterozoic Negaunee Iron Formation of the Marquette Range Supergroup in Minnesota, United States of America: A case study in post-Great Oxidation Event iron formation deposition

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The Negaunee Iron Formation (NIF) forms part of the metasedimentary Menominee Group of the Marquette Range Supergroup (MRS) of United States of America. A depositional age of ~1874 Ma has been suggested for the NIF [1]. NIF presents a unique research opportunity as its age places it much younger than the approximately 2.4 to 2.3 Ga Great Oxidation Event (GOE), [2]. The South African geological record contains multiple well-studied examples of IFs that pre-date the GOE, whereas post-GOE IFs are lacking, and this study aim to address that shortfall.

Stratigraphically, the NIF is a Superior - type IF, occurring in a dominantly marine sedimentary sequence. Diagnostic textural and mineral assemblages of granular textures are divided in two: (1) massive clastic textures of quartz clasts (1-5 mm) dispersed in a fine matrix; and (2) granular bands of thick massive quartz clasts alternating with medium sand (0,1-0.5 mm) oxide bands. Banded IFs are dominated by carbonate-oxide-silicate mixed facies with fewer end members. Massive IFs are divided into (1) Muddy Fe-bearing mudstones and (2) laminated silica rich microbands interlayered with massive clastic quartz laminae.

The major element geochemistry displays elevated concentrations for SiO2 and Fe2O3 and slightly elevated MgO, MnO, CaO and Al2O3 contents. Post Archean Australian Shale (PAAS)-normalised rare earth element and yttrium (REY) concentrations plot below that of PAAS that are slightly enriched in heavy rare earth elements (HREE) relative to light rare earth elements (LREE). REY plots yield positive anomalies for Y, Eu and Pr with some slight negative Ce anomalies. Positive Eu anomalies suggest hydrothermal fluid input whereas positive Y anomalies are indicative of rapid precipitation.

The observations show that the NIF was deposited in a marine environment that was transitional between above and below storm wave base, leading to both deposition of undisturbed laminated as well as wave reworked IF. When comparing the NIF to the Asbesheuwels Subgroup IFs of South Africa (pre-GOE), Mn contents are slightly elevated and the REY patterns are flatter (less HREE enriched relative to LREE) in NIF.

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The petrogenesis of the Pliocene Araral stratovolcano in the Andean Central Volcanic Zone (CVZ), northern Chile

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Araral is an extinct stratovolcano located on the border between Chile and Bolivia (21°35′29”S, 68°14′3”W). The volcano was constructed ~2.75 Ma (Pliocene) within the western border of the Altiplano-Puna Magma Body (APMB), a large regional melt anomaly underlying the Altiplano-Puna Volcanic Complex in the Andean Central Volcanic Zone (CVZ). To characterise the Araral eruptions, we present new petrography, major and trace element abundances and radiogenic Sr-Nd-Pb isotope ratios from 20 lava samples. These data are used to evaluate the magmatic processes involved and compare Araral with other extinct, dormant, and active volcanoes within the western APMB boundary. These new data also provide a timely update on the under-explored Pliocene volcanism in the CVZ.

The samples are characterised by SiO_2 = 59.47 – 66.65wt%; MgO = 1.535 – 3.394wt%; $^{87}Sr/^{86}Sr$ = 0.7069 – 0.7085; $^{143}Nd/^{144}Nd$ = 0.5123 – 0.5124; $^{208}Pb/^{204}Pb$ value = 38.80 – 38.92; $^{207}Pb/^{204}Pb$ = 15.65 – 15.66; and $^{206}Pb/^{204}Pb$ = 18.89 – 19.00. Preliminary results indicate high calc-alkaline andesites and dacites rich in plagioclase, pyroxene, biotite, hornblende, and olivine phenocrysts. The samples were grouped according to their most abundant mafic mineral(s): (1) olivine-rich; (2) pyroxene-rich; and (3) biotite-rich (this group includes hornblende). The olivine-rich group is exclusively andesitic and has the least number of samples. Most of the samples are part of the pyroxene-rich group and the group is predominantly andesitic. The biotite-rich group tends to be compositionally scattered and includes the sample with the highest SiO_2 content. Most of the biotite-rich samples are dacitic and one is trachyandesitic (the only sample in the data set that is not andesitic nor dacitic). Finally, the petrogenesis of the Araral volcanic rocks is likely controlled by similar magmatic processes as those in the area, such as significant contamination by felsic melts derived from the APMB.

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The Pletmos Basin: Fault Seal Analysis for Carbon Dioxide Storage

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Carbon Capture and Storage (CCS) is an expanding technology aimed at reducing CO_2 emissions and thereby combatting climate change. Geological storage as a component of CCS, is the underground disposal of CO_2 from significant point sources such as coal power plants. Supercritical CO_2 is injected under high pressure into deeply seated rocks that trap natural fluids. Saline formations which are widespread throughout the world have the capacity to securely hold vast amounts of CO_2, potentially equivalent to hundreds of years of man-made emissions.

An opportunity exists to lock away CO_2 within subsurface geological formations and depleted oil and gas reserves. However, a majority of South Africa's geological storage research has focused on the Zululand Basin, located in KwaZulu-Natal South Africa (Viljoen et al., 2010[1]; Chabangu et al., 2014[2]). For the reason, there is an urgent necessity to broaden the South African CO_2 storage knowledge by assessing an unfamiliar Pletmos Basin which is well fractured and possesses very thick sandstone packages within a saline formation.

This study made use of well log, core, and 3D seismic data to create a static geological model showcasing the fault orientation within the Pletmos Basin, incorporating facies, porosity, permeability, shale volume and flow zone attributes. Juxtaposition analysis was carried out to identify seal distribution possibilities whereas Shale Gouge Ratio (SGR) and Clay Smear Potential (CSP) calculations confirmed the seal capacity within the basin.

The study's primary aim was to determine whether faults would seal or act as conduits for CO_2 storage in the Pletmos Basin.

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The Pongola Supergroup stratigraphy of the Buffalo River Gorge, northern KwaZulu-Natal: Preliminary investigations

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The Mesoarchaean Pongola Supergroup in southeastern Africa represents one of the earliest well-preserved supracratonic, volcano-sedimentary sequences in the world. The lithological grouping which crops out in a north-south trending, 260km long by 60km wide, intracratonic basin on the Kaapvaal Craton is subdivided into the lower Nsuze and upper Mozaan groups. Exposures occur from Amsterdam in the Mpumalanga Province, through southern Eswatini, with the locus of deposition in the Hartland region west of Paulpietersburg. To the south, in KwaZulu-Natal, exposures are restricted to numerous isolated inliers, the most extensive of which occur in the White Mfolozi, Nsuze and Buffalo rivers. Despite a detailed lithostratigraphic framework having been established for the main basin, correlations with the southern inliers have until recently been very limited.

As part of an active regional mapping programme operated by the Council for Geoscience, the stratigraphy of the Buffalo River Inlier is investigated. Multidisciplinary research utilising remote sensing and geophysical data have been combined with field mapping and interpretations from previous studies to define composite stratigraphic reference profiles for the inlier. Sedimentological comparisons are utilised to aid regional lithostratigraphic correlations with currently accepted subdivisions in the Nkandla region, and the main basin.

Exposures within the inlier are highly fragmentary, compartmentalised into four main fault blocks which are displaced along thrusts and/or strike slip faults. Folding and faulting has further disrupted the stratigraphy within each fault block. Although previous researchers proposed that no direct correlations could be made with stratigraphy in the main Pongola basin, new sedimentological interpretations suggest correlations with both Nsuze and Mozaan Group stratigraphies. Nsuze Group lithostratigraphy includes the complete sequence from the basal Mantonga Formation to the upper Ozwana Subgroup. Although lithologic variations occur in the volcanic units, with increased volcaniclastic deposition compared to the main basin, genetic correlations are applicable for the sedimentary units. Within the Mahlaba and Mangeni fault blocks to the north of the inlier, mapping has for the first time identified Mozaan Group stratigraphy with direct correlations to the main basin. The identification of diamictite sequences similar to that of the Klipwal Member in the main basin suggests a likely correlation with upper Mozaan Group stratigraphy. Whilst further research is needed to fully comprehend and accurately revise the lithostratigraphy of the inlier, these results have allowed for preliminary lithostratigraphic subdivisions and correlations of the Pongola Supergroup within the Buffalo River Inlier.

Keywords: Pongola Supergroup; Buffalo River; lithostratigraphic framework

The potential of hydrocarbons in Durban Basin, South Africa

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South African offshore basins are the hotspot for global hydrocarbon exploration, and South African western and southern offshore are continuously explored due to their huge hydrocarbon composition and production, whilst the eastern offshore basin has been underexplored. This study focuses on the characterisation of sandstone reservoirs located in the eastern offshore of the Durban Basin. Petrophysical and petrographic analyses were integrated to investigate the reservoir quality. Wireline logs of three wells (Jc-A1, Jc-B1, and Jc-C1) were used to classify reservoir intervals and determine net pay reservoirs. Thin section (thin slide of rocks) analyses were extensively used to study mineral types, rock texture, and diagenesis. Scanning Electron Microscopy (SEM) was used to identify clay minerals that reduce reservoir porosity.

On wireline logs, ten net-pay reservoirs were identified by their cut-off porosity, shale volume, and water saturation calculated values. The average results for all net pay zones in porosity were 22.04%, water saturation was 33.90%, and clay volume was 26.94%. SEM and thin sections observation revealed good porosity and permeability. Durban Basin reservoir quality is good due to clay and feldspar dissolutions, which created secondary porosity.

Keywords: Durban Basin, pay reservoir, reservoir quality, petrography, petrophysics.

The power, versatility, and the use of TIMA in resolving spatial distribution of critical metals in ore deposits

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Rock features such as texture and mineralogy play a very important role on how the ore responds in the processing plant and can have impact on the project's economic feasibility. In recent years, there has been developments in technologies that measure high-resolution information from rocks at different scales (Graham, 2018). For example, SEM-based automated mineralogy analyzer such as TIMA can collect statistically representative mineralogical data that include metal liberation, mineral association, elemental deportment, element locking, grind size (Hrstka et al., 2018). In base metal, petroleum and PGEs research, TIMA is used to provide statistical analyses on porosity, which can be correlated with liberation as well as to access the potential of recovering PGEs from mine tailings.

TIMA application is not only limited to metallurgy, but is also utilized to quantify spatial distribution of REEs in coal and fly ash. In petrology, TIMA is used to identify minerals by means of their chemical composition, to search for datable phases as well as to quantify their proportion and understand their textural relationship on a larger scale. This talk aims to introduce the application of TIMA in geometallurgy and mineralogy and to provide insights on the TIMA capabilities as well as its limitations. This will include different examples, ranging from liberation characteristics, particle size distribution of PGEs, gold deportment as well as understanding gold liberation and the textural characteristics, pore analyses in copper ore which is a very important step on copper leaching. In non-metallic material such as fly ash and coal, this talk will report the ore variability, and the question of whether or not we can separate couple of grains from the fly ash. In addition to this, this talk will report on the issue of heavy element settling during the sample preparation of fly ash. In coal the talk will report on variation in the mineralogy of the coal as well as whether the coal contains REEs.

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The segmented Zambezi sedimentary system from source to sink: 2. Geochemistry, Clay Minerals, and Detrital Geochronology

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Elemental geochemistry, Nd isotopes, clay minerals, and U-Pb zircon ages integrated by petrographic and heavy-mineral data offer a multi-proxy panorama of mud and sand composition across the Zambezi sediment-routing system. Detrital-zircon geochronology highlights the four major episodes of crustal growth in southern Africa: Irumide ages predominate over Pan-African, Eburnean, and Neoarchean ages. Smectite, dominant in mud generated from Karoo basalts or in the equatorial/winter-dry climate of Mozambican lowlands, prevails over illite and kaolinite. Elemental geochemistry reflects quartz addition by recycling (Uppermost Zambezi), supply from Karoo basalts (Upper Zambezi), and first-cycle provenance from Precambrian basements (Lower Zambezi). Mildly negative for sediments derived from mafic granulites, gabbros, and basalts, εNd values are most negative for sand derived from cratonic gneisses. Intrasample variability among cohesive mud, very coarse silt, and sand is principally caused by the concentration of Nd-rich monazite in the fine tail of the size distribution. The settling-equivalence effect also explains deviations from the theoretical relationship between εNd and TNd, DM model ages, suggesting that monazite carries a more negative εNd signal than less dense and less durable heavy minerals. Elemental geochemistry and Nd isotopes reveal that the Mazowe-Luenha river system contributes most of the sediment reaching the Zambezi Delta today, with minor supply by the Shire River. Sediment yields and erosion rates are lower by an order of magnitude on the low-relief Kalahari Plateau than in rugged Precambrian terranes. On the Plateau, mineralogical and geochemical indices testify to extensive breakdown of feldspars and garnet unjustified by the presently dry climate. Detrital kaolinite is recycled by incision of Cretaceous-Cenozoic paleosols even in the wetter lower catchment, where inefficient hydrolysis is testified by abundant fresh feldspars and undepleted Ca and Na. Mud geochemistry and surficial corrosion of ferromagnesian minerals indicate that, at present, weathering increases only slightly downstream in the Zambezi River.

The Segmented Zambezi sedimentary system from source to sink:1. Sand Petrology and Heavy Minerals

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The Zambezi River rises at the center of southern Africa, flows across the low-relief Kalahari Plateau, meets Karoo basalt, plunges into the Victoria Falls, follows along Karoo rifts, and pierces through the Precambrian basement to eventually deliver its load into the Mozambican passive margin. Reflecting its polyphase evolution, the river is subdivided into segments with different geological and geomorphological characters, a subdivision finally fixed by man's construction of large reservoirs and faithfully testified by sharp changes in sediment composition. Pure quartzose sand recycled from Kalahari desert dunes in the uppermost tract is progressively enriched in basaltic rock fragments and clinopyroxene. Sediment load is renewed first downstream of Lake Kariba and then downstream of Lake Cahora Bassa, documenting a stepwise decrease in quartz and durable heavy minerals. Composition becomes quartzo-feldspathic in the lower tract, where most of the sediment is supplied by high-grade basements rejuvenated by the southward propagation of the East African rift. Feldspar abundance in the Lower Zambezi sand has no equivalent among big rivers on Earth and far exceeds that in sediments of the northern delta, shelf, and slope, revealing that provenance signals from the upper reaches have ceased to be transmitted across the routing system after closure by the big dams. This high-resolution petrologic study of Zambezi sand allows us to critically reconsider several dogmas, such as the supposed increase of mineralogical "maturity" during long-distance fluvial transport, and forges a key to unlock the rich information stored in sedimentary archives, with the ultimate goal to accurately reconstruct the evolution of this mighty river flowing across changing African landscapes since the late Mesozoic.

The significance of isotopic decoupling in the mafic-ultramafic layered sequence of the Bushveld Complex

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There is controversy regarding the mode of emplacement, magma source(s), and the metallogenesis of the Rustenburg Layered Suite (RLS) of the Bushveld Complex. There is an agreement, however, based on the stratigraphic variations in bulk rock Sr-Nd isotopes that the RLS was formed through (1) the mixing of multiple pulses of magma in a chemically evolving magma chamber, and (2) there was significant pre-emplacement crustal and/or lithospheric mantle contamination of the parent magmas. Lu-Hf isotopes of accessory zircon show a limited range in εHf (at 2.06 Ga) of -8.6 ± 1.2 throughout the entire RLS, in sharp contrast with the bulk rock Sr-Nd variability. The homogenous zircon isotopic values indicate that there is decoupling between the major rock-forming silicates and the accessory minerals that crystallised from the trapped melt. The bulk rock isotopic data, therefore, provide only a partial story about the solidification history of the RLS. Competing models have been suggested for the origin of this homogeneous εHf isotopic signature including melting/contamination of asthenosphere-derived Bushveld magmas by the sub-continental lithospheric mantle and high-level crustal contamination of the RLS by fluids derived from the Transvaal Supergroup during crystallisation. In this study, we analysed Sr-Nd isotopes in apatite, which is also an accessory mineral in the RLS, and which crystallised in close association with zircon from the trapped melt. Our new Sr-Nd isotopes measured using LA-MC-ICP-MS show that apatite records homogeneous isotopic compositions (average initial 87Sr/86Sr of 0.7088 and εNd of ~-7 ± 1.4 at 2.06 Ga). Additionally, we show that apatite in the Phalaborwa Complex has similar Sr-Nd isotopic values to the RLS (average initial 87Sr/86Sr of 0.7107 and εNd of ~-8 ± 0.8 at 2.06 Ga). Samples from the Main Zone, Upper Zone, and the Phalaborwa Complex contain F-rich apatite while the Critical Zone pyroxenites contain Cl-rich apatite. Merensky Reef norites contain both F-rich and Cl-rich apatite, which may reflect an influx of chemically distinct hydrothermal fluids and/or melts in a chemically evolving magma chamber. Our new Sr-Nd isotopic data in apatite corroborate the existence of isotopic decoupling in the cumulates of the RLS. We speculate on the origin of this isotopic decoupling with hypotheses including (i) melt percolation in the crystal mush that led to isotopic homogenisation of the trapped melt, and (ii) the emplacement of isotopically distinct cargoes of silicate crystals in an isotopically homogeneous carrier liquid during the emplacement of magmas into the RLS chamber.

The stratigraphic interpretation of the T-Goob Succession and its correlation to the Western Aggeneys Terrane

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The Mesoproterozoic Namaqua Mobile Belt is composed of several large tectonostratigraphic terranes, juxtaposed against one another during the accretion of Rodinia (1). The T-Goob Succession is located within the western Namaqua Mobile Belt, within the eastern Aggeneys Terrane which represents a zone of high strain with isolated fold structures separated by intra-terrane thrusts and large granitoid sheet intrusives (2). The T-Goob Succession forms part of a host of stratigraphic units defined by isolated double vergent isoclinal fold structures that represent new fragmented stratigraphic units not seen in the western Aggeneys terrane. The T-Goob Succession is subdivided into three sequences each being representative of an isolated isoclinal fold structure namely; the Poort se Berg, T-Goob, and Lekdam Sequences.

The T-Goob Succession is defined by nodular rhythmic gneisses, poorly bedded quartzites, biotite-sillimanite schist, biotite gneiss, and volcanic/chemogenic units of actinolite, amphibolite, diopside, and feldspathic quartzite. Massive sillimanite ore is also associated with the T-Goob succession (3). Upon restoration, using the upright limbs of the various isolated isoclinal fold structures that resemble the different stratigraphic assemblages within the eastern Aggeneys Terrane, the lower stratigraphic units and the T-Goob succession can be related to the upper sequence of the Wortel Formation, which is the lowermost formation within the Aggeneys Subgroup (4). While the upper stratigraphic units represent stratigraphic assemblages not seen within the Western Aggeneys Terrane (2).

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Three-dimensional structure of Cloudina and Namacalathus from the Nama Group, Northern Cape, South Africa

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The Ediacaran Period, ~635–541 Ma, represents a critical interval where the oceans experienced significant changes in oxygen concentration and simultaneously, the first complex animals emerged. The Nama Group, a unique succession of fossiliferous carbonate and siliciclastic rocks that extends for over 1000 km from southern Namibia across the Orange River and into north-western Republic of South Africa, spans the terminal stages of the Ediacaran ~550–538 Ma. The South African sections along the Orange River in the Northern Cape are poorly studied but have recently but have been the focus of detailed mapping (Nelson et al., 2022).

New occurrences of Ediacaran-type biota including several genera of erniettomorphs and skeletal fossils of Cloudina and Namaclathus have been described (Nelson et al., 2022). In this study, we report on two techniques used to create three-dimensional (3D) reconstructions of well-preserved fossils from these sections. Micro-computed tomography (micro-CT) was applied to virtually reconstruct pyritized Cloudina fossils from the Nudaus Formation. This allowed for the fossils to be studied non-invasively for taxonomically relevant features. Prior to micro-CT scanning, the fossils simply appeared as tapering tubes. However, after virtually separating the fossils from the sediment, the characteristic "cone-in-cone" structure found in cloudinids was revealed. Serial grinding was used to virtually reconstruct calcified Namacalathus from the Mooifontein Member of the Zaris Formation. One sample contained an aggregate of closely packed individuals, so their spatial arrangement in relation to one another was mapped in 3D. The grinding process revealed the presence of spines on some individuals, specifically on the outer surfaces of their cups and stalks. We present the 3D reconstructions of each specimen, as well as highlight and discuss notable morphological features.

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Time-lapse velocity changes during an open-pit mine slope failure

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Background

Landslides are widespread geological events that directly impact thousands of people every year and cause significant loss of life. Landslides are often triggered by extreme weather events or earthquakes. Similar slope failures occur in mining environments, causing huge disruptions to these operations and even loss of life. In both cases they are predicted to occur more frequently with increased extreme weather due to climate change, While most slope monitoring approaches focus on surface deformation (e.g. using radar), there is evidence that by the time changes manifest at surface, it can be too late to provide adequate early warning.

Methodology

Seismic ambient noise correlation has been successfully applied in landslide monitoring (for example, for a recent review, see Le Breton et al., 2021). This approach measures time-lapse seismic velocity changes in the subsurface of a slope. Several cases of precursory changes have been shown using seismic ambient noise correlation and shows promise in providing early warning of failure.

Key results

We present a case study from a dense borehole geophone array installed beneath a well instrumented slope of an open-pit mine in Australia. We applied seismic ambient noise correlation across a period of slope failure and measured a decrease in seismic velocity approximately two weeks prior to the initiation of the slope failure. We investigated this change and its relationship to seismicity, rainfall and surface deformation recorded during this period.

Main conclusions drawn from these results

Seismic interferometry has the potential to detect precursory velocity variations in the subsurface that could indicate an impending slope failure in open pit mines. With many mines likely to be built over the next decade to meet increased demands for minerals, seismic interferometry might play a key role in preventing such failures. This would potentially save lives and significantly reduce the economic impact to the mine. Given this approach can be extended to time-lapse monitoring of natural landslides, it could play another important role mitigating the increased hazard of natural landslides due to climate change.

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To tell the stories in the stones…

Supporting Geotourism development in Southern Africa through sharing experiences and observations from the emerging field of Geological nature guiding.

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South and Southern Africa's spectacular and unique geodiversity is well known - but not to everyone. Many people are unaware of the vast literal and figurative wealth - our shared heritage - that lies in the rocks of the region and in their fascinating stories. Geotourism is a rapidly growing field, both internationally and in South Africa. It is a powerful addition to the tourism-based activities in the region, and will significantly increase employment opportunities in the subcontinent.
The author outlines a recent process of developing materials, techniques and approaches for meaningfully sharing and explaining geology and geomorphology with the public. Successful geology-focused walks, talks, displays and short courses for primary and high school children, students, teachers and the adult public, including the elderly, are briefly described, as are initial observations about geological guiding in Southern Africa. Opportunities it may offer as a career path for nature guides and university graduates will be discussed. This presentation offers a networking platform from which to support the further development of geology guides and guiding in Southern Africa.

Totally molten magma chambers may grow in months to years

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Knowledge of magma emplacement timescales is critical for understanding how volcanic and igneous plumbing systems operate in the Earth's crust. The timescales of processes that create space for magma chambers are particularly poorly constrained. The vertical growth rate of basaltic magma chambers remains largely unknown with available estimates (0.5 to 20 cm/yr) being highly uncertain. Here, we propose a novel approach to address this issue using petrological constraints from the Skaergaard layered intrusion, Greenland – a classic example of closed-system differentiation in a ~4 km thick magma body with a total volume of ~300 km3. The onion-skin chemical structure of the Skaergaard intrusion indicates a parallel evolution in liquidus parageneses, suggesting that it crystallized from all margins inwards after it had been completely filled with magma(1). This evidence can be used to thermally calculate the minimum rate of magma emplacement that kept the growing Skaergaard magma chamber completely molten (<1% crystals). Our numerical simulations indicate that the required vertical growth rate was on the order of several 100s to a few 1000s m/yr, corresponding to volumetric flow rates of 10s to 100s of km3/yr. These rates are several orders of magnitude higher than other estimates(2) and were likely achieved by catastrophically rapid subsidence of the floor rocks along faults lubricated by magma(1, 3). We propose that the Skaergaard and possibly other layered intrusions can be viewed as plutonic equivalents of super-eruptions, or catastrophic intrusions that grow via extremely rapid magma emplacement into the crust from staging chambers at depth, producing shallow crustal and totally molten magma chambers in a matter of a few months to dozens of years.

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Towards internal chronological frameworks for Plio-Pleistocene U-Pb dated flowstones from the Cradle of Humankind: a matter of time

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South Africa hosts some of the oldest hominid fossil remains, centered in the Cradle of Humankind. Climatic and environmental change played a pivotal role in the adaptation and diversification of our early prehuman relatives. However, the sedimentary and climatic archives in which their fossils are preserved are often discontinuous or difficult to date. Fortunately, calcite formations such as flowstones are ubiquitous across the Cradle caves and represent significantly wetter conditions in the past. They form the "golden standard" among palaeoclimatic archives as they can be precisely and accurately dated using U-series (U-Th and U-Pb) dating techniques. It is, however, difficult to develop age-depth models for the Pliocene-Early Pleistocene U-Pb dated flowstones due to large and overlapping uncertainties of the individual U-Pb ages, hindering climatic proxy records to be anchored in time for this period. Therefore, here we focus on flowstones from just two carefully chosen cave sites, Gladysvale and Malapa. Two flowstone samples, GV01 and M9, are in macro appearance very similar to each other, even though they are from separate caves. Preliminary dating of GV01 shows it formed continuously between 344-337 ka (glacial maximum of MIS 10). The published U-Pb age for flowstone M9 is 2.026 ± 0.021 Ma[1]. This flowstone interval is of great significance as it forms the base of a sedimentary unit containing the fossil type specimens of Australopithecus sediba. We first establish an internal growth chronology for the younger U-Th dated GV01 flowstone by developing a tightly constrained age-depth model and using thin-section petrography, trace elements and visible layer counting. This record can then be used as a robust and well-understood analogue to build the first chronological framework for a high-resolution palaeoclimate proxy record for sample M9. This approach and model can eventually be applied to other, older Plio-Pleistocene Cradle flowstones, of which there are many.

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Trace element geochemistry and U-Pb dating of the limestone-dominated Lime Acres Member, of the Campbell Group, Transvaal Supergroup, South Africa: Implications for Neoarchean carbonate platform formation, diagenesis and dolomitization

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The Neoarchean Lime Acres Member is a remarkably well-preserved, stromatolitic limestone-dominated unit. It is situated in 2.52 Ga to 2.642 Ga Ga dolomite-dominated carbonate successions in the stratigraphic record known as Campbell Group in the Griqualand West sub-basin, Transvaal Supergroup. The ancient limestones have great potential to reconstruct the ancient surface conditions. Although Lime Acres is a limestone-rich unit, dolomite is present but rare. Elemental and mineral phase maps obtained by SEM-EDS analysis using a Tescan-integrated-mineral-analyser (TIMA) show that dolomite is restricted to stratiform and cross-cutting veins associated with silica veins, ankerite, and muscovite. SEM-EDS maps further show that limestones are made up of up to 95% calcite and contain small to no amounts of detrital material, implying that the Lime Acres Member is dolomitized. It is not well understood why most parts of Lime Acres Member are devoid of dolomitization.

New trace element data allow to investigate aspects of carbonate depositional environments and ambient sweater compositions. MUQ-normalised REE+Y patterns of limestone and calcite veins show positive La and Y anomalies and depletion in LREE, which is comparable to modern seawater composition. Dolomite samples have slight positive Gd anomalies which is a tetrad effect seen in seawater compared to limestone and calcite veins. Cerium is not anomalous suggesting non-oxidized waters and no effects from later post-Great Oxygenation Event (GOE) fluid infiltration. Europium is not consistent in all lithofacies; however, it is more enriched in limestone when compared to dolomite suggesting that the hydrothermal input was minimal. The enrichment of europium is consistent with open ocean vs isolated shallow marine (i.e., a lagoon as indicated by e.g., fine-grained micritic limestone).

In situ U-Pb dating of calcite was carried out using LA-SF-ICPMS. An apparent age was obtained of 2689.2 ± 96.7 Ma (n=30; MSWD=2.7) from calcite in the micritic limestone (from the middle section of stratigraphy ca. 60m). This age is comparable to the reported 2.552 and 2.642 Ga constrained by U-Pb zircon within tuff in the carbonates and BIF at Campbell Group where Lime Acres Member is situated. Two additional ages of calcite veins and calcite associated with dolomite veins are 2220. 2±89.0 (n=28; MSWD=2.0), which is interpreted as an early diagenetic event, and 2179.9±62.8 (n=23; MSWD=5.2), interpreted as a secondary diagenetic event.

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Trace metal detection along an AMD-contaminated stream using VNIR-SWIR spectroscopy

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Background

Trace metal contamination of the environment is a major concern linked to acid mine drainage (AMD). Conventional wet chemical methods of detecting and monitoring trace metal contamination in a large area involve time-consuming, tedious and costly data collection and laboratory analysis. Reflectance spectroscopy offers an in situ and potentially cost-effective tool for detecting trace metals based on their distinct spectral absorption features.

Methodology

Overbank sediments and ground spectral data (over 350 – 2500 nm wavelength range of the electromagnetic spectrum) were collected at six sample locations along a portion of the Blesbokspruit River at Emalahleni, Mpumalanga, to (i) derive spectral absorption feature parameters (SAFPs) such as absorption-band position, depth, width and asymmetry from the ground spectra for correlation with mineralogy and trace metal (Cu, Pb, As, Cr and Cd) contents in overbank sediments and (ii) evaluate the potential of the SAFPs to predict trace metal contents in overbank sediments using the coefficient of determination (R2) of univariate regression models.

Key results

The derived SAFPs included Depth433 and Width433, associated with goethite, and Depth1366, Asym1366, Width1366, Depth2208, Asym2208 and Width2208, associated with kaolinite. Depth433, Depth1366, Depth2208 (which are associated with metal quantity) exhibited very strong positive correlations, indicated by R2 = 1 with Width433, Width1366, Width2208, respectively. These suggest that, like adsorption depth, adsorption-band width is strongly related to metal quantity. Copper, Pb and Cd showed the strongest correlations with the goethite-related SAFPs, whereas As showed moderate correlation with goethite- and kaolinite-related SAFPs and Cr showed the strongest correlation with the kaolinite-related SAFPs. Inputs to the univariate regression analysis were based on the strongest correlations between the SAFPs and trace metal contents. The strongest predictive models were established for Cd (R2 = 0.74) and Cu (R2 = 0.72) with weaker predictive models established for Cr (R2 = 0.59), As (R2 = 0.58) and Pb (R2 = 0.49).

Main conclusions drawn from these results

Overall, the results showed that several toxic trace metals (even at ppb levels) can be detected indirectly using the SAFPs associated with iron oxides such as goethite and clay minerals such as kaolinite. This is an important benefit of reflectance spectroscopy considering the difficulty typically associated with analyzing 'trace' metal concentrations using conventional geochemical methods.

Translating the geological record into isiXhosa

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Outreach and education work is commonly conducted in English1, but people engage more and understand better when the conversation is in their native tongue2–4.

In South Africa, English is a first language for under 10% of the population, yet it dominates scientific discourse, alienating huge sections of the population5. We summarised the most compelling, relevant parts of South Africa's geological history, and translated those stories into isiXhosa. IsiXhosa is the mother tongue of over 8 million people, and is mutually intelligible with Zulu, Northern Ndebele and Southern Ndebele, meaning it is potentially accessible to 23 million people.

This project eschews stuffy science writing in favour of compelling stories about our shared geological history that can spark conversation in social settings. The stories are hosted on our website (chosindabazomhloba.com)6 and on Instagram, and we plan to record them as podcasts.

The translation work was challenging for two reasons. First, many African languages are poorly represented on common translation and learning platforms such as Google translate or Duolingo. It is therefore critical that projects such as these are led by native speakers. Secondly, many geological terms such as meteorite or magma have no direct equivalent in isiXhosa. Therefore, part of this project involves enriching isiXhosa by building an open access geological dictionary. This presents an exciting opportunity to generate new, more intuitive and accessible vocabulary. The production of a geological dictionary in isiXhosa could provide a tool to transform geology departments, museums and public outreach events. It could also support international geologists to better engage with communities in their field areas.

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Ultra Trace Element Concentrations of Olivine In Olivine-Phyric Shergottites And Chassignite-Nakhlite Meteorites

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Background:

Shergottites are the most abundant (~ 88 %) of all known martian meteorites by both quantity and mass [1]. They are chemically diverse and can be classified based on (i) light rare earth element (LREE) abundances and isotopic compositions into depleted, enriched and intermediate, and (ii) texture into basaltic, olivine-phyric, gabbroic, and poikilitic shergottites [2-5]. Olivine-phyric shergottites are porphyritic textured rock comprised of olivine macrocrysts and pyroxene phenocrysts set in a fine-grained groundmass. The olivine macrocrysts in these shergottites are the first phase to have crystallised and as such, record the composition of their parent magma. There is however debate on the phenocrystic, antecrystyic or xenocrystic nature of olivines in these rocks: if xenocrystic they cannot be used to assess parent melt compositions, and if antecrystic, can only be used if they are co-genetic with groundmass material. In this study, a newly developed laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) technique [6] with improved sensitivity is used to determine the ultra-trace element concentrations (down to ~0.1 ppb) of olivine macrocrysts in selected depleted, intermediate and enriched olivine-phyric shergottites, as well as one chassignite and one nakhlite. This improved method facilitates the acquisition of complete REE patterns for martian olivine, allowing us to constrain the origin of olivine in these meteorites. The primary aim of the study is to test whether olivine and bulk-rock REE concentrations are in equilibrium.

Methodology:

The trace and ultra-trace element concentrations of olivine macrocrysts from 10 olivine-phyric samples, one chassignite and one nakhlite were measured by LA-ICP-MS, using an Agilent 7700cs quadrupole ICP-MS coupled with a Photon Analyte G2 193nm ArF Excimer laser system equipped with a HelEx II Cell, housed at Macquarie GeoAnalytical (Department of Earth and Planetary Sciences, Macquarie University, Australia).

Results and Discussion:

Our preliminary results show that olivine macrocrysts in depleted olivine-phyric shergottites crystallised from depleted melts consistent and are in equilibrium with the bulk-rock data. Most of the analysed olivine in the intermediate and enriched shergottites are also LREE depleted (i.e., La/YbCI > 0.24) and comparable to olivine in depleted shergottites. These LREE-depleted olivine in the intermediate and enriched shergottites appear to have crystallised from depleted sources and are therefore not in equilibrium with their bulk-rock. Thus, bulk-rock analyses of intermediate and enriched shergottites are unlikely representative of their parent magmas and should not be used to estimate mantle melting conditions.

Ultra-deep Perovskite-bearing Xenoliths from a Kimberlite Complex, Liberia, West Africa.

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J.D. Bernal in 1936 suggested that increases in seismic velocities, due to density changes in rock type, might also result from crystallographic structural changes in mineralogy. Orthorhombic olivine transforms to cubic spinel (ringwoodite), is stable to 660 km and is the lower boundary of the Transition Zone (TZ); the upper boundary, at the 410 km seismic discontinuity, is ortho-compressed Ol to wadsleyite. The post-spinel era predicted, then confirmed, that Rwd decomposes at 22 GPa to MgO (periclase) + MgSiO3 (ortho-enstatite structurally transformed to cubic perovskite Pvr, CaTiO3). Bridgmanite (Brg), marks the lower mantle [LM] onset and the most abundant mineral on Earth.

The unusual xenoliths described here are related to lamellar pyroxene-ilmenite intergrowths*, first described by Williams (1932) at Kimberley, but with the addition of Pvr. Common in carbonatites, Pvr is late stage in groundmass kimberlites and is extremely rare in mantle xenoliths. Host kimberlites here are diamond-bearing and because Pvr is found in diamond inclusions elsewhere, the xenolith suite is permissibly related to high P-T silicate-Pvr from the TZ/LM. Symplectic Cpx-Ilm (Type 1) is extended to include Ol-Ilm-Pvr (Type 2), and Ol-Sp-Pvr (Type 3) with Ol (Fo 86-92); Ilm (MgO 12 wt.%); Pvr (Na2O 1-2, SrO 2-3 wt.%); and Sp (Mt 72-80). Perfectly euhedral Pvr in Type 2 contains Ol inclusions with minor wűstite; bulk compositions are stable at >20 GPa. Pvr in Type 3 has crystallographically controlled Sp exsolution-like lamellae with a bulk composition of Ca2FeTi2O7 stable at >15 GPa. Lamellar Sp is anisotropic, orthorhombic, or tetragonal at P >15-24 GPa. Low solubilities of Ti at high P in Ol, Gt and Px are insufficient to form Ilm and Pvr on decomposition, but ultra-high pressure Pvr-structured silicates are possible precursors. Bulk compositions of Type 1 are within a 55 GPa solvus, whereas Types 2 and 3 fall in a 35 GPa 1700^{o}C solvus in the system MgSiO3-MgTiO3-CaSiO3-CaTiO3. Initial high pressures were modified and mineral stabilities in the system MgSiO3-MgTiO3, indicate 20-24 GPa at 1600^{o}C. In conclusion, a Ca-Fe-Mg-Ti Brg from ~750 km is implied for the xenolith suite with equilibration in the TZ demonstrating that Pvr, in structure and chemistry, is key to deep Earth dynamics.

* John Gurney (1973) on Type 1 (Lesotho Kimberlites, Ed P.H. Nixon) is analytically comprehensive, a hallmark of his publications.

Underrated and Overlooked: The magmatic-hydrothermal transition recorded by trace elements-in-quartz.

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Although quartz is a common rock-forming mineral it is typically considered inconsequential in exploration. However, with modern techniques such as LA-ICP-MS, this is changing. The ability to measure trace element variations in quartz provides a new window into the evolution of mineral deposits.

Granites can host late-stage magmatic-hydrothermal mineralisation, such as Sn and other critical metals [1]. The Nebo, Bobbejaankop and Lease granites in the Zaaiplaats Tin Field of the Bushveld Complex, are host to various expressions of endogranitic Sn-mineralisation [1; 2]. Zaaiplaats comprises the Nebo Granite at the base that grades into the Bobbejaankop Granite and then the Lease Granite, which forms the fine-grained cupola [2; 3]. These granites exhibit an increasing degree of hydrothermal alteration respectively, with mineralisation restricted to the Bobbejaankop and Lease phases. High-grade Sn-bearing tourmaline-quartz hydrothermal pipes radiate up through the Bobbejaankop into the Lease Granite and terminate below the roof contact [2; 3].

Trace element analysis of quartz from these granites exhibit evidence that supports the suggested fractionation and fluid-saturation models of ore genesis [2; 3]. The Al/Ti and Ge/Ti ratios in quartz increase from the base to roof and illustrate the sequential evolution of the system and an increasing degree of fluid-rock interaction. The quartz from the high-grade cassiterite-bearing pipes is distinct with very low-Ti, high-Al and high-Ge, which indicates crystallisation from a very low-temperature late-stage and highly acidic fluid.

The trace element data displays a shift from an ordered magmatic fractionation-controlled evolution to a hydrothermally-controlled system that reflects more erratic trends. Therefore, trace element variations in quartz are able to define the point of fluid-saturation and record the magmatic-hydrothermal transition. The identification of the most evolved and fluid-saturated facies can guide exploration by indicating lithologies with the best mineralisation potential. The use of trace elements-in-quartz extends beyond granite-hosted deposits and may be applicable to various mineralised systems.

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Using 1D and 2D Basin and Petroleum Systems Modelling (BPSM) to "Unravel" the Karoo Basin's Hydrocarbon Resource Potential

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The Karoo Basin of South Africa is considered prolific for hydrocarbon resources, particularly shale gas, with an estimated resource potential between 15 and 485TCF. The South African government initiated the Shale Gas Strategic Project (SGSP) to evaluate the shale gas resource potential of the Karoo Basin and establish a geo-environmental baseline to regulate shale gas development in South Africa effectively.

This study aims to qualitatively estimate the hydrocarbon potential retained in the Karoo Basin's organic-rich shales using an integrated basin and petroleum system modelling approach from existing and new data.

The Karoo Basin is a vast and tectonostratigraphic complex sedimentary basin onshore South Africa where world-class source rocks of the Permian Lower Ecca were widely deposited, particularly the Whitehill Formation. Multiple oil and gas shows in the basin suggest an active petroleum system; however no commercial hydrocarbon discovery yet. Furthermore, the limited data and the inherent limitations of data in the Karoo Basin render it relatively under-explored.

1D and 2D basin and petroleum systems analysis and modelling (BPSM) was undertaken to assess the possible shale plays of the Karoo Basin. 1D BPSM involved reviewing and collating data and building base case scenarios for subsequent 2D basin modelling. Five regional 2D cross-sections were constructed, tied to 30 wells and outcrop s. The 2D BPSM suggests that thermal maturation is purely burial driven and not volcanic as previously thought. Moreover, a basin consistent burial and uplift history model, constrained by temperature, vitrinite reflectance, and apatite fission track analysis, could explain regional maturation variations. Large amounts of erosion (up to 7km) are estimated proximal to the front of the Cape Fold Belt, resulting from either thrust sheets or syn-tectonic sediments. Other regions are at the maximum burial or experienced moderate erosion of 1-2km.

Modelling suggests that the dolerite and Drakensberg lava emplacement only affected thermal maturity at intrusions sites. This has extended the shale gas sweet spot further north below the southern limit of the Karoo dolerite intrusions due to far less thermal degradation linked to dolerite emplacement. Strong indications are that wet gas, and condensate gas could be preserved in situ in the organic-rich shale of the Lower Ecca. Based on this, Petroleum Agency SA revised its in-house shale gas resource estimate to a technically recoverable gas in place of 405 TCF (P50).

Using InSAR to detect soil expansion: A new way to explore for kimberlites

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BACKGROUND

There is a predicted total of 2000 kimberlites in the Kalahari craton alone, though only 770 of these kimberlites were reported by 1991. It is argued that most of the 2000 kimberlites are unreported due to their relatively small size, poor exposure and in some cases low economic value and interest. Other possibilities are kimberlite burial in stable-craton settings and/or extensive kimberlite weathering under unstable near-surface conditions. Whatever the case, it is believed that there are hundreds of kimberlites hidden beneath the earth's surface, awaiting discovery. InSAR systems are an innovative and fast-growing remote sensing geodetic tool that may be the most ideal and convenient way to explore for these hidden treasures. When InSAR was first developed in the 1990s, it was primarily used for mapping surface deformation resulting from natural and man-driven processes. It has been used over the years to study the geomorphology of the earth, recording deformation at milimeter scale. Hamilton and Webb (2003) showed a prominent elevation anomaly coincident with a known kimberlite. The proposed hypothesis was that the elevation anomaly was due to clay expansion from the underlying weathered kimberlite. Hamilton and Webb (2003) found there to be an increase in surface elevation above the kimberlite during the rainy season when moisture levels are high and a lower elevation during the dry season.

METHODOLOGY

First, unprocessed Sar images of a known kimberlite cluster in Southern Africa will be downloaded and coregistered or "merged" according to their acquisition dates relative to the wet and dry seasons. This will produce several poor quality interferograms that still require some processing under predefined pixel parameter conditions that will yield results that are best suited to represent elevation changes. Next, the reflectivity map of the study area will be removed from the interferograms to enhance the pixel quality and increase the reliability of the results. After this, the amplitude stability index will be calculated and used as the threshold for the signal strength that will be used in the interferometric process. Lastly, a digital elevation model (DEM) will be used to georeference the interferograms, and remove the topographic phase for enhanced graphic coherence. The final interferometric products should show the surface variations over the kimberlites over time.

RESULTS

This study is still in the methodology stage, so no results or conclusions are available as yet.

Using kimberlite indicator mineral geochemistry to better constrain lithospheric chemical and thermal structure of the Kaapvaal Craton: correlations with S-to-P receiver functions

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The application of single-mineral thermobarometry to kimberlite indicator minerals (KIMs e.g., garnet, Ryan et al., JGR:SE, 1996) has advanced our understanding of the evolution of the subcontinental lithospheric mantle (SCLM) by enabling the vertical and horizontal mapping of the lithospheric mantle. Recent seismological studies have discovered sharp velocity changes within the lithospheric mantle, between the Moho and the lithosphere-asthenosphere boundary. Mid-Lithosphere Discontinuities (MLDs) can either be negative (positive) velocity gradients (NVG or PVGs), suggestive of decrease (or increase) of velocity with depth. Metasomatism is proposed as a probable reason for NVGs (Krueger et al., G-cubed, 2021).

We present data constraining the thermal and chemical structure of the SCLM beneath the Kaapvaal craton based on the mineral major and trace element geochemistry (and PCr–TNi values calculated from them, Ryan et al., 1996) of peridotitic garnets from the Kimberley and adjacent Barkly West kimberlite clusters. The age difference between Group II and Group I kimberlite magmatism (≈ 25 Myr) allows the evolution of the SCLM over this time interval to be evaluated. Garnets from Group II kimberlites are typically more Cr-saturated and magnesian, and less enriched in incompatible elements (i.e., Zr, Y, Ti) and HREE relative to garnets from Group I kimberlites. Plotting the geochemical data in cross-sections through the Barkly West cluster reveals a layer of metasomatic enrichment at depths ca. 90 to 150 km. Additionally, the P-T profile shows a layer of thermal heterogeneity at similar depths. We calculated separate paleogeotherms for G10 (cpx-free) and G9 (cpx-bearing) garnets to characterise thermal and compositional effects of metasomatism at each time interval. At Group II kimberlite time, G10 and G9 garnets constrain two distinct paleogeotherms. G9 and G10 Group I time paleogeotherms are consistent with the G9-based Group II paleogeotherm. We interpret that the Group II G10-based paleogeotherm is characteristic of steady state conditions, while the rest are snapshots of the 'perturbed' limb of the Kaapvaal craton geotherm, as it evolves thermally and chemically.

Despite extensive evidence of metasomatism, the Kaapvaal craton has PVGs rather than NVGs at these depths. PVGs can be a result of phase transition from spinel to garnet peridotite, presence of eclogites, or storage of significant volumes of carbon as diamond (Krueger et al., G-cubed, 2021). This study aims to resolve a geochemical reason for these PVGs.

Using manganese-rich minerals to trace the rise of oxygen

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The evolution of oxygen-producing cyanobacteria drove major changes to Earth's atmosphere, and was a pre-requisite for the rise of aerobic metabolisms, including metazoans. We know that cyanobacteria evolved by the Great Oxidation Event, ~2.4 billion years ago, but they may have appeared much earlier. Unequivocal body fossils of cyanobacteria are rare, but geochemical or geological evidence for the presence of oxygen can provide indirect support for the presence of cyanobacteria. One approach to this problem is to examine the nature of the primary sediments, because the mineralogy of chemical precipitates is closely linked to the seawater redox state. Although they have undergone multiple, complex phases of alteration since deposition, marine sediments can preserve information about seawater chemistry during their formation, providing a snapshot of conditions on the early-Earth. The Neoarchean–Paleoproterozoic Transvaal Supergroup, South Africa, has only experienced low-grade metamorphism, has a well-documented stratigraphy, and includes a range of lithologies, making it an excellent target. We sampled drill-core REX 42 which spans the base of the carbonate-rich Moodraai Formation, through the interbedded banded iron formation-manganese ore units of the Hotazel Formation, to the top of the volcanic Ongeluk Formation. These lithologies are mostly very fine-grained, so several different analytical techniques were used for mineral identification, including (1) transmitted and reflected light optical microscopy; (2) X-ray diffraction analysis (XRD); (3) backscattered electron (BSE) imaging; and (4) major element composition determined by SEM–energy dispersive X-ray spectrometry (EDS). Together, these observations were used to build a detailed paragenetic sequence model. The minerals in the manganese ore beds can be grouped into oxides and oxy-hydroxides, carbonates, and silicates. The oxidation state of manganese in these phases varies between Mn(II), Mn(III), and Mn(IV). Given its very fine grain size and cross-cutting relationships with other minerals, pyrolusite, a Mn(IV)-oxide mineral, appears to be the earliest phase, and potentially precipitated in the water column. However, other oxide phases formed later, during early/late diagenesis to metasomatic/hydrothermal origin. The presence of primary, Mn(IV)-minerals implies that oxidation processes were important in the genesis of Mn ore bodies, although this did not necessarily require molecular O2. This is in contrast with recent paragenetic models for iron ore, which suggest the deposition of primary Fe(II)-minerals under fully anoxic conditions. If these models are both correct, then these Mn beds may mark the first traces of oxygen in surface environments, with Mn and Fe-rich sediments representing deposition above and below a shallow chemocline, respectively.

Using passive sampling to evaluate aquatic pesticide pollution in the Western Cape, South Africa.

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Agriculture is an essential sector to South Africa's economy, which has made it the leading user of pesticides in Sub-Saharan Africa (1). Consequently, there is an urgent need to improve our understanding of the transport pathways that cause pesticides to enter non-target environments. The presence of pesticides in non-target environments, such as surface water or groundwater, could potentially affect aquatic ecosystems and human health.

Our research focuses on monitoring for pesticides in the rivers of three agricultural catchments (Grabouw, Hex River Valley, and Piketberg) within the Western Cape, South Africa. Passive samplers will be deployed from March 2022-March 2023, adding to a preexisting dataset of analytical and pesticide application data from 2017(2)-2019. Field and laboratory methods are being developed at Stellenbosch University to analyze for pesticides using Liquid Chromatography-Mass Spectrometry. Duplicate samples will be analyzed at the Swiss Federal Institute of Aquatic Research as a quality control step.

The 2017-2019 data found that 83% of samples contained five or more pesticides. 2018 results (i.e., post drought) indicated that approximately half the number of pesticides were detected. Total pesticide concentrations were typically attributable to a single/few compounds per catchment. Six pesticides exceeded Environmental Quality Standard (EQS) values in at least one of the sampling campaigns. Imidacloprid was highlighted as a pesticide of concern due to consistently exceeding EQS values over all sampling rounds (3).

Detection/exceedances of pesticides generally coincided with their application and rainfall events except for imidacloprid and terbuthylazine. This indicates that alternate transport pathways such as input from groundwater are important, and that the current sources and transport processes for pesticides are poorly understood(3). 2022 data indicates similar trends of detection for imidacloprid as well as the identification of a new pesticide dimethomorph.

It is important to establish a long-term data set regarding pesticide pollution to help better understand the risk newly detected and reoccurring pesticides may pose to the aquatic environment in the Western Cape.

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Using process mineralogy to characterise an antimony tailings dam from the Murchison Greenstone Belt

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Reprocessing of historical tailings repositories is gaining momentum around the world to address the demand for critical metals and minerals, and environmental concerns associated with tailings storage facilities (TSFs). Limited information about these repositories is available, hence the need to fill this knowledge gap. A process mineralogical investigation was conducted on an antimony tailings repository from the Murchison Greenstone Belt (MGB) to quantify the characteristics of the economic minerals present in terms of aspects such as modal mineralogy, mineral associations (i.e. co-existing phases) as well as other parameters such as mineral grain size, locking and mineral liberation. A site-specific sampling strategy was identified and based on the size and accessibility of the TSF, holes were drilled from the top to the bottom of the TSF. Tailings samples were studied using a 600F Mineral Liberation Analyzer (MLA) to characterise tailings for re-treatment purposes.

Bulk chemical analyses conducted using ICP-MS reveal considerable amounts of antimony (3740 to >10000 ppm) in the TFS of the MGB. A combination of MLA and XRD revealed that quartz (22 to 38 wt%) is the most abundant mineral within the MGB antimony tailings repository, followed by magnesite (7 to 25 wt%), chlorite (9 to 17 wt%) and dolomite (5 to 11 wt%). Stibnite (3 to 55 wt%) and chapmanite (12 to 61 wt%) were the most abundant antimony ore minerals. Other antimony-bearing ore minerals such as schafarzikite (8.77 to 26.26 wt%), gudmundite (1 to 21 wt%) and berthierite (0.5 to 15 wt%) were also identified. The MLA revealed that berthierite is the coarsest antimony-bearing mineral, followed by stibnite and senarmontite, whereas valentinite and ottensite are the finest. The antimony ore minerals were primarily associated with primary silicates with lesser associations to secondary silicates and carbonate minerals. Stibnite and tetrahedrite were more liberated (48 and 39 %, respectively) as compared to other antimony ore minerals. Chapmanite and valentinite were mainly locked in ternary particles (80 and 79 %, respectively) than in binary particles (14 and 13 %, respectively). The obtained process mineralogy information can be used to effectively select a suitable beneficiation process for the treatment of antimony tailings and other comprehensive utilization of these tailings.

Using Sm-Nd isotopic data from the Namaqua-Natal Metamorphic Province to constrain the potential sources of NYF pegmatites in the Orange River pegmatite belt.

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The Orange River pegmatite belt (ORPB) consists of > 30 000 pegmatites that intruded the Namaqua Sector of the Mesoproterozoic Namaqua-Natal Metamorphic Province (NNMP) in Southern Africa at ca. 1 Ga. The Kakamas Domain (KD), located in the central part of the NNMP, is dominated by the occurrence of niobium-, yttrium- and fluorine-enriched (NYF) pegmatites, classified here as either simple or complex pegmatites based on their field appearance, texture and concentration of REE-U-Th bearing minerals.

We provide in situ U-Pb ages along with Sm-Nd isotopic compositions of titanite and monazite from simple and complex pegmatites, respectively. We compare these data with literature data for whole rock Sm-Nd isotopic compositions of country rocks in the NNMP to constrain the potential source rocks of simple and complex NYF pegmatites in the KD.

Simple and complex pegmatites yielded emplacement ages from 1043 ± 5 Ma to 1025 ± 6 Ma and from 985 ± 4 Ma to 969 ± 5 Ma, respectively. Simple pegmatites have average εNd(t)titanite values between -6 and -3 whereas complex pegmatites have average εNd(t)monazite values of -4 to -3. Simple pegmatites have two-stage depleted mantle model ages (T2DM) of 2.1 to 1.9 Ga and complex pegmatites between 1.8 to 1.9 Ga. The Sm-Nd whole rock isotopic compositions of lithologies from the KD, such as pre- to syn-tectonic granitoids and gneisses (eg, Riemvasmaak Gneiss) and post-tectonic granitoids (eg, Keimoes Suite) are similar to the pegmatites albeit with a wider and generally higher range in average εNd(t) values from -3.0 to +3.7 and with mantle extraction ages between 1.5 to 1.9 Ga reflecting a Paleoproterozoic crustal component. This suggests that the parental magma for the pegmatites may have formed from partial melting of KD country rocks.

Pegmatite emplacement in the KD overlaps in age with igneous rocks located in the southern part of the Bushmanland Subprovince (BSP) such as the mainly A-type granitoids of the Spektakel Suite (1100-1030 Ma), the mafic igneous rocks of the Koperberg Suite (1060-1010 Ma) and the Steenkampskraal REE-Th deposit (1050-1025 Ma). Most igneous rocks from the southern BSP, including the pre- to syn-tectonic granitoids of the 1200 to 1190 Ma Little Namaqualand Suite, have average εNd(t) values from -5.7 to +1.4 with T2DM model ages between 2.2 to 1.6 Ga. This suggests that the mineralizing processes in the southern BSP do not differ from the KD and both processes may be related to late-orogenic mafic magmatism.

Vehicle and Train traffic seismic interferometry: Examples and future applications for the African continent

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In the last two decades seismic interferometry has become a standard technique in a seismologist's toolbox. Of the various applications of seismic interferometry, ambient noise tomography is perhaps the best known. The main reason being that it uses the pervasive ambient seismic field generated by natural processes. On the other hand, the anthropogenic contribution to the ambient seismic field has received less attention, although examples that use noise from traffic, industrial sites and even buildings are present in the literature.

In this study, we analyze unpublished traffic noise datasets and explore previously published datasets with new approaches. The focus of our analyses is the extraction of body waves, and more specifically reflections generated by subsurface targets. These datasets include highway, train, and mining traffic noise recordings. Different approaches are tested, such as cross-coherence, and deconvolution interferometry and compared with standard cross-correlation results to determine the best method for each dataset. In addition, different binning and stacking methods are tested to determine which produces the most coherent body wave retrievals.

Finally, different sites are proposed for future surveys within South Africa that can take advantage of the anthropogenic noise field to address reflection imaging of deep targets, such as the imaging of the crystalline basement under thick sedimentary covers.

Ventersdorp-related metamorphism in lower Witwatersrand Supergroup rocks exposed in the Vredefort Dome

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The lower Witwatersrand Supergroup rocks exposed in the Vredefort Dome have been metamorphosed to mid-amphibolite facies. The age of this metamorphism has long been proposed to be related to the emplacement of the Bushveld Complex at 2.06 Ga. This proposition has been based on circumstantial evidence relating to the P-T conditions and calculated depths necessary for the pressure determinations; however, there are no unambiguous chronological data to confirm this timing.

A garnet-bearing metapelite from the inner collar of the Dome has been analysed to determine P-T conditions of the metamorphism and high-precision Sm-Nd garnet chronology has been conducted to provide a robust age for garnet growth, and thus metamorphism.

Microtextural and mineral compositional analysis suggests at least two metamorphic events with distinctly different P-T conditions preceding the Dome-forming meteorite impact at 2.02 Ga. THERMOCALC mineral equilibrium calculations yield P-T conditions of 500 °C, 3.1 kbar for the M1 mineral assemblage of garnet1-plagioclase-muscovite-biotite-chlorite-ilmenite. Thin, discontinuous, garnet2 overgrowths on the garnet1 porphyroblasts define a subsequent, M2, event with P-T conditions of 530 °C, 5 kbar. Garnet Sm-Nd chronology yields an isochron age of 2796.0 ± 1.5 Ma, indicating an early Ventersdorp (Klipriviersberg) timing of M1 metamorphism. The M2 overgrowths are volumetrically too small to date; however, the calculated pressure is consistent with the predicted overburden thickness above the lower Witwatersrand Supergroup during emplacement of the Bushveld Complex. While elevated, the M2 apparent geotherm (30 °C/km) is significantly lower than the M1 apparent geotherm (46 °C/km). Thermal modelling suggests that both events benefitted from local perturbations caused by contemporaneous sill emplacement.

Our results thus show that the initial garnet-forming, mid-amphibolite facies metamorphism in the collar of the Dome is not related to the emplacement of the Bushveld Complex, but rather to the early stages of magmatism associated with the Ventersdorp Large Igneous Province (LIP). Nonetheless, elevated heat flow associated with the Bushveld LIP also reached comparable amphibolite facies conditions.

Vertical vs Horizontal tectonics: Insights from the tectonic style along the southern margin of the Barberton Greenstone Belt, Eswatini

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The Barberton Greenstone Belt (BGB) and many other orogenic belts in cratonic basements have been classically thought to be large, first-order synclinal structures, thus supporting vertically-dominated models of early Earth lithosphere formation. We here argue for a late phase of BGB deformation involving significant horizontal shortening along the long, polymetamorphosed linear southern margin of the BGB with the gneisses of the Ancient Gneiss Complex of central Eswatini by investigating the Ntaba Mhlope Syncline and Malolotsha Synform. These structures represent the few preserved remnants of Moodies Group strata of the southern BGB.

Ntaba Mhlope, a steeply doubly (inwardly) plunging, highly strained syncline of Moodies Group (ca. 3.22 Ga) strata is about 3 km long and 0.6 km wide. Its subvertically dipping, upper-greenschist-facies-metamorphosed strata consist of (from base to top) conglomerates, quartzose sandstones and subordinate shales and siltstones a few hundred m thick. Strain of conglomerate clasts is markedly constrictional; plunge is uniform and steep throughout the tight syncline, suggesting that strain followed folding.

Malolotsha Synform, a tightly re-folded imbricate thrust stack in which metavolcanic and -volcaniclastic strata of the Onverwacht Group, deposited at 3.34-3.29 Ga, have been thrust on top of ca. 3.22 Ga siliciclastic strata of the Moodies Group. Here the structurally highest element, the Malolotsha Synform, forms a tectonic klippe of substantial size and is >1450 m thick. Forward modelling of a balanced cross section indicates that this thrust stack was part of a northwestward-verging orogen along the southern margin of the BGB and records a minimum horizontal displacement of 33 km perpendicular to its present-day faulted, ductily strained and multiply metamorphosed margin. Strain is strongly partitioned between the Onverwacht Group and Moodies Group strata which is controlled in part by competency differences.

Our findings indicate that the southern BGB underwent substantial north-northwestward-directed shortening by folding and thrusting in high-strain zones at elevated temperatures, perpendicular to the BGB margin, which was then followed by tightening and refolding. Strain is produced by transport-parallel elongation and modified by strain partitioning between the rheologically strong Moodies Group siliciclastics and rheologically weak talc schists of the Onverwacht Group. These observations suggest that the late-stage tectonic architecture of the BGB may be highly asymmetrical and that both vertically- and horizontally-dominated deformation styles interfered with each other at small regional and short temporal scales.

What does the future look like for geosciences in Africa: an industry perspective

Sifiso Siwela

With the increasing demand for critical metals especially from Africa, the critical geoscientific skills to discover these metals are becoming even more relevant.

Exploration budgets have continued to rise post the Covid-19 pandemic, driven by the demand for green metals and electric vehicles as part of the low carbon energy transition. The economic climate, albeit with the minerals industry experiencing a recession in the short term, is expected to improve due to the demand for these minerals. The green energy transition requires mines to be already in operation. Therefore, some of Africa's prospective mineral belts for critical metals including nickel, copper, graphite, lithium and manganese in countries such as DRC, Botswana, Mozambique, Tanzania, etc., are experiencing a revitalisation in exploration. Besides traditional hotspots in West Africa, the DRC and southern Africa, newer mining regions in Morocco and eastern Africa are also experiencing renewed exploration and mining interest. Mergers and acquisitions are expected to continue not only in these critical minerals, but also gold and PGEs.

Socio-political factors also affected the minerals industry and many geoscientists globally. Political risk in some jurisdictions is not only affecting exploration for minerals, but also favourably and unfavourably affecting supply and demand dynamics, and commodity prices.

Environmental, social, and corporate governance (ESG) and compliance has been even more important for exploration and mining projects. The ESG drive globally has created opportunities for some geoscientists who are playing a key role in advancing these important considerations. This includes an appreciation of elements such as mine closure and rehabilitation, including tailings management. These aspects along with the UN sustainable Development Goals will necessarily be in the geoscientist's toolkit, ensuring a sustainable and "green" geoscientist of the future.

With the onset of the 4th Industrial Revolution driving big data and machine learning, the new-age geoscientist should have the critical skills to effectively utilise this data and technology in the discover of minerals, which is becoming even more challenging. Geologists will be equipped with skills in geometallurgy and mineralogy, which are key for determining part the viability of projects, including those at early stages of the mine value chain. The future-of-work has brought about borderless ways of working with the potential for work globally for geoscientists. Geoscientists in Africa are now commonly working in countries outside the continent including Turkey, Saudi Arabia, Mongolia and Kazakhstan. The ability to operate in historically high-risk jurisdictions has also proved to be important.

The research and development components will require even more monetary resources and human capital to unearth undiscovered deposits and to advance methodologies and technologies to enhance prospectivity research. Academics will play a role in tailoring education of new-age geologists. Geophysical and geochemical techniques continue to improve relative to the changing minerals industry and therefore those disciplines will continue to be applied in the minerals industry.

The world is changing fast and is suffering an economic crisis, but geoscientists are more crucial to our society than ever before.

Whole-rock boron isotope variation within a single monogenetic cone: La Poruña (21°53'S, 68°30'W), Central Andes

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La Poruña (21°53'S, 68°30'W) is a monogenetic volcanic structure related to the sub-arc magmatism of the Altiplano-Puna Volcanic Complex (21°-24°S). Previous works suggested that selective contamination of sub-arc parental melts was an important petrogenetic process during La Poruña magmatic evolution [1]. In this work we present the first results of boron isotope analysis of whole-rock La Poruña samples, performed by the LA-MC-ICP-MS at the Department of Geological Sciences, University of Cape Town. Results of repeat analyses of standards and samples yield external 2σ errors < 0.5 ‰. These new isotopic composition of La Poruña erupted products, coupled with boron elemental analysis and previous geochemical results, are used to constrain the hydration conditions of the subarc mantle below Central Andes.

La Poruña δ11B values range from -1.39 to +0.94‰, and show positive and negative correlations with SiO2 composition and 87Sr/86Sr isotopic, respectively. These observations indicate that the magmatic δ11B compositions of La Poruña are controlled through assimilation of a 11B-isotope depleted component such as the local Andean continental crust (average δ11B -8.7‰). Conversely, boron elemental abundances of La Poruña samples range from 14 to 20 µg/g and do not co-vary with magmatic differentiation. These relatively high boron contents suggest that La Poruña was fed from a hydrated and/or metasomatized mantle source region, consistent with other volcanoes within the surface extent of the Altiplano-Puna Magma Body (21°-23°S). The boron isotopic composition of La Poruña differs from those observed for volcanic structures located further south (e.g., Lascar and Cerro Overo) suggesting different hydration conditions and/or composition of the sub-arc mantle.

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Zoophycos in the Witpoort Formation (Witteberg Group, Cape Supergroup, South Africa)

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Background

The names Zoophycos and Spirophyton have been used interchangably by Cape Supergroup researchers since the early 20th Century. The names describe a helical spreite trace fossil comprising probes radiating from a central axis, which occur in shallow marine strata throughout much of the Devonian sequence, ranging from the Early Devonian lower Bokkeveld Group to the Late Devonian Witpoort Formation. However, Spirophyton should only be used for helicoidal Zoophycos-like structures that are approximately circular in plan view and are less than 8 cm in diameter (Miller 1991).

Methodology

We studied numerous Zoophycos and Spirophyton from various horizons in the Witpoort Formation of the Eastern Cape to assess their environments of occurrence and morphology.

Key results

Our analysis indicates that they occurred in oxygen-poor lagoonal and estuarine muds and associated immature sands, recording infaunal activities by similar tracemakers. Spirophyton in the Witpoort Formation appears to be a diminutive form of Zoophycos, probably formed by a similar tracemaker. The validity of ichnogenus Spirophyton is questioned as the only clear criterion for its distinction from Zoophycos is diameter.

Main conclusions drawn from these results

Size and morphological variability of the traces is likely to reflect environmental factors such as salinity gradients and oxygen concentration within marginal marine substrates. The archetypal Zoophycos ichnofacies, representing deep marine, continental slope facies, is inapplicable for Palaeozoic strata (including the Cape Supergroup) (Bottjer 1988).

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