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ABSTRACTS

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3.45 Ga FELSIC MELT INCLUSIONS FROM THE BARBERTON GREENSTONE BELT

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Keywords: Archean, rhyolite, melt inclusion, TTG

As a first approximation, Archaean felsic magmatism associated with the Barberton Greenstone Belt (BGB) can be broadly subdivided into an early (~3.5 – 3.2 Ga), Na-rich stage that formed the TTG series, and a generally later (<3.2 Ga), K-rich component that resembles post-Archean granites (Viljoen and Viljoen, 1969). Thisshift in the compositions of granitoids in the Archaean has been interpreted to attests to secular variations in the Earth's thermal regime, and to unique petrogenetic conditions during that time. Petrogenetic models favour production of "TTG melt" by melting of mafic rocks at either water-saturated or water-undersaturated conditions and at variable pressure, whereas potassic magmas are believed to be the result of TTG melting (Kelinhanns et al., 2003; Clemens et al., 2006; Moyen, 2011). However, the melt composition on which all petrologic considerations rely is not known, and has to be inferred from whole-rock analyses.

Here, we present preliminary results of a melt inclusion study of the 3.45 Ga old volcanic-subvolcanic Buckridge Volcanic Complex, upper Onverwacht Group. The Buckridge Volcanic Complex is characterised by immobile trace (rare earth and high-field strength) element compositions that closely match the coeval TTG-type plutons that crop out to the south-west of the BGB. Because of these similarities, a genetic link has been previously proposed (de Wit et al., 1987). However, mobile elements were strongly modified by widespread alteration and metasomatism, including silicification, Na depletion and K enrichment, which affected large portions of the Onverwacht succession (e.g. Hofmann and Harris, 2008). Therefore, the study of melt inclusions can give important indications on the original melt composition. Melt inclusions are relatively abundant in quartz-phyric rocks of the Buckridge Complex, but many are poorly-preserved, due to pervasive fracturing of the host quartz and to decrepitation. However, well-preserved inclusions melted completely at temperatures greater than 930°C, and were quenched to a crystal-free glass, suitable for microanalysis.

Electron microprobe analyses indicate that the melt was rhyolitic, and metaluminous to slightly peraluminous (A/NCK = 0.95 – 1.18). Melt inclusions have significantly higher Na_2O ($\leq$5.5 wt.%) and CaO ($\leq$1 wt.%), and lower Fe_2O_3 and MgO contents ($\leq$1.0 wt.% and <0.3 wt.%, respectively) compared to whole-rock analyses. Melt inclusion compositions are similar to TTG plutons in terms of high Na_2O, relatively low Mg/(Mg + Fe), and relatively high CaO, but the high K_2O ($\leq$8.6 wt.%) and the K_2O/Na_2O around 1 are much higher than the TTG plutons, so that melt inclusion compositions plot in the potassic field in major element classifications such as the Na-K-Ca. Volatile components are present in low-moderate amounts (Cl $\leq$0.17 wt.%, S $\leq$0.03 wt.%, F <0.1 wt.%).

These difference s can be explained through 2 hypotheses: 1) melt inclusions represent a K-rich evolved stage of TTG melt; or 2) melt inclusions represent a previously unrecognised melt, sharing some characteristics with TTG intrusions and some with K-rich (granitic sensu stricto) intrusions.

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TRACE ELEMENT DISTRIBUTION PATTERNS IN PYRITE FROM THE SHEBA MINE, USING LA-ICP-MS MAPPING

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Keywords: LA-ICP-MS mapping, Sheba Mine

LA-ICP-MS mapping results show that the pyrite of the Sheba Mine from the Barberton Greenstone belt (BGB) is zoned. Zoning in the pyrite is indicated by variation in the trace-element compositions, which reflect different domains or tiny mineralogical inclusions within the pyrite lattice. These different domains in the pyrite cause variation in the ablation rate. The short ablation time used (0.5 sec.) emphasizes the domains effect relative to longer ablation times, where several domains may contribute to the individual analyses.

Standardization to a minor (Ni, Co, etc.) or major elements (S, Fe) in pyrite, as determined by electron microprobe, will not be possible, because of the rapid changes ablation behavior even with small composition changes. Therefore, we present data from LA-ICP-MS in count per second.

Ni (or Co) substitute for Fe in pyrite, and a negative correlation between Ni and Fe concentrations should be expected. However, a positive slope between the counts per second of Ni and Fe is observed. The variation in Ni and Fe cps is dominated by the effects of different ablation rates and disguises the true concentration relationship.

In profiles across pyrite grains, the variations in ablation behaviour lead to larger fluctuations than can be explained by compositional variations (substitutions). However, zonal variations of minor elements, or variations due to inclusions are identifiable. These compositional variations an assemblages of inclusions reflect the conditions during pyrite formation.

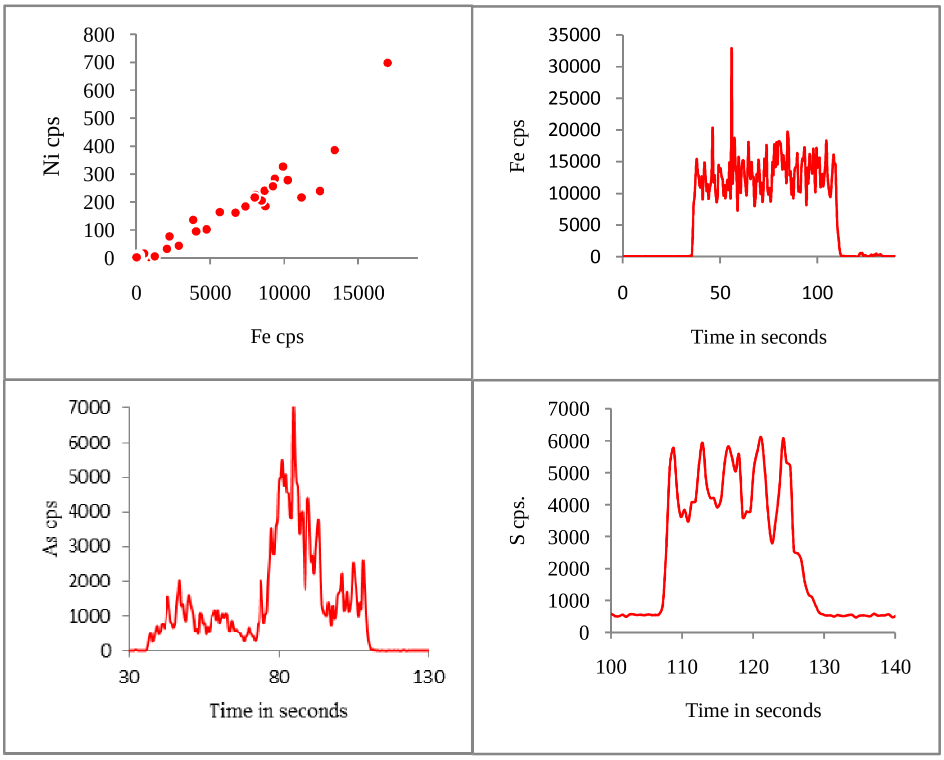

Figure (1): The distribution of some elements in pyrite from the Sheba Mine.

GRANITOIDS FROM RAJASTHAN (NW INDIA): EMPLACEMENT IN A RODINIAN ANDEAN-TYPE ARC AND DEFORMATION IN A GONDWANAN COLLISION

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Keywords: granite, Rajasthan (India), zircon geochronology, Ar-Ar dating, Rodinia, Gondwana

The ~125 km^{2}Mt. Abu granitic pluton in Rajasthan, northwestern India consists of variably deformed, subsolvus, dominantly metaluminous, I-type, porphyritic hornblende-biotite granitoids that are crosscut by both granitic and mafic dykes. Weakly deformed varieties occur mainly in the central regions of the pluton, and gneissic varieties, including distinctive augen gneisses are found on the margins, especially on the northwestern side. Modest diversity in major and trace element chemistry (SiO_2 = 72.8 ± 2.8 wt.%; La = 100-400x chondrites) is attributed to variable partial melting processes rather than to fractional crystallization. U-Pb zircon analyses (TIMS method) for 3 samples yield nearly concordant dates of 765 ± 5 Ma, which we interpret as the time of magmatic crystallization. This demonstrates that the Mt.Abu granitoids are coeval and correlative with volcanic and plutonic rocks of the nearby Malani Igneous Suite, rather than with the Erinpura granites, which are demonstrably older by ~100 m.y. We further show that Mt Abu granitoids are geochemically and petrologically distinct from Erinpura granitoids, but match those from the Malani Igneous Suite and Praslin group granitoids of the Seychelles, which, along with northern Madagascar, formed now-fragmented components of an Andean-type magmatic arc on the margin of the Rodinia supercontinent. $^{40}Ar/^{39}Ar$ isotopic data on a hornblende separate from a foliated granite yields an age of 509 ± 2 Ma, which we interpret as representing the time of amphibolite grade metamorphic resetting, and cannot have been caused by syn-orogenic magmatic emplacement, as has been previously inferred. This late Pan-African age demonstrates that the effects of Gondwana assembly and collapse extend into northwestern India, and must have also affected sedimentary rocks of the Marwar Supergroup, which are likely equivalents of the extensive earliest Paleozoic sandstones of North Africa. Deformation of the Mt.Abu granitoids and Marwar supracrustal rocks may be related to extensional strike-slip collapse of the Pan-African mountains formed during the final assembly of the Gondwana supercontinent.

WHAT CONSTITUTES AN ARGON-ARGON AGE: EXAMPLES FROM DIFFERENT TERRAINS

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Keywords: Argon-argon, geochronology, Limpopo Belt, Munnar granite, amphibole

^{40}Ar-^{39}Ar method is a variant of the K-Ar method, in which samples are irradiated in a nuclear reactor prior to analysis. Luckily, the Pelindaba Nuclear Research Centre is situated in the vicinity of Johannesburg, making our research process less problematic. Subsequent to irradiation, stepwise heating of the sample is implemented by infrared laser in order to release argon. Further, all the argon isotopes are routinely analyzed with the noble gas mass spectrometer MAP 215-50. Our system (laser and spectrometer) was kindly given to the University of Johannesburg by the De Beers Geosciences Lab.

A high precision of the mass spectrometer in its electron multiplier mode allows grains of very small size (<0.5 mm) being analyzed. The small sample size also means that many grains can be irradiated in a single batch. A better age reliability is achieved via study of a few grains per sample, which helps with the data interpretation as well.

We present some of the ages we obtained from various K-rich minerals (mica, amphibole, eudialyte etc.), and their "plateau" behavior is further discussed. A thorough stepwise heating analysis can reveal intriguing effects, for instance for amphiboles from the Limpopo Belt. Even if they do not yield precise ages, they allow to distinguish polymetamorphic from monometamorphic rocks (Figure 1a). Other examples include dehydration zones developed in the Munnar alkali granite of Southern India (Figure 1b).

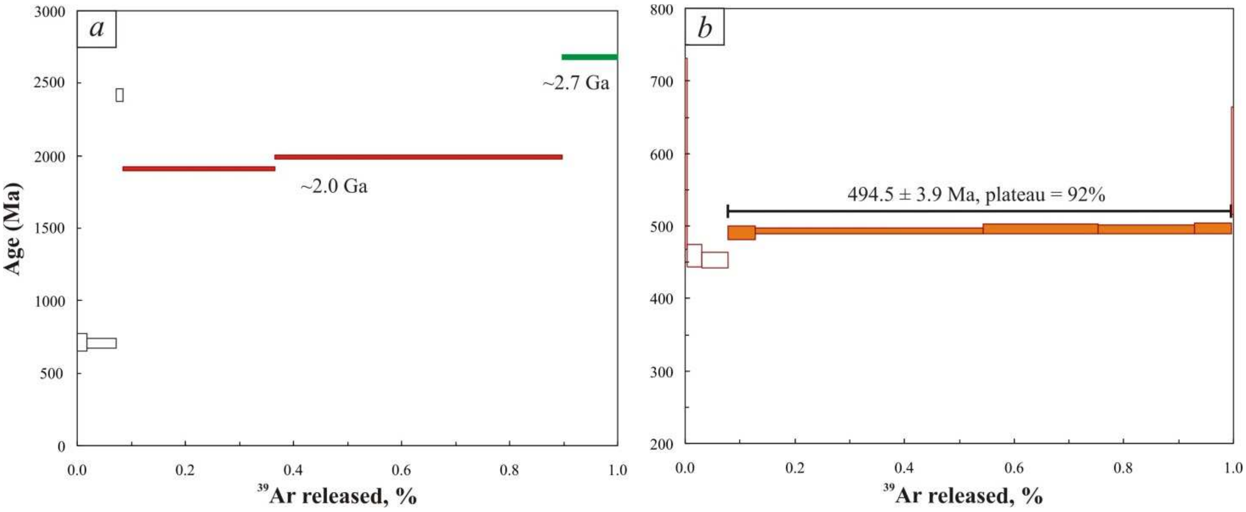

Figure 1. Argon-argon age spectra for amphiboles from the Limpopo Belt (**a**) and Munnar granite of Southern India (**b**). All errors are 2σ, plateau steps are filled, rejected steps are open.

DEFORMATION-ENHANCED MAJOR AND TRACE ELEMENT DIFFUSION IN ROCK FORMING MINERALS: FIRST RESULTS

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Keywords:plastic deformation, major and trace elements; EPMA

The existing literature shows for a number of mineral species (e.g. zircon, cordierite, tourmaline) that plastic deformation significantly enhances diffusion rates of cations and has the potential to modify the mineral composition and element distribution in deformed crystal domains. However, very little is known about the importance of deformation temperature or deformation intensity, the chemical environment, or the importance of cation sources and sinks in the matrix of the deformed crystals. The current study has been carried out as reconnaissance work and has investigated olivine, orthopyroxene, and phlogopite from harzburgitic mantle xenoliths from Kimberly, and plagioclase, alkali feldspar and quartz from medium- to high-grade metamorphic felsic crustal rocks.

Preliminary EPMA data show correlations between elemental compositions and presence or absence of deformation textures such as undulose extinction, subgrain formation, or recrystallisation. Migmatitic plagioclase, deformed under (lower?) amphibolite facies conditions, shows a significant drop in anorthite content from an_{30-34} to an_{20-30} in subgrains and recrystallised grains, whereby crystal domains showing undulose extinction maintain their primary composition. Less significant are the compositional variations in migmatitic plagioclase deformed under upper amphibolite to granulite facies conditions. The investigated alkali feldspar is close to the orthoclase endmember in composition and does not show significant variation in major element contents, regardless of the textural position from where the EPM analysis was obtained. The available data might support some Ba uptake in deformed domains with an increase by about 100-1000 ppm, but the results are fuzzy and the data set needs to be expanded. Similarly erratic is the data set on Fe and Ti as trace elements in deformed quartz. The compositional heterogeneity and the probable extraction of Ti from quartz domains showing undulose extinction, subgrains, or recrystallisation, have significance for the application of the Ti-in-Qtz thermometer.

Neither olivine nor orthopyroxene or phlogopite in sheared mantle xenoliths shows significant major element variations. Particularly in Fe and Mg contents and ratios remain constant amongst old grains, subgrains and recrystallised grains, suggesting that mineral growth and deformation/recrystallisation occurred at more or less constant *P*-*T* conditions. Orthopyroxene shows systematically increasing Ti, Ca and Cr contents in recrystallised grains. Titanium increases from ~140 to 300 ppm, Ca from ~2000 to 4000 ppm, and Cr from ~2200 to ~3000 ppm. Nickel and manganese remain constant at ~700-800 ppm and 640-750 ppm, respectively. By contrast, trace element contents in olivine do not vary significantly with deformation intensity with ~20 ppm Ti, 550-640 ppm Mn, ~2800 ppm Ni, and up to 160 ppm Cr in either old and recrystallised grains. Only Ca might increase slightly from 80-170 to 200-240 ppm in recrystallised grains. In phlogopite, the Ti content increases to ~3000-~7000 ppm in recrystallised grains and subgrains from <2000 ppm in old grains.

The relatively small data set from a small number of samples does not allow far reaching conclusions as yet. However, Na and Ca mobilization in plagioclase appear to require substantial deformation, forming subgrains and recrystallised grains, and this mobilization might increase with a larger temperature difference between crystal growth and deformation temperatures. Under mantle conditions, the fairly simple major elemental composition of orthopyroxene, olivine and phlogopite seems to be insensitive to plastic deformation. Recrystallisation of orthopyroxene correlates with significant incorporation of Ca, Cr and Ti, a pattern that is not seen in forsteritic olivine despite of near identical deformation features. Since our study does not show complementary extraction of these element species from any other phase present in the peridotite, we assume synkinematic influx of a fluid phase as the source of additional Cr, Ti, and Ca.

PHYSIOCHEMICAL DISCONNECT IN METAMORPHOSED COAL: A GEOLOGICAL FEATURE OR ANALYTICAL MISMATCH?

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Keywords: Metamorphism, Schmidt Hammer, Proximate analysis

The mechanics and chemical variations created during metamorphism of organic geological compounds such as coal is a subject which has been often overlooked. The fundamental structure of organic materials is different to that of inorganic materials such as minerals and rocks, as organic compounds are subject to generalities of both structure and chemistry. This creates problems in evaluating the products of metamorphism in these materials. The metamorphism of coal is of obvious economic importance in South Africa, and new approaches are needed to quantify the effects of contact metamorphism and low temperature hydrothermal metasomatism in coal-bearing rocks. Coal as a material can be broken down into macerals which can be directly compared to minerals within rocks with the physiochemical nature of the coal and its macerals generally quantified using thermogravimetric proximate analysis. This technique aims to give “chemical” data to define the properties of the coal through the quantification of “moisture”, “ash”, “volatiles” and calorific value.

In an effort to better understand the physical and chemical alterations imparted onto coal during the intrusion of mafic dykes, a new approach was introduced to analyse the physical properties of the coal in close proximity to an intrusion. A Schmidt hammer was employed to directly quantify *in situ* physical variation within the coal systematically away from the intrusion. Conventional proximate analysis was employed to estimate the “chemical” variations within the coal. It was expected that the link between the chemical properties and physical character of the coal would be apparent in the resultant analysis. This was, however, not the case, as no direct link is visible between the proximate analysis and Schmidt hammer results. The lack of correlation between these results poses the question of whether this disconnect is as a result of inherent heterogeneity of coal or a display of the shortcomings of the proximate analysis approach.

INVESTIGATING MAGMA DYNAMICS AND CRUSTAL DELAMINATION AT THE MOHO USING GIANT HIGH-PRESSURE ORTHOPYROXENE CRYSTALS

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Keywords:crustal delamination, crust formation, Proterozoic anorthosites,

High-aluminium orthopyroxene megacrysts (up to 1 m in length) are common cogenetic features of Proterozoic anorthosite massifs and are amongst the deepest crystallisation products in this magmatic system, at upper mantle or lower crustal depths (11-15 kbar). The anorthositic intrusives which host these megacrysts are enigmatic features of the Proterozoic, with ongoing debate surrounding their source (mantle vs. mafic lower crust), tectonic setting, and restricted temporality. Using the geochemistry of megacrysts and their host anorthosites, we assess the petrogenesis of the anorthosites and magmatic processes operating at deep levels in these systems.

Isotopic compositions from three populations of megacrysts in classic Proterozoic anorthosite localities (Mealy Mountains Intrusive Suite, Rogaland Anorthosite Province and Nain Plutonic Suite) indicate that the highest-pressure (highest Al_2O_3) megacrysts crystallised from isotopically homogenous magmas, 130-110 m.y. before host anorthosite crystallisation (Figure 1). The most tenable means of creating such equilibrium crystallisation scenarios is for the rising mafic magmas to pond and begin crystallising at the Moho. Most of these mafic cumulates sink into the mantle, but some megacrysts are entrained by plagioclase-rich crystal mushes that rise from the Moho to upper crustal levels (3-4 kbar) to form the anorthosite massifs. This new isotopic data provide the first, direct petrological and geochemical evidence for commonly proposed, yet inadequately documented and poorly understood, magmatic processes occurring at the Moho, such as the ponding of magmas, the formation of ultramafic cumulates and density-driven delamination of these cumulates into the mantle. Similar ultramafic cumulates are likely to form and sink into the mantle wherever basaltic magmas impinge on the base of the crust, providing a mechanism explaining the fundamental difference between melts from the mantle and observed average continental crust compositions.The duration of anorthosite crystallisation varies from 12-80 m.y., and in combination with these megacryst ages, indicates that the entire magmatic system was in operation for about 100 m.y. An Andean-arc setting for Proterozoic anorthosite formation is therefore likely, given its capability of sustaining such prolonged, voluminous, geographically-restricted magmatism.

These results provide constraints on the dynamics of mafic magma rise through the lithosphere and refine our current understanding of the fundamental mechanisms involved in crustal delamination, as well as the source and tectonic setting of enigmatic Proterozoic anorthosites.

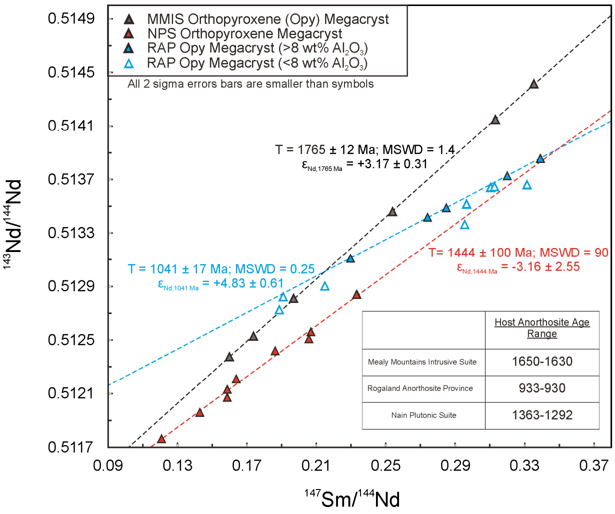

Figure 1: ^{147}Sm-^{144}Nd vs. $^{143}Nd/^{144}Nd$ isochron diagram illustrating equilibrium crystallisation in three different populations of high-alumina orthopyroxene megacrysts.

AN INCONVENIENT TRUTH - THE TRAPPED LIQUID SHIFT EFFECT IN MAFIC INTRUSIONS

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Keywords:cumulate rocks, trapped liquid shift effect

Many petrological interpretations regarding layered mafic intrusions depend upon the use of mg# - Mg/(Mg+Fe) – and also trace element concentrations, both for minerals and wholerocks. Both of these parameters can be strongly influenced by the presence of trapped liquid in the cumulate (Barnes, 1986). Ignoring this “trapped liquid shift effect” (TLSE) renders many interpretations incorrect. A number of examples from the Bushveld Complex are used to demonstrate these complexities. Some simple calculations are used to illustrate the problem.

1. mg# (mineral or whole rock) as a function of proportion of mafic minerals to plagioclase. Consider pyroxene (mg# = 80) accumulating from a liquid with an mg# of 50. If the cumulate rock contained 80% pyroxene and 20% interstitial liquid, it would solidify to about 90% pyroxene(s) and 10% plagioclase. The final whole-rock and pyroxene mg# would be about 76 (n.b. mg# are not linearly additive because absolute abundances of Mg and Fe are involved in each ratio). If the next layer of rock contained 70% plagioclase and 10% pyroxene as cumulus phases and 20% interstitial liquid (all with the same composition as before) the bulk rock would have an mg# of about 60. The mg# of the pyroxene in these two examples will be identical to the mg# value of the bulk rock. Thus, massive differences in mg# can appear in adjacent layers that have nothing to do with fractionation. This effect has been quantified by Cawthorn (1996a) in rocks from the upper Critical Zone. Further examples will be shown from the Main Zone.
2. REE in orthopyroxene. REE contents in minerals have been used to infer the composition of the source magma. Such an interpretation assumes that the mineral analysed retained the cumulus composition. Application of the TLSE shows how extremely wrong such calculations can be. An error of a factor of 10 in the REE abundance of the magma producing the Merensky pyroxenite has been shown by Cawthorn (1996b). A series of orthopyroxene mineral separates from across the lower Critical to upper Critical Zone boundary have been analysed for REE and shown to be highly variable in a vertical section. Ignoring the TLSE would result in having to appeal to random variations of a factor of 5 in REE content in the source melt between samples only a few metres apart. Inclusion of the variable proportion of trapped liquid in these rocks, based on variations in the whole-rock Zr content, yields a simple solution with all pyroxenes having formed from a magma of constant REE abundance.
3. REE in apatite. Very large variations in the REE content of apatite in the upper most rocks of the Upper Zone have been reported and attributed to the formation of large-scale liquid immiscibility (Vantongeren and Mathez, 2012). A re-examination of the data shows that rocks with a small cumulus apatite component and moderate interstitial liquid component produce re-equilibrated apatite grains that contain abundant REE. In contrast, rocks with a very high cumulus apatite component produce re-equilibrated apatite grains relatively depleted in REE. The differences in Eu* and the REE differences reported by Vantongeren and Mathez (2012) can be related completely to the TLSE. There is no evidence for large-scale liquid immiscibility at the top of the Bushveld.

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THE DISTRIBUTION OF DOLERITE SILLS IN THE KAROO SUPERGROUP

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Keywords: Dolerites, Karoo Supergroup, lateral distribution, thicknesses

The distribution of dolerite sills within the Karoo Supergroup was reported by Winter and Venter (1970). They had access to 19 deep boreholes drilled through the entire Karoo Supergroup with a wide geographic distribution. They chose to present their results by showing the ratio of total dolerite thickness to sediment thickness in each borehole, which created an impression of higher intensity of sills in an elongate northeast-southwest belt from Warden to Barkley East. The paucity of boreholes from Beaufort West to the Vaal Dam makes their contouring highly speculative. I re-examined the borehole logs which are stored with the Council for Geoscience with the original purpose of determining typical thicknesses of dolerite sills. From these data sets I was able to determine the range of thicknesses of dolerite sills, the number of sills and their total thickness in each borehole. Of the 139 sills intersected, very few exceed 50 m in thickness (and these may be composite). This information leads me to present the data in a different way from that presented by Winter and Venter (1970).

Total thicknesses of dolerite in each borehole range from only 9 metres (near Bloemfontein) to 900 metres near Barkley East. The major limitation to any interpretation is that the entire sedimentary column of the Karoo Supergroup is not intersected in all boreholes. Most boreholes are missing the Stormberg Group and those in the northeast are also missing the Beaufort Group. Hence, all the reported thicknessesare minimum values for dolerite thickness through the entire Karoo sedimentary succession (except near Lesotho). However, the most important feature can be seen around the main area of outcrop of the Drakensberg lavas. The three boreholes nearest to these volcanics do retain the maximum succession of the Karoo rocks, and yet have relatively thin dolerite packages (95, 104 and 165 m). This dearth of dolerites can be traced northwest-southeast from Kimberley toward Durban and represents a tract of minimum thickness of intrusions. Note that this direction is perpendicular to the maximum intensity axis of Winter and Venter (1970).

The maximum thickness of dolerites occurs westof Barkley East where they total 900 m. The next thickest is near Beaufort West where 600 m is preserved. However, unknown thicknesses of the upper part of the Karoo Supergroup and its dolerites have been eroded here. The original thickness of dolerite would have been greater, and so Beaufort West represents a region of major dolerite emplacement.

The next thickest succession of dolerite can be found southeast of Johannesburg toward Warden with over 400 m preserved. Only the Ecca and Dwyka are present there, and so much greater thicknesses of dolerite might have existed in the overlying (now-eroded) succession. These observations raise the possibility that the (shale-dominant) lower units of the Karoo contain a greater abundance of sills than the upper units.

A rather cautionary caveat can be added to these models. To the immediate southwest of Kokstad lies the Mount Ayliff Intrusion, of which the Insizwa Complex is the best-known component. It reaches at least 1000 m in thickness. Hence, this section alone dwarfs all the other intersections through the entire Karoo Supergroup.

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ASSEMBLY OF A FELSIC MAGMA CHAMBER: MARYSVILLE IGNEOUS COMPLEX, AUSTRALIA

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Keywords:ignimbrites; S-type; experimental petrology; magma pulses; magma evolution

The Late Devonian (374 Ma) Cerberean Cauldron forms the northern part of the Marysville Igneous Complex, in Central Victoria, Australia, filled with around 900 km^3 of intra-caldera ignimbrites. The basal volcanic formation is the rhyolitic high-Al Rubicon Ignimbrite, overlain by a larger volume of more crystal-rich, rhyolitic, low-Al Rubicon Ignimbrite. This grades upward into the voluminous, rhyodacitic Lake Mountain Ignimbrite. The rocks are all S-type in character, with phenocrysts of garnet and cordierite/sekaninaite. Initial $^{87}Sr/^{86}Sr$ fall in the range 0.709 to 0.710 with εNd_t varying from -4.7 to -6.0. Greywacke protoliths seem most likely. The chemistry of the volcanic rocks is incompatible with formation by a differentiation mechanism. Experimentally determined phase relations of a low-Al Rubicon Ignimbrite and a Lake Mountain Ignimbrite imply that early crystallisation of the Lake Mountain magma began at > 450 MPa and > 875 °C (possibly up to 940 °C), with an initial magma H_2O content of 4.1 to 5.3 wt%. In the pre-eruption chamber, the Rubicon Ignimbrite magma had a temperature of ≥ 780 °C and contained ≥ 4 wt% H_2O. Each formation, and indeed smaller volumes of rock, appear to have been produced by partial melting of slightly contrasting greywackes in a protolith that had spatial variations in its chemistry and mineralogy, with the magmas delivered in batches to a high-level, subvolcanic chamber. The Rubicon Ignimbrite magmas were most probably initially pure liquid partial melts but underwent crystallisation and some internal differentiation, probably by crystal settling, prior to eruption. The Lake Mountain Ignimbrite was most likely generated as a magma containing some entrained, source-derived solids. Variations in this unit are most probably due to small but variable degrees of peritectic phase entrainment. The limited gradations between the low-Al Rubicon Ignimbrite and Lake Mountain Ignimbrite are due to minor, pre-eruption mixing across the magma interface. Such limited mixing between individual magma batches appears typical of anatectic granitic magmas.

PROGRESS AND OBSERVATIONS OF THE TJAKASTAD ICDP BARBERTON CORE

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Keywords: ICDP, Barberton, komatiites

The Barberton International Continental Drilling Program (ICDP) has drilled and recovered cores from four sites in the Barberton greenstone belt in South Africa. The BARB 1 (417 m) and BARB 2 (431 m) cores are drilled through a section of the Komati formation. These cores are drilled at a 45° angle, 50 m apart, and have a 140 m stratigraphic overlap. The BARB 1 and BARB 2 cores contain discernible komatiite and komatiitic basalt flow units along with unique volcanic textures such as spinifex, hyaloclastite and harrisite. A tumulus feature is present within the top 100 m of the BARB 1 core.

The tumulus unit is 90 m thick and consists of a coarse-grained, basal olivine cumulate layer, a harrisite layer, a pyroxene spinifex layer and a hyaloclastite upper layer. Using major and trace element analyses together with petrological observations these layers are compared with komatiite flows (1-3 m thick) found in other parts of the core. The olivine cumulates from the tumulus layer are macrocrystic, ellipse shaped (2 cm in length) and contain a higher MgO content (45%) then the corresponding euhedral (0.5 mm) olivine cumulates of the komatiite flows which contain 34% MgO. Harrisitic texture forms by skeletal olivine megacrysts crystallizing upward from cumulate layers. The harrisite layer in the tumulus forms in the traditional fashion (above a cumulate layer) and is 14 m thick. It is similar in chemistry and texture to a unique harrisite layer (1.5 m thick) that has formed in a single komatiite flow. The harrisite in the tumulus has higher MgO content and larger skeletal olivines than the komatiite flow. The spinifex in the tumulus is predominantly pyroxene, whilst some flows contain olivine spinifex. The spinifex in the tumulus is commonly centimeters long, reaching a maximum of 20 cm and is light green grey in colour. The spinifex from the flows reaches a maximum of 5 cm in length; are green-grey to dark grey in colour and are often randomly oriented. The tumulus spinifex has 14-31% MgO whilst the spinifex in the flows has 25-32% MgO. The hyaloclastite, a quench fragmentation texture, in the tumulus section is analogous to the chill zones of the komatiite flows. It consists of fractured blocky fragments (30 cm in length) of lava, surrounded by a matrix of spherical particles of glass (0.5 mm to 1 cm) which have chill margins and inward cooling textures. It is important to determine which of these features is comparable to the chill margin of the flows and to establish if this glassy matrix material has been derived from a different source. The hyaloclastite comprises 24% volume of the tumulus, while chill margins comprise 15% volume. Comparing the chemistry and petrography of the tumulus to komatiite flows gives insight into processes occurring during tumulus formation.

The komatiite flows have the classic cumulate, spinifex and chill structure. The flows show a distinct chemical progression from cumulate to spinifex and have well developed trends between MgO and; FeO, Al_2O_3, Cr_2O_3, Zr, and TiO_2. These trends indicate an intercept between 40 - 43% MgO which indicates an unusual control by both orthopyroxene and olivine by which relatively evolved olivine (Fo_{90}) is in equilibrium with orthopyroxene of En_{92}. CIPW norm calculations, together with geochemistry, indicate 1:2 olivine: pyroxene ratio (Figure 1) in the controlling assemblage.

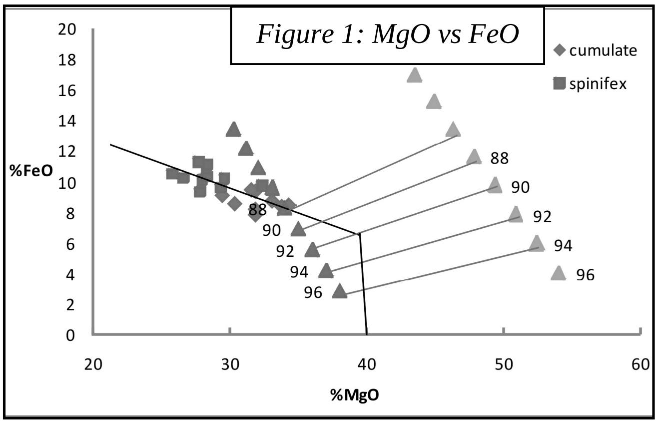

Figure 1: MgO vs FeO

THE TERRANES OF THE NAMAQUA-NATAL METAMORPHIC COMPLEX

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Keywords: Namaqua, Rodinia, terranes, Grenvillian

The Namaqua-Natal Metamorphic Complex consists of tectonites representing a broad variety of plutonic, volcanic and sedimentary rocks. The compositional and structural properties were established before and during the time of Rodinia when it formed part of the Kalahari Craton. Reconstruction of the geological history of the complex requires a multidisciplinary continental scale synthesis of all geological, geophysical and isotopic attributes of rocks that were severely deformed by two global orogenies (Grenvillian and Eburnian). The complex is today largely covered by Phanerozoic rocks. There are essentially two outcrop regions: Namaqualand, Bushmanland and part of Griqualand in the west and Natal in the east. The complex geology is best understood by recognition of tectonostratigraphic terranes bounded by major thrust and shear zones, each with its own igneous, sedimentary and metamorphic attributes. In the western region there is the Kheis Terrane (composed of the Olifantshoek-, Grootdrink- and Upington Terranes) and the Namaqua region (with the Kenhardt-, Augrabies-, Grünau-, Pofadder-, Aggeneys-, Steinkopf-, Okiep- and Garies Terranes). In the eastern region there are the Tugela-, Mzumbi- and Margate Terranes. It is necessary to also recognize other terranes revealed by geophysical surveys in the southern region covered by Phanerozoic rocks, notably the east-west trending Cape-Karoo Terrane that is bounded by prominent anomalies, the Cape conductive belts.

B1 MAGMA IS A DERIVATIVE, NOT THE PARENTAL MAGMATO THE LOWER AND LOWER CRITICAL ZONES OF THE BUSHVELD COMPLEX

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Keywords: Bushveld, B1 parent magma, modelling, adiabat_1ph

We demonstrate that despite the B1 magma having been widely accepted as the parental magma to the Lower Zone (LZ) and Lower Critical Zone (LCZ) of the Bushveld Complex this is unlikely, despite the work of Davies et al. (1980), Cawthorn et al. (1981) and Cawthorn & Davies (1983) in this regard. We demonstrate that the B1 magma is not a primary magma, but a broad grouping of magma batches derived from contamination of a far more ultramafic magma at depth. Even if the B1 magma can satisfactorily reproduce the crystallization order observed in the LZ, it cannot account for the abundance of olivine. Moreover, if the hypothesis of Irvine (1977), i.e. crystallizing chromite at the olivine-spinel liquidus is accepted, the necessity of an olivine-rich primitive melt is not compatible with the B1 magma. Chills interpreted as B1 melt compositions are, in detail, extremely variable in composition, from olivine normative to quartz normative, and include both dry and wet melts.Melts which contain ~ 54-56% SiO_2 cannot be responsible for the olivine budget of the LZ.The relative paucity of olivine cumulates in the anomalously chromite-rich LCZ is similarly untenable with this hypothesis.

Our approach is based on a mixing algorithm and thermodynamic modelling using adiabat_1ph (Smith & Asimow, 2005) based on a mantle-derived komatiitic melt that accumulated in a deep staging chamber (7-10 kbar). The ultramafic composition of this was initially tempered by melting of the crustal cappingto the staging chamber. This mixture of komatiitic melt (including olivine + chromite crystals) and crustal material produced a mafic melt loosely equivalent to the B1. This melt was injected, probably as multiple pulses into the shallow crustal Bushveld chamber *prior* to formation of the bulk of the LZ and LCZ. Olivine and chromite in rocks fractionated from these magmas were introduced as xenocrysts. The range in composition of the B1 group of magmas can be envisaged whereby increasing amounts of crustal component was assimilated into the staging chamber at depth. The bulk of the LZ and LCZ, however, accumulated after the deep staging chamber had expanded due to injection of numerous fluxes of komatiitic melt (that also mixed with the resident liquid + crystals at depth). The ensuing mixed magma was then injected into the Bushveld intrusion, typically containing slurries of olivine and/or orthopyroxene and/or chromite crystals. Magmas rich in crystal slurries are thought to have been derived from near the base of the staging chamber. The complex sequence of cumulates observed within the LZ and LCZ is consistent with their formation from multiple batches of magmas with quite variable compositions, from relatively primitive crystal-rich magmas through mafic melts with a high degree of crustal contamination. The possibility of identifying precise parental magmas, e.g., B1 through B3 etc, should be avoided. The findings of Eales & Costin (2012) whereby they quantified the importance of identifying the crystal-rich nature of many of the U-type magmas is fundamental in establishing that a range of magma compositions should be identified within the LZ and LCZ.

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“MELT POCKETS” INCLUSIONS IN GARNET OF TYPE-I ECLOGITES, ROBERTS VICTOR: METASOMATIC MELT RESPONSIBLE FOR GROSPIDITE FORMATION

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Key words: melt pockets, type-I eclogite, grospidite, Roberts Victor

Some type-Ieclogites from Roberts Victor (RV) diamond mine, show globular inclusions in garnet, usually called “melt pockets” (e.g. Gréau et al., 2011). The size of the inclusions ranges from 0.2 to 2 mm and they consist of phlogopite, diposide, calcite, glass and minor pyrrhotite. The EPMA averaged glass composition is SiO_2 51.85, Al_2O_3 24.16, K_2O 3.43, CaO 4.65 Na_2O 0.79, (H_2O-CO_2) ~15%. Euhedral phlogopite grains nucleated at the boundary of the “melt pocket” and a clear reaction zone developed between the “melt pocket” and garnet, consisting of chlorite, spinel-hercynite and plagioclase. Ca-rich overgrowths on eclogitic omphaciteand garnet were found. Thin veins of brown glass containing grains of K-feldspar, phlogopite and plagioclase(An_{62})cross-cut eclogitic garnet and omphacite. In few samples affected by the same type of veins, kyanite, coesite and sanidine were found spatially related to the brown glass. The bulk composition of the “melt pockets” in garnet was reconstructed based on EPMA data of the analysed phases, combined with estimated phase proportions using image analysis of the BSE images. We assume that the colourless to yellowish glass, optically isotropic, found inside the “melt pockets”, represents a residual melt, evolved by crystallization of diopside, phlogopite and calcite. Using Rock-Maker 2.0 (Büttner, 2012), the bulk composition of the “melt pocket” was reconstructed: SiO_2 41.51 TiO_2 0.94 Al_2O_3 18.49 Cr_2O_3 0.02 FeO 6.26 MnO 0.06 MgO 5.74 CaO 9.16 Na_2O 0.83 K_2O 5.67 H_2O 6.20 CO_2 3.66 SO_3 0.71.

We consider that the melt pockets may represent relict of the melt responsible of theextensive metasomatism of RV eclogites. We suggest that, at depths of 190-200 km, this meltwas carbonatite-rich at low melt fraction (<0.5%), while, by increasing melt fraction (>1%), the partial melt tends to kimberlitic composition(Dalton & Presnall, 1998). Our reconstructed melt was probably generated at melt fraction 0.5-1%, and it produced the metasomatism of type-II eclogites to form type-I eclogites (in agreement with the model of Gréau et al., 2011 and Huang et al., 2012). The higher CaO and K_2O content of the melt was largely consumed in generating the Ca-rich overgrowths of clinopyroxene and garnet (or, at higher extent, generating the grospidites), as well as to form phlogopite, respectively. High SiO_2 , Al_2O_3 and K_2O of the evolved melt (see glass composition) can be responsible for the formation of kyanite eclogites as well as the kyanite-coesite-sanidine assemblage in grospidites, as metasomatic/reaction product. When the melt fraction was high enough to carry up into the lithospheric mantle small eclogitic bodies, the melt trapped in garnet crystallized phlogopite, diopside and calcite, while the residual, evolved melt, rich in SiO_2, Al_2O_3, CaO, K_2O and H_2O was decompressed and quenched, liberating H_2O and reacting with garnet to form chlorite, spinel and plagioclase in the reaction corona. The presence of glass in the melt pocket, together with the radiogenic data of Huang et al., 2012, clearly suggest that the timing of metasomatsm is similar with RV kimberlite eruption (128-130 Ma, see Huang et al., 2012). RV kimberlitic melts sampled type-I together with pristine type-II eclogites and metasomatized harzburgites from various depths above the asthenosphere-lithosphere boundary. Locally, late zeolites (analcime) probably formed in sub-surface conditions, from glass devitrification of the “melt pockets”.

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MINERALOGY AND REACTION TEXTURES OF A CHROMITITE STRINGER, UPPER CRITICAL ZONE, WINNAARSHOEK

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Keywords: Bushveld Complex, Upper Critical Zone, anorthosite, chromitite stringer, reaction textures

The chromitite stringer examined here is from a sample located at a depth of 422.2 m in drill-hole WH1. The core log of this drill-hole was presented by Mitchell & Scoon (2007) and is representative of the sequence between the UG2 chromitite layer and the Merensky reef at the Winnaarshoek locality in the eastern limb of the Bushveld Complex. The chromitite stringer is located approximately 5 m vertically above the UG3A chromitite layer, occurring on the contact between a layer of feldspathic orthopyroxenite (hangingwall to the UG3A) and a prominent layer of anorthosite. This anorthosite is a regional marker, persistent throughout the central sector of the eastern limb, occurring at the base of a thick (> 350 m) sequence of leucocratic cumulates generally designated as the Merensky Footwall unit. The feldspathic pyroxenite, as well as the anorthosite contains minor amounts of disseminated chromite. Rare disseminated chromite is very sparsely developed throughout the Merensky Footwall unit. Despite being sub-parallel to the much thicker UG2, UG3, and UG3A chromitite layers, this type of occurrence is described as a stringer as it is only one-or-two grains in thickness. Individual grains average approximately 0.2 mm in thickness. Clusters of grains are partially annealed and exhibit triple junctions, a characteristic of the thicker layers (Eales & Reynolds, 1986). Individual grains within the stringer are remarkably euhedral.The composition of the chromite in the stringer has been determined by electron microprobe analysis in the laboratory at Rhodes University. The Cr/Fe and other inter-element ratios are typical of chromite in the uppermost part of the Upper Critical Zone. Possibly the most significant finding is the occurrence of discrete grains (few microns up to 0.1 mm in size) of rutileand phlogopite throughout the chromitite stinger,as well as more localized grains of corundum and anorthite. Obvious reaction textures are pointed out by element maping showing orthopyroxene reacting with plagioclase to form clinopyroxene (diopside), in the vicinity of the chromitite stringer. The chromite grains are included in (or surrounded by) plagioclase. Scoon & Teigler (1994) distinguished the stringers from thicker, basal layers by the description of "reaction" chromitite. Whereas, the thicker, basal chromitites typically occur at, or toward the base of units, reaction chromitites may occur on the uppermost or lowermost contacts of ultramafic layers. The possibility that chromite forms as a consequence of mixing of two radically different pulses of magma, the U and A magmas of Sharpe & Irvine (1982) in the Bushveld, was proposed by Irvine (1977). We suggest that the principles of this hypothesis may well be fundamentally correct, but suggest the most likely derivative of an A melt would be induced in situ due to partial melting of earlier-formed noritic-anorthositic cumulates (Opx + Plg $\rightarrow$ Cpx + Liq). Melting was triggered by heat associated with intrusion of ultramafic magma. This hypothesis is consistent with Mitchell & Scoon (2007), whereby the noritic-anorthositic (early-formed) and ultramafic (later-formed) components of so-called units (they are not magmatic cycles) crystallized from discrete magma pulses injected non-sequentially. "Reaction" chromitite stringers may thus form at both footwall and hangingwall contacts within complexly layered successions of cumulates. Field relationships and textures are, however, also consistent with an origin whereby the chromite was an early crystallite of new pulses of ultramafic magma which was deposited along the margins of the ultramafic "sills" against the earlier-formed leucocratic cumulates. The association of the chromite with rutile and corundum is possibly indicative that Cr-spinel was transported as xenocrysts from a deep source within the magma.

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THE METAMORPHIC EVOLUTION OF AN ANCIENT ACCRETIONARY WEDGE, SOUTHERN ZONE, DAMARA BELT, NAMIBIA

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Keywords: Damara Belt, Southern Zone, P-T path, accretionary wedge

The Southern Zone of the Damara Belt in central Namibia comprises highly strained metamorphosed clastic sedimentary rocks and slices of basalt and gabbro, with apparent stratigraphic thickness exceeding 100 km. One of the only modern geological environments in which such vast amounts of sediments can be accumulated, with intercalated mafic rocks, are in accretionary wedges above subduction zones, where sediments are also subjected to high-pressure – low-temperature metamorphic conditions and deformation to high strains.

Samples collected from two localities in the Southern Zone, namely the Gaub and Kuiseb Canyons, include representative rocks of both metapelitic and metamafic compositions. The peak mineral assemblage in the metapelitic rocks comprises moderately zoned garnet, staurolite and in some cases, kyanite porphyroblasts set in a fine grained matrix of chlorite, biotite, muscovite, epidote, quartz and minor opaques, predominantly ilmenite. The matrix exhibits a strong penetrative foliation defined by the alignment of the micaeous minerals. The garnet, staurolite and kyanite porphyroblasts overprint this fabric. By contrast, the metamafic rocks are holistically very fine grained with a peak mineral assemblage of zoned amphibole, epidote, rutile, sphene, quartz and minor micas, specifically chlorite and biotite.

The results of pseudosection modelling using THERMOCALC indicate that the peak metamorphism occurred at temperatures of 550 - 605°C and pressures of 9.2 – 10.8 kbar. This equates to an apparent geothermal gradient of 15-20°C/km, which is slightly warmer, but comparable to the geothermal gradient observed in known accretionary wedges. However, it is evident that the micaceous minerals that define the foliation in the metapelites may also have formed at ~ 10 kbar, but at temperatures of less than 500°C. These conditions correspond to a lower apparent geothermal gradient of <15°C/km.

Based on the fabric relations of prograde and peak metamorphic assemblages, the likely P-T path for these rocks involves a near-isobaric increase in temperature of at least 50-100°C while the rocks were at peak pressure. This temperature increase occurred in a static environment and post-dates the main phase of deformation exhibited in the samples. A possible explanation for this is the subduction of a heat source, for example a spreading ridge, after a period of long-lived convergence. We speculate that the subduction of this spreading ridge led to the cessation of the accretionary phase of the Damara Orogeny.

MODELLING CRUSTAL DIFFERENTIATION

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Keywords:crustal differentiation, magma compositions, magma reintegration.

Despite the clear understanding that strongly peraluminous (S-type) granites are produced through the partial melting of aluminous metasedimentary sources, a substantial mismatch exists between the melt compositions predicted to exist within such sources under granulite facies conditions by current best-practice modelling and the compositions of S-type granites. This highlights shortcomings in the way we are able to model crustal differentiation, with serious consequences for studies that aim to use magma reintegration into restitic granulites to provide information on the composition of the protolith and its anatectic behaviour, as well as for studies that seek to use a modelling approach to understand the magma compositions and volumes produced from metasedimentary sources during crustal differentiation events. The melt compositions produced by THERMOCALC (or any other software programme using the same thermodynamic dataset) at best only match the most leucocratic granites and not average granite compositions nor the large compositional range seen in granites. Additionally, THERMOCALC melts generally have Na/Ca ratios that are considerably higher than S-type granites. Variable degrees of peritectic assemblage entrainment to the magma in the source has been proposed as a mechanism to explain the range of compositions portrayed by S-type granites, as well as the fact that such granites are typically more mafic than the strongly leucocratic melt compositions produced by experimental studies of granulite facies anatexis of appropriate sources (Stevens et al. 2007). These findings suggest that crustal differentiation likely involves the mobilization of crystal-bearing magmas out of the source, not pure melts, and that the crystals entrained to the magma are the assemblage of phases produced by the incongruent melting reaction. This can potentially be modelled by modification of the method for melt reintegration to restitic granulites proposed by White et al. (2004), if peritectic assemblage entrainment can be incorporated into the model in a reasonable way.

In order to evaluate the possible approaches, this study has modelled magma reintegration into two different melt depleted metapelitic granulites in three different ways: Firstly, by using the method of White et al (2004); Secondly, by substituting an average S-type granite composition for melt; Thirdly, by incorporating a proportion of the peritectic assemblage into the melt predicted by THERMOCALC. The peritectic assemblage was considered to consist of all minerals that grew in mode, as well as feldspar where the feldspar mode decreased but the composition changed. This recognises the fact that diffusion in feldspar is remarkably slow and that on incongruent melting a second generation of feldspar crystals is likely to form. Entrainment was proportional with increase in mode and, for feldspar, decrease in mode and degree of compositional change.

All three methods produced similar changes in the assemblageof phases going down temperature i.e. with the addition of melt/magma to the restitic granulite. However, there were significant differences in the resultant bulk compositions at the wet solidus, as well as in the modelled magma compositions and volumes. Reintegrating either typical S-type granite or melt with entrained peritectic phases moved the compositions of the restitic granulites toward the range of average sedimentary protolith compositions, which the conventional melt reintegration method did not achieve. Additionally, magmas consisting of THERMOCALC melts with added peritectic phases were considerably closer in composition to typical S-type granites than were the melts on their own, which had Fe+Mg contents that were too low and Na/Ca ratios that were too high.

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LA-ICP-MS ELEMENTAL MAPPING: AN EXAMPLE FOR PYRITE FROM SHEBA MINE, BARBERTON

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Keywords:gold, pyrite, LA-ICP-MS, mapping

There are several different habits of pyrite associated with gold mineralisation at Sheba Mine in the Barberton Greenstone Belt (BGB). Some pyrite grains show elemental zonation which is distinctive to each type of pyrite habit. Different element associations are typically considered to be indicative of genetic origin, so that the elemental mapping of multiply zoned grains can potentially illustrate the sequence of mineralising events and identify those associated with gold deposition. Traditionally performed by EPMA, LA-ICP-MS mapping affords the opportunity to map elemental abundances at trace levels, revealing subtle associations and trends that few other instrumental techniques can equal.Textural and trace element data may not be able to uniquely identify stages in genetic evolution of the deposits in the BGB, but they do provide clear evidence for the different events and their impact on Au distribution.

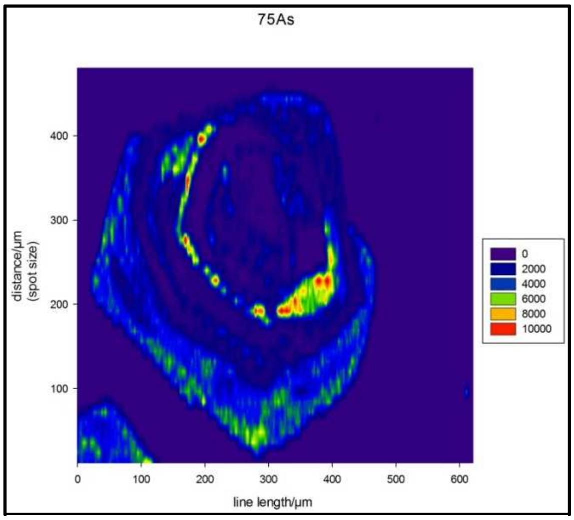

Figure 1. As distribution in a pyrite from Sheba.Concentration in the low ppm range. Concentration shown as counts per second.

Gold-bearing pyrite is generally assumed to be arsenic-bearing, in order for the gold to be accommodated in the pyrite lattice. This, however, is simplistic, as Au is found in As-free as well as high-As pyrite. In addition, much Au in pyrite has been termed "invisible gold", either lattice-bound or as sub-microscopic inclusions, with resolution of its exact nature uncertain at best. With time-resolved LA-ICP-MS analyses the identity of these inclusions can be resolved at far greater resolution.

Whereas EPMA elemental mapping has great precision, with a resolution down to 1 µm, it can only map at best major, minor and a few trace elements, at levels down to a ~hundred ppm. LA-ICP-MS can do the same, with some washout, but the strengths of LA-ICP-MS lie in its ability to detect low levels of elements, to low ppm and ppb levels, depending on the scan speed and spot size. An EPMA with 5 WDX detectors can map a 1 mm x 1 mm area in 8 hours – in 4 hours the same area can be mapped for 32 isotopes by LA-ICP-MS but at a lower spatial resolution. The greatest strength of LA-ICP-MS over EPMA is the ability to reveal features which would never be picked up by EPMA, such as subtle zonation and element distribution, which can provide important information for the genesis of the mineral grains and the deposit.

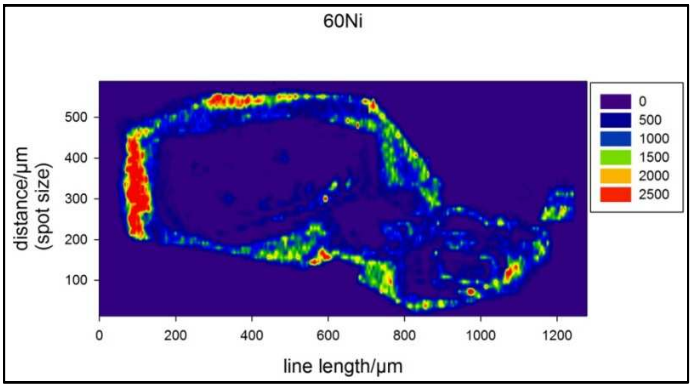

Figure 2. Ni distribution around pyrite from Sheba. Concentration in the low ppm range, showing several generations of crystal growth of this composite grain. Concentration shown as counts per second.

ORIGIN OF THE GOLD MINERALISATION IN THE WITWATERSRAND BASIN

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Keywords:gold, hydrothermal, Witwatersrand Basin

Though it has long been theorised that the gold deposits of the Witwatersrand Basin are at least partially hydrothermal in origin, there has been little trace element analysis associated with gold from around the basin to evaluate this hypothesis. There are currently a number of competing hypotheses for the origin on the gold in the conglomeratic reefs in the Witwatersrand Basin, from hydrothermal to alluvial and variations between the two extremes. Most studies have looked at specific areas and extrapolated the results to the whole basin.

A basin-wide study looking at the gold mined from the different gold fields in the Witwatersrand Basin has been conducted, and shows that each goldfield can be discriminated on the basis of the trace elements associated of the gold.

The results of this vertical and lateral study show that while some of the gold in the conglomeratic reefs in the Witwatersrand Basin is alluvial in nature, this is restricted more to the reefs in the upper portion of the West Rand Group, while the gold in the lower reefs is almost all hydrothermal in origin. Looking at gold recovered from different reefs from a single shaft in the West Wits goldfield, it could be seen that there were two distinct types of gold – one which can be attributed to a hydrothermal origin and the other to an alluvial origin. The gold in the Carbon Leader Reef is hydrothermal in origin, whereas the Ventersdorp Contact Reef has gold of both hydrothermal and alluvial origin. The trace element characteristics of the hydrothermal gold show that the gold was not remobilised from nearby, as postulated by some authors, but rather was derived from sediments within the basin. The extent of the mineralisation, as well as the quantity of gold deposited, published dates for mineralising events and recent oxygen isotope work, show that gold was deposited over time with the trace element characteristics of the gold in each goldfield consistent within a particular goldfield, but differing between them as an indication of the source of the sediments from which the gold was derived.

ZIRCON HELPS TO INTERPRET ANTARCTIC TONALITE GEOCHEMISTRY

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Keywords:tonalite, zircon, arc magmatism, metamorphic overprinting

The geology of the Sør Rondane Mountains, eastern Dronning Maud Land, is characterised by Mesoproterozoic tonalites and Pan-African gneisses (Shiraishi et al., 1997). The tonalites (and associated mafic and felsic instrusives) appear little affected by pervasive deformation and metamorphism in the field, but thin sections show variable replacement of plagioclase by epidote, and biotite by chlorite; garnet is present in more iron-rich samples, and calcite and muscovite are occasionally found as minor phases. In all but the most felsic samples, hornblende is the dominant ferromagnesian mineral. Evidence for localised shearing is already obvious in the field.

All analysed samples fall within the field of calcic granitoids in terms of the modified alkali-lime index (Na_2O+K_2O-CaO) of Frost et al. (2001), and, apart from one greenstone enclave, have TiO_2 contents < 0.8 wt.%. These characteristics strongly suggest a subduction zone as their tectonic setting.
Zircon studies on two samples yielded U-Pb ages of 992 ± 4 and 1010 ± 12 Ma, with initial epsilon Hf values between +5 and +10 for both samples. This juvenile Hf isotopic signature agrees with an oceanic arc setting.

The ubiquitous evidence for metamorphic overprinting and deformation raises the question to what extent the whole rock geochemical signature is still representative of the igneous precursor: K, Rb, Cs and Ba are present in surprisingly low concentrations in some samples (e.g. < 0.2 wt.% K_2O at 74% SiO_2). However, the behaviour of elements that are less mobile during metamorphism and alteration, such as the Rare Earth Elements (REE) and High Field-Strength Elements (HFSE) indicates that different suites of rocks are present, with varying enrichment of the incompatible elements. REE patterns are also varied, with a range of La/Lu ratios, Ce- and Eu-anomalies.

The question to what extent alteration and crystal accumulation played in role in the observed geochemical characteristics was assessed by laser ablation ICP-MS analysis of zircons. Zircon/whole rock distribution coefficients were calculated to see whether the whole rock analyses could represent melts. This showed that the positive Eu-anomaly observed in some whole rock samples must result from crystal accumulation, and that these cumulate characteristics might also explain the low alkali concentrations. The observed negative Ce-anomaly of some whole rocks could not unequivocally be shown to be an alteration feature. However, the erratic occurrence of this negative Ce-anomaly is more suggestive of alteration processes than of a source characteristic.

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MODELLING OF THE LIQUID LINE OF DESCENT IN THOLEIITIC MAGMAS: A FRESH LOOK

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Keywords: Liquid line of descent, tholeiitic, differentiation

The differentiation of tholeiitic magmas in nature has been studied, but the evolution of magmatic liquid responsible for crystallising differentiated Fe-rich rocks, (the liquid line of descent -LLD) remains a point of controversy. Why is it that ten or so different LLDs have been proposed for the same magmatic body? Does crystallisation, as Bowen (1928) suggests, follow a silica-rich fractionation trend toward the final stages of crystallisation, or does it follow the “Fenner” trend toward a Fe-rich end? Fenner (1929) predicts that the residual liquid will always become enriched in Fe, but that there are other factors acting to reduce the amount of Fe. These external factors include the likes of oxygen fugacity and the timing of Fe-Ti oxide precipitation. An increased Fe content is contrary to the idea that any differentiating magma will tend toward a granitic composition, and is a balancing act between external processes and regular differentiation. This study looks at common methods of deriving an LLD, and questions the assumptions behind these models, in order to assess their accuracy in predicting the true LLD. The study shows that the modelling of LLDs is very dependent on the assumed values for external processes and factors, and can at times produce more than ten different LLDs for the same intrusion. This implies that much greater care needs to be taken with these LLD models, in order to reach a geological reasonable conclusion. As assumed values for external processes have such a large bearing in the modelling of the final LLD, Fenner-type differentiation is a valid option, and can be combined with new research to formulate a better method for determining the LLD of tholeiitic magmas.

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COMMON-LEAD CORRECTED U-PB AGE DATING OF PEROVSKITE BY LA–SF–ICP–MS

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Keywords: U-Pb geochronology, laser-ablation, in-situ dating, perovskite, kimberlites, emplacement ages, diamond exploration

Perovskite is a very useful mineral for dating the age of emplacement of kimberlites and associated rocks. Conventionally, U-Pb dating of perovskite is achieved using isotope dilution (ID-TIMS) or ion-probe (SHRIMP) techniques, which are time- and cost-intensive. The potential of the rapid and inexpensive laser ablation ICP-MS technique for U-Pb dating of perovskite has been demonstrated recently. The main obstacle for obtaining accurate and precise U-Pb age dates from perovskite by laser ablation techniques based on quadrupole ICP-MS instruments is the large amount of common lead that is incorporated into perovskite and the associated difficulty to perform accurate common lead corrections due to the high mercury blanks of the gases (i.e. Ar and He) used in LA-ICP-MS.

We therefore investigated the benefits (very high sensitivity, very low dark noise and a large linear dynamic range) of single collector magnetic sectorfield ICP-MS (SF-ICP-MS) instruments for U-Pb dating of perovskite by laser ablation. To this end perovskites from two kimberlites from Garnet Lake, W Greenland, and Pyramidefjeld, SW Greenland, have been separated. Multigrain aliquots of both perovskite separates were U-Pb dated by ID-TIMS, yielding emplacement ages of 568 ±11 Ma for the Garnet Lake kimberlite and 151 ±2 Ma for the Pyramidefjeld kimberlite. After embedding in epoxy, grinding and polishing, multiple perovskite grains from both samples have been dated in-situ with high spatial resolution (spot analyses using a 30 µm beam diameter) by laser ablation employing a ThermoFinnigan Element2 SF-ICP-MS coupled to a NewWave UP 213 laser system. A common lead correction was applied based on the measured ^{204}Pb intensity (after correction for the measured ^{204}(Pb+Hg) gas blank). Perovskite from the Ice River Complex, British Columbia, was used as a secondary standard for quality control purposes. Multiple in-situ measurements of the Ice River perovskite in two different analytical sessions yielded concordia ages of 359 ±3 Ma and 357 ±3 Ma, in excellent agreement with the age of 356 Ma determined by ID-TIMS (Heaman, *pers. comm.*). Nineteen in-situ analyses of perovskite grains extracted from the Garnet Lake kimberlite yielded a concordia age of 566 ±5 Ma, also in excellent agreement with the age obtained by ID-TIMS. Because of the very low Pb contents in perovskites from the Pyramidefjeld (around 1 ppm) and the associated large uncertainties of the common lead correction, no concordia age could be obtained. However, the in-situ laser ablation analysis yielded a common lead corrected weighted average ^{206}Pb/^{238}U age of 152 ±3 Ma which is again in excellent agreement with the weighted average ^{206}Pb/^{238}U age of 152 ±2 Ma obtained by ID-TIMS. We therefore conclude that laser ablation SF-ICP-MS is a fast and inexpensive method for precise and accurate common lead corrected U-Pb dating of perovskite, and hence diamond exploration.

GEOCHEMICAL FINGERPRINT OF GOLD IN THE BLACK REEF CONGLOMERATE, EAST RAND, IN COMPARISON WITH B-REEF, WELKOM AND SHEBA MINE, BARBERTON MOUNTAINLAND

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Keywords: Gold fingerprint, Black Reef, B-Reef, epithermal gold, Sheba Mine

The Palaeoproterozoic (2642-2584 Ma) Black Reef Formation is a widespread thin small pebble unit at the base of the Transvaal Supergroup. In the East Rand, Randfontein and Klerksdorp areas the unit contains considerable gold, less U, as well as minor associated PGE mineralization. Henry and Master (2008) identified shortcomings in our understanding of the genesis of Au mineralization, and the occurrence of Au, U and PGEs hosted by the Black Reef (BR). The source of gold in these reefs has long been a matter of speculation which should however be understood because the genesis and provenance of Au, U and PGE mineralization in the Black Reef has exploration significance.

Extensive sedimentological evidence, suggests a strictly detrital origin. The gold associated with mainly pyrite, has been described as "in situ" hydrothermal deposition with the underlying Kimberley Reefs as proposed source. However, mineralogical and geochemistry studies performed by Barton and Hallbauer (1996) on the pyrite grains of the Black Reef argue against this. Debated possible sources of BR gold could be a) reworked conglomeratic upper Witwatersrand reefs, b) epithermal gold of granite-greenstone terrain hinterland, or c) pyrite-associated gold of underlying Archaean VMS deposits. To produce new data helping to understand the gold provenance question, geochemical fingerprinting of gold and pyrite using electron microprobe (FE-EMPA), synchrotron micro-XRF (SR-µ-XRF), and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) has been carried out.

A detailed investigation of the mineralogy of the mineralization in selected profiles of the arenitic to conglomeratic BR reveals chromite, sphalerite, chalcopyrite, galena, uraninite, cassiterite, tourmaline, carbon, Pt-Ni-As minerals and Ni-Co-sulpharsenides such ascobaltite and gersdorffite next to abundant pyrite, as well as free gold.An overprint by late-stage hydrothermal fluids altered BR rocks to a minor extent and remobilized Au grains into their present form, as evidenced by few associated alteration minerals such as chlorite, pyrophyllite and sericite.

EMP analyses show a fineness of BR gold between 825 and 882, as well as elevated Hg contents, and minor concentrations of Fe, S, Co and Ni, as well as detectable copper values (max.450 ppm). BR gold has a lower fineness, and a lower Hg and Cu content compared to the B-Reef gold, whereas its Fe, S, Ti and Ni concentrations are higher. Qualitative synchrotron micro-XRF spectra of BR gold confirm the EMP results revealing the presence of Cr, Ni and Ta at higher concentrations than in B-Reef gold, whereas B-Reef gold contains higher amounts of Cu. LA-ICP-MS measurements have lower detection limits but a larger variability as EMP data, probably caused by the ablation of larger volumes, complicating their interpretation. The overall similar heavy mineral content in the BR and several Witwatersrand reefs argues in favour of a reworked Witwatersrand gold origin of the BR gold. The frequency of concretionary pyrite with an unradiogenic Pb isotope composition (Barton & Hallbauer, 1996) in the BR argues however against a reworking of Wits material. In the same way, the less abundantly occurring Ni-Co-Fe-sulpharsenide in the Witwatersrand reefs, however its frequent appearance in BR reasons against a re-working. The epithermal gold of ShebaMine has the lowest Ag, Hg, and Th, S, Fe concentration of the Au provinces, however a high Cu content and, based on multivariate statistics, appears to be more similar to Wits than to BR Gold. As benefit for exploration the data could imply that underlying Witwatersrand strata and/or greenstone terrains are not a necessary requirement for the BR to potentially host an orebody. To judge this more data is needed.

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IDENTIFYING A MESOARCHAEN LARGE IGNEOUS PROVINCE ON THE KAAPVAAL CRATON

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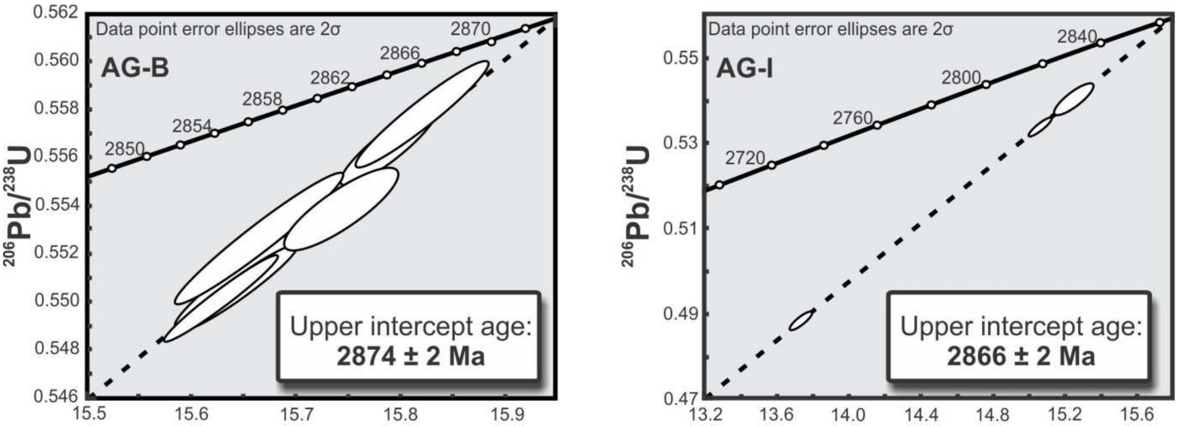
Keywords: Hlagothi Complex, Large Igneous Province, Magmatic Barcode, Virtual Geographic Pole

Herein we present geochronological and palaeomagnetic results from the Hlagothi Complex, as well as a NW-trending dolerite dyke swarm on the southeastern region of the Kaapvaal Craton in northern KwaZulu-Natal, South Africa. The Hlagothi Complex consists of layered sills of meta-peridotite, pyroxenite and gabbro intruding into quartzites of the Nsuze Group in the Nkandla sub-basin of the Pongola Supergroup. U–Pb baddeleyite ages on the Hlagothi Complex and a NW-trending dyke of 2866±2 Ma and 2874±2 Ma respectively, reveal a *ca*. 2.87 Ga magmatic event on this south-easternmost window of the Kaapvaal Craton. Additional units on the Kaapvaal Craton can be linked with this new magmatic event based on spatial and temporal association: 1) the Thole Complex, 2) possibly parts of the Usushwana Complex, and 3) flood basalts within the Mozaan Group and Central Rand Group, such as the Crown, Bird, Tobolsk and Gabela lavas. The association between all these units suggests would suggest a previously unrecognised Large Igneous Province on the Swaziland and Witwatersrand blocks of the Kaapvaal Craton. In addition, palaeomagnetic data identifies a possible primary magnetisation within the least altered lithologies of the Hlagothi Complex (with a virtual geographic pole at 23.4°N, 53.4°E, dp=8.2° and dm=11.8°). The bulk of samples however, displayed two episodes of remagnetisation. These are likely to be associated with the approximately 2.85 to 2.75 Ga aged granitoids across the southeastern Kaapvaal Craton, as well as tectonic activity in the nearby Meso- to Neoproterozoic Namaqua–Natal mobile belt. A short-lived (≤8 Ma) mantle plume is proposed to have caused this*ca*. 2.87 Ga magmatism, which may also have controlled sedimentation within the larger Mozaan–Witwatersrand basin. Volcanism after uplift and erosion of the underlying strata would have been fed through a series of feeder dykes, sills and layered complexes, of which the Hlagothi Complex and NW-trending dykes are part of.



U-Pb concordia diagrams for AG-B (north-west trending dyke) and AG-I (Hlagothi Complex)

C-, O- AND H-ISOTOPE STUDY OF GROUP II KIMBERLITE: THE ROLE OF MAGMATIC WATER, WATER-ROCK INTERACTION, AND CRUSTAL CONTAMINATION

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Keywords:stable isotope, kimberlite, volatiles

Kimberlites are known to be volatile-rich, but the origin of the volatiles remains controversial. In order to carry mantle xenoliths from depths as great as 250 km, the magmas have to have had both low viscosity and be significantly less dense than the surrounding mantle. This implies that a significant component of the water or CO_2 in kimberlite has to be of mantle origin. However, it has also been suggested (e.g. Kurszlaukis & Lorenz, 2008) that the eruptive style of kimberlite magmas resulted from the interaction between the ascending kimberlite magma and descending groundwater. In practise, it is difficult to determine if alteration is the inevitable consequence of formation from volatile-rich magma, or a superimposed alteration effect caused by influx of ground water into the ascending magma. A third potential source of volatiles is from low-T alteration; olivine-rich ultramafic rocks are highly susceptible to chemical weathering and the carbonate and hydrous minerals could be of low-temperature origin.

To try and resolve these issues, samples from the Swartruggens and Star Group II kimberlite dyke swarms have been analysed for their C-, O- and H isotope compositions. We analysed the calcite present for C- and O-isotopes, and the bulk silicate material for O- and H-isotopes. Calcite $\delta^{13}C$ and $\delta^{18}O$ values are midway between typical mantle values and those of local surficial carbonates. This is consistent with the calcite being a mixture of magmatic/deuteric and low-temperature origin. Bulk-rock silicate $\delta^{18}O$ values range from 6 to 14 ‰ and are consistent with deuteric alteration rather than exchange with meteoric fluid at high temperatures. Star samples have lower bulk-silicate δD values (average -103 ‰) than Swartruggens (average -71 ‰), which cannot be explained by differences in ambient rainfall. Interaction with organic material derived from the intruded Permian-Triassic sedimentary rocks at Star could explain these differences. The $\delta^{13}C$ values at Star are on average 1 ‰ lower than at Swartruggens, and this is consistent with the interaction and assimilation of organic material having a $\delta^{13}C$ of ~-25 ‰ by kimberlite magma with a fluid dominated by mantle-derived CO_2. Swartruggens is exposed below the level of the presumed Permian – Triassic cover; and a similar contamination process could have occurred, but its effect removed by erosion. Correlations between δD and K_2O content suggest that most of the H is present in phlogopite. This requires that the addition of an organic volatile component occurred at high (magmatic?) temperatures.

DETERMINING THE CONDITIONS UNDER WHICH THE HOLOCENE VOLCANICS OF MARION ISLAND CRYSTALLISED

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Keywords: Marion Island, fractional crystallisation, thermodynamic modelling,PELE

Marion Island is a volcanic island, situated in the Southern Ocean. It has been suggested that it owes its existence to a mantle hotspot, responsible for the rifting of Gondwana, which also produced the Karoo Flood Basalts in the Early Jurassic. Two main periods of volcanism has been identified – one during the Pleistocene, the other during the Holocene. The volcanic rocks erupted from its crater have been shown to form an evolutionary sequence, attributed exclusively to a single evolutionary process: fractional crystallisation. Additionally, the occurrence of large euhedral clinopyroxene phenocrysts within some of the younger volcanics seems to suggest that petrogenesis and magma evolution might have occurred inside a relatively deep-seated magma chamber, where early formed mineral phases were crystallised and separated from the melt, to form coarse-grained cumulate rocks. Modelling of the crystallisation processes has been attempted with the aid of the computer software package, PELE, which is capable of taking the chemical observations made on both whole rock samples, as well as on single mineral phases, into account. Constraining the model required the estimation of the system's initial conditions, prior to crystallisation. These conditions were expressed in terms of interdependent thermodynamic variables, such as volatile content, oxygen fugacity and pressure conditions. A process, which involves the systematic reiteration of a crystallisation model at different starting conditions, was followed to quantitatively determine a theoretical model that best reflects the tangible observations made on the crystallisation products.

SILICATE CONSUMPTION AND THE FORMATION OF OXIDE ORE LAYERS, PANZHIHUA INTRUSION, SW CHINA

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Keywords: H_2O, Fe-Ti oxide, reaction rim, kaersutite, crystal slurry, Panzhihua

The Panzhihua Intrusion occurs in the Panxi region of the Emeishan Large Igneous Province (ELIP), SW China. This region is host to numerous mafic layered intrusions containing Fe-Ti oxide ore layers (e.g. Baima, Hongge, Taihe), which are unique to the area and hence termed Panzhihua-type oxide ore deposits. Fe-Ti oxide ore layers occur at the base of the Panzhihua Intrusion and are comprised of abundant Ti-magnetite ± ilmenite, plagioclase, clinopyroxene and olivine.

Silicate primocrysts (plagioclase and clinopyroxene) within the ore layers are highly embayed and typically surrounded by rims of amphibole and olivine with lesser plagioclase, hercynitic spinel and clinopyroxene. We present here new mineralogical data for these distinct rims observed on silicate primocrysts in Fe-Ti oxide ore layers as well as new data for silicate primocrysts and oxides from both gabbroic rocks and ore layers. Amphibole observed as rims are Na-poor kaersutite. Olivine rims are enriched in Fo content relative to coarse grains in the same sample. Plagioclase observed associated with rims is enriched in An content relative to primocrysts. Plagioclase compositions for individual samples show a relatively large range in An content, which is generally characterised by higher An contents of the fine grains. Plagioclase shows a distinct reversal in An content within the middle zone A (MZa). Clinopyroxene shows no reversal in Mg# associated with plagioclase reversal but shows a minor reversal in TiO_2 content.

Fe-Ti oxides within both the ore layers and gabbroic rocks crystallise late after silicate primocrysts, which is clearly indicated by the highly embayed silicates in the ore layers and interstitial textures in gabbroic rocks. Furthermore this indicates that the silicate primocrysts were consumed at the time of abundant Fe-Ti oxide concentration. The initial H_2O content of the Panzhihua parent magma is estimated at ± 1 wt % based on the plagioclase composition of microgabbros analysed and the average composition of plagioclase primocrysts analysed (An_{57}). Reaction rim assemblages associated with silicate consumption in the Fe-Ti oxide ores are very similar to that of hydrous partial melting reaction assemblages produced by experimental studies. We suggest that an influx of H_2O-rich liquid resulted in silicate disequilibrium and consumption and resultant in Fe-Ti oxide concentration within ore layers. Furthermore we believe that Ti-magnetite crystallised at depth and was subsequently intruded as H_2O-rich and Ti-magnetite-rich crystal slurries into the Panzhihua chamber.

GEOCHEMICAL PATTERNS OF (ULTRA)MAFIC ALKALINE MAGMATISM IN SOUTHWESTERN AFRICA

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Keywords: kimberlite, melilitite, carbonatite, radiogenic isotopes, magmatism

The western margin of southern Africa (South Africa and southern Namibia) is notable for the fact that it is intersected by three age-progressive, mafic to ultramafic, alkaline igneous lineaments of Late Cretaceous to Early Tertiary age (80 to 50 Ma). These are oriented SW-NE, roughly parallel to the direction of African plate motion during this time. Each lineament is composed of at least several, to more than 100, plugs, pipes and igneous complexes containing rocks such as alkali basalt, olivine nephelinite, melilitite, kimberlite and carbonatite. These are (1) the Western Cape melilitite province (WCMP, Duncan et al., 1978; Janney et al., 2002) and (2) the Garies-Gamoep-Warmbad (GGW) melilitite-kimberlite province (Moore & Verwoerd, 1985) of western South Africa, as well as (3) the "Schwarzeberg-Dicker Willem-Gibeon" (S-DW-G) nephelinite-carbonatite-kimberlite province of southern Namibia (e.g., Reid et al., 1990). Other common characteristics shared by the three magmatic lineaments are an association with carbonatite complexes (Saltpetre Kop in the WCMP, Zandkopsdrift in the GGW and Dicker Willem in the S-DW-G provinces) and the fact that radiogenic isotope affinities in the rocks vary from compositions similar to the "high-μ" (HIMU) mantle endmember (i.e., high $^{206}Pb/^{204}Pb$, unradiogenic Sr and mildly radiogenic Nd) to those more similar to the "enriched mantle 1" (EM 1) endmember (low $^{206}Pb/^{204}Pb$, radiogenic Sr and unradiogenic Nd). This suggests that the alkaline igneous rocks were derived from chemically heterogeneous and carbonate-rich mantle source regions. The samples with HIMU Sr-Nd-Pb isotopic affinities also tend to have strongly unradiogenic $^{176}Hf/^{177}Hf$ relative to $^{143}Nd/^{144}Nd$, suggesting the possibility that the HIMU source(s) sampled by these rocks may represent ancient melting products of garnet-bearing mantle (e.g., pyroxenite veins). Recent investigation of Sr-Nd-Pb-Hf isotope variations in clinopyroxene megacrysts from the Pofadder and Gibeon kimberlites (in the GGW and S-DW-G provinces, respectively; Janney and Bell, 2011), selected to span the widest possible range in the evolution of their parental magmas, suggests that the unradiogenic $^{176}Hf/^{177}Hf$ component is located within the lithosphere rather than in the underlying convecting mantle (as proposed by Janney et al., 2002). The possibility that any of these three alkaline magmatic lineaments is the product of long-lived mantle plume activity seems unlikely given the lack of young volcanism in areas of the South Atlantic that could represent the recent expression of such plumes (WCMP and GGW provinces) or the lack of isotopic similarity and poor time-space correspondence between the continental S-DW-G province and the putative Vema and Discovery plumes that have been proposed as its possible cause (e.g., Reid et al., 1990; Davies et al., 2001). Neither is there clear evidence that any of the lineaments overlie the extensions of South Atlantic fracture zones (c.f. Marsh, 1973). Geochemical and geochronological data for the three provinces will be summarized and possible scenarios for the origin of these provinces will be evaluated. We will also discuss plans for future sampling, dating and geochemical characterization of these rocks to better understand the genesis of mafic/ultramafic and carbonatitic magmatism in the region.

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CHEMICAL EVOLUTION OF THE PALEOPROTEROZOIC ROOIBERG GROUP, KAAPVAAL CRATON, SOUTH AFRICA: NEW INSIGHTS INTO THE FORMATION OF SILICIC LARGE IGNEOUS PROVINCES (SLIPs)

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Keywords: silicic volcanism, Rooiberg Rhyolites, Bushveld Complex

With an estimated erupted volume of 300,000 km^3 and an areal extent of more than 200,000 km^2,the Paleoproterozoic (2.06 Ga) silicic volcanic rocks of the Rooiberg Group (Kaapvaal Craton) in northern South Africa forms one of the largest and to the same time oldest silicic large igneous provinces (SLIPs) known. This large volume of rocks can be sub-divided into four formations: the Dullstroom, Damwal, Kwaggasnek and Schrikkloof Formations. The Dullstroom Formation, composed of basalts to rhyolites (high Mg-felsite), is overlain by the Damwal Formation with similar compositions. The major difference between the two formations is the presence of low Mg-felsites within the Damwal Formation. The Kwaggasnek and Schrikkloof Formations overlie the Damwal Formation and are mainly composed of low Mg-felsites. Despite the uniqueness of these rocks and their scientific importance regarding the formation of SLIPs worldwide, the Rooiberg Group received little attention in the past. Therefore, a geochemical and petrological study was initiated to further investigate the petrogenesis of the Rooiberg Group, provide constraints on the magma forming processes and to come up with an explanation on the wide extent of its rhyolitic lava flows.

The Loskop Dam area in the Mpumulanga province, ca. 120 km east of Pretoria, and one of the type localities for the Rooiberg Group, was found suitable as study area because of its good outcrop conditions and the fact that most of the described formations can be found here. The studied rocks vary from dacites to rhyolites. The dacitic to rhyolitic Damwal Formation is characterized by a majority of grey, aphanitic lavas bearing amygdales and spherulitic textures. Furthermore, intercalations of tuffs and meta-sandstones can be observed. The rhyolitic Kwaggasnek Formation is characterized by the occurrence of flow-bands, amygdales and spherulitic textures. No sedimentary or pyroclastic units were observed in this formation. The rhyolitic Schrikkloof Formation is characterized by an absence of spherulites but the occurrence of quartz veins. The dacites can mainly be described as high-Mg felsites (HMF) whereas the rhyolites can be described as low-Mg felsites (LMF). Nevertheless, LMFs of dactic composition can occur as well. Especially from the Damwal to the Schrikkloof Formation an increase in low-Mg felsites can be observed. This transition from dacitic to rhyolitic composition can macroscopically be observed by an increase in the abundance of flow-banding within the study area. Such differences in geochemistry may mainly be due to fractional crystallization. This is supported by the occurrence of HMF, low-Ti basaltic andesite, high-Ti-Fe-P and some LMF in the Damwal Formation. This more basic (andesitic) group of rocks is overlain by the LMF of the Kwaggasnek and Schrikkloof Formations. Therefore, crystallization may have commenced with the more Mg-rich rocks from the melt (mainly the HMF) during which the concentration of the LMF relatively increased in the melt. After this crystallization, saturation of the melt in Si commenced the crystallization of Si-rich rocks (LMF) to form the Kwaggasnek and Schrikkloof Formations.The Rooiberg Group exhibits high amounts of K_2O (2-6 wt.%) and rare earth elements but low MgO (0-2.3 wt.%) and CaO (0-3.5 wt.%) contents, similar to other SLIPs around the world. Comparison of trace elements and REEs of the Rooiberg Groups with other major SLIPs around the world show remarkable similarities. The Karroo (South Africa) and Ferrar (Antarctica), the Gawler Range (Australia) and the Keweenawan (USA) volcanic provinces are very similar in trace element concentration, thus suggesting similar magma sources for the different SLIPs. Subsequent studies will further address possible similarities or differences between these SLIPs in order to find formational mechanisms and processes common to these volcanic provinces. Furthermore, studies on the intensive parameters (eruption temperature, viscosity, etc.) of the Rooiberg lavas will try to explain the wide extend of the rhyolitic lava flows of this remarkable SLIP.

PGE NANO STRUCTURES IN NATURAL Ni-Cu-S SYSTEMS

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Keywords: platinum group elements, clusters, experimental petrology, synthetic sulphide systems

The feasibility of cluster formation as the primary binding mechanism of platinum group elements (PGE) in a magmatic environment was investigated. Variable concentrations of As and PGE (Pt, Pd and Ru) were added to constant amounts of S, Cu and Fe. The experiments were manipulated to best present a natural Cu-Ni-S ±PGE system. Samples were prepared using the silica-tube technique. The final products were investigated using scanning electron microscopy (SEM) and scanning auger microscopy (SAM). Preliminary results indicated that Pt formed agglomerations of about 10-100 atoms during the early stages of experiments, probably due to its siderophile behaviour. The existence of PGE clusters within a mono-sulphide phase would indicate that an initial primary physical (mechanical) binding process is more dominant during early crystallization than chemical association with sulphide bonds. This behaviour cannot be explained by sub-solidus immiscibility properties as has been suggested to account for the frequent presence of PGE in base metal sulphide minerals (BMS).

IMPACT-MODIFIED MANTLE SPOTS

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You may have read about the newly discovered Maniitsoq impact structure in southern West Greenland (in Garde et al 2012, the September 2012 issue of our Geobulletin, or elsewhere), which is 1 Ga older and possibly significantly larger than the ca 2 Ga old Vredefort Dome, previously estimated to be the largest impact structure on Earth. The nearly perfect geographical overlap of the Maniitsoq impact structure with contemporaneous, Ni-mineralised noritic intrusions and two ~800 Ma younger, conjugate clusters of boninitic norite (BN) dykes (Hall & Hughes 1987) has led us to speculate that the Maniitsoq impact may have been large enough to physically mix continental crust down into the underlying subcontinental lithospheric mantle. Our research group plans to test this working hypothesis on samples to be collected in the field in 2013. We are open to collaboration on this exciting new topic and welcome applications from postdoctoral candidates.

At the IMSG 2013, we will first present the field relationships between the BN dykes and the Maniitsoq structure. We will then evaluate geochemical data on these and other BN-dykes across the World, as well as some of the World's largest mafic-ultramafic layered intrusions (including the Bushveld Complex, Great Dyke of Zimbabwe and Stillwater; see review by Srivastava 2008), which all appear to have been fed by similar boninitic parental magmas. Contrary to oceanic boninite lavas that are found within Phanerozoic back-arcs and Archaean greenstone belts, Craton-hosted BN-dykes and related layered intrusions appear to have been generated from a different source and emplaced during a relatively restricted period (2.71 to 2.06 Ga) of volcanic rifting.

Previously, continental boninitic melts have been interpreted as either (1) komatiitic, high-degree partial mantle melts that were subjected to contamination by large volumes of Archaean crust, or (2) more moderate-degree partial melts from a highly depleted, fossilized mantle wedge that had been enriched by slab-derived adakitic melts. With this work we propose to test a new hypothesis, i.e. that buoyant continental crust may be physically mixed into the underlying, denser mantle by large meteorite impact events, thereby producing a SiO_2- and LREE-enriched subcontinental lithospheric mantlesource that might give rise to boninitic primary magmas. The 3.0 Ga Maniitsoq impact into a receptive, juvenile Archaean lithosphere may have been forceful enough to do so, whereas heavy meteorite bombardment of Earth at around 3.85 Ga (as observed on the Moon) probably totally demolished any pre-existing continental lithosphere.

If the Maniitsoq impact indeed gave rise to mechanical mixing of continental crust and subcontinental lithospheric mantle, this would offer an entirely new model source for other BN-dyke clusters and large layered mafic-ultramafic intrusions (including the enigmatic Bushveld Complex; see review in Olsson et al. 2011), and possibly in turn lead to the discovery of other impact centers. It might even be speculated that such recognition of additional areas of chemical modification of the mantle by Archaean impacts challenges the usual interpretation of mantle plume hot spots, across which the Earth's oldest known supercontinent rifted and broke apart during the Palaeoproterozoic.

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CHROMITITES OF THE EASTERN CHROME MINE, SOUTH AFRICA: SETTING AND PGE ENDOWMENT

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Keywords: Bushveld Complex, chromitites, PGE minerals, formation processes

A section of the Bushveld Complex at Eastern Chrome Mine near Steelpoort was sampled with special attention to the distribution of chromitite layers. The drill core sampled contains Critical Zone chromitites from the LG-6 to the UG-3a. The sample location is approximately 3.5 km north of the Steelpoort Fault Zone. Reported effects of the close proximity to the fault zone include changes in thickness of (chromitite) layers, increased reef disturbances such as pegmatoids/ potholes, and changes in the mineralogy of PGE associated with the BIC chromitites.

The chromitites of the Lower Critical Zone are hosted in pyroxenite containing mainly orthopyroxene, with those of the Upper Critical Zone hosted in cumulates of pyroxenite, norite and anorthosite. The LG-6 and LG-7, important targets for chrome exploitation, consist of massive chromitite layers. The MG layers are “diluted” within the host rock, and the MG-2, which usually marks the boundary between Upper and Lower CZ, is only present as a thin chromite stringer. Four UG layers are present. Below the footwall of the LG-6, there is a coarse-grained pyroxenite termed “pegmatoidal replacement” by local nomenclature.

The layers LG-6 to UG-1 are deficient in sulphide and in PGE. Ruthenium phases (laurite) dominate in the LG-6 and -7. The relative abundance of the Pt-Pd-Rh group increases upwards. The MG-4 stands out as the only layer in this succession to contain appreciable amounts of PGMs large enough to analyze. The UG-2, -3 and -3a contain more sulphide and PGMs. The replacement pegmatoid below the LG-6 contains disseminated sulphides including pyrite, pyrrhotite, pentlandite, chalcopyrite and millerite, but no PGE sulphides.

The platinum-group mineralogy of this particular succession of chromitites is dominated by Pt-Pd phases, particularly Pt-Pd sulphides.The MG-4, UG-2 and UG-3a chromitites were examined to reveal their PGE mineralogy. Pt-Pd sulphide was dominant in the MG-4, while Pt telluride and Pt-Pd sulphide was found in the UG-2. In the UG-3a Fe-Pt alloys were dominant. The modes of occurrence of PGM and base metal sulphide indicate a primary magmatic origin for both, with the exception of the UG-2 chromitite. Abundant pyrite in this particular layer may be ascribed to the action of a late hydrous fluid which did not alter the primary PGE mineral assemblage. This concurs with the sulphide discovered in the replacement pegmatoid.

EXTENSIVE PALAEPROTEROZOIC FLUID PERCOLATION IN CHERTS OF THE ONVERWACHT GROUP

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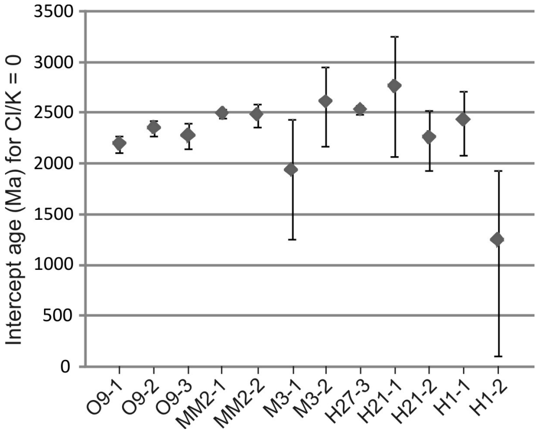
Keywords: Archean Cherts, Ar/Ar dating, Fluid activity

Cherts of the Onverwacht Group in the Barberton Mountain Land, many of them clearly silicified shales, have been the focus of many studies, aimed at such diverse things as finding early microfossils (Westall et al., 2001; 2006), determining ocean temperature (Knauth and Lowe, 1978; 2003) or oxygen levels (Siebert et al., 2005) in the Archean, or extrapolating the seawater Sr isotope curve to the mid-Archean (Weis and Wasserburg, 1987a). Alexander (1973) found that “cherts (of the Barberton Mountainland) have excess argon”. Weis and Wasserburg (1987b) obtained a Rb-Sr isochron age of 2.12 Ga which they ascribed to isotope resetting in an unspecified thermal event. In a new project aimed at testing the integrity of the chert record, we have carried out ^{40}Ar/^{39}Ar dating experiments on a suite of cherts from the Onverwacht Group, using the SANGOMA laboratory at UJ (stepheating by continuous Nd-YAG infrared laser, and isotope measurements on MAP 215-50 mass spectrometer). Our Ar isotope results also yield Ca/K and Cl/K ratios of the samples for progressive heating steps.

All ^{40}Ar/^{39}Ar stepheating results reveal qualitatively consistent, but quantitatively differing apparent age spectra. Low temperature degassing steps have invariably very high apparent ages, often greater than the age of the Earth, confirming the excess argon diagnosis of Alexander (1973). Spectra then go through a minimum, which lies between 2.2 and 3.7 Ma (and thus bears no relation to the depositional age), followed by a staircase-type pattern of increasing apparent ages. Three aspects are of particular interest: (1) the lower the minimum age, the better defined the plateau is; (2) the poorest plateaus and highest minimum ages occur in the lowermost part of the Onverwacht succession; (3) Cl/K ratios vary along with the apparent ages of spectrum steps and are linearly correlated with the ^{40}Ar(rad)/^{39}Ar ratios that determine the apparent ages (Ca/K ratios are very low and show no systematic variation).

The data negate the notion of a simple thermal resetting of the system (Weis and Wasserburg, 1987b). The conundrum that presents itself is that there is evidence of both argon loss (minimum step ages mostly younger than the deposition ages) and excess Ar. The good correlations of Cl/K with ^{40}Ar(rad)/^{39}Ar can be accounted for by assuming a complete Ar loss at some time in the past, followed by fluid access that delivered Ar and Cl in variable amounts.



When did this happen? Regression of the correlations yields ^{40}Ar(rad)/^{39}Ar ratios corresponding to Cl/K = 0, and the apparent ages corresponding to these ^{40}Ar(rad)/^{39}Ar ratios would correspond to the time of fluid activity (Ar loss and excess Ar + Cl addition) These dates mainly cluster between 2.2 and 2.5 Ga. The lowest (and best) apparent plateau ages are within this range. There is no known tectonic or metamorphic event associated with this age bracket, but in view of the consequences for paleontological and paleo-environmental studies that have been carried out on these cherts, we need to take these data seriously and understand the processes that were at play in the early Proterozoic in these Archean sediments.

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TECTONIC EVOLUTION OF THE NORTHERN DAMARA BELT, NAMIBIA

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Keywords: fold interference pattern, structural geology, tectonics,Damara belt, Pan-African Orogeny

Detailed descriptions of structures associated with remote sensing analysis and microstructural observationswereperformed in the Northern Zone of the Damaraorogenic belt (Namibia). Passive margin siliciclastic and carbonatesequencesof the NeoproterozoicDamarabelt were polymetamorphosed to the biotite zone of the greenschistfacies and polydeformed during pene-coeval late Neoproterozoic to late Cambrian closure of two highly oblique oceanic domains: the NS trendingAdamastor Ocean to the west and the NE-SW trending DamaraOceaninthe study area. Subtle relict structures and fold pattern analyses reveal the existence of an early N-S shortening which was thenalmost obliterated by a pervasive and major E-W shortening, related to the closure of the AdamastorOceanic domain and subsequent formation of the NS striking Kaoko belt to the West of the Northern Zone. Early km-scale E-W trending steep folds were refolded during this event, producing either TypeI or TypeII fold interference patterns visible in remote sensing images. During final NW-SE convergence in the Damara belt,a rigid Paleoproterozoic basement-high located north of the Northern Zone indented the weak metasedimentaryrocks and produced a deformation front on its southern edge. The NW-SE convergence is responsible for NW-verging asymmetric metre-scale folding associated withtop-to-the-NW shear zones andkm-scale bending around a vertical axis of the Type I and Type II refolded folds. Variations in map shapes of these spectacular fold interference patternswill be discussed as well as the tectonic significance of thesedeformation eventsfor the evolution of the Damarabelt.

VOLATILE (H_2O, CO_2, S) AND HALOGEN (Cl, F) SYSTEMATICS OF SMAR MORB (44-52.5ºS)

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Keywords:volatiles, halogens, South Atlantic, MORB

New SIMS volatile (H_2O, CO_2, S) and halogen (Cl, F) concentration data have been obtained for fresh MORB glasses (>6wt% MgO) from the slow-spreading southern Mid-Atlantic Ridge (SMAR; 44-52.5ºS), to complement previous data from the faster-spreading northern East Pacific Rise (EPR; 8-10ºN and 12-14ºN; le Roux et al., 2006). The selected MORB samples span the previously observed compositional range between enriched and depleted mantle source regions along this section of the SMAR (le Roux et al., 2002b), as well as the range of magma crystallization characteristics (le Roux et al., 2002a).

The pre-eruption transit of MORB magmas through the upper oceanic crust has the potential to result in compositional contamination through assimilation of e.g. sea-water altered material and/or saline brines. This would most-likely lead to significant addition of sea-water derived Cl, resulting in excess Cl concentrations and elevated Cl/Nb ratios in erupted MORB lavas (le Roux et al., 2006; Michael & Cornell, 1998).

Dissolved H_2O and CO_2 concentrations in these MORB glass samples provide pressure estimates of eruption initiation, and therefore the final crustal depth at which significant magma compositional modification occurred (D_{sat}; le Roux et al., 2006). Unlike the northern EPR region, no geophysical data are available for this section of the SMAR to allow comparison of D_{sat} with the depth of imaged magma chambers (le Roux et al., 2006). However, estimates of the calculated pressures of MORB magma crystallization for these SMAR samples (le Roux et al., 2002a) can be compared with D_{sat}.

The volatile and halogen compositions of these SMAR MORB could therefore allow significant insight into the pre-eruption magma compositional processing, with comparison possible with the significantly different tectonics setting of the northern EPR.

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LIGHT FROM DARKNESS - GEOCHEMISTRY OF POSSIBLE LIQUID IMMISCIBILITY STRUCTURES IN THE VENTERSDORP LAVAS

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Keywords: Ventersdorp lavas, ocelli, liquid immiscibility

A section of the volcanic Meredale member at the base of the Ventersdorp Supergroup is exposed at an abandoned quarry. In the section, light-coloured spherical structures called ocelli are hosted in dark-coloured layers in a succession of alternating dark and light layers (Cawthorn and McCarthy, 1977). The ocelli are found exclusively in the dark layers and are commonly concentrated directly beneath the light layers.

Analyses of the ocelli and light layers show low concentrations of Al_2O_3(8%) andhigh MgO (12%). Charlier and Grove (2012) suggested that low Al content can induce liquid immiscibility. There is a remarkably small compositional difference between the light and dark layers, thus, suggesting that the immiscible liquids may have separated close to the top of the solvus. Smaller ‘blobs’, originally thought to be amygdales, of dark-coloured material mixed in an emulsion texture with light-coloured material and light-coloured ‘blobs’ mixed in an emulsion texture with dark-coloured material, at the contact between the dark and light layers, suggest a second stage of liquid immiscibility which took place after extrusion of the magma. There appears to be chemical variation within the ocelli and light layers. The bottom part of the overlying light layer as well as the bottom half of one of theocelli appear to contain a higher concentration of MgO, Fe_2O_3 and Al_2O_3 but lower SiO_2 than the top part of the overlying layer and top half of the ocelli. This chemical variation is suggested to be attributed to the second stage of liquid immiscibility. Furthermore, analyses also show abnormally low extent of Fe enrichment (11% total as FeO), preceding the onset of immiscibility, in the dark layers which contrasts with the generally accepted hypothesis of extreme Fe enrichment preceding the onset of liquid immiscibility.

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MINERALOGICAL AND GEOCHEMICAL INTERPRETATIONS ON THE PEGMATOIDAL AND NON-PEGMATOIDAL MERENSKY REEF, WESTERN BUSHVELD COMPLEX

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Keywords: Bushveld complex, Merensky reef, pegmatoidal, non-pegmatoidal, chromitite

This study was undertaken in the south western portion of the Western Limb of the Bushveld complex. The stratigraphy of the Critical Zone of the Bushveld complex consists of seven major rhythmic layered units. The Merensky reef forms the base of the sixth unit and the uppermost seventh unit commences with the Bastard reef. The Merensky reef is referred to as either a pegmatoid reef if a pegmatoidal pyroxenite is present or a non pegmatoidal reef if it is absent. In the latter the chromitite layer rests on a footwall of anorthosite. In the former case, the reef is defined by a pegmatoidal (feldspathic in certain areas) pyroxenite bounded by a thin top and bottom chromitite layer. The vertical distribution of the PGE is influenced to a large extent by the separation between these two chromitite layers or the absence of one chromitite layer. The mineralogy and geochemistry are described on two sets of core, across both reef types from the area. Samples were analysed by optical microscopy. Mineral chemistry was investigated using a SEM, by means of energy dispersive X-Ray spectrometry. Major elements were determined by using XRF and trace elements by using ICP-MS. Results indicate that in the pegmatoidal reef the plagioclase in the footwall is a cumulus phase in contrast to plagioclase in the hangingwall that is interstitial. The hangingwall of the non-pegmatoidal Merensky reef show whole rock Mg#s ranging between 0.73 and 0.77, with the footwall values ranging between 0.39 and 0.75 with the values decreasing towards the chromite stringer. The hangingwall of the pegmatoidal Merensky reef show whole rock Mg#s ranging between 0.68 and 0.77, with the footwall values ranging between 0.66 and 0.68 with the values decreasing towards the top chromite stringer and increasing towards the bottom chromite stringer. The pegmatoid layer also shows significantly higher values of 0.75 – 0.81.

FIRST LITHOFACIESANALYSIS ON THE GEODYNAMIC SETTING OF A PALAEOPROTEROZOIC SILICIC LARGE IGNEOUS PROVINCE: THE ROOIBERG GROUP, KAAPVAALCRATON, SOUTH AFRICA

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Keywords: SLIP, Precambrian, Rooiberg Group, lithofacies, fissure eruptions, stratovolcanoes

The 2.06 GaRooiberg Group of South Africa, related to the greater Bushveld complex forming event, is one of the unique silicic large igneous provinces (SLIPs) found in the Precambrian rock record. Akin to the Gawler Range Volcanics (Australia), the Sierra Madre Occidental (Mexico), the Trans-Pecos volcanic field (USA), and other silicic dominated LIPs, the Rooiberg Group is subaerial, dominated by voluminous silicic lava flows and formed in an intracontinental setting. The original extent of the Rooiberg Group is thought to be as much as ~200,000 km^2, of which 50,000-67,000 km^2 remains after erosion, though aneruption volume of ~300 000km^3 has also been proposed.

The Rooiberg Group, overlying the metasediments and metavolcanics of the Transvaal Supergroup on the KaapvaalCraton, can be subdivided into four formations, which are in stratigraphical order: the Dullstroom, Damwal, Kwaggasnek and Schrikkloof Formation. The best outcrop conditions for the Rooiberg Group can be found in the Loskop Dam area in the Mpumalanga Province, ca. 120 km E of Pretoria, where three of the four formations can be encountered in the field. After extensive mapping in this area, a lithofacies analysis was initiated in order to provide for the first time a properly constrained and detailed set of the lithofacies types that can be encountered within the Rooiberg Group.

So far and within the scope of the study area (Loskop dam), eightlithofacies types have been identified, ranging from coherent lava flows and massive tuffs to cross-bedded sandstones and conglomerates. The lithofacies types can be grouped into syn-, inter- and post-eruptive lithofacies associations, thus illustrating changes in time and space as shown by intercalated products of effusive and explosive eruptions, and clastic sediments characterising times of relative quiescence. The tectonic situation within the KaapvaalCraton and the predominance of lava flows is seen as evidence for fissure eruptions in the Loskop dam area. Thick pyroclastic units elsewhere within the extent of the Rooiberg Group, however, suggest the existence of larger volcanic features such as stratovolcanoes and related explosive eruptions, probably contemporaneous with the fissure eruptions.

The new information gained in the course of this study will enable the reconstruction of the geodynamic setting in which the Rooiberg Group formed and thus also help us to understand the conditions under which SLIPs can form in general.

GREENSTONE BELT OR AMPHIBOLITE BELT?: METAMORPHISM IN THE GIYANI GREENSTONE BELT

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Keywords: Giyani Greenstone Belt, classification, greenstone, greenstone belt, greenschist facies, amphibolite facies.

Using petrography and pseudosection modelling, the northern Giyani Greenstone Belt (GGB) was studied so as to classify and quantify its metamorphism. Greenstone belts are generally elongate, early to late Archean preserved continents which formed at protocontinental margins. They comprise intrusive and extrusive mafic to ultramafic igneous rocks, irregular felsic volcanics, and cover sedimentary rocks. Greenstones are generally of low to moderate metamorphic grade.Greenschists and greenstones are low-grade metamorphic rocks that contain chlorite, actinolite, epidote and albite, the minerals which basically typify greenstone belts. However, this is not the case in many observed greenstone belts such as the Barberton and Murchison Greenstone belts, where metamorphic grade reaches up to amphibolite facies conditions.

The GGB reached up to upper amphibolite facies conditions coupled with partial melting. The samples contain minerals of medium to high grade metamorphism such as staurolite, anthophyllite, garnet and sillimanite. These are clearly not greenschist facies minerals representative of low grade metamorphism. Peak metamorphic conditions reached by the northern GGB are between 550-650˚C and 5.6-6.5 kbar. Now the question is, “Is it fitting to still call these terranes “greenstone” belts though some parts of them are no longer greenstones?”

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REE ABUNDANCES IN APATITE IN THE BUSHVELD COMPLEX – A CONSEQUENCE OF THE TRAPPED LIQUID EFFECT

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Keywords: Bushveld, apatite, REE, trapped liquid shift effect

The Bushveld Complex contains cumulus apatite toward the top of the Upper Zone, and contains high concentrations of REE (Vantongeren and Mathez, 2012). The uppermost 300 m of a borehole (Bierkraal) have been sampled to investigate apatite abundance and whole-rock composition in detail. Two cycles of apatite abundance are recognised, showing a sharp increase at the base (up to >15 % by mode) and gradual decrease upward. Apatite abundance correlates with olivine and magnetite proportions, but their respective sinking velocities are not consistent with hydraulic equilibrium. Hence, settling and sorting are not accountable for the formation of apatite-bearing cycles.

The REE abundances of apatite have been calculated using the assumption that all REE are concentrated in apatite. Given the large partition coefficient into apatite compared to the other phases present, this assumption is considered valid. Using this method it is found that the REE abundance in apatite varies inversely as a function of modal proportion of apatite; with Ce contents in apatite ranging from 500 to 1400 ppm for modal abundances of 16 to 2 %. These values are similar to data presented by Vantongeren and Mathez (2012), who suggested that such differences were due to liquid immiscibility.

An alternative model is presented here that relates to the trapped liquid shift effect (Barnes, 1986), as applied to incompatible trace elements (Bédard, 1994; Cawthorn, 1996). In this model the REE in the trapped liquid surrounding the cumulus grains were strongly partitioned into the primary apatite as the trapped liquid solidified. Calculations show the trapped liquid effect for a liquid with 100 ppm Ce which crystallized apatite with 500 ppm. If the cumulus apatite proportion was 2% and the trapped liquid 30%, the final re-equilibrated apatite would contain 1370 ppm Ce. If the cumulus apatite was 16% the increase in Ce in the re-equilibrated apatite would only be 640 ppm. These abundances are consistent with those calculated from whole-rock analyses in this study and the data of Vantongeren and Mathez (2012).

All other REE behave similarly and can be quantitatively modeled as for Ce, except for Eu. Eu can also enter plagioclase, and so the assumption that all REE partition in to apatite is not valid for Eu. Including the partitioning of Eu into plagioclase in these calculations produces a negative Eu anomaly in the REE pattern for apatite, the magnitude of which increases as the proportion of apatite decreases, exactly as observed in the two data sets.

It is concluded that the trapped liquid effect for the redistribution of REE during intercumulus solidification can best explain the variations in abundances observed in apatite from near the top of the Bushveld Complex.

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NEW CHEMISTRY AND AGE DATA ON THE LATE-NEOPROTEROZOIC GOAS INTRUSIVE COMPLEX, NAMIBIA

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Keywords: Pan-African magmatism, subduction, U-Pb age.

The Pan-African Damaraorogen (Namibia) records the Neoproterozoic-early Palaeozoic amalgamation of West Gondwana, and traces the NS-trending coastal branches of the Kaoko and Gariep belts, and the ENE-trending inland branch of the Damara belt. Different issues concerning the genesis of the Damara belt either as an intracontinental or as an accretionary orogen remain under debate. An intracratonic origin with exclusively ensialic processes has been suggested mainly by the lack of subduction-related metamorphism (no eclogites and/or HP metamorphism and ophiolites) and on the basis of isotope systematics, which would suggest an origin by HT melting of mafic lower crust (Jung et al., 2002). However, a subduction scenario would reconcile the 400 km ENE-WSW-trendingMatchless amphibolite belt, where scattered MORB-type pillow basalts are recorded.In this respect, absence of typical subduction-related metamorphism could be due to its obliteration by later tectono-metamorphic events. A central roleto this debate is played by theGoas intrusive complex: located NW of the Matchless belt, it represents the earliest magmatic activity of the Damaranorogen, and, according to many authors, its setting andgeochemical signature would suggestNW-vergingsubduction of an oceanic domain (Miller et al., 2008, and references therein).In order to improve the knowledge of the Goas complex and constrain its timing of emplacement, new geochemical data and LA-ICPMS U-Pb ages on single zircons have been collected. The suite is composed of two relatively small tholeiitic meta-gabbroic intrusions (Neikhoes and Audawib) and by six main calc-alkaline bodies (Oamikaub, Okatuwo, Gamikaub, Okongava, Palmental and Mon Repos) with a widespread distribution from mafic to felsic rocks. The meta-gabbroid intrusions outcrop mainly as Ol- and Px-cumulates or as slightly differentiated products, often altered to hornblendites, while the main intrusions span from diorites to granites, or from monzodiorites to quartz monzonites and granites, according to their alkali content. The main mineral phases in mafic to intermediate rocks are Pl, Hbl, Bt, Fsp and Qtz, with Ttn, Chl and Ep in various proportions as secondary minerals, while granitoid rocks are dominated by Kf, Qz, Pl, Bt and secondary Ms. A more alkaline character with a potassic signature is recorded in Palmental and Mon Repos intrusions. Trace element abundances show a LFSE enrichment and a marked negative anomaly in Nb, Ta, and Ti. A negative Hf anomaly is present in the Gamikaub, Palmental and Mon Repos bodies. REE patterns show a general enrichment of LREE during crystallization, together with depletion of HREE, compatible with fractionation of amphibole. The Eu anomaly increases with decreasing Sr, indicating that plagioclase played a major role during fractional crystallization. The granitoids are mostly peraluminous, show I- and S-type affinity, and fall in the ‘volcanic-arc’ field in tectonic discrimination diagrams. The distribution of Th/Ta vs. Yb and Th/Hf vs. Ta/Hf invariably plot these magmas into the ‘active continental margin’ field. New U-Pb ages on metagabbros confirm their early formation in the Damaran plutonic event (573±9 Ma and 570±6 Ma for Audawib; 567±7 Ma for Neikhoes), but they are not much older than other Goas intrusions, as previously believed. Ages of the main intrusions are constrained in a range of circa 12 Ma (± errors), and reveal that the oldest diorite age (Gamikaub, 569±8 Ma) is coeval with the metagabbros. Slightly younger are two granodioritic and granitic samples from Oamikaub (563±12 Maand 562±8 Ma) and a diorite from Okatuwo (562±6Ma). The youngest ages belong to the Mon Repos and Palmental bodies (respectively 558±8 Ma in a quartz monzonite and 557±10 Ma in a monzonite). Interestingly, the latter two correspond to the K-rich intrusions, so that the K_2O vs. SiO_2 diagram for the whole Goas suite shows a noticeable trend from tholeiitic to calcalkaline to high-K calcalkaline rocks with decreasing ages, as expected in evolutionary arc magmatic suites. The issue, however, needs to be further investigated, as it cannot be excluded that geochemical trends and isotope signatures represent the result of AFC processes in a non-subduction setting.

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LEUCOSOME FORMATION BY DISEQUILIBRIUM MELTING AND MELT LOSS: LIMPOPO BELT

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Keywords: Limpopo Belt, granulite, fluid-absent partial melting, disequilibrium melting

In many granulite facies metamorphic belts, the biotite fluid-absent melting reactions which produced the leucosomes in metapelitic migmatites are well constrained by the assemblage of peritectic minerals produced within the residua from which the melts separated. The melt compositions produced by these reactions are well documented from experimental studies and from melt inclusions within garnet from metapelitic granulites. Leucosome compositions typically depart markedly from those of melts. The main areas of major-element compositional miss-match involve K_2O, Na_2O and CaO, with the leucosomes commonly having lower K_2O and lower Na_2O:CaO ratios than the melts, although examples of anomalously high K_2O also exist. As the leucosomes form as a consequence of segregation of melt or magma, this compositional miss-match has been interpreted to reflect processes affecting the leucosomes after their formation. Fractional crystallization of plagioclase in the leucosomes and/or K_2O and H_2O migration out of the leucosomes are the most commonly invoked mechanisms. The leucosomes produced within metapelitic granulites of the South Marginal Zone of the Limpopo Belt are markedly low in K_2O and have Na_2O:CaO ratios similar to their source rocks. Anatexis of these rocks has occurred via two biotite breakdown reactions which can be modelled as: 1. Bt + Sil + Qtz + Pl^1 = Grt + Pl^2 + Melt; and at higher temperature, 2. Bt + Qtz + Pl^1 = Opx + Pl^2 + Melt. The lower temperature reaction produces stromatic leucosomes which underwent solid-state deformation before the formation of nebulitic patch leucosomes by the nominally higher temperature, lower pressure reaction which destroyed the earlier formed fabric. The zircon U:Pb ages for both leucosomes, 2714 ± 6.4 Ma and 2713 ± 5.4 Ma respectively, are within error identical and there is no evidence for poly metamorphism of these rocks. Thus, the magma formed by reaction 1. appears to have segregated and formed the mechanically solid stromatic veins whilst temperature was increasing and pressure possibly decreasing. As a consequence, an explanation is required for how the magma solidified during PT evolution of the rocks that should have resulted in increasing magma volume. As the leucosomes predominantly consist of quartz, plagioclase and minor garnet, the process that forms the solid leucosomes at high temperature cannot simply be entrainment of the peritectic plagioclase (Pl^1) and garnet produced by reaction 1. and the precipitation of these crystals from the magma following segregation and prior to melt escape from the structure. In this scenario, the quartz in the leucosmes is the consequence of crystallization from the melt on cooling. Thus, quartz mode should correlate positively with K_2O content and Na_2O/CaO ratio in the leucosomes. No such correlations exist necessitating a mechanism to precipitate quartz and plagioclase without cooling. The trace element compositions of the leucosomes and residua appear to hold the key to identifying this process.Leucosome REE compositions are characterised by marked positive Eu anomalies, whilst their residua show no significant Eu anomaly. Modelling of trace element behaviour under equilibrium melting followed by precipitationn of peritectic plagioclase produces leucosomes that have smaller positive Eu anomalies and residua with slight positive Eu anomalies. Consequently, we suggest a disequilibrium melting process that was characterised by a lack of incongruency in the plagioclase behaviour in the source. We suggest that the outer zones of plagioclase crystals melts completely in the source, with no production of a more calcic peritectic plagioclase. This produces a higher than equilibrium amount of Anorthite molecule in the melt and recovery from this state occurs after melt has segregated into the leucosomes. This process is characterised by a lack of Eu fractionation on melt formation and segregation (batch melting of plagioclase in the source), with the crystallization of relatively An-rich plagioclase in the leucosome structures coupled with co-precipitation of quartz due to the influence of plagioclase precipitation of melt SiO_2 content. These findings argue that the melt leaves the source instantaneously. The leucosome volumes significantly underestimate the volume of melt lost from the rocks. Individual leucosome volumes do not represent the volume of melt or magma present at any one time in the locality occupied the leucosome. Rather they form incrementally as melt leaving the source dump its disequilibrium plagioclase load, as well as quartz and entrained ferromagnesian peritectic minerals, in sites of melt transfer.

MANGANOAN FAYALITE IN THE MN-RICH MESOARCHEAN NTOMBE FORMATION, MOZAAN GROUP

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The Mesoarchean Mozaan Group constitutes the stratigraphically upper part of the Pongola Supergroup in South Africa and Swaziland. It is characterized by sandstone and shale interbedded with minor iron formation. In the study area of the White Umfolozi Inlier, the Mozaan Group has experienced a greenschist grade metamorphic overprint. Major element analyses of shale and sandstone of the Ntombe Formation have revealed appreciable Mn contents. However, the origin of Mn enrichment remains poorly understood. In this work, petrographical, mineralogical and geochemical investigations have been performed to illustrate the variation of Mn contents through the Ntombe Formation, to establish the manganiferous mineral phases and to evaluate the processes involved in Mn enrichment.

A Mn-rich olivine mineral phase has been observed in shale and sandstone of the Ntombe Formation. Its chemical composition ranges between $(Fe_{1.5}Mn_{0.5})SiO_4$ and $(Mn_{1.5}Fe_{0.5})SiO_4$, close to knebelite ($FeMnSiO_4$), which is a manganoan variety of fayalite, belonging to the fayalite-tephroite series. The manganoan fayalite is present as a fracture filling associated with Mn-rich carbonate ranging between rhodochrosite-calcite solid solution (probably Mn-rich kutnahorite), and Fe- and Mn-rich phyllosilicate phases. The olivine variety also occurs as a late mineral phase in intergranular space associated with Fe-rich pyrophanite, Mn- and Fe-rich silicate and phyllosilicate phases. The manganoan fayalite is a common mineral phase, found in Mn- and Fe-rich sedimentary rocks,occurring in a wide range of temperature in metamorphic and/or hydrothermal context. As part of this study, its formation is thought to have taken place during fluid-rock interactions associated withalteration of Mn-rich sedimentary carbonate (e.g. siderite and ankerite) and Mn-rich metamorphic silicate during peak metamorphism experienced by the Ntombe Formation at ca. 2.6 Ga ago. These processes allowed Mn enrichment reaching more than 15 wt. % MnO.

Such high Mn content represents an uncommon feature for sedimentary rocks of that age. Better constraining mineral phases associated with Mn and the processes involved in Mnenrichment are fundamental, as they allow for a better evaluation of the potential of Mn deposits in Archaean rocks in general and in the Pongola Supergroup in particular.

LINKING PLUTONIC CUMULATES TO THEIR VOLCANIC PRODUCTS IN THE 132 MA ETENDEKA LIP, NAMIBIA

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Keywords: Doros Complex; Tristan mantle plume; Paraná-Etendeka Large Igneous Province

The 132 Ma Paraná-Etendeka Large Igneous Province has been attributed to the impact of the Tristan mantle plume and the associated opening of the South Atlantic Ocean, during the Early Cretaceous breakup of West Gondwana. On the Namibian side of the rift, this is preserved as the extensive bimodal Etendeka flood volcanics, and the Damaraland Intrusive Suite, a series of subvolcanic intrusions within the Damara Orogenic Belt.

The Doros Complex is a relatively small (~4 km x 7 km) mafic layered intrusion fromthe Damaraland Suite. It consists of a series of stacked layers of massive or foliated olivine gabbro, with varying compositions and mineral proportions, cut by gabbro pegmatite, monzodiorite and dolerite dykes. Depleted ε_{Nd} of +3.34 to +6.46, moderate $^{87}Sr/^{86}Sr$ (0.703970 – 0.709525) and trends in incompatible trace element ratios indicate that the Doros magma was derived primarily from enriched Tristan plume melts with a significant component of entrained depleted upper mantle and minor crustal or lithospheric mantle contamination.

It has previously been suggested by Marsh *et al.* (2001) that Doros may be the eruptive source of the Tafelkop basaltic lavas of the Etendeka, due to their relatively close proximity and the apparent thickening of the lavas towards Doros. We show that the Doros gabbros also have strong geochemical affinities with the Tafelkop lavas. These common features include near-Bulk Silicate Earth initial Sr ratios and low positive ε_{Nd}, high and variable Ti/Y, Ti/Zr and Zr/Y and relatively low heavy rare earth element concentrations. Pb isotopic compositions of the suites overlap and ^{207}Pb trends are almost identical.Furthermore, trace element modeling of the Doros cumulates from whole-rock chemistry, assuming equilibrium and a closed system,suggests a parental magma composition remarkably similar to the Tafelkop magma type. The Doros-Tafelkop magma series thus represents a set of relatively uncontaminated, predominantly plume-derived melts and derivative cumulates within the Paraná-Etendeka and provides insight into the early stages of magma generation.

PETROGRAPHIC EVIDENCE FOR CRYSTAL-LIQUID REACTION AND DISEQUILIBRIUM, UPPER CRITICAL ZONE, BUSHVELD COMPLEX

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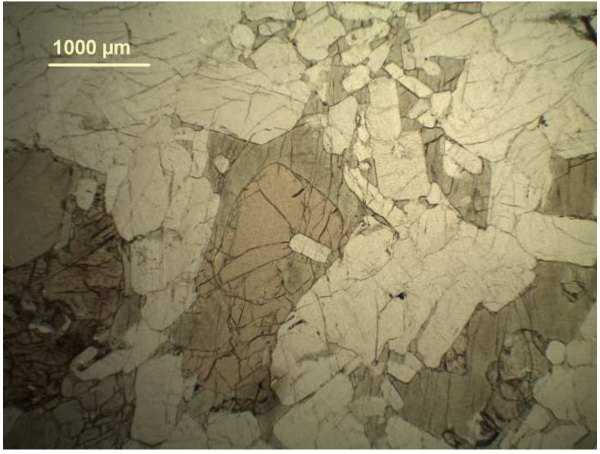
Although the mafic rocks of the Bushveld Complex in general, and the Upper Critical Zone in particular, have been extensively studied over the past century, a number of what appear to be fundamental textural features have been identified which have not, for the most part, been interpreted in the context of magmagenesis. Previous workers have noted complex plagioclase relationships (apparently xenocrystic grains with distinct zoning and morphology relative to neighbouring grains), and isotopic evidence for disequilibrium with interpretations ranging from primary magmatic to late hydrated fluid activity. Textures associated with the Merensky Reef and UG-2 include a range of textural features involving the major silicate phases, plagioclase, orthopyroxene and clinopyroxene. Phenomena such as rounded inclusions of plagioclase in orthopyroxene, plagioclase in plagioclase, rounded orthopyroxene in subhedral orthopyroxene, all suggest a complex magmatic history. Of particular interest are rounded knobs of orthopyroxene within interstitial (often oikocrystic) clinopyroxene.



Resorbed opx within interstitial cpx, hosted within plag laths.

Discontinuous rim of cpx along plag-opx grain boundary.

These textures all require that the rocks did not crystallise in situ as an equilibrium assemblage from a single parent magma. This is not, or should not, be taken as a profound deduction in the sense that complex crystal-liquid interactions have long been proposed for mafic magmas, and those of the Bushveld in particular. Nonetheless, the rocks continue to be modelled as though they are derived from crystallisation of known parent magmas (such as Sharpe's B1, B2 magmas, among others), when clearly these rocks are not representative of parent magma compositions, and are in fact mixtures. It is evident that the mixtures involve magmas which were not in equilibrium, as early primocrysts have been resorbed and then "ended up" hosted within other liquids (either the crystal or the liquid having been transported to facilitate this juxtaposition).

Additional textures of interest include discontinuous rims of clinopyroxene occurring along grain boundaries between orthopyroxene and plagioclase. As these are not reaction rims, possible interpretations include migrated exsolved high-Ca pyroxene, or migrating slivers of trapped interstitital liquid. Localised disequilibria associated with olivine-plagioclase grain boundaries, in the form of immature corona development, are also evident, and are typically characteristic of prolonged heating or slow cooling of the host rock.

APPLICATION OF NOVEL ANALYTICAL TECHNIQUES AND INNOVATIONS IN THE CHARACTERIZATION OF PLATINUM ORES

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Keywords:platinum, nano-minerals, transmission electron microscopy, x-ray computed tomography

We report on new results of a combined FIB/HRTEM investigation of PGE-rich samples from the Merensky Reef of the Bushveld Complex in South Africa. Chromitites and pegmatiticmelanorite from the Northam and Rustenburg Platinum mines contain Ru-Rh- Pt arsenide nanocrystals (< 50 nm in size) as inclusions in pyrrhotite and pyrite, as well as Ru-Rh-Os, Ru-Rh-Pt-Ir and Ru-Rh-Ptsulphidenanocrystals in pyrrhotite and pentlandite. Chalcopyrite did not incorporate nanometre-sized PGE-bearing minerals (PGM). These nano-scale PGM inclusions form a new population that was hitherto unknown from the Merensky Reef. The PGM inclusions are found as idiomorphic, plate-like nanocrystals, but which are differently oriented with respect to the host base metal sulphide (BMS). In one TEM foil we observed Ru-Rh-Pt-sulphidenanocrystalsexsolved from its pentlandite matrix with a common crystallographic orientation that is visible in TEM dark-field images. However, this phenomenon is only patchily developed and ahead of the exsolution front the pentlandite still contains Ru-Rh in solid solution. Occasionally the PGM inclusions form clusters, develop a flow texture or they are aligned like pearls on a string. These observations are inconsistent with sub-solidus exsolution and suggest that the nano-scale PGM had already crystallized before solidification of the sulphide melt and the formation of their BMS hosts. There is evidence from recently performed laboratory experiments on silicate melts with additives of Ru and Pd that discrete Fe-rich Fe-Ru-Pd alloys (nanometre-sized) can indeed crystallize early upon cooling. These experiments raise the possibility that the PGE-bearing nanocrystal inclusions found in the BMS of the Merensky Reef might represent preserved relicts of an early phase of magmatic PGM that precipitated from the silicate melt and afterwards were collected by the sulphide melt. Combined FIB/HRTEM techniques open up a window through which the nano-scale mineral population can be viewed. PGE previously thought to be present in BMS solid solution might actually be an artefact of inadequate spatial resolution.Application of X-Ray Computed Tomography (XRCT) to the investigation of mineral assemblages has the potential of revolutionising metrology of natural materials. The distribution of mineral aggregates in three dimensions provides a more rigorous approach to quantitative measurements of textural associations, mineral modes and thus their confident interpretation. Mineralized samples from the Merensky Reef of the Bushveld Complex have been subject to XRCT analysis and the results will be presented and discussed. The procedure involves the collection of X-Ray projections during rotation of the sample, usually a rock specimen or epoxy mount, that results in a series of grey scale images. The image stack is reconstructed into a 3D volume that is composed of voxels (3D pixel), each of which has a grey scale value proportional to their X-Ray transmissivity. The latest flat panel detector provides 16-bit greyscale images with 65 000+ values, thereby enhancing the resolution of individual minerals through segmentation. Since each voxel is referenced in X-Y-Z space, the subsequent visualization procedure provides important spatial information that can be utilised for quantitative petrographic characterization. One of the most powerful features of the XRCT visualization is the rendering of mineral textures in animated 3D. Mineral separation can be achieved digitally and the distribution of platinum group minerals (PGM) and base metal sulphides (BMS) accurately depicted and quantitatively estimated. Such true volumetric modes have the potential to supercede the conventional modal analysis that is restricted to planar sections (eg. rock slabs, thin sections). Voxel analysis has enabled the confirmation of continuous networks of BMS throughout the Merenskylithologies (pegmatitic reef, chromitite, pyroxenite), thus providing evidence for enhanced permeability. BMS-Chromite and BMS-Silicate boundaries are highlighted as preferential sites of PGM location. XRCT is a rapid technique to detect PGM in rock samples subject to limited pre-preparation, without the need for prolonged assay procedures or specialized electron microscopy.

PETROLOGICAL ASPECTS OF DEEP CRUSTAL XENOLITHS FROM SOUTHERN AFRICAN KIMBERLITES

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Keywords: lower crust, granulite, xenoliths, Kaapvaal Craton, Natal Metamorphic Province

The present erosion surface of the Kaapvaal Craton does not provide a lot of direct evidence of its deeper structure and composition. Apart from the fact that much of the craton is hidden below the Karoo cover, the metamorphic overprint of the exposed rocks typically reaches greenschist to amphibolite facies. Exposures of Archaean granulite-facies rocks are rare and restricted to a small number of greenstone belts, the central uplift of the Vredefort Dome, and a few localities in Swaziland. The granulite occurrences of the northernmost Kaapvaal Craton relate to the Limpopo orogeny. Thus, access to rocks originating from the deeper Archaean crust of southern Africa is very limited, mainly due to the fact that much of the Kaapvaal Craton has remained geologically stable since its consolidation about 3 Ga ago. Only some of the Swaziland granulite occurrences relate to a younger orogenic event affecting the craton margin at about 2.7 Ga (Hofmann et al., in prep.).

Nevertheless, according to evidence from crustal xenoliths in kimberlites, granulitic lower crust appears to be widespread in the Kaapvaal Craton. While previous research on xenoliths has largely focused on mantle material brought up with the kimberlites, the crustal components have attracted much less attention. Hence, knowledge about the deeper Archaean crust and its evolution remains fragmentary.

A current project focuses on xenoliths from kimberlite mines of east-central South Africa and Lesotho. Initial results of petrological studies show that many of the metamorphic rock types encountered have no counterparts in surface exposures. Garnet-rich granulites are present as well as quartzo-feldspathic rocks with high-temperature deformation fabrics. Ultrahigh-temperature (UHT) metamorphism, previously described from Lace xenoliths (Dawson et al., 1997), appears to have been widespread. Indicators are sapphirine-quartz and spinel-quartz assemblages. The UHT granulites show a range of reaction textures, mostly of retrograde nature, that allow reconstructing P-T paths to some extent. High-temperature reaction textures include coronas around peak-metamorphic minerals, and unmixing of ternary feldspars and Ti-rich quartz.

Across the southern margin of the Kaapvaal Craton, the situation is similar in respect of finding abundant granulitic xenoliths while the closest exposures in the Natal Metamorphic Province are confined to amphibolite-facies peak metamorphism. Amongst the crustal samples are high-pressure granulites (as reported by Schmitz & Bowring, 2004). However, UHT granulite, though less common, is also present. Such a variation in metamorphic pressure-temperature conditions requires an explanation. Evidently, detailed studies of deep-crustal xenoliths are crucial, not only for obtaining information on peak metamorphism and pressure-temperature histories, but more generally for understanding the Archaean to Proterozoic processes of formation and evolution of continental crust in southern Africa.

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CATASTROPHIC COMPACTION IN THE UPPER ZONE OF THE BUSHVELD CENTRE

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Keywords: Upper Zone, Bushveld, compaction, crystallisation, trapped liquid

Compaction is a common process in most layered intrusions, in which the crystallisation front formed by *in-situ* crystallisation collapses under the weight of the overlying crystal mush, and trapped liquid, with an enriched and differentiated character, is forced into the overlying crystal mush. This process results in increased incompatible trace element content in the overlying crystal pile, and is often considered to be a constant process operating throughout the crystallisation history of the intrusion. However, in the Upper Zone of the Bushveld Complex, the behaviour of incompatible trace elements such as Zr implies that the compaction process in this intrusion was episodic rather than constant in nature. In studies of the Bierkraal borehole, several silicate cycles are clearly identifiable, marked by the occurrence of magnetitite layers at the base and top of each cycle. Zr is at its maximum at the base of the silicate pile, and then shows a systematic decrease with height in the intrusion, until a minimum is reached approximately halfway up the cycle. From this point onwards, Zr shows a more traditional increasing fractional crystallisation trend. This cycle of depletion followed by enrichment is most likely explained as the result of a catastrophic collapse of the early formed magnetitite crystallisation front, and the subsequent expulsion of incompatible-enriched liquid previously trapped in the magnetite mush. The trace element abundance in the silicate unit above the collapsed magnetite front is thus determined by the proportion of expelled liquid present, rather than by fractional crystallisation, and can be modelled as such. This process of episodic collapse has not been observed in other layered intrusions or in other portions of the Bushveld Complex, and may be related to the processes which lead to the early crystallisation of large quantities of magnetitite.

THE LOWER MAIN ZONE IN THE NORTHERN LIMB OF THE BUSHVELD COMPLEX: A PRODUCT OF MUSH EMPLACEMENT

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Keywords: Bushveld Complex, Main Zone, crystal mushes, staging chamber, crustal contamination

The 1563.02 m deep Moorkopje (MO-1) drill core, drilled on the Northern Limb of the Bushveld Complex sampled a ~1.3 km section of mainly gabbronoritic rocks belonging to the lower Main Zone of the Complex. The lower Main Zone is characterized by a number of interesting features, including very limited large scale differentiation as exemplified by parameters such as the An% of plagioclase, the Mg# of pyroxenes and the Modified Differentiation Index (MDI), the near-absence of inverted pigeonite (which becomes a cumulus phase at much lower levels of the intrusion at other localities within the Bushveld Complex), non-cotectic proportions of plagioclase : pyroxene, the decoupling of the differentiation trends of plagioclase and pyroxene, and importantly, significant Sr-isotopic disequilibrium between co-existing plagioclase and pyroxene. The features of the lower Main Zone as exposed by MO-1 and as presented above were interpreted to have resulted from the repeated influx of crystal mushes from a sub-Bushveld staging chamber that has been variably contaminated with melts derived from lower and upper crustal sources. Nd-Sr isotopic models suggest that the observed isotopic compositions of plagioclase and co-existing orthopyroxene may have resulted from a multi-chambered staging chamber, with plagioclase crystallizing in a part of the chamber contaminated by a larger proportion of lower crustal material and with orthopyroxene crystallizing in a part of the chamber contaminated by a proportionately higher amount of upper crustal material. The composition of the Outer Granite Gneiss and the Inlandsee Leucogranofels as exposed within the Vredefort Dome were used as proxies for the upper and lower crust, respectively. It is proposed that separate plagioclase- and orthopyroxene-charged mushes mixed during ascent prior to emplacement into the main Bushveld magma chamber to yield rocks of a gabbronoritic composition.

THE CHARACTERIZATION OF PYRITE FROM THE VENTERSDORP CONTACT REEF OF KLOOF GOLD MINE IN THE WITWATERSRAND BASIN IN SOUTH AFRICA

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Keywords: Witwatersrand Basin; Ventersdorp Contact Reef; Pyrite; Trace Elements

The 2.9 Ga Witwatersrand (Wits) basin hosts numerous auriferous reefs, most of which also contain large concentrations of sulphide minerals, primarily pyrite. The Ventersdorp Contact Reef (VCR) in the West Wits area contains rounded and angular pyrite grains. The pyrites were studied using reflected light microscope (RLM), scanning electron microscope (SEM), particle induced x-ray emission (PIXE), electron microprobe (EMP), and laser ablation inductively coupled mass spectrometry (LA-ICP-MS), to characterize the shapes, textures, inclusions, chemical zonations, and overgrowths, as well as the major, minor and trace element content of the pyrites. The rounded porous pyrites have either sponge-like textures or are massive. These grains host inclusions of arsenopyrite, chalcopyrite, galena, gold, and zircon. The angular pyrites generally have massive textures, with inclusions of chalcopyrite, pyrrhotite, and gold. The highest concentrations of Ni, Co, Ag, As, Cu, Zn, Au, Pb, Pt, and Pd were observed in individual rounded pyrite grains. Nevertheless, average concentrations of these elements are higher in the angular pyrite grains than in the rounded pyrite grains.The angular pyrite grains contain high average concentration of 0.08 wt % Co (average of 10 data points, ranging from 0.01 to 0.2 wt % Co); and low average of 0.24 wt % Ni, ranging from 0.09 to 0.59 wt % Ni, and giving low Ni/Co ratio of 3.05. Comparatively, the rounded pyrite grains gave high Ni/Co ratio of 7.55, but low Co average concentration of 0.04 wt % (averaging 8 data points, ranging from 0.03 to 0.09 wt %), and high average of 0.27 wt % Ni, ranging 0.01 to 0.58 wt % Ni. The Ni/Co ratio is therefore about 2.5 times larger for angular pyrite grains than for rounded pyrite types.The data gathered indicates that the angular grains are hydrothermally formed, whereas rounded grains are detrital in origin.

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THE JAMESTOWN ARCHEAN OPHIOLITE AND THE BON ACCORD OXIDE BODY

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Keywords: Barberton greenstone belt, nickel mineralisation, mantle-crust interaction

The Jamestown Suite occurs in the northern section of the Barberton greenstone belt. It consists mainly of an ultramafic sheet, highly depleted in LILEs, and the contacts of with the surrounding granite batholiths are intensely brecciated. These indications that the rock suite is neither a primary magma, nor autochthenous, has led to the interpretation that it represents the deleted mantle portion of an Archean ophiolite. Near the northern edge of the ultramafic rocks there is anunusual and enigmatic little oxide body which is highly enriched in nickel (>35% NiO, whole rock), from which 6 new Ni minerals (silicates, a carbonate and a borate) were described by de Waal in the late 1960s and early 1970s. The fact that it is also anomalously enriched in the platinum-group elements (PGE) has led some investigators in the past, including de Waal himself, to interpret the body as the remnant of a paleo-meteorite. However, a good case can also be made for a scenario in which the body is of terrestrial origin and has co-evolved with the ultramafic host. Some recent Cr isotopic data will be presented, which supports the latter model rather than the former one.

PILANESBERG EUDIALYTE - THE GEOCHRONOLOGICAL AND GEOCHEMICAL CONSTRAINTS

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Keywords: eudialyte, lujavrite, Ar-Ar isotope, syenite

The Pilanesberg Complex has proved to be of great interest not only due to its high proportion of rare earth elements (REE's), large ion lithophile elements (LILE) and high field strength elements (HFSE) but also due to the insufficient data available on the Pilanesberg Alkaline Complex.The Mesoproterozoic Pilanesberg Alkaline Complex, emplaced into the Paleoproterozoic Bushveld Complex, has been reported to have occurrences of eudialyte group mineralisation (EGM). Lurie (1973) reported eudialyte as an accessory mineral in a number of the major rock types occurring within the complex. The present project aims to characterise the eudialyte mineralisation associated with lujavrites from the Pilanesberg alkaline complex. The lujavrite studied occurs as an arcuate ring-dike unit in the southern part of the complex.

Eudialyte, a sodium, calcium, cerium, iron, manganese, zirconium hydrous silicate, is a complex mineral, which creates difficulty when trying to analyse it. Compilation of mineral chemical data on eudialytes from different alkaline complexes around the world indicates that there are two main groups of eudialyte, with their Mn/Fe ratio being important. The first group which is rich in iron is formed by magmatic processes; the second, a manganese-rich EGM forms by post-magmatic or hydrothermal processes. Mitchell and Liferovich (2006) identified eudialyte within aegirine lujavrites from the Pilanesberg alkaline complex; these eudialytes are believed to have been altered due to hydrothermal processes. The eudialyte minerals studied from the Ledig lujavrites in this study are rich in iron and show a magmatic to late-magmatic origin. The early magmatic origin of eudialytes studied here goes hand in hand with their general association with amphibole (Figure 1A and B), similar to those reported from the literature. Our compilation exercise using mineral chemical data shows that early magmatic eudialytes (Figure 1C and D) are associated with specific mineral assemblages, while post-magmatic or hydrothermal ones are associated with different minerals. Preliminary Ar-Ar isotope studies have been carried out on the eudialytes from the Ledig region, resulting in two prominent ages which could possibly be linked to the two processes.

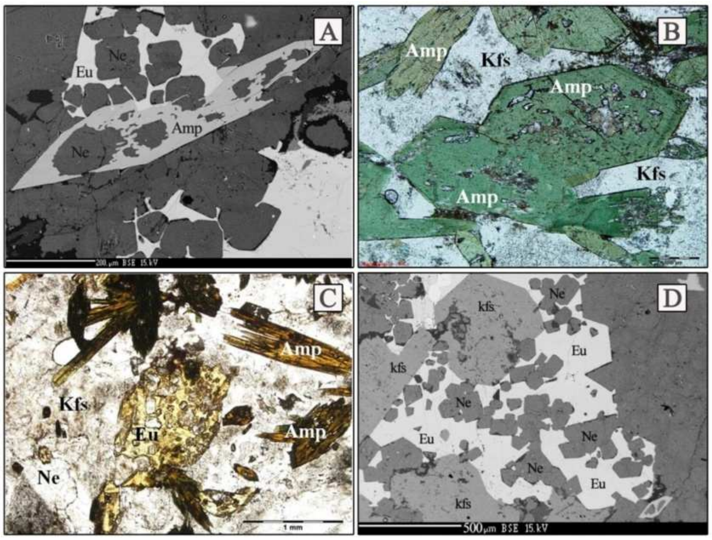

Figure 1: Some characteristic textures and mineral relationships seen in the lujavrite from the Pilanesberg alkaline complex. (A) Back-scattered electron image and (B) a photomicrograph in plane polarised light of euhedral amphibole grains with a poikilitic texture. (C) Photomicrograph in plane polarised light and (D) back-scattered electron image of an anhedral poikilitic eudialyte grain containing nepheline inclusions.

Hf –U–Pb ISOTOPES, TRACE ELEMENTS AND INCLUSIONS IN BUSHVELD ZIRCONS

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Keywords: Bushveld Complex, Hf isotopes, zircons, crust, mantle

Hf isotopes and the ratio of Hf^{176} to Hf^{177} are powerful indicators of how and when the crust formed because of the supposed complementary reservoirs of enriched continental crust and depleted mantle, coupled with the strongly incompatible properties of Hf. Model ages reflect when separation took place of crustal material from the mantle source. Zircons are widely used in Hf isotope studies because of the relative ease of measurement and high precision obtained. Relatively few zircons plot between the time integrated depleted mantle curve and that for new crust indicating that pre-existing crust has been recycled into the mantle for at least the last 3 billion years (Hawksworth *et al.*, 2010); Dhuime *et al.*, 2011).

The Bushveld Complex has long been known to have a strong crustal signature (Kruger, 1994) but recent studies of primitive sequences in the Lower Zone have revealed the existence of early-stage primitive magmas that gave rise to high-Mg olivines (Fo91.5) that are consistent with a primitive mantle source. At least two such magmas were present with one having 19% MgO, possibly of komatiitic origin, and the other a precursor to the popular B1 magma with 16.5% MgO (Wilson, 2012a; Wilson 2012b; Yadovskaya *et al.*, 2012). The interaction of crust and mantle sources in controlling the parental magmas to the Bushveld Complex may hold the key to understanding its enormous mineral wealth.

As part of this understanding a study has been conducted on Hf isotopes in zircons from the Bushveld Complex from a range of environments and is preliminary to a much more detailed study currently underway. Zircons were extracted from Critical Zone rocks, the Merensky Reef, the Main Zone and Upper Zone. U-Pb ages, internal zoning patterns, mineral inclusions and Ti-in-zircon thermometry reveal that the zircons of all units crystallised at ca. 2.055 Ga from quartz-saturated melts at variable temperatures: Merensky Reef (890°C), Critical and Lower Main Zone (>850-800°C), and Upper Zone (>730°C). Despite these variations most zircons show similar Li, Y, and REE contents, and Eu/Eu^*_N, Yb/Sm_N, Nb/Ta ratios, except zircons from the Upper Zone. Important trace element variations within samples can be explained mostly by post-zircon growth alteration, which is reflected by diffuse zoning patterns, dark CL, and high Ca, Li and/or Fe contents. Recrystallized melt inclusions in zircon, reveal granitic to ultramafic to mafic compositions, and hint that the zircons formed from highly evolved and diversified intercumulus melts, perhaps in disequilibrium with the surrounding cumulus phases.

The Hf isotope data reveal that most of the magmas parental to the different Bushveld units were low-radiogenic, and contained important amounts of much older crust, which was either assimilated during the emplacement of Bushveld magmas at 2.06 Ga, and/or more likely re-molten within the SCLM, where it resided for up to 1.5 billion years; perhaps remnants of much older, hydrothermally altered oceanic crust (>85%) and felsic crust (<15%), that became “subducted” during the various stages of amalgamation of the Kaapvaal Craton at 3.25, 3.0 and 2.7 Ga.

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Some local information:

Reliable taxi companies

Bloem Taxi	051 433 3776 / 072 349 9738
Happy Cabbies	086 14 277 9222
MAS cabs	073 8693155/7975443
Phalima Shuttle Service	082 575 1549

Some of the nearby restaurants (see Bloemfontein map in the voyer):

On campus: Thakaneng Bridge and Foodzone Convenience Store

Off campus (all reachable in <10 minutes):

1. Coobah (lunch, supper, cocktails): laid back
2. Burning Spear Spur: you know what to expect
3. House of Bread (lunch): coffee house
4. Mimosa shopping mall: many options for both lunch and supper
5. Mystic Boer (supper - pizzas only): rock music hang-out, mainly SA bands
6. Oolong Lounge (supper): eastern fusion
7. Barba's: pub
8. Cubaña (supper): cocktail lounge and light meals
9. New York (supper): upmarket steakhouse, but not too pricy
10. Bella Casa (supper): Italian
11. Avanti (lunch and supper): Italian
12. Mr Chinese (lunch and supper): guess what?
13. Waterfront shopping mall: many options for both lunch and supper