

Mineralogical and geochemical investigation of Uranium conglomerate ores of the Dominion Reef Group, Western Witwatersrand, South Africa

Thesis submitted in fulfillment of the requirements for the degree of

Master of Science

handed in by
Ulrike Rantzsch

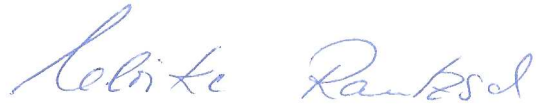
In the Faculty of Science
University of the Free State
Bloemfontein, South Africa
Department of Geology

Supervisor: Prof. Dr. Christoph D.K. Gauert
Co-supervisor: Prof. Dr. Willem A. van der Westhuizen

February 2009

Declaration

I, Ulrike Rantzsch declare that this thesis is my own, unaided work. It is being submitted for the Degree of Master of Science in the University of the Free State, Bloemfontein, South Africa.



Leipzig, the 20th February 2009

Abstract

Throughout the thesis, the genesis of the Dominion Reefs as Au-U placer deposits with particular focus of their paragenetic sequences whose detrital and/or hydrothermal origin was investigated. Dominion conglomerate Reefs are composed of quartz pebbles and detrital heavy minerals supported by an argillaceous matrix of illitic-chloritic composition. Geochemistry and mineralogy of two distinct Reefs has been characterized using petrographic studies, various whole rock geochemical analyses, and electron microprobe analyses.

XRF analyses yield numerous results. Dominion conglomerates could be classified as sublitharenite, litharenite, and Fe-sands by major element geochemistry. The heavy mineral paragenesis (garnet, pyrite, monazite, zircon, chromite, magnetite, ilmenite, and phases containing uranium and thorium) suggests that the source of sediments is most likely similar to Archean granite-greenstone terrains. For tectonic setting of the sediments a passive margin and continental rift setting can be considered. Provenance investigation based on REE analysis suggests sedimentary recycling of felsic- and upper continental crust material as source rocks. Furthermore, the evaluation of geochemical data using the Pearson correlation coefficient suggests relationships of identified minerals. Elements, hosted in detrital minerals show a good correlation as well as elements hosted in hydrothermal- or hydrothermally altered minerals.

Petrographic and SEM observations provided the opportunity to discriminate different generations of U-bearing minerals present in the Reefs. The chemical composition of U-bearing minerals can be correlated with their origin. Preserved uraninite sub-rounded grains occur associated with the primary detrital heavy mineral paragenesis. Moderate to high Th content (up to 9.30 wt% ThO₂) of uraninite grains provided by EMPA support their magmatic origin. All uraninite identified are of detrital origin. Moreover, the chemical results allow distinguishing two individual groups and suggest that uraninite grains have been extracted from at least two distinct granitic or pegmatitic sources. However, the majority of U mineralization is represented by re-crystallized phases as secondary uranium bearing phases (pitchblende without Th), coffinite, U-Ti and U-Th phases occurring with the uranium redistribution by later hydrothermal processes.

LA-ICP-MS analyses revealed a distinct age of 3100 ± 90 Ma for the primary mineralisation. The initial stage involved the placer development with deposition of detrital uraninite and related minerals. The younger age of 2700 ± 100 Ma as hydrothermal fluid event is recognised in the geochronological data, which correspond in time to the extrusion of the Ventersdorp lavas at ~ 2720 Ma. In this stage hydrothermally growth of mineral phases including secondary U bearing phases, galena and other minerals occurred.

Zusammenfassung

In dieser Studie wurde die Genese der Dominion Riffe als Au-U Seifenlagerstätten mit dem Schwerpunkt detritische und/oder hydrothermale Entstehung der Minerale erforscht. Die Konglomerate der Dominion Riffe bestehen aus Quarzkiesel mit detritischen Schwermineralen in einer Illit und Chlorit Tonmineral Matrix. Zahlreiche Petrographische Studien, Roentgenfluoreszenzanalysen, sowie Elektronenmikrosondenanalysen wurden an zahlreichen Riffproben durchgeführt.

Roentgenfluoreszenzanalysen ergaben zahlreiche Ergebnisse. Die Sedimente der Dominion Riffe wurden als Sublitharenite, Litharenite und Fe-Sand klassifiziert. Geochemische Daten liefern Informationen zu moeglichen Herkunftsgebieten fuer die eingetragenen Sedimente. Archaische Granit-Gruenstein Gebiete sind als moegliche Provenienz denkbar. Als tektonischer Rahmen wurde ein passiven Kontinentalrand und ein kontinentaler Graben bestimmt. Die SEE Untersuchungen ergaben, dass recycelte Sedimente von felsischen oberen Krustenmaterial als Liefergesteine für detritische Minerale denkbar sind.

Des weiteren konnte mit Hilfe Geochemischer Daten, die Beziehungen der Minerale in den Dominion Sedimenten mit dem Pearson Korrelationskoeffizienten untersucht und bestimmt werden. Elemente in detritischen Mineralen zeigten einen hohen Korrelationsgrad, wie auch Elemente in hydrothermal gebildeten Mineralen.

Mit Hilfe von petrographischen und REM Analysen wurden verschiedene Generationen von Urantragenden Phasen identifiziert. Die chemische Zusammensetzung der einzelnen Minerale kann mit deren Entstehung korreliert werden. Gut gerundete Uraninitkoerner bilden mit detritischen Schwermineralen Paragenesen. Mittlerer bis hoher Th Gehalt (bis zu 9.30 wt % ThO₂) der Uraninite wurden mit Mikrosondenanalysen nachgewiesen und belegen eine magmatische Entstehung. Allen Uraniniten kann eine detritische Entstehung zugeordnet werden. Uraninitanalysen ergaben die Existenz von zwei Generationen, die wahrscheinlich von verschiedenen Muttergesteinen stammen, von pegmatitischen und granitischen Gesteinen. Die Mehrheit der Uran fuehrenden Minerale sind rekristallisierte sekundaere Urantragende Phasen (Pechblende ohne Th), Coffinit, U-Ti and U-Th Phasen.

LA-ICP-MS Untersuchungen ergaben für die Erstmineralization ein Alter von 3100 ± 90 Millionen Jahre. Dises Alter entspricht der Seifenentstehung mit der Ablagerung von detritischen Uraninit und verwandten Mineralen. Das juengere Alter von 2700 ± 100 Millione Jahren wurde mit Hilfe von Geochronologischen Daten als hydrothermaler Fluid Prozess erfasst und korrespondiert mit der Extrusion der Ventersdorp Lavas vor ~ 2720 Millionen Jahren. In dieser Phase kam es zur Bildung von sekundaere U haltigen Phasen, Galenit und anderen sekundaeren Mineralen.

Acknowledgements

I would like to express my appreciation to Prof. Dr. Christoph Gauert from the Department of Geology, UFS, Bloemfontein, for initiating the project and providing dedicated and stimulating supervision throughout my work. Prof. Dr. Willem v/d Westhuizen is thanked for the worthy comments on the research subject. Special thanks to Rina Immelman for the organisation and support of my sojourn in South Africa. I would also like to thank the laboratory personnel of the Department of Geology for preparing my polished thin sections and fusion disks for the geochemical analyses. The personnel from centre of microscopy (UFS) will be thanked for the assistance during the SEM analyses.

We are grateful to the geology staff of Uranium One Africa, especially to the Dr. Richard Stewart and Stephan Stander for initiating this near-industry research project and for the hospitality, support, and provision of logistics and data. The management of Uranium One Africa is acknowledged for allowing access to their lease areas and for their permission to carry out this research.

I am grateful to all scientists and departments that contributed to my work providing not only data but also knowledge and inspiration: Prof. Dr. Michel Cuney and MSc Isabelle Duhamel from the Faculté des Sciences, Université Henri Poincaré Nancy, France. I would like to express my special thanks to MSc Isabelle Duhamel for the assistance and support during my stay in France. Thanks to Dr. Axel Gerdes from the University of Frankfurt in Germany for the analytic support and providing LA-ICP-MS data as well as scientific input.

I would especially like to thank my sister Susanne for the critical reading of my work scripts.

List of figures

Fig.1-1	Overview map of South Africa with Dominion project location (http://www.uranium1.com)	1
Fig.1-2	Distribution of the main Archean stratigraphic units of the Kaapvaal Craton, modified from Schmitz et al. (2004)	4
Fig.1-3	Simplified geological map of the Witwatersrand basin, modified from Frimmel and Minter (2002)	5
Fig.1-4	Surface geology of the Klerksdorp area with mining operation areas and sampled boreholes (modified from Harley & Dixon 2006)	6
Fig.1-5	A: stratigraphic column and ages of the Witwatersrand basin (modified from Robb and Meyer 1995) B: Dominion Group stratigraphy valid for Dominion and Rietkuil area (modified from sxr Uranium One Inc. exploration geologists 2006)	8
Fig.1-6	Illustration of the Unmodified Placer model proposed for the origin of gold and uraninite in the Witwatersrand Basin (modified from Kirk et al. 2001)	10
Fig.1-7	Illustration of the Modified Placer model proposed for the origin of gold and uraninite in the Witwatersrand Basin (modified from Kirk et al. 2001)	11
Fig.1-8	Illustration of the metamorphic/ hydrothermal model proposed for the origin of gold and uraninite in the Witwatersrand Basin (modified from Kirk et al. 2001)	11
Fig.1-9	Mining areas with underground development and resources estimates (http://www.uranium1.com)	15
Fig.1-10	Diagram of historical uranium production and consumption (http://www.uranium1.com presentation U3O8-Market Fundamentals, 4 Oct07, page 18)	16
Fig.2-1	Autoradiography method, A: samples overlaid with a thin photographic film and covered with lead, B: the produced image of the radioactive minerals on films	23
Fig.3-1	Sample DRT 034 BO 8627	32
Fig.3-2	Sample DRT 079 AO 5268	33
Fig.3-3	Sample DRT 095 CO 7744	34
Fig.3-4	Sample DRT 100 CO 7422	35
Fig.3-5	Sample DDR 007 DO 3337	36
Fig.3-6	Sample DDR 077 CO 5602	37

Fig.3-7	Image of the radioactive minerals on photographic film with the thin section, autoradiography method (Rogers 1979) on sample DDR 077 CO 5602	38
Fig.3-8	Microscopic pictures under reflected light (rl), A: altered uraninite (ur) B: uraninite (ur) with linear cracks and specks of galena (gl) between quartz pebbles (qtz pebbles), C: rounded coffinite (coff) grain next to U-Th mineral phases (U-Th) and specks of pyrite (py) within the chloritic/sericitic/quartz matrix (chl/ser/qtz) D: oval uraninite (ur) grain with cloudy U-Ti mineral phases (U-Ti) and quartz (qtz) as infilling, E: uraninite (ur) rimed by U-Ti mineral phases and pyrite, the core consists of quartz, F: U-Ti phases (U-Ti) appears next to zircon (zr) and pyrite, the brownish leucoxene overgrowths zircon (zr/leu), the zircon core is hardly visible	44
Fig.3-9	Microscopic pictures under reflected (rl) and transmitted light (tl) within chloritic and sericitic matrix, A: well rounded monazite (mon), fractured (rl), B: rounded monazite (mon) with fractures (metamict material as infilling) next to altered uraninite (ur) with U-Ti phases (U-Ti) as rim, C: zoned zircon (zr) (crossed tl) with orange alteration rim, D: zoned zircon (zr) (tl) with fractures, E: oval columbite (cb) (rl), F: zoned zircon (zr) in a close bond with uraninite (ur) (rl)	46
Fig.3-10	Microscopic pictures under reflected light (rl) and transmitted light (tl), A: magnetite (mag) with isometric original structures in both grains (rl), B: elongate rutile (ru) with magnetite (crossed tl), C: anatase (ana) as cloudy patchy mass (rl) next to leucoxene (leu), D: cracked chromite grain (chr) accompanied by pyrite and uraninite grains, E: rutile (ru) next to leucoxene (leu), accompanied with pyrite (py), F: corroded magnetite (mag) grain (rl)	48
Fig.3-11	Microscopic pictures of pyrite (py) under reflected light (rl), A: allogenic pyrite (py) with sphalerite (sp) inclusions and abraided outlines, B: authigenic reconstituted pyrite (py), C: authigenic reconstituted pyrite (py) in triangle shape, D: concretionary authigenic pyrite (py) around quartz (qtz), E: concretionary pyrite (py) grain with typical zoning, F: concretionary pyrite (py) grain, next to fine dispersed pyrite (py II)	51

Fig.3-12	Microscopic pictures of pyrite under reflected light (rl), A: arsenopyrite (ars) next to sphalerite (sp) and pyrite (py), B: pyrite (py) with sphalerite (sp) and galena (gl), C: pyrite (py) with chalcopyrite (cp), C: galena (gl) as specks in uraninite (ur) next to zoned zircon (zr) and pyrite (py)	52
Fig.3-13	Microscopic pictures under transmitted light (tl), A: rounded garnet (gn), corroded and fractured (tl), B: rounded garnet (gn), fractured (crossed tl), C: quartz (qtz), fine dispersed sericitic and chloritic matrix (chl/ser) (tl), D: sericitic, chloritic (chl/ser), quartzitic matrix (qtz) with sulphides (sulph) (tl)	54
Fig.3-14	Texture of minerals in sample DRT 034 DO 8628 (gn = garnet, py = pyrite, sulph = sulphides, chl/ser = chlorite and sericite, qtz = quartz)	56
Fig.3-15	Texture of minerals in sample DDR 077 CO 5512 (A), and DRT 039 DO 6920 (B) (py = pyrite, sulph = sulphides, chl/ser = chlorite and sericite, qtz = quartz, sulph fillings= sulphide fillings)	58
Fig.3-16	Texture of minerals in sample DDR 077 CO 5602 (py = pyrite, sulph = sulphides, chl/ser = chlorite and sericite, qtz pebble = quartz pebble, sulph filled= fractures filled with sulphides)	59
Fig.4-1	Classification of all analysed Dominion Reefs samples in the Sand Class System from Herron (1988)	64
Fig.4-2	Discrimination diagram which evaluates quartz, feldspar, pyroxene/ amphibole and clay/mica mineral composition of all sediment samples from the Rietkuil, and the Dominion section	65
Fig.4-3	Ternary diagram using the proportions of $(Al_2O_3-(Na_2O+K_2O))/2$ and Na_2O+K_2O and $(MgO+MnO+Fe_2O_3)/3$, the general weathering trend would tend towards the left corner (red arrows), the studied Dominion Reef samples display a significant trend towards mica and chlorite (black arrows)	67
Fig.4-4	Discrimination bivariate plot for sandstones from Bhatia (1983) of Al_2O_3/SiO_2 versus Fe_2O_3+MgO , the fields within the diagram represent different geological settings	69
Fig.4-5	Discrimination function plot after Roser and Korsch (1988) for determination of the possible original source rocks of the Dominion Reef sediments	70

Fig.4-6	Chondrite normalized REE pattern after Nakamura (1974) of analysed sediment samples from the Dominion Reefs and the Upper Continental Crust (UCC), the Lower Continental Crust (LCC)	72
Fig.4-7	Plot after Floyd and Leveridge (1987), modified by Nagender Nath et al. (2000) illustrates Hf versus La/Th (in ppm) ratios indicates possible source materials such as felsic- and Upper Continental Crust material for the analysed Dominion Reef samples, (TOIS= Tholeiitic Ocean Island source, AAS= Andesitic Arc source, LCC= Lower Continental Crust, UCC = Upper Continental Crust)	73
Fig.4-8	Plot after McLennan et al. (1993) illustrates the Zr/Sc versus the Th/Sc ratios (in ppm) of the analysed Dominion Reef samples, the samples display a trend which can be attributed to recycling of older sedimentary source rocks	74
Fig.4-9	Harker diagrams (Harker 1909) for Al ₂ O ₃ , TiO ₂ , MnO, Fe ₂ O ₃ , and P ₂ O ₅ , CaO, K ₂ O MgO versus SiO ₂ , geochemical relationships displayed as trend line, (r-pearson coefficient)	78/79
Fig.4-10	Variation diagram of Y versus Zr, the bulk of Dominion Reefs whole rock samples are displayed between Zr/Y ratio lines 2 and 4	81
Fig.4-11	Variation diagram of Co versus Ni from Dominion Reefs whole rock samples, perfect geochemical relationship is displayed as linear trend line	83
Fig.4-12	Variation diagram of U versus Th with whole rock Dominion Reefs samples with mean rock compositions and significant Th/U ratios	86
Fig.5-1	Semi-quantitative analyses of sample DRT 039 DO 6920, A: tabular values, B: EDX-spectrum displaying elements	89
Fig.5-2	Element mapping of sample DRT 039 DO 6920	91
Fig.5-3	BSE image of sample DRT 039 DO6920 with all identified minerals (ur = uraninite, pitch = pitchblende, U-Th = U-Th phases, U-Ti = U-Ti phases cr = chromite, C = carbon, zr = zircon)	92
Fig.5-4	Semi-quantitative analyses of sample DRT 079 AO 5268, A: tabular values, B: EDX-spectrum displaying elements	92
Fig.5-5	Element mapping of sample DRT 079 AO 5268	94
Fig.5-6	BSE image of sample DRT 079 AO 5268 with all identified minerals (ur = uraninite, mon = monazite, gn = garnet, sulph = sulphides, zr = zircon, qtz pebble = quartz pebble)	95

Fig.5-7	BSE images of monazite grains in sample DO 8628-A (A), DO 6920 (B), DO 8628-A (C), DO 8628-A (D), mon=monazite, gn=garnet, ur=uraninite, sulph=sulphides, gl=galena	96
Fig.5-8	Bivariate plot of the ThO ₂ contents of monazite and xenotime versus the UO ₂ contents	98
Fig.5-9	Bivariate plot of SiO ₂ contents of monazite and xenotime versus the UO ₂ contents	98
Fig.5-10	Bivariate plot of the LREE contents of monazite and xenotime versus the UO ₂ contents	99
Fig.5-11	BSE images of uraninite grains with their alteration rims in sample AO 5268-D (A), DO 6920 (B), AO 5268-D (C), DO 6920 (D)	100
Fig.5-12	Bivariate plot of ThO ₂ versus UO ₂ of different U-bearing mineral phases from the Dominion Reefs, the name of mineral species and sample reference are respectively quoted in the legend	101
Fig.5-13:	Bivariate plot of UO ₂ (wt %) versus SiO ₂ (wt %) to evaluate the silica distribution and enrichment in the main uranium bearing phases	103
Fig.5-14	Bivariate plot of UO ₂ (wt %) versus TiO ₂ (wt %) to evaluate the titan distribution and enrichment in the main uranium bearing phases	104
Fig.5-15	Bivariate plot of UO ₂ (wt %) versus PbO (wt %) to evaluate the lead distribution and enrichment in the main uranium bearing phases	105
Fig.5-16	Bivariate plot of the Y ₂ O ₃ contents versus the UO ₂ contents to evaluate the Y distribution and enrichment in the main uranium bearing phases	106
Fig.5-17	U-Pb data for monazite 1 and 2 (data-point error ellipses are 2σ, MSWD = Mean Squared Weighted Deviates)	107
Fig.5-18	U-Pb data for zircon 1, zircon 2 and zircon 3 (data-point error ellipses are 2σ, MSWD = Mean Squared Weighted Deviates)	108
Fig.5-19	U-Pb data for rutiles (data-point error ellipses are 2σ, MSWD = Mean Squared Weighted Deviates)	109
Fig.5-20	U-Pb data for U phases (data-point error ellipses are 2σ, MSWD = Mean Squared Weighted Deviates)	109
Fig.5-21	Pb-Pb age data summary display two main ages for all analysed mineral phases	111

List of tables

Table 1-1	Rietkuil Gold Fields-historical gold production	13
Table 1-2	Mineral resource statement at 1 st June 2006 for Dominion Uranium Project	14
Table 2-1	Standards used for the calibration of the XRF	25
Table 2-2	Reference measurements for trace elements and REE	26
Table 2-3	Standards and X-ray lines used for monazite analyses	28
Table 2-4	Standards and X-ray lines used for uraninite mineral analyses	29
Table 3-1	Modal proportions (in %) of the main mineral content in 32 investigated polished thin sections (py = pyrite, gn = garnet, gl = galena, sp = sphalerite, qtz = quartz, leu= leucoxene, ana = anatase, sec. u = secondary uraniferous phases (mostly ghost minerals), ur = uraninite, chl/ser = chlorite/sericite, zr = zircon)	39
Table 3-2	Optical properties of common minerals in the conglomerates as observed during petrographic studies	40/41
Table 4-1	Pearson correlation matrix of the major elements, all correlation coefficients above or below 0.5 are significant and represent geochemical relationships (blue and black marked), <D.L.= values are below detection limit	77
Table 4-2	Pearson correlation matrix of the chalcophile elements, all correlation coefficients above or below 0.5 are significant and represent geochemical relationships (blue marked)	83
Table 4-3	Pearson correlation matrix of elements hosted in detrital minerals, all Correlation coefficients above or below 0.5 are significant and represent geochemical relationships (blue marked)	84
Table 4-4	Pearson correlation matrix of the elements which correspond with U and Th, all correlation coefficients above or below 0.5 are significant and represent geochemical relationships (blue marked)	85
Table 6-1	Mineral appearances within the Dominion Reefs in different stages proved by petrographic study	115

Abbreviations

Minerals and rocks

ana	anatase
ars	arsenopyrite
c	carbon
cp	chalcopyrite
chl	chlorite
cb	columbite
chr	chromite
coff	coffinite
gl	galena
gn	garnet
HREE	heavy rare earth elements from Gd to Lu
kaol	kaolinite
k-fel	potassium feldspar
kln	kaolinite
leu	leucoxene
LREE	light rare earth elements from La to Gd
mag	magnetite
mon	monazite
pitch	pitchblende
py	pyrite
qtz	quartzite
REE	rare earth elements from La to Lu
ru	rutile
sec. u	secondary uraniferous phases
ser	sericite
sp	sphalerite
sulph	sulphides
ur	uraninite
U-Th	uranium-thorium phases
U-Ti	uranium-titanium phases
zr	zircon

General abbreviations

AAC	Anglo American Corporation
AAS	Andesitic Arc Source
CIA	Chemical Index of Alteration
CIP	Carbon In Pulp gold plant
EDX	Energy-Dispersive X-Ray Spectroscopy
EMPA	Electron Probe Microanalyser
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
LA-ICP MS	Laser Ablation Inductively Coupled Plasma Mass Spectrometry
LLC	Lower Continental Crust
LLD	Lowest limit of detection
LOI	Loss on ignition
MSWD	Mean Squared Weighted Deviates
r	Pearson correlation coefficient
rl	reflected light
SAMREC	South African Code for Reporting of Mineral Reserves prepared by the South African Mineral Resource committee under the auspices of the South African Institute of Mining and Metallurgy, March 2000
SEM	Scanning Electron Microscope
SRK	Steffen, Ribertsen and Kirsten (South Africa) (Pty) Limited
TOIS	Tholeiitic Ocean Island Source
tr	transmitted light
UCC	Upper Continental Crust
WDXRF	Wavelength Dispersive X-Ray Fluorescence
XRF	X-Ray Fluorescence
2 σ	corrected for background, common Pb and within-run Pb/U fractionation and subsequently normalised to GJ-1 (ID-TIMS value/measured value)

Contents

Declaration	ii
Abstract	iii
Zusammenfassung	v
Acknowledgements	vi
List of Figures	vii
List of Tables	xii
Abbreviations	xiii

Chapter One: Introduction 1

1.1	General Introduction	1
1.2	Geological setting	2
1.2.1	Geological framework of the Dominion Group	7
1.2.2	Stratigraphy of the Dominion Group	7
1.2.3	Structural geology of the mining area	9
1.2.4	Theories for the heavy mineral deposition within the Witwatersrand basin	9
1.3	Exploration history	12
1.3.1	Gold recovery	12
1.3.2	Uranium recovery	13
1.3.3	Economic background and market development	15
1.4	Previous work	16
1.5	Objectives of the project	19

Chapter Two: Methodology 21

2.1	Sampling procedure	21
2.2	Criteria of choosing boreholes	21
2.2.1	Boreholes from the Rietkuil area	21
2.2.2	Boreholes from the Dominion area	22
2.3	Petrography	22
2.3.1	Macroscopic description	22
2.3.2	Microscopic description	22
2.3.3	Autoradiography	23

2.4	Geochemistry	23
2.4.1	X-Ray-Fluorescence (XRF)	23
2.4.2	REE analyses	25
2.4.3	Carbon analyses (LECO)	26
2.4.4	EDX/SEM	27
2.4.5	Electron-Microprobe (EMPA)	27
2.4.6	LA-ICP-MS	30
	 Chapter Three: Petrography	 31
3.1	Hand specimen petrographic description	31
3.1.1	Rietkuil area	31
3.1.2	Dominion area	36
3.2	Microscopic description	37
3.2.1	Radioactive minerals	41
3.2.2	Non-radioactive oxide minerals	47
3.2.3	Sulphide minerals	49
3.2.4	Silicate minerals	53
3.2.5	Gold	54
3.2.6	Textural descriptions of certain thin sections	55
3.3	Summary of the Petrography	60
	 Chapter Four: Whole rock geochemistry	 62
4.1	Whole rock geochemistry – XRF	62
4.1.1	Major elements	63
4.1.1.1	Sediment classification	63
4.1.1.2	Chemical index of alteration	65
4.1.1.3	Provenance and tectonic setting derived from major elements	68
4.1.2	Rare earth elements and trace elements	70
4.1.2.1	Rare earth geochemistry	71
4.1.2.2	Provenance derived from trace elements	72
4.2	Geochemical overview of element relationships	75
4.2.1	Major element chemistry and possible correlations	75

4.2.2	Minor and trace element chemistry and possible correlations	80
4.2.2.1	Yttrium and Zirconium	80
4.2.2.2	Sulphide minerals	81
4.2.2.3	Detrital minerals	83
4.2.2.4	Uranium and Thorium	85
4.3	Summary of the whole rock geochemistry	87
Chapter Five: Mineral geochemistry		89
5.1	Mineralogy and mineral chemistry – SEM	89
5.2	Mineralogy and mineral chemistry- Electron Microprobe	95
5.2.1	Primary detrital mineral phases	96
5.2.1.1	Monazite and xenotime	96
5.2.1.2	Uraninite	99
5.2.2	Secondary hydrothermal remobilised mineral phases	102
5.2.2.1	Pitchblende	102
5.2.2.2	Coffinite	102
5.2.2.3	U-Ti phases	103
5.2.2.4	Th-U phases	105
5.3	Mineral dating with LA-ICP-MS	106
5.4	Carbon analyses	111
5.5	Summary of mineral geochemistry	111
Chapter Six: Discussion and Conclusion		114
6.1	Discussion	114
6.1.1	Petrography study on the Dominion Reef samples	114
6.1.2	Whole rock geochemistry study on the Dominion Reef samples	115
6.1.3	Mineral chemistry study on the Dominion Reef samples	117
6.1.4	Genetic model for the Dominion Reef sediments	118
6.2	Conclusions	119
6.3	Suggestions for further investigation	120
References		121
Sources		131

Appendices

- Appendix I
 - Sample locations
 - Examination methods
- Appendix II
 - Autoradiography
 - Carbon analyses
- Appendix III
 - XRF data
 - Pearson correlation matrix
 - Standards for XRF analyses
 - REE analyses
- Appendix IV
 - EMPA analyses
- Appendix V
 - LA-ICP-MS data

Chapter One: Introduction

1.1 General Introduction

Strong commodity prices in the last few years have led to a remarkable renaissance of uranium exploration in South Africa. In the last few years, the Klerksdorp area, the location of the Dominion Reefs (reef is a synonym for mineralized placer all through the Witwatersrand), has become an important region for uranium exploration. Uranium in the Dominion Reefs is not a new discovery, for parts of the territory have a long history of mostly gold and minor uranium mining. Nowadays uranium hosted in placer deposits has become the focus of exploration. For economic recovery, two conglomerate horizons are currently considered for mining and uranium extraction. The ore from underground mining will be processed at a uranium processing plant on the mines property. The mine property is divided into two operating areas, - the Rietkuil and Dominion sections. Mining is currently undertaken by the Canadian company SXR Uranium One Inc. The mine's property is situated about 30 kilometres to the West of Klerksdorp at an latitude $26^{\circ} 47'S$ and an longitude $26^{\circ} 29'E$ in the North West Province of South Africa, as illustrated in figure1-1.

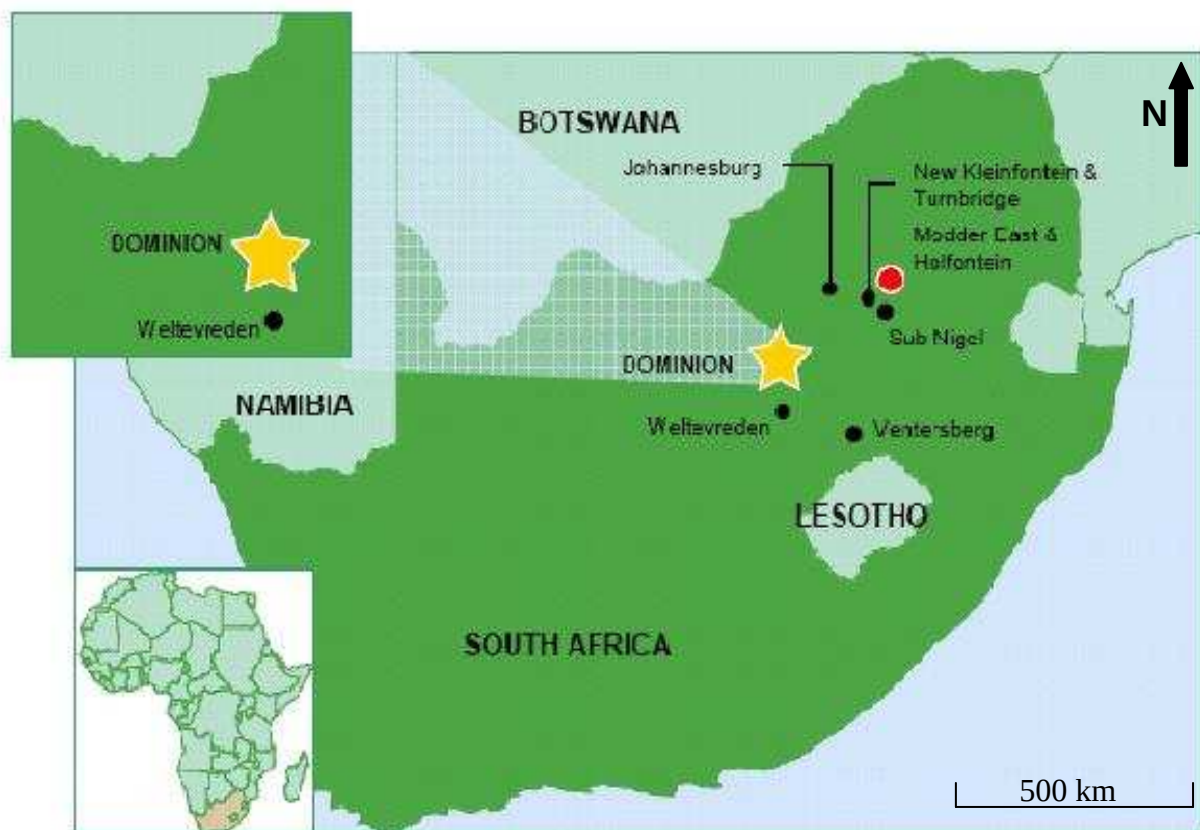


Fig.1-1: Overview map of South Africa with Dominion project location (<http://www.uranium1.com>)

1.2 Geological setting

Numerous authors have studied the geological setting of the Witwatersrand system. The following description provides a short review of the geological setting with the Dominion Reefs as the focus of the investigation.

The Witwatersrand basin is located in the Kaapvaal Craton (3.7-2.7 Ga) of Southern Africa and is known as the largest gold province in the world. In figure 1-2, the main Archean stratigraphic units of the Kaapvaal Craton including the Dominion Group are presented. The crustal development of the units corresponds with tectonic processes in and around the Craton. Two main periods are significant for the formation of the basin (De Wit et al. 1992). The first period (3.64-3.08 Ga) was dominated by the formation of the continental lithosphere of the Kaapvaal Craton associated with pulse deposition (3.2 Ga). The second main period was a major pulse of magmatic intrusives during basin development. At the end of the Archean time, a collision between the Zimbabwe Craton with the Kaapvaal Craton occurred along the Limpopo Belt (Frimmel 2005).

Pre-Witwatersrand basement

Kröner and Tegtmeier (1994) claimed the oldest known Kaapvaal Craton fragment from a Gneiss Complex in Swaziland to be of ~3.64 Ga age. Within the Barberton greenstone belt, residual products of Palaeoarchean crust formation are well preserved. Synorogenic deposits (Moodies Group) are known to be 3.2 Ga old and belong to the top unit of the greenstone belt (Frimmel 2005). Tectonic activities occurred 3.1 Ga accompanied by diffused gold mobilization along shear zones (De Wit et al. 1992). A combination of the described events most likely led to the start of the intra-continental basin formation and to the opening of the intracratonic Dominion Group with following Witwatersrand basin.

The Dominion Group as a narrow volcano-sedimentary unit underlies the Witwatersrand succession (Stanistreet and McCarthy 1991). Armstrong et al. (1991) determined the age of the volcanics (Syferfontein Porphyric Lava) as end of the Dominion Group succession at 3074 Ma and the underlying Archaean granite-greenstone basement at 3120 Ma. Dominion sedimentary and volcanic rocks were deposited over a short period of geological time, between 3086 Ma and 3074 Ma proved by zircon U-Pb dating techniques, (Armstrong et al. 1991; Barton et al. 1989; Robb et al. 1990a; 1992) in a continental rift.

Witwatersrand basin development

After the consolidation of the Kaapvaal Craton from series of greenstone belts and granitic intrusives, episodic and pulse sediment deposition occurred in the 350 by 200 km Witwatersrand basin. The sedimentary deposition history started between 2910 and 2714 Ma (Stanistreet and McCarthy 1991). Hiatuses in sediment deposition corresponded with episodic granitoid plutonism, and continued during the evolution of the basin (Robb and Meyer 1995). In figure 1-3, a simplified geological map (later cover removed) of the Witwatersrand basin is displayed.

The Witwaterand Supergroup starts of with 5 km thick argilleceous sedimentary rocks of the West Rand Group deposited in a continental passive margin setting, followed by 2.6 km thick arenaceous and rudaceous sedimentary rocks of the Central Rand Group deposited in a foreland basin (Liebenberg 1955).

Post-Witwatersrand development

Tectono-thermal events influenced the sediments of the Witwatersrand basin during and after deposition. The Ventersdorp Supergroup, stratigraphically above the Witwatersrand Supergroup achieves a thickness of more than 3600 m in some regions. U-Pb dating of the Ventersdorp lava revealed an age of 2714 Ma, according to Engelbrecht et al. (1986). The Klipriviersberg Group overlaying the Venterspost Conglomerate Formation composes of a thick flood basalt succession is the product of eruptions of channelized lava flows over sediment (Hall 1997). Volcanic rocks and siliclastic sediments of the Platberg Group overlay the Klipriviersberg Group.

The Transvaal Supergroup was deposited from around 2400-2020 Ma (Robb and Meyer 1995). The parts are the Chuniespoort and the overlying Pretoria Group. Important parts for economic reasons are the basal conglomerate unit, known as Black Reef followed by the dolomites of the Malmani Supergroup.

Felsic volcanic rocks of the Rooiberg Group overlay the Transvaal Supergroup. As last disturbance within the Witwatersrand stratigraphy is the 30 km wide Vredefort Dome with an age of 2023 ± 2 Ma (Kamo et al. 1996, Moser 1997).

Several fluid circulation phases through the Witwatersrand basin are recognized (Frimmel 2005). The corresponding tectonic events were the early Transvaal thermal subsidence around 2580 Ma, the Pretoria extension around 2200 Ma and the Bushveld event around 2060 Ma (Kositcin and Krapez 2004). None of the events younger than the Ventersdorp extension are

of great significance for the post-depositional alteration history of the Dominion Group according to Frimmel (2005).

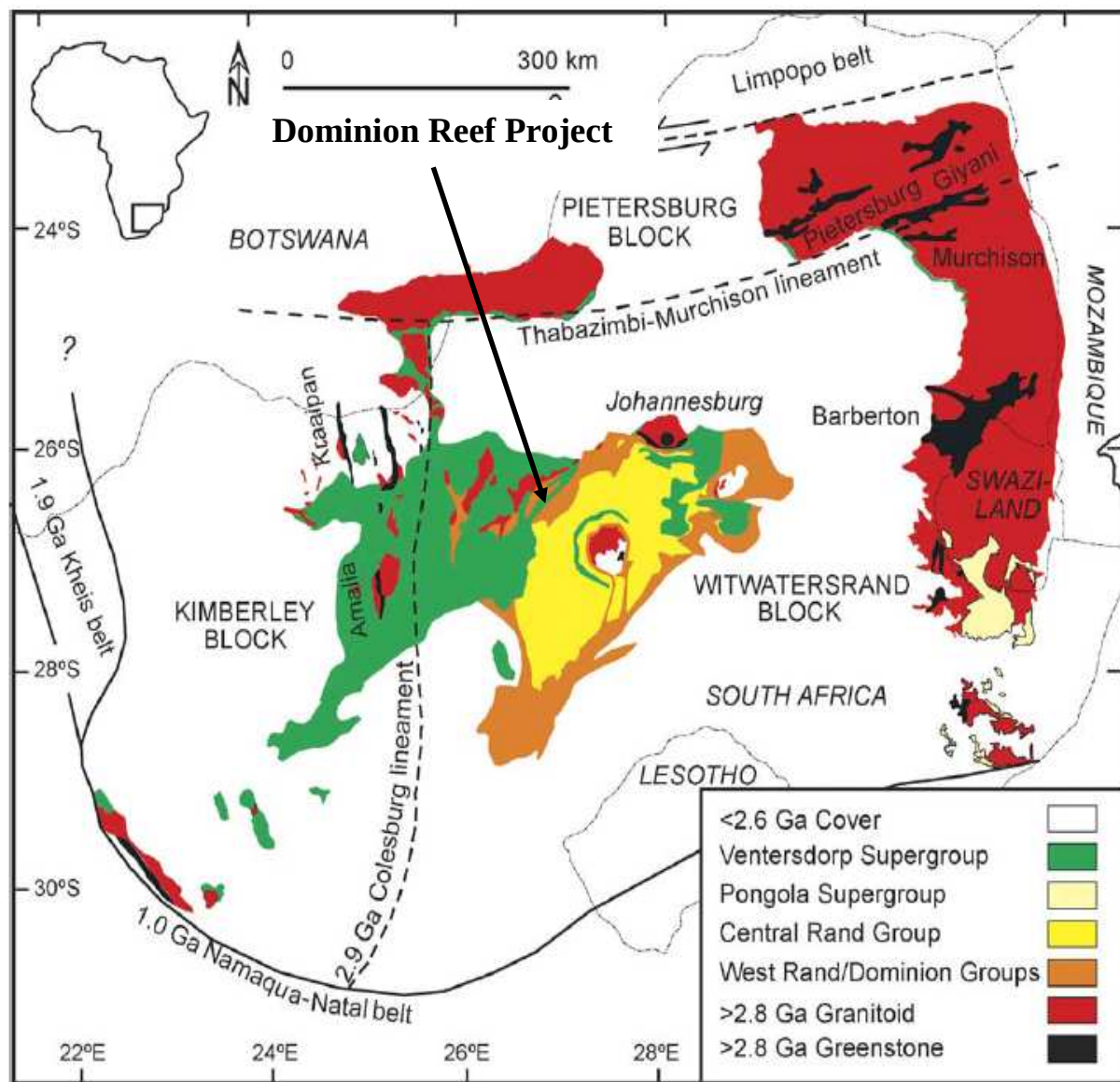
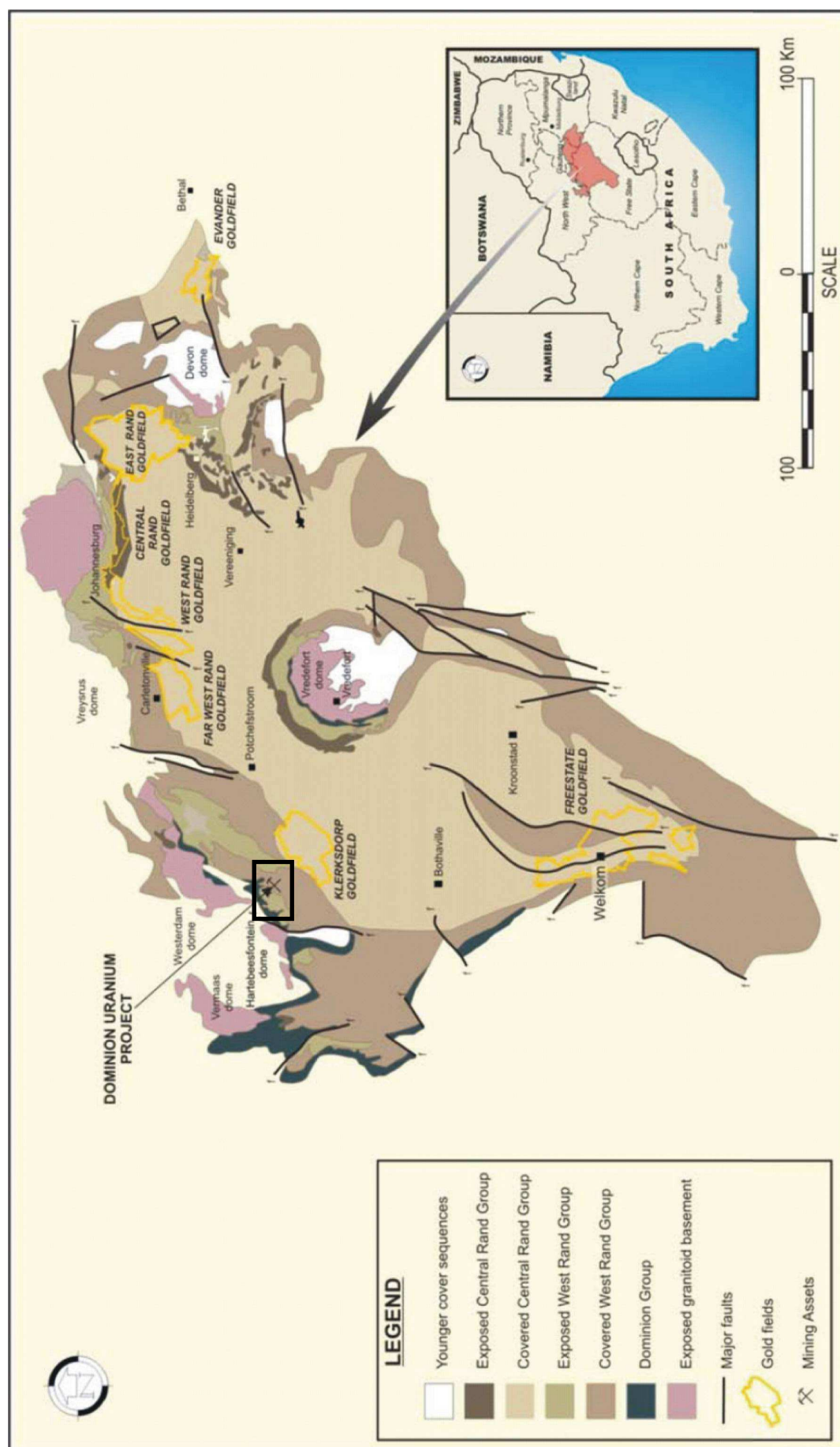


Fig.1-2: Distribution of the main Archean stratigraphic units of the Kaapvaal Craton, (modified from Schmitz et al. 2004)



1.2.1 Geological framework of the Dominion Group

The map in figure 1-4 illustrates the surface geology of the Klerksdorp area. The investigation of the Rietkuil and Dominion Blocks location of the minesite and the sampled boreholes are considered in this investigation.

Uranium and Gold mineralization is primarily hosted within two narrow sedimentary successions located within the lower sedimentary unit of the Dominion Group. The successions are known as Lower and Upper Reefs comprising of quartz-pebble conglomerate units that are well preserved with channel features incising into the underlying granitic rocks (Button and Tyler 1981). The Upper Reef can be described as more laterally persistent than the Lower Reef. Between Lower and Upper Reefs a laterally poorly developed intermediate quartz-pebbly Reef can occur.

The Lower and Upper Reef conglomerates are representative of high energy sedimentary accumulations above eroded Archean granitoid rocks. Both Reefs typify a braided stream environment above extensive eroded surfaces. The distribution of the heavy minerals can be explained as point bar sediment deposition with channelization (Harley and Dixon 2006).

Volcanic activity started soon after the deposition of the Dominion Reef sediments. The Rhenosterspruit Formation consists of mafic lavas and felsic volcanics with a greenschist metamorphic grade overprint. It is assumed that the felsic volcanics most likely originated by partial melting of crustal sources (Jackson 1991). The Syferfontein porphyry lava was probably deposited by pyroclastic flows after a short period of time. The upper unit of the Syferfontein formation consists of tuffaceous rocks. It is believed that volcanism started off slowly, with peak-time in the mafic extrusions of the middle Rhenosterspruit Formation, and declined during Syferfontein deposition (Jackson 1991). The Dominion volcanics are representative of extensive magmatic activity within the northwest flank of the Witwatersrand basin.

1.2.2 Stratigraphy of the Dominion Group

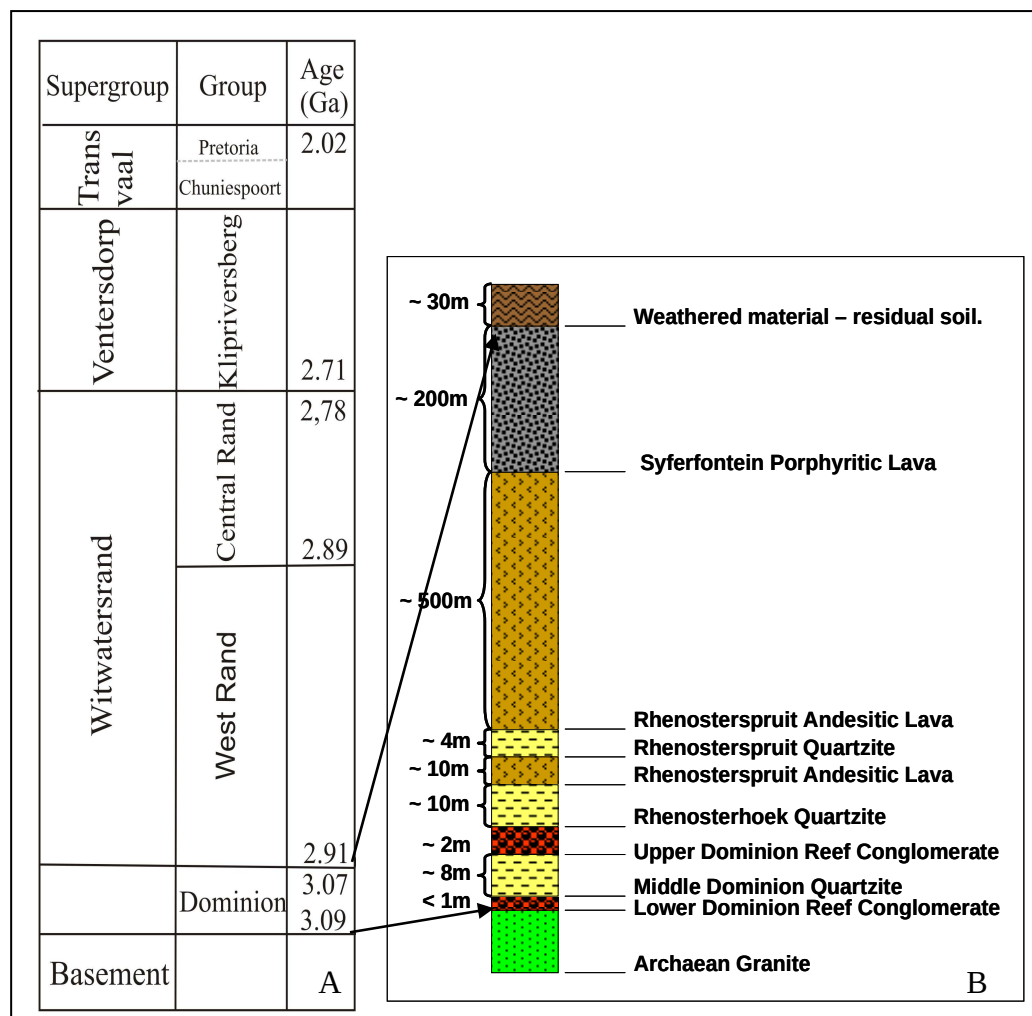
The Dominion Group as a volcano-sedimentary sequence consists of the Dominion conglomerate Reefs, the Rhenostershoek quartzite, the Rhenosterspruit formation, and the Syferfontein lava (Fig. 1-5). The Dominion Reefs, the basal part, consist of two terrigenous sedimentary units, locally known as Lower and Upper Reefs.

The Lower Reef is a thin quartz-pebble conglomerate bed with a thickness less than 5 m and overlies directly the Archean granitoid rocks. The intermediate unit is a poor to moderately mineralised quartz-pebble unit and is termed Middle Dominion Quartzite. The Upper Reef overlies the Middle Dominion Quartzite and can range from a few centimetres to a maximum

of three metres thickness. The Upper Reef is host of the majority of uranium minerals and can contain up to 1 % U_3O_8 at the top over 0.05 m of the conglomerate (Liebenberg 1955, Von Backstrom 1975). The Upper Reef is overlain by the Rhenosterhoek quartzite. This unit comprises circa 10 m of yellow sericitic quartzite. The Rhenosterhoek quartzite is overlain by the Rhenosterspruit succession without gap.

The Rhenosterspruit formation can be divided in the Rhenosterspruit Quartzite, and the Rhenosterspruit Andesitic Lava. The quartzite, within the Rhenosterspruit Andesitic Lava, can be described as coarse arkosic grey rocks with a thickness of circa 4 m (Watchorn 1980, 1981). The Rhenosterspruit andesitic lava is developed to a maximum thickness of 550 m. The succession consists of green and grey andesitic lavas with tuffs in the uppermost 150 m (Von Backstrom 1975).

The overlying Syferfontein porphyritic lava occurs as a 200 m thick sequence. This sequence can be divided into a lower medium grained porphyry, middle silicified porphyry, and upper medium grained porphyry rocks (SACS 1980). Figure 1-5 illustrates the stratigraphy of the Dominion Group in detail. The thickness of the constituents of the Dominion Group are estimates by exploration geologists from Uranium One Inc.



1.2.3 Structural geology of the mining area

The tectonic setting in which the Dominion Group was deposited has a direct bearing on the depositional environment of the Witwatersrand succession. The Dominion Group supracrustals have been assumed to be an pre-depositional product of the Witwatersrand Basin (Jackson 1991). The following description provides a short review of the structural geology. The information about the structural features of the mining area was provided by the exploration geologists of Uranium One Inc., and the SRK Independent Technical Report (Harley and Dixon 2006).

The mine's property can be divided in two main operational sections: the Dominion and the Rietkuil-Rhenosterhoek Block. The Blocks are split by the south striking and east dipping Hartbeesfontein thrust fault and the Rietkuil thrust fault. The easterly vergent Rietkuil thrust fault borders the east part of the Rietkuil Block and caused an uplift of the Dominion lithologies over younger Witwatersrand Supergroup rocks. The separate Rhenosterhoek Block can be described as an anticlinal structure between both main Blocks. The Dominion Block displays as wide syncline over the whole area. The main faults in the whole area have a north-south strike orientation and the younger northeast-southwest orientation. North-trending synclines which plunge to the south are the most common in the Rietkuil-Rhenosterhoek Block. Most of the present faults appear with a replacement of a maximum of 350 m.

1.2.4 Theories for the heavy mineral deposition within the Witwatersrand basin

Since the discovery of gold and uraninite in the Witwatersrand basin, the question about their genesis was present. The placer deposit contains a wide variety of ore minerals. The fluid dynamic processes involved in the placer formation are invariably very complex. Extensive research on the origin of the mineralization in the conglomerates of the Witwatersrand exists. Since early times two main schools were published, the "placerists" and the "hydrothermalists" (Ramdohr 1958). Nowadays, three main theories have been advanced to explain the presence of gold and uranium placer deposits in the conglomerates within the sediment successions. A short review of the three main theories of the mineral deposition history within the Witwatersrand basin is given below. The modified model for the heavy mineral deposition very likely is valid for the mineralization within the Dominion Reefs.

1. The placer model (Fig. 1-6) was originally proposed by Mellor (1916). According to Pretorius (1974), Hallbauer and Utter (1977), uraninite and gold were formerly mechanically deposited as detrital particles under oxygen-poor atmospheric conditions before 3074 Ma. It is assumed that the dense detrital minerals were concentrated during sediment deposition and derived from older Archean granite-greenstone source areas.

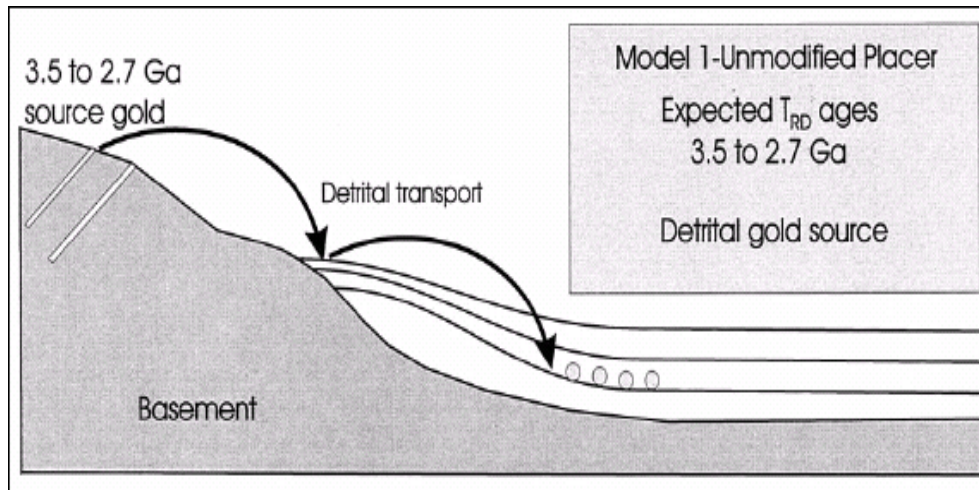


Fig.1-6:
Illustration of the
Unmodified
Placer model
proposed for the
origin of gold and
uraninite in the
Witwatersrand
Basin (modified
from Kirk et al.
2001)

2. The model assumes similar that although detrital minerals gold, uraninite and related minerals were detrital in origin. These minerals have been locally remobilized and recrystallized after burial to account for secondary grain shape and composition (Fig. 1-7). Nowadays, most of the geologists support the modified placer theory (Liebenberg 1955, Ramdohr 1958, Schildowski 1981, Minter 1976, Utter 1980). It is assumed that the sediments were deposited along borders of a fluvial system. Sediments and heavy minerals were brought from an elevated source area to the northwest of the basin (Robb and Meyer 1995). A lacustrine littoral system distributed fine sediments at the length of the shoreline of an early inland sea. Heavy mineral concentrated by gravity settling and pulsating wave and current action. Liebenberg (1955), Frimmel and Gartz (1997), and Minter (1999) assumed a remobilization of uraninite and gold by hydrothermal fluids, followed by local re-precipitation with various associated phases. Several stages of enhanced fluid circulation through the Witwatersrand Basin are recognised, ranging from a number of diagenetic basin dewatering to hydrothermal fluid infiltration events. Most reliable hydrothermal events cluster around 2720 Ma (Ventersdorp extension), 2580 Ma (early Transvaal thermal subsidence), possibly around 2200 Ma (Pretoria extension), 2060 Ma (Bushveld event) and Vredefort 2020 Ma (Armstrong et al. 1995, Kositcin and Krapez 2004, Robb et al. 1990, Frimmel 1999).

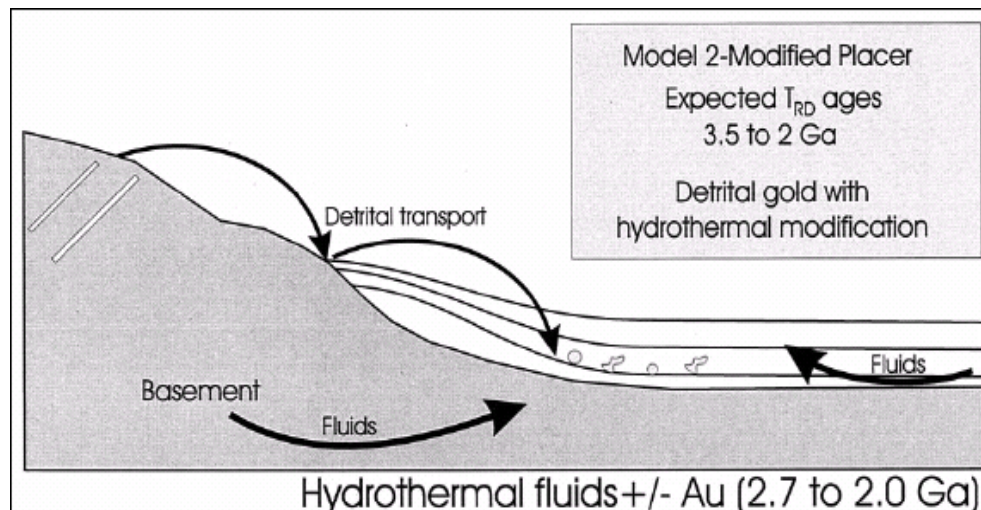


Fig.1-7:
Illustration of the Modified Placer model proposed for the origin of gold and uraninite in the Witwatersrand Basin (modified from Kirk et al. 2001)

3. In the metamorphic/hydrothermal models (Fig. 1-8) it is assumed that gold and uraninite was transported in solution inside the basin by external hydrothermal/metamorphic fluids. According to Philips and Law (1994) and Barnicoat et al. (1997), the deposition occurred after the basin sedimentation had ceased. The presence of ore minerals in the conglomeratic host rocks is the consequence of basin fluid flow corresponding with structural and chemical controls (Philips and Law 2000). Different hydrothermal models are present for the origin of the ore minerals. One indicates a separate origin for gold, uraninite and carbonaceous matter (Philips and Law 2000), on the contrary another model infers a co-genetic origin (Barnicoat et al. 1997). According to these models, almost all detrital minerals are supposed to be absent within the Witwatersrand Basin.

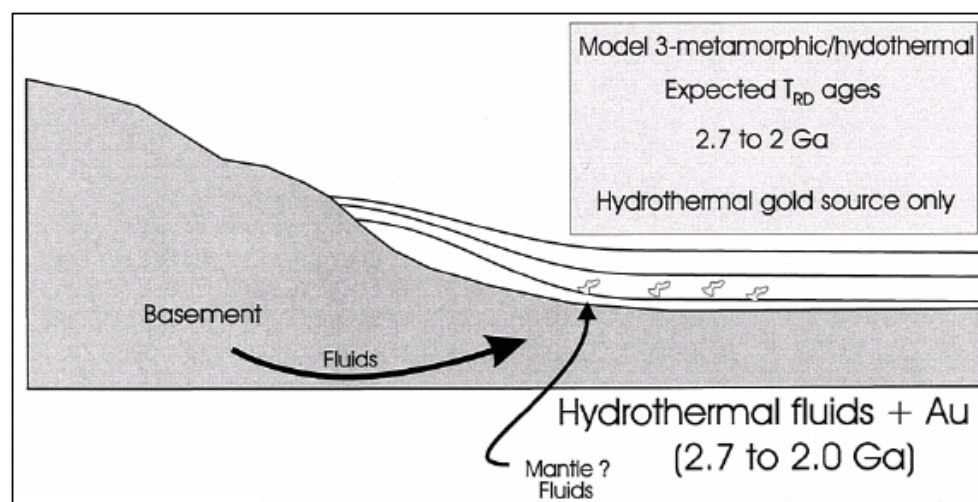


Fig.1-8:
Illustration of the metamorphic/hydrothermal origin of gold and uraninite in the Witwatersrand Basin (modified from Kirk et al. 2001)

1.3 Exploration history

Historical information of uranium and gold recovery has been extracted from an independent technical report for the Dominion Uranium Project (Harley and Dixon 2006).

1.3.1 Gold recovery

After the first gold discovery, close to Johannesburg, the gold rush in the Witwatersrand basin started. In August 1886, P. Roos discovered gold in a conglomerate outcrop at the top of the southern hills of Klerksdorp. Fortunately, in November of the same year, J. Moody-Lane discovered gold 15 km west of Klerksdorp on the Rietkuil Block 626. The area was opened for prospecting in July 1887 and the Rietkuil Gold Fields opened in the same year.

Operations in the Wolverand and the Rietkuil Mine started in the year 1888. The Afrikander Lease Company became the successor of these mines in 1892. In fact a certain number of mines were established in 1895. Four companies (the Rietkuil Gold Mining Company, the Klerksdorp Main Reef, the Elandslaagte Gold Mine and the Afrikander Gold Mining Company) had a significant interest in the Rietkuil Gold Field. During the last years of the nineteenth century, various small mines were operated. These mines belonged to the African Lease Company, the Rietkuil Kopje Mine, the Wolverand Gold Mining Company, the Worcester Hope Block, the East Anglian Block, the Scott's Block, the Huguenot Syndicate, the Van Der Stel Mining Company, the Ball Buoy Syndicate, and the Afrikander Syndicate.

Until the 1930s the small mines continued with their conventional operations. The mining was consolidated into only three big mining companies. The northeast and the southwest sections of the Rietkuil Gold Fields belonged to the Afrikander Lease Limited and the Babrosc Mines Limited. In the year 1957 all three areas had been united into the Afrikander Lease Limited which continued with underground mining operations until 1964. During the 1970s, the Anglo American Corporation started test mining for uranium on the Dominion Reefs to the north of the Rietkuil Syncline. Eventually, two subsidiary companies of AAC (the Vaal Reefs Exploration and the Mining Company Limited) started underground mining operations for gold at the Afrikander Lease Limited, and they used a conventional CIP gold plant for the gold recovery. The historical gold production between 1888 and 1997 is listed in table 1-1.

In late 1998, AAC acquired an interest in the Afrikander Lease Limited. In 1998, exploration studies determined gold resources near the surface, which could be mined from an open pit situated within the Inner Basin with further processing at the existing CIP (Carbon In Pulp gold plant) mill. The gold resources turned out to be oxidized so that a less expensive heap leach extraction could be used. As a result, the CIP plant was replaced by heap leaching for

gold in the year of 1999. Between January 2000 and December 2004, 3,277 kg of gold was produced.

Table 1-1: Rietkuil Gold Fields-historical gold production

Mines	Period from to	Tonnage (Mt)	Au Output (kg)	Recovered Grade (g.Au/t)	content U (t)	Uranium Grade (% U₃O₈)
Dominion Group Reefs Dominion Reef Mine	1898-1936	-	-	-	-	-
	1936-1955	4 351 920	16 199	3.72	-	-
	1956-1961	1 029 063	9 549	9.28	1,823	0.31%
	1958-1961	80 000	-	-	108	0.24%
West Rand Group Reefs Afrikander Lease	1889-1898	41 680	544	13.05	-	-
	1903-1921	3 613	37	10.24	-	-
	1922-1932	5 830 899	3 966	0.68	-	-
	1933-1964	3 164 446	15 077	4.76	-	-
	1982-1997	7 086 000	8 711	1.23	-	-
Babrosco	1922-1930	84 000	662	7.88	-	-
	1934-1960	3 212 316	16 193	5.04	-	-
Bonanza	1893-1894	4 134	49	11.85	-	-
West Bonanza	1888-1911	79 513	952	11.97	-	-
Elandslaagte	1894-1896	49 648	504	10.15	-	-
	1903-1930	39 665	257	6.48	-	-
	1936-1941	35 035	138	3.94	-	-
Total Gold production	1888-1997	25 091 932	72 838	—	—	—

1.3.2 Uranium recovery

Between 1936 and 1961, the Dominion Reefs were mined for gold and uranium. The uranium operation started in the year 1956. Unfortunately, the mine was closed in 1961 due no uranium contracts being terminated. Based on historical mining records, the production was about 1, 900 tonnes uranium concentrate in six years. The ore grades varied between 0.77 kg/t (in 1960) and 1.17 kg/t (in 1956).

As a result of the recovered market for uranium, an existing historical uranium resource on the Dominion sites was re-evaluated. Historical data were reviewed and validated. Even the archived cores were re-sampled for new chemical analyses. In 2005, exploration work and engineering studies on the Western Mining Assets were done by Aflease, and its consultants. A twin-hole program of drill holes, consisting of six diamond drill holes confirmed the presence of mineralization within the Upper and Lower Dominion Reefs.

A Canadian uranium and gold resource company, Uranium One Inc. (formerly Aflease), has owned the Dominion Uranium Project since 2005. Uranium One Inc. began processing ore from underground at the Dominion and Rietkuil section in February 2007.

The reported Mineral Resource Estimate statement in table 1-2 are based on results from the Uranium One drilling programme. The reported tonnes and grades show a Life-of-Mine (LoM) plan of 11 years by accessing Probable Reserves only. The inferred resources and the indicated resources are displayed for the mining areas within the figure 1-9.

Table 1-2: SRK Audited Mineral Resource Estimate (1,2,3) at Dominion (December 31, 2007)

Reef Unit	Tonnes (000's)	U₃O₈ Grade (kg/tonne)	Contained U₃O₈ (lbs 000's)	Gold Grade (g/tonne)	Contained Gold (ozs 000's)
Rietkuil Upper Reef	38,004	0.59	49,043	0.69	838
Rietkuil Lower Reef	12,372	0.53	14,338	0.97	386
Dominion Upper Reef	18,963	0.62	26,072	0.55	338
Dominion Lower Reef	11,740	0.89	22,963	1.13	427
Total Indicated	81,080	0.63	112,416	0.76	1,989
Rietkuil Upper Reef	37,047	0.50	40,492	0.66	782
Rietkuil Lower Reef	40,896	0.43	39,010	0.70	922
Dominion Upper Reef	59,728	0.31	40,320	0.47	893
Dominion Lower Reef	37,123	0.23	18,529	0.78	937
Total Inferred	174,795	0.36	138,351	0.63	3,534

Additional information:

1. The mineral resources have been reported in accordance with the classification criteria of the South African Code for Reporting of Mineral Resources and Mineral Reserves (the SAMREC Code). SRK Consulting considers that the mineral resources estimate would be identical if reported in accordance with CIM standards.
2. The mineral resource was estimated by Dr. Carina Lemmer of Geological & Geostatistical Services, an independent consultant, and reported to a cut-off of 30 cmkg/t U₃O₈ for Dominion and Rietkuil, and 0.00 g/tonne gold.
3. Mineral resources are not mineral reserves and do not have demonstrated economic viability.

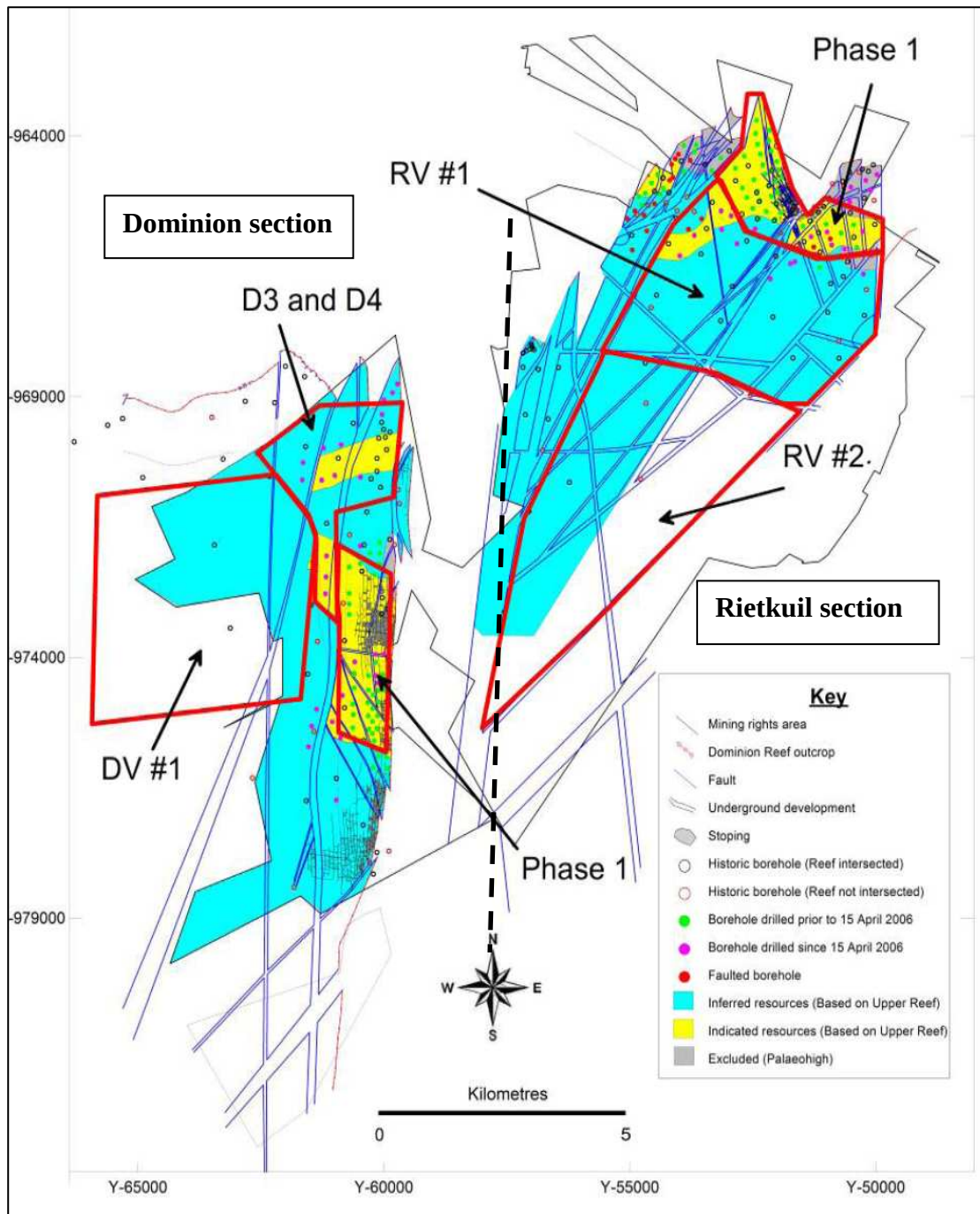


Fig.1-9: Mining areas with underground development and resources estimates (<http://www.uranium1.com>)

1.3.3 Economic background and market development

All information about the economic background of the Dominion Reefs operating mines and the uranium market are from reports displayed on the Uranium One Inc. homepage. The economics of mining in the Dominion Reefs have been largely controlled by the uranium price. Relatively high commodity prices in the last few years (since 2004) have lead to a remarkable renaissance of uranium exploration in the Dominion Reefs.

The worldwide uranium price is governed by the supply and the demand for industrial use. In figure 1-10, the historical uranium production and the consumption are displayed. Within the diagram an increasing trend based on the uranium consumption is obvious. The uranium prices in the 80s and 90s were relatively low. It is assumed that the large excess stockpiles and the government sales depressed the prices.

The growth in demand most likely can be explained by the use of uranium for nuclear power. Nowadays, 16 % of global electricity is generated by nuclear power. More than 350 Reactors are presently under construction or planned in seven countries. The result emerging from the economic background is that in the future the need of uranium will increase.

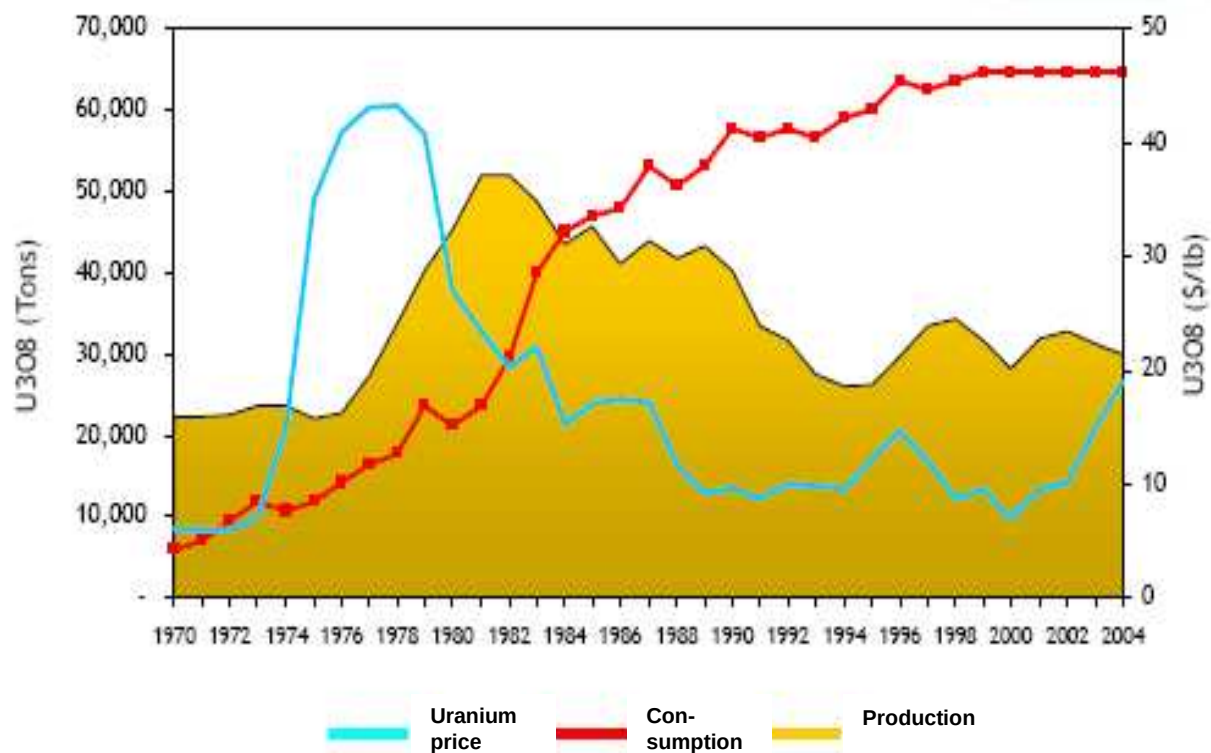


Fig.1-10: Diagram of historical uranium production and consumption (<http://www.uranium1.com>, presentation U3O8-Market Fundamentals, 4 Oct07, page 18)

1.4 Previous work

The Witwatersrand basin contains the vast majority of known gold and uranium resources and has been of interest for economic recovery research projects. There are numerous descriptions of the minerals in the Witwatersrand Reefs, their distribution within the Reefs, the relations between the various minerals and their formation (Feather and Koen 1975, Feather 1981). The majority of scientists compared rock samples from the Dominion Reefs with other Reefs from the Witwatersrand basin. Some main reviews of these studies are given below.

Several scientists have been studying the Dominion Group in detail, with particular focus on the mineralized Reefs. The most detailed studies of the mineral occurrences in the Dominion Reefs have been done by Liebenberg (1955), Hiemstra (1968), Simpson and Bowles (1977), and Jackson (1991). A short abstract of some previous studies will be described below. For further information, more authors are listed in the references. Most studies can not be stated in detail since they do not play the most important part in this investigation.

Feather and Koen (1975) focussed in their study of the microscopic description of the minerals occurring in the economically important Witwatersrand Reefs. It was their aim to gather information about the origin of the different mineral phases. Geochemical data were obtained with the help of electron microprobe studies to prove a different genesis of the minerals.

Feather (1981) discussed in his work certain aspects of the mineralization within the Witwatersrand Reefs in detail. Especially uranium bearing minerals and the affecting temperatures while the main period of metamorphic activity was discussed. Feather claimed a temperature of metamorphic activity between 400-600 °C.

Samples from economically important Reefs were measured with the electron microprobe and the XRF, to determine their whole rock and mineral chemical composition. Microscopic observations of most samples were carried out. He revealed the result of a detrital origin of uraninite within the Reefs and the re-precipitation from solution. With the obtained UO_2/ThO_2 ratios he proposed a multiple granitic or pegmatitic detrital source

Hiemstra (1968), in his detailed study, focussed on the units hosting the economic U-Au deposits in the conglomeratic Reefs in the former Dominion Mine and the Afrikaaner Leases Mine. Hiemstra investigated the mineralogy, the petrology and the geochemistry of the uraniferous conglomerate units of the Dominion Reefs. A detailed study of the various mineral species and a data set on shape, size and roundness led to remarkable information about the origin of gold and uranium occurring in the Reefs. The geochemical investigation, with qualitative and quantitative analyses, determined geochemical trends which revealed the same conclusion. The obtained data sets showed evidence for the occurrence of uranium as detrital mineral originating from pegmatites and determined a hydrothermal overprinting in a later period. This metamorphic event could be verified on completely altered ore minerals within the Dominion Reefs.

Jackson (1991) discussed in his work the tectonic setting of the late Archean volcano-sedimentary units (Dominion Group) and implications for the Witwatersrand Basin's gold deposition. He described the lithology, the geochemistry, the petrography, and the stratigraphy of the Dominion Group in detail. Jackson compared the volcanic sequences within the Dominion Group with other similar volcanic suites in order to obtain geochemical correlations. As a result, he proved parts of former tectonic setting models and pointed out new question for further research.

Schildowski (1981) described uraninite, and their alteration products of the Witwatersrand conglomerates. He revealed information about the origin of uraninite and brannerite with the help of ore microscopic examinations and chemical analyses. This research project was done for implications for the Witwatersrand metallogeny.

Liebenberg (1955) described in detail the occurrence and the origin of gold and radioactive minerals in the Witwatersrand System, the Dominion Reef, the Ventersdorp Contact Reef and the Black Reef. He undertook a detailed microscopic work and X-ray studies on specimens from different locations. Liebenberg discussed the principal uraniferous constituent uraninite as detrital grains in conglomerate beds. He also described secondary uraninite within the Reefs. He assumed that the secondary uraninite is an alteration product of the detrital uraninite by metamorphic and/or chemical actions. He found evidence for a simultaneous deposition of gold and uraninite which supported his thesis of the modified placer theory for the origin of gold and uraniferous components.

Minter (1976, 1978, 1986, 1999,) focussed on the Witwatersrand Basin and their economically important Reefs. With the help of several studies, he proposed theories for the origin of the basin, the different occurrence of the minerals and the effects of metamorphic activities. Minter compared samples from a number of Reefs to obtain possible theories of their origin and to obtain information about their relationships.

Simpson and Bowles (1977) determined the controls of the principal uranium mineralization with different mineralogical methods. The usage of ore microscopy, electron microprobe analyses, radioisotope and stable isotope determinations, fission track studies of uranium distribution, and detailed analyses of fluid inclusions, was of utmost importance for their investigation. Simpson and Bowles developed two theories of uranium deposition: as

precipitation of uranyl ions from solutions and as detrital allogenic uraninite grains. They proposed both theories valid for the Dominion Reefs and for other uranium bearing Reefs within the Witwatersrand basin.

1.5 Objectives of the project

The aim of the presented study is to characterize the mineralization of the Dominion Conglomerate Reefs as gold-uranium placer deposits with particular focus of the paragenetic sequence and their genesis. This was achieved by studying the mineralogical and the geochemical characteristics of 78 selected borehole core samples from the Dominion Reefs to distinguish between primary and secondary mineral phases. In order to achieve these aims, several methods were applied which will be presented.

- Detailed light microscopic investigation and autoradiography had to be done in order to identify numerous mineral phases occurring in the Reefs and to document information about their size and shape
- Determination of the mineral modal proportions (with point counting) so as to resolve their distributions and associations within the Reefs
- Geochemical whole rock studies (major, trace and REE analyses) with the intention of determining:
 - Sediment classification
 - Provenance analysis
 - Source area
 - Chemical Index of Alteration (CIA) and weathering degree evaluation
 - Geochemical trends
 - Determination of genetic associations
- Quantitative Scanning Electron Microscope (SEM) analyses to receive information about the mineral distribution and to locate the main uranium bearing phases within the polished thin sections

- Geochemical Electron Probe Microanalyser (EMPA) studies on uranium bearing minerals, monazites and xenotimes with the aim of determining:
 - Geochemical signatures of monazites, xenotimes and uraniferous minerals
 - The origin of uraninite
 - The origin of the secondary minerals
 - Distinction of the geochemistry of primary and secondary formed uranium bearing minerals

- Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) dating of monazites, zircons, rutiles and uranium bearing minerals to determine primary mineralization age and secondary mineralization age

- Relationships between well known events which effected the Witwatersrand Basin and events effecting the Dominion Group

Chapter Two: Methodology

In this chapter, the methods used for the geochemical and mineralogical investigation of 78 rock samples from the Dominion Reef Group are described. Methods applied on individual samples are listed in Appendix I.

2.1 Sampling procedure

For sampling, representative boreholes from different Reef facies were selected in consultation with the mine and exploration geologists from Uranium One Inc. The geologists provided data sets with uranium grades and gold assay results from the mines laboratory for most of the drill cores. A number of cores with high uranium grade from the Rietkuil and the Dominion section were selected.

For this investigation, 70 samples from the Rietkuil, as the main area of this study, and 9 from the Dominion section were chosen. The locations of the 78 samples are listed in Appendix I. All selected intersections are stored in the core sheds of the company. After the boreholes and selected sections were cut by company employees to core samples quarters of 20 centimetres length. It was only possible to receive quarter cores because half cores had already been utilised for uranium and gold analyses. The other remaining quarter core has to be stored in the core sheds for possible further investigation. For the geochemical investigation, an additional 20 g of crushed core material from each selected section was provided by the company.

2.2 Criteria of choosing boreholes

2.2.1 Boreholes from the Rietkuil area

For this study, samples were collected from the Rietkuil section, representing different Upper Reef sedimentological facies. They were determined by exploration geologists as:

- Channel Facies
- Interchannel Facies
- Overbank Facies

Borehole maps with the location, the distribution of ore grades, and the different sedimentological facies were provided by the company's geologists. The different samples were selected from the different Reef facies, to ensure the diversity of the borehole locations. In general, one or two samples from each selected borehole intersection were collected. A total of 62 core samples were taken from the well developed Upper Reef and eight from the

poorly developed Lower Reef. The main criteria for the borehole selection, was choosing well mineralized samples with high uranium grades.

2.2.2 Boreholes from the Dominion area

The samples collected from the Dominion section belong to different sediment facies, which were classified by exploration geologists as:

- Small package conglomerate (Upper Reef)
- Middle package conglomerate (Upper Reef)
- Multiple bands (Upper Reef)
- Terrace facies (Lower Reef)

The company's geologists provided a map with all borehole locations and the corresponding uranium grades. A small number of samples with high uranium contents from this area were taken to get an overview of the distribution of uraniferous minerals in the Dominion section. Seven samples from the Upper Reef and two from the Lower Reef were chosen for this investigation.

2.3 Petrography

2.3.1 Macroscopic description

Before preparing 32 polished thin sections, all selected samples were photographed and a macroscopic description of the core samples was completed in order to receive information about the whole variety of samples from the Rietkuil and the Dominion section.

2.3.2 Microscopic description

Twenty-two polished thin sections were made from the Rietkuil and ten from the Dominion area at the University of the Free State in Bloemfontein. Two centimetre long pieces of samples were cut from the quarter core for the preparation of polished thin sections. The mineral petrography was carried out using a Nikon petrographic microscope.

To obtain the modal mineral proportions, a James Swift point counter was used. A total number of nine hundred points were counted on every slide at an enlargement of 100 times magnification. Points were counted at an interval of 205 μm in the length and 1,000 μm in the width of the thin sections. These intervals were chosen to ensure representative results of counting the ore minerals and other associated minerals.

2.3.3 Autoradiography

To locate uraniferous minerals, autoradiography (Rogers 1979) of ten thin sections was carried out (shown in Appendix II). The samples were overlaid with a thin photographic film and covered with lead for at least five days (Fig.2-1:A). After this time duration, the film was covered with photographic emulsion and developed an image on the film. The produced image is the visualisation of the distribution of the radioactive minerals within the thin sections (Fig.2-1: B).

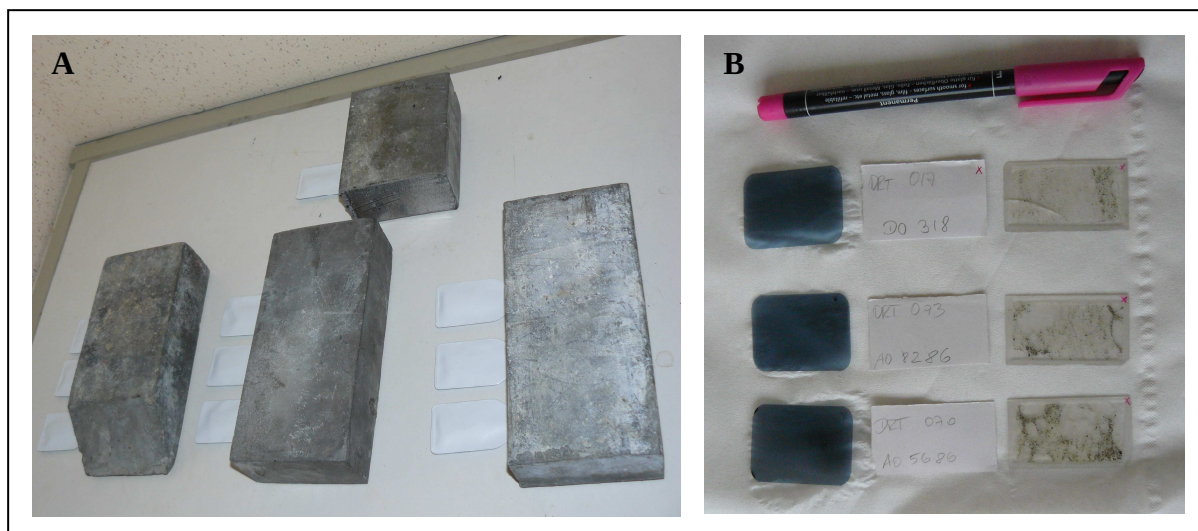


Fig.2-1: Autoradiography method, A: samples overlaid with a thin photographic film and covered with lead, B: the produced image of the radioactive minerals on films

2.4 Geochemistry

2.4.1 XRF

For a quantitative determination of the whole-rock element concentrations, X-ray fluorescence was used. All sample and standard analyses are listed in Appendix III. Before measuring, all samples were prepared as fusion disks, and as pressed powder pellets to ensure homogeneous element distributions for further analyses. For the whole-rock geochemical analyses with the XRF, 78 samples were prepared.

The company provided additional crushed samples for XRF analyses. All the crushing and milling was done by the Uranium One Inc. mines laboratory. At the University of the Free State's laboratory, the powder was weighed and afterwards dried at 110 °C for 24 hours. After that, it was weighed again, in order to determine the amount of adhesive water. Afterwards, the powder was roasted in a porcelain pan for another 4 hours at 1,000°C to release the volatile content. In the final process, the samples were weighed again to determine the loss on ignition (LOI).

The final fusion disks, used for the major element analyses, were produced from the roasted powder. The disks consist of 0.28 g roasted material and 1.52 g of a mixture of Li-meta- and Li-tetraborate. This mixture was placed in a in a platinum pan and exposed to 1,200°C for 20 min in a melting furnace. At the time of the melting process, the pan was swayed to ensure the sample was mixed. For analysing the major element concentrations, the programme major beads 2, was used. The major elements (SiO₂, Al₂O₃, TiO₂, Fe₂O₃, MnO, MgO, CaO, Na₂O, K₂O and P₂O₅) are determined as oxides in wt %.

The pressed powder pellets, for trace element analyses, consist of a homogenous mixture of 8 g rock material and 3 g Hoechst Wax. The mixture was pressed in a hydraulic press with 8 t to create the pellets. The trace element concentrations were analysed with the measuring programmes ‘VMS-traces 3’, ‘Sodium only’ and ‘Uranium only’. The values of the trace elements are stated in ppm. The elements measured with the programme are: S, Ca, Sc, Ti, V, Cr, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sn, Sb, Te, I, Ba, Yb, Hf, Ta, W, Hg, TI, Pb, Bi, Th and U.

Major and trace element analyses were done at the Department of Geology, UFS, with the PANalytical WDXRF Axios spectrometer. The spectrometer was used with SuperQ Version 4 Software with the two analytical options IQ+ for semi quantitative analysis and Protrace mode for quantitative analysis. The measuring programmes used for the analyses were already hardwired-programmes.

The rhodium anode X-ray tube within the operating XRF is of the end-window type. The tube consists of a ceramic construction and is sharp nosed in order to get as close as possible to the sample. The window is made of beryllium and is 75 µm thick. The anode operated with the following working specifications:

- Accelerator voltage : max 60 kV
- Current : max 160 mA
- Power level : max 4 kW

All calibrations for the XRF analyses have been carried out with the standards listed in table 2-1. The average lowest limit of detection (LLD) for each element is given in the XRF tables (Appendix III), and has been calculated from the LLD's of each analysis.

Table 2-1: Standards used for the calibration of the XRF

Elements	Standard names
Major elements	G-1, W-1, AGV-1, BCR-1, DTS-1, G-2, GSP-1, PCC-1, BHVO-1, MAG-1, SY-2, SY-3, MRG-1, ASK-1, ASK-2, GR,GA, GH, BR, MICA-FE, MICA-MG, DR-N, UB-N, BX-N, DT-N, VS-N, GS-N, FK-N, GL-O, AN-G, BE-N, MA-N, AL-I, IF-G, AC-E, JG-1, JG-1A, JG-2, JG-3, JB-1, JB-1A, JB-2, JB-3, JR-1, JR-2, JA-1, JA-2, JA-3, JF-1, JF-2, JP-1, JGB-1, JCH-1, JDO-1, JLK-1, JLS-1, JSD-1, JSD-2, JSD-3, JSI-1, JSI-2, JR-3, JGB-2, JH-1, NIM-D, NIM-G, NIM-L, NIM-N, NIM-P, NIM-S, SARM-39, SARM-40, SARM-41, SARM-42, SARM-43, SARM-44, SARM-45, SARM-46, SARM-47, SARM-48, SARM-49, SARM-50, SARM-51, SARM-52
Elements	Standard names
Trace elements	AC-E, AGV-1, AL-I, AN-G, ASK-1, ASK-2, BCR-1, BE-N, BHVO-1, BR, BX-N, DR-N, DT-N, DTS-1, FK-N, G1, G2, GA, GH, GL-O, GR, GS-N, GSP-1, IF-G, JA-1, JA-2, JA-3, JB-1, JB-1A, JB-2, JB-3, JCH-1, JDO-1, JF-1, JF-2, JG-1, JG-1A, JG-2, JG-3, JGB-1, JGB-2, JH-1, JLK-1, JLS-1, JP-1, JR-1, JR-2, JR-3, JSD-1, JSD-2, JSD-3, JSI-1, JSI-2, MAG-1, MA-N, MICA-FE, MICA-MG, MRG-1, NIM-D, NIM-G, NIM-L, NIM-N, NIM-P, NIM-S, PCC-1, SARM-39, SARM-40, SARM-41, SARM-42, SARM-43, SARM-44, SARM-45, SARM-46, SARM-47, SARM-48, SARM-49, SARM-50, SARM-51, SARM-52, SY-2, SY-3, TR-2, TR-7, TR-9, TR-14, TRMAC-1, TRMAC-2, TRMAC-3, TRMAC-4, TRMAC-5, TRMAC-6, UB-N, UREM-1, UREM-2, UREM-4, UREM-8, UREM-9, UREM-10, UREM-10/2, UREM-11, VS-N, W-1

2.4.2 REE Analyses

The rare earth element and some trace element concentrations were measured by Analytical Laboratories in Vancouver, Canada (www.acmelab.com). Sixteen selected rock pulp samples from the Dominion Reefs were provided to the ACME Labs. Rare earth and refractory elements are determined by ICP-MS (Inductively Coupled Plasma Mass Spectrometry) following a Lithium metaborate/tetraborate fusion and nitric acid digestion of a 0.1 g sample. Multiple standards were analyzed together with the submitted rock samples. Analyses by ACT Labs included compositionally different standards with well-defined elemental

concentrations. The standards used for reference measurements are listed in table 2-2. The data sets for all measured samples and the corresponding detection limits for each element are displayed in the Appendix III.

Table 2-2: Reference measurements for trace elements and REE

Ref. Mat.	Ba	Be	Co	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta	Th
STD SO-18	514	1	26.5	7.0	17.6	9.8	22.5	27.9	15	408.1	7.4	9.9
STD SO-18	504	<1	26.5	6.8	17.2	9.6	21.4	27.5	15	401.1	7.2	9.6
STD SO-18	518	2	27.7	7.1	17.9	10.2	22.2	29.1	15	420.9	7.4	10.4
STD SO-18	518	1	27.6	7.1	17.7	9.8	22.5	28.9	15	417.4	7.5	10.3
BLK	<1	<1	<0.2	<0.1	<0.5	<0.1	<0.1	<0.1	<1	<0.5	<0.1	<0.2
BLK	<1	<1	<0.2	<0.1	<0.5	<0.1	0.2	<0.1	<1	<0.5	<0.1	<0.2
Ref. Mat.	U	V	W	Zr	Y	La	Ce	Pr	Nd	Sm	Eu	
STD SO-18	16.4	203	15.0	291.3	31.6	12.0	27.1	3.36	14.6	2.96	0.87	
STD SO-18	15.9	199	14.6	286.9	31.2	12.0	26.8	3.35	14.3	2.92	0.86	
STD SO-18	16.7	211	15.5	297.6	32.7	12.6	28.0	3.51	15.0	3.03	0.90	
STD SO-18	16.7	210	15.3	296.5	32.6	12.4	27.8	3.46	14.7	3.00	0.89	
BLK	<0.1	<8	<0.5	<0.1	<0.1	<0.1	<0.1	<0.02	<0.3	<0.05	<0.02	
BLK	<0.1	<8	<0.5	<0.1	<0.1	<0.1	<0.1	<0.02	<0.3	<0.05	<0.02	
Ref. Mat.	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	La	Ce	Pr	
STD SO-18	3.01	0.49	3.00	0.60	1.78	0.28	1.84	0.26	12.0	27.1	3.36	
STD SO-18	2.94	0.50	3.00	0.60	1.74	0.28	1.79	0.26	12.0	26.8	3.35	
STD SO-18	3.01	0.52	3.06	0.62	1.86	0.29	1.84	0.28	12.6	28.0	3.51	
STD SO-18	2.97	0.52	3.03	0.63	1.81	0.29	1.82	0.27	12.4	27.8	3.46	
BLK	<0.05	<0.01	<0.05	<0.02	<0.03	<0.01	<0.05	<0.01	<0.1	<0.1	<0.02	
BLK	<0.05	<0.01	<0.05	<0.02	<0.03	<0.01	<0.05	<0.01	<0.1	<0.1	<0.02	

2.4.3 Carbon analyses

For determining the carbon content in 15 selected samples the acid method, based on the Mebius Method (Nelson and Sommers 1982, Prinsloo 1988, Wiltshire 1987), was used at the Department of Soil Science at the UFS. For these analyses, 1 g of crushed rock material was weighed and put into a glass beaker. Exactly 10 ml of 0.5NK₂Cr₂O₇ solution and 15 ml of concentrated H₂SO₄ was added and stirred in. The beaker was placed on a sand bath preheated to 130°C and the solution with the crushed rock material reacted for 10 minutes. Afterwards, the mixture was removed and 35 ml of cold distilled water was added. The excess chromate was titrated with 0.2 N ferrous ammonium sulphate solutions. The 15 analyses, carried out by using the acid method, are listed in the Appendix II.

2.4.4 EDX

A SHIMADZU SEM-SSX50 Scanning Electron Microscope EDX at the centre of microscopy at the University of the Free State in Bloemfontein was used to determine the mineral chemistry of ores and host minerals. No further thin section preparation was necessary for this investigation. Area mapping as method was carried out to determine the distribution of elements in the mineral phases and to verify different mineral assemblages.

At the Université Henri Poincaré in Nancy a second scanning electron microscope (Hitatshi FEG 4800), was used to produce images of mineral phases beyond the capabilities of ordinary optical microscopes for further EMPA analyses. The main target of the SEM analyses was to determine the quantitative elemental composition of the uranium bearing mineral phases to receive an overview about element distribution.

Four polished thin sections (DRT 039 DO 6920, DRT 034 DO 8628, DRT 079 AO 5268, DRT 058 AO 3883) were sputtered with carbon before handling SEM and EMPA analyses. Both microscopes were used with the following working specifications:

- Acceleration voltage : 15 kV
- Specimen current : 1 nA
- Take-off angle : 35.0 °
- Working distance : 17.0 mm
- Stage angle : 0.0°

2.4.5 EMPA

A CAMECA SX 100 electron probe microanalyser (EMPA), at the Université Henri Poincaré in Nancy, was used for quantitative determination of the uranium bearing mineral phases composition. The electron microprobe was used with five-wavelength dispersive spectrometers.

For the analyses, polished thin sections with the highest uranium grades were chosen. The polished thin sections were sputtered with carbon before handling or transferring for EMPA and SEM. Before the EMPA analyses, the nature of each crystal was studied by SEM imaging to identify the uranium bearing minerals in the section.

Monazites in two polished thin sections (DRT 039 DO 6920, DRT 034 DO 8628-A) were analysed in the first stage. One to eight spots were analysed on each mineral (depending on the mineral size) while one spot took about six minutes. A total number of 151 spots in monazite grains could be measured.

The measured elements are: Al, Si, P, Ca, Ti, Mn, Fe, Y, Zr, La, Ce, Pr, Nd, Sm, Th, U, Pb, Gd, and O in wt %, atomic %, and as oxides in wt %. All analyses, detection limits (in ppm), and standard deviation (in wt %) are listed in the Appendix IV. The following conditions of the electron microprobe were used for the monazite analyses, the standards used for the electron microprobe analyses are listed in table 2-3. The analyses carried out on uraninites and monazites are listed in the Appendix IV.

- Acceleration voltage: 20 kV
- Current: 10 nA
- Raster Length : 3 μm

Table 2-3: Standards and X-ray lines used for monazite analyses

Elt. Line	Spec	Xtal	Peak	Pk T. (S)	Bg Off1	Bg Off 2	Bg Time(S)	Calibration	Intensity (cps/nA)
Ce La 1	Sp1	PET	29251	10		450	5	CePO4 – mona_P_Ce013	374.8
La La 1	Sp1	PET	30451	10		500	5	LaPO4 – mona_La035	360.6
Ca Ka 1	Sp1	PET	38384	20		700	10	wollastonite-SX1_Ca017	435.0
Pb Mb 1	Sp1	PET	58031	60		170 0	30	PbCrO4 – mona_Pb022	51.2
Zr La 1	Sp2	TAP	23657	20		700	10	ZrO2 – mona_Zr037	617.2
Y La 1	Sp2	TAP	25112	30	-450	625	15	YPO4 – mona_Y036	412.5
Al Ka 1	Sp2	TAP	32442	20		800	10	albite-SX1_Na_Al024	202.2
Gd Lb 1	Sp3	LIF	45877	60	-400	450	30	GdTiGe – mona_Gd027	66.6
Fe Ka 1	Sp3	LIF	48098	20		700	10	hématite_Fe121	335.9
Mn Ka 1	Sp3	LIF	52197	20		600	10	MnTiO3-SX1_Ti_Mn014	141.0
Sm La 1	Sp3	LIF	54630	60	-600	600	30	SmPO4 – mona_Sm025	87.6
P Ka 1	Sp4	TAP	23974	20		800	10	CePO4 – mona_P_Ce013	247.7
Si Ka 1	Sp4	TAP	27734	20		800	10	orthose-SX1_Si001	753.0
Nd Lb 1	Sp5	LPET	24760	20		700	10	NdPO4 – mona_Nd045	920.5
Pr Lb 1	Sp5	LPET	25805	20	-370	750	10	PrPO4 – mona_Pr019	854.1
Ti Ka 1	Sp5	LPET	31411	10		600	5	MnTiO3-SX1_Ti_Mn014	1920.8
U Mb 1	Sp5	LPET	42438	60	-1447	793	30	UO2_U075	518.7
Th Ma 1	Sp5	LPET	47268	30	-1274	726	15	ThO2- -SX9_Th044	537.6

Uraniferous minerals in four polished thin sections (DRT 039 DO 6920, DRT 034 DO 8628-A, DRT 079 AO 5268, DRT 058 AO 3883) were analysed. Between two to twelve spots were observed on each mineral (depending on their grain size), one spot took about eight minutes, and a total of 241 analyses were carried out. The measured elements are: Al, Si, S, Ca, V, Fe,

Pb, U, Ti, La, Th, Mn, Y, Ce, P, Nd, Dy, Nb, Gd, Yb, Ta, F, and O in wt %, atomic %, and as oxides in wt %. All analyses, detection limits (in ppm) and standard deviation (in wt %) are listed in the Appendix IV. The following conditions of the electron microprobe are valid for the uraninite and their alteration products mineral analyses. The standards used for the electron microprobe analyses are listed in table 2-4.

- Acceleration voltage: 15 kV
- Current: 10 nA
- Raster Length : 2 μm

Table 2-4: Standards and X-ray lines used for uraninite mineral analyses

Elt. Line	Spec	Xtal	Peak	Pk T. (S)	Bg Off 1	Bg Off 2	Bg Time(S)	Calibration	Intensity (cps/nA)
Al Ka 1	Sp4	TAP	32463	20		800	10	albite-SX1_Al005	185.1
Si Ka 1	Sp4	TAP	27739	20		800	10	orthose-SX1_Si002	584.2
S Ka 1	Sp1	PET	61409	20		600	10	SrS – SX9_S_Sr014	49.1
Ca Ka 1	Sp1	PET	38385	10		700	5	wollastonite-SX1_Ca018	253.7
V Ka 1	Sp3	LIF	62176	20		600	10	V – SX9_V031	142.5
Fe Ka 1	Sp3	LIF	48084	20		600	10	hematite-SX1_Fe013	149.6
Pb Ma 1	Sp1	PET	60430	50		170 0	25	PbCrO4 – mona_Pb021	47.8
U Mb 1	Sp1	PET	42454	60		500	30	UO2_U076	110.1
Ti Ka 1	Sp5	LPET	31418	20		600	10	MnTiO3-SX1_Ti_Mn015	1041.1
La La 1	Sp5	LPET	30475	20		500	10	LaPO4 – mona_P_La006	696.3
Th Ma 1	Sp5	LPET	47271	60		500	30	ThO2- -SX9_Th045	370.0
Mn Ka 1	Sp3	LIF	52196	20		600	10	MnTiO3-SX1_Ti_Mn015	68.1
Y La 1	Sp4	TAP	25118	20	- 450	775	10	YPO4 – mona_Y033	340.4
Ce La 1	Sp1	PET	29259	30		500	15	CePO4 – mona_P_Ce014	206.8
P Ka 1	Sp4	TAP	23983	20		600	10	CePO4 – mona_P_Ce014	203.3
Nd Lb 1	Sp3	LIF	53818	30	- 991	114 3	15	NdPO4 – mona_P_Nd020	24.5
Dy Lb 1	Sp3	LIF	42447	30	- 500	450	15	DyRu2Ge2_Dy021	17.7
Nb La 1	Sp5	LPET	65391	20		800	10	LiNbO3-sx4_Nb007	202.2
Gd Lb 1	Sp3	LIF	45867	30	- 500	500	15	GdTiGe – mona_Gd028	30.0
Yb La 1	Sp3	LIF	41483	30	- 943	474	15	Monazite-YbCo2Si2_Yb025	42.7
Ta Ma 1	Sp4	TAP	28224	20		800	10	LiTaO3-sx4_Ta002	456.9
F Ka 1	Sp2	PC1	30992	40	- 260 0	280 0	20	topaze-SX1_F005	146.0

2.4.6 LA-ICP-MS

Three monazites, three zircons, two rutiles, and four uraniferous minerals from sample DDR 007 DO 3337 and DRT 034 DO 8628 were analysed within prepared polished thin sections. A total of 56 U-Pb ages were obtained by LA-ICP-MS techniques at Johann Wolfgang Goethe University Frankfurt (JWG) using a Thermo-Scientific Element II sector field ICP-MS coupled to a New Wave UP213 UV laser system equipped with a teardrop-shaped, lower-volume laser cell (Gerdes and Zeh 2006,2008). In Laser Ablation Inductively Coupled Plasma Mass Spectrometry the sample is directly analyzed by ablating with a pulsed laser beam. The created aerosols are transported into the core of inductively coupled argon plasma (ICP), which generates temperatures of approximately 8000°C. The plasma in ICP-MS is used to generate ions that are then introduced to the mass analyzer.

The spot size of the LA-ICP-MS for zircons varied from 8-20 µm, for monazites from 20-30 µm, for rutile from 20-40 µm and for uraniferous mineral phases from 20-40 µm. The raw data were corrected for laser-induced elemental fractionation and mass bias by normalization to the reference zircon GJ-1 ($^{206}\text{Pb}/^{238}\text{U} = 0.0986 \pm 0.0004$; $^{207}\text{Pb}/^{206}\text{Pb} = 0.06016$). Earlier, the drift in interelemental fractionation (Pb/U) during sample ablation was corrected by applying a linear regression through all measured ratios. Correction for common-Pb was done whenever the corrected $^{207}\text{Pb}/^{206}\text{Pb}$ was outside the internal errors of the uncorrected ratio. The reported uncertainties (2σ) were publicized by addition of the external reproducibility (2SD, standard deviation) obtained from the standard zircon GJ-1 during the analyses. The method was verified with reference measurements after each nine analyses.

Results are presented in table 1 in Appendix V.

Chapter Three: Petrography

This chapter focuses on the examination of the different mineral phases and their occurrence in the Dominion Reefs. For this purpose, macroscopic description and identification of the minerals by reflected light microscopy were of utmost importance.

3.1 Hand specimen petrographic description

In the following passage, the hand specimens of the Lower and Upper Reef of the Dominion Group are described in detail. The Dominion Reef samples originate within the same stratigraphic sequences and do not significantly differ in their composition. The described samples were selected from different sedimentological facies (names were given by exploration geologists in Juni 2007) to ensure the representivity. The facies distribution for the Lower and Upper Reef has been modelled by Uranium One Inc. exploration geologists by extensive core logging. Mapping of these sedimentary structures (also done by Uranium One geologists) was important to facilitate source estimations. Only representative samples of different facies were selected and described according to Pettijohn (1987) and Folk and Ward (1957).

The following general description is valid for the Dominion Reef samples within both the Rietkuil and Dominion sections. Both Reefs can be described as coarse-grained conglomeratic sedimentary units with a range in thickness from a few centimetres to a few metres. The uranium and gold mineralization occurring in the Reefs is stratabound.

3.1.1 Rietkuil area

The following different sediment facies of the Rietkuil mining area for the Upper Reef will be described by means of typical hand specimen (Fig.3-1 to 3-3). The sediment facies determination for the Lower Reef is still in progress by the mines exploration geologists. One sample will be described representing the Lower Reef unit (Fig.3-4) within the Rietkuil section.

Upper Reef: Channel Facies

Sample: DRT 034 BO 8627 (Fig.3-1)

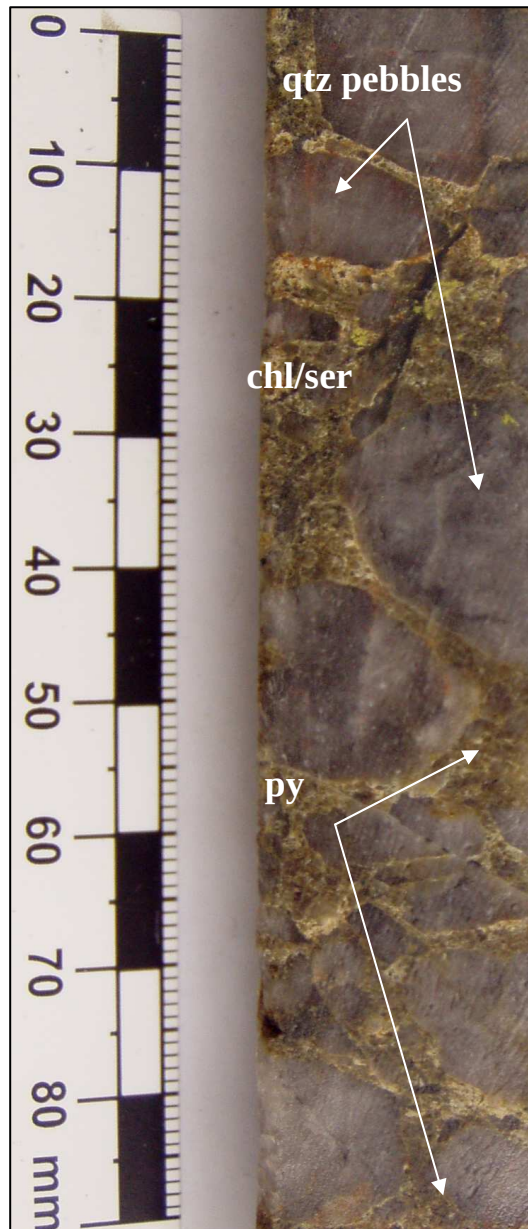
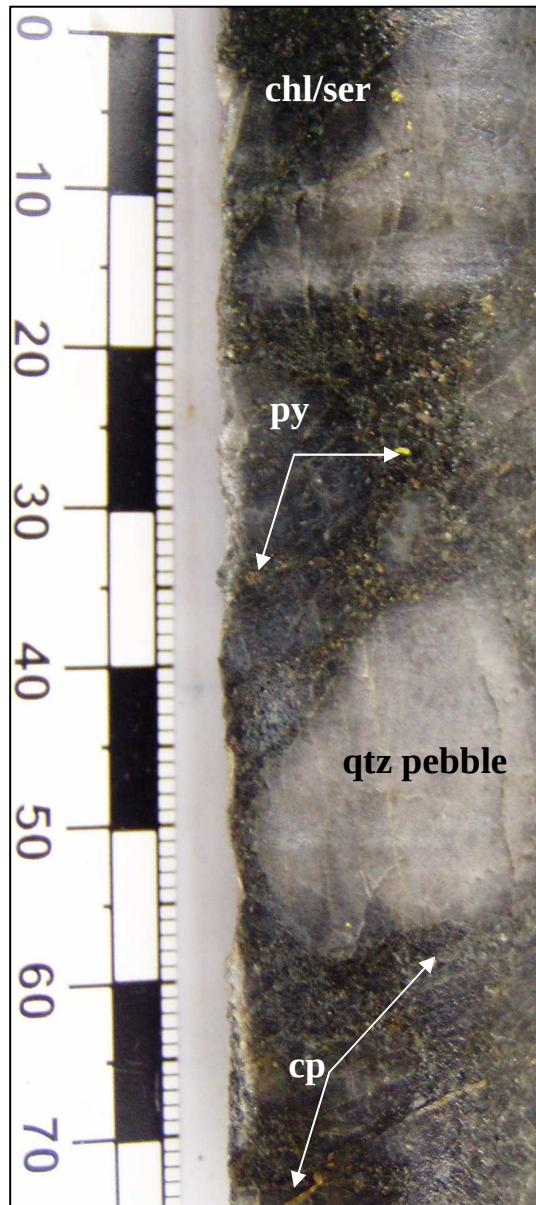


Fig.3-1: Sample DRT 034 BO 8627

- Lithology and sedimentological name: quartz-pebble conglomerate (Upper Reef), Channel Facies
- Number of samples: 24
- Clast packing density: MATRIX SUPPORTED conglomerate (modal packing density varies between 40 % and 50 % clasts, the majority of clasts will be separated from other clasts by the matrix)
- Sorting (Folk and Ward 1957): well sorted
- Visible minerals: quartz (qtz), chlorite/sericite (chl/ser), pyrite (py)
- Pebble size: 0.5 cm-2 cm
- Pebble shape (Pettijohn et al. 1987): mixture of sub-spherical (big pebbles) to well rounded (small pebbles)
- Pebble colour: whitish to dark grey
- Matrix colour: slightly yellowish and greenish
- Estimating percentage in the matrix: 15 %-20 %

Upper Reef: Interchannel Facies

Sample: DRT 079 AO 5268 (Fig.3-2)



- Lithology and sedimentological name: quartz-pebble conglomerate (Upper Reef), Interchannel Facies
- Number of samples: 17
- Clast packing density: PEBBLY QUARTZITE (quartzite with 20 % to 40 % pebbles)
- Sorting (Folk and Ward 1957): well sorted
- Visible minerals: quartz (qtz), chlorite/sericite (chl/ser), pyrite (py), chalcopyrite (cp)
- Pebble size: 2 cm-2.5 cm
- Pebble shape (Pettijohn et al. 1987): sub-spherical
- Pebble colour: slightly whitish to dark grey
- Matrix colour: medium to dark grey
- Estimating percentage in the matrix: 10 %-15 %

Fig.3-2: Sample DRT 079 AO 5268

Upper Reef: Overbank Facies

Sample: DRT 095 CO 7744 (Fig.3-3)

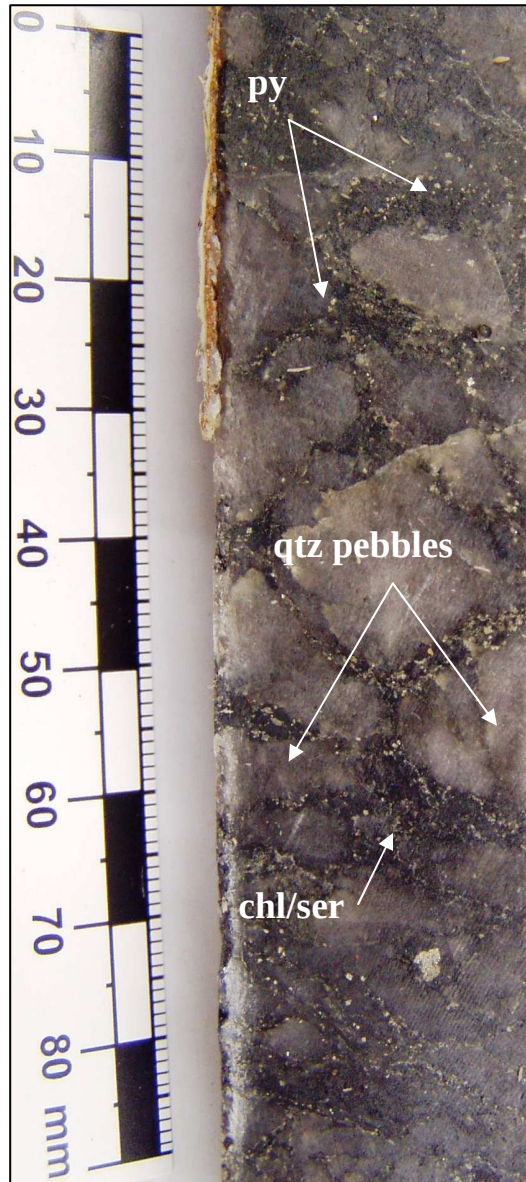
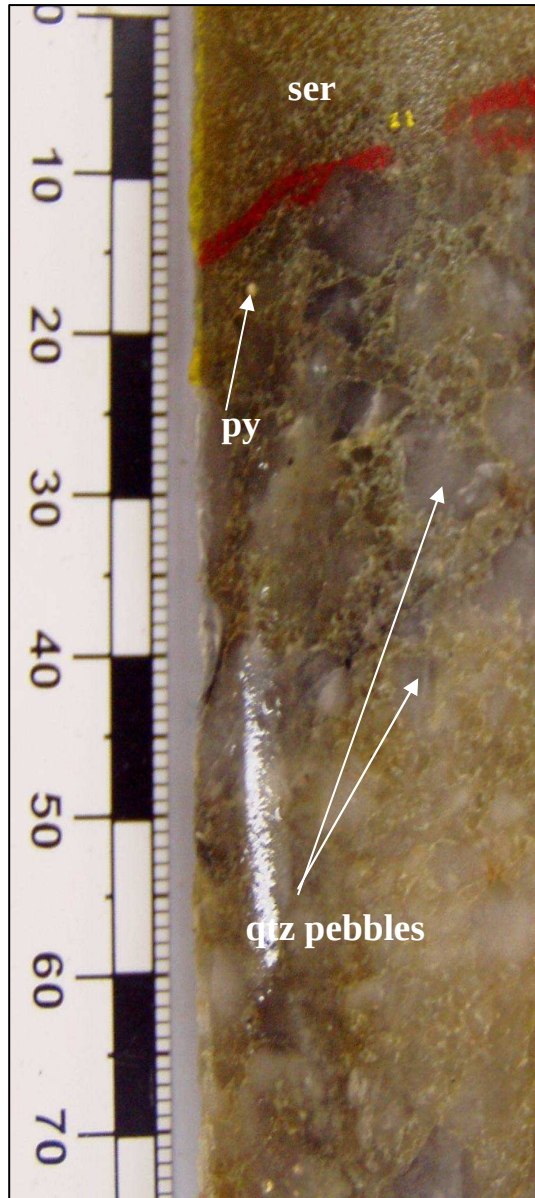


Fig.3-3: Sample DRT 095 CO 7744

- Lithology and sedimentological name: quartz-pebble conglomerate (Upper Reef), Overbank Facies
- Number of samples: 21
- Clast packing density: MATRIX SUPPORTED conglomerate (modal packing density between 40 % and 50 % clasts, the majority of clasts separated by matrix)
- Sorting (Folk and Ward 1957): well sorted
- Visible minerals: quartz (qtz), chlorite/sericite (chl/ser), pyrite (py)
- Pebble size: 1 cm-2 cm
- Pebble shape (Pettijohn et al. 1987): angular to sub-spherical
- Pebble colour: whitish to dark grey
- Matrix colour: dark grey to black
- Estimating percentage in the matrix: 25 %-30 %

Lower Reef

Sample: DRT 100 CO 7422 (Fig.3-4)



- Lithology: quartz-pebble conglomerate (Lower Reef)
- Number of samples: 9
- Clast packing density: PEBBLY QUARTZITE (quartzite with 20 % to 40 % pebbles)
- Sorting (Folk and Ward 1957): well sorted
- Visible minerals: quartz (qtz), mostly sericite (ser), less chlorite (chl), pyrite (py)
- Pebble size: 0.5 cm-1 cm
- Pebble shape (Pettijohn et al. 1987): sub-spherical
- Pebble colour: whitish to grey
- Matrix colour: slightly yellowish and greenish
- Estimating percentage in the matrix:
10 %-15 %

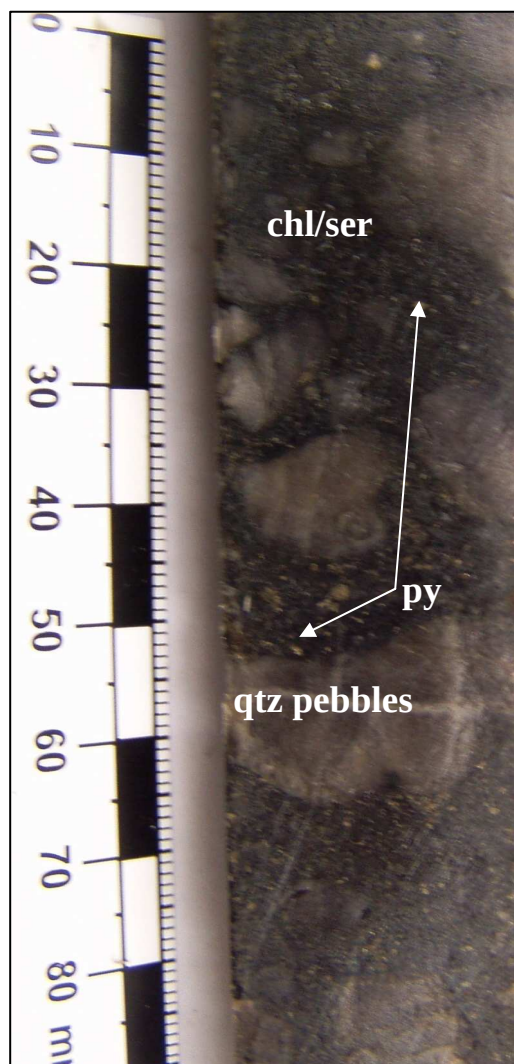
Fig.3-4: Sample DRT 100 CO 7422

3.1.2 Dominion area

Exploration geologists distinguished the conglomerates of the Reefs within the Dominion section by the same criteria. Different sediment facies will be described by means of typical hand specimen for the Upper Reef (Fig.3-5), and the Lower Reef of the Dominion Group (Fig.3-7).

Upper Reef: Middle Package Conglomerate (MPC)

Sample: DDR 007 DO 3337 (Fig.3-5)



- Lithology and sedimentological name: quartz-pebble conglomerate (Upper Reef), Middle Package Conglomerate
- Number of samples: 4
- Clast packing density: PEBBLY QUARTZITE (quartzite with 20 % to 40 % pebbles)
- Sorting (Folk and Ward 1957): well sorted
- Visible minerals: quartz (qtz), chlorite/sericite (chl/ser), pyrite (py)
- Pebble size: 1 cm-2.5 cm
- Pebble shape (Pettijohn et al. 1987): sub-spherical
- Pebble colour: whitish to grey
- Matrix colour: dark grey
- Estimating percentage in the matrix: 15 %-20 %

Fig.3-5: Sample DDR 007 DO 3337

Lower Reef: Thick Reef

Sample: DDR 077 CO 5602 (Fig.3-6)

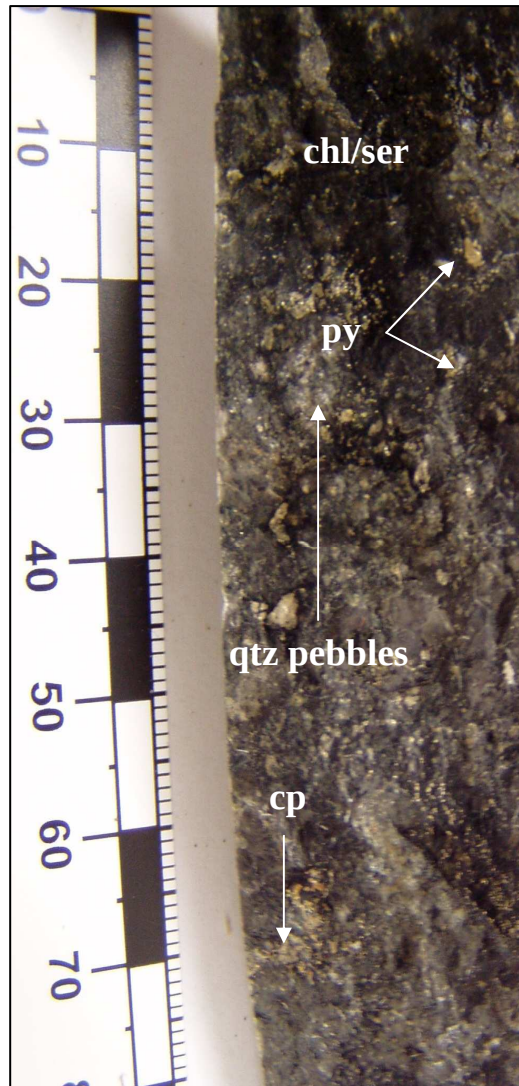


Fig.3-6: Sample DDR 077 CO 5602

- Lithology and sedimentological name: quartz-pebble conglomerate (Lower Reef), Thick Reef
- Number of samples: 2
- Clast packing density: PEBBLY QUARTZITE (quartzite with 20 % to 40 % pebbles)
- Sorting (Folk and Ward 1957): well sorted
- Visible minerals: quartz (qtz), chlorite/sericite (chl/ser), pyrite (py), chalcopyrite (cp)
- Pebble size: maximum of 1 cm
- Pebble shape (Pettijohn et al. 1987): sub-spherical
- Pebble colour: light grey
- Matrix colour: dark grey
- Estimating percentage in the matrix: 10 %-15 %

3.2 Microscopic Description

For the preparation of 32 polished thin sections, selected samples with high uranium contents were chosen for this investigation. The microscopic examination reveals radioactive, and non radioactive minerals like sulphides, oxides, and silicates. For locating uraniferous minerals within several thin sections, autoradiography (Fig.3-7) was carried out.



Fig.3-7: Image of the radioactive minerals on photographic film with the thin section, autoradiography method (Rogers 1979) on sample DDR 077 CO 5602

As a quantitative method, point counting (total of 900 counts), was carried out on 32 polished thin sections. The modal proportions of the most common minerals are listed in table 3-1. The sericite and chlorite modal proportions are given as a total because distinction between the minerals was not possible during the point counting. The obtained values vary significantly in the investigated thin sections because the observed minerals are heterogeneously distributed within the Dominion Reef sediments. This leads to the result that the obtained data must be considered as a rough guide for mineral distribution.

Table 3-1: Modal proportions (in %) of the main mineral content in 32 investigated polished thin sections

(py = pyrite, gn = garnet, gl = galena, sp = sphalerite, qtz = quartz, leu= leucoxene, ana = anatase, sec. u = secondary uraniferous phases (mostly ghost minerals), ur = uraninite, chl/ser = chlorite/sericite, zr = zircon)

core number	sample name	py	gn	gl	Sp	qtz	leu/ana	sec.u	ur	chl/ ser	zr
DRT 034	DO 8628	17,9	4,2	4,4	3,4	29,1	5,2	9	3,1	18,1	5,4
DRT 070	AO 5686	16,1	2,1	6,8	10,2	27,7	5,7	4,1	5,3	16,2	5,8
DRT 034	DO 8627	8,6	0,1	7,4	3,4	38	7,9	3,6	3,1	23,6	4,3
DRT 039	DO 6920	14,3	1,6	5,8	1,3	31,6	11,7	6,9	1,7	21	4,2
DRT 076	AO 8521	13,4	5,7	9,0	3,3	31,3	1,3	5,3	2,6	27	0,8
DRT 079	AO 5274	23,6	9,6	6,8	1,0	35,1	3,1	4,1	0	16,4	0,3
DRT 043D1	AO 3735	7	1,2	13,9	6,8	30,2	6	3,2	1,3	26,2	4,1
DRT 094	EO 5633	5,6	0	6,7	3	45,1	1,1	3,3	0	34,3	0,9
DRT 058	AO 3886	12	3,9	11	2,9	34,9	3	4,6	0,7	26,2	0,9
DRT 079	AO 5268	26,1	3,3	8,8	8	27,8	1,8	8,2	0,9	12,4	2,7
DRT 106	EO 3270	15,3	0,9	13,7	6,9	25,3	3,3	5,9	0,1	25,1	3,4
DRT 056	AO 1292	24,8	1,3	8,4	2,7	30,4	2,7	6,3	0,7	22,4	0,2
DRT 043	AO 3613	7,9	0,8	10,9	2,8	36,8	4,8	7,2	0	27,4	1,4
DRT 050	AO 1638	5,2	0	2,9	0,3	46,8	3,6	2,7	0	37,2	1,3
DRT 100	CO 7422	4,8	0,1	11,9	8,8	29,2	9	8,8	2,9	24,1	0,4
DRT 017	DO 318	14,8	0,9	14,6	10,2	27,7	1,3	6,6	1,9	21,8	0,3
DRT 173	FO 5548	13,9	2	14,8	8,7	27,4	7	5,1	0,3	20,7	0,1
DRT 095	CO 7744	31,1	0,1	12	6,8	23,9	2,3	8,4	1,1	13,3	0,9
DRT 073	AO 8286	26,4	3,7	5,3	3,1	30,6	1,4	6,7	1,4	21	0,3
DRT 056	AO 1320	11,6	0	0,8	1	45,8	0,9	2,7	1,3	35,8	0,2
DRT 108	FO 5732	9,6	2,2	14,2	11,4	21	10,8	11,3	3,3	15,7	0,4
DRT 179	FO 948	6,9	0	1,7	1,4	48,8	2,7	2,2	0,9	35	0,4
DDR 007	DO 3337	23,6	4,3	6,4	5,8	25	9,9	5,1	2,4	16,4	1,0
DDR 007	DO 3342	4,6	0	2,2	0,8	52,6	0,6	3,6	0,8	34,8	0,2
DDR 077	CO 5512	29,4	7,8	3,7	3,1	30,2	3,1	3,8	6,3	11,8	0,8
DDR 077	CO 5516	11,9	1	10,3	6,8	33,8	4,4	3,8	2,9	25,1	0
DDR 077	CO 5602	11	0,7	10,4	9,6	33,4	3	4,1	5,6	22,2	0
DRT 104	CO 8296	8,3	0,6	7,3	6,4	39,1	5,1	3,9	3,2	26	0
DRT 108	FO 5722	8,4	0	12,3	7,3	28,9	7,1	8,2	3,4	23,8	0,4
DRT 024	DO 1823	25,7	0,7	5	2,9	28	4,7	5,1	1,2	25,4	1,3
DRT 101	EO 1040	21,4	3	5,1	1,8	33,8	6,2	8	3,6	17,1	0
DRT 058	AO 3883	23	6,8	5,1	3,2	32,9	2,9	7,4	4,1	14,2	0,3

Within the following optical observation, a brief description of all observed minerals will be given. Table 3-2 displays the basic optical properties and their discriminative features for all identified minerals. Based on these features, all occurring minerals could be differentiated and identified.

Table 3-2: Optical properties of common minerals in the conglomerates as observed during petrographic studies

Mineral	formula	crystal system	colour	pleochroism	anisotropy	internal reflections
uraninite	UO ₂	cubic	brownish grey	not present	isotropic	dark brown to reddish brown
coffinite	U(SiO ₄) _{1-x} (OH) _{4x}	tetragonal	black (some fracture faces may appear grayish-black)	not present	isotropic	brownish
leucoxene	TiO ₂	tetragonal	white to khaki-grey, brownish, nearly black	not present	not present	brownish to yellow
anatase	TiO ₂	tetragonal	brown yellowish	weak, mostly not present	not present	yellow
monazite	(Ce,La,Nd,Th,Y)PO ₄	monoclinic	yellow to brown or orange-brown	not present	not present	amber coloured
columbite	(Fe,Mn)(Ta,Nb) ₂ O ₆	orthorhombic	grey-white with brown tint	weak	anisotrop distinct,	Fe rich, deep red
zircon	Zr(SiO ₄)	tetragonal	colorless, purple, yellow	strong	present	strong, red, yellow, greenish
cassiterite	SnO ₂	tetragonal	reddish brown to brown/grey	dark brown/ lighter brown	present	amber coloured
rutile	TiO ₂	tetragonal	light yellowish	distinct	present	yellowish, to reddish brown
ilmenite	Fe ²⁺ TiO ₃	trigonal	black	weak	strong, in grey shades	grey to light brown
chromite	(Fe,Mg)(Cr,Al) ₂ O ₄	cubic	dark grey to brownish grey	not present	usually absent	red brown, absent in Fe-rich samples
magnetite	Fe ²⁺ Fe ³⁺ O ₄	cubic	greyish to black	not present	isotropic	reddish brown
pyrite	FeS ₂	cubic	yellowish white	not present	isotropic	not present
galena	PbS	cubic	white, rarely with pink tint	not present	isotropic	not present
arsenopyrite	FeAsS	monoclinic	white	weak	strong; blue, green	not present
sphalerite	(Zn,Fe ²⁺)S	cubic	grey, with brown tint	not present	isotropic	white, yellow reddish brown
chalcopyrite	CuFeS ₂	tetragonal	brassy yellow	weak	weak	not present

Mineral	formula	crystal system	colour	pleochroism	anisotropy	internal reflections
pyrrhotite	Fe_{1-x}S	hexagonal	creamy pinkish brown	very distinct, creamy to reddish brown	very strong, yellow grey	not present
garnet	general- $\text{X}_3\text{Y}_2(\text{SiO}_4)_3$ $\text{X}=\text{Ca, Fe, ...}$ $\text{Z}=\text{Al, Cr, ...}$	rhombic dodecahedra or cubic	virtually all colours	none/only in certain varieties	present	not present
quartz	SiO_2	rhombohedral	brown to grey	weak	strong	not present
chlorite	$(\text{Fe, Mg, Al})_6(\text{Si, Al})_4\text{O}_{10}(\text{OH})_8$	monoclinic	greenish to brownish	very strong, light green to dark green	present	not present
sericite	$\text{KAl}_2(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH, F})_2$	monoclinic	white to greenish grey,	strong	present	not present

3.2.1 Radioactive Minerals

The principal radioactive minerals identified within the thin sections are uraninite, coffinite, secondary uraniferous mineral phases, uraniferous leucoxene, monazite, columbite and radioactive zircon. These minerals will be described in detail according to their occurrences. The presence of uraninite, coffinite, secondary uraniferous mineral phases, and leucoxene within the Dominion Reef samples are displayed in figure 3-8. Columbite, monazite, and zircon grains are displayed in figure 3-9.

Uraninite

Uraninite grains occur more or less altered in all observed sections. Primary massive dense cubic completely unaltered uraninite grains are not present. The bulk of the grains are mostly heterogeneous in various stages of alteration. The appearance can best be described as patchy and isolated rather than typical clusters, well known in other Witwatersrand Reefs (Liebenberg 1955). The shape of the observed uraninites can be described mostly as oval to rounded, and subhedral (Fig.3-8: A). Rounded to sub-angular uraninite mineral grains vary in size between 50-100 μm . Uraninite mostly occurs within the same rounding stage as zircon, chromite and monazites.

In most of the highly altered grains, dust-like inclusions of galena form infillings in veinlets or form rims. Galena sometimes replaces uraninite grains completely. The inner part is often partially dissolved and replaced by sulphides (pyrite, pyrrhotite, chalcopyrite) or phyllosilicates. The replacement material can form crack fillings within the uraninite grains.

Remarkable is that original outlines can be completely destroyed. More preserved grains rarely contain inclusions of sulphides and phyllosilicates.

Typical radial textures possibly filled with uraninite or altered uranite could be observed in two samples (Fig.3-8: B) which are orientated perpendicular to the outline of the grain. For definitive identification, electron microprobe analyses are necessary. Petrographic study could not clearly distinguish between detrital and reworked uraninite.

Coffinite

Coffinite as a black mineral phase is present in some of the polished thin sections. The mineral is present as a microcrystalline, relatively heterogenous phase. The U-silicate is intimately overgrown with numerous impurities like sulphides and silica (Fig.3-8: C). Notable is that TiO₂ (probably anatase) is often associated with coffinite. Based on the described observations a distinction between coffinite and other associated mineral phases is difficult. Coffinite occurs as small grains up to 50 µm. filling the interstices between the quartz pebbles.

U-Th mineral phases

The U-Th mineral phases are rarely distributed, patchy in “ghost minerals” in all investigated thin sections. The appearance can be described as cloudy and as replacement or represent pseudomorphs at uraninite grains (Fig.3-8: C). The bulk of the uraniferous mineral phases form encrustations around uraninites. Ramdohr (1958) termed the material as "ghosts" because the outlines are not clearly detectable. Inclusions of pyrrhotite, anatase and galena grains are common in the mineral phase. The secondary mineral phases sometimes replace detrital matrix constituents like sericite and quartz. The masses occur mostly in a very small size between 10 and 20 µm.

U-Ti phases

A low proportion of U-Ti mineral phases could be observed in the thin sections. The U-Ti phases occur in or around "ghost minerals" within the polished thin sections similar to U-Th mineral phases. Mostly the U-Ti phases form rims around highly altered uraninite grains. Distinguishing between the U-Ti and the U-Th mineral phases is difficult based on their similar appearance. The bulk of the grains are seen with irregular outlines and appear interstitial within quartz and/or other minerals, or with tiny inclusions of galena (Fig. 3-8: D).

U-Ti phases vary in size between 20 and 50 μm , and sometimes replace zircon grains as shown in figure 3-8: F. Remarkable is the main occurrence of U-Ti phases with anatase, uraninite (Fig.3-8:E). Frequently uraninite occurs next to zircon grains illustrated in figure 3-8: F.

Leucoxene

A very low proportion of leucoxene could be observed in the thin sections. Most grains are non-radioactive and can be determined as anatase derived from ilmenite. Leucoxene crystals can also be termed as "ghosts" and form rims around highly altered uraninite grains. Leucoxene grains appear with a size up to 20 μm in size and occur next to Ti-bearing phases as displayed in figure 3-8: F.

Zircon

Zircon has been described under the category of radioactive minerals since several authors, such as Hiemstra (1968), proposed in their studies that the bulk of zircons are radioactive.

Zircon is present in all investigated samples as a minor constituent and can reach proportions of approximately six per cent (table 3-1: modal proportions). The bulk of the radioactive mineral appears as purple euhedral grains with tiny inclusions of galena. Some grains show bright orange alteration rims as displayed in figure 3-9:C. The rim of the mineral can be assumed to be of radiogenic origin (Hiemstra 1968).

Non-radioactive zircons are present as a well zoned pinkish mineral with rare inclusions of galena. They are slightly angular to well rounded in shape. Different stages of metamictization were noticed within the Reef samples. Most of the zircon occurs highly corroded and partially replaced by quartz, Ti-bearing mineral phases and pyrite. Remarkable is that the zircon grains are often enclosed by uraninite and secondary U-Ti phases.

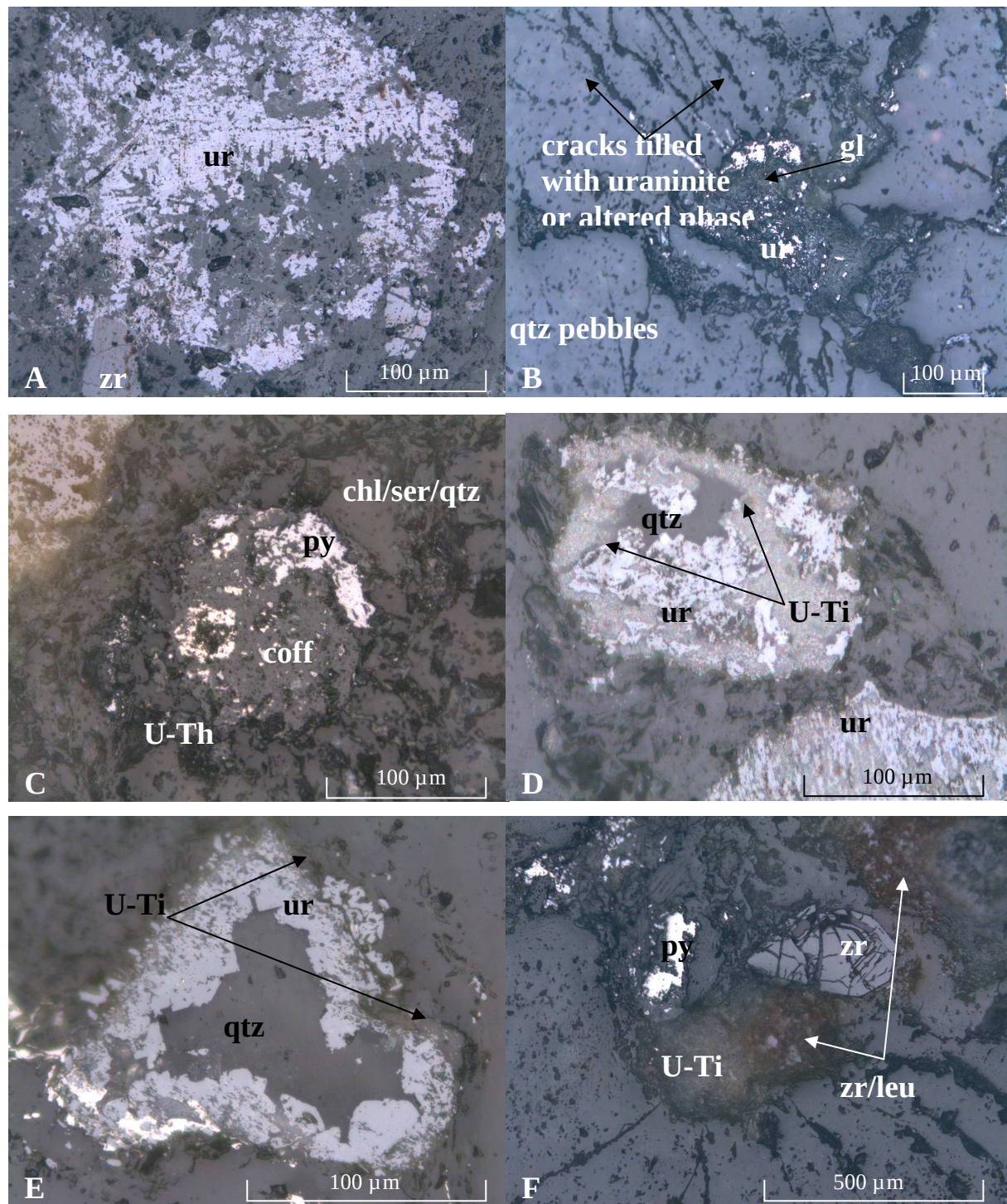


Fig.3-8: Microscopic pictures under reflected light (rl), A: altered uraninite (ur) B: uraninite (ur) with linear cracks and specks of galena (gl) between quartz pebbles (qtz pebbles), C: rounded coffinite (coff) grain next to U-Th mineral phases (U-Th) and specks of pyrite (py) within the chloritic/sericitic/quartz matrix (chl/ser/qtz) D: oval uraninite (ur) grain with cloudy U-Ti mineral phases (U-Ti) and quartz (qtz) as infilling, E: uraninite (ur) rimmed by U-Ti mineral phases and pyrite, the core consists of quartz, F: U-Ti phases (U-Ti) appears next to zircon (zr) and pyrite, the brownish leucoxene overgrowths zircon (zr/leu), the zircon core is hardly visible

Columbite

Columbite is rarely distributed in most of the investigated thin sections in different stages of replacement by metamictic material (Fig.3-9: E). Most of grains are present with a high level of rounding and sphericity. A large proportion of observed grains show signs of peripheral alteration to unknown mineral phases. Hiemstra (1968) reported the presence of betafite, and euxenite after heating diffraction patterns. Both alteration products of columbite could not be identified with the optical observations of the investigated polished thin sections.

Most grains occur as euhedral crystals and anhedral aggregates. Inclusions of cassiterite, galena, rutile, ilmenite and uraninite could be observed. Columbite can also form intergrowths with uraninite.

Monazite

Monazite is a common heavy mineral in the Upper Reef, and is mostly associated with uraninite grains. Within the Lower Reef conglomerates, monazite is rarely distributed.

The bulk of monazites as main rare earth element bearing phosphate mineral, appear as small well-preserved grains with a high degree of roundness (Fig.3-9: A, B).

Different stages of alteration associated with the monazites could be observed. Some grains are fractured and show a high degree of alteration. The fractures contain mostly matrix constituents like quartz, chlorite and sericite. A replacement by phyllosilicates can be assumed.

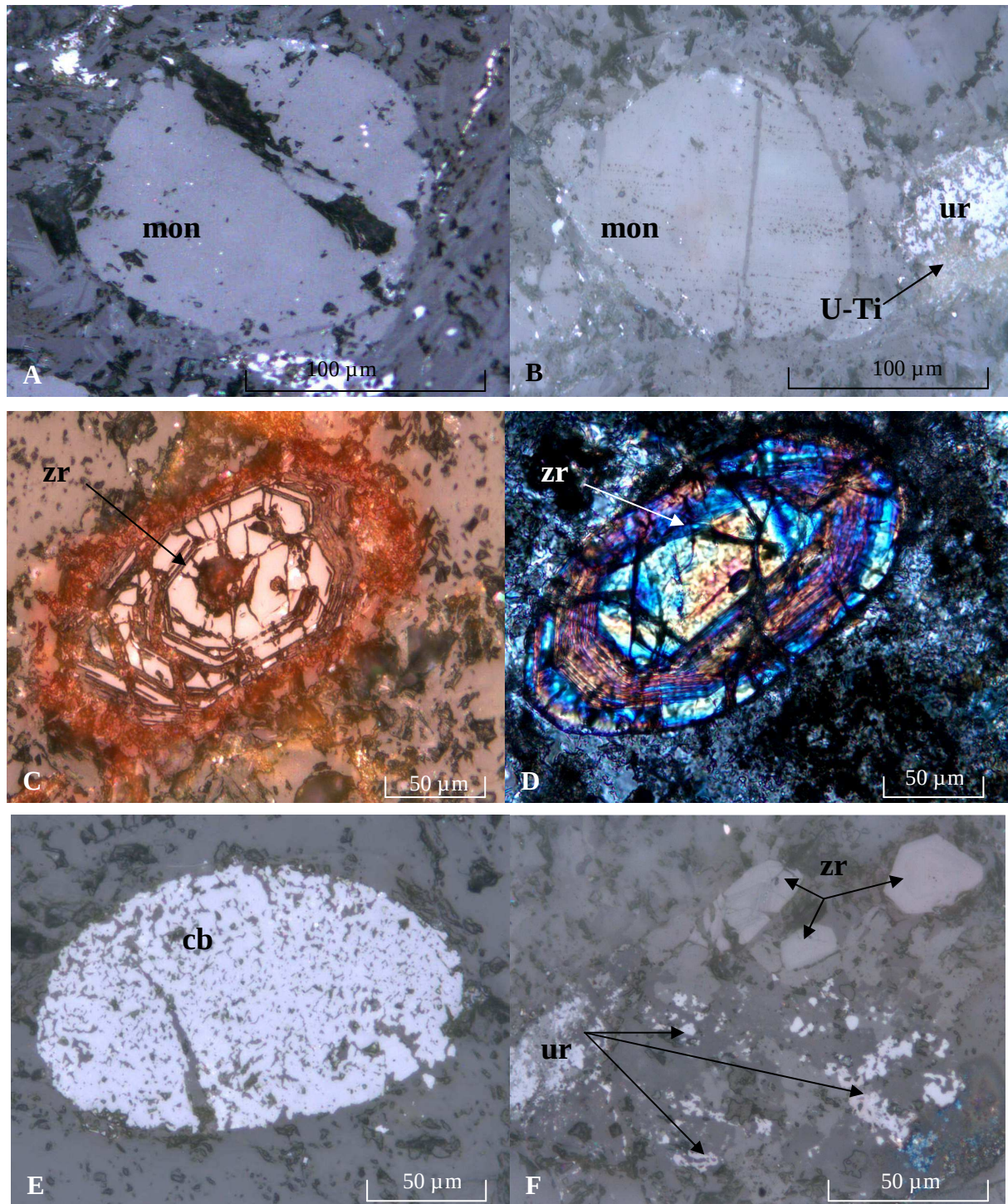


Fig.3-9: Microscopic pictures under reflected (rl) and transmitted light (tl) within chloritic and sericitic matrix, A: well rounded monazite (mon), fractured (rl), B: rounded monazite (mon) with fractures (metamict material as infilling) next to altered uraninite (ur) with U-Ti phases (U-Ti) as rim, C: zoned zircon (zr) (crossed tl) with orange alteration rim, D: zoned zircon (zr) (tl) with fractures, E: oval columbite (cb) (rl), F: zoned zircon (zr) in a close bond with uraninite (ur) (rl)

3.2.2 Non-radioactive oxide minerals

The non radioactive oxide minerals identified in the 32 thin sections are cassiterite, anatase, magnetite, rutile and chromite (Fig.3-10). Radioactive oxide minerals like zircon have already been described above.

Cassiterite

Cassiterite is rarely distributed and could only be identified in some thin sections. Under the microscope, the mineral could be recognized as compact anhedral masses and as subhedral to euhedral crystals. Sulphide minerals like pyrite, sphalerite, galena, and pyrrhotite mostly appear associated with cassiterite grains. Galena and sphalerite overgrow cassiterite.

Rutile

A low proportion of rutile could be noticed within the thin sections. The grains appear to be recrystallization products. The mineral occurs mainly as pale prismatic to columnar crystals bedded in chlorite and sericite matrix. Some of them show polysynthetic twin lamellae (Fig.3-10: B). Remarkable is that the rutile grains are approximately the same size as accompanied zircon grains.

Ilmenite

Ilmenite is rarely distributed in the Dominion Reef samples as detrital grains, only occur next to rutile. Nearly all grains seem to be altered to anatase or leucoxene.

Anatase

Anatase most likely is rarely distributed within the Dominion Reefs. The mineral occurs as patchy cloudy masses together with leucoxene (Fig. 3-10: C). Anatase is present as a "ghost" like mineral in patchy masses. Clear outlines of the mineral could not be identified. It can be assumed that the non radioactive leucoxene most likely can be termed anatase derived from ilmenite.

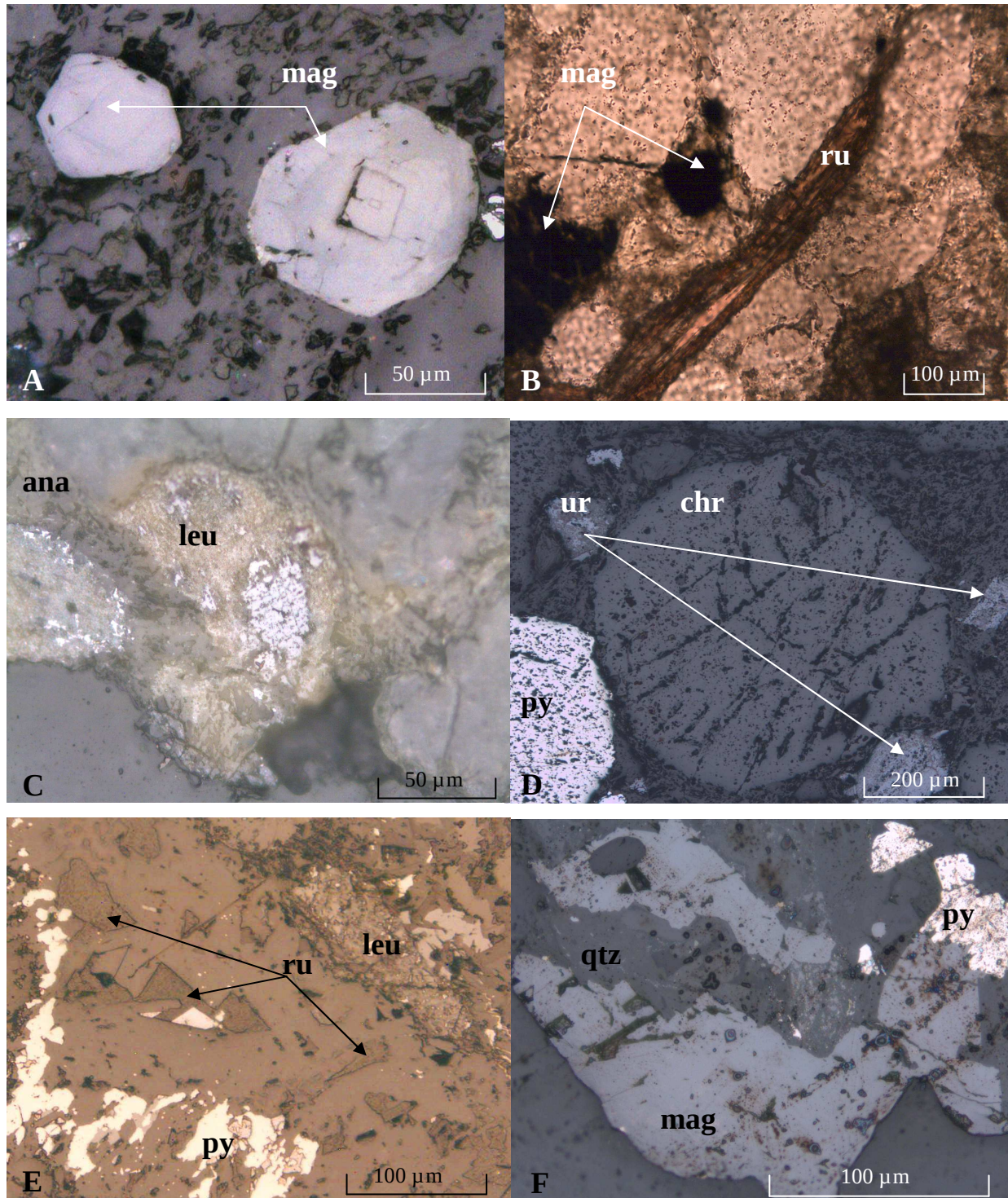


Fig.3-10: Microscopic pictures under reflected light (rl) and transmitted light (tl), A: magnetite (mag) with isometric original structures in both grains (rl), B: elongate rutile (ru) with magnetite (crossed tl), C: anatase (ana) as cloudy patchy mass (rl) next to leucoxene (leu), D: cracked chromite grain (chr) accompanied by pyrite and uraninite grains, E: rutile (ru) next to leucoxene (leu), accompanied with pyrite (py), F: corroded magnetite (mag) grain (rl)

Chromite

Chromite is present in small quantities in most of the thin sections. The minority of the grains appear as subhedral to euhedral or as coarse crystalline aggregates. The bulk of the chromite grains occur as well rounded oval minerals. The majority of the grains appear fractured (Fig.3-10: D). The fracture infilling is mainly sericite, less common chlorite and rarely pyrite. Even zoning of the oxide mineral is common.

Magnetite

Magnetite grains are rarely distributed within the examined polished thin sections. The mineral occur as well rounded oval grains. Notable is the appearance of some zoned grains (Fig.3-10: A) with original isometric crystal structures. The size of the grains varies between 50 and 70 μm and can be compared with the sizes of uraninite, zircon and chromite.

3.2.3 Sulphide minerals

The sulphide minerals (pyrite, galena, chalcopyrite, arsenopyrite and sphalerite) that could be identified within most of the observed thin sections. They represent, next to the radioactive minerals, the most common constituents apart from the gangue-minerals in the polished thin sections. Their typical appearances are displayed in figure 3-11 and 3-12.

Pyrite

Pyrite is the most abundant opaque mineral of the Dominion Reef conglomerates. According to Ramdohr (1958), Saager (1970) and Köppel and Saager (1974), pyrite can be distinguished in three types as allogenic, concretionary authigenic, and reconstituted authigenic grains. All three types could be identified in the investigated samples (Fig.3-11).

The first type is the dominant occurrence of pyrite in the Dominion Reefs. The grains appear well rounded, compact, homogeneous, and sometimes with abraded outlines. It is generally believed that this pyrite type has a detrital origin well known as buckshot pyrite. The first type is known as oldest pyrite according to Simpson and Bowles (1977). The cubic cleavage of the original crystals is sometimes visible. Most of the grains contain inclusions of other sulphide minerals with galena as most common. Exsolution sparkles of galena are separated from intergrowths of pyrite and galena as a result of the radiogenic lead migration from uraninite grains, according to Simpson and Bowles (1977).

The second type of pyrite differs from the first one by its porous and concretionary appearance. The heterogeneous grains are coarser than the allogenic grains and can show

zoning. A large amount of pyrite concretions appear intimately intergrown with silicate phases and sulphides. The pores are filled with galena, sphalerite, and rare chalcopyrite. These descriptions lead to the interpretation that concretionary pyrite had been transported to its present location, and did not originate in situ (Simpson and Bowles 1977).

The third pyrite type is present as euhedral grains in the matrix or forms overgrowths on detrital grains. Ramdohr (1958) reported that these grains are authigenic (formed by remobilization and recrystallization during metamorphism) and are the youngest pyrite grains within the Dominion Reefs.

Galena

Galena grains are widely distributed in small quantities in all investigated samples. The mineral phase appears as tiny inclusions in uraninite and other secondary uranium bearing mineral phases, monazite, columbite and zircon. It is also observed in small veinlets and porous zones of primary sulphide minerals such as pyrite (type I and II) and arsenopyrite.

Figure 3-12, picture B and D illustrates common occurrences.

Chalcopyrite

Chalcopyrite is not present in all investigated thin sections. The microscopic study detected the rarity of the sulphide mineral within the Dominion Reefs. The homogeneous mineral phase occurs as xenomorph grains mostly associated with pyrite or as tiny inclusions in other sulphides. The typical form is illustrated in figure 3-12-C.

Arsenopyrite

Arsenopyrite is rarely distributed within the investigated thin sections. The sulphide mineral is present as euhedral to subhedral, isolated homogeneous patchy mass (Fig.3-12 A). Other sulphide minerals mainly accompany arsenopyrite.

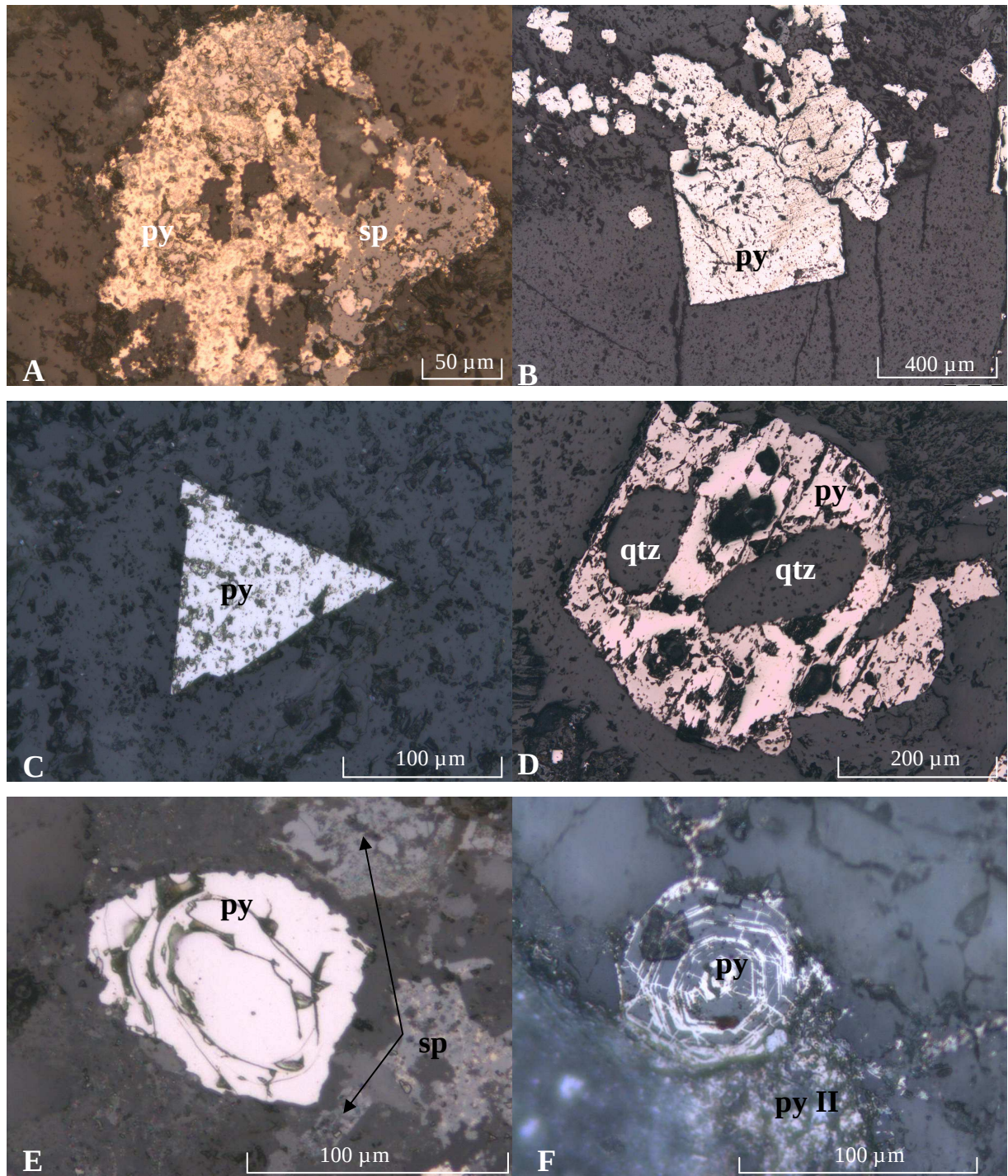


Fig.3-11: Microscopic pictures of pyrite (py) under reflected light (rl), A: allogenic pyrite (py) with sphalerite (sp) inclusions and abraded outlines, B: authigenic reconstituted pyrite (py), C: authigenic reconstituted pyrite (py) in triangle shape, D: concretionary authigenic pyrite (py) around quartz (qtz), E: concretionary pyrite (py) grain with typical zoning, F: concretionary pyrite (py) grain, next to fine dispersed pyrite (py II)

Sphalerite

Sphalerite is a well distributed ore mineral in most of the observed samples. The grains occur as irregular anhedral masses with asymmetrical outlines. Remarkable is the appearance of xenomorphic sphalerite in figure 3-12-B with significant corroded outlines. Other sulphide minerals like pyrite, galena, chalcopyrite and pyrrhotite are mainly associated with sphalerite. In some grains, tiny inclusions of pyrite could be observed.

Pyrrhotite

Pyrrhotite is rarely distributed in the observed thin sections. The grains are present as anhedral granular homogeneous masses, associated with pyrite and other sulphide minerals. Sometimes pyrrhotite appears within quartz grains.

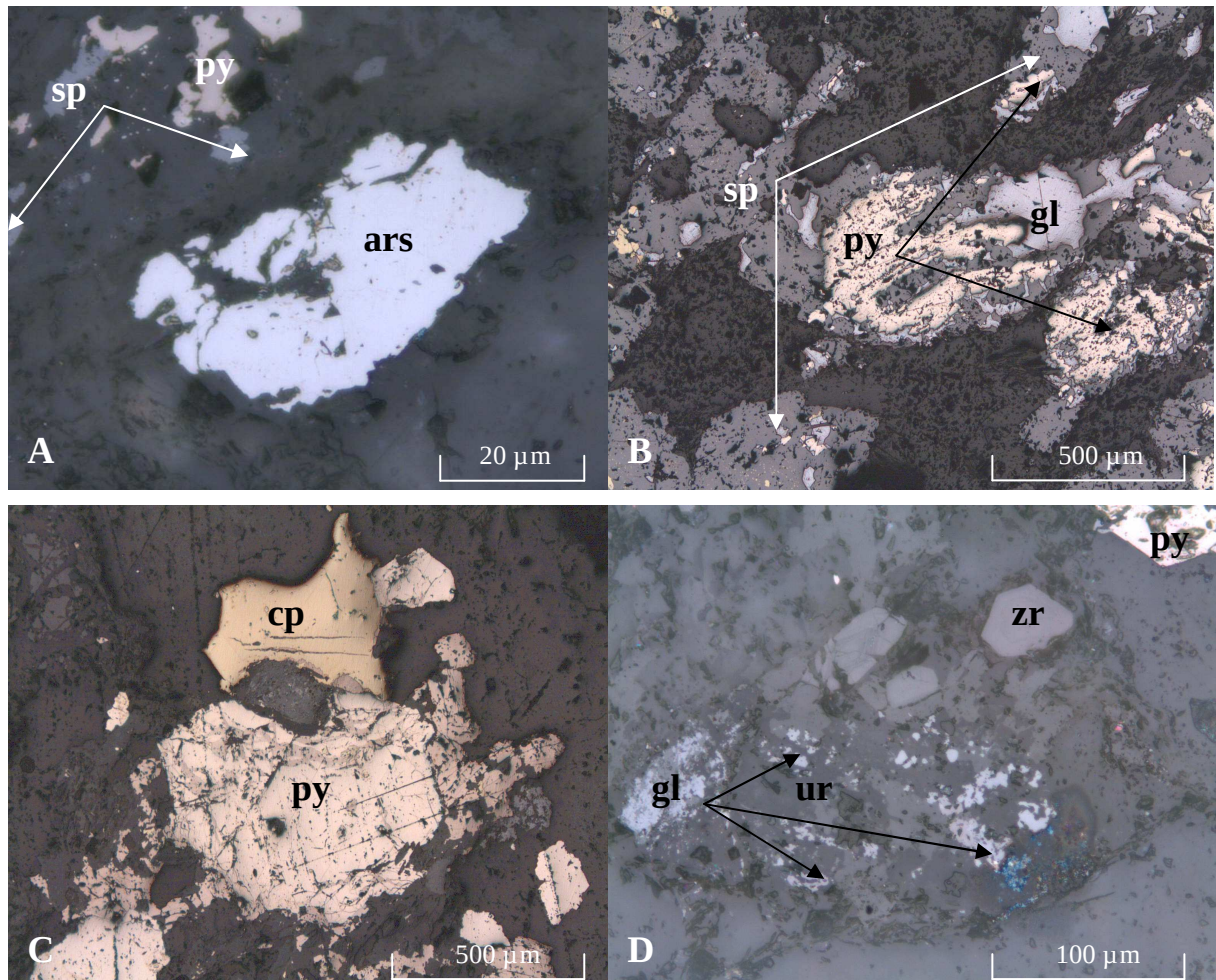


Fig.3-12: Microscopic pictures of pyrite under reflected light (rl), A: arsenopyrite (ars) next to sphalerite (sp) and pyrite (py), B: pyrite (py) with sphalerite (sp) and galena (gl), C: pyrite (py) with chalcopyrite (cp), C: galena (gl) as specks in uraninite (ur) next to zoned zircon (zr) and pyrite (py)

3.2.4 Silicate minerals

Quartz and the phyllosilicates as constituents of the matrix, and garnet are recognised as the most abundant accessory minerals. The appearance of the minerals is displayed in figure 3-13.

Garnet

Garnet is the main accessory mineral in the Dominion Reefs. Two types of garnet could be differentiated - bright yellow and rose coloured garnet. Some of the grains show a rose colour and some are bright yellow. Hiemstra (1968) determined the composition of the bright yellow as 60% almandine and 40% andradite and the rose coloured garnet with a composition of 76% almandine, 20% pyrope, and 4% grossularite.

Garnet grains are extensively replaced by chlorite along their peripheries or even completely. Most of the grains are present as well rounded grains with fractures and inclusions of sulphide minerals. Garnet is the most abundant heavy detrital silicate mineral in the conglomerate of the Dominion Reefs.

Quartz

Quartz is present in all observed thin sections as constituents of the matrix. The grains occur in a close association with chlorite and sericite in the matrix. The bulk of the quartz is present as pebbles as illustrated in the hand specimen. It can be assumed that quartz occurs in two generations. The first group (pebbles) from primary detrital origin comparable with heavy minerals genesis, whereas the second group (matrix) can be claimed from secondary origin. Quartz intergrowths with detrital minerals and proves a secondary origin.

Chlorite

Chlorite is a secondary alteration product, and is present as a major constituent of the matrix in all observed sections. The greenish mineral often replaces garnet, chromite and other detrital minerals. The mineral most likely derived from detrital biotite. Biotite primary grains could not be identified within the sections.

Sericite

Sericite, as a matrix component, is well distributed in all sections. The mineral mostly appears in association with quartz and chlorite as a component of the matrix. As the alteration product

of muscovite, the mineral is interstitially present or even replaces garnet and other detrital minerals.

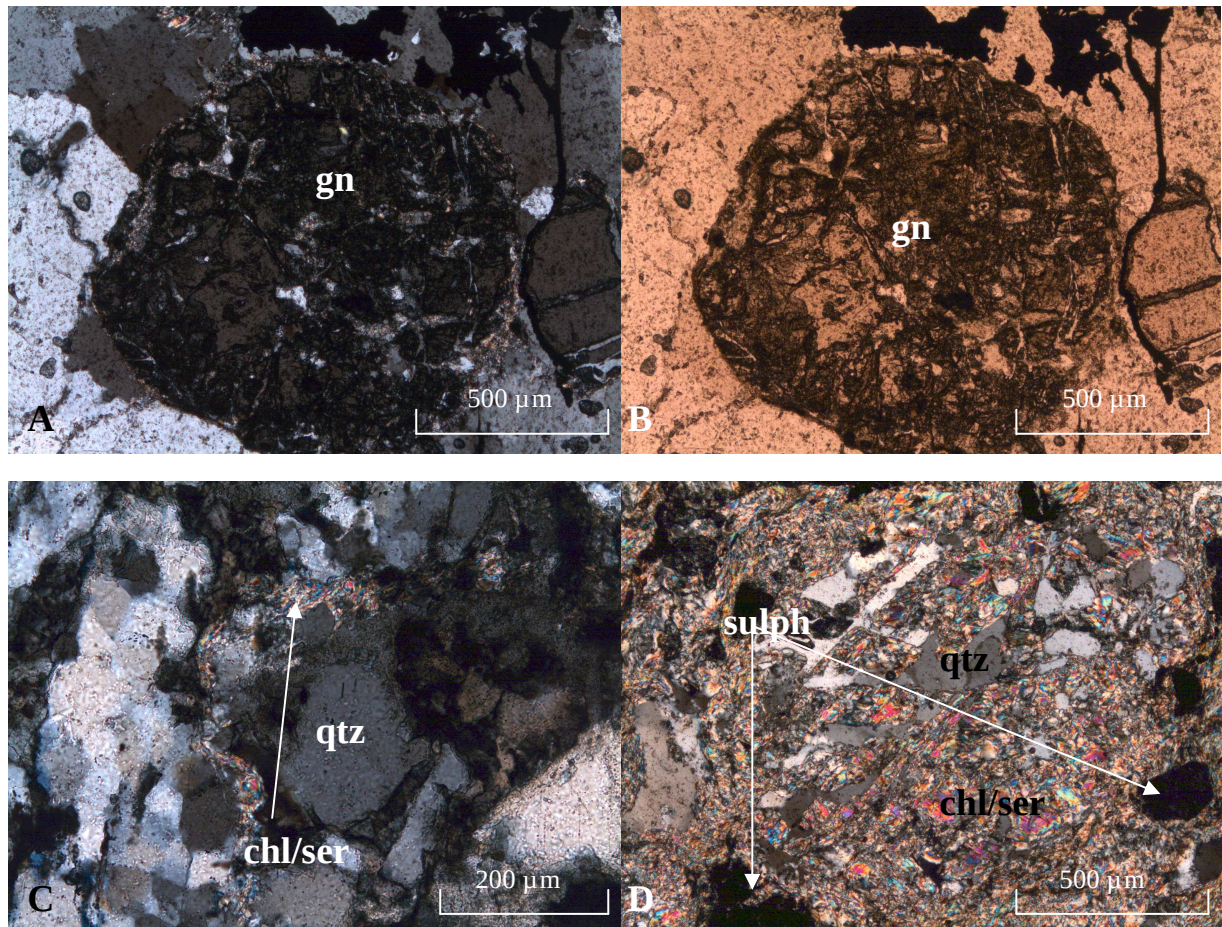


Fig.3-13: Microscopic pictures under transmitted light (tl), A: rounded garnet (gn), corroded and fractured (tl), B: rounded garnet (gn), fractured (crossed tl), C: quartz (qtz), fine dispersed sericitic and chloritic matrix (chl/ser) (tl), D: sericitic, chloritic (chl/ser), quartzitic matrix (qtz) with sulphides (sulph) (tl)

3.2.5 Gold

Gold was proposed to occur as extremely irregular small grains. Most of the gold is supposed to be present in clusters, which are distributed through two or more mineral phases (Hiemstra 1968). Gold could not be identified within this microscopic investigation of the 32 polished thin sections. Laboratory results from sxr Uranium One Inc. suggested the definite presence of a small amount of gold within the Dominion Reefs (typically 1 g/t).

3.2.6 Textural descriptions of certain thin sections

Typical mineral textures of representative polished thin sections from the Upper and Lower Dominion Reef are shown in figure 3-14, -15 and -16. The selected polished thin sections give a mineralogical overview and simultaneously represent the texture of the bulk mineralized quartz pebble conglomerates. Their typical mineral appearances, illustrated within the section scans, are described briefly.

Sample DRT 034 DO 8628

The scan of sample DRT 034 DO 8628 from the Upper Reef within the Rietkuil section illustrates the presence of the major minerals distributed in the conglomerates (Fig.3-14). Most of the ore minerals appear with a high degree of shericity. The most common accesory minerals are chlorite, sericite and quartz as matrix constituents. The grains occur as very small flakes and can not be distinguished. Within this thin section, the greenish chlorite is more common than the yellowish sericite. Notable is that chlorite often partially replaces garnet to an extend stage. Garnet grains are clearly visible and occur with a high rounding degree. Another main conglomerates component is quartz and appears as matrix constituent and as large pebbles. The euhedral quartz pebbles with a size up to 2 cm are traversed by 1-3 cm long fractures. Most of the fractures are filled with pyrite and other non-distinguishable sulphide minerals.

Pyrite, is the most abundant opaque mineral, and is supposed to be present in all three types. Within the investigated sample DRT 034 DO 8628, pyrite occurs in veinlets and cracks. Other small pyrite grains show typical crystal structures and tend to occur in groups. Other sulphide minerals, like galena and sphalerite are present, most likely as very small grains disseminated throughout the rock. They are also present as inclusions in altered detrital minerals.

Large garnet crystals with a size up to 0.2 cm appear broken and replacement by the matrix components is visible. The well rounded mineral grains contain inclusions of galena and pyrite. Remarkable is the constant orientation of the fractures within the section caused by stress which affected the conglomerates.

The petrographic study emphasizes that the main uranium bearing minerals appear as very small grains with varying size between 10-100 μm bedded within the matrix (revealed optically).

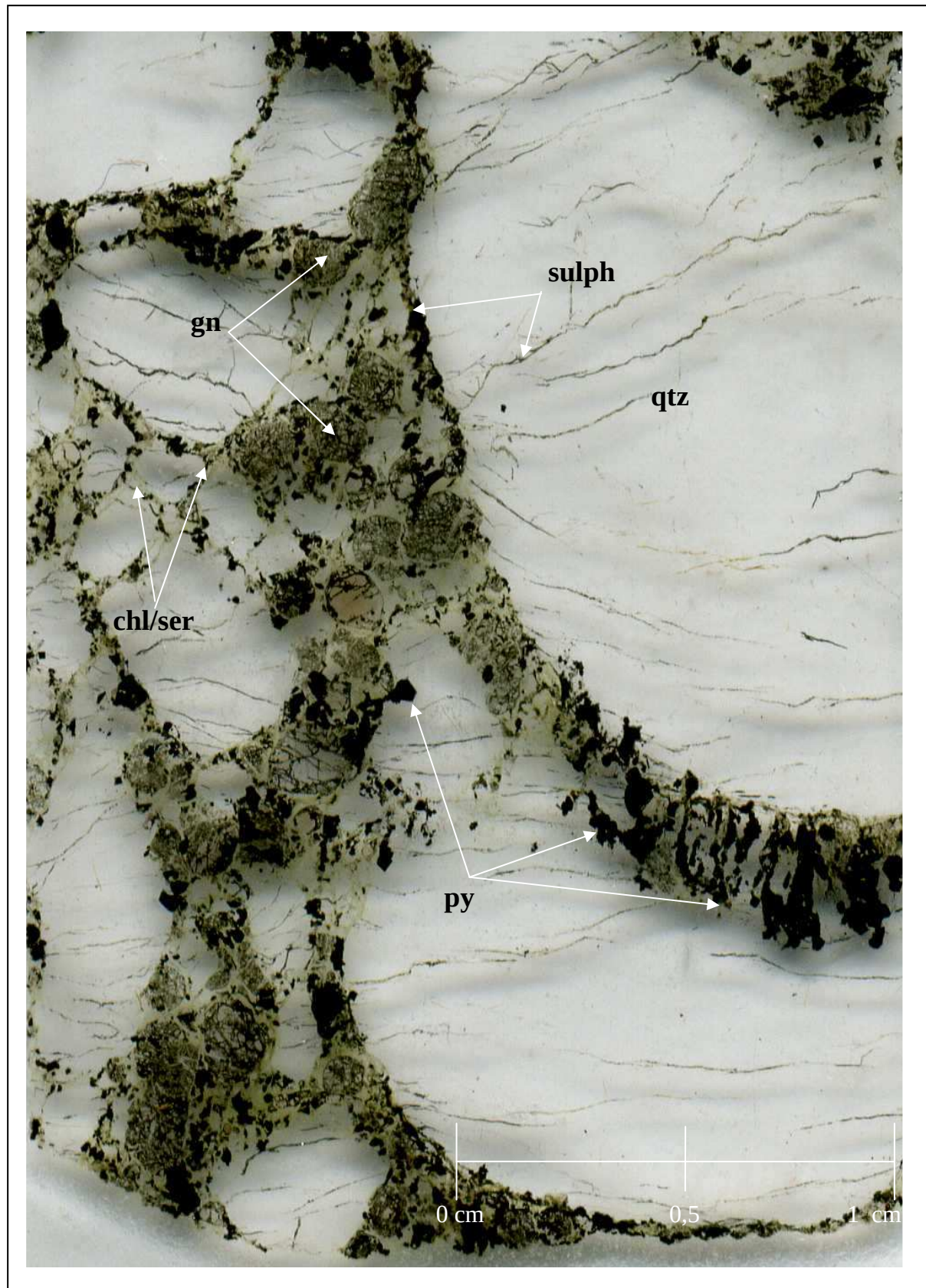


Fig.3-14: Texture of minerals in sample DRT 034 DO 8628

(gn = garnet, py = pyrite, sulph = sulphides, chl/ser = chlorite and sericite, qtz = quartz)

Sample DDR 077 CO 5512

The scan of sample DDR 077 CO 5512 represents a typical texture of the well sorted Dominion Reefs conglomerates of the Dominion area. Compared to the samples from the Rietkuil area, no significant difference of the mineralization could be revealed.

Quartz pebbles occur next to chlorite and probably a small amount of sericite (fig.3-15: A) with numerous fractures and the sizes varies between 0.2 and 1 cm. Notable are the cracks with two different orientations with angles of 90° to each other.

The whole section is dominated by the well distributed chlorite. The small flakes surround most of the accompanied minerals. Garnet is well-rounded within the section and appears mostly replaced and corroded. Sulphide minerals which can be determined as pyrite (type III and minor type II) do not occur as single grains, they are mainly related to the quartz fractures as infillings.

As comparison to the above mentioned sample the fractures within sample DDR 077 CO 5512 also show a distinct orientation. The mineral assemblages show no orientation within the thin section. The well sorted grains do not vary significantly in their grain size and shape.

Sample DRT 039 DO 6920

The scanned sample was selected from the Upper Reef within the Rietkuil section and represents a well-sorted polymictic conglomerate (Fig.3-15: B). The section mostly comprises sericite and minor proportions of chlorite. The sericite flakes appear interstitially between quartz grains. The quartz pebbles are rarely distributed and their size varies between 0.2-0.4 cm.

A weak orientation of the sericite flakes and accompanied minerals can be noticed. Notable is the big 0.5 cm long fracture in the left corner of the section, filled with the most abundant sulphide mineral pyrite. The pyrite (type III) occurs in patchy masses with an angular shape. Apart from this mineral phase, all other very small grains appear with a similar grain size and shape.

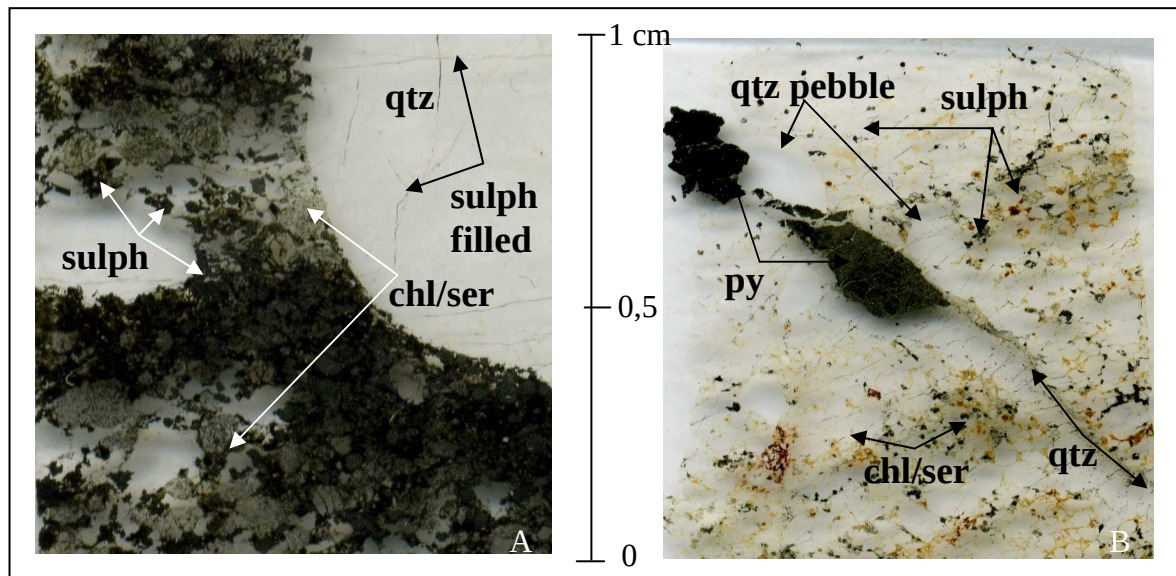


Fig.3-15: Texture of minerals in sample DDR 077 CO 5512 (A), and DRT 039 DO 6920 (B) (py = pyrite, sulph = sulphides, chl/ser = chlorite and sericite, qtz = quartz, sulph fillings= sulphide fillings)

DDR 077 CO 5602

The scanned sample DDR 077 CO 5602 was selected from the same borehole within the Dominion mining area like DO 5512. The thin section was prepared from a Lower Dominion Reef sample and represents a typical texture. In figure 3-16 a small part of the section is illustrated to identify the textural features in detail. The Lower Reef is well known less mineralized than the Upper Reef (Liebenberg 1955).

The main mineral phases observed within the section are chlorite accompanied by minor sericite. Both minerals occur as cloudy patchy masses around the main ore minerals. Pyrite (type I and III) as the most abundant sulphide mineral is the main component within the section next to chlorite.

Quartz grains appear as 1 cm to 2 cm large pebbles with few fractures. The infilling mineral most probably might be, as mentioned above, pyrite. Another occurrence of pyrite can be described as mostly angular in mineral assemblages. Other sulphides like galena, sphalerite and chalcopyrite are possibly abundant but they could not be identified.

Compared to the Upper Reef sample CO 5512, most of the minerals in CO 5602 occur in a lower stage of rounding but do not differ in their sizes. Notable is that garnet which is common in the Upper Reef sample is not present within the Lower Reef. Apart from garnet, the mineral assemblages can be determined as comparable.

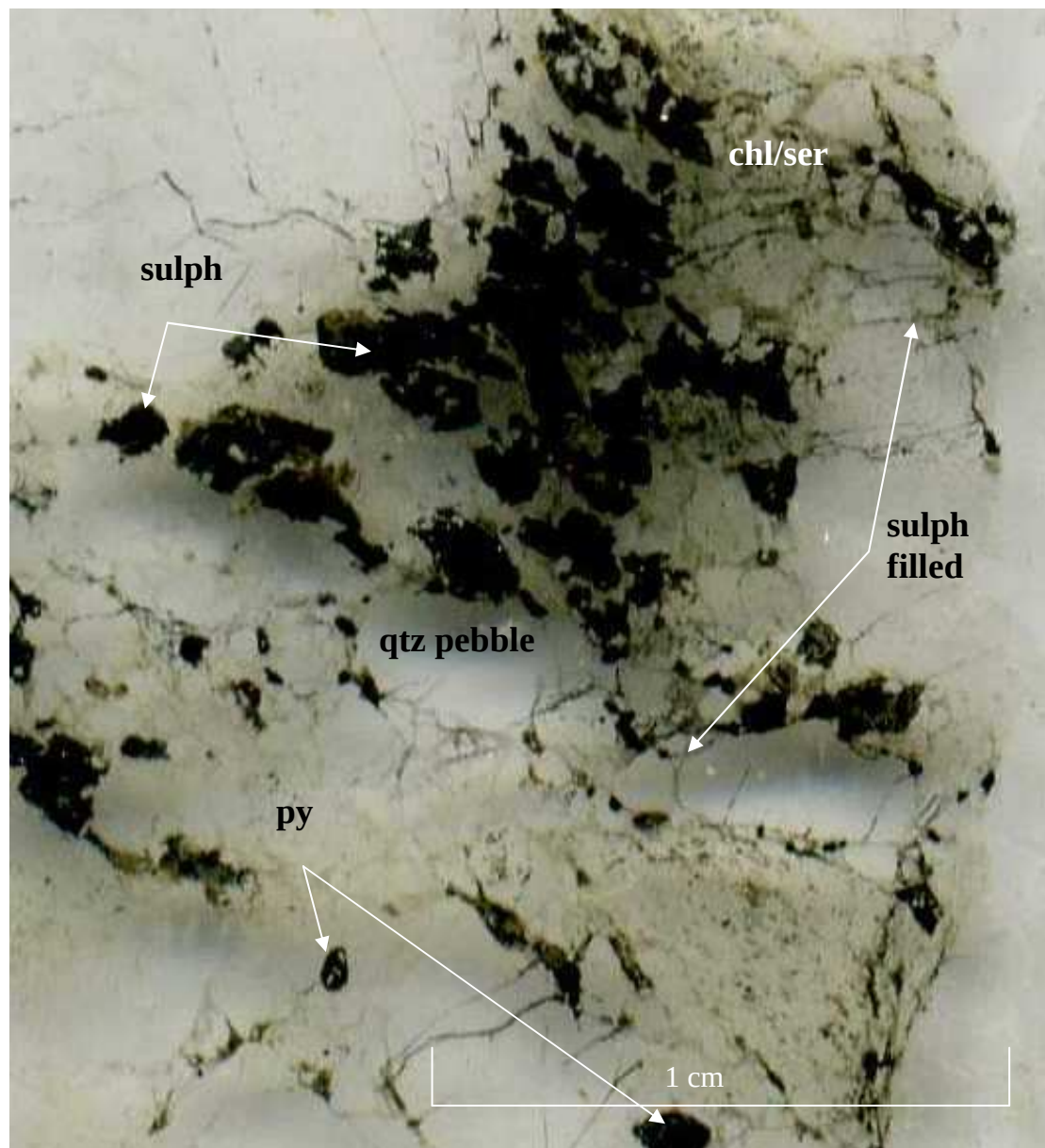


Fig.3-16: Texture of minerals in sample DDR 077 CO 5602 (py = pyrite, sulph = sulphides, chl/ser = chlorite and sericite, qtz pebble = quartz pebble, sulph filled= fractures filled with sulphides)

3.3 Summary of the petrography

In this chapter, the petrography of the selected hand-specimen and polished thin sections was described in detail with the help of autoradiography and light microscopy. The modal proportions of the main distributed minerals were counted for all 32 investigated thin sections. The quartz pebble conglomerates from the Dominion Reefs do not vary significantly in their appearance in each hand specimen. The Upper Reef dark coloured pebble conglomerate samples contain small vein quartz pebbles in a fine matrix of sericite, chlorite, and quartz. The main distributed sulphide mineral is pyrite within all samples, whereas other sulphides are not visible by macroscopic observations. The Lower Reef conglomerate samples consist of white vein quartz pebbles in a yellowish-greenish matrix of mostly sericite and less common chlorite. The pebbles within the conglomerate samples are well-sorted.

To determine the modal proportions of the main distributed minerals, point counting on 32 thin sections was carried out. This method was very low in precision because only the ten main minerals present in the conglomerates could be determined. Information about the minor constitutions in the rocks could not be revealed by this quantitative method.

Microscopic observations revealed different generations of the minerals within the conglomerate samples. Some mineral species appear in different degrees of roundness, shape and size.

Uraninite grains appear as well rounded grains and can be considered to be from primary detrital origin. The degree of rounding of the uraninites is in accord with the rounding of other primary minerals like monazite, zircon and columbite. Within the samples, the heavy mineral assemblages are in accord with regards to size and shape and a common sorting mechanism attributed.

Some mineral phases appear based on the petrographic studies in different generations (e.g. pyrite, uranium bearing phases). Several authors claimed the origin for the U-Ti mineral phases as a reaction product of detrital Ti-phases like ilmenite and rutile with uraninite (Hiemstra 1968) during post depositional alteration processes. Leucoxene as secondary uranium bearing phase were derived from the U-Ti mineral phases during weathering (Davidson 1957). Other authors suggested the origin was from the reaction of detrital Ti-phases and uraninites (Hiemstra 1968) during post depositional alteration.

The proved appearance of secondary uranium bearing minerals like coffinite, U-Ti-, and U-Th mineral phases suggests the assumption that metamorphic or hydrothermal activities resulted in mineral modification in agreement with Minter (1976). Petrographic studies suggested that chromite, garnet and zircon were partial replaced by phyllosilicates. As result, the three

mineral phases must be older than the phyllosilicates. Influencing hydrothermal solutions caused obviously corrosion of uraninite, chromite, monazite, zircon, garnet and other detrital minerals. The degree of the corrosion differs extremely and most likely is based on the resistance of each mineral against hydrothermal influences.

Sulphide mobilisation of some iron bearing minerals (e.g. pyrite) probably formed the secondary pyrite. Galena inclusions within primary mineral like uraninite most likely were formed by radiogenic lead and mobilized sulphur during hydrothermal action. The microscopic study confirms that the bulk of the sulphide minerals are formed in a secondary stage.

Chapter Four: Whole rock geochemistry

This chapter focuses on the major and trace element geochemistry to evaluate geochemical trends, relationships, element/mineral provenance, source rock chemistry and the tectonic setting of sediments. For this purpose XRF- and ICP-MS analyses of the whole rock samples were carried out.

4.1 Whole rock geochemistry – XRF

The geochemical data sets, listed in Appendix III, include the major and trace element chemistry of 78 whole rock samples. It is the purpose to show how the obtained geochemical data can be used to gain information about the geological setting, the degree of alteration, possible source areas, geochemical relationships, element associations and trends within the mineralization.

Weathering trends in the whole rock geochemistry will be explained with the help of the chemical index of alteration. For determination of the tectonic setting and the possible source areas of the Dominion sediments, major elements will be displayed in provenance discrimination diagrams. The geochemical relationships of major and trace elements get described with the Pearson correlation coefficient (r) as a statistical parameter. The main possible mineral relations will be shown in harker diagrams and adequate bivariate plots. Geochemical trends within the plots will be explained in detail.

Controlling factors on the whole-rock geochemistry

The geochemical character of sediments is signified by the detrital and authigenic mineral content. Various factors might control the geochemistry of the siliclastic sediments. These factors can include (a) composition of the source area, (b) chemical weathering, (c) hydraulic sorting, (d) diagenesis, (e) metamorphism, and (f) hydrothermal alteration (McLennan 1989, Fralick and Kronberg 1997). There is a strong possibility that all these factors most likely change the initial geochemistry of the sediments to a certain extent. A combination of these factors can affect the sediment geochemistry.

For the study of the Dominion Reefs sediments, the control of most factors on the bulk rock geochemistry is summarized in the following paragraphs. To minimize recent weathering effects, special care was taken to select only fresh, un-weathered core material.

4.1.1 Major elements

The results of the major element analyses with the average detection limits for all measurements are presented in table 1 in the Appendix III. The major element calculations are made for cations accompanied by an amount of oxygen. The sum of major element oxides will have a total of about 100 %. The iron contents are expressed as Fe_2O_3 in total. NaO_2 content was measured for all whole rock samples, but all analyses were set under the lowest detection limit and did not play a significant role for the calculations.

4.1.1.1 Sediment classification

Similar to petrographic descriptions, bulk rock geochemistry data can be used to classify sedimentary deposits. The Sand class system from Herron (1988) was chosen to classify the sediment samples in well logs [x-axis: $\log \text{SiO}_2/\text{Al}_2\text{O}_3$; y-axis: $\log \text{Fe}_2\text{O}_3/\text{K}_2\text{O}$] based on the numerous classification details (Fig. 4-1). The most used parameter $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio (Potter 1978), reflecting the abundance of quartz as well as clay and feldspar and the $\text{Fe}_2\text{O}_3/\text{K}_2\text{O}$ ratio (Herron 1988) is a measure of mineral stability.

The quartz rich sediments of the Dominion Reefs are displayed within the diagram in figure 4-1. Two samples represent arkose, three samples subarkose, and one sample can be classified as quartzarenite. The bulk of the samples can be categorized as sublitharenite, litharenite, and Fe-sand. The represented classification of the Dominion Reef sediments verifies the obtained results from the petrography study. The sediment classification after Herron (1988) is adequate for all samples from the Dominion- and the Rietkuil area. As a result it can be proposed that the Dominion Reef samples are quartz rich sediments with rare feldspar contents. The fact that the majority of the samples plot in the Fe-sand field a high mineral stability can be considered.

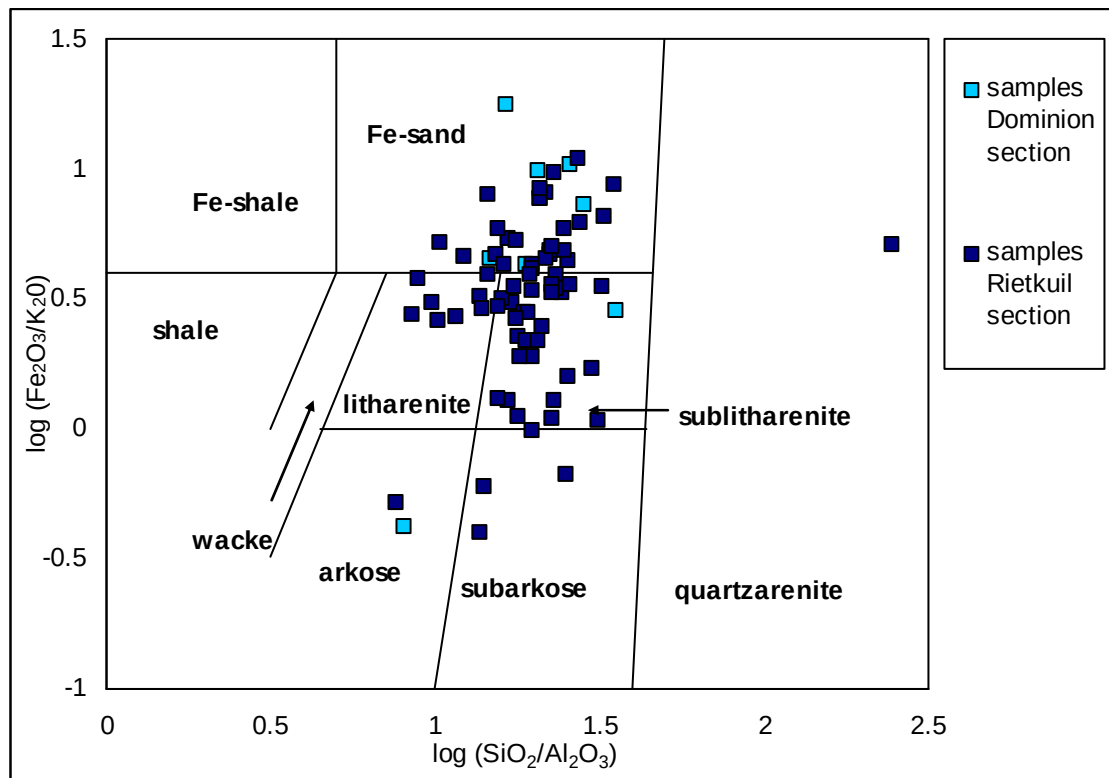


Fig.4-1: Classification of all analysed Dominion Reefs samples in the Sand Class System from Herron (1988)

The discrimination diagram in figure 4-2 displays the absolute proportions of quartz, clay/mica, feldspar and pyroxene/amphibole based on two discrimination functions [x-axis: $\text{Al}-(\text{Na}+\text{K}+2\text{Ca})$, y-axis: $\text{Si}/3-(\text{K}+\text{Na}+2\text{Ca}/3)$].

The diagram confirms that the conglomerate samples consist of a mixture of variable proportions of quartz and clay/mica minerals. Quartz has the highest modal proportion within the samples and can be determined as the main whole rock component. The displayed trend within the diagram tends towards the clay/mica domain along the quartz-muscovite line. The presented geochemical composition shown in the diagram confirms the presence of mica as the main matrix constituent. Feldspar and pyroxene/amphibole proportions could not be verified for all samples. Additionally it can be stated that all samples from the Rietkuil and Dominion section have similar whole rock geochemistries.

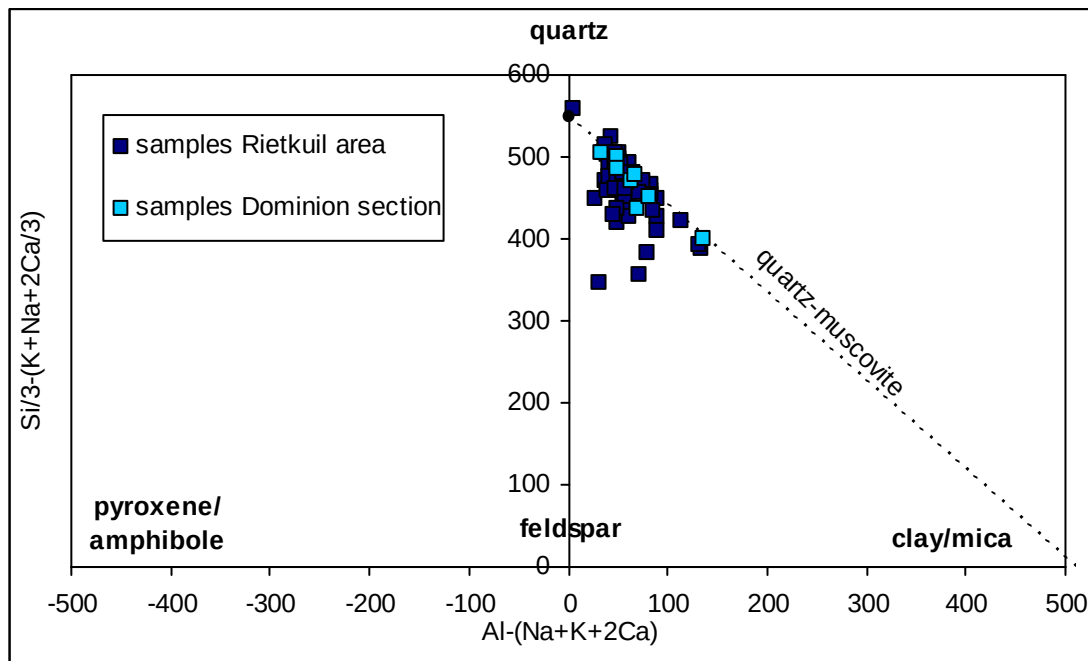


Fig.4-2: Discrimination diagram which evaluates quartz, feldspar, pyroxene/amphibole and clay/mica mineral composition of all sediment samples from the Rietkuil, and the Dominion section

4.1.1.2 Chemical index of alteration

The chemical index of alteration (CIA) was introduced by Nesbitt and Young (1982). The index has been established as a general measure of the degree of weathering (McLennan et al. 1993). The CIA and the trends in triangular weathering plots are used to describe chemical history of rocks after deposition.

The oxides are expressed as molar proportions and CaO in silicates as opposed to carbonates and phosphates. Based on this assumption, the CIA was calculated using the absolute proportions with:

$$CIA = Al_2O_3 / (Al_2O_3 + CaO^* + Na_2O + K_2O) \times 100$$

The measured concentration of Na_2O in all studied samples was under the lowest limit of detection and could not be used for the calculation. The CIA was determined for all samples and is listed in the Appendix III. CaO^* represents the CaO associated with the silica fraction of the sample.

Size sorting during transportation and deposition of the sediments can have influenced the CIA. Therefore the CIA must be considered as a guide for the degree of alteration.

The average CIA of the studied samples is 77.65 which suggest a moderate to high weathering degree. Typical CIA values for clay and shale vary between 70 and 75 (Nesbitt

and Young, 1982). The calculated CIA for the Dominion Reefs sediments ranges from 73 up to a maximum of 83 and can be considered as small-scale variations. The lowest CIA indicates a moderate weathering degree and the maximum of 83 suggests a higher weathering degree (Nesbitt and Young 1996).

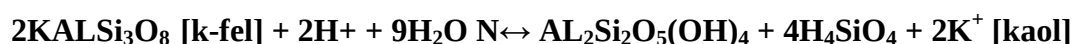
Small-scale variations in the CIA most likely reflect dispersive metasomatism caused by fluid flow (Frimmel 2005). It can also be assumed that hydrothermal activities are responsible for the small-scale variations of the calculated CIA. The hydrothermal fluids most likely affected the Dominion Reefs sediments in different stages and caused a moderate weathering. In contrast, a high-scale variation (e.g. from 50 up to 90) points to a systematic change in the environmental conditions like increase in temperature towards the sediments with a high CIA.

Weathering trends

According to the calculated CIA, a moderate weathering degree for the Dominion Reef sediments can be proposed. The weathering trends of sediments can be illustrated in ternary diagrams using the proportions of $(Al_2O_3 - (Na_2O + K_2O))/2$ and $Na_2O + K_2O$ and $(MgO + MnO + Fe_2O_3)/3$. The studied Dominion Reefs sample element proportions are displayed within the diagram (Fig.4-3). The trends on the triangular plot has been used to determine chemical changes in a recent weathering profile. Deviations from recent weathering profiles can be used to gather chemical changes resulting from diagenesis or metasomatism (Nesbitt and Young 1984, 1989).

As a general assumption, it can be proposed that sediments are enriched in Al_2O_3 during weathering of the source rock while alkali and alkaline earths are depleted (Nesbitt and Young, 1982). This leads to the result that general weathering trends will point towards the Al_2O_3 rich corner in the ternary diagram. This would represent the conversion of unstable minerals (e.g. feldspars and mica to clay) after McLennan et al. (1993) in weathered minerals. A good example for mineral transformation is the conversion of potassium feldspar [k-fel] to kaolinite [kaol] during weathering (Bjørlykke 1989).

reaction formula:



During this reaction, potassium is released and removed from the sediment. The potassium feldspar is transformed to kaolinite which is located in the left corner of the ternary diagram. The corresponding calculated CIA would change, according to Nesbitt and Young (1982), from 100 to 50.

The studied samples do not clearly follow the general weathering trend towards the Al_2O_3 corner. In the diagram, one main weathering trend can be determined. The studied samples follow a significant trend parallel to the Al_2O_3 corner. The trend displays a clear influence of $(\text{MgO}+\text{MnO}+\text{Fe}_2\text{O}_3)/3$ indicating that post-depositional mineral transformations might occurred. As an example, the transformation of plagioclase to chlorite and quartz plays a significant role for the sediment alteration. The process of chloritization indicates depletion in K and enrichment in Fe as shown in the diagram (grey arrows). Chemical changes in the sediments took place after its formation, usually through interaction with a fluid.

chloritization reaction:

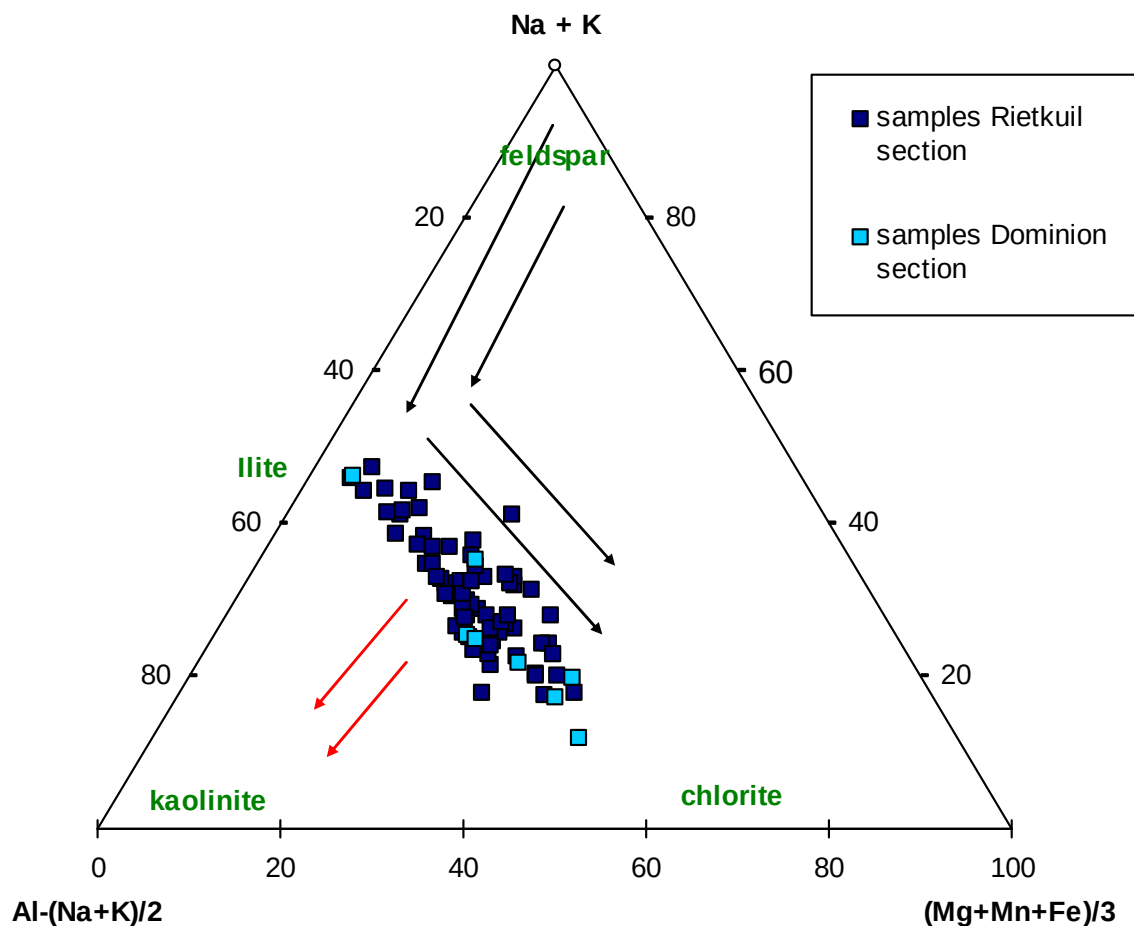
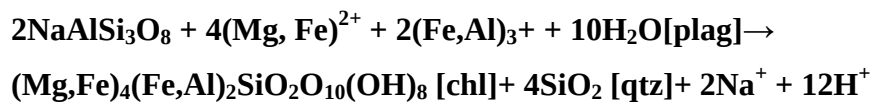


Fig.4-3: Ternary diagram using the proportions of $(\text{Al}_2\text{O}_3-(\text{Na}_2\text{O}+\text{K}_2\text{O}))/2$ and $\text{Na}_2\text{O}+\text{K}_2\text{O}$ and $(\text{MgO}+\text{MnO}+\text{Fe}_2\text{O}_3)/3$, the general weathering trend would tend towards the left corner (red arrows), the studied Dominion Reef samples display a significant trend towards mica and chlorite (black arrows)

The alteration process should be regarded as a dynamic system which evolves with time. It can be assumed that certain mineral assemblages of the Dominion Reefs sediments were formed as a result of hydrothermal alteration during a period of time. For a further classification of the fluid character, fluid inclusion studies would be of utmost importance.

4.1.1.3 Provenance and tectonic setting from major elements

Determination of the tectonic setting of siliclastic rocks has numerous difficulties. The Dominion Group (including the lava's) was deposited over a long period of time with a gapless sedimentation followed by the sediment sequences of the West Rand Group and Central Rand Group.

The bivariate XY-plot (Bhatia 1983) is considered applicable for the study of Dominion Reefs samples. The plot implies information of the general tectonic setting of the investigated samples. No other plot for the tectonic setting classification found was applicable for the studied samples.

The displayed results show that not all samples could be distinctly classified (Fig.4-4). Some of the samples suggest a passive margin as tectonic setting. The bulk of the studied samples could not be confidently classified. Remarkable is that the original sediment deposition of the Dominion Group took place in a continental rift (Frimmel 2005). The displayed samples indicate a passive margin which most probably belongs to the deposition of the West Rand Group (Kositcin and Krapez 2004). The West Rand Group was deposited after the Dominion Group and is the interstitial lower part of the Witwatersrand Supergroup. It is proposed that the samples which do not belong to the passive margin must have been deposited in a continental rift. Other displayed tectonic settings can be proposed as not being significant.

Tectonic events most likely caused changes in the tectonic setting and can be described as continuing process over a period of time. This might explain the passive margin as revealed tectonic setting for sediments deposited in the sequence boundary between the Dominion Group and the West Rand Group.

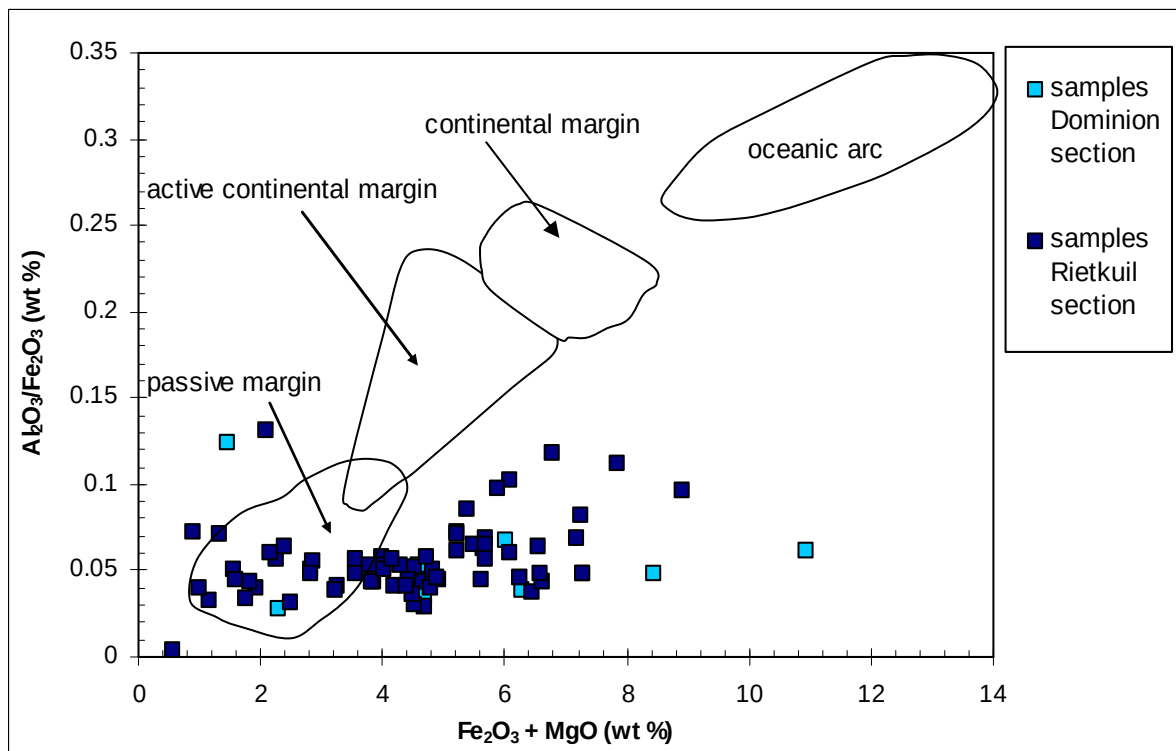


Fig.4-4: Discrimination bivariate plot for sandstones from Bhatia (1983) of $\text{Al}_2\text{O}_3/\text{SiO}_2$ versus $\text{Fe}_2\text{O}_3 + \text{MgO}$, the fields within the diagram represent different geological settings

Provenance diagrams based on discrimination functions (Bhatia 1983, Roser and Korsch 1988) combine several of the major elements. The discrimination functions can be calculated using the absolute proportions with:

$$\begin{aligned} \text{Discriminant function 1} &= -1.773 \text{ TiO}_2 + 0.607 \text{ Al}_2\text{O}_3 + 0.760 \text{ Fe}_2\text{O}_3 - 1.500 \text{ MgO} \\ &\quad + 0.616 \text{ CaO} + 0.509 \text{ Na}_2\text{O} - 1.224 \text{ K}_2\text{O} \\ \text{Discriminant function 2} &= 0.445 \text{ TiO}_2 + 0.070 \text{ Al}_2\text{O}_3 - 0.250 \text{ Fe}_2\text{O}_3 - 1.142 \text{ MgO} \\ &\quad + 0.438 \text{ CaO} + 1.475 \text{ Na}_2\text{O} + 1.426 \text{ K}_2\text{O} \end{aligned}$$

The plot after Roser and Korsch (1988) contains information about the source rocks (Fig.4-5). The clustering of the samples points to intermediate rocks as the main sources for the Dominion Reef sediments. Samples with lower Fe_2O_3 and Al_2O_3 content (less clay and Fe-hydroxides) plot more in the middle of the diagram. This leads to the result that possible source areas should mostly contain mafic and felsic material.

Vennemann et al. (1992, 1995) revealed the result that the Witwatersrand quartz pebbles mainly derived from Archean granite and pegmatite rocks. The granitic and/or pegmatitic source was also determined by Feather and Koen (1975). All three scientists proved their assumptions through the rare occurrence of detrital cassiterite, uraninite and columbite. Gartz

(1996) agreed with this thesis based on bright cathodoluminescence of detrital quartz grains. According to the occurrence of detrital chromite, the conclusion can be drawn that mafic to ultramafic components can be expected in the source area.

The Archean greenstone terrains within the Kapvaal craton contain mafic and ultramafic rocks as well as siliceous chemical sedimentary rocks and felsic volcanic rocks. A comparable terrain will be assumed to be the source area of the quartz pebbles and the heavy detrital minerals. It can be concluded, that Archean greenstone terrains, surrounding the Witwatersrand basin, were possible the source areas for the heavy minerals within the Dominion quartz pebble conglomerates.

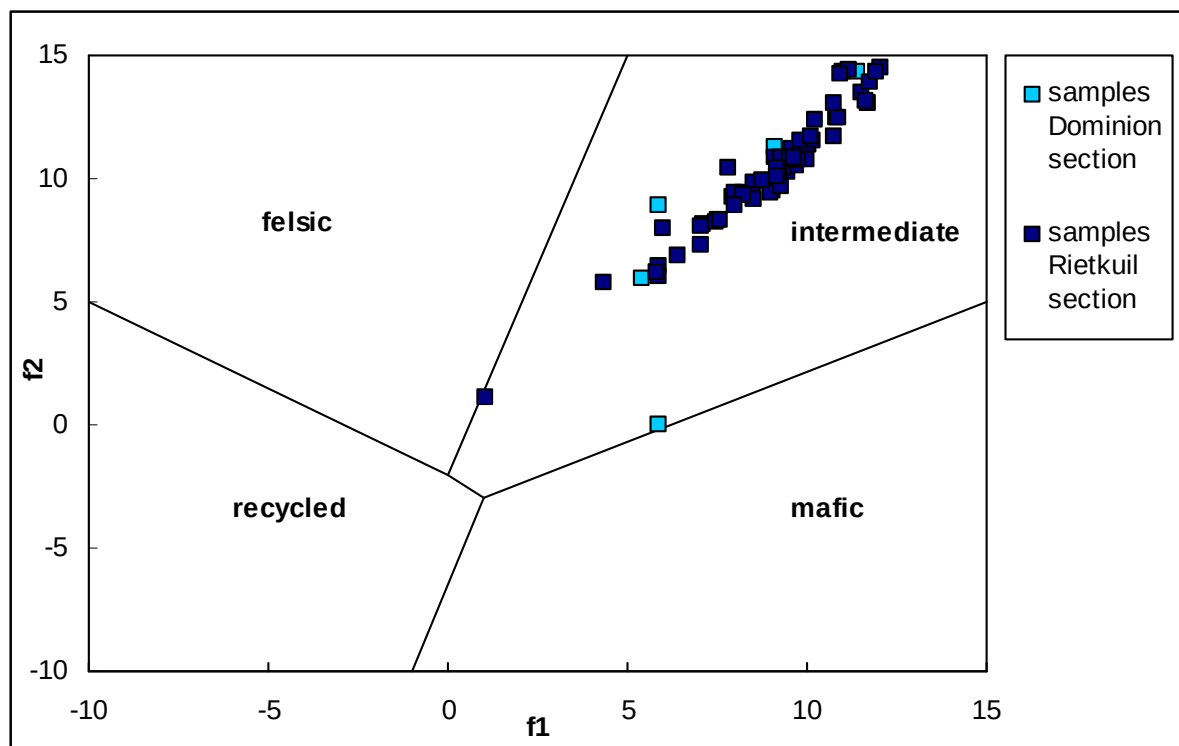


Fig.4-5: Discrimination function plot after Roser and Korsch (1988) for determination of the possible original source rocks of the Dominion Reef sediments

4.1.2 Rare earth elements and trace elements

The rare earth element analyses are presented in table 3 and the trace elements in table 2 in the Appendix III. Most of the measured trace elements show values above the detection limit and will not be used for further interpretations.

Generally, it can be proposed that many trace elements and rare earth elements are immobile during sedimentary processes (Cullers et al. 1988). Consequently, they are transported and quantitatively deposited into sedimentary rocks (Bhatia and Crook 1986, Roser and Nathan 1997, Toulkeridis et al. 1999). The element enrichment and dilution of the trace elements is generally dependant on the original source material and can be used as provenance classifier.

4.1.2.1 Rare earth element geochemistry

The REE (rare earth elements) comprise the elements from La to Lu. The rare earth elements can be separated in the LREE (La to Sm) and the HREE (Gd to Lu). Lithophile REE are generally considered to be chemically immobile. It can be assumed that average REE pattern of source rocks are nearly quantitatively transferred to siliclastic sediments during sedimentation (McLennan 1989). Diagenetic processes do not affect bulk-rock REE patterns significantly (Fleet 1984, McLennan et al. 1993).

The REE fill lattice sites in eight-fold coordination in most rock forming minerals. The rare earth elements mostly replace available elements in geochemically analogous minerals. The most familiar elements are Ca^{2+} and Na^{2+} which hold a similar size and charge. REE mainly substitute Ca within rock forming minerals. One of the main substitution is Eu^{2+} for Ca^{2+} in place for Sr^{2+} within plagioclase (McLennan 1989) with a positive Eu anomaly of plagioclase as result.

Chondrite normalisation is a widely used and accepted method for the comparison of REE values of various whole rock samples. In figure 4-6 the REE pattern of sediments from the Dominion Reefs were normalized relative to the chondrite values after Nakamura (1974). In addition to the pattern of the Reef samples, the plot includes the REE pattern of the Upper-, and the Lower Continental Crust as presented by McDonough and Sun (1995).

Comparing the REE values with the Continental Crust a clear result is obvious. The Lower Continental Crust pattern shows a slightly positive Eu anomaly and can not be compared. In contrast the Upper Continental Crust shows a distinct negative Eu anomaly and a similar geochemical trend to the analysed Reef samples. The magnitude of the Eu anomaly, Eu/Eu^* , is calculated as: $\text{Eu}_{\text{CN}}/(\text{Sm}_{\text{CN}} \cdot \text{Gd}_{\text{CN}})^{0.5}$ with chondrite normalization of Eu, Sm, and Gd as given by McDonough and Sun (1995). The calculated values for the Dominion Reef samples vary from 0.01 to 0.06 and reflect a strong negative Eu anomaly as displayed in figure 4-6. There is a strong enrichment in REE contents of the Dominion samples compared to chondrite. The ratio Eu/Eu^* is a measure of the enrichment or depletion of Eu relative to the rare earth elements Sm and Gd. Calculated values lower than 0.95 indicate definitely depletion and values above 1.05 enrichment relative to Sm and Gd (Taylor and McLennan 1985). The REE pattern are distinct from all of the analysed samples.

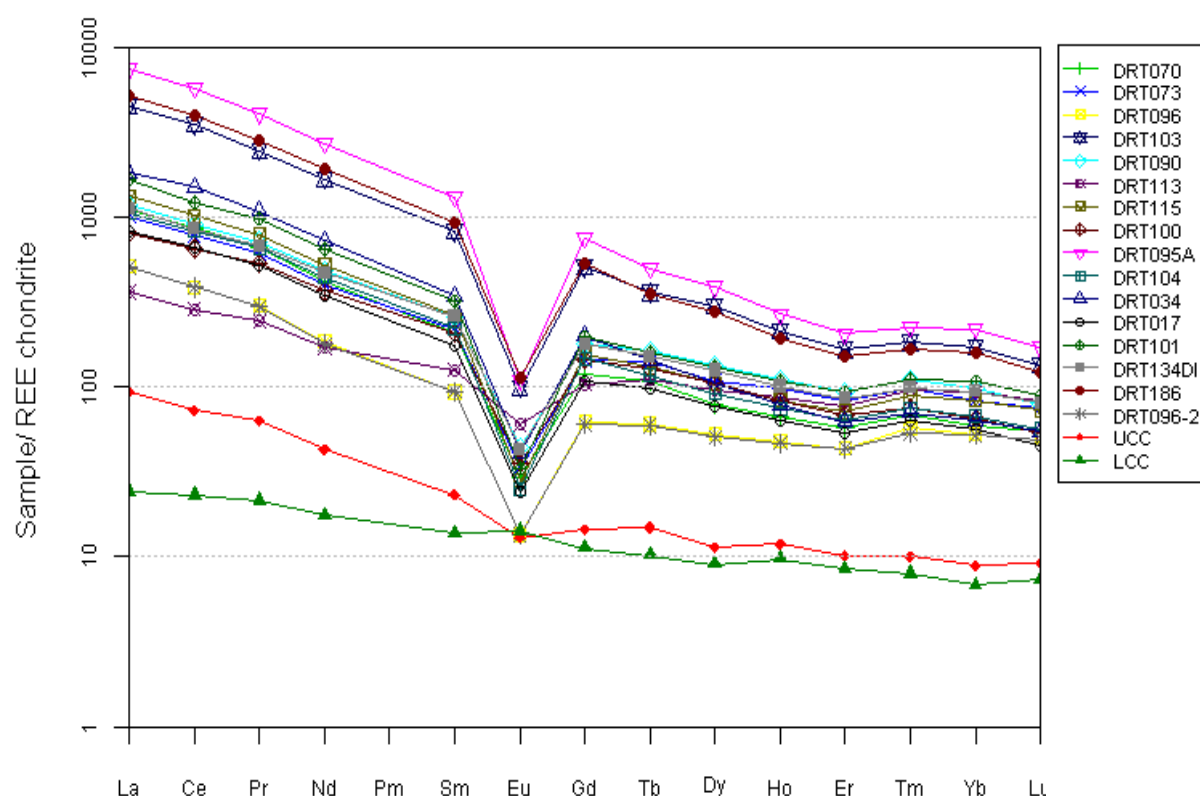


Fig.4-6: Chondrite normalized REE pattern after Nakamura (1974) of analysed sediment samples from the Dominion Reefs and the Upper Continental Crust (UCC), the Lower Continental Crust (LCC)

Enrichment in LREE from La to Eu and a depletion in HREE from Gd to Lu of the Reef samples is present and comparable to the pattern of the Upper Continental Crust. Generally it can be proposed that LREE are more enriched in silica rich rocks than in alkaline rocks (Taylor and McLennan 1985, Wronckiewicz and Condie 1987). This is in accordance with bulk rock geochemical analyses of the Dominion Reef sediments which indicate silica as main component within the sediments.

Rare earth elements are present in heavy minerals like zircon, monazite and garnet (McLennan 1989, Taylor and McLennan 1985). Previous studies of the Dominion Reef sediments revealed that monazite and zircon are widely distributed within the analysed samples. Taylor and McLennan (1985) noticed clay minerals as important carrier of REE. The petrographic study confirms presence of clay minerals within the Dominion Reef sediments.

4.1.2.2 Provenance derived from trace elements

For provenance studies immobile elements such as La and Th and mobile elements like Sc and Co are of utmost importance. Cullers et al. (1988) claimed that the immobile elements are more abundant in felsic rocks and that mobile elements are more often in basic rocks. Different element ratios as displayed in figures 4-7 and 4-8 will be used to distinguish

between mafic and felsic source material.

The plot in figure 4-7 after Nagender Nath et al. (2000) and Floyd and Leveridge (1987) emphasizes different source components for the analysed samples. The La/Th ratio and the Hf content give information about the possible source material (Nagender Nath et al. 2000). La/Th ratios do not differ significantly suggesting that the source material was not derived from Tholeiitic Ocean Islands, Andesitic Arcs, and Lower Continental Crust.

The displayed samples in figure 4-7 contain variable Hf contents. According to their Hf contents some samples may not plot in determined fields probably due to having a mixed sedimentary source.. The trend emerging from the plot can be interpreted as source material derived from felsic- and Upper Continental Crust material. High Hf values indicate increasing composition of possibly pre-Dominion sediments as source material.

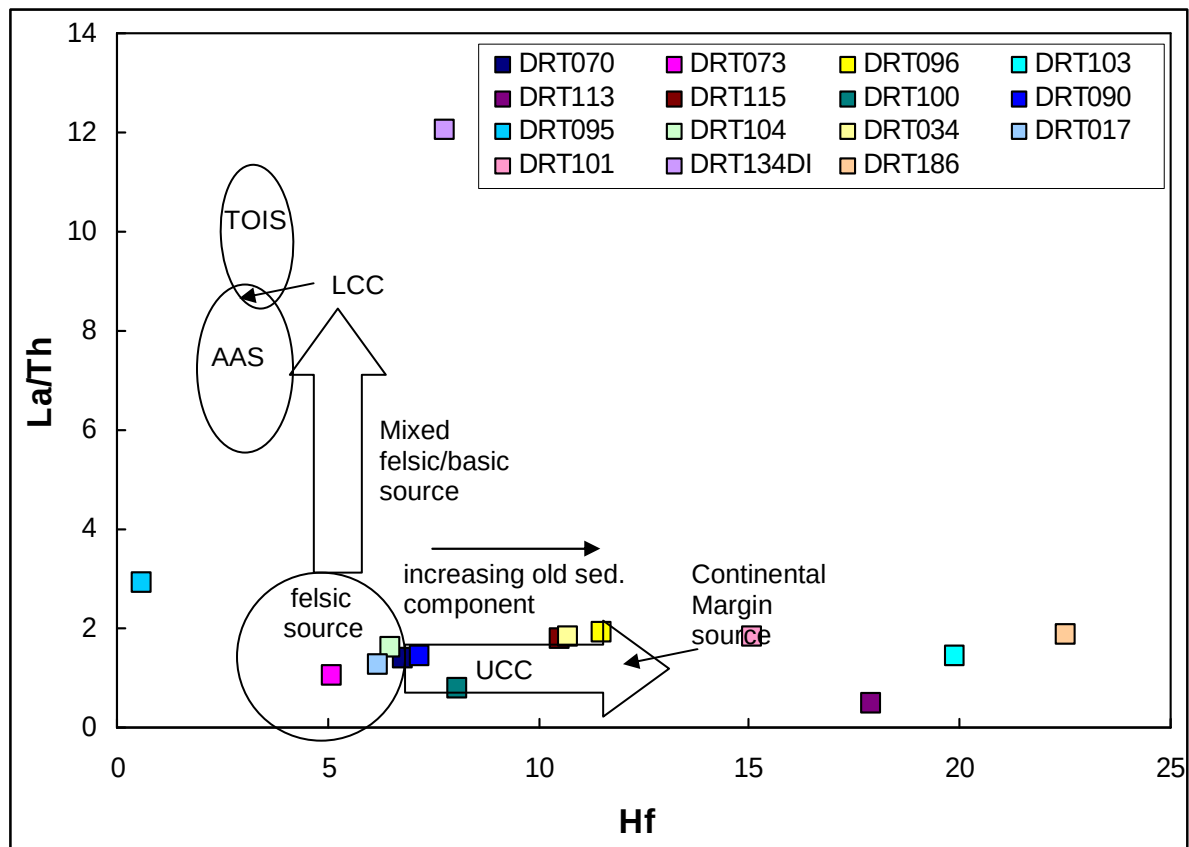


Fig.4-7: Plot after Floyd and Leveridge (1987), modified by Nagender Nath et al. (2000) illustrates Hf versus La/Th (in ppm) ratios indicates possible source materials such as felsic- and Upper Continental Crust material for the analysed Dominion Reef samples, (TOIS= Tholeiitic Ocean Island source, AAS= Andesitic Arc source, LCC= Lower Continental Crust, UCC= Upper Continental Crust)

The plot after McLennan et al. (1993) in figure 4-8 displays the Th/Sc- and the Zr/Sc ratios of the analysed Dominion Reef sediment samples. The Th/Sc is used as indicator for differentiation processes of the main source materials. Within igneous systems Th as incompatible element and Sc as compatible element can hold provenance information (McLennan et al. 1993). The high Zr/Sc ratios indicate a clear sediment recycling which is equivalent to a zircon increase similar to the Nagender Nath plot in figure 4-7. Especially elements like Zr and Hf are directly related with heavy minerals. Therefore their occurrence within the sedimentary rocks is controlled by heavy mineral concentrations (McLennan 1989, McLennan et al. 1993). The plot in figure 4-8 after McLennan et al. (1993) shows that all samples contain high Zr/Sc ratios above 10 to max. 60 ppm. This leads to the conclusion that zircon was added as well as that source rocks was recycled through sedimentary processes. The plot in figure 4-8 point to a clear sediment recycling component of the analysed Dominion Reef samples.

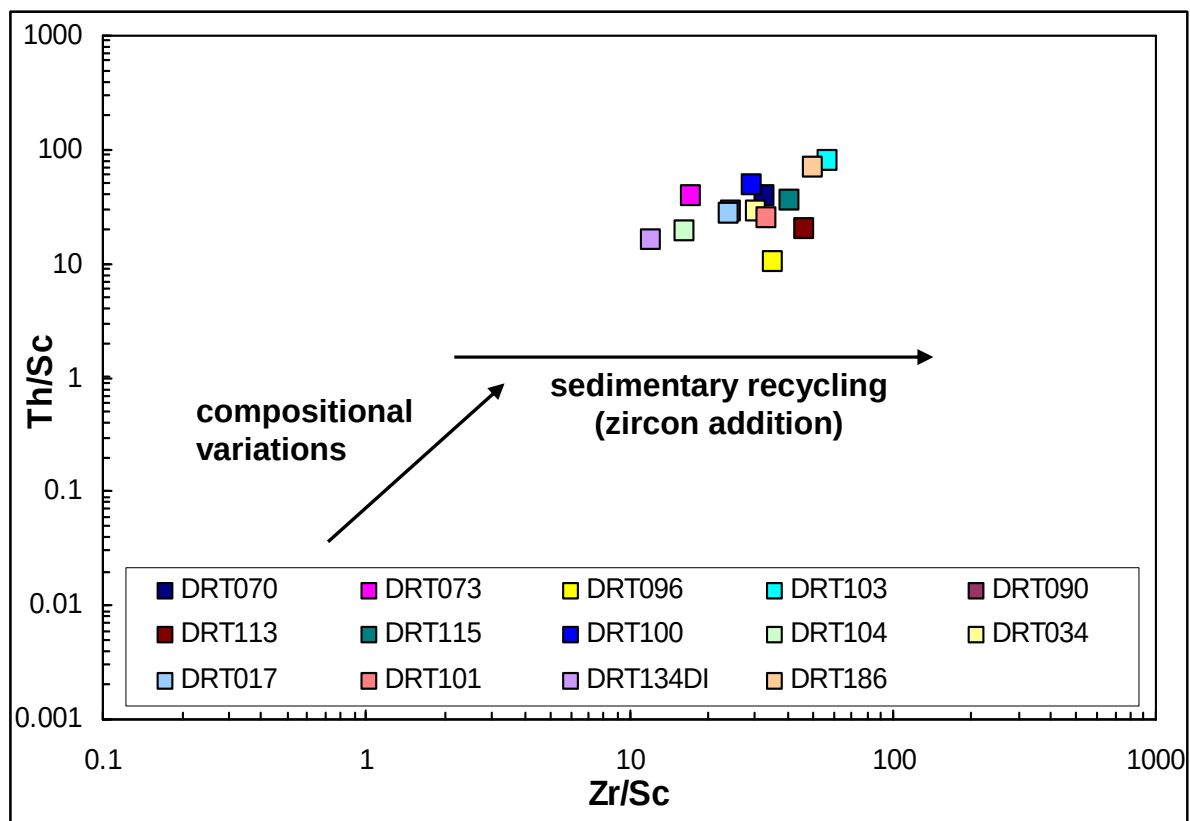


Fig.4-8: Plot after McLennan et al. (1993) illustrates the Zr/Sc versus the Th/Sc ratios (in ppm) of the analysed Dominion Reef samples, the samples display a trend which can be attributed to recycling of older sedimentary source rocks

4.2 Geochemical overview of element relationships

Correlation coefficient

To answer the main question about possible correlation between oxides and elements, the Pearson correlation coefficient was calculated for 49 oxides and elements with the help of the statistic program SPSS (Statistical Package for the Social Sciences). The correlation coefficient measures the strength of the association between two measured variables on a number of individuals (Cox and Clifford 1982) and can be seen as an initial step for the interpretation of geochemical relationships. The estimation of each pair was calculated on the base of the measured XRF data and is listed in the Appendix III as correlation matrix.

The calculated values vary from -1 to +1, values of +0.5 (or -0.5) can be determined as confidence limit, values higher than +0.5 (or below -0.5) indicate linear relationships. Negative correlations below -0.5 indicate perfect antipathy relationships. Values between 0.5 and -0.5 indicate the absence of any significant correlation between two sets of used data.

It will be assumed that elements with sympathetic correlation have a common origin. As a second assumption, it is considered that the elements are hosted in the microscopically identified minerals. According to these two hypotheses, the whole rock geochemical data will be interpreted with the help of the correlation matrix and displayed in variation diagrams.

4.2.1 Major element chemistry and possible correlations

In terms of major element composition, the studied Dominion Reef sediments are generally characterized by an SiO₂ content between 60-95 wt % that dominates all major elements. The major elements which also occur in the rock analyses in decreasing concentrations are Al, Fe, Mn, Ti, Ca, K, P, Mg, and Na.

In the following paragraph, the possible correlations between pairs of major elements will be explained in detail. To display geochemical data from sedimentary successions in Harker variation diagrams (Harker 1909), major elements versus SiO₂ (on the x-axis) were plotted to identify relationships and trends (Fig.4-9). SiO₂ was chosen as the plotting parameter for the suite of sedimentary Reef samples, because it is the major constituent of the rock and shows greater variability than any of the other oxides. All major elements are displayed as oxides in wt %.

SiO₂, as main constituent within the conglomerates and as main matrix component has an average content of 88.97 wt %. It is proposed that all major elements exhibit a negative trend towards SiO₂ according to the variable negative Pearson correlation coefficient shown in table 4-1. The sediment matrix also consists of sericite and chlorite which an average content of

4.87 wt % Al_2O_3 within the analyses. One sample from the Rietkuil area achieved a maximum concentration of 10.94 wt % Al_2O_3 . Sericite and chlorite appear to be the main constituents next to quartz in this sample. Garnet is the main accessory mineral within the Reef conglomerates, may also be abundant. The strong negative trend is obvious within the Harker diagram, confirmed by the significant Pearson correlation coefficient of Al_2O_3 against SiO_2 of $r = -0.74$.

The average of 3.99 wt % Fe_2O_3 (total Fe content) with a maximum of 10.22 wt % might be caused by the incidence of sulphides (pyrite, arsenopyrite, pyrrhotite, and chalcopyrite) in the Dominion Reef conglomerates. A certain Dominion Reef sample DDR 077 CO 5516, containing the highest Fe_2O_3 concentration, consists of 29 % pyrite (according to the obtained modal proportions in chapter three, table 3-1). The calculated correlation coefficient of -0.67 of Fe_2O_3 versus SiO_2 verifies the strong negative trend within the Harker diagram (Harker 1909).

K_2O occurs as a minor constituent within the conglomerates with an average value of 1.16 wt %, confirmed by the occurrence of sericite. Kalifeldspar and biotite which also contains K_2O might be additional host minerals within the sedimentary sequences. The correlation coefficient of -0.46 between K_2O and SiO_2 indicates a weak relationship, as confirmed by a more scattered trend within the diagram.

Titanium oxide is well distributed in the whole rock samples (average of 0.53 wt %). Within the Harker diagram, a strong negative trend (pearson correlation coefficient = -0.79) is observed. The main Ti-bearing mineral phases are rutile, ilmenite and secondary alteration minerals such as anatase and U-Ti phases.

The average MgO content of 0.51 wt % can be explained by the occurrence of chromite, chlorite, and garnet within the samples. The Rietkuil sample with the highest MgO content of 1.09 wt % contains a high proportion of garnet (pyrope) as revealed by microscopic studies. The strong negative trend within the diagram is established by the correlation coefficient of MgO versus SiO_2 of -0.62.

The CaO (average of 0.31 wt %), P_2O_5 (average of 0.19 wt %) and the MnO (average of 0.14 wt %) values are fairly low. The low manganese concentration might be the result of Mn-rich sphalerite within the samples. The scattered negative trend within the Harker diagram confirms the low correlation coefficient of -0.46. Other identified minerals do not contain large proportions of manganese which would be insignificant.

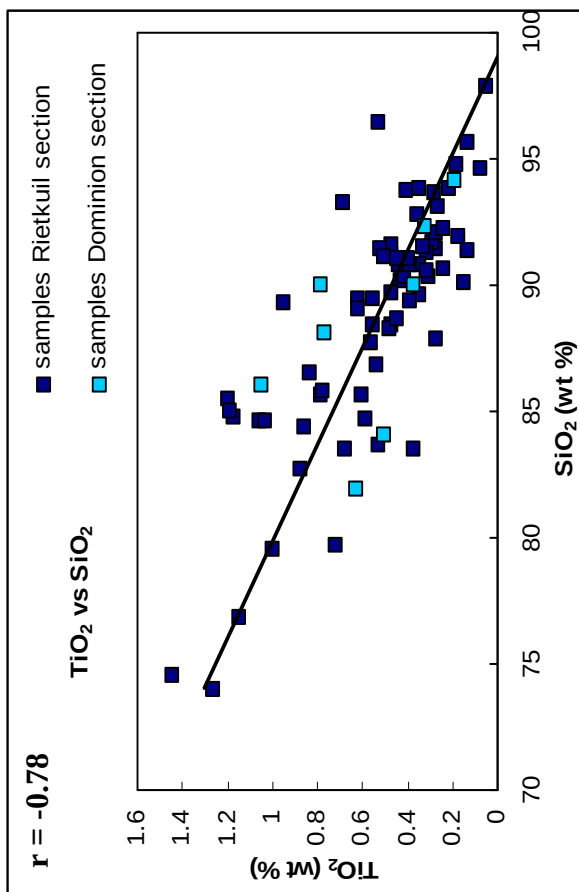
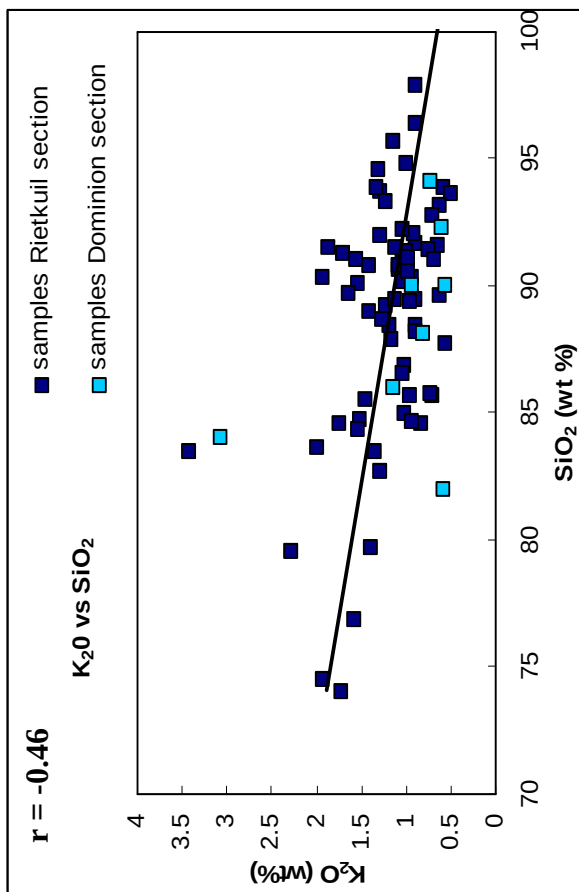
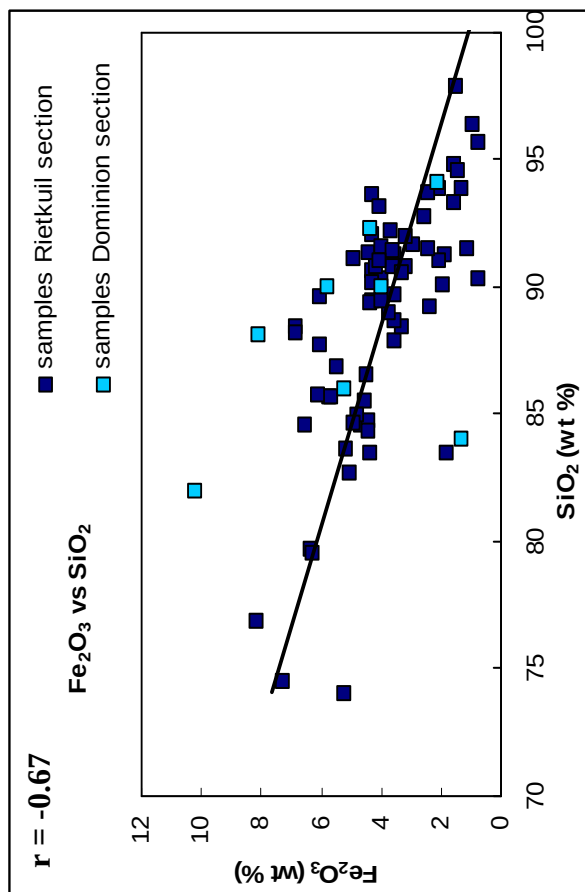
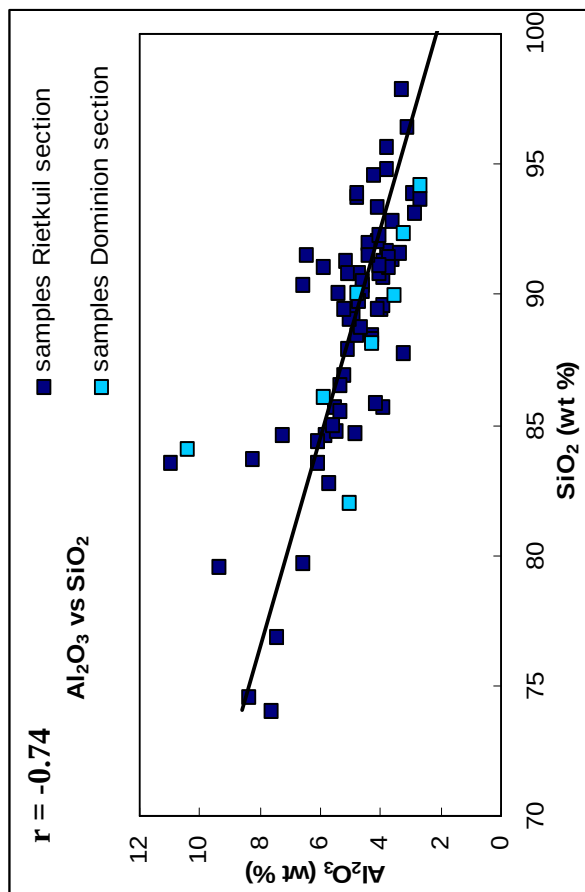
Calcium is most likely hosted in grossularite (garnet), which is rarely distributed within the conglomerates. Calcite also might be a possible host mineral for Ca which could not

determined microscopically. Hiemstra (1968) reported that only 4 % of the present garnets can be determined as grossularite. A weak negative correlation of -0.67 of CaO with SiO₂ confirms the assumption. The samples with a high phosphor content may contain the majority of monazites as well distributed main phosphate mineral.

In general it can be considered that the Harker diagrams contain a large volume of information and show qualitatively that there is an excellent negative correlation between most of the major elements displayed versus SiO₂. The strong geochemical coherence between the major elements most likely results from the mixing of the different components of the sediment constitutes.

Table 4-1: Pearson correlation matrix of the major elements, all correlation coefficients above or below 0.5 are significant and represent geochemical relationships (blue and black marked), <D.L.= values are below detection limit

element	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅
SiO ₂	1	-0.74	-0.67	-0.46	-0.62	-0.67	<D.L.	-0.46	-0.79	-0.79
Al ₂ O ₃	-0.74	1	0.16	0.12	0.24	0.32	<D.L.	0.90	0.52	0.41
Fe ₂ O ₃	-0.67	0.16	1	0.73	0.56	0.34	<D.L.	-0.19	0.54	0.45
MnO	-0.46	0.12	0.73	1	0.46	0.21	<D.L.	-0.26	0.47	0.32
MgO	-0.62	0.24	0.56	0.46	1	0.50	<D.L.	-0.01	0.69	0.51
CaO	-0.67	0.32	0.34	0.21	0.50	1	<D.L.	0.18	0.68	0.87
Na ₂ O	-0.13	0.01	0.06	0.03	0.15	0.12	0	-0.04	0.04	0.13
K ₂ O	-0.46	0.90	-0.189	-0.26	-0.01	0.18	<D.L.	1	0.27	0.21
TiO ₂	-0.78	0.52	0.54	0.47	0.69	0.68	<D.L.	0.27	1	0.71
P ₂ O ₅	-0.78	0.41	0.45	0.32	0.51	0.87	<D.L.	0.21	0.71	1



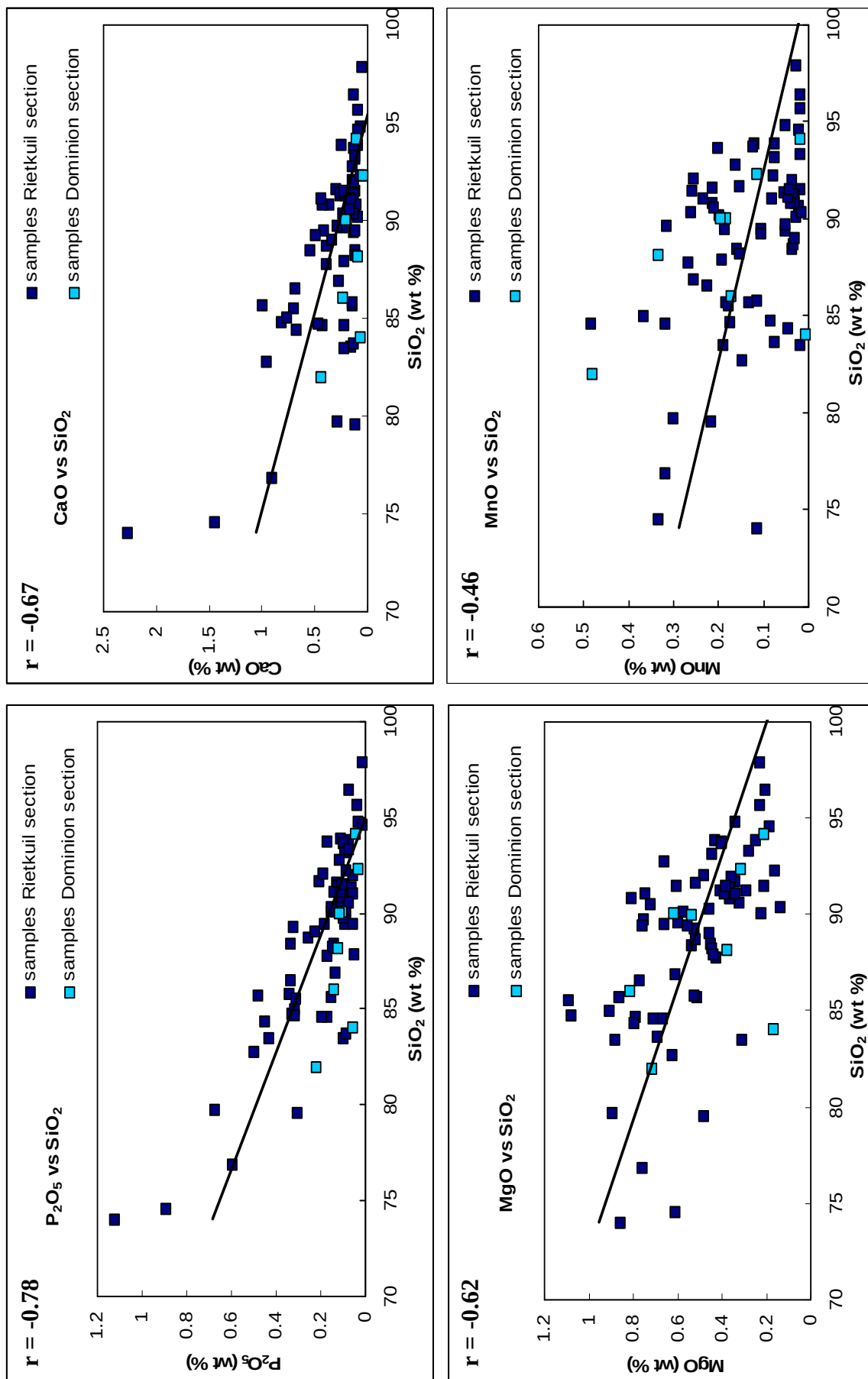


Fig.4-9: Harker diagrams (Harker 1909) for Al₂O₃, TiO₂, MnO, Fe₂O₃, P₂O₅, CaO, K₂O and MgO versus SiO₂, geochemical relationships displayed as trend line, (r=pearson coefficient)

4.2.2 Minor and trace element chemistry and possible correlations

Trace element concentrations are mostly present at a less than 0.1 % level, and will be expressed in parts per million (listed in Appendix III). In some cases trace elements form mineral species in their own right but mostly they substitute major elements in the rock forming minerals. Selected trace minerals will be used to explain geochemical processes, in particular, the alteration process.

In the following paragraph, trace elements will be studied in groups according to their chemical affinity to minerals in the Dominion Reef sediments. Deviations from group behaviour or systematic changes in behaviour within the group are used as indicator for different provenance, sedimentary sorting, and alteration processes.

4.2.2.1 Yttrium and Zirconium

Yttrium (Y) measured within the samples had an average content of 253 ppm and maximum values up to 1170 ppm, whereas Zirconium (Zr) has an average content of 363 ppm (maximum of 2640 ppm). A significant relation between Y and Zr is displayed in figure 4-10. Most of the samples show values at a low ratio between 2 and 4 which according to Cuney and Friedrich (1987) suggests that the bulk of the present monazites and zircons are well preserved. Microscopic studies revealed that some monazites occur in a more altered stage but the majority appear as well rounded unaltered grains. Another possible explanation for a low ratio could be that Y would also be present in other mineral phases maybe as a common impurity. A high correlation of P_2O_5 versus Y of 0.81 indicates that there is xenotime additionally present to monazite.

The geochemical relationship between Y and Zr imply, that the corresponding minerals monazite, xenotime, and zircon most likely have a similar origin. Feather and Koen (1975) claimed that both minerals are definitely from detrital origin. The high correlation coefficient of 0.88 between Zr and Y confirms the assumption (Appendix III).

Further studies on monazite grains were carried out with the electron microprobe. The obtained results and the interpretation will be explained in chapter five.

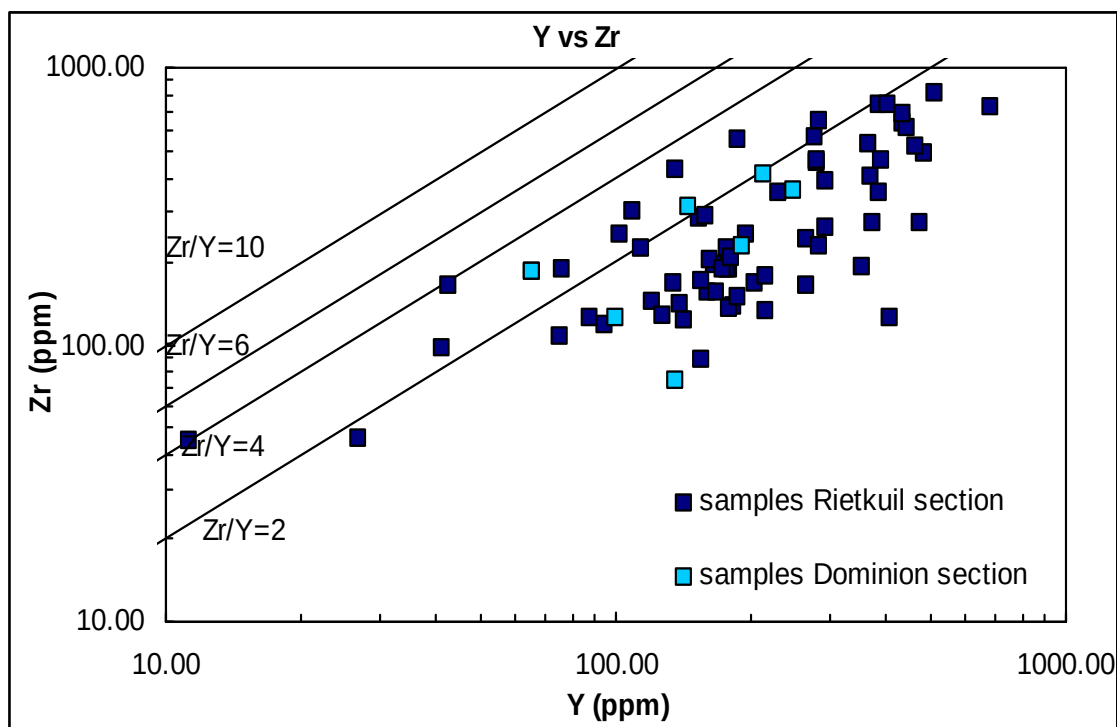


Fig.4-10: Variation diagram of Y versus Zr, the bulk of Dominion Reefs whole rock samples are displayed between Zr/Y ratio lines 2 and 4

4.2.2.2 Sulphide minerals

The elements which most likely occur within the identified sulphide minerals are Fe, Pb, Cu, As, Zn, and Ni. The corresponding host minerals within the Dominion Reefs are pyrite, galena, chalcopyrite, arsenopyrite, sphalerite, and pyrrhotite. Pentlandite and nickelin as possible host minerals might also be abundant (Hiemstra 1968) but could not be determined microscopically.

The Pearson correlation matrix shows the significant corresponding elements in table 4-2. Noteworthy is the correlation coefficient of 0.86 between Co and Ni which predicts the occurrence of cobaltite. Further, a low Co content with an average of 47 ppm and an average content of 103 ppm Ni could be measured. The diagram in figure 4-11 shows a linear trend which indicates a perfect geochemical relationship. Feather (1981) considered that cobaltite grains most likely occur as very small, less distributed minerals within the Witwatersrand basin. Within the thin sections the cobaltite crystals could not be identified microscopically. The significant correlation can be explained by the close position within the periodic table which implies a similar chemical behaviour. Both elements show relations to the same elements as confirmation of the assumption.

Arsenic displays a remarkable correlation with Co and Ni which leads to the conclusion that the host mineral arsenopyrite, pentlandite, nickelin and cobaltite very likely have the same origin. Feather and Koen (1975) claimed that both minerals are from detrital origin within the

Reefs of the Witwatersrand basin. Feather (1981) proposed a similar crystallization trend of cobaltite and arsenopyrite as detrital minerals.

The Cu content (average of 143 ppm) within the samples is significantly higher than Ni, Co, and As values. This reveals that the Cu host mineral chalcopyrite is well distributed within the samples. Notable is that there is no correlation with other chalcophile elements present, apart from Fe (Pearson correlation coefficient of 0.7). This may imply that different hydrothermal processes happened during or after deposition. During the weathering process, Cu could have been transported in solution and might have been re-precipitated. According to Feather and Koen (1975), Cu was incorporated into minerals and rebuilt by hydrothermal action after deposition. Davidson (1965) proposed the evidence of hydrothermal metallization on a group of heavy minerals within the Dominion Reefs. This assumption is in accordance with the studied correlation coefficient.

The high Fe content (average of 40271 ppm) can be explained with the occurrence of pyrite as the main sulphide mineral within the Reef conglomerates. Iron is furthermore a constituent of arsenopyrite, pyrrhotite, and chalcopyrite. Notable is that the correlation coefficient between Co-Ni and Fe is lower than the coefficient between Cu and Fe. This can lead to the assumption that the bulk of the pyrite might be of hydrothermal origin. According to mineralogical studies by Ramdohr (1958) both a detrital and hydrothermal origin of pyrite within the Reefs of the Witwatersrand are most probable.

Pyrrhotite might have its origin during secondary sulphide mineralization caused by metamorphism as said by Feather and Koen (1975). Most Witwatersrand basin investigators believe that pyrrhotite grains derived from pyrrhotitization of primary pyrite (Feather 1981). Microscopic observation, in chapter three, confirms the secondary origin of pyrrhotite. The Pearson correlation matrix reveals no evidence or counterevidence for this assumption.

The average measured Pb content of 772 ppm indicates that galena as host mineral is well distributed within the samples. One sample from the Rietkuil section reveals a maximum lead content of 6150 ppm. The high correlation with U could lead to the assumption that both elements have a similar geochemical behaviour and appear in the main uranium-bearing minerals and their alteration products. Uranium and Pb both show evidence of similar significant correlations to other elements. A correlation coefficient of Pb to Co and Ni above 0.5 indicates a relation to Co and Ni. As result a detrital origin as mentioned above for Co and Ni bearing minerals can be assumed for Galena as Pb hosting mineral phase. Simpson and Bowles (1977) assumed that the bulk of galena is from radiogenic origin and formed by hydrothermal sulphide mobilisation while hydrothermalism. This lead to the result that galena originated both as detrital and as redistributed hydrothermal mineral. The microscopic study of the minerals confirms the results.

The measured Zn content, (average of 493 ppm) can be attributed to sphalerite with no significant correlation to other elements. Feather and Koen (1975) claimed that sphalerite

originated as a secondary sulphide mineral within the Dominion Reefs which could not be proved wrong during this investigation.

Table 4-2: Pearson correlation matrix of the chalcophile elements, all correlation coefficients above or below 0.5 are significant and represent geochemical relationships (blue marked)

element	Fe	Co	Ni	Cu	Zn	As	Pb	S
Fe	1	0.49	0.44	0.70	0.12	0.24	0.12	0.62
Co	0.49	1	0.86	0.29	0.35	0.65	0.65	0.66
Ni	0.44	0.86	1	0.36	0.15	0.64	0.60	0.33
Cu	0.70	0.29	0.36	1	-0.03	0.12	-0.06	0.32
Zn	0.12	0.35	0.2	-0.03	1	0.18	0.48	0.30
As	0.24	0.65	0.64	0.12	0.18	1	0.53	0.28
Pb	0.1	0.65	0.60	-0.06	0.48	0.53	1	0.22
S	0.62	0.66	0.33	0.32	0.30	0.28	0.22	1

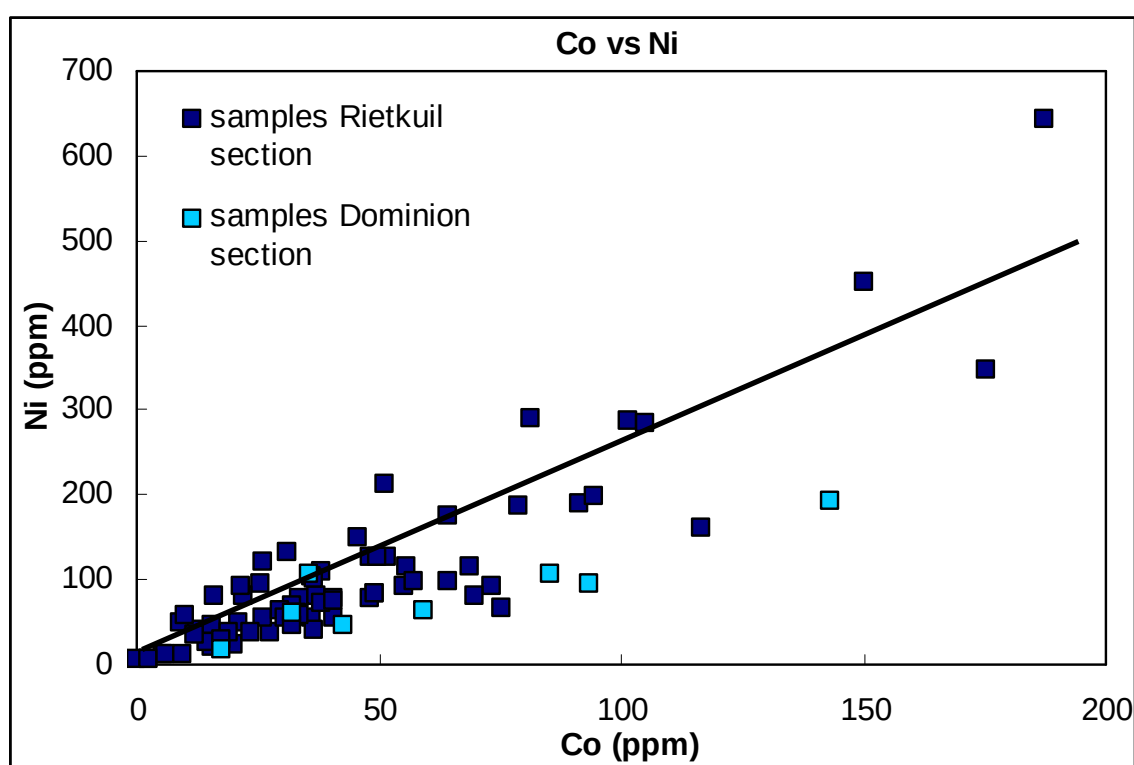


Fig.4-11: Variation diagram of Co versus Ni from Dominion Reefs whole rock samples, perfect geochemical relationship is displayed as linear trend line

4.2.2.3 Detrital minerals

With the help of the correlation matrix, it will be argued that the described minerals are from detrital origin. Elements like Ti, Zr, Sn, Cr and Nb-Ta are the main constituents of the detrital minerals. The Pearson correlation matrix of the elements which are hosted in detrital minerals is shown in table 4-3. Significant correlations between element pairs show evidence of geochemical relationships between the displayed elements.

The measured element concentrations within the whole rock samples vary significantly. Chromium with an average content of 580 ppm, mainly appears as chromite, and Zr with an average of 363 ppm, as zircon. Both minerals are well spread through out the samples.

Tantalum (average of 109 ppm) and Nb (average of 218 ppm), as main constituents of columbite, appear with a significant lower value. Xenotime and monazite which host the bulk of the Y and P₂O₅ content, was already described in the paragraph above.

Tin (average of 29 ppm) very likely is the main component of cassiterite grains which are rarely distributed. The Ti content (average of 5211 ppm) is bonded in rare distributed ilmenite, and secondary alteration mineral phases such as rutile, anatase and U-Ti phases. Remarkable is that Ti only correlates with Cr. This leads to the conclusion that titanium is hosted in detrital minerals like ilmenite. Nevertheless, petrographic evidence (chapter three) suggests that the bulk of Ti occurs in the secondary alteration mineral phases anatase and U-Ti phases.

A low correlation coefficient between Sn and Cr-Ti is obvious. Compared to the other minerals, cassiterite occurs within the sedimentary rocks as much smaller grains (revealed by petrographic studies) and will be considered of primary formation.

The obvious correlative relationship between Ta - Nb and Sn suggest that columbite and cassiterite might have a similar deposition history. Hiemstra (1968) assumed a different source area for the cassiterite origin and the origin of the other detrital minerals like chromite, monazite, zircon and columbite because of their deviation from different host rocks.

The correlation coefficients between most of the above mentioned elements are high. As shown in the correlation matrix most pairs have a coefficient above 0.5. This leads to the result that many detrital minerals have a similar deposition history. Petrographic studies suggested that detrital minerals (cassiterite as exeption) occur with similar grain size and shape. These common features can be explained by the sedimentological process of hydraulic sorting (Tucker 2001).

Table 4-3: Pearson correlation matrix of elements hosted in detrital minerals, all correlation coefficients above or below 0.5 are significant and represent geochemical relationships (blue marked)

element	Ti	Cr	Zr	Nb	Sn	Ta
Ti	1	0.51	0.49	0.32	0.24	0.25
Cr	0.51	1	0.58	0.49	0.41	0.40
Zr	0.49	0.58	1	0.76	0.65	0.74
Nb	0.32	0.49	0.76	1	0.85	0.98
Sn	0.24	0.41	0.65	0.85	1	0.89
Ta	0.25	0.47	0.74	0.98	0.89	1

4.2.2.4 Uranium and Thorium

The average whole rock U content measured in 78 samples is 898 ppm with a maximum of 7524 ppm. The average Th content is 495 ppm with a maximum of 3210 ppm. U and Th tend to be linked due to the same formation process- a high correlation coefficient confirms this result. Both elements seem to have the same correlations to other elements and appear repeatedly together in different mineral phases. The bulk of U and Th are present as uraninite grains. A low proportion of U and Th probably are present in the alteration products U-Th and U-Ti phases. The origin of the secondary minerals will be explained later in chapter five with the help of electron microprobe studies.

Within the Pearson correlation matrix, given in table 4-4, the elements which show a significant geochemical relationship with U and Th are displayed. Elements which are hosted predominantly in detrital minerals (as described in 4.2.2.3) like Cr, Ti (only Th), Co, Ni, Y, Zr, Sn, Pb, Nb, and Ta, show a remarkable correlations. Elements within hydrothermal originated minerals like Cr in chromite show no correlation with uranium and thorium.

The significant correlations between the element pairs lead to the result that their host minerals have the same depositional history. Therefore, it can be assumed that uraninite grains most likely are from detrital origin. Several scientists revealed the same genesis of the Dominion Reefs uraninite grains (Davidson 1965).

Table 4-4: Pearson correlation matrix of the elements which correspond with U and Th, all correlation coefficients above or below 0.5 are significant and represent geochemical relationships (blue marked)

element	Ti	Cr	Co	Ni	Y	Zr	Nb	Sn	Ta	Pb	Th	U
Ti	1	0.51	0.33	0.52	.42	0.49	0.32	0.24	0.25	0.10	0.52	0.22
Cr	0.51	1	0.59	0.61	0.52	0.58	0.49	0.41	0.47	0.37	0.54	0.30
Co	0.33	0.59	1	0.86	0.64	0.58	0.71	0.73	0.74	0.65	0.77	0.65
Ni	0.52	0.61	0.86	1	0.80	0.81	0.80	0.79	0.82	0.60	0.91	0.76
Y	0.42	0.52	0.64	0.80	1	0.88	0.92	0.75	0.89	0.64	0.82	0.70
Zr	0.49	0.58	.58	0.81	0.88	1	0.76	0.65	0.74	0.49	0.79	0.61
Nb	0.32	0.49	0.71	0.80	0.92	0.76	1	0.85	0.98	0.72	0.80	0.69
Sn	0.24	0.41	0.73	0.79	0.75	0.65	0.85	1	0.89	0.71	0.73	0.68
Ta	0.25	0.47	0.74	0.82	0.89	0.74	0.98	0.89	1	0.78	0.80	0.72
Pb	0.10	0.37	0.65	0.60	0.64	0.49	0.72	0.71	0.78	1	0.61	0.57
Th	0.52	0.54	0.77	0.91	0.82	0.79	0.80	0.73	0.80	0.61	1	0.89
U	0.22	0.31	0.65	0.76	0.70	0.61	0.69	0.68	0.72	0.57	0.89	1

The bivariate plot in figure 4-12 displays all studied samples and the typical U and Th content of shale, granite, granitoides, diorite, and gabbro. Within the variation diagram, all samples show a strong enrichment in U and Th in relation to average shale or granite. They show

lower Th/U ratios than the average crustal ratio of 4 except a few samples. Two groups of samples can be distinguished based on their Th/U ratio. A first group with the lowest Th and U contents has the highest Th/U ratio, mainly higher than one, whereas the second group with the highest U and Th contents has the lowest Th/U ratios between 1 and 0.5. Such a variation of Th/U ratios reflects the higher proportion of altered uraninite (personal remark by Prof. M. Cuney). The first group of samples with high Th/U ratios indicate more altered or even secondary uranium bearing minerals, whereas the second group with low Th/U ratios reveal a higher proportion of detrital more preserved uraninites.

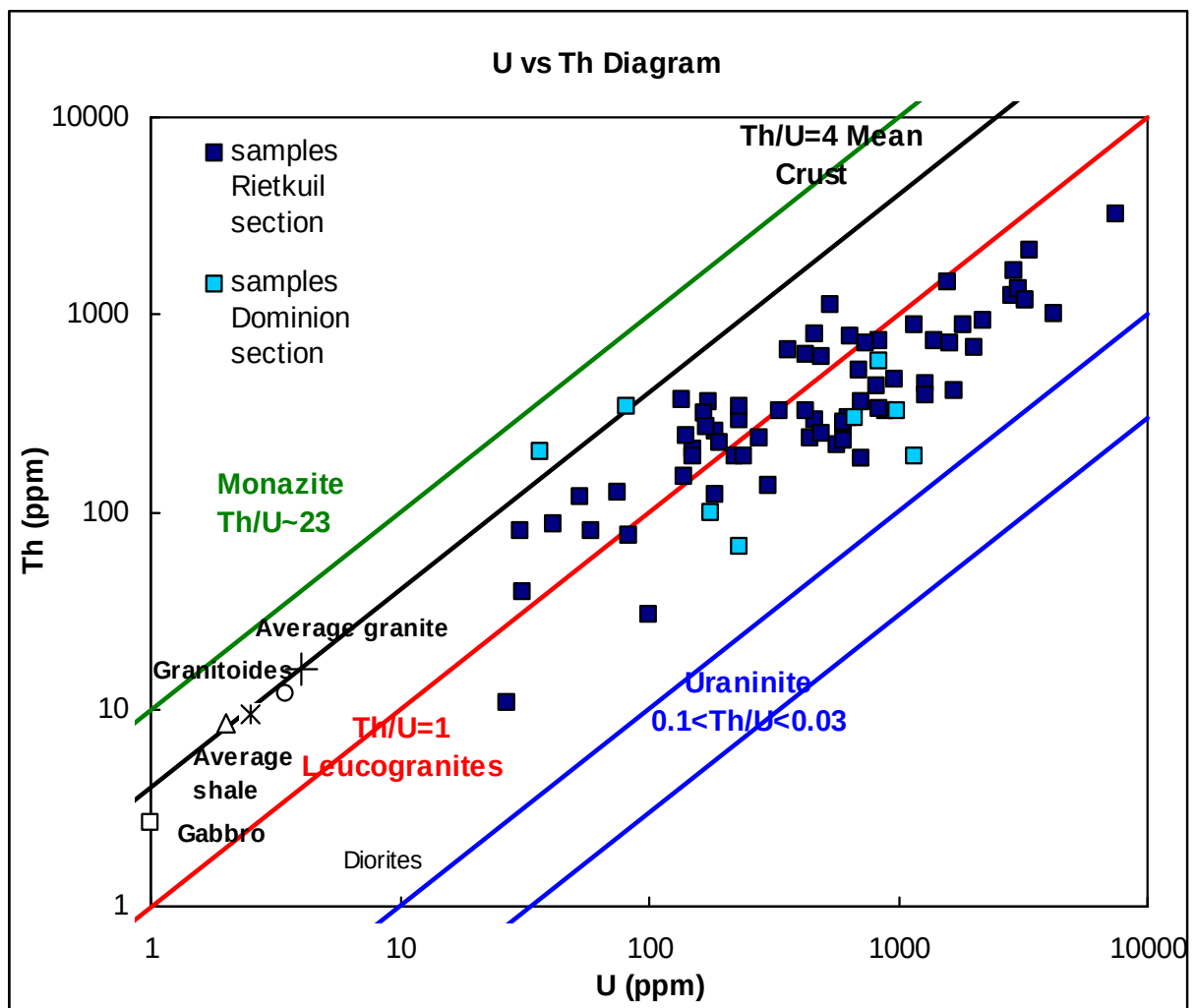


Fig.4-12: Variation diagram of U versus Th with whole rock Dominion Reefs samples with mean rock compositions and significant Th/U ratios

4.3 Summary of the whole rock geochemistry

The whole rock samples of the Dominion Reefs were analysed with XRF and ICP MS. The Dominion Reef samples could be classified, based on the detailed diagram from Herron (1988) as mainly sublitharenite, litharenite and Fe-sand.

Since trace elements are principally resistant to alteration, the alteration history is based on the major element geochemistry. The Dominion Reef sediments underwent moderate alteration during and after deposition of different degrees. For a better understanding, the chemical index of alteration was calculated for all samples. The average CIA of 78 is compatible to a moderate alteration degree which reflects dispersive metasomatism probably caused by fluid flow.

To evaluate the tectonic setting, the discrimination diagram after Bhatia (1983) for major elements was used. For the accumulation of the Dominion Group a continental rift can be proposed as tectonic setting. The displayed chemical data revealed for a part of the Dominion Reef sediments a passive margin as tectonic setting. The deposition of sediments in the sequence boundary between the Dominion Group and the West Rand Group probably explains the tectonic setting of a passive margin. The work with trace elements revealed that not all geochemical provenance diagrams are suitable, especially for extremely quartz-rich sediments. The dilution of all elements by SiO_2 , together with zircon enrichment and sedimentary recycling makes many classic provenance diagrams (Bathia 1983, Roser and Korsch 1986) ineffective. To evaluate the provenance a suitable provenance diagram after Floyd and Leveridge (1987), Nagender Nath et al. (2000) was used. The La/Th versus Hf diagram revealed a felsic source from various tectonic settings for the Dominion Reef sediments.

For determination of possible source areas, major element discrimination diagrams were considered. The discrimination diagram after Roser and Korsch (1988) revealed intermediate rock material as possible source rocks. Most investigators of the Witwatersrand Reefs suggested Archean granitic or pegmatitic rocks as source rocks. The trace- and rare earth elements proved to be of more importance as a provenance indicator. In general the source rocks of the Dominion Reef conglomerates can be assumed to be from Upper Continental Crust origin with mainly felsic source material (Fig.4-6 and 4-7). The very low Eu/Eu* ratios and the high Th/Sc ratios fit well these provenance types. From the results of the major and trace element analyses it can be proposed that recycling of older sediments occurred.

Furthermore, the geochemical data were used to determine the relationships and the association of minerals contained in the Dominion Reefs. The mineral genesis was explained

with the help of a statistical parameter – the Pearson correlation coefficient. It is proposed that the geochemical relationships between pairs of elements in the Dominion Reefs are controlled by the major influence of sedimentary and hydrothermal processes during and after sediment deposition. Elements, which are hosted within detrital minerals such as uraninite or garnet, possess a high degree of correlation. Elements hosted in hydrothermal- or hydrothermal reworked minerals such as galena, pyrite or chalcopyrite also reveal significant correlations. The correlation between elements hosted in detrital minerals and elements hosted in hydrothermal -or hydrothermal redistributed minerals was not significant.

Chapter Five: Mineral geochemistry

This chapter focuses on the chemical identification of the different uranium bearing mineral phases occurring in the Dominion Reefs and their geochemical relationships. For this purpose SEM- EMPA- and LA-ICP MS analyses on mineral phases were carried out.

5.1 Mineralogy and mineral chemistry – SEM

SEM analyses were performed on well mineralized conglomerate samples to determine the quantitative elemental composition of the minerals and to obtain an overview about the element distribution within the polished thin sections. For electron microprobe analyses back-scattered electron images (BSE) were done to locate uranium bearing minerals within the polished thin sections.

A few samples contain important mineral phases and were analysed with element mapping to identify the mineral distribution which appear closely related to uranium bearing minerals. Two areas of sample DRT 03 DO 6920 and DRT 079 AO 5268 will briefly be described as examples for the importance of Energy-Dispersive X-Ray Spectroscopy (EDX) measurements with element mapping and BSE images.

For the quantitative analysis of different mineral phases, thirteen selected elements were analysed. The reached counts of sample DRT 039 DO 6920 are presented within the graph together with the corresponding quantitative elemental compositions as table (Fig.5-1).

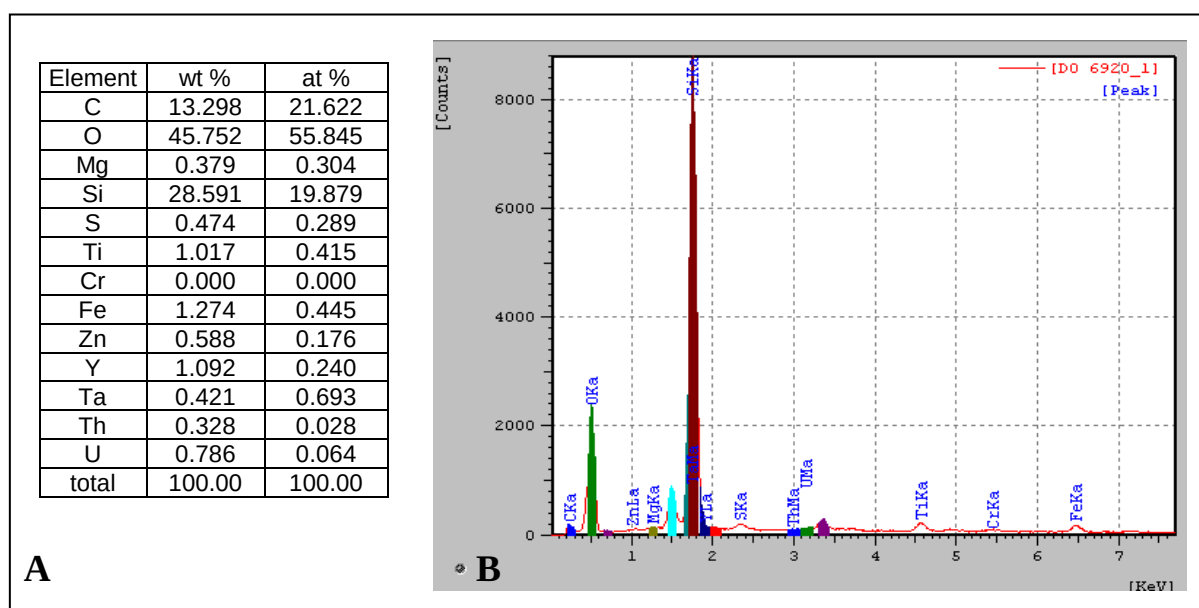


Fig.5-1: Semi-quantitative analyses of sample DRT 039 DO 6920, A: tabular values, B: EDX-spectrum displaying elements

Element mapping of the same selected area within sample DRT 039 DO 6920 demonstrates the element distribution (Fig.5-2). Silica is well distributed within the selected area, which can be explained by quartzite as the main constituent within the conglomerate. Magnesium and yttrium are distributed to a lesser extent which reveals no identification of a specific mineral. It can be assumed that both elements are present in very small amounts. Sulphur is rarely distributed and the appearance of sulphide minerals within this analysed area can be eliminated.

Tantalum is well dispersed over the whole area which can be explained by its occurrence in different minerals as an impurity. Zirconium and carbon are present in a close bond. It is assumed that a zircon grain is rimmed by carbon material. Well known is the rare occurrence of carbon within the Dominion Reefs (Ramdohr 1958).

Chromium and iron appear together within this selected area, probably as chromite. Other minerals, not clearly distinguishable might also bear iron in small amounts.

Titanium corresponds with uranium and mostly with fine dispersed thorium. All three elements occur around uraninite as alteration products. The main uranium hosting mineral with low Ti can be determined as uraninite. The titanium enriched mineral phases with lower uranium content around uraninite or as ghost mineral are known as secondary U-Ti phases. The thorium-rich secondary mineral phases around uraninite can be identified as U-Th phases.

The BSE image of sample DRT 039 DO 6920 with all identified mineral phases as listed in figure 5.1 and mapped in figure 5.2 is presented in figure 5-3. The uraninite grains appear to be heterogeneous within the image. The U-Ti and the U-Th mineral phases appear patchy and cloudy around uraninite and as ghost minerals. This can be based on the assumption that these are secondary mineral phases derived from primary uraninite grains. Remarkable are the radial fractures between the uraninites and the alteration products. This amplified the relationship between the mineral phases.

The appearance of carbon around zircon led suggests that uraninite is not the main carbon associated mineral. Several authors claimed that carbon partly or totally replaces the uraninite (Liebenberg 1955). Within this investigation of the Dominion Reefs, the distribution of carbon is rare. The SEM studies revealed arguments against the submitted theories for an association of carbon and uraninites.

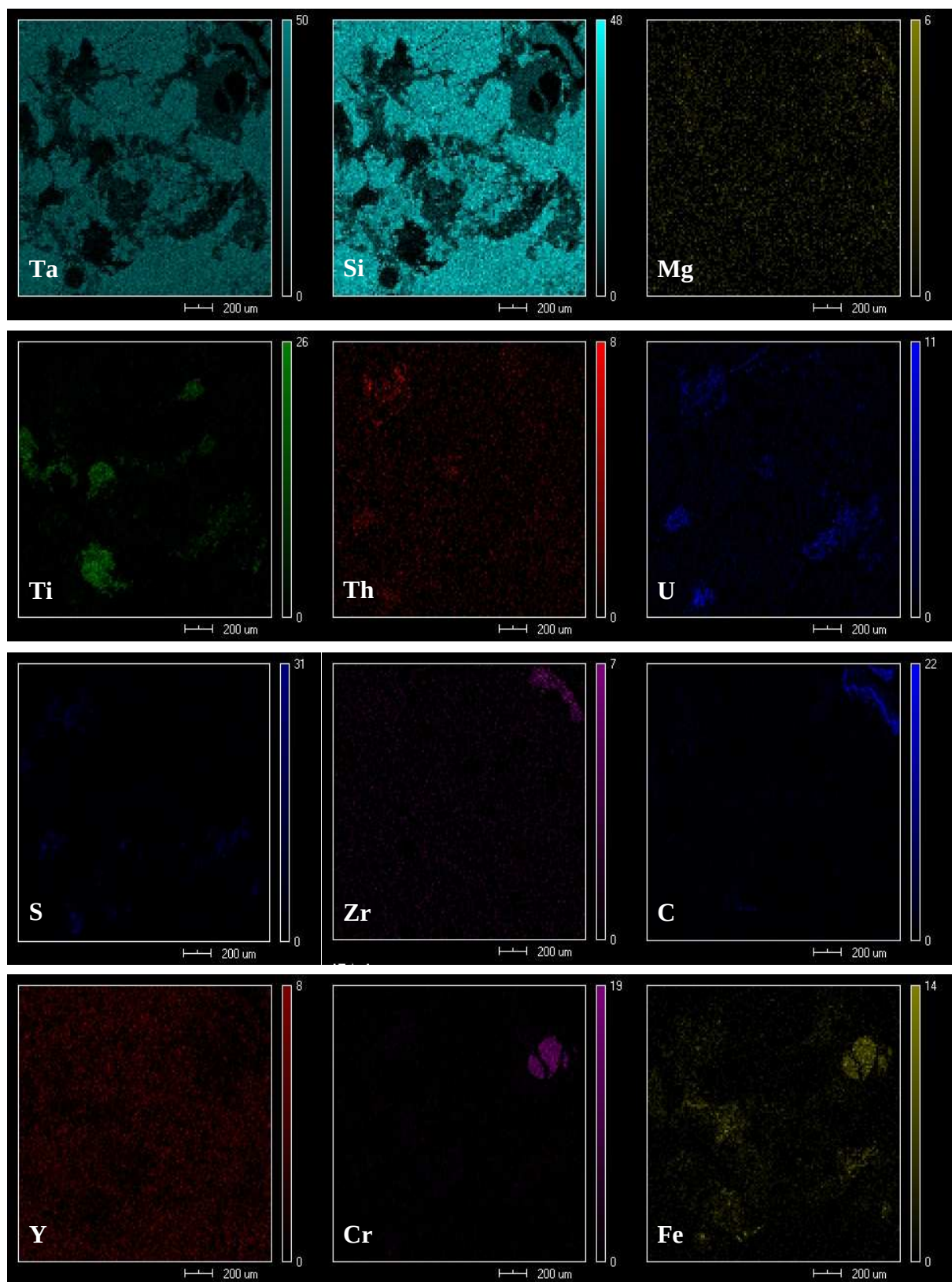


Fig.5-2: Element mapping of sample DRT 039 DO 6920

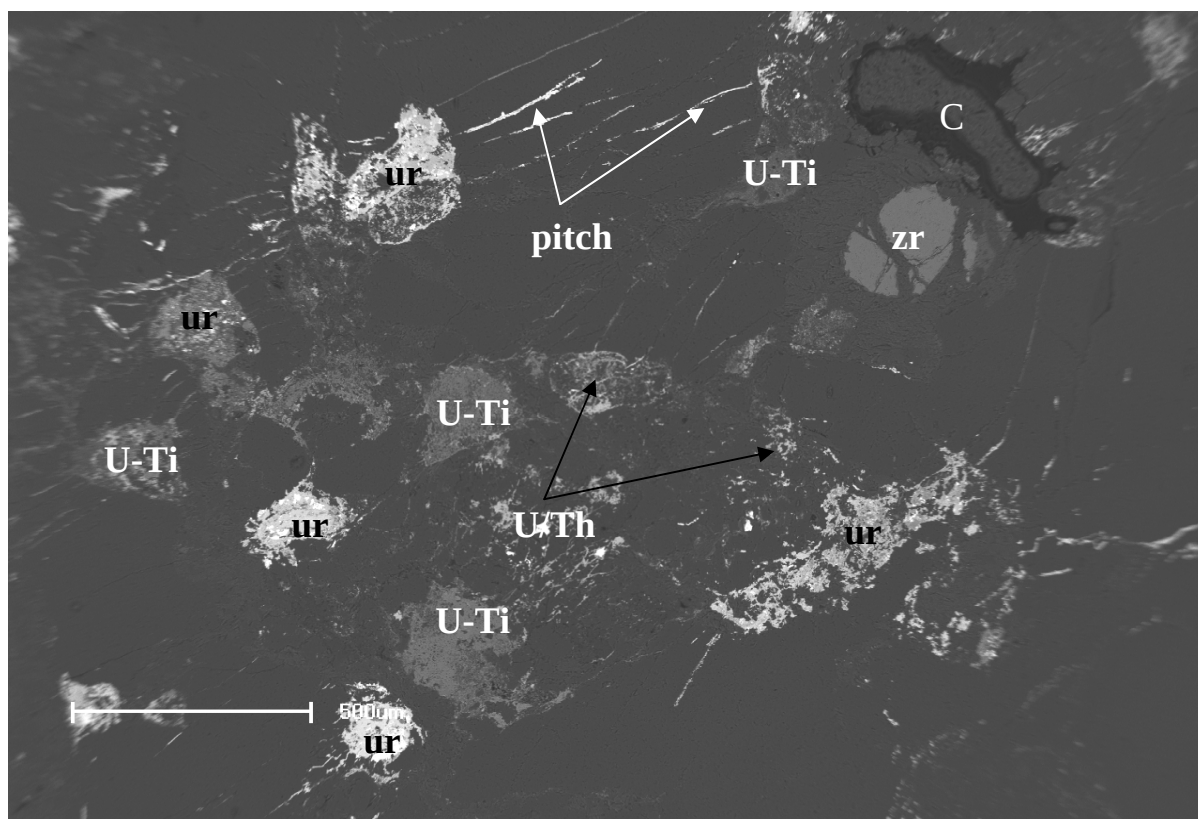


Fig.5-3: BSE image of sample DRT 039 DO6920 with all identified minerals (ur = uraninite, pitch = pitchblende, U-Th = U-Th phases, U-Ti = U-Ti phases cr = chromite, C = carbon, zr = zircon)

The element distribution and the received counts of sample AO 5268 is shown in figure 5-4.

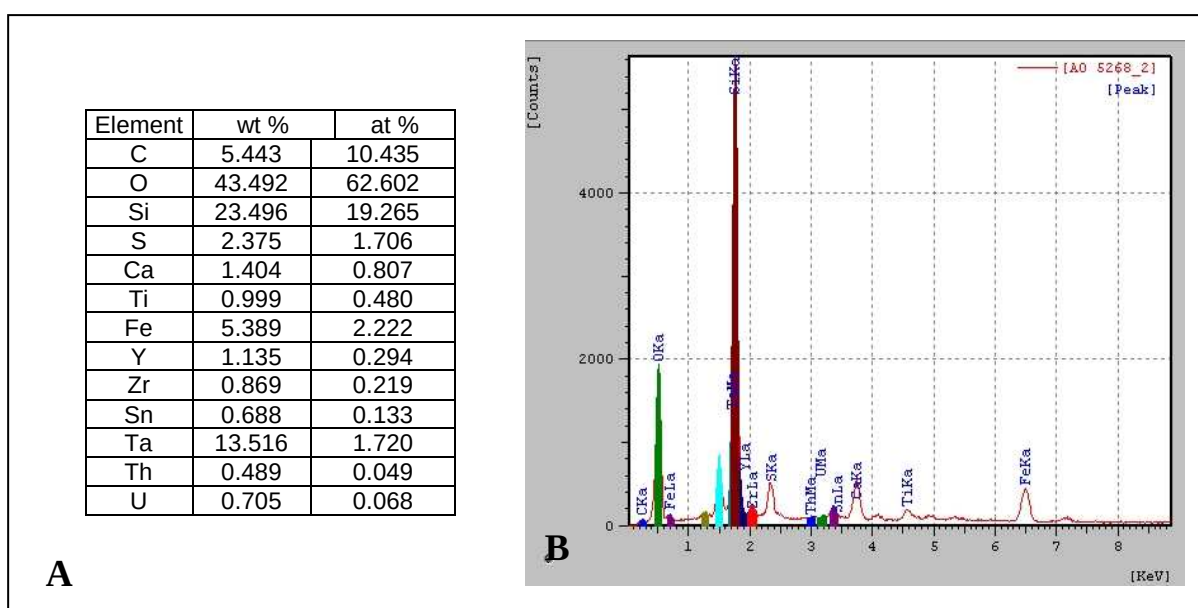


Fig.5-4: Semi-quantitative analyses of sample DRT 079 AO 5268, A: tabular values, B: EDX-spectrum displaying elements

Element mapping of the same selected area within the sample DRT 079 DO 5268 illustrates the element distribution (Fig.5-5). Silica is well distributed over the whole selected area explained by quartz as main matrix and pebble constituent within the sample. Oxygen and thorium are scarcely distributed associated with no specific mineral phase. It can be assumed that both elements are present in rarely distributed mineral phases. Sulphur and iron are clearly present and very likely tend to be hosted mostly in pyrite or other iron bearing sulphides.

Tantalum is finely dispersed over the whole area which can be explained by the occurrence in different elements as an impurity. Zirconium and calcium are present in a close relationship. It is assumed that zircon grains can contain calcium as an impurity. Carbon is dispersed and not significant in a special mineral phase.

Titanium does not correspond with the uranium distribution within this sample. This led to the result that the Ti bearing phases are not secondary U-Ti mineral phases. The main Ti bearing phases within this sample most likely are rutile, ilmenite and anatase. The main uranium hosting minerals can be assumed to be primary uraninite because no other element is present in the detected phases.

The BSE image of sample DRT 079 AO 5268 including all identified mineral phases is presented in figure 5-6. The image represents a large area within the sample, so a distinct determination of all identified mineral phases is difficult. Notable are the numerous fractures filled with the main secondary uranium bearing mineral phases traversing the quartz pebbles.

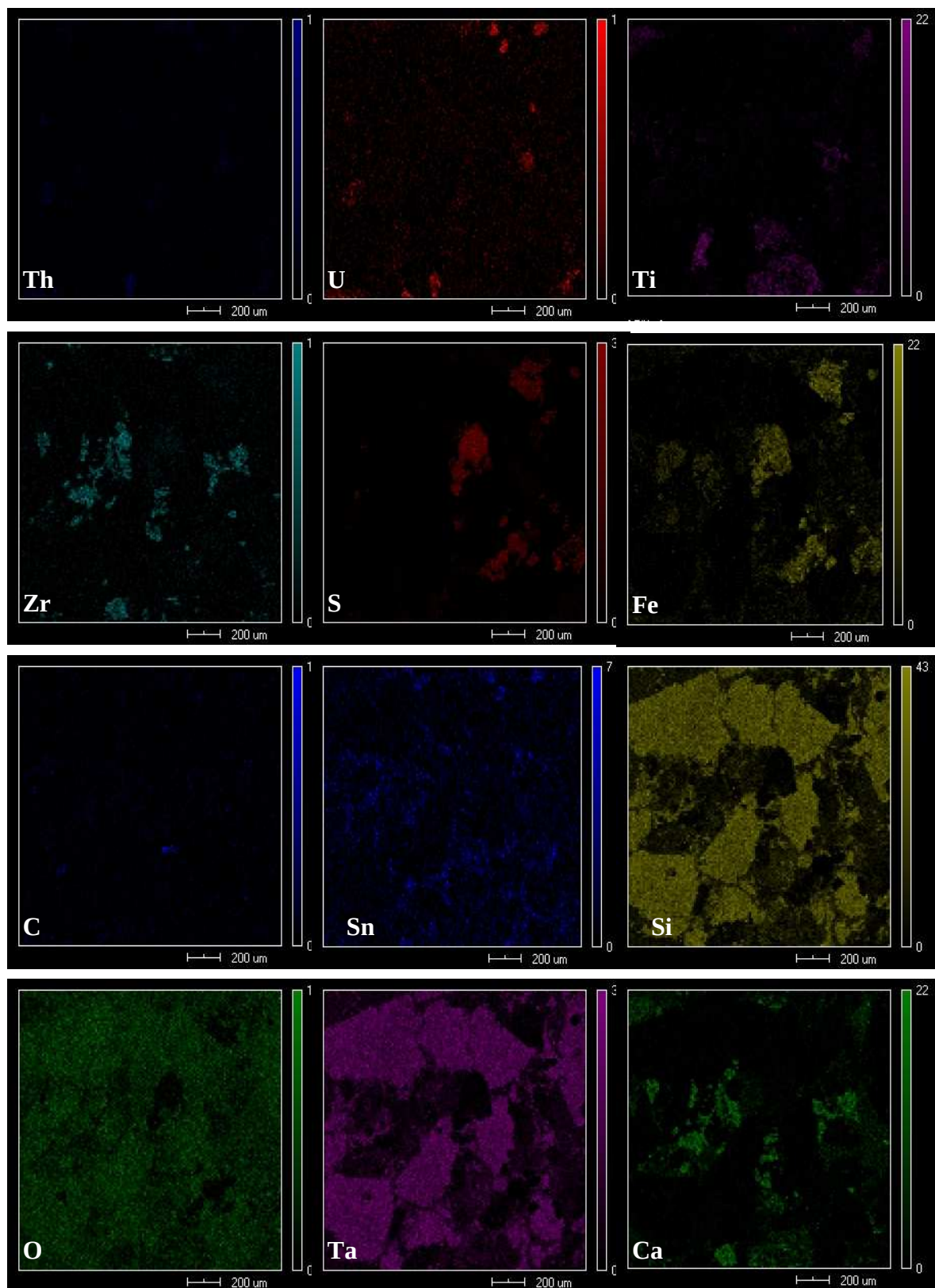


Fig.5-5: Element mapping of sample DRT 079 AO 5268

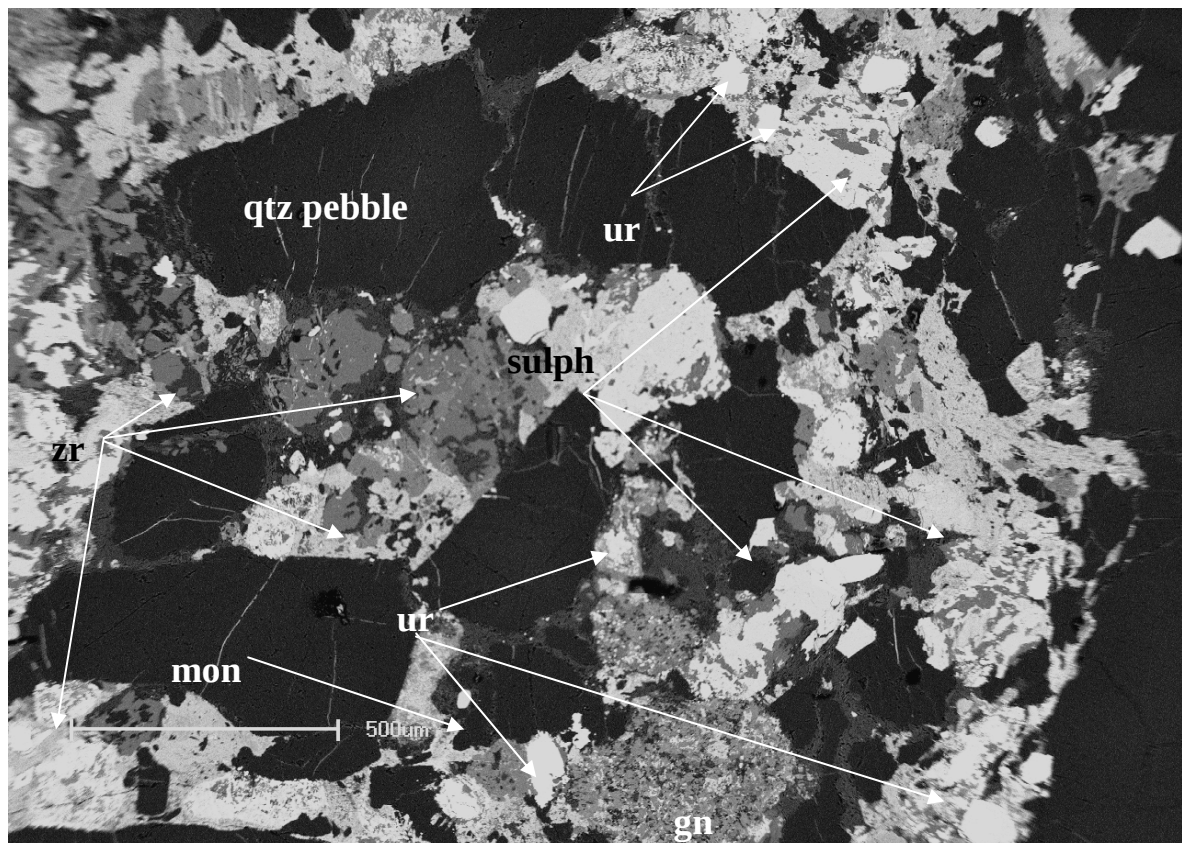


Fig.5-6: BSE image of sample DRT 079 AO 5268 with all identified minerals (ur = uraninite, mon = monazite, gn = garnet, sulph = sulphides, zr = zircon, qtz pebble = quartz pebble)

5.2 Mineralogy and mineral chemistry – Electron Microprobe

For a better understanding of uranium bearing minerals geochemical behaviour, electron microprobe studies were carried out on monazite, uraninite, secondary uranium bearing mineral phases such as U-Ti phases, U-Th phases, pitchblende and coffinite. Four well mineralized samples (DRT 039 DO 6920, DRT 034 DO 8628, DRT 079 AO 5268, DRT 058 AO 3883) underwent electron microprobe studies. Back scattered electron images of all observed mineral phases were done as shown in figure 5-7 and 5-11.

Wavelength-dispersive EMPA analyses of the U-bearing mineral phases are very heterogeneous because of their variable degree of alteration and their impregnation by tiny secondary quartz, sericite and sulphide crystals as revealed by optical observations. The results of an extensive EMPA examination are presented to complete the results of previous investigators and to reveal new information about the geochemical behaviour of the uranium bearing mineral phases hosted in the Dominion Reefs. Examined monazite, uraninite, U-Ti phases, U-Th phases, pitchblende and coffinite are used for interpretation of the alteration process. All wavelength-dispersive analyses are summarized in the Appendix IV.

5.2.1 Primary detrital mineral phases

5.2.1.1 Monazite and xenotime

Xenotime-(Y) and monazite, ideally CePO_4 are rare earth phosphate minerals. Monazite is well and xenotime rarely distributed within the Dominion Reef samples. In figure 5-7, backscattered electron images of some analysed monazites are displayed. A total of 143 EMPA analyses were used to characterize monazite and xenotime.

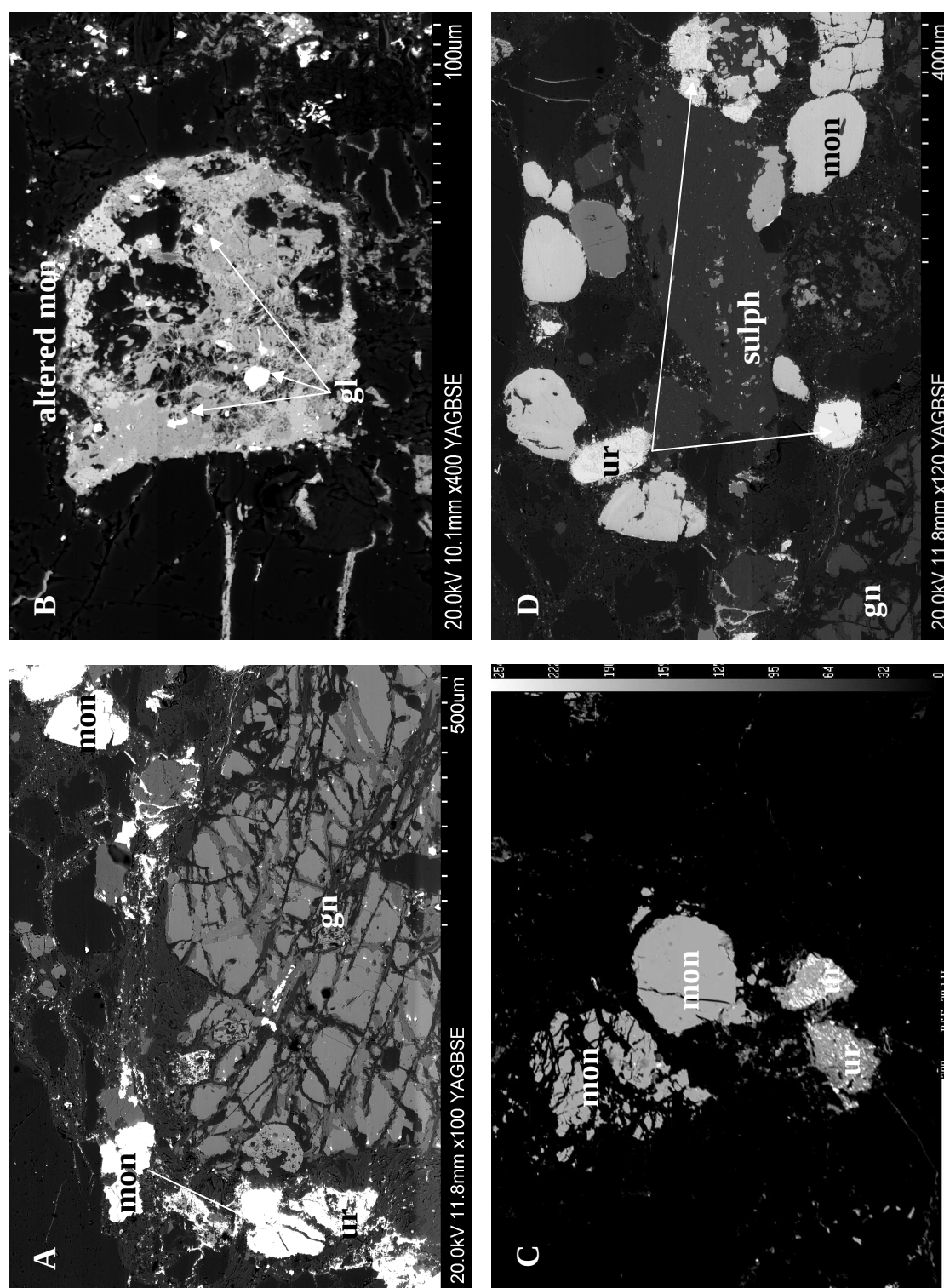


Fig.5-7: BSE images of monazite grains in sample DO 8628-A (A), DO6920 (B), DO 8628-A (C), DO 8628-A (D), mon = monazite,

gn = garnet, ur = uraninite, sulph = sulphides, gl = galena

The size of the analysed monazite grains vary between 50 and 100 μm . Well preserved monazites with grain sizes of 50-100 μm , have moderate UO_2 (average of 0.22 wt %), ThO_2 (average of 4.91 wt %), LREE (La_2O_3 average 16.54 wt %, Ce_2O_3 average 30.03 wt %, Pr_2O_3 average 2.42 wt %, Nd_2O_3 average 8.56 wt %, SmO average 1.53 wt %), and Y_2O_3 (average of 1.27 wt %) contents. The HREE analyses are below the detection limit and could not be considered.

Xenotime forms rims around monazite grains and vary in size (20-30 μm) and shape. Most analyses of xenotime are characterized by low analytical totals (average of 82.68 wt %). The xenotime analyses are presented in the Appendix IV. The xenotime grains present highly variable SiO_2 , P_2O_5 , TiO_2 , ThO_2 , and UO_2 contents. The actinide elements, Th and U, are high in concentration, with U always enriched relative to Th. The grains are particularly rich in UO_2 (up to 40.61 wt %) and ThO_2 (up to 14.3 wt %).

The ThO_2/UO_2 ratios for the monazite crystals vary between 10 and 50, (Fig. 5-8) whereas the xenotimes mirror ratios below 1. The uranium and thorium values of the monazites do not vary significantly within the diagram for sample DO 8628. This means that the grains have not been affected by hydrothermal fluid flow. In contrast, sample DO 6920 shows enrichment in U and decreasing in Th. Based on their appearance within the diagram in figure 5-8, monazites can be distinguished in two groups corresponding to different samples. As a result the monazite crystals within sample DO 6920 most likely were affected by the hydrothermal fluid flow and appear more altered. The uranium contents might have been derived from substitution processes during hydrothermal fluid flow.

The xenotime grains are slightly enriched in uranium but can be considered as one group. The grains appear to be relatively stable during hydrothermal alteration. Very little information is available on the stability of xenotime (Wolf and London 1995).

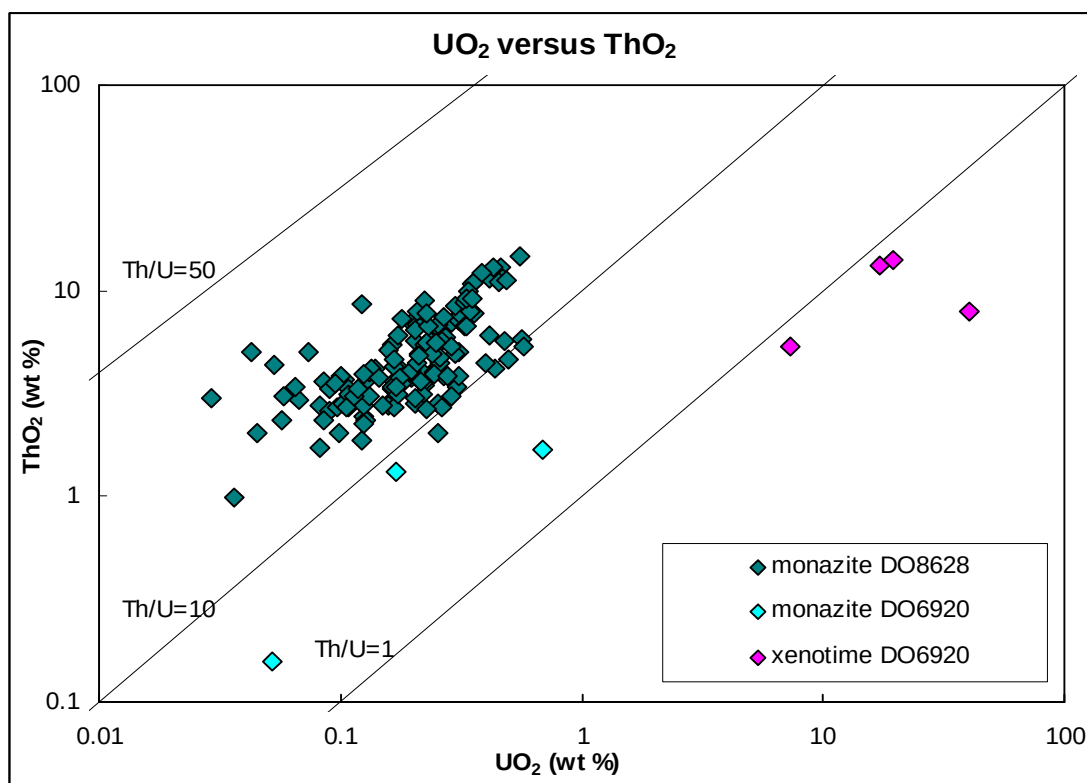


Fig.5-8: Bivariate plot of the ThO₂ contents of monazite and xenotime versus the UO₂ contents

The average content of 1 wt % SiO₂ of the monazites do not vary significantly as displayed in figure 5-9. None of the analysed samples show leaching or accumulation of silica as result of interaction with hydrothermal fluids. The average silica content of 15 wt % of the xenotime grains show no scattering.

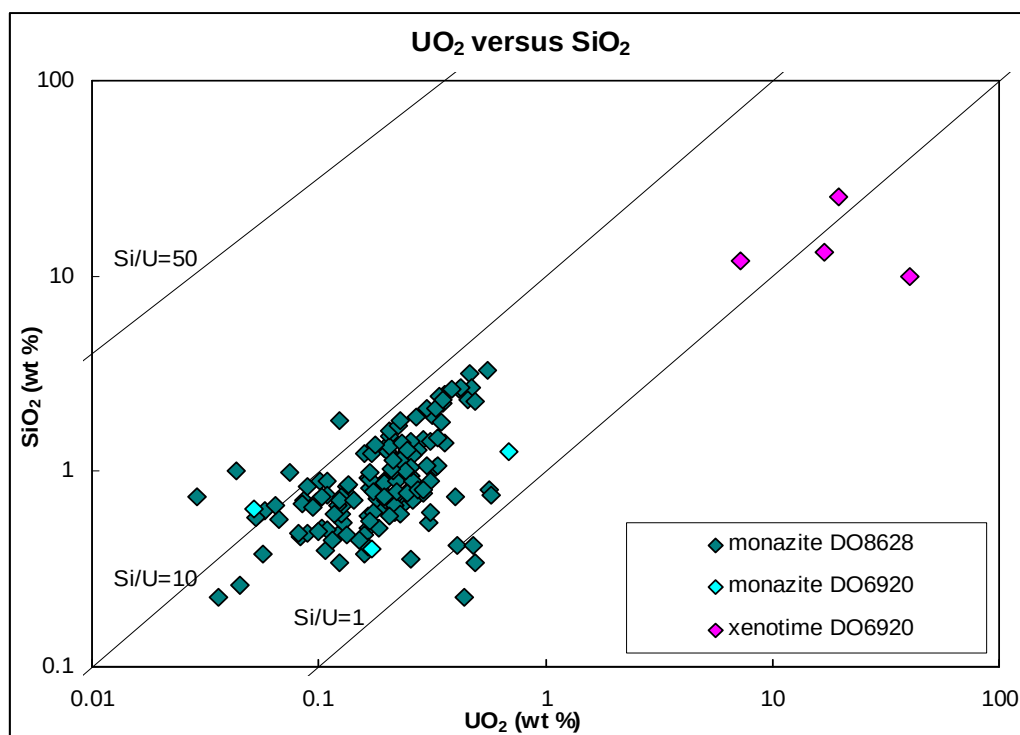


Fig.5-9:
Bivariate plot
of SiO₂ contents
of monazite
and xenotime
versus the
UO₂ contents

Within figure 5-10 the LREE contents of monazites from two sediment samples and xenotimes from one sample are displayed. The average LREE contents of monazite grains do not show any significant scattering. Sample DO 6920 contains more U than sample DO 8628 which might correspond with the decreasing ThO₂ contents displayed in figure 5-8. Xenotime grains contain a lower LREE content, the Ce content reaches values up to 2 wt %.

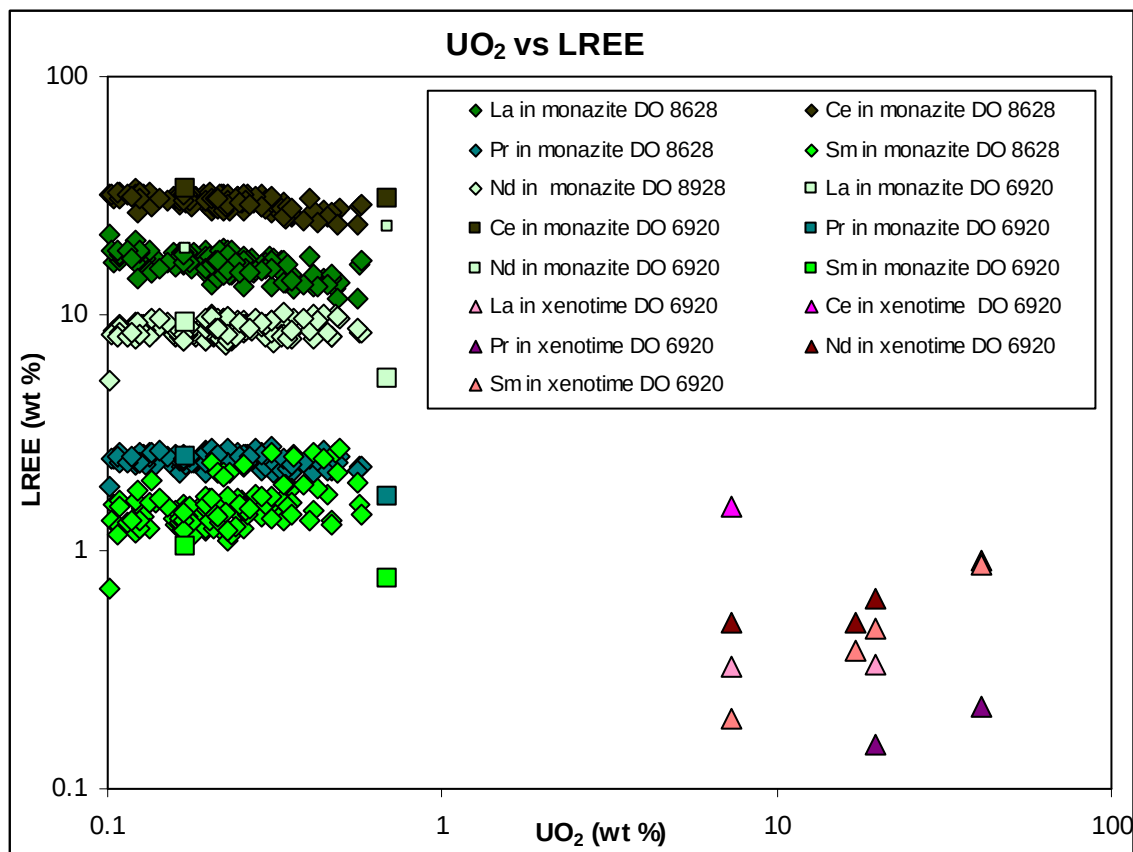


Fig.5-10: Bivariate plot of the LREE contents of monazite and xenotime versus the UO₂ contents

5.2.1.2 Uraninite

Uraninite as the main uranium bearing mineral phase has been analysed using EMPA. A total number of 164 analyses were done on the uraninite crystals. The size of the analysed uraninite grains vary between 50 and 100 µm. In figure 5-11, BSE images of some analysed altered uraninite grains are illustrated. Most of the grains appear heterogeneous because of their different alteration degree.

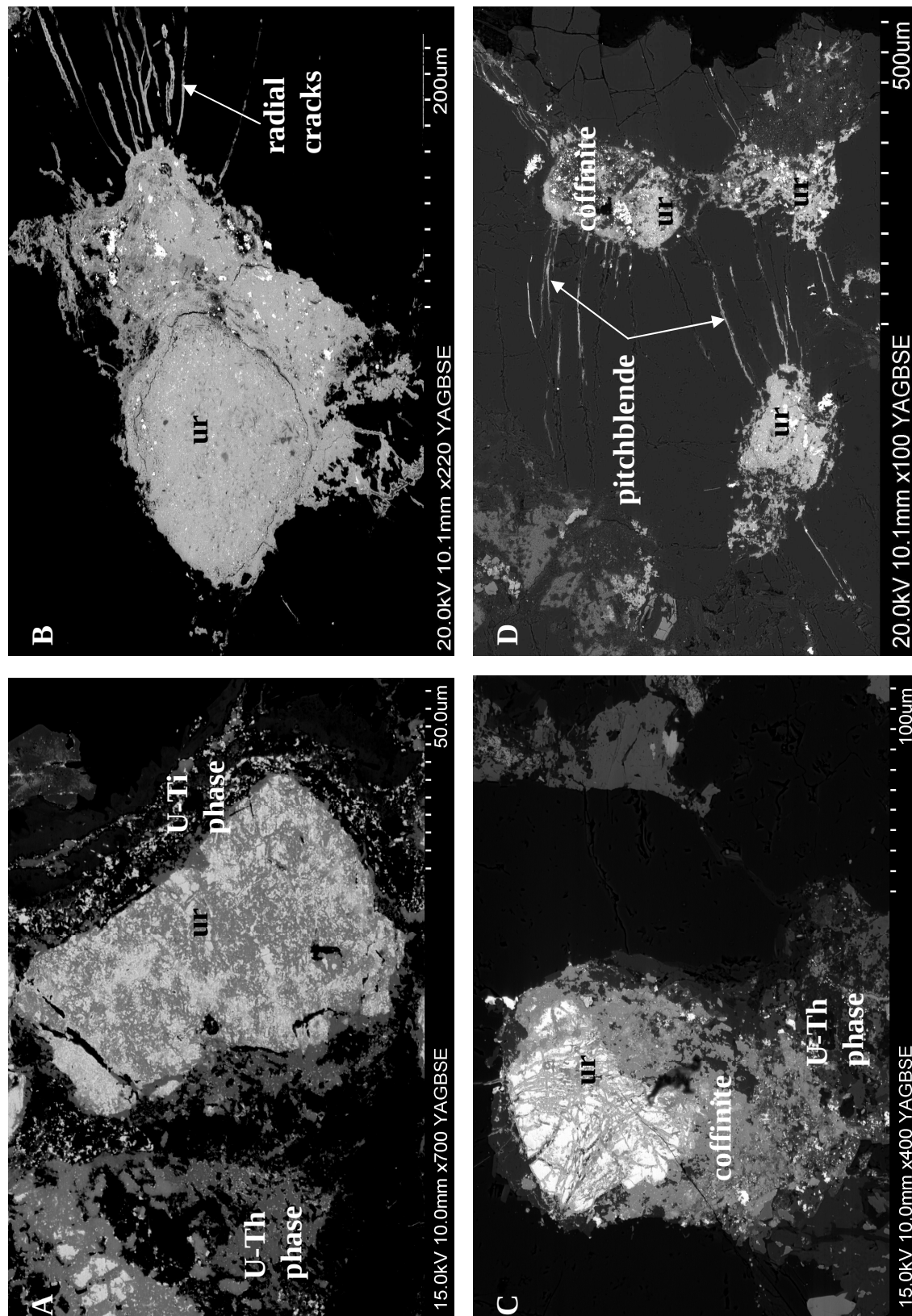


Fig.5-11: BSE images of uraninite grains with their alteration rims in sample AO 5269- D (A), DO 6920 (B), AO5268-D (C), DO 6920 (D)

Uraninite, is always more or less altered and has average UO_2 (66.33 wt %) ThO_2 (5.26 wt %), Y_2O_3 (2.61 wt %), LREE (0.78 wt %), TiO_2 (0.33 wt %), and PbO (10.54 wt %) contents respectively.

The UO_2 values of the grains are plotted against the ThO_2 content in figure 5-12. The analysed uraninites indicate a significant trend which implicates a loss in uranium with an increase in thorium during alteration processes. The assumption can be made that the grains with high uranium content are more preserved than the ones with a lower uranium value. This leads to the result, that some uraninite grains are more altered than others. Notable is the silica increase in altered uraninite analyses (average SiO_2 3.21 wt %) as a result of a coffinitization process during alteration.

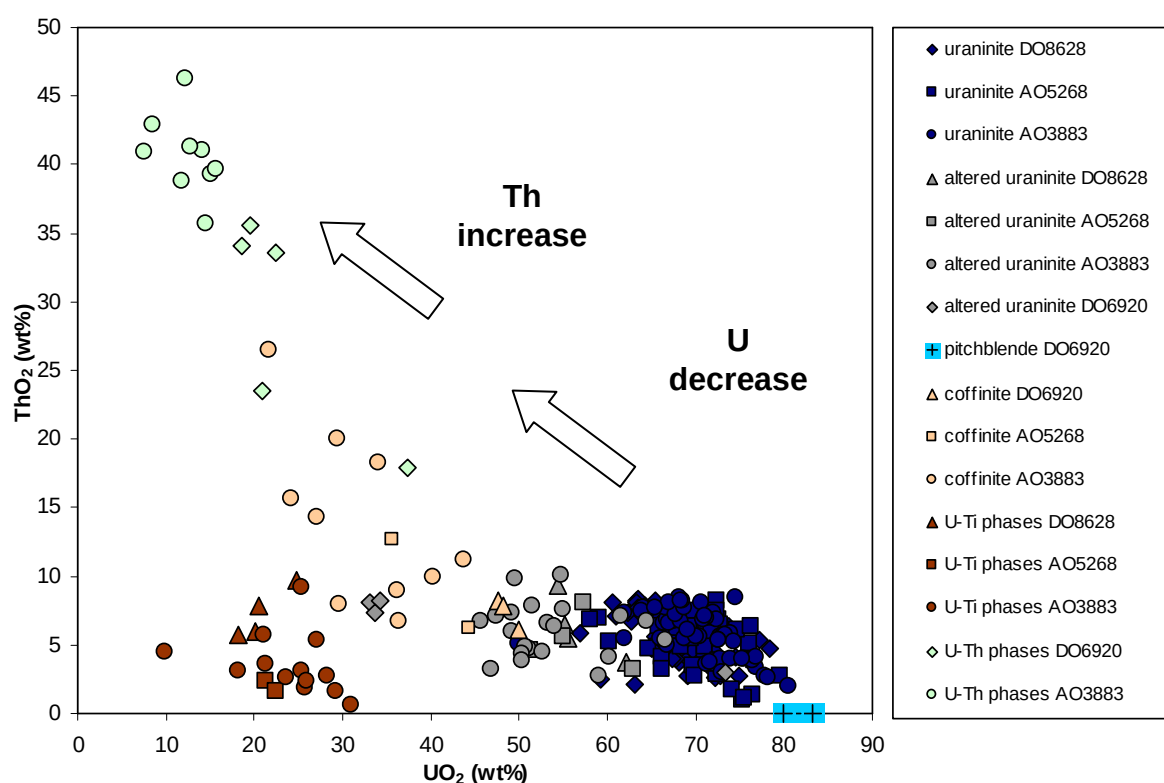


Fig.5-12: Bivariate plot of ThO_2 versus UO_2 of different U-bearing mineral phases from the Dominion Reefs, the name of mineral species and sample reference are respectively quoted in the legend

The more altered uraninites (Fig. 5-15) show enrichment in the PbO (sample AO 5268 up to 29.37 wt %) contents. Pb is generally leached out of the detrital uraninite structure or recrystallised as galena during hydrothermal events. Based on the assumption from the microscopic studies, galena often appears as small specks in more altered uraninites. Electron microprobe studies of detrital uraninites from other Witwatersrand Reefs revealed average lead contents between circa 19-25 wt % (Feather 1981).

The average TiO_2 and the Y_2O_3 concentrations can be seen as typical uraninite values according to Simpson and Bowles (1977). The Ti and Y contents do not vary significantly between detrital uraninites and altered uraninites.

One of the most important conclusions to be drawn from the results of the electron microprobe analyses is a primary detrital origin of the uraninite grains from the Dominion Reefs which show a significant silica enrichment with alteration. Coffinitization is confirmed with the application of EMPA analyses.

5.2.2 Secondary hydrothermal remobilised mineral phases

5.2.2.1 Pitchblende

Only four analyses could be determined as pitchblende. Pitchblende grains were too small to be studied optically. The rare distributed mineral appears around uraninite grains or along fractures. The EMPA analyses confirm the classification as pitchblende with a UO_2 content above 80 wt %, SiO_2 (average of 1.8 wt %), PbO (average of 1.5 wt %) and no ThO_2 content. The extremely high uranium concentration and the lack of thorium implies the secondary formation of the mineral pitchblende after uraninite. The U might have been available within the hydrothermal fluids whereas Th was not.

The low PbO contents as displayed in figure 5-15 leads to a young age of pitchblende when the radioactive decay had not started yet. Compared to other distributed secondary uranium mineral phases, pitchblende shows no enrichment in LREE, SiO_2 and TiO_2 which implies the origin after detrital preserved uraninite. Altered uraninites in contrast contain higher silica, lead and thorium values.

5.2.2.2 Coffinite

The coffinites appear around uraninite grains and have average UO_2 (40.26 wt %), ThO_2 (10.29 wt %), Y_2O_3 (6.63 wt %), SiO_2 (18.43 wt %), TiO_2 (0.82 wt %), and PbO (3.20 wt %) concentrations respectively. The crystals were too small to be studied optically. A few coffinite grains with high silica contents (up to 25 wt %) compared with relative low uranium and increasing thorium values (Fig. 5-12 and 5-13) indicated the presence of coffinite. A negative correlation of UO_2 and SiO_2 can be observed in these grains (Fig. 5-13). The origin of coffinite can be attributed to a different stage of the same hydrothermal process as mentioned under paragraph 5.2.2.1.

The low PbO contents (average 3.2 wt %), as shown in figure 5-15, in contrast to uraninite analyses suggest that uraninite lost Pb during alteration. The coffinite may lose radiogenic Pb

because of migration of Pb from the coffinite structure (Ramdohr 1980) to form radiogenic galena.

The high Y content (up to 8.76 wt %) as displayed in figure 5-16 may be the result of a possible Y enrichment during hydrothermal fluid flow. The coffinite most likely was formed by absorption of silica associated with low temperature hydro-thermalism. Hydrothermal alteration might have contributed to high concentrations of silica. Possibly silica was derived from authigenic silica and became later a constituent of coffinite.

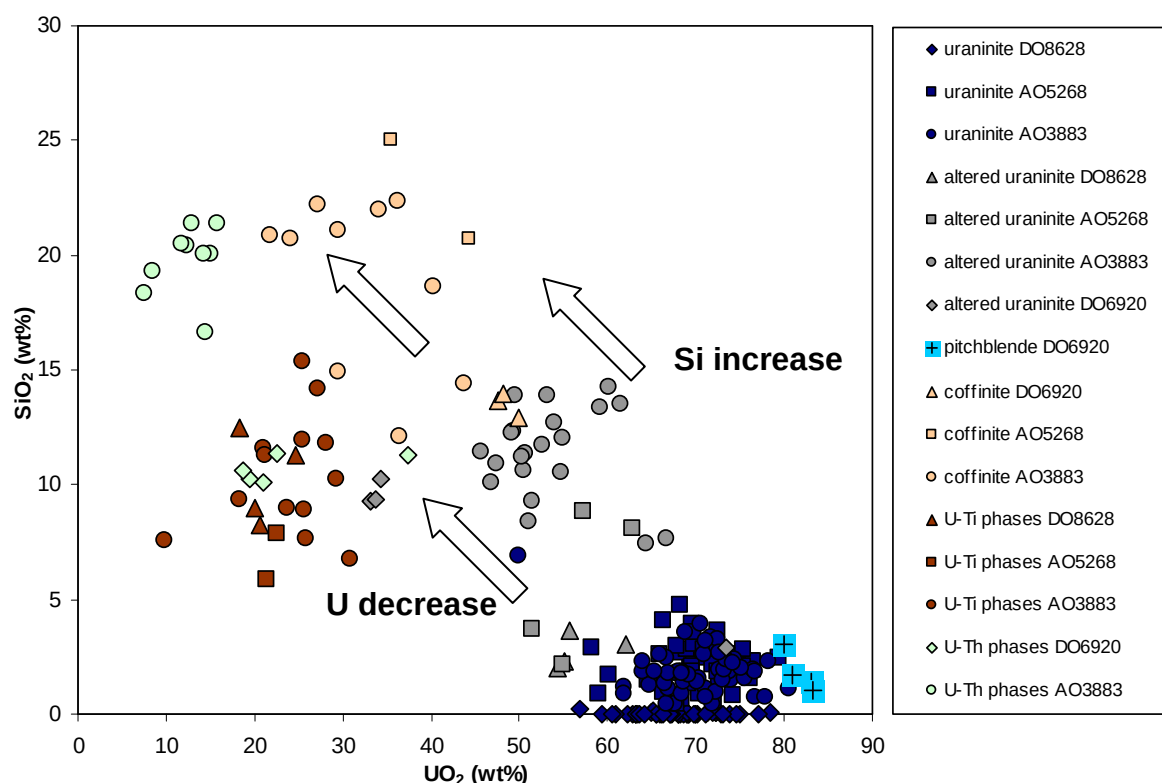


Fig.5-13: Bivariate plot of UO₂ (wt %) versus SiO₂ (wt %) to evaluate the silica distribution and enrichment in the main uranium bearing phases

5.2.2.3 U-Ti phases

Most of the Ti phases within the Dominion Reefs sediments could be determined as anatase originating from the alteration of ilmenite. Only a small part of Ti is used to form Ti-U phases. The U-Ti phases are rarely distributed as small grains around uraninite or in “ghost” minerals. U-Ti phases could be identified and analysed using EMPA.

The U-Ti phases have on average UO₂ (21.69 wt %), ThO₂ (4.53 wt %), Y₂O₃ (5.72 wt %), SiO₂ (8.77 wt %), TiO₂ (22.58 wt %), and PbO (9.46 wt %) concentrations.

The secondary mineral might be formed according to the PRONTO reaction (Ramdohr, 1957: **PRONTO reaction:** $\text{UO}_2 + 2\text{TiO}_2 \rightarrow \text{UTi}_2\text{O}_6$) between ilmenite and uraninite. Ilmenite grains underwent pyritization and the TiO₂ became available for the Pronto reaction with the

primary uraninite associated with hydrothermal action. The increase in the TiO_2 and the decrease in the UO_2 contents (Fig.5- 14) most likely confirm the origin of U-Ti phases from the detrital ilmenite and uraninite. Within figure 5-15, a slight lead loss from detrital uraninite to the U-Ti phases is obvious. The lower concentrations can be explained by possible Pb migration during or after alteration.

High concentrations of silica (Fig.5-13) were found in U-Ti phases. The silica most likely derived from authigenic silica and became a constituent of the U-Ti phases during hydrothermal events. Some samples show increase of Y_2O_3 (Fig.5-16) and can be explained by the availability of Y within the hydrothermal fluids. It seems that during hydrothermal alteration, the Y content of xenotime grains could have been released by hydrothermal fluids and be bonded in some U-Ti phases. In general most of the U-Ti bearing phases contain similar Y concentrations as the uraninites.

Most analyses of the altered U-Ti phases are characterized by low analytical totals (average of 90.15 wt %), resulting from a loss of U and/or Pb and from the hydration of the minerals caused by metamictization and alteration.

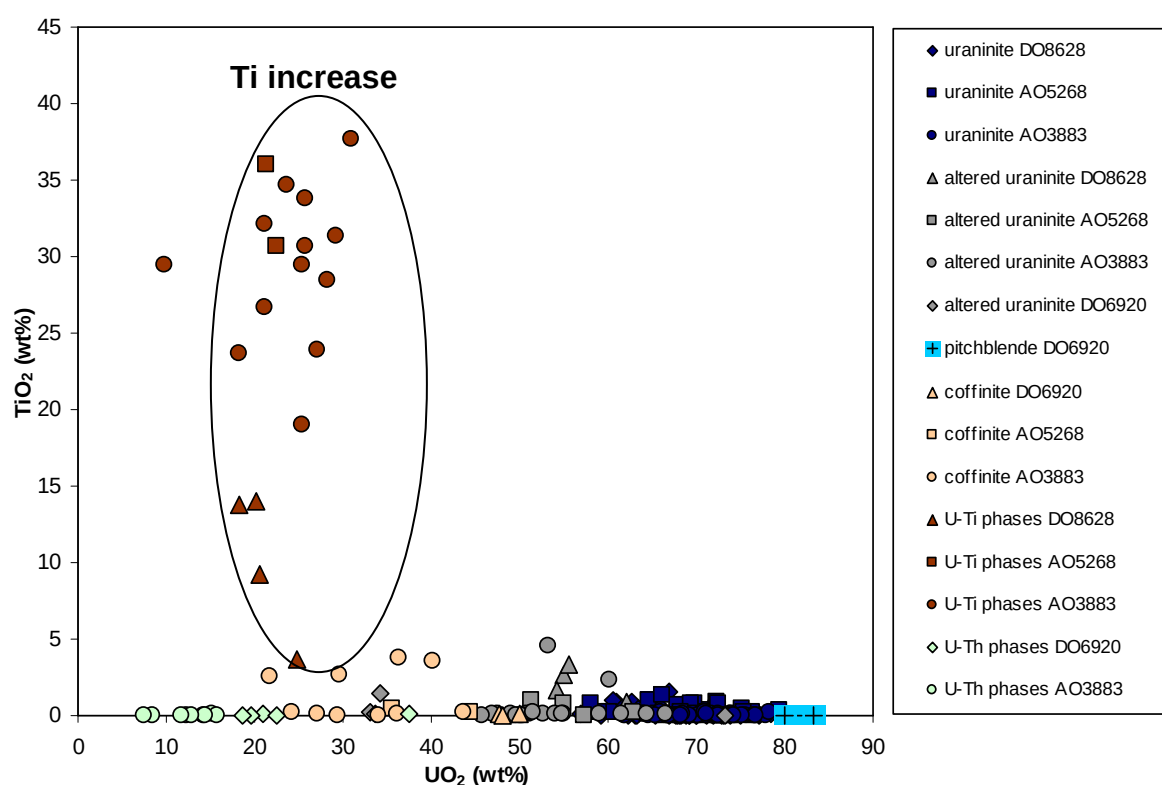


Fig.5-14: Bivariate plot of UO_2 (wt %) versus TiO_2 (wt %) to evaluate the titan distribution and enrichment in the main uranium bearing phases

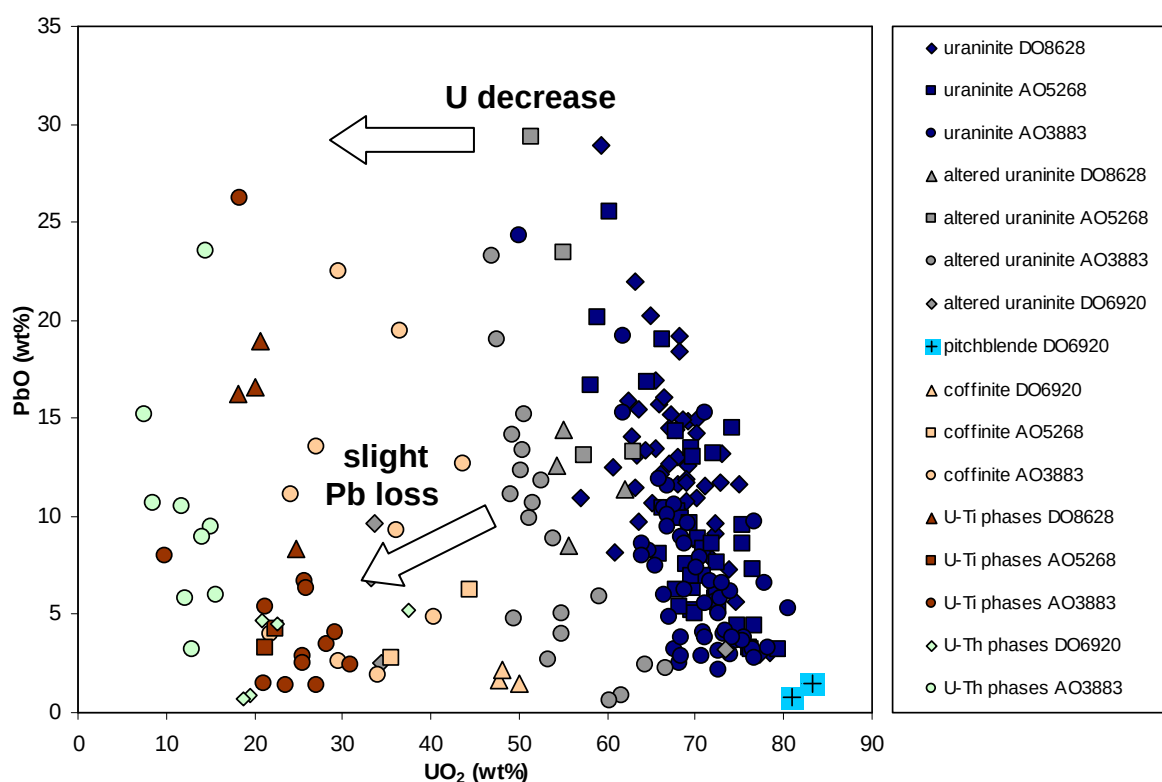


Fig.5-15: Bivariate plot of UO_2 (wt %) versus PbO (wt %) to evaluate the lead distribution and enrichment in the main uranium bearing phases

5.2.2.4 U-Th phases

The U-Th phases of the Dominion Reefs have remarkably high thorium contents. Responsible for this, according to Hiemstra (1968), is the thorium rich mineral uranothorite. The phase appears similar to the uraninite and could optically not be distinguished. For this reason, electron microprobe analyses were carried out to identify rarely distributed U-Th phases.

The rare distributed U-Th phases of the Dominion Reefs appear as patchy intergrowths (“ghosts”). The analysed grains have on average UO_2 (21.91 wt %), ThO_2 (29.89 wt %), Y_2O_3 (7.05 wt %), SiO_2 (12.88 wt %), TiO_2 (0.15 wt %), and PbO (5.30 wt %) concentrations.

The loss of U and the increase in Th (Fig.5-12) can be explained with the alteration of primary uraninite associated with hydrothermal events. Th as less mobile element within solutions originated from primary uraninite, whereas U as more mobile element was leached out during hydrothermal action.

The increase in yttrium as displayed in figure 5-16 can be explained by the possibly high accessibility of yttrium depending on its content in the hydrothermal fluids. Before or during sedimentation, the Y concentration most likely derived from detrital monazites, xenotime, or apatite.

The increase of silica as shown in figure 5-13 most likely originated authigenically during hydrothermal events similar to the U-Ti phases. Interpreting the data proposes that the U-Th phases are from secondary origin similar to the U-Ti phases caused by depletion in U during alteration.

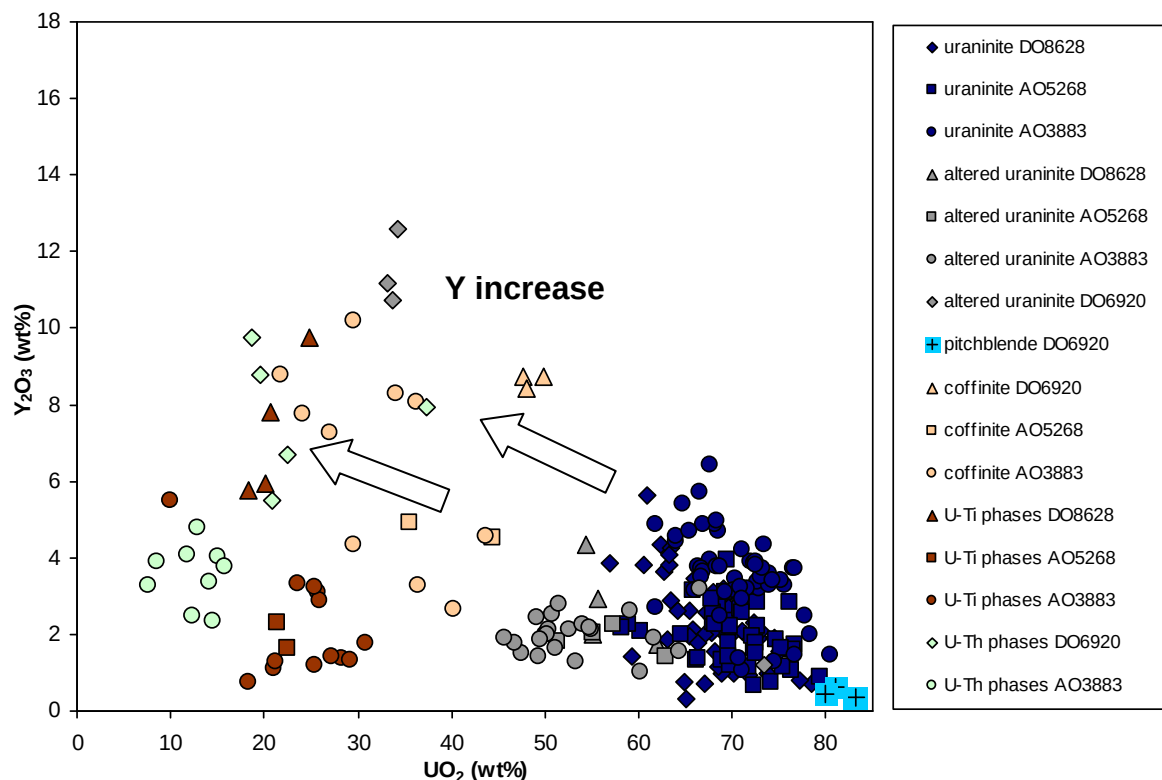


Fig.5-16: Bivariate plot of the Y_2O_3 contents versus the UO_2 contents to evaluate the Y distribution and enrichment in the main uranium bearing phases

5.3 Mineral dating with LA-ICP-MS

Several studies have shown that the U-Pb isotopic system using the LA-ICP-MS gives reliable ages for zircons (Gerdes & Zeh 2006, 2008). For this study different mineral phases such as monazites, rutiles, zircons and U phases within two selected samples DO 8628 and DO 337 from the Dominion Reef sediments were chosen for age determination.

All analyses are listed in table 1 in the Appendix V. The isochron diagrams (Fig. 5-17 to 5-20) display the measured U-Pb isotope ratios for the suite of sampled minerals. Analyses show different MSWD (Mean Squared Weighted Deviates) which means different scatter of the data points. The $MSWD \leq 1$ means that the scatter is lower than the analytical errors. $MSWD > 1$ is interpreted as excess scatter of data points and will be considered as not strictly an isochron. Based on the low number of analyses

Brooks et al. (1972) considered that a cut of 2.5 MSWD is acceptable. The data can be interpreted as isochron diagrams.

Monazites were used for age determination because of their detrital origin within the Dominion Reefs. Representative U-Pb LA-ICP-MS analyses of monazites illustrated in figure 5-17. Concordia ages of 3072 ± 11 Ma and 3065 ± 13 Ma are interpreted as main mineralization age. The upper intercepts with an age of 2983 ± 180 Ma for monazite 2 and 3127 ± 92 Ma as maximum ages fit well in the interpreted mineralization age. The lower intercepts at 2600 ± 770 (monazite 1) Ma and 2567 ± 340 Ma as minimum ages may point to a later remobilisation event most likely related to the formation of the Ventersdorp Supergroup.

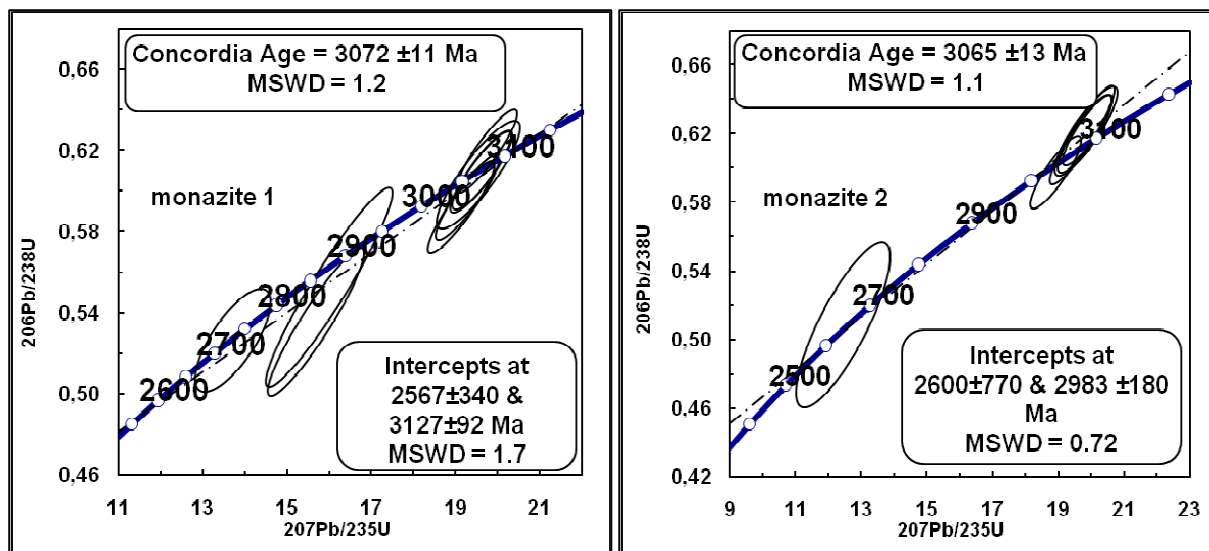


Fig.5-17: U-Pb data for monazite 1 and 2 (data-point error ellipses are 2σ , MSWD = Mean Squared Weighted Deviates)

The analysed zircons generate one significant age as displayed in the isochron diagram in figure 5-18. The intercept points yield isochron ages of $2728 \pm 18/-19$ Ma for zircon 1, 2735 ± 23 Ma for zircon 2 and $2750 \pm 26/-23$ Ma. The detected main zircon age can be attributed to the remobilization age similar to the younger monazite age. Zircon is supposed to be from detrital primary origin. The revealed age, younger than the monazites, suggest a resetting of the isotopic system by thermal fluids.

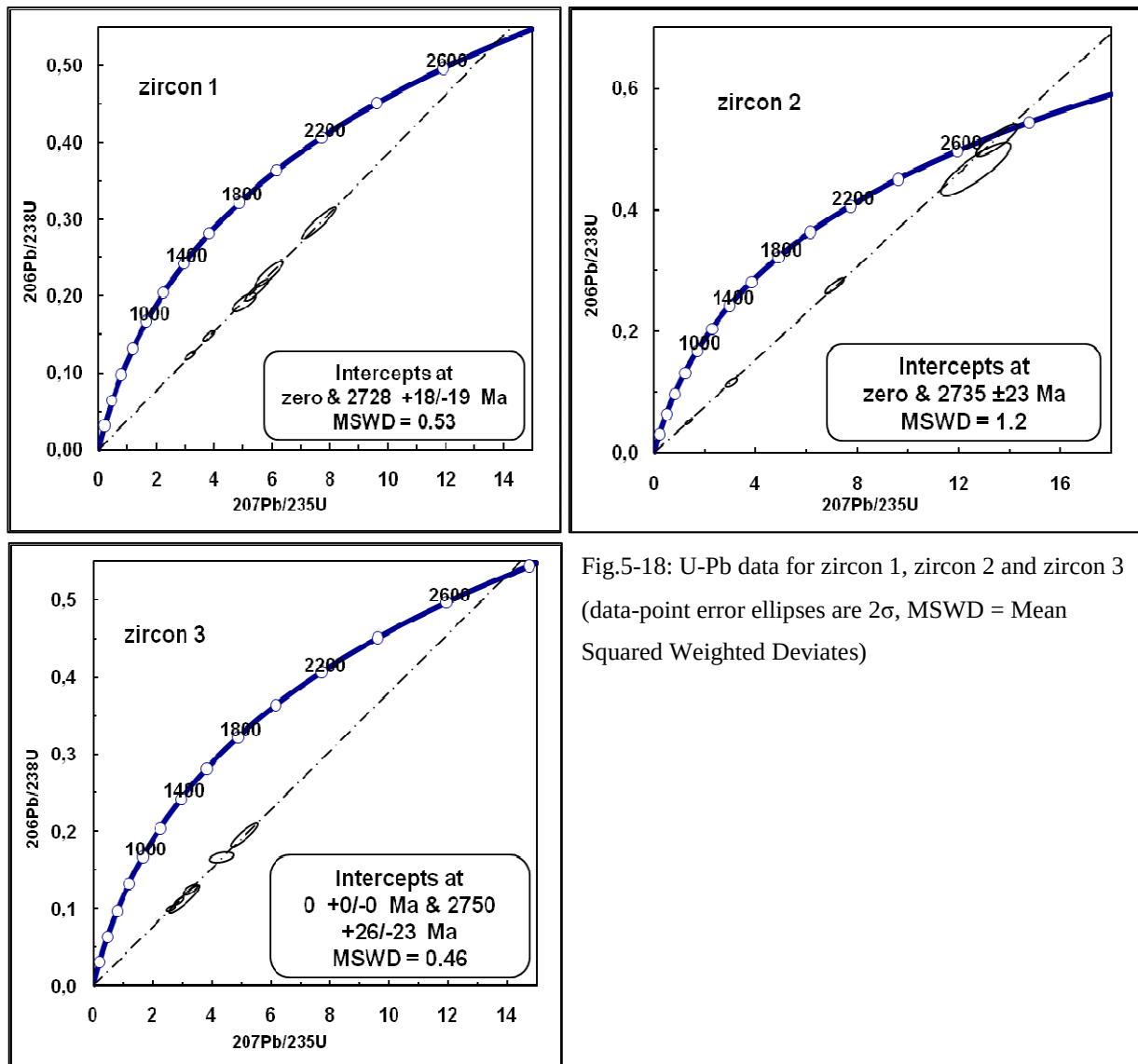


Fig.5-18: U-Pb data for zircon 1, zircon 2 and zircon 3 (data-point error ellipses are 2σ , MSWD = Mean Squared Weighted Deviates)

The $^{206}\text{Pb}/^{238}\text{U}$ ages of rutile grains range from $2797 \pm 78/73$ Ma to $2400 \pm 270/290$ Ma as displayed in figure 5-19. The different isotopic ages reveal that two rutile populations appear within the Dominion Reef sediments.

The older age might be more exact and therefore more probable than the younger. The older age includes an error of approximately $\pm 78/73$ Ma whereas the younger contains a large error $\pm 270/290$ Ma.

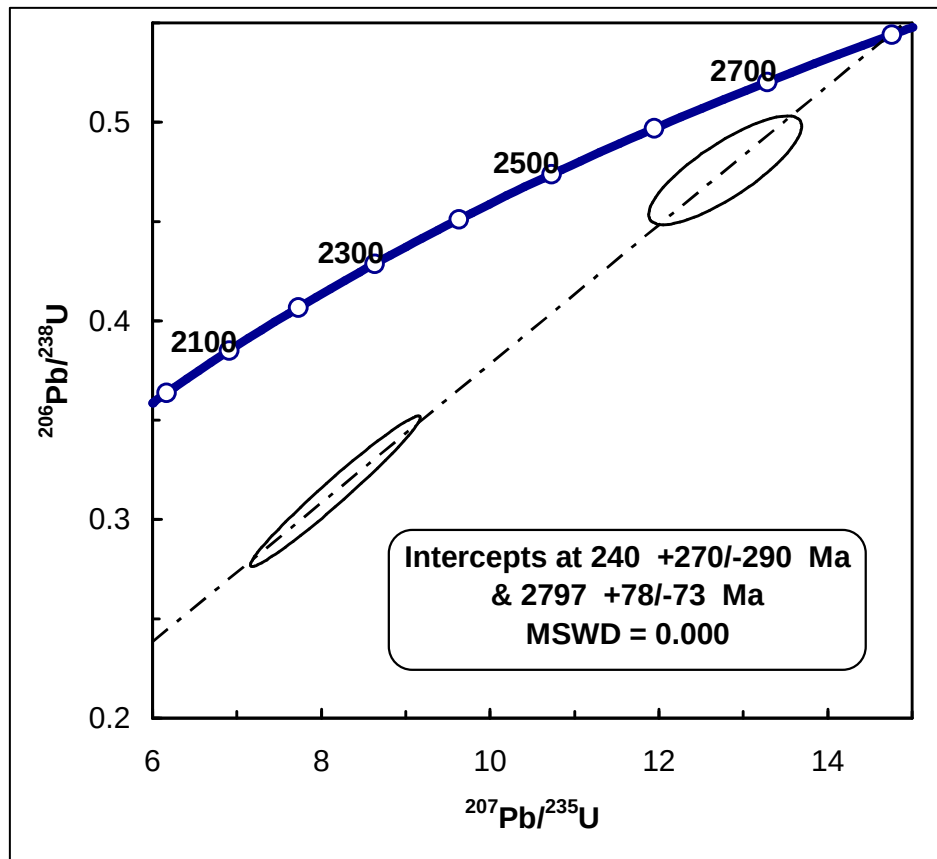


Fig.5-19: U-Pb data for rutiles (data-point error ellipses are 2σ , MSWD = Mean Squared Weighted Deviates)

The uranium bearing phases are secondary formed minerals according to the geochemical and optical study. The host mineral is supposed to be uraninite. The analyses of the uraniferous mineral phases within the samples revealed significant maximum ages 2704 ± 26 Ma and 2704 ± 26 Ma as displayed in figure 5-20. Only one main event is considered likely for the origin of the U bearing phases.

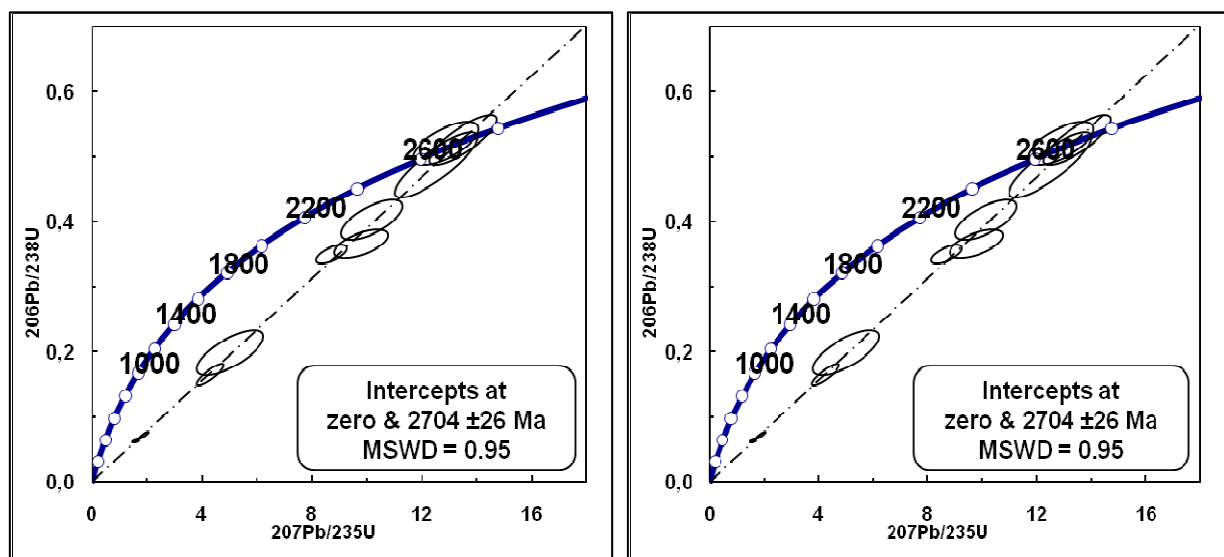


Fig.5-20: U-Pb data for U phases (data-point error ellipses are 2σ , MSWD = Mean Squared Weighted Deviates)

The Pb-Pb whole rock isochron diagram in figure 5-21 is used to identify the main geological processes involved in the Dominion Reef mineral formation. The diagram demonstrates the existence of two prominent age populations for the Dominion Reef sediments. A maximum age of circa 3100 ± 90 Ma and a minimum second age at around 2700 ± 100 Ma can be concluded. Optical and geochemical studies of the Dominion Reef sediments revealed that different generations of minerals are present (e.g. pyrite, uraninite with alteration products). The older age of circa 3100 Ma is interpreted as mineralization age of detrital minerals such as uraninite, pyrite (type I), zircon, chromite, and magnetite. The younger age of 2700 Ma point to a later remobilisation by hydrothermal action affecting the detrital minerals. The analyses confirm the assumption that monazites are definitely from detrital primary origin. Zircon is supposed to be from primary origin as well. The age detremination revealed a younger age which is interpreted as re-crystallisation age. The former isotopic system might be completely reseted by the hydrothermal action. Rutile and the uraniferous phases could be confirmed from secondary origin with an age of circa 2700 Ma.

The MSWD (illustrated in Fig. 5-17 to 5-20) above and below one of the analysed mineral phases is proposed to be relate to the isotopic disequilibrium during recrystallization. Coeherie and Albarede (2001) proposed that, if a geological system has remained closed from the early crystallisation of the mineral phase until the present, the MSWD of one or less will be obtained. If a geological system was affected by a geological event like fluid-mineral interaction with the result of mineral re-crystallisation, the MSWD would significantly increase.

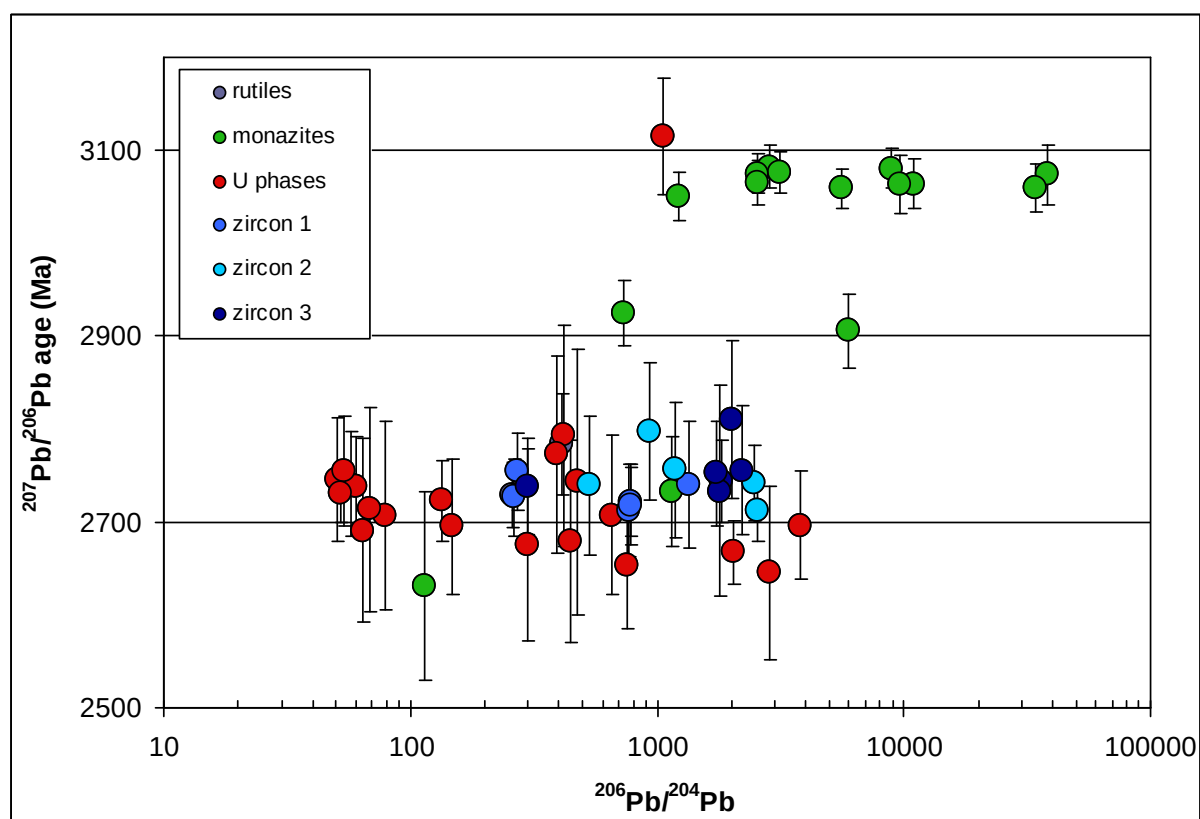


Fig.5-21: Pb-Pb age data summary display two main ages for all analysed mineral phases

5.4 Carbon analyses

Fifteen selected samples were analysed for their carbon content with the Acid method by the Department of Soil, Crop & Climate Sciences at the University of the Free State. The obtained data set is listed in the Appendix II. An average carbon content of 5957 ppm could be determined. The carbon concentration is low within the Dominion Reefs (Hallbauer 1975) compared to other Reefs within the Witwatersrand basin. Uranium and gold in association with carbonaceous matter is one of the most important modes of occurrence of these minerals in other well-studied Reefs like the Carbon Leader (Davidson and Bowie 1951).

Within the Dominion samples, carbon could be noticed with SEM quantitative studies as rim around zircon grains and finely dispersed. No single carbonaceous mineral phase could be identified within the samples. Moreover, the well known occurrence of carbonaceous matter with uraninite does not exist within the Dominion Reefs, as concluded from this study.

5.5 Summary of the mineral geochemistry

The SEM/EDX analyses were carried out to determine the semi-quantitative elemental composition of the minerals to obtain an overview of the element distribution within the thin

sections. An additional purpose of the semi-quantitative analyses was to identify and locate the main uranium bearing phases for the electron microprobe studies.

EMPA analyses were used to determine different uranium bearing mineral phases within the Dominion Reefs. Detrital monazite analyses possesses moderate UO_2 (average of 0.22 wt %), ThO_2 (average of 4.91 wt %), LREE (La_2O_3 average 16.54 wt %, Ce_2O_3 average 30.03 wt %, Pr_2O_3 average 2.42 wt %, Nd_2O_3 average 8.56 wt %, SmO average 1.53 wt %), and Y_2O_3 (average of 1.27 wt %) contents. Analyses of monazites revealed that two generations are present. The first group, occurred with moderate UO_2 , ThO_2 and LREE contents comparable to literature data (Mathieu et al. 2001). The second group of monazites showed slight increasing U and Th values. Both groups are of detrital origin while the second group is affected by hydrothermal action.

Xenotime of detrital, diagenetic and hydrothermal origin are known from placer deposits in Western Australia (van Emden et al. 1997). Detrital xenotime (as main Y bearing mineral phase) within the Dominion Reefs has been identified and characterized. The mineral phase contains variable contents of SiO_2 , P_2O_5 , TiO_2 , LREE, ThO_2 and UO_2 . The Th and U contents vary in concentration, with U always enriched relative to Th. The main mechanism for the Y and REE replacement by U and Th are charge-balancing substitutions with Si (**Substitution: (REE, Y) + P^{5+} $\leftrightarrow$ (Th, U) $^{4+}$ + Si^{4+}** , van Emden et al. 1997). In contrast hydrothermal xenotime have lower U and Th values than detrital xenotime (Kositcin et al. 2003). For distinctive geochemical signatures of xenotime and monazite within the Dominion Reefs further research should extend this study.

The analysed uraninite grains showed medium uranium and thorium concentrations. Several variation diagrams (Fig.5-12 to 5-16) display two groups of uraninites within the Dominion Reefs. It can be assumed that the first group with high UO_2 contents are well preserved. The second group with lower UO_2 contents appear in a more altered stage. The higher silica concentrations in altered uraninites confirm slight coffinization. The extensive research of the uraninites led to the result that the grains, containing the bulk of uranium, are from detrital origin whereas one group was affected by alteration. Analyses of more altered uraninites revealed that mineral phases with a significant higher silica content can be determined as coffinite.

A few analyses of mineral phases with the highest uranium and no thorium contents emphasized the occurrence of pitchblende within the Reefs. The analyses revealed that the origin as secondary uranium bearing mineral phase occurred from uraninite alteration. The hydrothermal fluids affecting detrital uraninite did not introduce any new uranium.

Analysed U-Ti phases show enrichment in TiO_2 . The phases most likely originated from a reaction of detrital uraninite with primary Ti-bearing mineral phases such as ilmenite during hydrothermal events. Lower UO_2 contents in contrast to the uraninite analyses emphasized a uranium loss. High silica concentrations most likely derived from authigenic silica and became a constituent of the U-Ti phases during hydrothermal events. Some samples show an increase of Y_2O_3 which can be explained by Y availability within the hydrothermal fluids affecting the Dominion Reefs. During hydrothermal alteration, Y of detrital minerals (e.g. monazite) could have been released by hydrothermal fluids and bonded in some U-Ti phases. In general most of the U-Ti bearing phases contain comparable Y concentrations similar to uraninites.

Most analyses of the altered U-Ti phases are characterized by low analytical totals (average of 90.15 wt %), resulting from a loss of U and/or Pb and from the hydration of the minerals caused by metamictization and alteration.

The U-Th phases within the Dominion Reefs have high thorium concentrations. The significant loss of U and the increase in Th can be explained by the alteration process of primary uraninite associated with hydro-thermalism. Secondary uranium bearing mineral phases suggest that different hydrothermal fluids during one event affected the Reefs. The different element compositions within the phases probably originated from different solutions or from different stages of the same process.

The LA-ICP-MS analyses revealed two ages for the mineral formation. The older age of 3100 ± 90 Ma is interpreted as main sedimentary mineralization age. Before 2700 ± 100 Ma the Dominion Reefs very likely became affected by hydrothermal fluids, which yields to the formation of the secondary mineral phases. The younger age corresponds with Ventersdorp Supergroup deposition (determined by U-Pb zircon age) between 2850 - 2650 Ma (Crow and Condie 1988).

Chapter Six: Discussion and Conclusion

The presented study dealt with the Dominion Group sedimentary successions of Archean age which is underlying the Witwatersrand Supergroup. Mineralogical and geochemical studies on 78 conglomerate samples were carried out to characterize metallogenesis, and hydrothermal alteration. In this chapter the results of the extensive research are summarized, discussed and compared.

6.1 Discussion

6.1.1 Petrography study on the Dominion Reef samples

The petrography studies revealed that Lower and Upper Reef samples are similar. The investigation emphasized small scale variations in size and shape of the quartz pebbles. The pebble sizes range between 0.5-2.5 cm with shapes from angular to well rounded. The majority of the quartz pebbles can be described as rounded to well rounded pebbles with an average size of 1.5 cm. The main conglomerate components are quartz, sericite and chlorite as matrix. The ore minerals are finely disseminated within the matrix and are mostly not visible to the naked eye.

The main minerals were determined by point counting on 32 selected thin sections. This method was very low in precision because only the ten main minerals present in the conglomerates could be determined. Information about the minor constitutions in the rocks could not be revealed by this method. Pyrite followed by galena and sphalerite as the main sulphide minerals could be detected with certainty.

Petrographic studies revealed different generations of identified mineral phases as displayed in table 6-1. Pyrite of detrital and hydrothermal origin could be optically identified. Monazite, columbite, cassiterite, chromite, magnetite and arsenopyrite are of detrital origin. Zircon and garnet (detrital origin) are noticed as main accessory minerals. Both minerals were partially replaced by phyllosilicates at a later stage. Galena as secondary formed mineral was observed as small specks within other sulphide minerals. Other secondary formed sulphide minerals are sphalerite, chalcopyrite and pyrrhotite.

Microscopic observations revealed different generations of uranium bearing mineral phases within the conglomerate samples. Uraninite grains, which are well distributed, appear as well rounded grains and more or less altered. The minerals often are traversed by cracks and other mineral phases such as galena and patchy “ghost” minerals. Based on petrographic studies uraninite can be considered to be exclusively from primary origin.

Some mineral phases occur around uraninite crystals or in “ghost” minerals in cloudy patchy masses. Different generations of uranium bearing mineral phases can be considered because they traverse and form rims around the uraninite grains. In proximity to uraninite crystals and based on optical appearance secondary uranium bearing minerals such as coffinite, U-Ti-, and U-Th mineral phases were identified.

The proved appearance of primary and secondary formed mineral phases suggested a multistage for the mineralisation of the Dominion Reefs. The primary stage involved with the deposition of detrital uraninite, pyrite (type I and II), monazite, columbite, zircon, cassiterite, chromite, magnetite and arsenopyrite. The Dominion Reefs mineral assemblage have been affected by hydrothermal alteration (as secondary mineralisation) that implicated hydrothermally induced authigenic growth of numerous minerals e.g. secondary uranium bearing minerals (U-Ti phase, U-Th phase, coffinite, leucoxene), pyrite (type III), galena, sphalerite, chalcopyrite and pyrrhotite.

Table 6-1: Mineral appearances within the Dominion Reefs in different stages proved by petrographic study

Mineral	primary mineralization	secondary mineralization
Uraninite	X	
U-Ti phase		X
U-Th phase		X
Coffinite		X
Rutile		X
Ilmenite	X	
Anatase		X
Leucoxene		X
Monazite	X	
Columbite	X	
Zircon	X	
Cassiterite	X	
Chromite	X	
Magnetite	X	
Pyrite	X (type I and II)	X
Galena		X
Arsenopyrite	X	
Sphalerite		X
Chalcopyrite		X
Pyrrhotite		X
Garnet	X	
Quartz	X	X
Gold (Feather and Koen 1975)	X	X

The relatively rare occurrence of gold within the Dominion Reefs compared to other Witwatersrand Reefs was observed during this study and is supported by the Dominion Reefs

Mine. Gold mineralisation has not been a primary topic within this research project. The geochemical behaviour of other Au-bearing Reefs within the Witwatersrand Basin is discussed by numerous authors such as Minter (1999) and Frimmel (2005).

6.1.2 Whole rock geochemistry study on the Dominion Reef samples

Major element data provide information about changes in the Dominion Reef sediments caused by sedimentation processes and weathering. The major element geochemistry within the diagram of Herron (1988) suggests that the Dominion Reef samples have to be classified, as sublitharenite, litharenite and Fe-sand. The sediments contain quartz as a main component, reflected by the high $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios, and numerous relatively chemically stable minerals mirrored by the high $\text{Fe}_2\text{O}_3/\text{K}_2\text{O}$ ratios.

These facts confirm the assumption of a moderate weathering degree after deposition. The chemical index of alteration was calculated for all samples. The average CIA of 78 is compatible to a moderate weathering degree. Major elements plotted in a adequate ternary plot (Fig.4-3) revealed that a “normal” weathering trend towards $\text{Al}-(\text{Na}+\text{K})$ could not be detected. A obvious influence of Mg and Fe indicating post-depositional mineral transformation of plagioclase to chlorite and quartz plays a significant role in the sediment alteration. Chloritization reflects depletion in K and enrichment in Fe. As a result, the post-deposition mineral transformations can be determined as most important processes for the small-scale variation in the CIA.

To evaluate the tectonic setting, a discrimination diagram after Bhatia (1983) for the major elements was used. For accumulation of the Dominion Group a continental rift can be proposed as tectonic setting. The chemical data suggests a passive margin as tectonic setting most probably belonging to the deposition of the West Rand Group (Kositcin and Krapez 2004). The dilution of all elements by SiO_2 , together with zircon enrichment and sedimentary recycling makes many classic provenance diagrams (Bhatia 1983, Roser and Korsch 1986) ineffective.

Major and trace element data provide information about the source area composition. Major elements revealed intermediate rock material as possible source rocks. Trace and rare earth elements proved to be of higher importance as provenance indicator based on the assumption that many trace elements are immobile during sedimentary processes (Cullers et al. 1988). The Nakamura (1974) chondrite normalized REEs were comparable to the normalized values of the Upper Continental Crust. As result the source rocks of the Dominion Reef conglomerates can be assumed to be of Upper Continental Crust origin. The very low Eu/Eu^*

ratios and the high Th/Sc ratios indicated felsic material as source rocks. The hafnium and zirconium enrichment as displayed in plot 4-8 indicate that sedimentary recycling was a main controlling factor. Most of the Witwatersrand Reefs investigators claimed Archean granitic or pegmatitic rocks as source rocks (Frimmel 2005).

Major and trace elements were also used to determine relationships and association of distributed minerals within the Dominion Reefs. The Pearson correlation coefficient was used as a statistical parameter. The statistical investigation indicated geochemical relationships between pairs of elements in the Dominion Reefs. The controlling factors in these relationships are sedimentary and post-burial hydrothermal processes. Elements hosted in detrital minerals showed a high degree of correlation. Elements hosted in hydrothermal- or hydrothermally reworked minerals also reveal significant correlations. The correlation between elements of detrital minerals and elements hosted in hydrothermal -or hydrothermally redistributed minerals was not considerable. As result, two distinct generations of mineral phases could be proved.

As the main target of this investigation the Th and U whole rock analyses were considered in detail. Whole rock analyses indicate varying Th/U ratios, the existence of detrital primary uraninite and secondary uranium bearing mineral phases within the Dominion Reef sediments. The increase of the Th/U ratio characterizes a decrease in U. The uraniferous minerals which contain most of the U and Th, correspond with the lowest Th/U ratio. The decrease in U and Th in sedimentary rocks might be explained by the separation of U from repeated cycles of weathering and re-sedimentation (McLennan and Taylor 1979).

6.1.3 Mineral chemistry study on the Dominion Reef samples

SEM analyses on the Dominion Reef samples were carried out to determine the quantitative elemental composition of the minerals contained and information of the element distribution. The main uranium bearing mineral phases were the main target of EMPA analyses.

EMPA analyses of monazites indicated distinct groups. The first well preserved group, showed moderate UO_2 , ThO_2 and LREE contents comparable to literature data (Mathieu et al. 2001). The other group could be considered as altered domains containing variable contents of ThO_2 and UO_2 contents. The enrichment in U and the decrease in Th might be related to hydrothermal action affecting the Dominion Reefs. U is more mobile than Th and might have been in solution during fluid flow. Uranium probably derived from detrital uraninite while hydrothermal alteration.

Another REE phosphate mineral named xenotime could be identified and characterized. The mineral phase shows similar geochemical behaviour as monazite. Both detrital minerals did not break down during hydrothermal action. A certain degree of leaching or enrichment in LREE, SiO₂, P₂O₅ and TiO₂ could not be detected with the help of the wavelength-dispersive EMPA.

EMPA studies support the existence of at least two generations of uraniferous phases. Primary more or less altered detrital uraninites could be determined according to their variable U/Th ratios. All identified uraninite is of detrital origin. The study shows that uraninite alteration did occur, evidenced by the U and Th leaching in secondary uranium-bearing phases (e.g. coffinite, U-Ti phases). Increasing Si-content of the secondary uraniferous mineral phases during alteration, characterize coffinitization of detrital uraninite. Coffinite, U-Ti and U-Th phases were formed in which U seemed to have been leached out. Hydrothermal fluids can be assumed as main cause for leaching processes. Hydrothermal fluids probably contained a notable amount of U, Ti and Si (leaching products of detrital minerals) which were trapped in secondary uraniferous mineral phases (coffinite, U-Ti phases, U-Th phases).

The fact that no Th is present in the pitchblende, is the result of no Th availability within solution during formation. Strong enrichment in U implies a possibly high oxidation potential and therefore availability of U (leaching of uraninite) in the hydrothermal fluids.

The LA-ICP-MS analyses revealed a distinct age of 3100 ± 90 Ma for the primary mineralisation. The initial stage involved the placer development with deposition of uraninite and other detrital minerals. Whereas the younger age of 2700 ± 100 Ma point to a later remobilisation by hydrothermal action. In this stage hydrothermally growth of mineral phases including secondary U bearing phases, galena and other minerals occurred. It is suggested that the younger event occurred during the Ventersdorp extension.

6.1.4 Genetic model for the Dominion Reef sediments

The modified placer model explains most obtained data and observations. Within the following paragraph the model for the deposition history of the mineralized Dominion sediments is explained according to the results of the geochemical and mineralogical investigation.

The deposition of the Dominion Reefs clastic sediments started off in the Dominion rift basin before 3074 Ma (Armstrong et al. 1991). Detrital minerals were derived from remote provenance areas (greenstones and granites; Robb et al. 1990a). According to the major and trace element analyses felsic source rock material can be expected. The surrounding Archean

greenstone terrains within the Kapvaal Craton contain both mafic and ultramafic rocks, siliceous chemical sedimentary rocks and felsic volcanic rocks. A comparable terrain is assumed to be source area.

The heavy detrital minerals from the greenstone terrains were mechanically carried into the basin by fluvial transport and concentrated according to their transport velocities. The low gold content within the Dominion Reefs could be a product of sorting mechanisms.

After deposition, multiple tectono-thermal events affected the Kaapvaal Craton (Frimmel and Minter 2002). The Dominion sediments are marked by recrystallisation and the formation of metamorphic mineral assemblages. Mineralogical and geochemical studies have been carried out to distinguish between several stages of post-depositional alteration. The fluid flows which interacted with the rocks were partially accompanied by leaching after the sediment deposition. Similar processes occurred in the Paraná Basin of Brazil (França et al. 2003). The fluid flow happened at a time when tectonic events affected the Witwatersrand basin. During the Kliprivierberg Group (2714 Ma) deposition, thrusting along the basin margins caused uplift and a steep hydraulic gradient causing a hydrothermal fluid flow towards the basin. For the main fluid flow within the Dominion Reefs, the Ventersdorp extension definitely corresponds with the dating of the hydrothermal redistributed Reef minerals (Armstrong et al. 1995, Robb et al. 1990a).

None of the younger hydrothermal actions, which affected several Witwatersrand Reefs, (Frimmel and Minter 2002) are of importance for the post depositional alteration of the Dominion Reefs.

6.2 Conclusions

The Dominion Reefs in South Africa, an important uranium province, hold information for the understanding of the genesis of the mineralized quartz pebble conglomerates. The geochemical and mineralogical characteristics of the conglomerates and the U-bearing minerals revealed the following conclusions:

- I** Distributed well rounded minerals/rock fragments/metal aggregates within the Dominion Reefs are definitely of primary detrital origin.
- II** Some minerals appear in different generations influenced by hydrothermal events. Pyrite appears in three generations. Primary uraninite accompanied by secondary formed minerals such as coffinite, U-Ti phases, U-Th phases could be determined.

- III** Elements hosted in detrital minerals show high degree of correlation.
- VI** Co and Ni, present in cobaltite, show high correlation with elements present in detrital minerals and can be assumed to be of similar origin. The abundant authigenic gersdorffite within other Witwatersrand Reefs does not occur.
- V** Elements present in hydrothermal or hydrothermally redistributed minerals show high degree of correlation.
- VI** Tectonic setting for the Dominion Reef sediments in a continental rift and passive margin setting is proposed.
- VII** It is considered that surrounding Archean greenstone terrains most likely provided felsic source rocks.
- VIII** Whole rock geochemistry indicates mineral transformations as main weathering process with a moderate chemical alteration index.
- IX** Monazites (detrital origin) could be detected in two groups. The second group is enriched in U and depleted in Th.
- X** Xenotime (detrital origin) as main Y bearing mineral could be identified and characterized.
- XI** Uraninite could be detected as main uranium bearing mineral and appear more or less altered with differences in the U and Si contents. Uraninite is of detrital origin.
- XII** Less abundant secondary mineral phases such as U-Ti, U-Th phases, coffinite and pitchblende were formed by U redistribution associated with hydrothermal processes.
- XIII** LA-ICP-MS analyses revealed a age of 3100 ± 90 Ma for the primary mineralisation and a younger age of 2700 ± 100 Ma (Ventersdorp extension) for the remobilisation by hydrothermal action.

XIV The hypothesis of the modified placer theory can be supported as genesis model.

6.3 Suggestions for further investigation

1. Fluid-inclusions studies would reveal information about the composition of the infiltrating solutions. Minerals with a hydrothermal origin could be determined. The corresponding pH and Eh would reflect the conditions under which the minerals within the Reefs were influenced. Even temperature estimation for the fluids which affected the minerals can be determined.
2. For a better understanding of the gold distribution within the Dominion Reefs, several analyses should be done. The correlation of Au and other elements hosted in the Reefs minerals would reveal distinct information of the genesis.
3. More monazite and xenotime EMPA analyses would disclose more information about possible hydrothermal influence. The geochemical change during alteration could be better understood.

References

- Armstrong, R.A., Compston, W., Retief, E.A., Williams, I.S., Welke, H.J.,** 1991. Zircon ion microprobe studies bearing on the age and evolution of the Witwatersrand Triad. *Precambrian Res.*, 53, 243–266.
- Armstrong, R.A., Fanning, C.M., Eldridge, C.S., Frimmel, H.E.,** 1995. Geochronological and isotopic constraints on provenance and post-depositional alteration of the Witwatersrand Supergroup. In: Barton, J.M.J., Copperthwaite, Y.E., (Eds.), *Centennial Geocongress (1995)*. Geological Society of South Africa, 1-1086.
- Barnicoat, A.C., Henderson, I.H.C., Knipe, R.J., Yardley, B.W.D., Napier, R.W., Fox, N.P.C., Kenyon, A.K., Muntingh, D.J., Strydom, D., Winkler, K.S., Lawrence, S.R., Cornford, C.,** 1997. Hydrothermal gold mineralization in the Witwatersrand basin. *Nature*, 386, 820-824.
- Barton, E.S., Compston, W., Williams, I.S., Bristow, J., Hallbauer, D.K., Smith, C.S.,** 1989. Provenance ages for the Witwatersrand Supergroup: constraints from the ion microprobe U-Pb ages of detrital zircons. *Econ. Geol.* 84, 2012-2019.
- Bhatia, M.R.,** 1983. Plate tectonics and geochemical composition of Sandstones. *J. of Geol.*, 91, 611-627.
- Bhatia, M.R., Crook, A.W.,** 1986. Trace element characteristics of graywackes and tectonic setting discrimination of sedimentary basins. *Contrib. Mineral. Petrol.*, 92, 181-193.
- Bjørlykke, K.,** 1989. *Sedimentology and Petroleum geology*. Springer-Verlag, Berlin, 1-363.
- Brooks, C., Hart, S.R., Wendt, T.,** 1972. Realistic use of two-error regression treatments as applied to rubidium-strontium data. *Rev. Geophys. Space Phys.*, 10, 551-577.
- Button, A., Tyler, N.,** 1981. The character and economic significance of Precambrian paleoweathering and erosion surfaces in southern Africa. *Econ. Geol.* 75th Ann. Vol., 686-709.

Cocherie, A., Albarede, F., 2001. An improved U-Th-Pb age calculation for electron microprobe dating of monazite. *Geoch. et Acta*, 65, 4509-4522.

Cox, K.G., Clifford, P., 1982 a. Correlation coefficient patterns in volcanic suites. *J. of the Geol. Soc., London*, 139, 658.

Cox, K.G., Clifford, P., 1982 b. Correlation coefficient patterns and their interpretation in three basaltic suites. *Contributions to Mineralogy and Petrology*, 79, 268–278.

Crow, C., Condie, K.C., 1988. Geochemistry and origin of late Archean volcanics from the Ventersdorp Supergroup. South Africa. *Precamb. Res.*, 42, 19-37.

Cullers, R.L., Basu, A., Suttner, L., 1988. Geochemical signature of provenance in sand-size material in soils and stream sediments near the Tobacco Root batholith, Montana, USA. *Chem. Geol.*, 70, 335-348.

Cuney, M., Friedrich, M., 1987. Physicochemical and crystal-chemical controls on accessory mineral paragenesis in granitoids. Implications on uranium metallogenesis., *Bull. Minéral.*, 110, 235-247.

Davidson, C.F., 1957. On the occurrence of uranium in ancient conglomerates. *Econ. Geol.*, 52, 668-693.

Davidson, C.F., 1965. The mode and origin of banket orebodies. *Institute of Mining and Metallurgy, London, Transcripts*, 74, 319-338.

Davidson, C.F., Bowie, S.H.U., 1951. On tucholite and related hydrocarbon-uraninite complexes. *Bull. Geol. Surv., G.B.* 3, 1-18.

De Wit, M.J., De Ronde, C.E.J., Tredoux, M., Roering, C., Hart, R.J., Armstrong, R.A., Green, R.W.E., Peperdry, E., 1992. Formation of an Archean continent. *Nature*, 357, 553-562.

Engelbrecht, C.J., Baumbach, G.W.S., Matthysen, J.L., Fletcher, P., 1986. The West Wits Line in Mineral Deposits of Southern Africa, I (CR Anhaeusser and S. Maske, eds). Geol. Soc. of S.A., Vol.I & II, 599-648.

Feather, C.E., 1981. Some aspects of the Witwatersrand mineralization with special reference to uranium minerals. Geological Survey Professional Paper, 1161, Q1-Q23.

Feather, C., Koen, G.M., 1975. The mineralogy of the Witwatersrand reefs. Minerals Science and Engineering, 7, 189-224.

Fleet, A.J., 1984. Aqueous and Sedimentary geochemistry of the Rare Earth Elements. In: Rare Earth Element Geochemistry (Ed P. Henderson), Developments in Geochemistry, 2, 343-373.

Floyd, P.A., Leveridge, B.E.,1987. Tectonic environment of the Devonian Gramscatho basin, south Cornwall: framework mode and geochemical evidence from turbiditic sandstones. J. Geol. Soc. London, 144, 531-542.

Folk, R.L., Ward, W., 1957. Brazos River bar: a study in the significance of grain-size parameters. Journal of Sedimentary Petrology, 27, 3-26.

Fralick, P.W., Kronberg, B.I., 1997. Geochemical discrimination of clastic sedimentary rock sources. Sed. Geol., 113, 111-124.

França, A.B., Araújo, L.M., Maynard, J.B., Potter, P.E., 2003. Secondary porosity formed by deep meteoric leaching: Botucatu eolinite, southern South America. Association of Petroleum Geologists Bulletin, 87, 1073-1082.

Frimmel, H.E., Gartz, V.H., 1997. Witwatersrand gold particle chemistry matches model of metamorphosed, hydrothermally altered placer deposits. Min. Dep., 32, 523-530.

Frimmel, H.F., Minter, W.E.L., 2002. Recent developments concerning the geological history and genesis of the Witwatersrand gold deposits, South Africa. In Goldfarb, R.J., Nielson, R.L., (Eds.), Integrated Methods for Discovery: Global Exploration in the Twenty-First Century. Soc. of Econ. Geol., Special Publication, 9, 17-45.

Frimmel, H.F., 2005. Archean atmosphere evolution: evidence from the Witwatersrand gold field, South Africa. *Earth-Science Reviews*, 70, 1-46.

Gartz, V.H., 1996. Post-depositional alteration of the Ventersdorp contact Reefs no. 10 shaft, Klerksdorp Goldfield. Unpublished MSc Thesis, University of Cape Town, 1-167.

Gerdes, A., Zeh, A., 2006. Combined U-Pb and Hf isotope LA-(MC-) ICP-MS analyses of detrital zircons: Comparison with SHRIMP and new constraints for the provenance and age of an Armorican metasediment in Central Germany. *Earth and Planetary Science letters*, 249, 47-62.

Gerdes, A., Zeh, A., 2008. Zircon formation versus zircon alteration – New insights from combined U-Pb and Lu-Hf in-situ La-ICP-MS analyses of Archean zircons from the Limpopo Belt. *Chemical Geology*, doi 10.1016/j.chemgeo.2008.03.005.

Germes, G.J.B., Schweitzer, J.K., 1994. A provisional model for the regional morphostratigraphy of the Venterspost Conglomerate Formation in the West Rand and Carletonville Goldfields. *South African J. of Geol.*, 97, 279-287.

Hall, R.C.B., 1997. The Ventersdorp contact reef: Final phase of the Witwatersrand basin, independent formation, or precursor to the Ventersdorp Supergroup? *South African Journal of Geology* 100, 213-222.

Hallbauer, D.K., 1975. The plant origin of the Witwatersrand carbon. *Minerals Science and Engineering*, 7, 111-131.

Hallbauer, D.K., Utter, T., 1977. Geochemical and morphological characteristics of gold particels from recent river deposits and the fossil placers of the Witwatersrand. *Mineral. Dep.*, 12, 296–306.

Hallbauer, D.K., Van Warmelo, K.T., 1974. Fossilized plants in tucholite from Precambrian rocks in the Witwatersrand, South Africa. *Prec. Res.*, 1, 199-212.

Harley, M., Dixon, R., 2006. Dominion Uranium Project, North-West Province, Republic of South Africa. Independent Technical Report: prepared by SRK Consulting for srx Uranium One Inc., 1-138.

Harker, A., 1909. The natural history of igneous rocks. Methuen, London.

Herron, M.M., 1988. Geochemical Classification of Terrigenous sands and Shales from Core or Log Data. J. of Sed. Petrology, 58, 820-829.

Hiemstra, S.A, 1968. The mineralogy and petrology of the uraniferous conglomerate of the Dominion Reefs Mine, Klerksdorp area. Transactions. Geol. Soc. of S.A., 71, 1-65.

Jackson, M.C., 1991. The Dominion Group: a review of the late Archaean volcano-sedimentary sequence and implications for the tectonic setting of the Witwatersrand Supergroup, South Africa. Inform. Circ. Econ. Geol. Res., Univ. Witwatersrand, 240, 1-41.

Kamo, S.L., Reimold, W.U., Krogh, T.E., Colliston, W.P., 1996. A 2.023 Ga age for the Vredefort impact event and a first report of shock metamorphosed zircons in pseudotachylitic breccias. Earth and Planetary Science Letters 144, 369-387.

Kirk, J., Ruiz, J., Chesley, J., Titley, S., Walshe, J., 2001. A detrital model for the origin of gold and sulfides in the Witwatersrand basin based on Re-Os isotopes. Geochemica et Cosmochemica Acta, 65, 2149-2159.

Kositcin, N., McNaughton, N.J., Griffin, B.J., Fletcher, I.R., Groves, D.I., Rasmussen, B., 2003. Textural and geochemical discrimination between xenotime of different origin in the Archean Witwatersrand Basin, South Africa. Geochemica et Cosmochemica Acta, 67, 709-731.

Kositcin, N., Krapez, B., 2004. SHRIMP U-Pb zircon geochronology of the Late Archaean Witwatersrand Basin of South Africa: relation between zircon provenance age spectra and basin evolution. Prec. Res., 129, 141-168.

Köppel, W.H., Saager, R., 1974. Lead isotope evidence on the detrital origin of the Witwatersrand pyrites and its bearing on the provenance of the Witwatersrand gold. *Econ. Geol.*, 69, 318-331.

Kröner, A., Tegtmeier, A., 1994. Gneiss-greenstone relationships in the Ancient Gneiss Complex of southwestern Swaziland, southern Africa, and implications for early crustal evolution. *Precambrian Research*, 67, 109-139.

Liebenberg, W.R., 1955. The occurrence and origin of gold and radioactive minerals in the Witwatersrand System, the Dominion Reef, the Ventersdorp Contact Reef and the Black Reef. *Transactions, Geological Society of South Africa*, 58, 101-227.

Mathieu, R., Zetterström, L., Cuney, M., Gauthier-Lafaye, F., Hidaka, H., 2001. Alteration of monazite and zircon and lead migration as geochemical tracers of fluid paleocirculations around the Oklo-Okélobondo and bangombé natural nuclear reaction zones. *Chemical Geology*, 171, 147-171.

McDonough, W.F., Sun, S.S., 1995. Composition of the Earth. *Chemical Geology*, 120, 223-253.

McLennan, S.M., 1989. Rare Earth Elements in Sedimentary Rocks: Influence of Provenance and Sedimentary Processes. In: *Geochemistry and Mineralogy of Rare Earth Elements* (Eds B.R. Lipin and G.A. McKay), *Reviews in Mineralogy*, 21, 169-200.

McLennan, S.M., Henning, S., McDaniel, D.K., Hanson, G.N., 1993. Geochemical approaches to sedimentation, provenance and tectonics. In: *Process Controlling the Composition of Clastic Sediments* (Eds M.J. Johnson and A. Basu), *Spec. Paper*, 284, 21-40.

Mellor, E.T., 1916. The conglomerates of the Witwatersrand. *Transactions of the Institute of Mining and Metallurgy*, 25, 226-348.

Mellor, E.T., 1916. The conglomerates of the Witwatersrand. *Trans. Inst. Min. Met. London*

Minter, W.E.L., 1976. Detrital gold, uraninite, and pyrite concentrations related to sedimentology in the Precambrian Vaal Reef placer, Witwatersrand, South Africa. *Econ. Geol.*, 71, 157-175.

Minter, W.E.L., 1978. A sedimentological synthesis of placer gold, uranium and pyrite concentrations in Proterozoic Witwatersrand deposits. In Miall, A.D. (ed.), *Fluvial sedimentology*. Canadian Society for Petroleum Geology, Memoir 5, 801-829.

Minter, W.E.L., 1986. The Welkom Goldfield. In Anhaeuser, C.R., Maske, S., (ed.). *Mineral Dep. of Southern Afr. Vol. I & II*, Geol. Soc. S. Afr., 497-539.

Minter, W.E.L., 1999. Irrefutable detrital origin of Witwatersrand gold and evidence of eolian signatures. *Econ. Geol.*, 94, 665-670.

Moser, D.E., 1997. Dating the shock wave and thermal imprint of the giant Vredefort impact, South Africa. *Geology* 25, 7-10.

Nagender Nath, B., Kundendorf, H., Plüger, W.L., 2000. Influence of Provenance, Weathering, and Sedimentary Processes on the Elemental Ratios of the Fine-Grained Fraction of the Bedload Sediments from the Vembanad Lake and the Adjoining Continental Shelf, Southwest Coast of India. *J. of Sed. Res.*, 70, 1081-1094.

Nakamura, K., 1974. Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. *Geochim. Cosmochim. Acta*, 38, 757-775

Nelson, D.W., Sommers, L.E., 1982. Total carbon, organic carbon and organic matter. In: A.L. Page (Ed.). *Methods of soil analysis. Part 2. chemical and microbiological properties*. Agronomy 9, 2nd edition, 539 – 580., particularly 571 - 573.

Nesbitt, H.W., Young, G.M., 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature*, 299, 715-717.

Nesbitt, H.W., Young, G.M., 1984. Prediction of some weathering trends of plutonic and volcanic rocks based upon thermodynamic and kinetic considerations. *Geoch. Cosmochim. Acta*, 48, 1523-1534.

Nesbitt, H.W., Young, G.M., 1989. Formation and diagenesis of weathering profiles. *J. Geol.*, 97, 129-147.

Nesbitt, H.W., Young, G.M., 1996. Petrogenesis of sediments in the absence of chemical weathering effects of abrasion and sorting on bulk rock composition and mineralogy. *Sedimentology*, 43, 341-358.

Pettijohn, F.J., Potter, P.E., Siever, R., 1987. *Sand and Sandstone*. Springer-Verlag, New York.

Philips, G.N., Law, D.M., 1994. Metamorphism of the Witwatersrand gold fields, a review. *Ore Geol. Rev.*, 9, 1-31.

Philips, G.N., Law, D.M., 2000. Witwatersrand gold fields: Geology, genesis and exploration. *SEG Reviews*, 13, 439-500.

Potter, P.E., 1978. Petrology and chemistry of big river sands. *J. Geol.*, 86, 423–449.

Prinsloo, M.A., 1988. Effects of cultivation on the content and availability of nitrogen in selected Orange Free State soils. M.Sc. (Agric.) Thesis, Department of Soil Science, U.O.F.S., Bloemfontein, 15-16.

Pretorius, D.A., 1974. Gold in the Proterozoic sediments of South Africa, systems, paradigms, and models. Information Circular, University of the Witwatersrand, Econ. Geol. Res. Unit, 87, 2.

Ramdohr, P., 1958. New observations on the ores of the Witwatersrand in South Africa and their genetic significance. *Transaction. Geol. Soc. of S. A.*, 61, 1-50.

Robb, L.J., Meyer, F.M., 1995. The Witwatersrand Basin, South Africa. Geological framework and mineralization processes. *Ore Geol. Rev.*, 10, 67-94.

Robb, L.J., Davis, D.W., Kamo, S.L., 1990a. U-Pb ages on single detrital zircon grains from the Witwatersrand Basin, South Africa. Constraints on the age of sedimentation and on the evolution of granites adjacent to the basin. *J. of Geol.*, 98, 311-328.

Robb, L.J., Davis, D.W., Kamo, S.L., Meyer, F.M., 1992. Ages of altered granites adjoining the Witwatersrand Basin with implications for the origin of gold and uranium. *Nature*, 357, 677-680.

Rogers, A., 1979. Techniques of autoradiography. Elsevier, 3rd Edition, 1-429.

Roser, B.P., Korsch, R.J., 1988. Provenance signatures of sandstone-mudstone suites determined using discriminant function analysis of major-element data. *Chem. Geol.*, 67, 119-139.

Roser, B.P., Nathan, S., 1997. An evaluation of element mobility during metamorphism of a turbidite sequence (Greenland Group, New Zealand). *Geological Magazine*, 134, 219-234.

Saager, R., 1970. The relationship of Silver and Gold in the Basal Reef of the Witwatersrand System, South Africa. *Mineral. Dep.*, 4, 93-113.

Saager, R., Stupp, H.D., 1983. U-Ti phases from Precambrian quartz-pebble conglomerates of the Elliot Lake area, Canada, and the Pongola basin, South Africa. *Mineralogy and Petrology*, 32, 83-102.

SACS, 1980. Stratigraphy of South Africa. Geological Survey of South Africa., Handbook 8, 1-690.

Schildowski, M., 1981. Uraniferous constituents of the Witwatersrand conglomerates: Ore-microscopic observations and implications for the Witwatersrand metallogeny. In Armstrong, F.C. (Ed.), *Genesis of U- and Au-bearing Precambrian Quartz-Pebble Conglomerates*. U.S. Geol. Surv. Prof. Paper, 1161-A-BB, 1-29.

Schmitz, M.D., Bowring, S.A., De Wits, M.J., Gartz, V., 2004. Subduction and terrane collision stabilize the western Kaapvaal craton tectosphere 2.9 billion years ago. *Earth and Planetary Science Letters*, 222, 363-376.

Simpson, P.R. and Bowles, J.F.W., 1977. Uranium mineralization of the Witwatersrand and Dominion Reef systems: *Phil. Trans. Royal Soc. London. Series A, Mathematical and Physical Sciences*, 286, 527-548.

Slingerland, R., Smith, N.D., 1986. Occurrence and formation of water-placers. *Annual Review of Earth and Planetary Sciences*, 14, 133-147.

Stanisstreet, I.S., McCarthy, T.S., 1991. Changing tectono-sedimentary scenarios relevant to the development of the late Archaean Witwatersrand Basin. *Journal of African Earth Sciences*, 13, 65-81.

Taylor, S.R., McLennan, S.M., 1985. *The Continental Crust. its Composition and Evolution.* Geoscience Texts. Blackwell Scientific Publications, Oxford, 1-312.

Toulkeridis, T., Clauer, N., Kröner, A., Reimer, T., Todt, W., 1999. Characterization, provenance, and tectonic setting of Fig Tree greywackes from the Archaean Barberton Greenstone Belt, South Africa. *Sedimentary geology*, 124, 113-129.

Tucker, M.E., 2001. An Introduction to the Origin of Sedimentary Rocks. In: *Sedimentary Petrology* 3rd edition. Blackwell Science, Oxford, 1-262.

Utter, T., 1980. Rounding of ore particles from the Witwatersrand Gold and Uranium deposit (South Africa) as indicator of their detrital origin. *Journal of Sedimentary Petrol.*, 50, 71-76.

Van Emden, B., Thornber, M.R., Graham, J., Lincoln, F.J., 1997. The incorporation of actinides in monazite and xenotime from placer deposits in Western Australia. *Can. Mineral.*, 35, 95-104.

Vennemann, T.W., Kesler, S.E., O'Neil, J.R., 1992. Stable isotope compositions of quartz pebbles and their fluid inclusions as tracers of sediment provenance. Implications for gold- and uranium-bearing quartz pebble conglomerates. *Geology*, 20, 837-840.

Vennemann, T.W., Kesler, S.E., Frederickson, G.C., Minter, W.E.L., Heine, R.R., 1995. Oxygen isotope sedimentology of gold- and uranium-bearing Witwatersrand and Huronian Supergroup quartz-pebble conglomerates. *Econ. Geol.*, 91, 322-342.

Von Backstrom, J.W., 1975. Uranium and the generation of power, a South African perspective. *Transactions, Geological Society of South Africa*, 78, 275-292.

Watchorn, M.B., 1980. Fluvial and tidal sedimentation in the 3000 Ma Mozaan Basin, South Africa. *Precambrian Research*, 13, 27-42.

Watchorn, M.B., 1981. Continental sedimentation and volcanism in the Dominion Group of the western Transvaal, a review. *Transactions, Geological Society of South Africa*, 84, 67-73.

Wiltshire, G.H., 1987. Laboratory notebook. 5, 96-102., 109.

Wolf, M.B., London, D., 1995. Incongruent dissolution of REE- and Sr-rich apatite in peraluminous granitic liquids. Differential apatite, monazite, and xenotime solubilities during anatexis. *American Mineralogist*, 80, 765-775.

Wronkiewicz, D.J., Condie, K.C., 1987. Geochemistry and provenance of sediments from the Pongola Supergroup, South Africa. Evidence for the 3.0 Ga-old continental creation. *Geochem. Cosmochem. Acta*, 53, 1537-1549.

Sources

<http://www.acmelab.com> (1.11.2008)

<http://www.uranium1.com> (04.10. and 10.11.2007)

APPENDIX I

Table 1: Sample descriptions with reef type, facies and location

Table 2: Applied examination methods on the samples

Table 1: Sample description with Reef type, facies and location

borhole ID	sample ID	reef type	reef facies	depth in m	X collar	Y collar	Z collar
DDR 007	DO 3337	UDOM	Middle Package Conglomerate	176.80-177.08	60205,851	2974392,956	1434,22
DDR 007	DO 3342	UDOM	Middle Package Conglomerate	177.98-178.18	60205,851	2974392,956	1434,22
DDR 007	DO 3391	LDOM	Terrace Facies	188.43-188.60	60205,851	2974392,956	1434,22
DDR 077	CO 5512	UDOM	Small P.C.-Middle P.C.	371.57-371.78	61261,628	2970283,168	1475,96
DDR 077	CO 5516	UDOM	Thick Reef	372.36-372.56	61261,628	2970283,168	1475,96
DDR 077	CO 5602	LDOM	Thick Reef	392.92-393.13	61261,628	2970283,168	1475,96
DDR 023	DO 1524	UDOM	Middle Package Conglomerate	38.91-39.14	59902,471	2973209,198	1444,98
DDR 023	DO 1525	UDOM	Middle Package Conglomerate	39.14-39.38	59902,471	2973209,198	1444,98
DRT 070	AO 5686	UDOM	Channel Facies	608.12-608.34	53180,03	2965734,29	1388,19
DRT 070	AO 5688	UDOM	Channel Facies	608.55-608.76	53180,03	2965734,29	1388,19
DRT 070	AO 8041	LDOM	-	621.69-621.88	53180,03	2965734,29	1388,19
DRT 070	AO 8042	LDOM	-	621.88-622.06	53180,03	2965734,29	1388,19
DRT 073	AO 8286	UDOM	Channel Facies	815.66-815.85	54019,62	2966594,24	1392,23
DRT 073	AO 8290	UDOM	Channel Facies	816.52-816.73	54019,62	2966594,24	1392,23
DRT 164	EO 4923	UDOM	Channel Facies	794.16-794.44	54156,69	2966787,76	1395,64
DRT 164	EO 4924	UDOM	Channel Facies	794.44-794.67	54156,69	2966787,76	1395,64
DRT 113	CO 6833	UDOM	Channel Facies	824.00-824.26	53724,11	2966200,89	1388,75
DRT 113	CO 7678	UDOM	Channel Facies	807.73-807.93	53724,11	2966200,89	1388,75
DRT 113	CO 6789	UDOM	Channel Facies	809.92-810.12	53724,11	2966200,89	1388,75
DRT 034	DO 8629	UDOM	Channel Facies	342.05-342.28	52511,35	2965128,51	1405,97
DRT 034	DO 8631	UDOM	Channel Facies	342.55-342.82	52511,35	2965128,51	1405,97
DRT 017	DO 318	UDOM	Channel Facies	224.07-224.32	51972,92	2965763,98	1399,31
DRT 017	DO 322	UDOM	Channel Facies	225.06-225.26	51972,92	2965763,98	1399,31
DRT 017	DO 324	UDOM	Channel Facies	225.42-225.68	51972,92	2965763,98	1399,31
DRT 050	AO 1618	UDOM	Channel Facies	185.45-185.63	51042,71	2965984,27	1396,80
DRT 050	AO 1620	UDOM	Channel Facies	185.82-186.01	51042,71	2965984,27	1396,80
DRT 050	AO 1638	UDOM	Channel Facies	189.68-189.95	51042,71	2965984,27	1396,80
DRT 024	DO 1823	UDOM	Channel Facies	206.67-206.89	52380,97	2964637,25	1415,00
DRT 039	DO 6920	UDOM	Channel Facies	337.51-337.68	52704,22	2964680,06	1411,03
DRT 034	DO 8627	UDOM	Channel Facies	341.63-341.83	52511,35	2965128,51	1405,97

borhole ID	sample ID	reef type	reef facies	depth in m	X collar	Y collar	Z collar
DRT 034	DO 8628	UDOM	Channel Facies	341.83-342.05	52511,35	2965128,51	1405,97
DRT 043 D1	AO 3735	UDOM	Channel Facies	128.69-128.86	52456,46	2963996,23	1422,24
DRT 115	CO 3621	UDOM	Channel Facies	no information	54596,40	2966981,62	1403,97
DRT 115	CO 3623	UDOM	Channel Facies	no information	54596,40	2966981,62	1403,97
DRT 115	CO 3637	UDOM	Channel Facies	no information	54596,40	2966981,62	1403,97
DRT 131	EO 3027	UDOM	Interchannel Facies	no information	53500,82	2966804,54	1388,46
DRT 131	EO 3058	LDOM	-	906.43-906.64	53500,82	2966804,54	1388,46
DRT 094	EO 5605	UDOM	Interchannel Facies	836.66-838.90	53490,76	2967422,06	1392,17
DRT 094	EO 5611	UDOM	Interchannel Facies	839.89-840.11	53490,76	2967422,06	1392,17
DRT 094	EO 5633	LDOM	-	852.66-852.86	53490,76	2967422,06	1392,17
DRT 096	BO 0439	UDOM	Interchannel Facies	546.27-546.47	52177,94	2967036,67	1378,51
DRT 096	BO 0445	UDOM	Interchannel Facies	547.51-547.72	52177,94	2967036,67	1378,51
DRT 098	CO 6608	UDOM	Interchannel Facies	488.54-488.75	51572,38	2967533,49	1376,01
DRT 098	CO 6613	UDOM	Interchannel Facies	489.56-489.80	51572,38	2967533,49	1376,01
DRT 056	AO 1292	UDOM	Interchannel Facies	228.76-228.97	50856,07	2966611,75	1388,20
DRT 056	AO 1320	LDOM	-	235.43-235.65	50856,07	2966611,75	1388,20
DRT 058	AO 3883	UDOM	Interchannel Facies	182.49-182.68	50420,25	2966432,81	1386,00
DRT 058	AO 3886	UDOM	Interchannel Facies	183.06-183.25	50420,25	2966432,81	1386,00
DRT 076	AO 8518	UDOM	Interchannel Facies	422.52-422.70	51676,95	2966704,03	1386,35
DRT 076	AO 8521	UDOM	Interchannel Facies	423.06-423.26	51676,95	2966704,03	1386,35
DRT 079	AO 5268	UDOM	Interchannel Facies	327.86-328.07	51259,67	2966564,91	1389,12
DRT 079	AO 5274	UDOM	Interchannel Facies	329.15-329.38	51259,67	2966564,91	1389,12
DRT 090	BO 8981	UDOM	Interchannel Facies	823.13-823.34	54104,55	2967070,81	1397,12
DRT 090	BO 8976	UDOM	Interchannel Facies	822.32-822.52	54104,55	2967070,81	1397,12
DRT 131	EO 3030	LDOM	-	no information	53500,82	2966804,54	1388,46
DRT 131	EO 3054	UDOM	Interchannel Facies	no information	53500,82	2966804,54	1388,46
DRT 100	CO 7375	UDOM	Overbank Facies	668.64-668.81	52045,46	2968199,38	1386,10
DRT 100	CO 7387	UDOM	Overbank Facies	670.76-671.01	52045,46	2968199,38	1386,10
DRT 100	CO 7422	LDOM	-	680.68-680.93	52045,46	2968199,38	1386,10
DRT 095	CO 7744	UDOM	Overbank Facies	790.67-790.67	53382,04	2968125,58	1399,13
DRT 095	CO 7753	UDOM	Overbank Facies	792.45-792.73	53382,04	2968125,58	1399,13
DRT 106	EO 3270	UDOM	Overbank Facies	775.47-775.67	52134,89	2968787,48	1401,90

borhole ID	sample ID	reef type	reef facies	depth in m	X collar	Y collar	Z collar
DRT 104	CO 8294	UDOM	Overbank Facies	625.06-625.26	51314,69	2968784,88	1392,42
DRT 104	CO 8296	UDOM	Overbank Facies	625.46-625.70	51314,69	2968784,88	1392,42
DRT 179	FO 0921	UDOM	Overbank Facies	699.74-699.94	52180,00	2968539,00	/
DRT 179	FO 0948	LDOM	-	710.18-710.38	52180,00	2968539,00	/
DRT 173	FO 5548	UDOM	Overbank Facies	456.88-457.08	51107,97	2967982,15	1373,40
DRT 099	CO 4575	UDOM	Overbank Facies	664.46-664.66	52608,72	2968235,91	1391,61
DRT 099	CO 4585	UDOM	Overbank Facies	666.26-666.45	52608,72	2968235,91	1391,61
DRT 101	EO 1035	UDOM	Overbank Facies	484.73-484.92	51240,51	2968294,65	1376,51
DRT 101	EO 1040	UDOM	Overbank Facies	485.70-485.96	51240,51	2968294,65	1376,51
DRT 108	FO 05722	UDOM	Overbank Facies	724.74-724.94	52335,57	2969800,64	1424,13
DRT 108	FO 05732	UDOM	Overbank Facies	726.54-726.74	52335,57	2969800,64	1424,13
DRT 108	FO 05737	UDOM	Overbank Facies	727.54-727.74	52335,57	2969800,64	1424,13
DRT 186	FO 9117	UDOM	Overbank Facies	no information	51668,00	2969064,00	/
DRT 186	FO 9112	UDOM	Overbank Facies	no information	51668,00	2969064,00	/
DRT 103	BO 517	UDOM	Overbank Facies	no information	50287,39	2966943,47	1382,24
DRT 103	BO 518	UDOM	Overbank Facies	no information	50287,39	2966943,47	1382,24
DRT 134	EO 6064	UDOM	Overbank Facies	no information	50202,83	2967452,91	1378,06

Table 2: Applied examination methods on the samples

borhole ID	sample ID	thin sections	point counting	autoradio-graphy	SEM analyses	carbon analyses	XRF analyses	REE analyses	LA-ICP-MS	EMPA analyses
DDR 007	DO 3337	x	x		x		x		x	
DDR 007	DO 3342	x	x		x		x			
DDR 007	DO 3391						x			
DDR 077	CO 5512	x	x		x		x			
DDR 077	CO 5516	x	x	x			x			
DDR 077	CO 5602	x	x	x	x		x			
DDR 023	DO 1524						x			
DDR 023	DO 1525						x			
DRT 070	AO 5686	x	x	x	x	x	x	x		
DRT 070	AO 5688						x			
DRT 070	AO 8041						x			
DRT 070	AO 8042						x			
DRT 073	AO 8286	x	x	x		x	x	x		
DRT 073	AO 8290						x			
DRT 164	EO 4923						x			
DRT 164	EO 4924						x			
DRT 113	CO 6833						x	x		
DRT 113	CO 7678						x			
DRT 113	CO 6789						x			
DRT 034	DO 8629						x			
DRT 034	DO 8631						x			
DRT 017	DO 318	x	x	x		x	x	x		
DRT 017	DO 322						x			
DRT 017	DO 324						x			
DRT 050	AO 1618						x			
DRT 050	AO 1620						x			
DRT 050	AO 1638	x	x			x	x			
DRT 024	DO 1823	x	x	x			x			
DRT 039	DO 6920	x	x		x	x	x		x	x
DRT 034	DO 8627	x	x		x	x	x			
DRT 034	DO 8628	x	x		x	x	x	x		x
DRT 043 D1	AO 3735	x	x		x					
DRT 115	CO 3621						x	x		
DRT 115	CO 3623						x			

borhole ID	sample ID	thin sections	point counting	autoradio-graphy	SEM analyses	carbon analyses	XRF analyses	REE analyses	LA-ICP-MS	EMPA analyses
DRT 115	CO 3637						X			
DRT 131	EO 3027						X			
DRT 131	EO 3058						X			
DRT 094	EO 5605						X			
DRT 094	EO 5611						X			
DRT 094	EO 5633	X	X			X	X			
DRT 096	BO 0439						X	X		
DRT 096	BO 0445						X			
DRT 098	CO 6608						X			
DRT 098	CO 6613						X			
DRT 056	AO 1292	X	X			X	X			
DRT 056	AO 1320	X	X			X	X			
DRT 058	AO 3883	X	X	X	X		X			
DRT 058	AO 3886	X	X		X	X	X			
DRT 076	AO 8518						X			
DRT 076	AO 8521	X	X	X	X		X			
DRT 079	AO 5268	X	X		X	X	X			X
DRT 079	AO 5274	X	X	X	X	X	X			
DRT 090	BO 8981					X	X	X		
DRT 090	BO 8976						X			
DRT 131	EO 3030						X			
DRT 131	EO 3054						X			
DRT 100	CO 7375						X			
DRT 100	CO 7387						X			
DRT 100	CO 7422	X	X				X	X		
DRT 095	CO 7744	X	X				X	X		
DRT 095	CO 7753						X	X		
DRT 106	EO 3270	X	X		X		X			
DRT 104	CO 8294						X			
DRT 104	CO 8296	X	X				X	X		
DRT 179	FO 0921						X			
DRT 179	FO 0948	X	X			X	X			
DRT 173	FO 5548	X	X				X			

borhole ID	sample ID	thin sections	point counting	autoradio-graphy	SEM analyses	carbon analyses	XRF analyses	REE analyses	LA-ICP-MS	EMPA analyses
DRT 099	CO 4575						x			
DRT 099	CO 4585						x			
DRT 101	EO 1035						x			
DRT 101	EO 1040	x	x				x	x		
DRT 108	FO 05722	x	x	x			x			
DRT 108	FO 05732	x	x				x			
DRT 108	FO 05737						x			
DRT 186	FO 9117						x	x		
DRT 186	FO 9112						x			
DRT 103	BO 517						x	x		
DRT 103	BO 518						x			
DRT 134	EO 6064						x	x		

APPENDIX II

A: Autoradiography of 10 polished thin sections

Table1: Carbon analyses with acid method (Mebius method)

A: Autoradiography of 10 polished thin sections

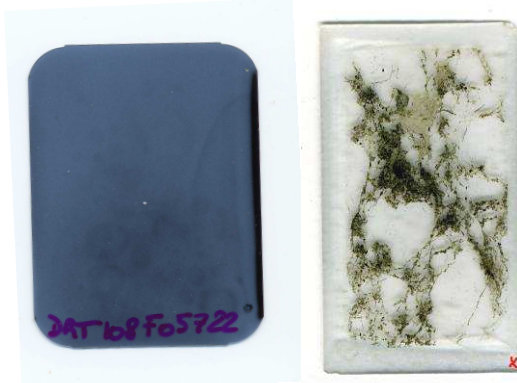
DRT 024 DO 1823



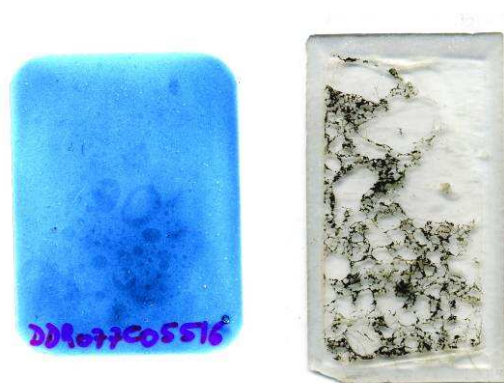
DRT 070 AO 5686



DRT 108 FO 5722



DDR 077 CO 5516



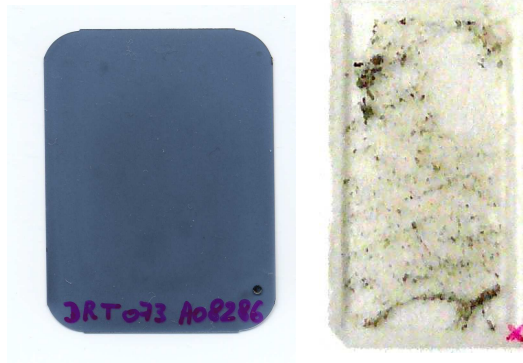
DDR 077 CO 5602



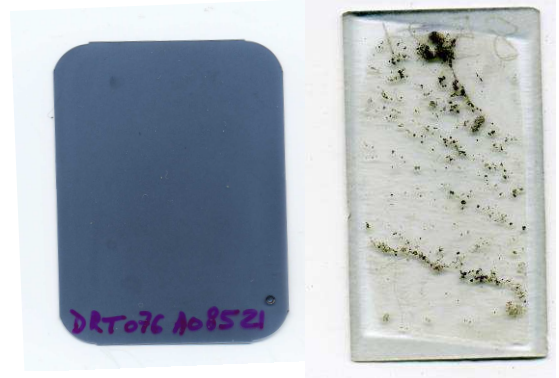
DRT 058 AO 3883



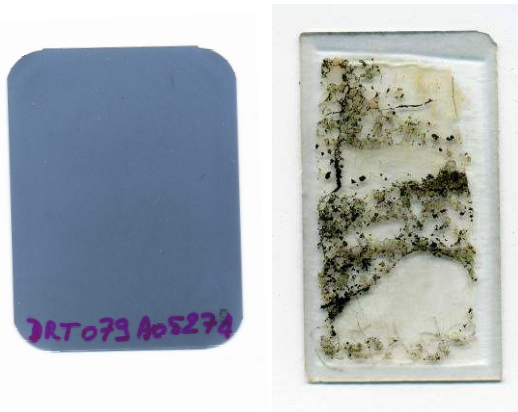
DRT 073 AO 8286



DRT 076 AO 8521



DRT 079 AO 5274



DRT 017 DO 318

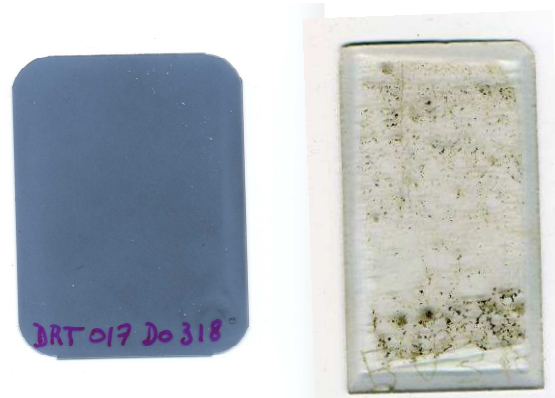


Table1: Carbon analyses with acid method (Mebius method)

borehole ID	sample ID	org. C (ppm)
DRT 056	AO 1292	6417
DRT 056	AO 1320	3213
DRT 050	AO 1638	1925
DRT 058	AO 3886	1948
DRT 079	AO 5268	7796
DRT 079	AO 5274	7404
DRT 073	AO 5686	11698
DRT 073	AO 8286	8863
DRT 076	AO 8561	7274
DRT 017	DO 318	2728
DRT 039	DO 6920	5667
DRT 034	DO 8627	7374
DRT 034	DO 8628	7690
DRT 094	EO 5633	1662
DRT 179	EO 0948	7704

APPENDIX III

Table 1: Major with calculated CIA on 78 whole rock samples

Table 2: Trace element XRF data

Table 3: REE and some trace element analyses

Table 4: Pearson correlation matrix calculated with statistic program SPSS,
blue marked display significant correlations (above 0.5 level)

Table 5: Standards for program sodium only

Table 6: Standards for program uranium only

Table 7: Standards for program major beads

Table 8: Standards for program vms trace 3

Table 1: Major element XRF data with calculated CIA and LLD on 78 whole rock samples

section	borehole ID	sample	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	total	CIA
Rietkuil	DRT 056	AO 1292	91,33	3,92	3,58	0,03	0,29	0,21	<D.L.	1,04	0,32	0,12	100,83	76
Rietkuil	DRT 056	AO 1320	90,13	5,39	1,95	0,03	0,22	0,20	<D.L.	1,53	0,15	0,15	99,74	76,5
Rietkuil	DRT 050	AO 1618	78,11	7,56	5,21	0,12	0,84	2,26	<D.L.	1,72	1,27	1,12	98,20	72,9
Rietkuil	DRT 050	AO 1620	91,02	4,37	3,19	0,04	0,36	0,13	<D.L.	1,30	0,17	0,06	100,62	65,5
Rietkuil	DRT 050	AO 1638	90,31	5,13	1,87	0,03	0,41	0,26	<D.L.	1,70	0,47	0,10	100,27	74,1
Rietkuil	DRT 058	AO 3883	89,38	4,60	4,00	0,26	0,45	0,23	<D.L.	0,94	0,30	0,15	100,31	79,3
Rietkuil	DRT 058	AO 3886	91,91	4,75	1,32	0,07	0,25	0,09	<D.L.	1,33	0,35	0,07	100,16	77
Rietkuil	DRT 079	AO 5268	85,74	3,93	5,74	0,18	0,51	0,99	<D.L.	0,71	0,60	0,48	98,87	69,6
Rietkuil	DRT 079	AO 5274	87,79	3,22	6,02	0,27	0,42	0,39	<D.L.	0,56	0,56	0,17	99,39	71,4
Rietkuil	DRT 070	AO 5686	76,60	8,37	7,25	0,33	0,61	1,45	<D.L.	1,94	1,45	0,89	98,88	70,3
Rietkuil	DRT 070	AO 5688	91,73	2,67	4,29	0,20	0,40	0,13	<D.L.	0,50	0,28	0,10	100,29	74,4
Rietkuil	DRT 70	AO 8041	94,93	3,26	1,52	0,03	0,23	0,05	<D.L.	0,90	0,05	0,02	100,97	75
Rietkuil	DRT 70	AO 8042	93,65	4,18	1,42	0,02	0,19	0,09	<D.L.	1,30	0,07	0,02	100,94	81,8
Rietkuil	DRT 073	AO 8286	82,78	5,69	5,07	0,15	0,62	0,95	<D.L.	1,29	0,88	0,50	97,92	72,2
Rietkuil	DRT 073	AO 8290	92,20	2,84	4,06	0,08	0,44	0,11	<D.L.	0,63	0,27	0,09	100,71	80,6
Rietkuil	DRT 076	AO 8518	89,51	3,98	4,28	0,10	0,66	0,41	<D.L.	0,88	0,62	0,18	100,63	74,8
Rietkuil	DRT 076	AO 8521	90,44	3,61	4,44	0,05	0,36	0,13	<D.L.	1,00	0,14	0,06	100,24	76,5
Rietkuil	DRT 096	BO 439	88,51	5,18	3,95	0,19	0,75	0,12	<D.L.	1,13	0,55	0,05	100,42	81,2
Rietkuil	DRT 096	BO 445	89,20	4,60	4,26	0,20	0,57	0,09	<D.L.	1,03	0,43	0,08	100,46	80,7
Rietkuil	DRT 103	BO 517	88,48	4,73	3,27	0,04	0,53	0,54	<D.L.	1,17	0,56	0,33	99,66	74,4
Rietkuil	DRT 103	BO 518	88,76	4,65	3,52	0,03	0,52	0,39	<D.L.	1,27	0,44	0,25	99,83	73
Rietkuil	DRT 090	BO 8976	89,33	4,92	2,34	0,11	0,52	0,49	<D.L.	1,23	0,95	0,32	100,20	74,2
Rietkuil	DRT 090	BO 8981	91,83	3,62	2,56	0,16	0,66	0,14	<D.L.	0,71	0,36	0,11	100,16	80
Rietkuil	DRT 115	CO 3621	90,67	3,34	3,96	0,21	0,52	0,30	<D.L.	0,64	0,47	0,13	100,24	76,7
Rietkuil	DRT 115	CO 3623	89,51	3,72	3,59	0,26	0,60	0,26	<D.L.	0,75	0,52	0,12	99,33	78,7
Rietkuil	DRT 115	CO 3637	83,55	10,94	1,78	0,02	0,31	0,22	<D.L.	3,41	0,37	0,10	100,70	75,3
Rietkuil	DRT 099	CO 4575	83,66	7,25	4,69	0,32	0,71	0,42	<D.L.	1,74	1,06	0,17	100,00	76,6
Rietkuil	DRT 099	CO 4585	88,49	4,69	4,17	0,21	0,37	0,10	<D.L.	1,07	0,35	0,10	100,00	79,7
Rietkuil	DRT 098	CO 6608	87,87	3,90	6,04	0,32	0,60	0,24	<D.L.	0,62	0,35	0,09	100,00	81,3
Rietkuil	DRT 098	CO 6613	87,94	5,09	3,55	0,19	0,44	0,22	<D.L.	1,17	0,27	0,05	98,91	78,1
Rietkuil	DRT 113	CO 6778	85,08	5,57	4,78	0,37	0,91	0,75	<D.L.	1,02	1,19	0,31	99,97	75,9
section	borehole ID	sample	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	total	CIA
Rietkuil	DRT 113	CO 6789	85,74	4,82	4,89	0,17	0,79	0,47	<D.L.	0,93	0,58	0,32	98,80	76,7
Rietkuil	DRT 113	CO 6833	94,37	4,06	1,57	0,02	0,28	0,12	<D.L.	1,22	0,69	0,07	100,39	77,4

Rietkuil	DRT 100	CO 7375	84,68	5,83	6,51	0,48	0,66	0,22	<D.L.	0,82	1,03	0,19	100,43	75,6
Rietkuil	DRT 100	CO 7387	93,32	4,04	3,67	0,08	0,16	0,06	<D.L.	1,03	0,24	0,08	100,67	84,1
Rietkuil	DRT 100	CO 7422	90,41	6,55	0,77	0,02	0,14	0,13	<D.L.	1,92	0,41	0,10	100,43	78,4
Rietkuil	DRT 095	CO 7744	77,90	7,42	8,16	0,32	0,76	0,91	<D.L.	1,57	1,15	0,60	98,76	80
Rietkuil	DRT 095	CO 7753	101,14	0,41	0,46	0,01	0,11	0,03	<D.L.	0,09	0,03	0,01	102,27	74,7
Rietkuil	DRT 104	CO 8294	91,89	4,02	3,60	0,04	0,81	0,43	<D.L.	1,09	0,39	0,10	100,36	75
Rietkuil	DRT 104	CO 8296	91,87	5,10	3,19	0,03	0,36	0,36	<D.L.	1,41	0,44	0,08	100,84	72,7
Rietkuil	DRT 024	DO 1823	91,74	3,74	2,92	0,15	0,34	0,13	<D.L.	0,88	0,29	0,21	100,41	77,7
Rietkuil	DRT 017	DO 318	93,92	2,92	2,08	0,12	0,43	0,24	<D.L.	0,59	0,21	0,11	100,61	78,1
Rietkuil	DRT 017	DO 322	95,87	3,75	1,58	0,05	0,34	0,06	<D.L.	0,99	0,18	0,03	100,85	78,4
Rietkuil	DRT 017	DO 324	92,54	6,45	1,11	0,02	0,21	0,11	<D.L.	1,86	0,28	0,09	100,65	76,8
Rietkuil	DRT 039	DO 6920	90,69	3,89	4,26	0,02	0,32	0,12	<D.L.	1,09	0,24	0,11	100,74	77,8
Rietkuil	DRT 034	DO 8627	83,57	6,05	4,34	0,19	0,88	0,15	<D.L.	1,34	0,68	0,43	97,62	79,6
Rietkuil	DRT 034	DO 8628	81,77	6,54	6,34	0,30	0,89	0,28	<D.L.	1,38	0,72	0,67	98,90	79,2
Rietkuil	DRT 034	DO 8629	94,10	4,09	4,32	0,25	0,48	0,15	<D.L.	0,92	0,27	0,19	100,77	79,2
Rietkuil	DRT 034	DO 8631	96,79	4,76	2,41	0,12	0,40	0,12	<D.L.	1,28	0,40	0,17	100,45	77,2
Rietkuil	DRT 101	EO 1040	89,46	4,09	4,32	0,05	0,56	0,13	<D.L.	0,96	0,39	0,09	100,04	78,8
Rietkuil	DRT 131	EO 3027	91,14	3,70	4,01	0,23	0,39	0,15	<D.L.	0,68	0,40	0,14	100,84	76,3
Rietkuil	DRT 131	EO 3030	92,11	5,86	2,04	0,08	0,34	0,16	<D.L.	1,55	0,45	0,05	100,64	82,3
Rietkuil	DRT 131	EO 3054	98,49	3,08	0,95	0,02	0,21	0,13	<D.L.	0,90	0,53	0,07	100,38	76,3
Rietkuil	DRT 131	EO 3058	96,73	3,80	0,77	0,02	0,23	0,09	<D.L.	1,14	0,13	0,04	100,94	73,1
Rietkuil	DRT 106	EO 3270	85,86	4,12	6,07	0,12	0,52	0,14	<D.L.	0,73	0,77	0,34	98,68	82,3
Rietkuil	DRT 164	EO 4923	86,59	5,32	4,45	0,22	0,77	0,68	<D.L.	1,04	0,83	0,34	100,24	75,7
Rietkuil	DRT 164	EO 4924	90,60	4,57	3,30	0,21	0,72	0,17	<D.L.	0,98	0,31	0,07	100,94	80,7
Rietkuil	DRT 094	EO 5605	86,93	5,22	5,47	0,26	0,61	0,27	<D.L.	1,02	0,53	0,14	100,43	81,1
Rietkuil	DRT 094	EO 5611	89,49	4,26	6,84	0,16	0,45	0,12	<D.L.	0,90	0,47	0,14	100,83	81,1
Rietkuil	DRT 094	EO 5633	89,31	4,25	6,83	0,15	0,44	0,12	<D.L.	0,90	0,48	0,14	100,61	80
Rietkuil	DRT 134	EO 6084	84,42	6,04	4,42	0,05	0,79	0,68	<D.L.	1,53	0,86	0,45	99,23	73,1
Rietkuil	DRT 101	EO1035	85,72	5,51	5,67	0,13	0,86	0,14	<D.L.	0,96	0,78	0,15	99,93	83,3
Rietkuil	DRT 173	FO 5548	87,44	3,93	5,15	0,04	0,70	0,44	<D.L.	1,01	0,53	0,11	99,33	74,1
Rietkuil	DRT 108	FO 5722	85,58	5,34	4,56	0,18	1,09	0,70	<D.L.	1,44	1,20	0,31	100,39	71,6
section	borehole ID	sample	SiO₂	Al₂O₃	Fe₂O₃	MnO	MgO	CaO	Na₂O	K₂O	TiO₂	P₂O₅	total	CIA
Rietkuil	DRT 108	FO 5732	84,82	5,46	4,42	0,08	1,08	0,81	<D.L.	1,51	1,17	0,33	99,67	71,2
Rietkuil	DRT 108	FO 5737	90,78	4,71	3,54	0,05	0,75	0,29	<D.L.	1,64	0,47	0,09	100,31	70,5
Rietkuil	DRT 186	FO 9112	83,73	8,20	5,19	0,07	0,69	0,13	<D.L.	1,98	0,53	0,08	100,60	79,6

Rietkuil	DRT 186	FO 9117	91,56	4,42	2,45	0,04	0,38	0,21	<D.L.	1,12	0,33	0,10	100,62	76,5
Rietkuil	DRT 179	FO 921	79,60	9,35	6,29	0,22	0,48	0,11	<D.L.	2,27	0,99	0,30	99,62	80,3
Rietkuil	DRT 179	FO 948	89,09	5,03	3,72	0,03	0,46	0,33	<D.L.	1,40	0,62	0,22	100,90	74,4
Dominion	DDR 007	DO 3337	91,21	4,26	8,06	0,33	0,38	0,10	<D.L.	0,82	0,76	0,12	100,03	82,4
Dominion	DDR 007	DO 3342	93,38	3,24	4,37	0,11	0,31	0,04	<D.L.	0,60	0,32	0,03	100,40	83,4
Dominion	DDR 007	DO 3391	84,09	10,39	1,29	0,01	0,17	0,06	<D.L.	3,08	0,51	0,05	99,66	76,7
Dominion	DDR 077	CO 5512	82,01	4,98	10,22	0,48	0,72	0,44	<D.L.	0,58	0,63	0,22	100,28	76,1
Dominion	DDR 077	CO 5516	91,06	3,50	5,76	0,20	0,54	0,20	<D.L.	0,55	0,38	0,11	100,31	81,4
Dominion	DDR 077	CO 5602	94,21	2,64	2,10	0,02	0,21	0,10	<D.L.	0,73	0,19	0,04	100,23	83
Dominion	DDR 023	DO 1524	91,11	4,76	3,99	0,18	0,62	0,19	<D.L.	0,94	0,78	0,10	100,67	80,8
Dominion	DDR 023	DO 1525	86,08	5,85	5,22	0,17	0,81	0,23	<D.L.	1,15	1,04	0,14	100,69	80,9
LLD	wt %	/	0,0014	0,0023	0,0059	0,0016	0,0012	0,0015	0,0194	0,0063	0,0049	0,0213	/	/

Abbreviations : LLD = Lowest limit of detection in wt %, CIA = calculation index of alteration, <D.L. = beyond Detection Limit

Table 2: Trace element XRF data

section	borehole ID	sample	S	Ca	Sc	Ti	V	Cr	Fe	Co
Rietkuil	DRT 056	AO 1292	2531	1908	15	3062	13	260	33747	49
Rietkuil	DRT 056	AO 1320	79	1822	1	1409	8	33	18711	27
Rietkuil	DRT 050	AO 1618	1135	20677	21	10620	25	1407	47246	187

Rietkuil	DRT 050	AO 1620	1155	1416	8	1979	6	101	33677	36
Rietkuil	DRT 050	AO 1638	56	2754	7	5809	13	51	20048	16
Rietkuil	DRT 058	AO 3883	2358	1863	15	2650	36	421	37876	56
Rietkuil	DRT 058	AO 3886	514	723	5	2708	18	285	12484	13
Rietkuil	DRT 079	AO 5268	3085	8885	9	4417	10	611	51808	102
Rietkuil	DRT 079	AO 5274	3240	3652	10	5109	7	418	61972	69
Rietkuil	DRT 070	AO 5686	4065	13534	19	11999	24	1468	59223	150
Rietkuil	DRT 070	AO 5688	1904	993	7	2763	8	141	43436	21
Rietkuil	DRT 70	AO 8041	47	328	0	517	2	14	14746	3
Rietkuil	DRT 70	AO 8042	40	959	0	823	4	14	14327	6
Rietkuil	DRT 073	AO 8286	2837	9099	10	7985	19	715	49610	81
Rietkuil	DRT 073	AO 8290	2764	938	8	2143	7	152	39927	41
Rietkuil	DRT 076	AO 8518	1887	3809	6	5731	14	374	44104	38
Rietkuil	DRT 076	AO 8521	3894	1254	5	1368	6	110	41062	40
Rietkuil	DRT 96	BO 439	310	1004	9	5720	12	207	47263	9
Rietkuil	DRT 096	BO 445	2189	627	7	3524	14	195	44235	26
Rietkuil	DRT 103	BO 517	2439	4318	18	4561	11	375	34624	64
Rietkuil	DRT 103	BO 518	990	4584	10	7343	33	868	24240	56
Rietkuil	DRT 090	BO 8976	729	1595	11	2753	27	405	28892	37
Rietkuil	DRT 090	BO 8981	1298	5904	11	6081	14	442	35521	51
Rietkuil	DRT 115	CO 3621	2223	2768	6	4819	29	1001	44318	34
Rietkuil	DRT 115	CO 3623	1596	2305	7	5036	29	906	38882	32
Rietkuil	DRT 115	CO 3637	1377	2068	4	3961	22	551	17934	20
Rietkuil	DRT 099	CO 4575	870	3709	10	11506	28	990	53140	26
Rietkuil	DRT 099	CO 4585	3355	657	9	3246	32	955	44452	33
Rietkuil	DRT 098	CO 6608	9568	4163	19	6141	32	1229	102782	143
Rietkuil	DRT 098	CO 6613	4905	1847	4	3819	37	1063	61881	86
Rietkuil	DRT 113	CO 6778	3475	766	6	1923	49	1094	21650	59
section	borehole ID	sample	S	Ca	Sc	Ti	V	Cr	Fe	Co
Rietkuil	DRT 113	CO 6789	5578	4461	16	5995	31	1223	53018	117
Rietkuil	DRT 113	CO 6833	1121	1067	6	7965	30	731	17004	19
Rietkuil	DRT 100	CO 7375	1343	1629	11	10397	13	551	74036	22
Rietkuil	DRT 100	CO 7387	4232	389	7	2121	32	808	40467	34
Rietkuil	DRT 100	CO 7422	139	1052	4	3759	24	562	7768	15
Rietkuil	DRT 095	CO 7744	4914	8811	16	12183	21	1053	79855	105

Rietkuil	DRT 095	CO 7753	0	89	0	237	33	396	4999	0
Rietkuil	DRT 104	CO 8294	522	4194	5	4103	13	253	38863	30
Rietkuil	DRT 104	CO 8296	575	3318	12	4477	17	242	33467	57
Rietkuil	DRT 024	DO 1823	0	2002	7	7756	44	428	51227	32
Rietkuil	DRT 017	DO 318	620	2605	8	10367	30	467	65184	36
Rietkuil	DRT 017	DO 322	2465	1045	12	2500	24	458	30417	91
Rietkuil	DRT 017	DO 324	662	2414	8	2138	17	335	24341	37
Rietkuil	DRT 039	DO 6920	574	486	4	1881	24	311	18687	6
Rietkuil	DRT 034	DO 8627	734	1109	5	2702	21	319	11737	23
Rietkuil	DRT 034	DO 8628	5737	690	17	6044	35	402	55531	93
Rietkuil	DRT 034	DO 8629	3673	285	11	3002	25	250	46539	43
Rietkuil	DRT 034	DO 8631	1013	567	7	5327	48	172	13080	17
Rietkuil	DRT 101	EO 1040	5488	3305	8	2909	21	365	31522	75
Rietkuil	DRT 131	EO 3027	2747	1315	19	5622	139	881	41532	94
Rietkuil	DRT 131	EO 3030	5109	2332	31	5784	54	1047	52679	175
Rietkuil	DRT 131	EO 3054	1856	1025	12	2436	22	380	25520	31
Rietkuil	DRT 131	EO 3058	1730	820	8	3213	39	480	21194	32
Rietkuil	DRT 106	EO 3270	1845	1329	12	7195	36	652	70687	22
Rietkuil	DRT 164	EO 4923	4710	1231	12	3797	33	467	45647	64
Rietkuil	DRT 164	EO 4924	2461	1080	10	3285	24	629	41820	38
Rietkuil	DRT 094	EO 5605	941	1581	6	3972	21	475	22610	12
Rietkuil	DRT 094	EO 5611	160	1287	1	5135	19	397	10148	10
Rietkuil	DRT 094	EO 5633	49	648	0	1279	16	325	8313	2
Rietkuil	DRT 134	EO 6084	1327	1370	11	8876	10	619	67358	46
Rietkuil	DRT 101	EO1035	1729	5841	9	7440	25	638	46087	48
Rietkuil	DRT 173	FO 5548	1749	5930	7	7395	24	633	46284	52
Rietkuil	DRT 108	FO 5722	3514	2529	10	5639	27	735	61936	41
section	borehole ID	sample	S	Ca	Sc	Ti	V	Cr	Fe	Co
Rietkuil	DRT 108	FO 5732	655	7723	14	13038	10	674	47894	31
Rietkuil	DRT 108	FO 5737	408	2833	9	5106	9	260	40059	10
Rietkuil	DRT 186	FO 9112	418	1163	5	6023	15	264	60596	16
Rietkuil	DRT 186	FO 9117	797	1853	13	3437	16	958	28233	36
Rietkuil	DRT 179	FO 921	3906	723	12	10057	20	629	66799	50
Rietkuil	DRT 179	FO 948	2838	2991	7	6609	4	83	38536	70
Dominion	DDR 007	DO 3337	655	7723	14	13038	10	674	47894	31

Dominion	DDR 007	DO 3342	408	2833	9	5106	9	260	40059	10
Dominion	DDR 007	DO 3391	418	1163	5	6023	15	264	60596	16
Dominion	DDR 077	CO 5512	797	1853	13	3437	16	958	28233	36
Dominion	DDR 077	CO 5516	3906	723	12	10057	20	629	66799	50
Dominion	DDR 077	CO 5602	2838	2991	7	6609	4	83	38536	70
Dominion	DDR 023	DO 1524	655	7723	14	13038	10	674	47894	31
Dominion	DDR 023	DO 1525	408	2833	9	5106	9	260	40059	10
LLD	ppm	/	2	13	4	12	5	4	15	/

section	borehole ID	sample	Ni	Cu	Zn	Ga	Ge	As	Se	Br
Rietkuil	DRT 056	AO 1292	83	171	1324	9	<D.L.	37	<D.L.	<D.L.
Rietkuil	DRT 056	AO 1320	36	53	1	9	<D.L.	51	<D.L.	<D.L.
Rietkuil	DRT 050	AO 1618	643	123	39	26	<D.L.	223	8	<D.L.
Rietkuil	DRT 050	AO 1620	55	59	7	6	<D.L.	23	1	<D.L.
Rietkuil	DRT 050	AO 1638	20	61	0	10	<D.L.	10	<D.L.	<D.L.
Rietkuil	DRT 058	AO 3883	92	76	99	7	2	203	1	<D.L.
Rietkuil	DRT 058	AO 3886	39	87	164	6	1	11	<D.L.	<D.L.
Rietkuil	DRT 079	AO 5268	288	129	228	12	<D.L.	629	<D.L.	<D.L.

Rietkuil	DRT 079	AO 5274	114	170	480	7	<D.L.	235	<D.L.	<D.L.
Rietkuil	DRT 070	AO 5686	450	291	29	18	<D.L.	880	2	<D.L.
Rietkuil	DRT 070	AO 5688	50	58	10	3	1	92	<D.L.	<D.L.
Rietkuil	DRT 70	AO 8041	5	25	11	3	<D.L.	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 70	AO 8042	12	26	2	4	<D.L.	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 073	AO 8286	291	157	29	11	<D.L.	475	1	<D.L.
Rietkuil	DRT 073	AO 8290	76	96	260	5	<D.L.	178	<D.L.	<D.L.
Rietkuil	DRT 076	AO 8518	109	165	25	4	<D.L.	55	<D.L.	<D.L.
Rietkuil	DRT 076	AO 8521	54	111	257	6	<D.L.	75	<D.L.	<D.L.
Rietkuil	DRT 96	BO 439	48	182	61	4	<D.L.	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 096	BO 445	56	123	133	7	<D.L.	16	<D.L.	<D.L.
Rietkuil	DRT 103	BO 517	174	92	0	0	<D.L.	50	2	<D.L.
Rietkuil	DRT 103	BO 518	115	213	190	7	<D.L.	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 090	BO 8976	41	62	122	9	<D.L.	113	1	<D.L.
Rietkuil	DRT 090	BO 8981	212	222	74	9	<D.L.	163	<D.L.	<D.L.
Rietkuil	DRT 115	CO 3621	78	104	400	5	0,98	110	<D.L.	<D.L.
Rietkuil	DRT 115	CO 3623	68	118	6	15	<D.L.	11	<D.L.	<D.L.
Rietkuil	DRT 115	CO 3637	24	29	525	10	0,92	48	<D.L.	<D.L.
Rietkuil	DRT 099	CO 4575	93	428	15	6	1,61	72	<D.L.	<D.L.
Rietkuil	DRT 099	CO 4585	60	155	75	10	1,45	92	<D.L.	<D.L.
Rietkuil	DRT 098	CO 6608	191	412	34	5	0,97	30	<D.L.	<D.L.
Rietkuil	DRT 098	CO 6613	107	97	6202	7	1,23	101	1	<D.L.
section	borehole ID	sample	Ni	Cu	Zn	Ga	Ge	As	Se	Br
Rietkuil	DRT 113	CO 6778	64	101	88	5	1,24	111	2	<D.L.
Rietkuil	DRT 113	CO 6789	79	141	8	8	<D.L.	309	<D.L.	<D.L.
Rietkuil	DRT 113	CO 6833	45	77	62	6	<D.L.	20	<D.L.	<D.L.
Rietkuil	DRT 100	CO 7375	104	405	61	10	<D.L.	92	<D.L.	<D.L.
Rietkuil	DRT 100	CO 7387	160	145	12975	22	0,78	44	<D.L.	<D.L.
Rietkuil	DRT 100	CO 7422	37	62	5	5	<D.L.	28	<D.L.	<D.L.
Rietkuil	DRT 095	CO 7744	80	356	8	6	1,45	212	2	<D.L.
Rietkuil	DRT 095	CO 7753	58	95	14	7	<D.L.	127	2	<D.L.
Rietkuil	DRT 104	CO 8294	26	31	0	8	<D.L.	118	<D.L.	<D.L.

Rietkuil	DRT 104	CO 8296	283	295	169	15	<D.L.	305	1	<D.L.
Rietkuil	DRT 024	DO 1823	6	19	199	13	<D.L.	543	<D.L.	<D.L.
Rietkuil	DRT 017	DO 318	64	152	8	9	<D.L.	126	<D.L.	<D.L.
Rietkuil	DRT 017	DO 322	99	192	440	7	<D.L.	3	<D.L.	<D.L.
Rietkuil	DRT 017	DO 324	37	32	10	8	<D.L.	56	<D.L.	<D.L.
Rietkuil	DRT 039	DO 6920	67	54	20	8	<D.L.	117	<D.L.	<D.L.
Rietkuil	DRT 034	DO 8627	198	142	5732	21	<D.L.	198	<D.L.	<D.L.
Rietkuil	DRT 034	DO 8628	346	137	3633	26	<D.L.	447	<D.L.	<D.L.
Rietkuil	DRT 034	DO 8629	55	44	1039	7	<D.L.	81	<D.L.	<D.L.
Rietkuil	DRT 034	DO 8631	47	58	138	6	<D.L.	65	<D.L.	<D.L.
Rietkuil	DRT 101	EO 1040	96	197	53	7	<D.L.	274	<D.L.	<D.L.
Rietkuil	DRT 131	EO 3027	72	151	26	5	<D.L.	52	1,70	<D.L.
Rietkuil	DRT 131	EO 3030	33	147	63	4	<D.L.	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 131	EO 3054	12	62	9	7	<D.L.	14	<D.L.	<D.L.
Rietkuil	DRT 131	EO 3058	6	25	467	11	<D.L.	33	1	<D.L.
Rietkuil	DRT 106	EO 3270	149	172	82	11	1	104	<D.L.	<D.L.
Rietkuil	DRT 164	EO 4923	125	143	39	7	1	233	1,17	<D.L.
Rietkuil	DRT 164	EO 4924	125	144	41	7	1	227	<D.L.	<D.L.
Rietkuil	DRT 094	EO 5605	75	177	51	6	1	16	<D.L.	<D.L.
Rietkuil	DRT 094	EO 5611	83	164	29	6	1	57	<D.L.	<D.L.
Rietkuil	DRT 094	EO 5633	30	59	2	10	<D.L.	38	<D.L.	<D.L.
section	borehole ID	sample	Ni	Cu	Zn	Ga	Ge	As	Se	Br
Rietkuil	DRT 134	EO 6084	187	244	27	15	<D.L.	19	2	<D.L.
Rietkuil	DRT 101	EO1035	91	272	876	13	<D.L.	57	1	<D.L.
Rietkuil	DRT 173	FO 5548	92	243	25	7	<D.L.	108	3	<D.L.
Rietkuil	DRT 108	FO 5722	121	380	22	10	<D.L.	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 108	FO 5732	131	303	38	14	<D.L.	23	2	<D.L.
Rietkuil	DRT 108	FO 5737	58	100	31	10	1	26	3	<D.L.
Rietkuil	DRT 186	FO 9112	80	189	7	9	<D.L.	32	<D.L.	<D.L.
Rietkuil	DRT 186	FO 9117	100	164	278	10	<D.L.	32	2	<D.L.
Rietkuil	DRT 179	FO 921	128	312	30	12	<D.L.	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 179	FO 948	82	85	44	10	<D.L.	272	<D.L.	<D.L.

Dominion	DDR 007	DO 3337	95	160	15	4	<D.L.	145	<D.L.	<D.L.
Dominion	DDR 007	DO 3342	46	80	8	13	<D.L.	17	<D.L.	<D.L.
Dominion	DDR 007	DO 3391	17	71	8	13	<D.L.	17	<D.L.	<D.L.
Dominion	DDR 077	CO 5512	191	411	34	5	1	58	<D.L.	<D.L.
Dominion	DDR 077	CO 5516	107	97	6202	7	<D.L.	76	<D.L.	<D.L.
Dominion	DDR 077	CO 5602	64	101	88	5	<D.L.	25	<D.L.	<D.L.
Dominion	DDR 023	DO 1524	61	91	200	7	<D.L.	51	2	<D.L.
Dominion	DDR 023	DO 1525	107	206	21	6	<D.L.	230	<D.L.	<D.L.
LLD	ppm	/	1	1	1	1	1	7	1	1

Abbreviations : LLD = Lowest limit of detection in wt %, <D.L. = beyond Detection Limit

section	borehole ID	sample	Rb	Sr	Y	Zr	Nb	Mo	Ag	Cd
Rietkuil	DRT 056	AO 1292	53	26	205	168	182	11	7	14
Rietkuil	DRT 056	AO 1320	80	0	407	126	210	15	<D.L.	<D.L.
Rietkuil	DRT 050	AO 1618	124	392	1171	2640	1012	<D.L.	19	7
Rietkuil	DRT 050	AO 1620	72	13	75	106	93	5	<D.L.	<D.L.
Rietkuil	DRT 050	AO 1638	110	20	153	284	189	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 058	AO 3883	30	17	182	137	232	16	<D.L.	10
Rietkuil	DRT 058	AO 3886	62	7	94	117	77	8	<D.L.	<D.L.
Rietkuil	DRT 079	AO 5268	39	76	483	489	533	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 079	AO 5274	31	27	266	239	253	2	7	8
Rietkuil	DRT 070	AO 5686	103	250	864	2142	726	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 070	AO 5688	23	8	121	144	140	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 70	AO 8041	41	4	11	45	10	<D.L.	<D.L.	<D.L.

Rietkuil	DRT 70	AO 8042	61	5	27	46	23	2	<D.L.	<D.L.
Rietkuil	DRT 073	AO 8286	69	165	533	1173	401	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 073	AO 8290	32	13	142	122	170	1	<D.L.	<D.L.
Rietkuil	DRT 076	AO 8518	35	14	178	134	141	34	<D.L.	<D.L.
Rietkuil	DRT 076	AO 8521	52	9	155	88	156	<D.L.	6	6
Rietkuil	DRT 96	BO 439	41	8	136	425	55	19	<D.L.	<D.L.
Rietkuil	DRT 096	BO 445	62	11	102	250	50	2	<D.L.	<D.L.
Rietkuil	DRT 103	BO 517	2	2	1	17	0	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 103	BO 518	40	12	179	188	190	20	<D.L.	<D.L.
Rietkuil	DRT 090	BO 8976	61	89	435	633	274	6	<D.L.	<D.L.
Rietkuil	DRT 090	BO 8981	53	26	205	168	182	11	13	<D.L.
Rietkuil	DRT 115	CO 3621	80	52	373	277	375	20	<D.L.	<D.L.
Rietkuil	DRT 115	CO 3623	36	22	176	222	135	19	<D.L.	<D.L.
Rietkuil	DRT 115	CO 3637	157	29	187	149	220	38	7	6
Rietkuil	DRT 099	CO 4575	51	12	264	164	294	28	<D.L.	<D.L.
Rietkuil	DRT 099	CO 4585	45	5	166	196	120	6	<D.L.	<D.L.
Rietkuil	DRT 098	CO 6608	37	7	278	565	147	24	<D.L.	<D.L.
Rietkuil	DRT 098	CO 6613	34	12	190	227	167	1	7	<D.L.
Rietkuil	DRT 113	CO 6778	49	6	136	74	89	15	<D.L.	<D.L.
Rietkuil	DRT 113	CO 6789	59	11	146	312	85	17	<D.L.	9
section	borehole ID	sample	Rb	Sr	Y	Zr	Nb	Mo	Ag	Cd
Rietkuil	DRT 113	CO 6833	48	10	88	125	60	41	<D.L.	<D.L.
Rietkuil	DRT 100	CO 7375	49	32	294	392	191	23	<D.L.	<D.L.
Rietkuil	DRT 100	CO 7387	56	59	383	732	212	4	8	9
Rietkuil	DRT 100	CO 7422	48	39	368	405	528	23	<D.L.	<D.L.
Rietkuil	DRT 095	CO 7744	62	9	188	550	173	18	<D.L.	7
Rietkuil	DRT 095	CO 7753	40	5	140	141	136	1	11	8
Rietkuil	DRT 104	CO 8294	56	19	161	156	114	<D.L.	<D.L.	6
Rietkuil	DRT 104	CO 8296	75	11	155	170	118	15	<D.L.	<D.L.
Rietkuil	DRT 024	DO 1823	82	72	610	1131	524	12	<D.L.	<D.L.
Rietkuil	DRT 017	DO 318	82	104	443	604	439	15	<D.L.	<D.L.
Rietkuil	DRT 017	DO 322	71	31	352	191	230	17	<D.L.	<D.L.
Rietkuil	DRT 017	DO 324	47	14	217	131	230	15	<D.L.	<D.L.
Rietkuil	DRT 039	DO 6920	74	19	214	409	135	26	9	<D.L.

Rietkuil	DRT 034	DO 8627	46	2	249	362	198	16	11	47
Rietkuil	DRT 034	DO 8628	50	3	293	267	413	5	27	33
Rietkuil	DRT 034	DO 8629	31	26	167	156	169	3	<D.L.	7
Rietkuil	DRT 034	DO 8631	48	5	41	97	26	10	<D.L.	<D.L.
Rietkuil	DRT 101	EO 1040	80	12	135	166	110	14	<D.L.	<D.L.
Rietkuil	DRT 131	EO 3027	31	3	100	126	83	13	<D.L.	<D.L.
Rietkuil	DRT 131	EO 3030	159	16	66	182	51	11	<D.L.	<D.L.
Rietkuil	DRT 131	EO 3054	159	16	66	182	51	12	<D.L.	<D.L.
Rietkuil	DRT 131	EO 3058	80	52	373	277	375	31	<D.L.	6
Rietkuil	DRT 106	EO 3270	36	22	176	222	135	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 164	EO 4923	64	21	285	229	146	19	<D.L.	<D.L.
Rietkuil	DRT 164	EO 4924	93	11	403	730	400	19	<D.L.	7
Rietkuil	DRT 094	EO 5605	91	15	678	727	882	16	<D.L.	<D.L.
Rietkuil	DRT 094	EO 5611	52	5	163	200	212	4	<D.L.	<D.L.
Rietkuil	DRT 094	EO 5633	69	7	158	289	154	10	<D.L.	<D.L.
Rietkuil	DRT 134	EO 6084	93	10	365	529	272	41	<D.L.	<D.L.
Rietkuil	DRT 101	EO1035	44	16	231	354	177	<D.L.	<D.L.	<D.L.
Rietkuil	DRT 173	FO 5548	30	8	177	185	195	8	<D.L.	<D.L.
Rietkuil	DRT 108	FO 5722	52	7	43	163	16	18	<D.L.	<D.L.
section	borehole ID	sample	Rb	Sr	Y	Zr	Nb	Mo	Ag	Cd
Rietkuil	DRT 108	FO 5732	62	8	76	187	56	71	<D.L.	<D.L.
Rietkuil	DRT 108	FO 5737	98	36	284	646	136	20	<D.L.	<D.L.
Rietkuil	DRT 186	FO 9112	43	15	389	458	311	6	<D.L.	<D.L.
Rietkuil	DRT 186	FO 9117	41	53	280	457	235	<D.L.	6	<D.L.
Rietkuil	DRT 179	FO 921	41	54	282	460	235	2	<D.L.	<D.L.
Rietkuil	DRT 179	FO 948	48	31	196	248	139	3	<D.L.	<D.L.
Dominion	DDR 007	DO 3337	55	6	127	128	119	8	<D.L.	<D.L.
Dominion	DDR 007	DO 3342	103	24	172	188	111	4	<D.L.	<D.L.
Dominion	DDR 007	DO 3391	107	108	513	814	251	4	<D.L.	<D.L.
Dominion	DDR 077	CO 5512	61	28	180	207	181	26	<D.L.	<D.L.
Dominion	DDR 077	CO 5516	102	32	113	222	73	31	<D.L.	20
Dominion	DDR 077	CO 5602	109	82	435	685	246	7	<D.L.	<D.L.
Dominion	DDR 023	DO 1524	35	22	385	350	439	4	8	<D.L.
Dominion	DDR 023	DO 1525	55	18	215	177	178	7	<D.L.	<D.L.

LLD	ppm	/	1	1	1	1	1	1	6	6
------------	------------	----------	----------	----------	----------	----------	----------	----------	----------	----------

Abbreviations : LLD = Lowest limit of detection in wt %, <D.L. = beyond Detection Limit

section	borehole ID	sample	Sn	Sb	Te	I	Ba	Yb	Hf	Ta
Rietkuil	DRT 056	AO 1292	25	<D.L.	<D.L.	8	87	<D.L.	8	95
Rietkuil	DRT 056	AO 1320	<D.L.	<D.L.	<D.L.	15	140	15	6	128
Rietkuil	DRT 050	AO 1618	181	<D.L.	<D.L.	<D.L.	1372	21	84	667
Rietkuil	DRT 050	AO 1620	18	<D.L.	<D.L.	11	131	<D.L.	<D.L.	40
Rietkuil	DRT 050	AO 1638	46	<D.L.	<D.L.	12	160	<D.L.	8	79
Rietkuil	DRT 058	AO 3883	35	<D.L.	<D.L.	<D.L.	39	<D.L.	8	110
Rietkuil	DRT 058	AO 3886	33	<D.L.	<D.L.	<D.L.	171	<D.L.	<D.L.	424
Rietkuil	DRT 079	AO 5268	103	<D.L.	<D.L.	<D.L.	87	<D.L.	19	54
Rietkuil	DRT 079	AO 5274	18	<D.L.	<D.L.	<D.L.	256	<D.L.	8	1
Rietkuil	DRT 070	AO 5686	1	<D.L.	<D.L.	<D.L.	68	<D.L.	66	5
Rietkuil	DRT 070	AO 5688	0	<D.L.	<D.L.	9	41	<D.L.	<D.L.	242
Rietkuil	DRT 70	AO 8041	94	<D.L.	<D.L.	11	63	<D.L.	<D.L.	82
Rietkuil	DRT 70	AO 8042	30	<D.L.	<D.L.	16	396	<D.L.	<D.L.	59
Rietkuil	DRT 073	AO 8286	9	<D.L.	<D.L.	<D.L.	65	<D.L.	37	89
Rietkuil	DRT 073	AO 8290	26	<D.L.	<D.L.	14	29	<D.L.	<D.L.	8

Rietkuil	DRT 076	AO 8518	0	<D.L.	<D.L.	<D.L.	71	<D.L.	<D.L.	10
Rietkuil	DRT 076	AO 8521	0	<D.L.	<D.L.	<D.L.	34	<D.L.	<D.L.	0
Rietkuil	DRT 96	BO 439	0	<D.L.	<D.L.	11	64	8	9	86
Rietkuil	DRT 096	BO 445	5	<D.L.	<D.L.	14	1	<D.L.	9	139
Rietkuil	DRT 103	BO 517	42	<D.L.	<D.L.	<D.L.	43	<D.L.	9	200
Rietkuil	DRT 103	BO 518	54	<D.L.	<D.L.	10	220	<D.L.	<D.L.	52
Rietkuil	DRT 090	BO 8976	6	<D.L.	<D.L.	9	166	<D.L.	6	62
Rietkuil	DRT 090	BO 8981	16	<D.L.	<D.L.	10	43	10	21	147
Rietkuil	DRT 115	CO 3621	72	<D.L.	<D.L.	12	198	<D.L.	8	45
Rietkuil	DRT 115	CO 3623	14	<D.L.	<D.L.	13	130	<D.L.	<D.L.	37
Rietkuil	DRT 115	CO 3637	0	<D.L.	<D.L.	12	28	<D.L.	6	81
Rietkuil	DRT 099	CO 4575	44	<D.L.	<D.L.	<D.L.	21	<D.L.	8	92
Rietkuil	DRT 099	CO 4585	68	<D.L.	<D.L.	11	29	<D.L.	17	29
Rietkuil	DRT 098	CO 6608	8	<D.L.	<D.L.	<D.L.	117	<D.L.	<D.L.	16
Rietkuil	DRT 098	CO 6613	6	<D.L.	<D.L.	<D.L.	97	<D.L.	11	83
Rietkuil	DRT 113	CO 6778	14	<D.L.	<D.L.	15	35	<D.L.	21	70
Rietkuil	DRT 113	CO 6789	3	<D.L.	<D.L.	10	154	<D.L.	<D.L.	298
Rietkuil	DRT 113	CO 6833	40	<D.L.	<D.L.	10	145	9	14	48
section	borehole ID	sample	Sn	Sb	Te	I	Ba	Yb	Hf	Ta
Rietkuil	DRT 100	CO 7375	10	<D.L.	<D.L.	<D.L.	68	<D.L.	6	57
Rietkuil	DRT 100	CO 7387	15	<D.L.	<D.L.	13	53	<D.L.	6	43
Rietkuil	DRT 100	CO 7422	11	<D.L.	<D.L.	<D.L.	18	5	<D.L.	35
Rietkuil	DRT 095	CO 7744	4	<D.L.	<D.L.	<D.L.	77	<D.L.	31	243
Rietkuil	DRT 095	CO 7753	54	<D.L.	<D.L.	<D.L.	74	<D.L.	19	424
Rietkuil	DRT 104	CO 8294	40	<D.L.	<D.L.	<D.L.	156	<D.L.	8	54
Rietkuil	DRT 104	CO 8296	18	<D.L.	<D.L.	<D.L.	78	<D.L.	<D.L.	254
Rietkuil	DRT 024	DO 1823	35	<D.L.	<D.L.	<D.L.	105	<D.L.	7	116
Rietkuil	DRT 017	DO 318	20	<D.L.	<D.L.	<D.L.	43	<D.L.	8	108
Rietkuil	DRT 017	DO 322	72	<D.L.	<D.L.	9	83	<D.L.	<D.L.	58
Rietkuil	DRT 017	DO 324	60	<D.L.	<D.L.	9	21	<D.L.	5	89
Rietkuil	DRT 039	DO 6920	18	<D.L.	<D.L.	<D.L.	133	<D.L.	11	254
Rietkuil	DRT 034	DO 8627	2	<D.L.	<D.L.	<D.L.	133	<D.L.	19	88
Rietkuil	DRT 034	DO 8628	2	<D.L.	<D.L.	<D.L.	130	<D.L.	2	7
Rietkuil	DRT 034	DO 8629	48	<D.L.	<D.L.	15	224	<D.L.	5	53
Rietkuil	DRT 034	DO 8631	23	<D.L.	<D.L.	15	385	<D.L.	10	32

Rietkuil	DRT 101	EO 1040	23	<D.L.	<D.L.	13	82	<D.L.	13	20
Rietkuil	DRT 131	EO 3027	14	<D.L.	<D.L.	17	78	<D.L.	<D.L.	20
Rietkuil	DRT 131	EO 3030	49	<D.L.	<D.L.	13	68	<D.L.	<D.L.	93
Rietkuil	DRT 131	EO 3054	140	<D.L.	<D.L.	13	46	<D.L.	<D.L.	260
Rietkuil	DRT 131	EO 3058	29	<D.L.	<D.L.	12	27	<D.L.	15	600
Rietkuil	DRT 106	EO 3270	12	<D.L.	<D.L.	<D.L.	56	<D.L.	16	105
Rietkuil	DRT 164	EO 4923	9	<D.L.	<D.L.	<D.L.	44	<D.L.	14	59
Rietkuil	DRT 164	EO 4924	26	<D.L.	<D.L.	18	103	<D.L.	11	106
Rietkuil	DRT 094	EO 5605	21	<D.L.	<D.L.	11	42	<D.L.	9	73
Rietkuil	DRT 094	EO 5611	0	<D.L.	<D.L.	<D.L.	98	<D.L.	<D.L.	79
Rietkuil	DRT 094	EO 5633	4	<D.L.	<D.L.	9	124	8	5	1
Rietkuil	DRT 134	EO 6084	2	<D.L.	<D.L.	<D.L.	54	<D.L.	22	15
Rietkuil	DRT 101	EO1035	34	<D.L.	<D.L.	18	32	<D.L.	12	40
Rietkuil	DRT 173	FO 5548	18	<D.L.	<D.L.	<D.L.	109	<D.L.	7	188
Rietkuil	DRT 108	FO 5722	23	<D.L.	<D.L.	10	130	<D.L.	8	103
Rietkuil	DRT 108	FO 5732	9	<D.L.	<D.L.	<D.L.	88	<D.L.	19	103
Rietkuil	DRT 108	FO 5737	23	<D.L.	<D.L.	<D.L.	114	<D.L.	15	49
section	borehole ID	sample	Sn	Sb	Te	I	Ba	Yb	Hf	Ta
Rietkuil	DRT 186	FO 9112	15	<D.L.	<D.L.	<D.L.	127	<D.L.	6	39
Rietkuil	DRT 186	FO 9117	8	<D.L.	<D.L.	8	55	<D.L.	14	45
Rietkuil	DRT 179	FO 921	9	<D.L.	<D.L.	12	78	<D.L.		94
Dominion	DRT 179	FO 948	9	<D.L.	<D.L.	11	105	11	10	67
Dominion	DDR 007	DO 3337	15	<D.L.	<D.L.	<D.L.	43	<D.L.	6	22
Dominion	DDR 007	DO 3342	41	<D.L.	<D.L.	<D.L.	83	<D.L.	6	99
Dominion	DDR 007	DO 3391	18	<D.L.	<D.L.	<D.L.	133	<D.L.	6	67
Dominion	DDR 077	CO 5512	35	<D.L.	<D.L.	12	29	<D.L.	9	22
Dominion	DDR 077	CO 5516	20	<D.L.	<D.L.	<D.L.	117	<D.L.	<D.L.	99
Dominion	DDR 077	CO 5602	72	<D.L.	<D.L.	<D.L.	97	<D.L.	9	218
Dominion	DDR 023	DO 1524	60	<D.L.	<D.L.	<D.L.	513	<D.L.	14	84
Dominion	DDR 023	DO 1525	18	<D.L.	<D.L.	<D.L.	44	<D.L.	11	222
LLD	ppm	/	5	7	0	8	N.D.	4	5	3

Abbreviations : LLD = Lowest limit of detection in wt %, <D.L. = beyond Detection Limit

section	borehole ID	sample	W	Hg	Tl	Pb	Bi	Th	U
Rietkuil	DRT 056	AO 1292	7	<D.L.	4	846	5	321	888
Rietkuil	DRT 056	AO 1320	24	<D.L.	7	2426	0	995	4268
Rietkuil	DRT 050	AO 1618	59	<D.L.	18	3588	133	3210	7524
Rietkuil	DRT 050	AO 1620	3	<D.L.	4	146	5	134	304
Rietkuil	DRT 050	AO 1638	11	<D.L.	4	165	0	294	464
Rietkuil	DRT 058	AO 3883	12	<D.L.	<D.L.	401	6	444	1303
Rietkuil	DRT 058	AO 3886	5	<D.L.	4	161	4	121	183
Rietkuil	DRT 079	AO 5268	20	<D.L.	10	2584	53	1230	2883
Rietkuil	DRT 079	AO 5274	11	<D.L.	<D.L.	650	10	433	824
Rietkuil	DRT 070	AO 5686	47	<D.L.	9	2396	83	2092	3410
Rietkuil	DRT 070	AO 5688	8	<D.L.	4	226	4	189	223
Rietkuil	DRT 70	AO 8041	<D.L.	<D.L.	<D.L.	22	0	10	27
Rietkuil	DRT 70	AO 8042	<D.L.	<D.L.	<D.L.	130	0	29	99
Rietkuil	DRT 073	AO 8286	28	<D.L.	10	1897	43	1357	3056
Rietkuil	DRT 073	AO 8290	5	<D.L.	3	614	5	219	566
Rietkuil	DRT 076	AO 8518	13	<D.L.	3	473	9	463	971
Rietkuil	DRT 076	AO 8521	7	<D.L.	<D.L.	453	7	186	715
Rietkuil	DRT 96	BO 439	10	<D.L.	<D.L.	58	1	79	30

Rietkuil	DRT 096	BO 445	6	<D.L.	<D.L.	49	1	149	139
Rietkuil	DRT 103	BO 517	2	<D.L.	<D.L.	6	0	934	2196
Rietkuil	DRT 103	BO 518	8	<D.L.	<D.L.	326	4	709	1627
Rietkuil	DRT 090	BO 8976	21	<D.L.	5	2070	20	736	1408
Rietkuil	DRT 090	BO 8981	18	<D.L.	8	690	21	236	449
Rietkuil	DRT 115	CO 3621	<D.L.	<D.L.	<D.L.	515	9	287	232
Rietkuil	DRT 115	CO 3623	9	<D.L.	<D.L.	2859	1	254	184
Rietkuil	DRT 115	CO 3637	6	<D.L.	7	219	5	520	704
Rietkuil	DRT 099	CO 4575	14	<D.L.	<D.L.	38	3	357	173
Rietkuil	DRT 099	CO 4585	21	<D.L.	<D.L.	486	15	209	151
Rietkuil	DRT 098	CO 6608	<D.L.	<D.L.	<D.L.	312	9	246	492
Rietkuil	DRT 098	CO 6613	12	<D.L.	4	1685	0	79	58
Rietkuil	DRT 113	CO 6778	9	<D.L.	5	305	4	666	362
Rietkuil	DRT 113	CO 6789	9	0,09	9	125	2	790	461
section	borehole ID	sample	W	Hg	Tl	Pb	Bi	Th	U
Rietkuil	DRT 113	CO 6833	9	<D.L.	<D.L.	113	5	302	637
Rietkuil	DRT 100	CO 7375	30	<D.L.	<D.L.	230	0	371	134
Rietkuil	DRT 100	CO 7387	23	<D.L.	<D.L.	1438	36	190	241
Rietkuil	DRT 100	CO 7422	16	<D.L.	<D.L.	768	21	359	710
Rietkuil	DRT 095	CO 7744	13	<D.L.	8	266	11	1437	1596
Rietkuil	DRT 095	CO 7753	13	<D.L.	5	565	6	<D.L.	<D.L.
Rietkuil	DRT 104	CO 8294	18	<D.L.	4	459	9	224	194
Rietkuil	DRT 104	CO 8296	16	<D.L.	<D.L.	850	19	229	607
Rietkuil	DRT 024	DO 1823	8	<D.L.	7	1439	22	684	2043
Rietkuil	DRT 017	DO 318	<D.L.	<D.L.	4	504	5	335	835
Rietkuil	DRT 017	DO 322	8	<D.L.	<D.L.	261	0	39	31
Rietkuil	DRT 017	DO 324	10	<D.L.	<D.L.	223	1	236	278
Rietkuil	DRT 039	DO 6920	4	<D.L.	10	170	3	406	1684
Rietkuil	DRT 034	DO 8627	4	<D.L.	33	95	4	880	1154
Rietkuil	DRT 034	DO 8628	17	<D.L.	26	95	4	1661	2943
Rietkuil	DRT 034	DO 8629	<D.L.	<D.L.	5	1473	8	320	335
Rietkuil	DRT 034	DO 8631	15	<D.L.	8	6150	0	319	166
Rietkuil	DRT 101	EO 1040	<D.L.	<D.L.	<D.L.	5838	27	273	601
Rietkuil	DRT 131	EO 3027	9	<D.L.	4	679	4	1168	3237

Rietkuil	DRT 131	EO 3030	16	<D.L.	<D.L.	1314	0	85	41
Rietkuil	DRT 131	EO 3054	15	<D.L.	<D.L.	637	16	124	74
Rietkuil	DRT 131	EO 3058	12	<D.L.	5	216	7	75	83
Rietkuil	DRT 106	EO 3270	<D.L.	<D.L.	4	515	9	872	1811
Rietkuil	DRT 164	EO 4923	7	<D.L.	6	218	9	781	643
Rietkuil	DRT 164	EO 4924	9	<D.L.	4	69	0	605	498
Rietkuil	DRT 094	EO 5605	28	<D.L.	<D.L.	26	2	267	170
Rietkuil	DRT 094	EO 5611	10	<D.L.	<D.L.	382	6	338	232
Rietkuil	DRT 094	EO 5633	7	<D.L.	4	1182	34	387	1302
Rietkuil	DRT 134	EO 6084	22	<D.L.	4	402	9	1105	537
Rietkuil	DRT 101	EO1035	24	<D.L.	5	402	8	327	423
Rietkuil	DRT 173	FO 5548	12	<D.L.	<D.L.	163	6	244	140
Rietkuil	DRT 108	FO 5722	19	<D.L.	<D.L.	164	2	732	838
section	borehole ID	sample	W	Hg	Tl	Pb	Bi	Th	U
Rietkuil	DRT 108	FO 5732	6	<D.L.	<D.L.	525	2	718	742
Rietkuil	DRT 108	FO 5737	32	<D.L.	<D.L.	346	10	190	149
Rietkuil	DRT 186	FO 9112	7	<D.L.	<D.L.	110	8	119	52
Rietkuil	DRT 186	FO 9117	9	<D.L.	7	58	2	285	607
Rietkuil	DRT 179	FO 921	6	<D.L.	<D.L.	223	13	630	427
Rietkuil	DRT 179	FO 948	31	<D.L.	9	599	4	1164	3234
Dominion	DDR 007	DO 3337	10	<D.L.	<D.L.	223	6	325	998
Dominion	DDR 007	DO 3342	4	<D.L.	<D.L.	1065	26	65	230
Dominion	DDR 007	DO 3391	4	<D.L.	<D.L.	27	1	97	178
Dominion	DDR 077	CO 5512	11	<D.L.	<D.L.	1573	3	572	831
Dominion	DDR 077	CO 5516	<D.L.	<D.L.	14	218	9	302	676
Dominion	DDR 077	CO 5602	9	<D.L.	<D.L.	69	0	191	1155
Dominion	DDR 023	DO 1524	13	<D.L.	5	26	2	199	36
Dominion	DDR 023	DO 1525	18	<D.L.	5	382	6	342	81
LLD	ppm	/	3	0	3	2	3	3	2

Abbreviations: LLD = Lowest limit of detection, <D.L. = beyond Detection Limit

Table 3: REE and some trace element analyses

Sample	Ba	Be	Co	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta	Th	U	V	W	Zr	Y	La
DRT070	7	59	<1	30	1	3	7	194	24	24	13	55	265	315	10	2	223	138
DRT073	8	57	<1	64	2	3	5	319	32	34	20	100	329	816	<8	2	144	195
DRT096	9	61	1	13	2	7	12	54	64	5	11	9	90	32	21	1	302	120
DRT103	11	118	2	65	10	6	20	546	72	66	104	201	909	2385	25	2	638	455
DRT090	10	33	1	42	2	4	7	203	35	13	20	71	272	523	30	2	233	210
DRT113	13	59	3	19	2	6	18	200	59	12	12	37	253	531	37	1	582	176
DRT115	7	52	1	31	1	5	11	179	37	10	27	48	245	193	34	2	286	187
DRT100	7	79	<1	16	4	8	7	151	75	4	15	37	340	725	28	2	205	162
DRT095	0	11	<1	1	<D.L.	1	1	1	2	<1	2	0	1	1	33	2	18	2
DRT095A	0	141	3	111	3	8	<D.L.	677	74	57	87	210	1394	1753	30	4	1194	548
DRT104	12	71	<1	30	3	7	7	136	57	14	22	39	219	187	15	1	187	166
DRT034	12	63	1	45	2	5	11	201	64	18	10	54	332	158	29	2	359	160
DRT017	8	58	1	23	4	7	6	137	72	6	13	48	219	254	19	1	196	129
DRT101	12	56	<1	27	2	7	15	225	43	27	20	65	306	406	34	2	410	232
DRT134DI	16	52	2	42	3	8	8	219	57	17	23	76	266	541	14	1	194	217
DRT186	13	90	4	85	4	7	23	538	73	43	113	194	926	460	21	2	661	395
MDL	4	1	1	0	0	1	0	0	0	1	1	0	0	0	8	1	0	0
Ref. Mat.																		
STD SO-18	514	1	27	7	18	10	23	28	15	408	7	10	16	203	15	291	32	12
STD SO-18	504	<1	27	7	17	10	21	28	15	401	7	10	16	199	15	287	31	12
STD SO-18	518	2	28	7	18	10	22	29	15	421	7	10	17	211	16	298	33	13

STD SO-18	518	1	28	7	18	10	23	29	15	417	8	10	17	210	15	297	33	12
BLK	<1	<1	<0.2	<0.1	<0.5	<0.1	<0.1	<0.1	<1	<0.5	<0.1	<0.2	<0.1	<8	<0.5	<0.1	<0.1	<0.1
BLK	<1	<1	<0.2	<0.1	<0.5	<0.1	0	<0.1	<1	<0.5	<0.1	<0.2	<0.1	<8	<0.5	<0.1	<0.1	<0.1

Sample	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
DRT070	750	74	268	42	2	33	5	27	5	13	2	13	2
DRT073	683	69	253	45	3	40	7	38	7	19	3	18	3
DRT096	337	34	117	19	1	17	3	18	3	10	2	12	2
DRT103	3074	278	1060	168	8	141	17	103	15	37	5	38	5
DRT090	798	81	305	53	3	50	8	47	8	21	3	22	3
DRT113	249	28	108	26	5	29	5	33	6	17	3	20	3
DRT115	884	89	333	54	2	43	6	36	6	16	3	18	2
DRT100	570	60	232	43	3	40	6	37	6	15	2	14	2
DRT095	8	1	3	0	0	0	0	0	0	0	0	0	0
DRT095A	5041	457	1721	268	8	210	24	134	19	47	7	49	6
DRT104	724	74	281	45	2	41	6	32	5	14	2	15	2
DRT034	1302	122	459	70	3	56	7	37	5	14	2	14	2
DRT017	583	59	220	36	2	30	5	27	5	12	2	12	2
DRT101	1070	111	411	65	3	55	8	45	8	21	3	24	3
DRT134DI	743	76	299	53	3	49	7	43	7	19	3	21	3
DRT186	3503	322	1231	189	9	148	17	96	14	34	5	36	4
MDL	0	0	0	0	0	0	0	0	0	0	0	0	0
Ref. Mat.													
STD SO-18	27	4	15	3	1	3	0	3	1	2	0	2	0
STD SO-18	27	3	14	3	1	3	1	3	1	2	0	2	0
STD SO-18	28	4	15	3	1	3	1	3	1	2	0	2	0
STD SO-18	28	3	15	3	0.89	3	1	3	1	2	0	2	0
BLK	<0.1	<0.02	<0.3	<0.05	<0.02	<0.05	<0.01	<0.05	<0.02	<0.03	<0.01	<0.05	<0.01
BLK	<0.1	<0.02	<0.3	<0.05	<0.02	<0.05	<0.01	<0.05	<0.02	<0.03	<0.01	<0.05	<0.01

Abbreviations: all elements measured in ppm, MDL = Minimum detection limit, Ref. Mat. = Reference Material, <D.L. = beyond Detection Limit,

Table 4: Pearson correlation matrix calculated with statistic program SPSS, blue marked display significant correlations (above 0.5 level)

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	S	Ca	Sc	Ti	V	Cr	Fe	Co
SiO ₂	1	-.741(**)	-.670(**)	-.462(**)	-.618(**)	-.674(**)	-0,131	-.464(**)	-.789(**)	-.786(**)	-.348(**)	-.662(**)	-.658(**)	-.748(**)	-0,179	-.566(**)	-.625(**)	-.655(**)
Al ₂ O ₃	-.741(**)	1	0,162	0,121	.244(*)	.322(**)	0,014	.899(**)	.518(**)	.409(**)	-0,021	.312(**)	.278(*)	.516(**)	0,152	.251(*)	0,175	0,192
Fe ₂ O ₃	-.670(**)	0,162	1	.726(**)	.559(**)	.344(**)	0,061	-0,189	.535(**)	.453(**)	.678(**)	.334(**)	.585(**)	.500(**)	0,068	.406(**)	.884(**)	.594(**)
MnO	-.462(**)	0,121	.726(**)	1	.463(**)	0,214	0,031	-.255(*)	.472(**)	.315(**)	.458(**)	0,186	.474(**)	.418(**)	0,220	.500(**)	.692(**)	.377(**)
MgO	-.618(**)	.244(*)	.559(**)	.463(**)	1	.502(**)	0,154	-0,006	.689(**)	.508(**)	0,127	.515(**)	.549(**)	.709(**)	0,158	.420(**)	.626(**)	.375(**)
CaO	-.674(**)	.322(**)	.344(**)	0,214	.502(**)	1	0,115	0,181	.676(**)	.866(**)	0,080	.982(**)	.443(**)	.598(**)	-0,085	.539(**)	.299(**)	.622(**)
Na ₂ O	-0,131	0,014	0,061	0,031	0,154	0,115	1	-0,040	0,044	0,130	0,211	0,114	0,173	0,048	0,054	.256(*)	0,079	.248(*)
K ₂ O	-.464(**)	.899(**)	-0,189	-.255(*)	-0,006	0,181	-0,040	1	.267(*)	0,207	-0,222	0,180	0,039	.291(**)	0,033	0,009	-0,182	-0,025
TiO ₂	-.789(**)	.518(**)	.535(**)	.472(**)	.689(**)	.676(**)	0,044	.267(*)	1	.709(**)	0,082	.651(**)	.523(**)	.961(**)	0,112	.565(**)	.536(**)	.423(**)
P ₂ O ₅	-.786(**)	.409(**)	.453(**)	.315(**)	.508(**)	.866(**)	0,130	0,207	.709(**)	1	.224(*)	.844(**)	.668(**)	.607(**)	0,155	.610(**)	.358(**)	.778(**)
S	-.348(**)	-0,021	.678(**)	.458(**)	0,127	0,080	0,211	-0,222	0,082	.224(*)	1	0,086	.510(**)	0,037	0,215	.394(**)	.617(**)	.659(**)
Ca	-.662(**)	.312(**)	.334(**)	0,186	.515(**)	.982(**)	0,114	0,180	.651(**)	.844(**)	0,086	1	.431(**)	.608(**)	-0,098	.521(**)	.295(**)	.623(**)
Sc	-.658(**)	.278(*)	.585(**)	.474(**)	.549(**)	.443(**)	0,173	0,039	.523(**)	.668(**)	.510(**)	.431(**)	1	.451(**)	.329(**)	.521(**)	.533(**)	.768(**)
Ti	-.748(**)	.516(**)	.500(**)	.418(**)	.709(**)	.598(**)	0,048	.291(**)	.961(**)	.607(**)	0,037	.608(**)	.451(**)	1	0,043	.509(**)	.540(**)	.326(**)
V	-0,179	0,152	0,068	0,220	0,158	-0,085	0,054	0,033	0,112	0,155	0,215	-0,098	.329(**)	0,043	1	.417(**)	0,049	.266(*)
Cr	-.566(**)	.251(*)	.406(**)	.500(**)	.420(**)	.539(**)	.256(*)	0,009	.565(**)	.610(**)	.394(**)	.521(**)	.521(**)	.509(**)	.417(**)	1	.416(**)	.591(**)
Fe	-.625(**)	0,175	.884(**)	.692(**)	.626(**)	.299(**)	0,079	-0,182	.536(**)	.358(**)	.617(**)	.295(**)	.533(**)	.540(**)	0,049	.416(**)	1	.489(**)
Co	-.655(**)	0,192	.594(**)	.377(**)	.375(**)	.622(**)	.248(*)	-0,025	.423(**)	.778(**)	.659(**)	.623(**)	.768(**)	.326(**)	.266(*)	.591(**)	.489(**)	1
Ni	-.752(**)	.324(**)	.497(**)	.313(**)	.481(**)	.855(**)	0,122	0,109	.611(**)	.946(**)	.325(**)	.850(**)	.695(**)	.519(**)	0,140	.610(**)	.436(**)	.859(**)
Cu	-.613(**)	.329(**)	.620(**)	.561(**)	.658(**)	.393(**)	0,001	0,059	.743(**)	.369(**)	.275(*)	.381(**)	.478(**)	.761(**)	0,008	.484(**)	.699(**)	.286(*)
Zn	-0,152	0,005	0,120	0,097	0,218	-0,001	.807(**)	-0,077	0,009	0,157	.301(**)	-0,009	.270(*)	-0,009	.400(**)	.331(**)	0,124	.350(**)
Ga	-.575(**)	.374(**)	0,194	0,088	.386(**)	.508(**)	.356(**)	.266(*)	.412(**)	.698(**)	0,125	.491(**)	.520(**)	.355(**)	.381(**)	.487(**)	0,134	.568(**)
Ge	-0,163	0,149	.302(**)	.492(**)	0,129	-0,016	-0,112	0,005	0,097	-0,051	0,163	-0,017	0,090	0,147	-0,027	0,179	.392(**)	-0,085
As	-.414(**)	0,108	.315(**)	.278(*)	0,197	.489(**)	0,149	-0,033	.316(**)	.589(**)	.284(*)	.488(**)	.413(**)	0,214	0,111	.338(**)	.236(*)	.648(**)
Se	-.382(**)	0,164	0,120	0,010	.262(*)	.712(**)	-0,041	0,108	.381(**)	.547(**)	-0,091	.702(**)	.283(*)	.334(**)	-0,075	.325(**)	0,141	.362(**)
Br	0,042	-0,041	0,030	-0,005	0,013	-0,038	-0,018	-0,067	-0,082	-0,022	0,061	-0,035	0,062	-0,090	-0,097	-0,074	0,044	-0,007
Rb	-.238(*)	.322(**)	-0,092	-0,171	0,068	0,209	-0,035	.355(**)	.224(*)	.256(*)	-0,153	0,203	0,067	.223(*)	0,192	0,101	-0,160	0,065
Sr	-.493(**)	.224(*)	0,161	0,058	.281(*)	.860(**)	0,081	0,134	.458(**)	.760(**)	-0,011	.858(**)	.334(**)	.383(**)	-0,033	.465(**)	0,103	.524(**)
Y	-.594(**)	.267(*)	.264(*)	0,117	.416(**)	.753(**)	0,119	0,143	.482(**)	.815(**)	0,082	.751(**)	.494(**)	.417(**)	0,114	.521(**)	0,220	.638(**)
Zr	-.602(**)	.322(**)	.243(*)	0,170	.371(**)	.805(**)	0,072	0,182	.573(**)	.827(**)	0,054	.796(**)	.457(**)	.493(**)	0,166	.580(**)	0,197	.581(**)
Nb	-.551(**)	.225(*)	.257(*)	0,146	.367(**)	.665(**)	.239(*)	0,111	.393(**)	.792(**)	0,148	.652(**)	.567(**)	.315(**)	0,160	.488(**)	0,201	.705(**)
Mo	-0,072	0,129	-0,023	0,041	.249(*)	0,044	0,030	0,153	0,176	-0,042	0,026	0,071	0,024	.271(*)	0,044	0,184	0,020	-0,058
Ag	-.287(*)	0,120	0,079	0,071	0,203	.245(*)	0,103	0,048	0,079	.450(**)	0,095	.246(*)	.462(**)	0,020	.282(*)	.251(*)	0,055	.467(**)
Cd	-0,197	0,039	0,110	0,097	.239(*)	0,037	.803(**)	-0,041	0,012	.226(*)	.305(**)	0,035	.363(**)	-0,007	.447(**)	.330(**)	0,107	.398(**)
Sn	-.536(**)	.247(*)	.324(**)	0,176	.252(*)	.620(**)	0,091	0,124	.340(**)	.714(**)	.230(*)	.603(**)	.518(**)	.244(*)	0,156	.406(**)	.236(*)	.731(**)
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	S	Ca	Sc	Ti	V	Cr	Fe	Co
Sb	-0,214	0,054	.247(*)	.234(*)	0,029	.248(*)	-0,035	-0,045	.231(*)	.257(*)	0,057	0,218	0,199	0,163	-0,081	0,074	.225(*)	0,183

Te	.408(**)	-0,189	-.252(*)	-0,182	-.273(*)	-.376(**)	-0,132	-0,077	-.317(**)	-.459(**)	-0,142	-.398(**)	-.231(*)	-.299(**)	-0,142	-.426(**)	-.226(*)	-.382(**)
I	.315(**)	-0,128	-0,073	0,049	-0,210	-.367(**)	0,083	-0,077	-.293(**)	-.451(**)	0,024	-.383(**)	-0,177	-.292(**)	-0,210	-.372(**)	-0,130	-.330(**)
Ba	-.435(**)	.241(*)	0,086	0,011	.251(*)	.693(**)	0,046	0,165	.336(**)	.666(**)	-0,070	.684(**)	.324(**)	.258(*)	0,155	.348(**)	0,042	.513(**)
Yb	-0,168	0,126	-0,076	-0,149	0,045	.343(**)	0,017	0,136	0,107	.327(**)	-0,207	.330(**)	0,038	0,077	-0,074	0,021	-0,171	0,203
Hf	-.594(**)	.305(**)	.259(*)	0,175	.351(**)	.810(**)	-0,040	0,174	.552(**)	.829(**)	0,057	.798(**)	.457(**)	.462(**)	0,131	.530(**)	0,201	.589(**)
Ta	-.538(**)	0,211	.248(*)	0,131	.329(**)	.646(**)	.230(*)	0,098	.344(**)	.797(**)	0,162	.632(**)	.572(**)	.253(*)	0,197	.474(**)	0,177	.737(**)
W	-.504(**)	.255(*)	0,213	0,072	.303(**)	.739(**)	-0,101	0,172	.492(**)	.679(**)	-0,018	.746(**)	.293(**)	.455(**)	-0,128	.381(**)	0,192	.455(**)
Hg	.356(**)	-0,154	-.239(*)	-0,145	-0,133	-.417(**)	.302(**)	-0,097	-.358(**)	-.455(**)	-0,058	-.430(**)	-0,178	-.334(**)	0,190	-0,106	-0,127	-.286(*)
Tl	-.383(**)	0,169	0,160	0,127	.294(**)	.314(**)	0,119	0,059	0,188	.580(**)	0,181	.307(**)	.463(**)	0,091	.605(**)	.377(**)	0,081	.606(**)
Pb	-.417(**)	0,175	0,202	0,132	.279(*)	.334(**)	0,119	0,065	0,194	.612(**)	0,215	.322(**)	.488(**)	0,096	.539(**)	.370(**)	0,116	.649(**)
Bi	-.559(**)	.242(*)	.271(*)	0,119	.250(*)	.824(**)	0,005	0,108	.457(**)	.804(**)	0,064	.809(**)	.402(**)	.359(**)	-0,020	.466(**)	0,217	.620(**)
Th	-.722(**)	.375(**)	.377(**)	.232(*)	.409(**)	.837(**)	0,123	0,208	.605(**)	.946(**)	0,210	.830(**)	.590(**)	.523(**)	0,082	.539(**)	.289(*)	.769(**)
U	-.478(**)	0,191	0,210	0,040	0,126	.671(**)	0,018	0,114	.316(**)	.742(**)	0,139	.661(**)	.388(**)	0,221	-0,002	.305(**)	0,087	.654(**)

	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Rb	Sr	Y	Zr	Nb	Mo	Ag	Cd	Sn	Sb
SiO₂	-.752(**)	-.613(**)	-0,152	-.575(**)	-0,163	-.414(**)	-.382(**)	0,042	-.238(*)	-.493(**)	-.594(**)	-.602(**)	-.551(**)	-0,072	-.287(*)	-0,197	-.536(**)	-0,214
Al₂O₃	.324(**)	.329(**)	0,005	.374(**)	0,149	0,108	0,164	-0,041	.322(**)	.224(*)	.267(*)	.322(**)	.225(*)	0,129	0,120	0,039	.247(*)	0,054

Fe ₂ O ₃	.497(**)	.620(**)	0,120	0,194	.302(**)	.315(**)	0,120	0,030	-0,092	0,161	.264(*)	.243(*)	.257(*)	-0,023	0,079	0,110	.324(**)	.247(*)
MnO	.313(**)	.561(**)	0,097	0,088	.492(**)	.278(*)	0,010	-0,005	-0,171	0,058	0,117	0,170	0,146	0,041	0,071	0,097	0,176	.234(*)
MgO	.481(**)	.658(**)	0,218	.386(**)	0,129	0,197	.262(*)	0,013	0,068	.281(*)	.416(**)	.371(**)	.367(**)	.249(*)	0,203	.239(*)	.252(*)	0,029
CaO	.855(**)	.393(**)	-0,001	.508(**)	-0,016	.489(**)	.712(**)	-0,038	0,209	.860(**)	.753(**)	.805(**)	.665(**)	0,044	.245(*)	0,037	.620(**)	.248(*)
Na ₂ O	0,122	0,001	.807(**)	.356(**)	-0,112	0,149	-0,041	-0,018	-0,035	0,081	0,119	0,072	.239(*)	0,030	0,103	.803(**)	0,091	-0,035
K ₂ O	0,109	0,059	-0,077	.266(*)	0,005	-0,033	0,108	-0,067	.355(**)	0,134	0,143	0,182	0,111	0,153	0,048	-0,041	0,124	-0,045
TiO ₂	.611(**)	.743(**)	0,009	.412(**)	0,097	.316(**)	.381(**)	-0,082	.224(*)	.458(**)	.482(**)	.573(**)	.393(**)	0,176	0,079	0,012	.340(**)	.231(*)
P ₂ O ₅	.946(**)	.369(**)	0,157	.698(**)	-0,051	.589(**)	.547(**)	-0,022	.256(*)	.760(**)	.815(**)	.827(**)	.792(**)	-0,042	.450(**)	.226(*)	.714(**)	.257(*)
S	.325(**)	.275(*)	.301(**)	0,125	0,163	.284(*)	-0,091	0,061	-0,153	-0,011	0,082	0,054	0,148	0,026	0,095	.305(**)	.230(*)	0,057
Ca	.850(**)	.381(**)	-0,009	.491(**)	-0,017	.488(**)	.702(**)	-0,035	0,203	.858(**)	.751(**)	.796(**)	.652(**)	0,071	.246(*)	0,035	.603(**)	0,218
Sc	.695(**)	.478(**)	.270(*)	.520(**)	0,090	.413(**)	.283(*)	0,062	0,067	.334(**)	.494(**)	.457(**)	.567(**)	0,024	.462(**)	.363(**)	.518(**)	0,199
Ti	.519(**)	.761(**)	-0,009	.355(**)	0,147	0,214	.334(**)	-0,090	.223(*)	.383(**)	.417(**)	.493(**)	.315(**)	.271(*)	0,020	-0,007	.244(*)	0,163
V	0,140	0,008	.400(**)	.381(**)	-0,027	0,111	-0,075	-0,097	0,192	-0,033	0,114	0,166	0,160	0,044	.282(*)	.447(**)	0,156	-0,081
Cr	.610(**)	.484(**)	.331(**)	.487(**)	0,179	.338(**)	.325(**)	-0,074	0,101	.465(**)	.521(**)	.580(**)	.488(**)	0,184	.251(*)	.330(**)	.406(**)	0,074
Fe	.436(**)	.699(**)	0,124	0,134	.392(**)	.236(*)	0,141	0,044	-0,160	0,103	0,220	0,197	0,201	0,020	0,055	0,107	.236(*)	.225(*)
Co	.859(**)	.286(*)	.350(**)	.568(**)	-0,085	.648(**)	.362(**)	-0,007	0,065	.524(**)	.638(**)	.581(**)	.705(**)	-0,058	.467(**)	.398(**)	.731(**)	0,183
Ni	1	.355(**)	0,149	.629(**)	-0,046	.643(**)	.590(**)	0,029	0,166	.773(**)	.796(**)	.809(**)	.799(**)	-0,095	.470(**)	0,217	.792(**)	.266(*)
Cu	.355(**)	1	-0,028	0,131	.296(**)	0,117	0,184	-0,022	0,001	0,137	0,192	0,217	0,105	0,189	-0,109	-0,026	0,035	0,159
Zn	0,149	-0,028	1	.445(**)	-0,182	0,184	-0,185	-0,041	-0,017	-0,043	0,121	0,033	.272(*)	0,085	.238(*)	.949(**)	0,206	-0,036
Ga	.629(**)	0,131	.445(**)	1	-0,214	.406(**)	.398(**)	-.243(*)	.630(**)	.570(**)	.756(**)	.673(**)	.784(**)	-0,034	.575(**)	.534(**)	.615(**)	0,114
Ge	-0,046	.296(**)	-0,182	-0,214	1	-0,100	0,043	0,000	-.391(**)	-0,145	-0,089	-0,096	-0,102	0,021	-0,090	-0,142	-0,146	0,066
As	.643(**)	0,117	0,184	.406(**)	-0,100	1	0,157	-0,111	-0,056	.454(**)	.591(**)	.520(**)	.675(**)	-0,221	.314(**)	.242(*)	.662(**)	.285(*)
Se	.590(**)	0,184	-0,185	.398(**)	0,043	0,157	1	-0,111	.247(*)	.784(**)	.647(**)	.719(**)	.547(**)	-0,097	.279(*)	-0,140	.462(**)	0,167
Br	0,029	-0,022	-0,041	-.243(*)	0,000	-0,111	-0,111	1	-.288(*)	-0,085	-0,190	-0,107	-0,202	0,080	-0,026	-0,046	-0,189	0,004
Rb	0,166	0,001	-0,017	.630(**)	-.391(**)	-0,056	.247(*)	-.288(*)	1	.342(**)	.291(**)	.356(**)	0,213	-0,010	0,128	-0,005	0,169	-0,075
Sr	.773(**)	0,137	-0,043	.570(**)	-0,145	.454(**)	.784(**)	-0,085	.342(**)	1	.819(**)	.913(**)	.695(**)	-0,093	.392(**)	0,014	.648(**)	.225(*)
Y	.796(**)	0,192	0,121	.756(**)	-0,089	.591(**)	.647(**)	-0,190	.291(**)	.819(**)	1	.878(**)	.922(**)	-0,059	.564(**)	0,211	.747(**)	0,208
Zr	.809(**)	0,217	0,033	.673(**)	-0,096	.520(**)	.719(**)	-0,107	.356(**)	.913(**)	.878(**)	1	.755(**)	-0,056	.432(**)	0,105	.649(**)	0,214
Nb	.799(**)	0,105	.272(*)	.784(**)	-0,102	.675(**)	.547(**)	-0,202	0,213	.695(**)	.922(**)	.755(**)	1	-0,151	.642(**)	.375(**)	.847(**)	.230(*)
Mo	-0,095	0,189	0,085	-0,034	0,021	-0,221	-0,097	0,080	-0,010	-0,093	-0,059	-0,056	-0,151	1	-0,195	0,035	-0,217	-0,126
Ag	.470(**)	-0,109	.238(*)	.575(**)	-0,090	.314(**)	.279(*)	-0,026	0,128	.392(**)	.564(**)	.432(**)	.642(**)	-0,195	1	.412(**)	.574(**)	0,054
Cd	0,217	-0,026	.949(**)	.534(**)	-0,142	.242(*)	-0,140	-0,046	-0,005	0,014	0,211	0,105	.375(**)	0,035	.412(**)	1	.252(*)	-0,038
Sn	.792(**)	0,035	0,206	.615(**)	-0,146	.662(**)	.462(**)	-0,189	0,169	.648(**)	.747(**)	.649(**)	.847(**)	-0,217	.574(**)	.252(*)	1	.267(*)
Sb	.266(*)	0,159	-0,036	0,114	0,066	.285(*)	0,167	0,004	-0,075	.225(*)	0,208	0,214	.230(*)	-0,126	0,054	-0,038	.267(*)	1
Te	-.421(**)	-0,148	-0,196	-.383(**)	0,026	-.392(**)	-0,212	0,185	-0,079	-.372(**)	-.545(**)	-.504(**)	-.481(**)	-0,017	-.339(**)	-0,217	-.410(**)	0,038
	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Rb	Sr	Y	Zr	Nb	Mo	Ag	Cd	Sn	Sb
I	-.452(**)	-0,094	-0,064	-.428(**)	0,050	-.438(**)	-.371(**)	0,144	-0,102	-.401(**)	-.613(**)	-.522(**)	-.569(**)	0,046	-.319(**)	-0,111	-.435(**)	-0,099
Ba	.696(**)	-0,050	0,034	.601(**)	-0,197	.255(*)	.738(**)	-0,122	.412(**)	.796(**)	.695(**)	.752(**)	.639(**)	-0,174	.585(**)	0,095	.677(**)	0,162
Yb	.295(**)	-0,177	-0,066	.293(**)	-.278(*)	0,022	.334(**)	-0,007	.243(*)	.435(**)	.466(**)	.402(**)	.375(**)	-0,024	.295(**)	-0,034	.312(**)	-0,018

Hf	.817(**)	0,200	-0,074	.636(**)	-0,062	.532(**)	.732(**)	-0,110	.327(**)	.916(**)	.885(**)	.979(**)	.765(**)	-0,103	.466(**)	0,008	.687(**)	.272(*)
Ta	.822(**)	0,055	.309(**)	.781(**)	-0,153	.672(**)	.521(**)	-0,159	0,201	.689(**)	.889(**)	.736(**)	.980(**)	-0,185	.696(**)	.405(**)	.887(**)	.244(*)
W	.668(**)	0,217	-.245(*)	.491(**)	0,017	.489(**)	.696(**)	-0,178	.242(*)	.809(**)	.890(**)	.820(**)	.735(**)	-0,014	.329(**)	-0,171	.589(**)	0,215
Hg	-.390(**)	-0,195	.317(**)	-0,185	0,013	-.565(**)	-0,172	0,136	-0,096	-.353(**)	-.446(**)	-.415(**)	-.374(**)	0,064	-0,077	.250(*)	-.283(*)	-0,198
Tl	.558(**)	-0,081	.489(**)	.647(**)	-.247(*)	.470(**)	0,155	-0,114	0,161	.339(**)	.596(**)	.483(**)	.665(**)	-0,067	.635(**)	.545(**)	.651(**)	0,072
Pb	.598(**)	-0,059	.480(**)	.683(**)	-.273(*)	.530(**)	0,124	-0,105	0,183	.355(**)	.643(**)	.489(**)	.716(**)	-0,082	.650(**)	.530(**)	.707(**)	0,128
Bi	.858(**)	0,134	-0,076	.559(**)	-0,098	.581(**)	.735(**)	-0,076	.230(*)	.899(**)	.838(**)	.878(**)	.780(**)	-.229(*)	.467(**)	-0,014	.796(**)	.317(**)
Th	.914(**)	.270(*)	0,115	.645(**)	-0,068	.571(**)	.562(**)	-0,027	0,213	.750(**)	.824(**)	.785(**)	.801(**)	-0,034	.450(**)	0,188	.727(**)	0,210
U	.757(**)	0,019	0,000	.469(**)	-0,185	.487(**)	.488(**)	-0,005	0,145	.641(**)	.704(**)	.614(**)	.687(**)	-0,141	.415(**)	0,064	.679(**)	0,192

	Te	I	Ba	Yb	Hf	Ta	W	Hg	Tl	Pb	Bi	Th	U
SiO₂	.408(**)	.315(**)	-.435(**)	-0,168	-.594(**)	-.538(**)	-.504(**)	.356(**)	-.383(**)	-.417(**)	-.559(**)	-.722(**)	-.478(**)
Al₂O₃	-0,189	-0,128	.241(*)	0,126	.305(**)	0,211	.255(*)	-0,154	0,169	0,175	.242(*)	.375(**)	0,191
Fe₂O₃	-.252(*)	-0,073	0,086	-0,076	.259(*)	.248(*)	0,213	-.239(*)	0,160	0,202	.271(*)	.377(**)	0,210
MnO	-0,182	0,049	0,011	-0,149	0,175	0,131	0,072	-0,145	0,127	0,132	0,119	.232(*)	0,040

MgO	-.273(*)	-.0210	.251(*)	0,045	.351(**)	.329(**)	.303(**)	-.0,133	.294(**)	.279(*)	.250(*)	.409(**)	0,126
CaO	-.376(**)	-.367(**)	.693(**)	.343(**)	.810(**)	.646(**)	.739(**)	-.417(**)	.314(**)	.334(**)	.824(**)	.837(**)	.671(**)
Na ₂ O	-0,132	0,083	0,046	0,017	-0,040	.230(*)	-0,101	.302(**)	0,119	0,119	0,005	0,123	0,018
K ₂ O	-0,077	-0,077	0,165	0,136	0,174	0,098	0,172	-0,097	0,059	0,065	0,108	0,208	0,114
TiO ₂	-.317(**)	-.293(**)	.336(**)	0,107	.552(**)	.344(**)	.492(**)	-.358(**)	0,188	0,194	.457(**)	.605(**)	.316(**)
P ₂ O ₅	-.459(**)	-.451(**)	.666(**)	.327(**)	.829(**)	.797(**)	.679(**)	-.455(**)	.580(**)	.612(**)	.804(**)	.946(**)	.742(**)
S	-0,142	0,024	-0,070	-0,207	0,057	0,162	-0,018	-0,058	0,181	0,215	0,064	0,210	0,139
Ca	-.398(**)	-.383(**)	.684(**)	.330(**)	.798(**)	.632(**)	.746(**)	-.430(**)	.307(**)	.322(**)	.809(**)	.830(**)	.661(**)
Sc	-.231(*)	-0,177	.324(**)	0,038	.457(**)	.572(**)	.293(**)	-0,178	.463(**)	.488(**)	.402(**)	.590(**)	.388(**)
Ti	-.299(**)	-.292(**)	.258(*)	0,077	.462(**)	.253(*)	.455(**)	-.334(**)	0,091	0,096	.359(**)	.523(**)	0,221
V	-0,142	-0,210	0,155	-0,074	0,131	0,197	-0,128	0,190	.605(**)	.539(**)	-0,020	0,082	-0,002
Cr	-.426(**)	-.372(**)	.348(**)	0,021	.530(**)	.474(**)	.381(**)	-0,106	.377(**)	.370(**)	.466(**)	.539(**)	.305(**)
Fe	-.226(*)	-0,130	0,042	-0,171	0,201	0,177	0,192	-0,127	0,081	0,116	0,217	.289(*)	0,087
Co	-.382(**)	-.330(**)	.513(**)	0,203	.589(**)	.737(**)	.455(**)	-.286(*)	.606(**)	.649(**)	.620(**)	.769(**)	.654(**)
Ni	-.421(**)	-.452(**)	.696(**)	.295(**)	.817(**)	.822(**)	.668(**)	-.390(**)	.558(**)	.598(**)	.858(**)	.914(**)	.757(**)
Cu	-0,148	-0,094	-0,050	-0,177	0,200	0,055	0,217	-0,195	-0,081	-0,059	0,134	.270(*)	0,019
Zn	-0,196	-0,064	0,034	-0,066	-0,074	.309(**)	-.245(*)	.317(**)	.489(**)	.480(**)	-0,076	0,115	0,000
Ga	-.383(**)	-.428(**)	.601(**)	.293(**)	.636(**)	.781(**)	.491(**)	-0,185	.647(**)	.683(**)	.559(**)	.645(**)	.469(**)
Ge	0,026	0,050	-0,197	-.278(*)	-0,062	-0,153	0,017	0,013	-.247(*)	-.273(*)	-0,098	-0,068	-0,185
As	-.392(**)	-.438(**)	.255(*)	0,022	.532(**)	.672(**)	.489(**)	-.565(**)	.470(**)	.530(**)	.581(**)	.571(**)	.487(**)
Se	-0,212	-.371(**)	.738(**)	.334(**)	.732(**)	.521(**)	.696(**)	-0,172	0,155	0,124	.735(**)	.562(**)	.488(**)
Br	0,185	0,144	-0,122	-0,007	-0,110	-0,159	-0,178	0,136	-0,114	-0,105	-0,076	-0,027	-0,005
Rb	-0,079	-0,102	.412(**)	.243(*)	.327(**)	0,201	.242(*)	-0,096	0,161	0,183	.230(*)	0,213	0,145
Sr	-.372(**)	-.401(**)	.796(**)	.435(**)	.916(**)	.689(**)	.809(**)	-.353(**)	.339(**)	.355(**)	.899(**)	.750(**)	.641(**)
Y	-.545(**)	-.613(**)	.695(**)	.466(**)	.885(**)	.889(**)	.890(**)	-.446(**)	.596(**)	.643(**)	.838(**)	.824(**)	.704(**)
Zr	-.504(**)	-.522(**)	.752(**)	.402(**)	.979(**)	.736(**)	.820(**)	-.415(**)	.483(**)	.489(**)	.878(**)	.785(**)	.614(**)
Nb	-.481(**)	-.569(**)	.639(**)	.375(**)	.765(**)	.980(**)	.735(**)	-.374(**)	.665(**)	.716(**)	.780(**)	.801(**)	.687(**)
Mo	-0,017	0,046	-0,174	-0,024	-0,103	-0,185	-0,014	0,064	-0,067	-0,082	-.229(*)	-0,034	-0,141
Ag	-.339(**)	-.319(**)	.585(**)	.295(**)	.466(**)	.696(**)	.329(**)	-0,077	.635(**)	.650(**)	.467(**)	.450(**)	.415(**)
Cd	-0,217	-0,111	0,095	-0,034	0,008	.405(**)	-0,171	.250(*)	.545(**)	.530(**)	-0,014	0,188	0,064
	Te	I	Ba	Yb	Hf	Ta	W	Hg	Tl	Pb	Bi	Th	U
Sn	-.410(**)	-.435(**)	.677(**)	.312(**)	.687(**)	.887(**)	.589(**)	-.283(*)	.651(**)	.707(**)	.796(**)	.727(**)	.679(**)
Sb	0,038	-0,099	0,162	-0,018	.272(*)	.244(*)	0,215	-0,198	0,072	0,128	.317(**)	0,210	0,192
Te	1	.517(**)	-.299(**)	-0,208	-.475(**)	-.455(**)	-.464(**)	0,212	-.441(**)	-.471(**)	-.399(**)	-.441(**)	-.327(**)
I	.517(**)	1	-.330(**)	-0,201	-.513(**)	-.539(**)	-.543(**)	.377(**)	-.471(**)	-.476(**)	-.462(**)	-.479(**)	-.403(**)
Ba	-.299(**)	-.330(**)	1	.574(**)	.776(**)	.681(**)	.609(**)	-0,124	.509(**)	.503(**)	.784(**)	.686(**)	.666(**)
Yb	-0,208	-0,201	.574(**)	1	.421(**)	.378(**)	.494(**)	-0,049	.269(*)	.337(**)	.402(**)	.463(**)	.620(**)
Hf	-.475(**)	-.513(**)	.776(**)	.421(**)	1	.754(**)	.854(**)	-.462(**)	.479(**)	.500(**)	.905(**)	.793(**)	.657(**)

Ta	-455(**)	-.539(**)	.681(**)	.378(**)	.754(**)	1	.669(**)	-.329(**)	.724(**)	.780(**)	.797(**)	.800(**)	.717(**)
W	-464(**)	-.543(**)	.609(**)	.494(**)	.854(**)	.669(**)	1	-.528(**)	.275(*)	.328(**)	.805(**)	.735(**)	.672(**)
Hg	0,212	.377(**)	-0,124	-0,049	-.462(**)	-.329(**)	-.528(**)	1	-0,165	-0,210	-.408(**)	-.466(**)	-.413(**)
Tl	-.441(**)	-.471(**)	.509(**)	.269(*)	.479(**)	.724(**)	.275(*)	-0,165	1	.961(**)	.418(**)	.568(**)	.508(**)
Pb	-.471(**)	-.476(**)	.503(**)	.337(**)	.500(**)	.780(**)	.328(**)	-0,210	.961(**)	1	.462(**)	.605(**)	.572(**)
Bi	-.399(**)	-.462(**)	.784(**)	.402(**)	.905(**)	.797(**)	.805(**)	-.408(**)	.418(**)	.462(**)	1	.800(**)	.736(**)
Th	-.441(**)	-.479(**)	.686(**)	.463(**)	.793(**)	.800(**)	.735(**)	-.466(**)	.568(**)	.605(**)	.800(**)	1	.887(**)
U	-.327(**)	-.403(**)	.666(**)	.620(**)	.657(**)	.717(**)	.672(**)	-.413(**)	.508(**)	.572(**)	.736(**)	.887(**)	1

Table 5 : Standards for program sodium only

Standard	DT-N	G2	GA	GH	GS-N	GSP-1	JG-1	SY-2
Total (%)	100,061	99,694	99,999	100,027	100,069	100,111	100,005	100,01
Na2O (%)	0,04	4,06	3,58	3,87	3,81	2,81	3,4	4,32
Al2O3 (%)	60,29	15,39	14,64	12,55	14,83	15,14	14,26	12,08
As (ppm)	0,2	0,25	1,7	0,4	1,6	0,1	0,36	17,3
Ba (ppm)	130	1882	840	20	1400	1310	462	460
CaO (%)	0,04	2	2,47	0,69	2,53	2,08	2,19	7,99
Ce (ppm)	134	160	76	60	135	399	45,9	175
CeO2 (ppm)	134	160	/	60	/	399	/	/

Co (ppm)	15	4,6	5	0,3	65	6,6	4	8,6
Cr (%)	260	8	12	3	55	13	64,6	9,5
Cr2O3 (%)	0,0379	0,0008	0,0017	0,0004	0,008	0,0018	0,009	0,0013
Cu (ppm)	7	11	16	3	20	33	1,5	5,2
F (ppm)	40	1260	500	3500	1050	3630	496	5030
Fe2O3 (%)	1	3	3	1	4	4	2	6
Hf (ppm)	10	7,9	4	6,6	6,2	15,5	3,79	7,7
HfO2 (ppm)	10	7,9	/	6,6	/	15,5	/	/
K2O (%)	0,12	4,48	4,07	4,78	4,68	5,52	3,99	4,47
La (ppm)	21,5	89	89	40	75	75	22,4	75
La2O3 (ppm)	90	89	/	25	/	184	/	/
MgO (%)	0,04	0,75	0,96	0,03	2,33	0,96	0,74	2,7
MnO (%)	0,01	0,034	0,09	0,05	0,06	0,04	0,06	0,32
Sc (ppm)	2,10	3,50	7,00	0,80	7,30	6,20	6,54	7,00
Ti (ppm)	/	0,91	/	1,80	/	/	1,00	1,50
SO3 (ppm)	/	100	/	70	/	320	/	/
Cd (ppm)	/	0,01	/	/	/	0,06	/	/
Ge (ppm)	4,90	1,14	1,70	2,00	1,30	1,36	1,70	/
Ag (ppm)	/	40,00	/	/	/	/	/	/
Bi (ppm)	/	43,00	/	/	0,18	/	/	/
Cs (ppm)	/	1,40	/	/	/	/	/	/
Sm (ppm)	/	7,20	/	/	/	/	/	/
Ta (ppm)	/	0,80	/	4,80	2,60	/	/	2,00
Te (ppm)	/	/	/	/	/	/	0,02	/
W (ppm)	120,00	0,10	1,50	1,60	450,00	0,30	/	/
Standard	DT-N	G2	GA	GH	GS-N	GSP-1	JG-1	SY-2
Yb (ppm)	/	0,86	/	/	/	/	/	/
Mo (ppm)	0,50	1,10	0,50	2,00	1,20	0,80	1,46	1,80
Nb (ppm)	34,00	12,00	12,00	85,00	21,00	27,90	12,60	29,00
Nd (ppm)	52,00	58,00	27,00	29,00	49,00	196,00	19,50	73,00
Ni (ppm)	14,00	5,00	7,00	3,00	34,00	8,80	6,00	9,90
P2O5 (%)	0,09	0,13	0,12	0,01	0,28	0,28	0,10	0,43
Pb (ppm)	25	30	30	45	53	55	26,2	85
Rb (ppm)	6	170	175	390	185	254	181	217
Sb (ppm)	0,25	0,06	0,2	/	0,7	3,2	0,35	/
SiO2 (%)	37,1	69,22	70,56	76,12	66,53	67,4	72,6	60,32
Sn (ppm)	2,2	1,4	2,7	10	3	6,6	4,1	5,7
Sr (ppm)	30	478	310	10	570	234	184	271
Th (ppm)	2	24,7	17	87	41	106	13,5	379

TiO2 (%)	1,43	0	0,38	0,08	0,69	0,65	0,26	0,15
U (ppm)	2,3	2,07	5	18	7,5	2,54	3,3	284
V (ppm)	150	36	38	5	65	53	25	50
Y (ppm)	6,6	11	21	75	16	26	28,5	128
Zn (ppm)	28	86	80	55	48	104	41,5	248
Zr (ppm)	370	309	150	150	235	530	114	280
Cl (ppm)	/	66	250	100	450	330	60	140
S (ppm)	/	100	80	70	140	320	11,3	160
Ga (ppm)	30	23	16	23	22	23	17	29

Table 6: Standards for program uranium only

[illegible]

[illegible]

Tl (ppm)	1,5	1,5	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Ge (ppm)	/	1,4	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
W (ppm)	/	1,1	1023	/	523	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
C (%)	/	/	/	/	/	/	50	/	/	/	/	/	/	/	/	/	/	/	/	/
ZnO (%)	/	/	/	/	/	/	/	/	/	/	/	100	/	/	/	/	/	/	/	/
Ag (ppm)	/	/	1015	/	503	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Se (ppm)	/	/	1003	/	406	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/

Table 7: Standards program major elements

Standard	AC-E	AGV-1	AL-1	AN-G	ASK-1	ASK-2	BCR-1	BE-N	BHVO-1	BR	BX-N	DR-N	DT-N	DTS-1	FK-N	G-1	G-2	GA	GH
Total (%)	100	100	100	100	106,9	110,3	100	100,1	100	100,1	99,95	100	100,1	100,6	100	100	100,01	100	100,03
SiO₂ (%)	70,65	59,83	69,86	46,6	68,83	66,5	54,3	39,33	49,5	39,29	8,4	53,91	37,12	40,43	65,4	72,52	69,4	70,56	76,12
Al₂O₃ (%)	14,76	17,44	18,73	30	21,52	23,07	13,69	10,37	13,7	10,49	61,52	17,87	60,29	0,19	18,72	14,23	15,45	14,64	12,55
Fe₂O₃ (%)	3	6,86	0,08	3,38	5	7	13,51	13,21	12,3	13	26,29	9,9	1	8,78	0	1,94	2,7	3	1
MnO (%)	0,06	0,09	0	0,04	0,16	0,05	0,18	0,21	0,17	0,21	0,06	0,22	0,01	0,12	0,01	0,03	0,03	0,09	0,05
MgO (%)	0,03	1,56	0,04	1,81	1,27	2,45	3,49	13,54	7,17	13,66	0,12	4,49	0,04	49,62	0,01	0,36	0,75	0,96	0,03
CaO (%)	0,34	5,02	0,39	16	3,2	0,75	6,97	14,28	11,3	14,2	0,19	7,19	0,04	0,17	0,11	1,37	1,97	2,47	0,69
Na₂O (%)	6,57	4,33	10,67	1,64	0,93	0,02	3,28	3,27	2,24	3,14	0,05	3,05	0,04	0,02	2,6	3,33	4,1	3,58	3,87
K₂O (%)	4,51	2,97	0,14	0,13	4,86	6,5	1,7	1,43	0,52	1,44	0,06	1,73	0,12	0	12,88	5,51	4,5	4,07	4,78
TiO₂ (%)	0,11	1,07	0,01	0,22	1,06	0,92	2,25	2,69	2,69	2,67	2,69	1,11	1,43	0,01	0,02	0,27	0,48	0,38	0,08
P₂O₅ (%)	0,01	0,5	0,04	0,01	0	0	0,36	1,08	0,27	1,07	0,15	0,26	0,09	0	0,02	0,08	0,14	0,12	0,01
Ag (ppm)	0	0	0	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
As (ppm)	2,3	0,88	0,8	0,2	1	25	0,65	1,8	0,4	2	115	3	0,2	0,034	0,3	0,7	0,25	1,7	0,4

Yb (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
----------	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Standard	JG-3	JGB-1	JGB-2	JH-1	JLK-1	JLS-1	JP-1	JR-1	JR-2	JR-3	JSD-1	JSD-2	JSI-1	JSI-2	Kim?	MA-N	MAG-1	MICA-FE	MICA-MG
Total (%)	99,998	100,2	100,1	100,2	100	100	100	100	100	100	100	101	100	100	0	99,5	103	99,95	99,98
SiO ₂ (%)	67,5	43,64	47,12	49,05	64,7	0,2	43,6	76	77	73,3	68,5	63,1	63,2	63	/	67,6	58,07	34,65	38,68
Al ₂ O ₃ (%)	15,61	17,74	23,54	5,63	19,1	0	0,64	13	13	12,2	15,1	13,1	18,8	19	/	17,9	18,88	19,64	15,35
Fe ₂ O ₃ (%)	3,76	15,23	6,91	10,46	7,75	0	9	1	1	4,81	5,27	12,1	7,28	7,1	/	0	7,95	26	9,55
MnO (%)	0,07	0,17	0,13	0,19	0,31	0	0,12	0,1	0,1	0,09	0,1	0,13	0,07	0,1	/	0,04	0,11	0,35	0,26
MgO (%)	1,8	7,87	6,3	17,32	1,99	1,1	45,9	0,1	0,1	0,05	1,91	2,94	2,64	2,6	/	0,04	3,46	4,58	20,6
CaO (%)	3,78	12,04	14,33	15,2	0,77	99	0,58	0,6	0,5	0,09	3,17	3,8	1,52	2,1	/	0,6	1,58	0,43	0,08
Na ₂ O(%)	4,05	1,24	0,93	0,73	1,19	0	0,02	4,1	4,1	4,73	2,82	2,59	2,34	1,5	/	5,93	4,42	0,3	0,12
K ₂ O (%)	2,65	0,24	0,06	0,53	3,14	0	0	4,5	4,5	4,38	2,26	1,2	3,03	3,1	/	3,23	4,09	8,81	10,1
TiO ₂ (%)	0,48	1,63	0,59	0,68	0,76	0	0	0,1	0,1	0,21	0,67	0,66	0,78	0,8	/	0,01	0,87	2,52	1,65
P ₂ O ₅ (%)	0,12	0,05	0,01	0,11	0,24	0,1	0	0	0	0,01	0,12	0,08	0,2	0,2	/	1,41	0,19	0,45	0,01
Ag (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
As (ppm)	0,37	1,11	1,06	1,12	27,7	0,2	0,34	16	20	0,72	2,36	39,4	15,6	12	/	13	9,2	3	/
Ba (ppm)	453	63	/	/	/	/	17	40	39	/	/	/	/	/	/	42	479	150	4000
Bi (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	1,9	/
Standard	JG-3	JGB-1	JGB-2	JH-1	JLK-1	JLS-1	JP-1	JR-1	JR-2	JR-3	JSD-1	JSD-2	JSI-1	JSI-2	Kim?	MA-N	MAG-1	MICA-FE	MICA-MG
Cd (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Ce (ppm)	40,1	7,86	/	/	89,1	0,9	0,2	47	39	/	35,4	20,7	60,5	71	/	0,9	88	420	0,35
Cl (ppm)	/	/	/	/	/	/	50	920	730	/	/	/	/	/	/	140	31000	500	800
Co (ppm)	11,4	61,6	28	53	18,1	/	116	0,7	0	1	10,9	48	14,7	15	/	0,5	20,4	23	24
Cr (ppm)	23,6	59,3	130	630	69	3	2970	2,3	2,6	2,5	22	104	58	64	/	3	97	90	100
Cs (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Cu (ppm)	6	86,8	11	9	59,8	/	5,7	1,4	0,4	2,1	22,2	1114	40	41	/	140	30	5	5
F (ppm)	335	150	/	/	/	/	10	942	1087	/	/	/	/	/	/	17000	770	16000	28500
Ga (ppm)	17	/	/	/	/	/	0,5	18	18	/	/	/	/	/	/	59	/	95	21
Ge (ppm)	/	/	/	/	/	/	/	/	2,4	/	/	/	/	/	/	3,5	/	3,2	1,55
Hg (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
La (ppm)	20,7	3,74	/	/	41,3	0,2	0,1	0,7	0,9	/	18,6	12,3	29,9	33	/	0,5	43	200	0,32
Mo (ppm)	0,44	0,45	/	/	/	/	/	3,2	2,9	/	/	/	/	/	/	0,3	1,6	1,2	0,25
Nb (ppm)	5,6	2,8	/	/	/	/	1,2	16	19	/	/	/	/	/	/	173	12	270	116
Nd (ppm)	16,8	5,65	/	/	/	/	0,07	24	21	/	/	/	/	/	/	0,4	38	180	0,08
Ni (ppm)	13	25,4	13,8	56	36,9	0,3	2460	0,7	0,8	1,1	6,9	94	38,5	39	/	53	3	35	110
Pb (ppm)	12,3	1,9	/	/	45	/	0,11	19	22	34,5	14	151	18	21	/	29	24	13	9
Rb (ppm)	66	4	/	12	144	/	/	257	297	458	65	27	285	116	/	3600	149	2200	1300

Ba (ppm)	10	120	450	100	46	2400	1,2	1700	310	820	250	25	50	900	180	75	290	/	220
Bi (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Cd (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Ce (ppm)	/	195	240	6	/	12	0,1	85	160	60	30	20	210	100	110	20	860	/	30
Cl (ppm)	400	170	1200	100	100	80	71	/	/	/	/	/	/	/	/	/	/	/	/
Co (ppm)	210	4	8	58	110	3	112	77	20	15	35	4	8	41	56	79	0,7	/	40
Cr (ppm)	2900	12	0	30	24000	12	2730	1300	35	123	4310	195	384	256	559	1984	23	/	357
Cs (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Cu (ppm)	10	12	13	14	18	19	10	58	10	53	17	5	0	1	566	5	10	/	84
F (ppm)	/	4200	4400	/	/	120	12	/	/	/	/	/	/	/	/	/	/	/	/
Ga (ppm)	/	27	54	16	8	11	/	/	/	/	10	/	50	/	/	/	/	/	/
Ge (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Hg (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
La (ppm)	0,2	109	250	3	2	5	0,052	/	/	/	/	/	/	/	/	/	/	/	/
Mo (ppm)	4	3	4	/	/	/	2	5	10	5	5	/	15	/	10	/	5	/	/
Nb (ppm)	/	53	960	/	/	4	/	110	10	/	8	/	96	27	/	/	202	/	10
Nd (ppm)	/	72	48	3	/	6	0,042	/	/	/	/	/	/	/	/	/	/	/	/
Ni (ppm)	2050	8	1	120	560	7	2380	994	25	122	125	252	15	80	125	2221	/	/	85
Standard	NIM-D	NIM-G	NIM-L	NIM-N	NIM-P	NIM-S	PCC-1	SARM-39	SARM-40	SARM-41	SARM-42	SARM-43	SARM-44	SARM-45	SARM-46	SARM-47	SARM-48	SARM-49	SARM-50
Pb (ppm)	/	40	43	7	6	5	10	25	20	30	10	/	30	20	13000	60	135	/	25
Rb (ppm)	8,5	320	190	6	5	530	0,066	52	10	59	22	/	13	142	20		291	/	14
S (ppm)	/	/	/	/	/	/	20	1500	500	1500	200	400	300	500	1700	200	/	/	300
Sb (ppm)	/	0,6	/	/	/	0,6	1,28	/	/	/	/	/	/	/	/	/	/	/	/
Sc (ppm)	7	1	0,3	38	29	4	8,4	/	/	/	/	/	/	/	/	/	/	/	/
Sn (ppm)	2	4	/	/	2	/	1,6	/	/	/	/	/	/	/	/	/	/	/	/
Sr (ppm)	3	10	4600	260	2	62	0,04	1400	1600	4	37	8	5	92	25	3	29	5	95
Ta (ppm)	/	4,5	22	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Th (ppm)	0,8	51	66	0,6	1	1	0,013	10	12	12	5	/	50	21	/	/	113	/	6
Tl (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
U (ppm)	/	15	14	0,6	0,4	0,6	0,005	/	/	/	/	/	/	/	/	/	/	/	/
V (ppm)	40	2	81	220	230	10	31	109	27	139	94	/	395	266	225	16	8	/	216
W (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Y (ppm)	/	143	22	7	5	20	0,1	17	33	17	11	/	84	63	20	5	436	/	23
Zn (ppm)	90	50	400	68	100	10	42	70	25	76	44	10	271	74	5900	45	53	5	81
Zr (ppm)	20	300	11000	23	30	33	10	239	87	146	192	/	406	322	101	/	300	/	86
Hf (ppm)	3,76	12	190	/	/	/	0,04	/	/	/	/	/	/	/	/	/	/	/	/
Li (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
CeO ₂ (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	110	/	/	/	/
HfO ₂ (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
La ₂ O ₃ (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
SO ₃ (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	1700	/	/	/	/

Cr₂O₃ (%)	0,42	0	0,0015	0,0044	3,5078	0,0018	0,3959	0,1898	0,0051	0,018	0,625	0,0283	0,0557	0,0371	0,0811	0,2897	0,0033	/	0,0518
Se (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Te (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Yb (ppm)	/	14,2	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/

Standard	SARM-51	SARM-52	SY-2	SY-3	UB-N
Total (%)	99,901	100,165	100,01	100,045	100,069
SiO₂ (%)	49,44	64	60,32	59,77	44,79
Al₂O₃ (%)	17,36	10,38	12,08	11,78	3,29
Fe₂O₃ (%)	26,85	21,82	6	7	9,47
MnO (%)	0,31	0,3	0,32	0,32	0,14
MgO (%)	1,35	0,66	2,7	2,67	40
CaO (%)	1,26	0,41	7,99	8,26	1,36
Na₂O(%)	0,1	0,11	4,32	4,13	0,11
K₂O (%)	0,48	0,28	4,47	4,24	0,02
TiO₂(%)	1,2	1,44	0,15	0,15	0,12
P₂O₅ (%)	0,31	0,1	0,43	0,54	0,05
Ag (ppm)	/	/	/	/	/
As (ppm)	/	/	17,3	18,8	10
Ba (ppm)	410	460	450	27	
Bi (ppm)	/	/	/	/	
Cd (ppm)	/	/	/	/	
Ce (ppm)	210	175	2230	0,8	
Cl (ppm)	/	140	150	800	

Co (ppm)	81	8,6	8,8	100	
Cr (ppm)	1300	9,5	11	2300	
Cs (ppm)	/	/	/	/	
Cu (ppm)	219	5,2	17	28	
F (ppm)	/	5030	6960	95	
Ga (ppm)	/	15	29	27	/
Ge (ppm)	/	/	/	1,4	/
Hg (ppm)	/	/	/	/	/
La (ppm)	/	/	75	1340	0,35
Mo (ppm)	/	/	1,8	1	0,55
Nb (ppm)		11	29	148	0,05
Nd (ppm)	/	/	73	670	0,6
Standard	SARM-51	SARM-52	SY-2	SY-3	UB-N
Ni (ppm)	178	182	9,9	11	75
Pb (ppm)	5200	1200	85	133	13
Rb (ppm)	37	20	217	206	4
S (ppm)	2400	200	160	510	200
Sb (ppm)	/	/	/	/	0,3
Sc (ppm)	/	/	7	6,8	/
Sn (ppm)	/	/	5,7	6,5	/
Sr (ppm)	44	25	271	302	9
Ta (ppm)	/	/	2	30	/
Th (ppm)	10	11	379	1003	0,07
Tl (ppm)	/	/	1,5	1,5	/
U (ppm)	/	/	284	650	0,07
V (ppm)	181	346	50	50	75
W (ppm)	/	/	/	1,1	/
Y (ppm)	21	20	128	718	2,5
Zn (ppm)	2200	264	248	244	85
Zr (ppm)	121	250	280	320	4
Hf (ppm)	/	/	7,7	9,7	0,1
Li (ppm)	/	/	/	/	/
CeO ₂ (ppm)	/	/	/	/	/
HfO ₂ (ppm)	/	/	/	/	/

La₂O₃(ppm)	/	/	/	/	/
SO₃ (ppm)	/	/	/	/	/
Cr₂O₃ (%)	0,0738	0,1885	0,0013	0,0016	0,3358
Se (ppm)	/	/	/	/	/
Te (ppm)	/	/	/	/	/
Yb (ppm)	/	/	/	/	/

Table 8 Standards for program vms trace 3

Standard	AC-E	AN-G	ASK-1	ASK-2	ASK-3	BE-N	BHVO-1	BR	DT-N	FK-N	GA	GH	GS-N	GSP-1	JA-1
Total (%)	100	100,02	106,915	110,262	35,04	100,102	100,084	100,084	100,06	100,02	99,999	100,027	100,069	100,111	100,011
S (ppm)	70	140	400	20000	/	300	102	390	/	60	80	70	140	320	23
CaO (ppm)	3400	160200	32000	7500	/	142800	113000	142000	400	1100	24700	6900	25300	20800	57200
Sc (ppm)	0,11	10	7	17,5	/	22	31,8	25	2,1	0,05	7	0,8	7,3	6,2	28,4
TiO₂ (ppm)	1100	2200	10600	9180	60	26900	26900	26700	14300	200	3800	800	6900	6500	8800
V (ppm)	3	70	45	200	/	235	317	235	150	0,5	38	5	65	53	105
Cr (ppm)	3,4	50	50	90	/	360	289	380	260	5	12	3	55	13	7,3
Fe₂O₃ (ppm)	25400	33800	46000	69000	350000	132100	122500	132500	6700	900	28500	13500	38000	43600	70100
Co (ppm)	0,2	25	6	27	/	60	45	52	15	14	5	0,3	65	6,6	11,8
Ni (ppm)	1,5	5	120	150	/	267	121	260	14	1,5	7	3	34	8,8	1,8
Cu (ppm)	4	19	7	124	/	72	136	72	7	2	16	3	20	33	42,2
Zn (ppm)	224	20	96	160	/	120	105	160	28	10	80	55	48	104	90,6
Ga (ppm)	39	18	30	24	6	17	21	20	30	23	16	23	22	23	17,3
Ge (ppm)	2,3	/	2	1	/	1,2		1,2	4,9	2,5	1,7	2	1,3	1,36	/
As (ppm)	2,3	0,2	1	25	/	1,8	0,4	2	0,2	0,3	1,7	0,4	1,6	0,1	2,92
Se (ppm)	/	0,06	0,07	3	17	/	/	/	/	/	/	/	/	/	/
Br (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Rb (ppm)	152	1	85	160	/	47	11	47	6	860	175	390	185	254	11,8
Sr(ppm)	3	76	680	100	/	1370	403	1320	30	39	310	10	570	234	266
Y (ppm)	184	7,5	/	/	/	30	27,6	30	6,6	0,5	21	75	16	26	30,6
Zr (ppm)	780	11	400	170	/	260	179	260	370	0,7	150	150	235	530	88,3

Nb (ppm)	110	0,7	60	30	/	105	19	98	34	0,3	12	85	21	27,9	1,7
Mo (ppm)	2,5	0,2	5	60	/	2,8	1,02	2,4	0,5	0,25	0,5	2	1,2	0,8	2
Ag (ppm)	0	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Cd (ppm)	0	/	/	/	310	/	/	/	/	/	/	/	/	0,058	/
Sn (ppm)	13	1,4	3	3	/	2	2,1	2	2,2	0,3	2,7	10	3	6,6	0,78
Sb (ppm)	0,4	0,1	0,03	5	/	0,26	0,16	0,2	0,25	0,45	0,2	/	0,7	3,2	0,26
Te (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	0,023	/
I (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Ba (ppm)	55	34	1100	8000	/	1025	139	1050	130	200	840	20	1400	1310	307
Yb (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Standard	AC-E	AN-G	ASK-1	ASK-2	ASK-3	BE-N	BHVO-1	BR	DT-N	FK-N	GA	GH	GS-N	GSP-1	JA-1
Hf (ppm)	27,9	0,38	10	/	/	5,6	4,38	5,6	10	0,04	4	6,6	6,2	15,5	2,41
Ta ppm)	6,4	/	8	7	/	5,7	/	6,2	/	/	/	4,8	2,6	/	/
W ppm)	0	105	/	/	/	29	/	1,3	120	120	1,5	1,6	450	0,3	3,9
Hg ppm)	0	/	/	/	8	/	/	/	/	/	/	/	/	/	/
Tl ppm)	0,9	/	/	/	/	0,04	/	/	/	/	/	1,8	/	/	/
Pb ppm)	39	2	6	40	/	4	2,6	5	25	240	30	45	53	55	5,8
Bi ppm)	0,4	/	/	/	32	/	/	/	/	/	/	/	0,18	/	/
Th ppm)	18,5	0,04	16	13	/	10,4	1,08	11	2	0,15	17	87	41	106	0,82
U ppm)	4,6	0,12	5	22	/	2,4	0,42	2,5	2,3	0,15	5	18	7,5	2,54	0,34
Al₂O₃ ppm)	1E+05	300200	215200	230700	/	103700	136800	104900	602900	187200	146400	125500	148300	151400	151000
SiO₂ ppm)	7E+05	466400	688300	665000	/	393300	495000	392900	371200	654000	705600	761200	665300	674000	645600
Sm ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Ce ppm)	154	4,7	260	90	/	152	39	151	134	1	76	60	135	399	13,5
La ppm)	59	2,2	125	46	/	82	15,8	82	21,5	0,029	89	40	75	75	2,8
MnO (%)	0,06	0,04	0,16	0,05	/	0,21	0,17	0,21	0,01	0,01	0,09	0,05	0,06	0,04	0,15
Nd ppm)	92	2,4	95	30	/	67	25,2	65	52	0,3	27	29	49	196	11
Cs ppm)	0	/	/	/	/	/	/	/	/	/	/	/	/	/	/
C (%)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
ZnO (%)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
Cl ppm)	180	300	100	15	/	200	92	350	/	20	250	100	450	330	35
Cr₂O₃ (%)	5E-04	0,0073	0,0073	0,0131	/	0,0526	0,0422	0,0555	0,0379	0,0007	0,0017	0,0004	0,008	0,0018	0,0011
F ppm)	2100	120	1050	1300	/	1000	385	1000	40	30	500	3500	1050	3630	180
K₂O(%)	4,51	0,13	4,86	6,5	/	1,43	0,52	1,44	0,12	12,88	4,07	4,78	4,68	5,52	0,79
MgO (%)	0,03	1,81	1,27	2,45	/	13,54	7,17	13,66	0,04	0,01	0,96	0,03	2,33	0,96	1,62

[illegible]

[illegible]

Li (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/
----------	---	---	---	---	---	---	---	---	---	---	---	---	---

Standard	TR-12	TR-13	TR-14	TR-2	TR-3	TR-4	TR-5	TR-6	TR-7	TR-8	TR-9	TRMAC-1	TRMAC-2
Total	100,433	100,965	100,819	100,287	100,231	100,355	100,234	100,623	100,368	100,528	100,77	100	100
S (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/
CaO (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/
Sc (ppm)	/	/	/	/	/	/	/	/	/	1624	/	/	/
TiO2 (ppm)	/	/	/	/	/	/	/	/	/	/	2523	/	/
V (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/
Cr (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/
Fe ₂ O ₃ (ppm)	100000	100000	100000	100000	100000	100000	100000	100000	100000	100000	100000	/	/
Co (ppm)	/	850	/	/	/	/	/	933	/	/	/	/	/
Ni (ppm)	/	/	/	/	/	/	/	/	/	/	991	/	/
Cu (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/
Zn (ppm)	/	/	/	/	/	/	/	/	/	1050	/	/	/
Ga (ppm)	/	895	/	/	/	/	/	439	/	/	/	/	/
Ge (ppm)	/	/	/	/	/	569	/	/	/	/	/	/	/
As (ppm)	/	/	/	/	493	/	/	/	/	/	/	/	/
Se (ppm)	/	/	1003	/	/	/	/	/	406	/	/	/	/
Br (ppm)	/	/	/	/	/	746	/	/	/	/	/	/	/
Rb (ppm)	/	/	/	/	700	/	/	/	/	/	/	/	/
Sr (ppm)	2248	/	/	/	/	/	838	/	/	/	/	/	/
Y (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/
Zr (ppm)	/	/	/	/	/	671	/	/	/	/	/	/	/
Nb (ppm)	/	/	/	/	600	/	/	/	/	/	/	/	/
Mo (ppm)	/	/	/	844	/	/	/	/	/	/	1360	/	/
Ag (ppm)	/	/	1015	/	/	/	/	/	503	/	/	/	/
Cd (ppm)	/	/	/	/	/	/	/	/	/	419	/	/	/
Sn (ppm)	/	/	/	/	/	980	/	/	/	/	/	/	/
Sb (ppm)	/	/	/	680	/	/	/	/	/	/	1119	/	/
Te (ppm)	/	/	/	/	/	/	/	/	/	/	/	/	/
I (ppm)	/	1181	/	/	/	/	/	933	/	/	/	/	/
Ba (ppm)	2085	/	/	/	/	/	1499	/	/	/	/	/	/
Yb (ppm)	/	/	1133	/	/	/	/	/	536	/	/	/	/

[illegible]

APPENDIX IV

Table 1: Electron microprobe analyses of uranium bearing mineral phases in weight %

Table 2: Electron microprobe analyses of uranium bearing mineral phases as oxides in weight %

Table 3: Electron microprobe analyses of uranium bearing mineral phases in atomic %

Table 4: Electron microprobe analyses of monazite in weight %

Table 5: Electron microprobe analyses of monazite as oxides in weight %

Table 6: Electron microprobe analyses of monazite in atomic %

Table1: Electron microprobe analyses of uranium bearing mineral phases in weight %

sample	Al	Si	S	Ca	V	Fe	Pb	U	Ti	La	Th	Mn	Y	Ce	P	Nd	Dy	Nb	Gd	Yb	Ta	F	O	Total
DO8628	0,03	0,39	0	1,50	0	0,38	13	60	0	0	4	1	2	0	0	0	1	0	1	0	0	0	12	95,79
DO8628	0,02	0,77	1	2,45	0	0,38	6	64	0	0	4	1	2	0	0	0	1	0	0	0	0	0	13	94,55
DO8628	0,00	0,12	0	1,06	0	0,76	10	62	0	0	5	0	2	0	0	0	1	0	1	0	0	0	11	94,66
DO8628	0,05	1,07	1	1,51	0	0,39	13	49	2	0	6	1	2	0	0	0	0	1	0	0	0	0	13	91,72
DO8628	0,01	0,15	0	0,41	0	0,57	15	58	0	0	6	0	2	0	0	0	0	0	1	0	0	0	11	93,48
DO8628	0,02	0,36	0	0,80	0	0,56	12	60	0	0	6	0	2	0	0	0	0	0	1	0	0	0	12	95,49
DO8628	0,00	0,32	0	0,76	0	0,50	12	58	0	0	5	0	2	0	0	0	1	0	1	0	0	0	12	94,29
DO8628	0,00	0,14	0	0,89	0	0,68	12	61	0	0	5	1	3	0	0	0	1	0	1	0	0	0	12	96,39
DO8628	0,00	0,22	0	1,03	0	0,39	11	60	0	0	5	0	2	0	0	0	1	0	1	0	0	0	11	93,64
DO8628	0,00	0,04	0	0,56	0	0,55	11	61	0	0	5	1	2	0	0	0	1	0	1	0	0	0	11	94,35
DO8628	0,14	3,87	2	0,30	0	0,71	18	18	6	0	7	0	8	0	2	0	1	3	1	1	0	1	21	93,26
DO8628	0,18	5,29	0	0,35	0	0,21	8	22	2	0	9	0	12	0	3	0	2	3	2	1	0	1	21	91,64
DO8628	0,01	0,27	1	1,70	0	0,41	14	61	0	0	2	1	2	0	0	0	0	0	0	0	0	0	12	96,31
DO8628	0,00	0,12	2	0,75	0	0,42	27	52	0	0	2	1	1	0	0	0	1	0	0	0	0	0	12	99,65
DO8628	0,06	0,79	1	1,93	0	0,37	8	64	0	0	2	1	2	0	0	0	0	0	0	0	0	0	13	95,75
DO8628	0,00	0,14	0	1,71	0	0,71	11	66	0	0	2	1	1	0	0	0	0	0	0	0	0	0	12	96,49
DO8628	0,05	0,77	1	1,85	0	0,41	9	64	0	0	2	1	1	0	0	0	0	0	0	0	0	0	12	94,54
DO8628	0,02	0,38	1	1,07	0	0,37	20	56	0	0	2	0	1	0	0	0	0	0	0	0	0	0	12	96,73
DO8628	0,00	0,22	0	1,45	0	0,57	11	64	0	0	2	1	2	0	0	0	0	0	0	0	0	0	11	94,29
DO8628	0,00	0,10	0	0,53	0	0,39	18	60	0	0	4	0	1	0	0	0	0	0	0	0	0	0	11	96,38
DO8628	0,03	0,53	0	2,21	0	0,49	7	63	0	0	3	1	2	0	0	0	0	0	0	0	0	0	12	94,04
DO8628	0,05	0,52	2	2,02	0	0,56	19	57	0	0	4	1	1	0	0	0	0	0	0	0	0	0	14	102,40
DO8628	0,05	0,71	0	3,24	0	0,46	3	69	0	0	4	1	1	0	0	0	0	0	0	0	0	1	13	96,06
DO8628	0,00	0,68	0	2,98	0	0,55	3	68	0	0	5	1	1	0	0	0	0	0	0	0	0	0	13	95,40
DO8628	0,03	0,73	1	2,59	0	0,45	7	63	0	0	5	1	1	0	0	0	0	0	0	0	0	1	13	96,20
DO8628	0,00	0,24	0	1,96	0	0,63	7	65	0	0	6	1	1	0	0	0	0	0	0	0	0	0	12	94,33
DO8628	0,10	1,43	1	0,86	0	0,71	11	55	1	0	3	0	1	1	0	1	1	2	1	0	0	0	13	92,47
DO8628	0,00	0,17	0	0,99	0	0,91	14	62	0	0	4	1	1	0	0	0	0	0	0	0	0	0	11	95,59
DO8628	0,00	0,41	0	2,25	0	0,70	11	61	0	0	4	1	1	0	0	0	0	1	0	0	0	0	12	94,36
DO8628	0,00	0,38	0	0,94	0	0,70	14	60	0	0	4	0	1	0	0	0	0	0	0	0	0	0	12	94,61
DO8628	0,00	0,52	0	2,80	0	0,55	5	66	0	0	4	1	1	0	0	0	1	0	0	0	0	1	13	96,22
DO8628	0,01	0,14	0	0,47	0	0,88	12	64	0	0	3	0	2	0	0	0	0	0	0	0	0	0	11	94,80

sample	Al	Si	S	Ca	V	Fe	Pb	U	Ti	La	Th	Mn	Y	Ce	P	Nd	Dy	Nb	Gd	Yb	Ta	F	O	Total
DO8628	0,00	0,06	0	0,91	0	0,52	17	60	0	0	3	0	2	0	0	0	0	0	1	0	0	0	11	97,58
DO8628	0,03	0,70	0	1,76	0	0,57	10	61	0	0	4	1	2	0	0	1	0	0	0	0	0	0	13	96,13
DO8628	0,01	0,21	0	0,88	0	0,51	13	62	0	0	4	0	2	0	0	0	0	0	0	0	0	0	11	94,46
DO8628	0,02	0,59	0	1,91	0	0,37	8	61	0	0	4	1	2	0	0	0	0	0	1	0	0	0	12	94,50
DO8628	0,00	0,20	1	1,45	0	0,60	11	63	0	0	3	1	2	0	0	0	0	0	0	0	0	0	11	94,40
DO8628	0,03	0,36	0	2,12	0	0,29	13	60	0	0	4	0	2	0	0	1	1	0	0	0	0	0	12	96,73
DO8628	0,02	0,36	1	1,08	0	0,51	14	59	0	0	4	0	2	0	0	1	0	0	0	0	0	0	12	95,20
DO8628	0,66	4,19	0	0,40	0	1,78	15	18	8	0	5	0	5	0	1	0	1	5	1	0	1	0	22	92,53
DO8628	1,08	5,85	0	0,66	0	2,40	15	16	8	0	5	0	1	0	1	0	0	6	0	0	3	0	22	87,65
DO6920	0,07	4,34	0	0,71	0	0,00	6	29	0	0	7	0	9	0	4	1	1	0	2	1	0	1	19	86,01
DO6920	0,09	4,78	0	0,81	0	0,14	2	30	1	0	7	0	10	1	4	1	2	0	2	1	0	1	21	88,33
DO6920	0,10	4,37	1	0,70	0	0,18	9	30	0	0	6	0	8	0	4	1	1	0	1	1	0	1	19	88,24
DO6920	0,09	4,72	3	0,73	0	4,62	4	18	0	0	21	0	4	1	2	0	1	0	1	0	0	1	20	86,82
DO6920	0,07	5,27	1	0,55	0	0,00	5	33	0	0	16	0	6	0	3	1	1	0	2	1	0	1	19	93,99
DO6920	0,11	5,31	1	0,98	0	0,00	4	20	0	0	29	0	5	1	3	1	1	0	1	0	0	1	20	93,45
DO6920	0,02	0,20	0	0,93	0	0,09	0	0	0	15	2	0	0	30	0	6	0	0	0	0	0	7	10	72,84
DO6920	0,07	0,05	0	0,61	0	0,97	0	0	0	14	1	0	0	30	0	8	0	0	0	0	0	7	10	73,34
DO6920	0,00	0,03	0	0,43	0	0,29	0	0	0	15	0	0	0	31	0	8	0	0	1	0	0	7	10	72,44
DO6920	0,00	0,05	0	0,52	0	0,21	0	0	0	15	1	0	1	30	0	8	0	0	0	0	0	7	10	72,31
DO6920	0,16	0,19	0	1,33	0	0,44	0	0	0	15	5	0	0	29	0	6	0	0	0	0	0	7	11	75,10
DO6920	0,65	0,67	0	1,69	0	0,66	1	73	0	0	0	0	0	1	0	1	0	0	0	0	0	0	13	93,64
DO6920	0,05	0,48	0	1,66	0	0,72	1	73	0	0	0	0	0	1	0	1	0	0	0	0	0	0	12	93,38
DO6920	0,09	0,79	0	1,34	0	0,41	1	71	0	0	0	0	0	2	0	1	0	0	0	0	0	0	12	91,43
DO6920	0,25	1,42	0	1,06	0	0,65	2	70	0	0	0	0	0	2	0	1	0	0	0	0	0	0	13	92,42
DO6920	0,11	0,73	0	1,28	0	0,81	0	1	0	14	0	0	0	28	0	7	0	0	0	0	0	8	10	72,38
DO6920	0,07	4,79	1	0,91	0	0,68	1	17	0	0	31	0	7	0	4	1	1	0	1	1	0	1	21	94,04
DO6920	0,07	4,98	1	0,92	0	1,64	1	16	0	0	30	0	8	1	4	1	1	0	2	1	0	1	22	95,88
DO6920	0,00	0,02	0	0,42	0	0,28	0	0	0	14	0	0	1	29	0	9	0	0	1	0	0	7	10	72,16
DO6920	0,02	0,02	0	0,37	0	0,09	0	0	0	16	0	0	0	31	0	8	0	0	0	0	0	8	10	73,29
DO6920	0,17	6,03	1	0,40	0	0,31	1	44	0	0	5	0	7	0	2	1	1	0	1	1	0	1	20	92,33
DO6920	0,15	6,38	0	0,39	0	0,28	2	42	0	0	7	0	7	0	2	0	1	0	2	1	0	1	20	91,62
DO6920	0,26	6,52	0	0,33	0	0,00	2	42	0	0	7	0	7	0	2	1	1	0	1	1	0	1	20	91,96
DO6920	0,08	1,34	0	0,68	0	0,44	3	65	0	0	3	0	1	1	0	1	0	0	0	0	0	0	12	89,29

sample	Al	Si	S	Ca	V	Fe	Pb	U	Ti	La	Th	Mn	Y	Ce	P	Nd	Dy	Nb	Gd	Yb	Ta	F	O	Total
DO8628	0,07	0,64	0	1,69	0	0,50	10	57	0	0	4	0	0	0	0	0	0	0	0	0	0	0	11	87,23
DO8628	0,00	0,62	1	1,71	0	0,33	13	59	1	0	5	0	1	0	0	0	0	1	0	0	0	0	13	98,11
DO8628	0,01	0,27	10	0,00	0	0,05	70	7	0	0	1	0	0	0	0	1	0	2	0	0	0	0	17	109,79
DO8628	0,00	0,37	0	0,49	0	0,54	13	55	1	0	6	1	3	0	0	0	1	0	1	0	0	0	13	97,89
DO8628	0,00	0,34	0	1,14	0	0,68	11	58	0	0	6	0	3	0	0	0	1	0	1	0	0	0	12	96,17
DO8628	0,00	0,00	0	0,32	0	0,41	15	55	0	0	6	0	3	0	0	0	1	0	1	1	0	0	11	94,38
DO8628	0,00	0,92	0	0,34	0	0,59	12	48	1	0	8	0	3	0	0	0	1	1	1	0	0	0	13	90,61
DO8628	0,01	0,67	0	1,52	0	0,53	8	54	1	0	6	1	4	0	0	1	1	1	1	0	0	1	13	93,98
DO8628	0,00	0,48	0	0,67	0	0,81	12	53	1	0	7	0	3	0	0	0	1	1	1	0	0	0	12	93,97
DO8628	0,00	0,07	0	1,26	0	0,54	11	56	0	0	7	1	3	0	0	1	1	0	1	0	0	1	12	94,82
DO8628	0,00	0,19	0	1,17	0	0,45	9	56	0	0	7	1	3	0	0	1	1	0	1	0	0	0	12	94,16
DO8628	0,00	0,06	0	0,60	0	0,56	12	56	0	0	7	0	3	0	0	1	1	0	1	0	0	0	11	94,39
DO8628	0,06	1,69	0	1,71	0	0,43	8	49	2	0	5	1	2	0	0	0	1	2	0	0	0	0	14	89,60
DO8628	0,01	0,08	0	0,26	0	0,52	16	58	0	0	7	0	2	0	0	1	1	0	0	0	0	0	11	96,03
DO8628	0,00	0,16	0	0,77	0	0,96	12	59	0	0	7	1	2	0	0	0	0	0	1	0	0	0	11	95,10
DO8628	0,00	0,07	0	0,36	0	0,60	15	58	0	0	7	0	1	0	0	0	0	0	0	0	0	0	11	95,46
DO8628	0,00	0,23	1	0,61	0	0,43	14	56	0	0	7	0	2	0	0	0	0	0	1	0	0	0	11	95,20
DO8628	0,13	1,77	0	0,82	0	0,40	10	50	0	0	5	0	3	1	0	1	1	0	1	0	0	0	14	91,38
DO8628	0,00	0,16	0	1,08	0	0,39	12	57	0	0	7	0	2	0	0	0	0	0	1	0	0	0	11	93,94
DO8628	0,07	1,25	0	1,16	0	0,73	13	59	1	0	5	0	1	0	0	0	0	1	0	0	0	0	13	93,31
AO5268	0,48	3,78	0	0,69	0	0,36	6	61	0	0	5	1	1	0	0	0	0	0	1	0	0	0	13	96,35
AO5268	0,01	0,71	1	0,60	0	0,44	12	55	0	0	3	1	1	0	0	0	0	0	0	0	0	0	16	99,62
AO5268	0,41	2,74	2	0,14	0	1,11	16	57	1	0	4	1	2	0	0	0	1	0	0	0	0	0	14	90,49
AO5268	1,25	3,67	0	0,21	0	2,26	3	19	22	1	2	0	3	3	0	2	1	3	1	0	1	0	25	91,32
AO5268	0,03	1,00	0	0,68	0	0,48	4	20	18	1	1	0	3	3	0	2	1	2	1	0	1	0	25	95,58
AO5268	0,05	0,87	1	1,03	0	0,62	6	61	0	0	5	1	2	0	0	1	1	0	1	0	0	0	13	95,83
AO5268	0,04	0,72	0	1,13	0	0,75	5	64	0	0	6	1	2	0	0	0	1	0	0	0	0	0	13	94,77
AO5268	0,05	0,79	0	0,61	0	0,34	3	67	0	0	4	2	2	0	0	0	1	0	0	0	0	0	12	105,14
AO5268	0,02	0,72	3	1,01	0	0,59	24	53	0	0	5	1	2	0	0	0	0	0	0	0	0	0	15	95,98
AO5268	0,10	1,24	1	0,86	0	0,50	6	64	0	0	6	1	2	0	0	0	1	0	0	0	0	0	13	96,90
AO5268	0,00	0,42	1	1,12	0	1,11	10	60	0	0	5	1	2	0	0	0	1	0	0	0	0	0	13	97,49
AO5268	0,12	1,21	1	0,89	0	0,93	8	62	0	0	6	1	2	0	0	0	1	0	1	0	0	0	13	94,26
AO5268	1,46	11,68	1	0,11	0	0,16	7	58	0	0	6	1	2	0	0	0	1	0	1	0	0	0	13	90,17

Comment	Al	Si	S	Ca	V	Fe	Pb	U	Ti	La	Th	Mn	Y	Ce	P	Nd	Dy	Nb	Gd	Yb	Ta	F	O	Total
AO5268	0,14	1,32	0	0,67	0	0,61	4	66	0	0	5	1	1	0	0	0	0	0	1	0	0	0	13	95,08
AO5268	0,14	1,02	1	0,38	0	0,26	7	61	0	0	6	1	1	0	0	0	0	0	0	0	0	0	13	97,17
AO5268	0,08	1,21	0	0,89	0	0,67	3	31	0	0	11	0	4	2	0	1	1	0	0	0	0	0	23	96,35
AO5268	0,02	0,33	2	0,90	0	0,86	22	48	0	0	5	0	2	0	0	0	0	1	1	0	0	0	13	93,00
AO5268	0,15	1,14	0	0,80	0	0,62	9	60	0	0	4	1	2	0	0	0	1	0	0	0	0	0	12	95,79
AO5268	0,11	0,97	1	0,63	0	0,53	8	63	0	0	4	1	2	0	0	0	0	0	0	0	0	0	13	96,81
AO5268	0,18	1,44	1	0,73	0	0,60	12	61	0	0	3	1	1	0	0	0	0	0	0	0	0	0	13	100,19
AO5268	0,19	1,68	2	0,54	0	0,51	12	62	0	0	2	1	1	0	0	0	0	0	0	0	0	0	15	96,84
AO5268	1,24	9,69	1	0,07	0	0,13	7	64	1	0	3	1	1	1	0	1	0	1	1	0	0	0	14	90,89
AO5268	0,31	1,75	1	0,29	0	0,36	6	39	0	0	5	0	4	1	0	1	1	0	1	0	0	0	21	104,20
AO5268	0,15	1,12	4	0,87	0	0,64	27	45	1	0	4	0	1	1	0	0	0	1	0	0	0	0	16	95,50
AO5268	0,02	0,42	0	0,62	0	0,48	5	64	0	0	7	1	1	0	0	0	0	0	0	0	0	0	13	96,72
AO5268	0,17	1,37	1	0,64	0	0,71	19	52	0	0	6	1	2	0	0	0	1	0	0	0	0	0	12	95,09
AO5268	0,24	1,37	1	0,45	0	0,45	6	60	0	0	6	1	2	0	0	1	1	0	1	0	0	0	13	95,23
AO5268	0,07	0,87	1	0,95	0	0,49	15	51	0	0	6	1	2	0	0	1	0	0	1	0	0	0	13	94,20
AO5268	0,08	0,91	0	1,22	0	0,64	5	61	0	0	6	1	3	0	0	0	1	0	1	0	0	0	13	94,67
AO5268	0,33	1,89	0	0,43	0	0,51	4	68	0	0	3	2	1	0	0	0	1	0	0	0	0	0	13	95,08
AO5268	0,14	0,63	1	0,74	0	0,53	10	58	1	0	4	1	1	1	0	0	0	1	0	0	0	0	14	95,55
AO5268	0,00	0,22	0	0,56	0	0,76	9	61	0	0	6	1	2	0	0	0	1	0	1	0	0	0	12	96,52
AO5268	0,03	1,07	0	1,22	0	0,61	13	60	0	0	5	0	2	0	0	0	1	0	0	0	0	0	12	95,87
AO5268	0,07	1,02	0	1,22	0	0,48	3	67	0	0	6	2	1	0	0	0	0	0	0	0	0	0	13	96,53
AO5268	0,11	1,31	1	0,80	0	0,70	8	63	0	0	5	1	1	0	0	0	0	0	0	0	0	0	13	94,90
AO5268	0,00	0,28	1	1,10	0	0,32	6	63	0	0	4	1	2	0	0	0	0	0	1	0	0	0	13	96,41
AO5268	0,06	0,44	0	0,98	0	0,47	12	64	0	0	3	1	2	0	0	0	0	0	1	0	0	0	12	97,15
AO5268	0,16	1,32	1	0,67	0	0,62	18	58	0	0	3	1	1	0	0	0	0	0	0	0	0	0	12	97,57
AO5268	0,16	1,83	2	0,49	0	0,48	6	64	0	0	3	1	1	1	0	0	0	0	0	0	0	0	15	95,91
AO5268	0,06	0,87	1	1,00	0	0,59	6	61	0	0	5	1	1	1	0	1	0	1	1	0	0	0	14	94,87
AO5268	0,01	0,21	0	0,05	0	10,29	6	64	0	0	7	1	1	0	0	0	0	0	0	0	0	0	12	43,26
AO5268	0,02	0,03	14	0,00	0	7,00	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	37,24
AO5268	0,11	1,06	14	0,99	0	0,78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	96,77
AO5268	0,13	1,30	1	0,77	0	0,64	7	67	0	0	1	1	1	0	0	0	1	0	0	0	0	0	13	96,80
AO5268	0,12	1,14	1	1,02	0	0,64	8	66	0	0	1	1	1	0	0	1	0	0	0	0	0	0	13	95,45
AO5268	0,01	0,37	0	1,04	0	0,66	3	70	0	0	2	2	1	0	0	0	0	0	0	0	0	0	13	96,85

AO5268	0,13	0,98	1	1,07	0	0,72	13	65	0	0	2	1	1	0	0	0	0	0	0	0	0	0	12	97,44
AO5268	0,40	4,13	1	0,43	0	0,41	9	66	0	0	1	2	1	0	0	1	0	0	0	0	0	0	13	97,57
AO5268	0,12	1,66	1	0,83	0	0,56	12	51	0	0	7	1	2	0	0	0	0	0	0	1	0	0	16	94,80
AO5268	0,18	2,21	0	0,62	0	0,47	5	62	0	0	7	1	2	0	0	0	1	0	1	0	0	0	13	94,62

sample	Al	Si	S	K	Ca	V	Fe	Zr	Pb	U	Na	Mg	Ti	Mo	La	Th	Mn	Y	Ce	P	Nd	Dy	Ta	O	Total
AO3883	0.02	0.35	0	0.15	1.67	0	0.57	0	9	68	0	0	0	0	0	3	1	1	0	0	0	0	0	12	97.289
AO3883	0.04	0.54	1	0.13	1.35	0	0.76	0	14	63	0	0	0	0	0	3	1	1	0	0	0	0	0	14	100.426
AO3883	0.00	0.33	0	0.23	1.59	0	0.43	0	6	69	0	0	0	0	0	2	1	2	0	0	0	1	0	12	96.072
AO3883	0.03	0.51	1	0.22	1.45	0	0.64	0	5	71	0	0	0	0	0	2	1	1	0	0	0	0	0	13	96.463
AO3883	0.05	1.06	1	0.18	0.95	0	0.75	0	3	69	0	0	0	0	0	2	1	2	0	0	0	0	0	13	94.429
AO3883	0.22	1.84	2	0.21	0.68	0	0.77	0	3	62	0	0	0	0	0	7	1	1	0	0	0	1	0	13	92.766
AO3883	0.50	3.46	3	0.14	0.54	0	0.75	0	2	57	0	0	0	0	0	6	1	1	1	0	1	0	0	14	88.613
AO3883	0.17	1.10	1	0.18	1.03	0	0.69	0	3	66	0	0	0	0	0	7	1	1	0	0	1	0	0	13	95.831
AO3883	0.91	6.49	6	0.38	0.64	0	0.30	0	3	47	0	0	3	0	0	6	0	1	0	0	0	0	0	18	87.375
AO3883	1.17	6.32	6	0.28	0.75	0	0.45	0	1	54	0	0	0	0	0	6	0	2	1	0	0	0	0	18	91.613
AO3883	0.99	9.85	10	0.05	0.43	0	0.07	0	2	26	0	0	0	0	0	18	0	8	0	0	1	1	0	21	89.207
AO3883	1.18	10.29	10	0.10	0.51	0	0.04	0	2	30	0	0	0	0	0	16	0	7	0	0	0	1	0	22	90.617
AO3883	0.00	0.57	1	0.21	0.70	0	0.67	0	22	57	0	0	0	0	0	4	1	3	0	0	0	1	0	15	108.649
AO3883	0.01	0.70	1	0.10	1.02	0	0.54	0	3	65	0	0	0	0	0	5	1	3	0	0	1	1	0	12	93.792
AO3883	1.09	6.65	7	0.26	0.78	0	0.35	0	1	53	0	0	1	0	0	4	0	1	1	0	0	0	0	18	88.391
AO3883	0.00	0.67	1	0.19	0.70	0	0.62	0	10	59	0	0	0	0	0	6	1	3	0	0	1	1	0	13	95.046
AO3883	0.00	0.21	0	0.16	0.80	0	0.56	0	10	60	0	0	0	0	0	6	1	3	0	0	0	0	0	12	95.226
AO3883	0.00	0.20	0	0.10	0.87	0	0.62	0	9	59	0	0	0	0	0	6	1	3	0	0	0	1	0	12	94.276
AO3883	0.01	0.51	1	0.17	0.86	0	0.72	0	9	59	0	0	0	0	0	6	1	3	0	0	0	1	0	12	94.228
AO3883	0.00	0.22	0	0.12	0.85	0	0.58	0	5	63	0	0	0	0	0	6	1	3	0	0	1	1	0	12	95.218
AO3883	0.00	0.46	0	0.16	0.87	0	0.71	0	5	64	0	0	0	0	0	6	1	3	0	0	0	1	0	12	95.086
AO3883	0.00	0.40	0	0.18	0.94	0	0.65	0	8	60	0	0	0	0	0	6	1	3	0	0	1	1	0	13	95.513
AO3883	0.00	0.33	0	0.22	0.90	0	0.69	0	5	63	0	0	0	0	0	6	1	3	0	0	0	0	0	12	93.821
AO3883	0.74	3.94	4	0.19	0.51	0	0.31	0	9	45	0	0	0	0	0	4	0	1	1	0	1	0	0	15	83.752
AO3883	0.86	5.32	5	0.09	0.54	0	0.38	0	14	45	0	0	0	0	0	4	0	2	0	0	1	0	0	17	93.389
AO3883	1.01	5.75	6	0.23	0.65	0	0.40	0	13	43	0	0	0	0	0	5	0	1	1	0	0	0	0	18	92.158
AO3883	1.01	5.10	5	0.14	0.44	0	0.32	0	18	42	0	0	0	0	0	6	0	1	1	0	1	1	0	18	95.89
AO3883	0.74	4.18	4	0.15	0.69	0	1.00	0	6	23	0	0	18	0	1	2	0	2	2	0	1	0	1	24	88.639
AO3883	1.09	5.52	6	0.12	0.81	0	1.27	0	3	25	0	0	17	0	1	2	0	1	2	0	1	0	1	25	87.271

sample	Al	Si	S	K	Ca	V	Fe	Zr	Pb	U	Na	Mg	Ti	Mo	La	Th	Mn	Y	Ce	P	Nd	Dy	Ta	O	Total
AO3883	0.05	0.74	1	0.16	0.94	0	0.52	0	7	62	0	0	0	0	0	5	1	3	0	0	0	1	0	13	94.683
AO3883	0.02	0.54	1	0.15	0.80	0	0.62	0	18	55	0	0	0	0	0	5	1	2	0	0	0	1	0	13	98.466
AO3883	0.03	0.85	1	0.15	0.98	0	0.70	0	5	64	0	0	0	0	0	5	1	3	0	0	0	0	0	13	95.13
AO3883	0.00	0.65	1	0.17	0.92	0	0.51	0	8	61	0	0	0	0	0	5	1	3	0	0	0	1	0	12	93.843
AO3883	1.49	8.70	9	0.26	0.95	0	0.54	0	5	36	0	0	2	0	0	9	0	2	1	0	0	0	1	22	89.937
AO3883	0.00	0.65	1	0.18	0.97	0	0.58	0	7	62	0	0	0	0	0	5	1	2	0	0	0	0	0	12	93.04
AO3883	0.05	1.13	1	0.15	0.69	0	0.87	0	11	59	0	0	0	0	0	4	1	3	0	0	0	0	0	13	95.746
AO3883	0.94	6.72	7	0.16	0.69	0	0.39	0	12	39	0	0	0	0	0	10	0	4	0	0	0	0	0	19	95.46
AO3883	0.56	4.21	4	0.08	0.18	0	1.11	0	1	21	0	0	21	0	1	2	0	3	3	0	2	0	1	25	86.175
AO3883	0.01	0.73	1	0.21	1.00	0	0.68	0	4	67	0	0	0	0	0	3	1	3	0	0	1	0	0	13	93.692
AO3883	0.03	0.89	1	0.16	0.93	0	0.74	0	5	64	0	0	0	0	0	3	1	3	0	0	0	1	0	13	93.38
AO3883	0.05	0.87	1	0.16	0.89	0	0.73	0	6	65	0	0	0	0	0	4	1	3	0	0	0	1	0	13	96.21
AO3883	0.17	1.56	2	0.19	0.77	0	0.58	0	6	63	0	0	0	0	0	3	1	3	0	0	0	1	0	14	95.387
AO3883	0.01	0.68	1	0.20	0.97	0	0.69	0	6	64	0	0	0	0	0	3	1	3	0	0	0	1	0	13	93.683
AO3883	0.55	3.24	3	0.10	0.33	0	0.41	0	23	44	0	0	0	0	0	5	0	2	1	0	0	0	0	16	98.733
AO3883	0.00	0.91	1	0.22	0.94	0	0.76	0	3	67	0	0	0	0	0	3	1	3	0	0	1	1	0	13	95.29
AO3883	0.04	0.88	1	0.26	0.94	0	0.75	0	3	68	0	0	0	0	0	4	1	3	0	0	0	1	0	13	95.043
AO3883	0.06	0.95	1	0.19	0.93	0	0.77	0	3	66	0	0	0	0	0	4	1	3	0	0	0	1	0	13	94.398
AO3883	0.79	4.71	5	0.13	0.36	0	0.21	0	22	41	0	0	0	0	0	3	0	1	1	0	1	0	0	18	95.994
AO3883	0.93	4.96	5	0.21	0.34	0	0.20	0	12	44	0	0	0	0	0	4	0	2	1	0	1	0	0	17	90.013
AO3883	0.96	5.48	5	0.21	0.29	0	0.34	0	11	46	0	0	0	0	0	4	0	2	1	0	0	0	0	17	90.866
AO3883	0.96	5.57	6	0.14	0.83	0	1.29	0	3	22	0	0	18	0	1	3	0	1	2	0	1	0	3	25	87.218
AO3883	0.75	4.36	4	0.11	0.56	0	1.26	0	24	16	0	0	14	0	0	3	0	1	2	0	1	0	2	24	96.78
AO3883	1.50	10.39	10	0.22	0.45	0	0.04	0	13	24	0	0	0	0	0	13	0	6	0	0	0	1	0	22	92.665
AO3883	1.42	10.46	10	0.09	0.46	0	0.06	0	9	32	0	0	0	0	0	8	0	6	0	0	0	1	0	22	92.367
AO3883	1.27	9.69	10	0.06	0.49	0	0.03	0	10	21	0	0	0	0	0	14	0	6	0	0	0	1	0	21	87.559
AO3883	0.02	0.60	1	0.20	0.59	0	0.64	0	8	57	0	0	0	0	0	7	1	4	0	0	0	1	0	12	91.767
AO3883	0.00	0.41	0	0.15	0.59	0	0.49	0	14	55	0	0	0	0	0	6	1	4	0	0	0	1	0	13	96.882
AO3883	0.02	0.64	1	0.14	0.68	0	0.65	0	6	59	0	0	0	0	0	7	1	5	0	0	1	0	0	12	92.391
AO3883	0.02	0.84	1	0.18	0.73	0	0.77	0	3	60	0	0	0	0	0	6	1	5	0	0	0	1	0	12	91.887
AO3883	0.74	6.98	7	0.08	0.46	0	0.09	0	21	26	0	0	2	0	0	7	0	3	0	0	0	0	0	19	88.757
AO3883	0.65	5.65	6	0.17	0.51	0	0.14	0	18	32	0	0	2	0	0	6	0	3	0	0	0	0	1	18	89.587
AO3883	0.95	5.43	5	0.10	0.85	0	1.49	0	1	19	0	0	16	0	1	5	0	1	3	0	1	0	3	24	82.809

sample	Al	Si	S	K	Ca	V	Fe	Zr	Pb	U	Na	Mg	Ti	Mo	La	Th	Mn	Y	Ce	P	Nd	Dy	Ta	O	Total
AO3883	0.77	9.37	9	0.09	0.21	0	0.03	0	9	13	0	0	0	0	0	34	0	3	0	0	0	1	0	21	95.016
AO3883	0.75	9.36	9	0.05	0.28	0	0.10	0	8	12	0	0	0	0	0	36	0	3	0	0	0	0	0	21	93.404
AO3883	0.90	10.01	10	0.12	0.17	0	0.10	0	6	14	0	0	0	0	0	35	0	3	1	0	1	0	0	21	92.761
AO3883	0.79	9.56	10	0.08	0.29	0	0.05	0	5	11	0	0	0	0	0	41	0	2	0	0	0	0	0	21	93.323
AO3883	0.60	7.77	8	0.07	0.23	0	0.09	0	22	13	0	0	0	0	0	31	0	2	0	0	0	0	0	21	101.03
AO3883	0.63	3.55	4	0.12	0.60	0	1.40	0	7	9	0	0	18	0	0	4	0	4	2	0	1	0	4	23	80.903
AO3883	0.10	1.65	2	0.19	0.79	0	0.57	0	6	61	0	0	0	0	0	7	1	2	0	0	0	1	0	13	94.693
AO3883	0.01	0.81	1	0.11	0.93	0	0.51	0	9	61	0	0	0	0	0	5	1	2	0	0	0	0	0	13	95.786
AO3883	0.07	0.92	1	0.21	0.93	0	0.58	0	4	65	0	0	0	0	0	5	1	3	0	0	0	1	0	13	94.244
AO3883	0.03	1.10	1	0.19	0.84	0	0.65	0	4	65	0	0	0	0	0	5	1	3	0	0	0	0	0	13	94.868
AO3883	0.07	1.23	1	0.19	0.71	0	0.73	0	11	58	0	0	0	0	0	5	1	2	0	0	0	1	0	14	96.354
AO3883	0.22	1.53	2	0.17	0.77	0	0.78	0	2	64	0	0	0	0	0	5	1	3	0	0	0	0	0	13	92.986
AO3883	0.08	1.03	1	0.18	1.04	0	0.69	0	4	65	0	0	0	0	0	5	1	3	0	0	0	0	0	13	94.319
AO3883	0.06	1.24	1	0.20	0.77	0	0.61	0	3	64	0	0	0	0	0	5	1	3	0	0	0	0	0	13	92.906
AO3883	0.07	1.21	1	0.20	0.81	0	0.65	0	4	63	0	0	0	0	0	6	1	3	0	0	0	1	0	13	93.601
AO3883	0.13	1.48	1	0.21	0.82	0	0.76	0	4	63	0	0	0	0	0	6	1	2	0	0	0	0	0	13	93.862
AO3883	1.05	5.23	5	0.15	0.32	0	0.32	0	11	44	0	0	0	0	0	3	0	2	1	0	1	0	0	16	88.006
AO3883	1.05	5.92	6	0.12	0.34	0	0.37	0	8	48	0	0	0	0	0	6	0	2	1	0	1	0	0	18	91.706
AO3883	0.54	3.58	4	0.17	0.48	0	0.73	0	2	59	0	0	0	0	0	5	1	3	1	0	1	1	0	15	91.523
AO3883	1.04	6.26	6	0.23	0.31	0	0.53	0	5	52	0	0	0	0	0	2	0	2	1	0	1	0	0	18	91.927
AO3883	0.52	3.59	4	0.04	0.74	0	1.30	0	6	23	0	0	20	0	0	2	0	2	2	0	1	0	1	25	89.071
AO3883	0.75	4.80	5	0.11	0.71	0	1.43	0	4	26	0	0	19	0	1	1	0	1	2	0	1	0	1	25	88.462
AO3883	0.00	0.86	1	0.13	0.74	0	0.57	0	4	60	0	0	0	0	0	7	1	4	0	0	1	1	0	13	92.821
AO3883	0.01	0.85	1	0.18	0.73	0	0.66	0	2	60	0	0	0	0	0	7	1	4	0	0	1	0	0	12	90.57
AO3883	0.02	0.87	1	0.17	0.61	0	0.58	0	8	56	0	0	0	0	0	7	1	3	0	0	0	1	0	13	92.637
AO3883	0.05	1.07	1	0.24	0.57	0	0.68	0	7	56	0	0	0	0	0	7	1	4	0	0	1	1	0	13	93.321
AO3883	0.00	0.85	1	0.16	0.67	0	0.58	0	5	59	0	0	0	0	0	7	1	4	0	0	0	1	0	12	92.088
AO3883	0.04	0.87	1	0.15	0.61	0	0.59	0	7	58	0	0	0	0	0	7	1	4	0	0	1	1	0	13	93.459
AO3883	0.00	0.84	1	0.14	0.70	0	0.61	0	3	60	0	0	0	0	0	7	1	4	0	0	1	1	0	12	91.64
AO3883	0.75	4.34	4	0.15	0.30	0	0.52	0	10	45	0	0	0	0	0	7	0	2	1	0	0	1	0	16	90.127
AO3883	1.05	5.72	6	0.16	0.25	0	0.28	0	10	43	0	0	0	0	0	6	0	2	1	0	1	0	0	17	90.68
AO3883	1.28	6.51	7	0.12	0.28	0	0.20	0	4	44	0	0	0	0	0	9	0	1	1	0	1	0	0	17	86.678
AO3883	1.19	9.77	10	0.06	0.37	0	0.21	0	4	19	0	0	2	0	0	23	0	7	0	1	1	1	0	23	91.597

sample	Al	Si	S	K	Ca	V	Fe	Zr	Pb	U	Na	Mg	Ti	Mo	La	Th	Mn	Y	Ce	P	Nd	Dy	Ta	O	Total
AO3883	0.86	9.03	9	0.03	0.18	0	0.08	0	10	7	0	0	0	0	0	38	0	3	1	0	0	0	0	21	92.629
AO3883	0.84	8.59	9	0.11	0.20	0	0.02	0	14	7	0	0	0	0	0	36	0	3	1	0	1	0	0	20	93.725
AO3883	0.93	9.99	10	0.09	0.18	0	0.09	0	3	11	0	0	0	0	0	36	0	4	1	0	0	0	0	21	89.503
AO3883	0.98	9.57	10	0.06	0.11	0	0.00	0	10	10	0	0	0	0	0	34	0	3	1	0	1	0	0	21	92.725
AO3883	0.99	5.64	6	0.07	0.25	0	0.29	0	5	48	0	0	0	0	0	7	0	2	1	0	1	0	0	17	88.457
AO3883	1.03	5.36	5	0.10	0.25	0	0.26	0	9	40	0	0	0	0	0	6	0	2	1	0	1	0	0	16	82.823
AO3883	0.56	3.17	3	0.10	0.43	0	1.17	0	2	27	0	0	23	0	0	1	0	1	2	0	1	1	1	25	90.13
AO3883	0.92	4.92	5	0.21	0.32	0	0.32	0	4	48	0	0	0	0	0	9	0	2	1	0	0	0	0	16	87.904
AO3883	0.82	7.17	7	0.11	0.77	0	0.99	0.06	2	22	0	0	11	0	1	8	0	3	3	1	1	0	1	25	88.932
AO3883	1.04	5.28	5	0.10	0.73	0	1.83	0	5	19	0	0	19	0	0	3	0	1	2	0	1	0	1	26	87.298
AO3883	1.03	6.62	7	0.16	0.84	0	1.07	0	1	24	0	0	14	0	1	5	0	1	2	0	1	0	2	24	84.961

sample	Al ₂ O ₃	SiO ₂	SO ₂	CaO	V ₂ O ₃	FeO	PbO	UO ₂	TiO ₂	La ₂ O ₃	ThO ₂	MnO	Y ₂ O ₃	Ce ₂ O ₃	P ₂ O ₅	Nd ₂ O ₃	Dy ₂ O ₃	Nb ₂ O ₃	Gd ₂ O ₃	Yb ₂ O ₃	Ta ₂ O ₅	F	Total
DO8628	0,00	0,13	1	1,27	0	0,67	18	68	0	0	4	0	2	0	0	0	0	0	1	0	0	0	97,82
DO8628	0,07	1,50	1	2,46	0	0,73	11	69	0	0	4	1	3	0	0	1	0	0	0	0	0	0	96,35
DO8628	0,01	0,45	0	1,23	0	0,66	14	70	0	0	4	1	2	0	0	0	0	0	0	0	0	0	94,72
DO8628	0,04	1,27	0	2,67	0	0,48	9	70	0	0	5	1	3	0	0	1	0	0	1	0	0	0	94,69
DO8628	0,00	0,43	0	2,03	0	0,77	12	71	0	0	4	1	2	0	0	0	0	0	0	0	0	0	94,64
DO8628	0,06	0,77	1	2,97	0	0,37	14	68	0	0	4	1	2	0	0	1	1	0	1	0	0	0	96,94
DO8628	0,04	0,78	1	1,51	0	0,65	15	67	0	0	4	0	3	0	0	1	0	0	0	1	0	0	95,46
DO8628	1,24	8,96	3	0,55	0	2,28	17	20	14	0	6	0	7	0	3	0	1	6	1	1	1	0	92,54
DO8628	2,04	12,51	1	0,92	0	3,08	16	18	14	0	6	0	1	1	1	0	0	7	0	0	3	0	87,65
DO6920	0,12	9,29	1	0,99	0	0,00	7	33	0	0	8	0	11	0	9	1	2	0	2	1	0	1	86,07
DO6920	0,16	10,22	0	1,14	0	0,18	3	34	1	0	8	0	13	1	10	1	2	0	2	1	0	1	88,36
DO6920	0,19	9,35	1	0,98	0	0,24	10	34	0	0	7	0	11	0	8	1	1	0	2	1	0	1	88,31
DO6920	0,17	10,09	6	1,01	0	5,94	5	21	0	0	23	0	6	1	5	0	1	0	1	0	0	1	86,89
DO6920	0,13	11,27	1	0,77	0	0,00	5	37	0	0	18	0	8	0	6	1	1	0	2	1	0	1	94,08
DO6920	0,21	11,36	1	1,37	0	0,00	5	23	0	0	34	0	7	1	6	1	1	0	1	1	0	1	93,55
DO6920	0,04	0,43	0	1,31	0	0,11	0	1	0	18	2	0	0	35	0	8	0	0	0	0	0	7	73,07
DO6920	0,12	0,12	0	0,85	0	1,25	0	0	0	17	1	0	0	36	0	9	0	0	0	0	0	7	73,45
DO6920	0,00	0,05	0	0,61	0	0,37	0	0	0	17	0	0	0	36	0	10	0	0	1	0	0	7	72,62
DO6920	0,01	0,10	0	0,73	0	0,27	0	0	0	17	1	0	1	35	0	9	1	0	0	0	0	7	72,50
DO6920	0,31	0,41	0	1,87	0	0,56	0	0	0	17	6	0	0	33	1	7	0	0	0	0	0	7	75,22
DO6920	1,23	1,43	0	2,36	0	0,85	1	83	0	0	0	0	0	1	0	1	0	0	0	0	0	0	93,88
DO6920	0,09	1,03	0	2,32	0	0,93	1	83	0	0	0	0	0	1	0	1	1	0	0	0	0	0	93,62
DO6920	0,17	1,69	0	1,87	0	0,52	1	81	0	0	0	0	1	2	0	1	1	0	1	0	0	0	91,70
DO6920	0,46	3,04	0	1,49	0	0,84	2	80	0	0	0	0	0	2	0	1	0	0	0	0	0	0	92,75
DO6920	0,22	1,56	0	1,79	0	1,05	0	1	0	16	0	0	0	33	0	8	0	0	0	0	0	8	72,72
DO6920	0,13	10,25	2	1,28	0	0,88	1	20	0	0	36	0	9	1	8	1	1	0	1	1	0	1	94,14
DO6920	0,14	10,65	2	1,28	0	2,11	1	19	0	0	34	0	10	1	9	2	2	0	2	1	0	1	95,94
DO6920	0,00	0,05	0	0,59	0	0,36	0	0	0	17	0	0	1	34	0	11	0	0	1	0	0	7	72,34
DO6920	0,04	0,05	0	0,52	0	0,12	0	0	0	18	0	0	0	36	0	10	0	0	0	0	0	8	73,50
DO6920	0,32	12,89	1	0,56	0	0,40	1	50	0	0	6	0	9	0	5	1	1	0	1	1	0	1	92,46
DO6920	0,29	13,64	1	0,55	0	0,36	2	48	0	0	8	0	9	0	5	0	1	0	2	1	0	1	91,74
DO6920	0,49	13,94	0	0,46	0	0,00	2	48	0	0	8	0	8	0	5	1	1	0	1	1	0	1	92,05
DO6920	0,16	2,86	0	0,95	0	0,57	3	73	0	0	3	0	1	1	0	1	0	1	0	0	0	0	89,50

sample	Al ₂ O ₃	SiO ₂	SO ₂	CaO	V ₂ O ₃	FeO	PbO	UO ₂	TiO ₂	La ₂ O ₃	ThO ₂	MnO	Y ₂ O ₃	Ce ₂ O ₃	P ₂ O ₅	Nd ₂ O ₃	Dy ₂ O ₃	Nb ₂ O ₃	Gd ₂ O ₃	Yb ₂ O ₃	Ta ₂ O ₅	F	Total
DO8628	0,14	1,36	0	2,36	0	0,64	11	65	0	0	5	0	0	0	0	0	0	1	0	0	0	0	87,50
DO8628	0,00	1,32	2	2,39	0	0,42	15	67	2	0	6	0	1	0	0	0	0	1	0	0	0	0	98,27
DO8628	0,01	0,57	19	0,00	0	0,06	76	8	1	0	1	0	0	0	0	1	0	2	0	0	0	0	109,80
DO8628	0,00	0,78	3	0,69	0	0,70	14	63	1	0	7	1	4	0	0	1	1	1	1	1	0	0	98,08
DO8628	0,00	0,72	0	1,59	0	0,88	12	66	1	0	7	1	3	0	0	1	1	0	1	0	0	0	96,35
DO8628	0,00	0,00	0	0,45	0	0,53	16	62	0	0	7	0	4	0	0	0	1	0	1	1	0	0	94,58
DO8628	0,00	1,97	0	0,47	0	0,76	13	54	2	0	9	0	4	0	1	0	1	1	1	0	0	0	90,72
DO8628	0,01	1,43	0	2,13	0	0,68	8	61	1	0	7	1	6	0	0	1	1	1	1	0	0	1	94,12
DO8628	0,00	1,03	0	0,94	0	1,04	13	61	1	0	8	0	4	0	0	0	1	1	1	0	0	0	94,07
DO8628	0,00	0,15	0	1,77	0	0,70	11	63	0	0	8	1	4	0	0	1	1	0	1	0	0	1	95,03
DO8628	0,00	0,40	0	1,64	0	0,58	10	63	0	0	8	1	4	0	0	1	1	0	1	0	0	0	94,39
DO8628	0,00	0,13	0	0,83	0	0,71	13	63	0	0	8	0	4	0	0	1	1	0	1	0	0	0	94,65
DO8628	0,11	3,62	1	2,39	0	0,56	9	56	3	0	5	1	3	0	1	0	1	3	0	0	0	0	89,62
DO8628	0,03	0,17	0	0,36	0	0,67	17	65	0	0	8	0	2	0	0	1	1	0	0	0	0	0	96,31
DO8628	0,00	0,34	0	1,07	0	1,24	13	67	0	0	8	1	2	0	0	0	1	0	1	0	0	0	95,34
DO8628	0,00	0,15	0	0,51	0	0,78	16	66	0	0	8	1	2	0	0	0	0	0	0	0	0	0	95,65
DO8628	0,00	0,49	0	0,85	0	0,55	15	64	0	0	8	0	3	0	0	1	0	0	1	0	0	0	95,43
DO8628	0,24	3,80	2	1,15	0	0,51	11	57	0	0	6	0	4	1	0	1	1	0	1	1	0	0	91,58
DO8628	0,00	0,35	0	1,51	0	0,50	13	64	0	0	8	1	3	0	0	0	0	0	1	0	0	0	94,21
AO5268	0,13	2,68	0	1,62	0	0,94	6	70	0	0	6	2	1	0	0	0	0	0	1	0	0	0	93,56
AO5268	0,90	8,08	3	0,96	0	0,46	13	63	0	0	3	1	1	0	0	0	0	0	0	0	0	0	96,53
AO5268	0,02	1,51	3	0,84	0	0,56	17	65	1	0	5	1	2	0	0	0	1	1	0	0	0	0	99,80
AO5268	0,78	5,87	1	0,19	0	1,43	3	21	36	1	2	1	4	4	0	2	1	4	1	0	1	0	90,49
AO5268	2,36	7,85	1	0,30	0	2,91	4	22	31	1	2	0	4	4	0	2	1	3	1	0	1	0	91,32
AO5268	0,05	2,15	2	0,95	0	0,62	7	69	1	0	6	2	2	0	0	1	1	0	1	0	0	0	95,79
AO5268	0,09	1,87	1	1,44	0	0,80	5	73	0	0	7	2	2	0	0	0	1	0	1	0	0	0	96,08
AO5268	0,08	1,55	0	1,58	0	0,97	3	76	0	0	5	2	3	0	0	0	1	0	0	0	0	0	95,13
AO5268	0,09	1,69	6	0,86	0	0,44	26	60	0	0	5	1	2	0	0	0	0	0	0	0	0	0	105,30
AO5268	0,03	1,53	1	1,41	0	0,76	6	73	0	0	6	2	3	0	0	0	1	0	0	0	0	0	96,24
AO5268	0,19	2,64	1	1,21	0	0,65	10	68	0	0	6	2	2	0	0	0	1	0	0	0	0	0	97,08
AO5268	0,00	0,90	1	1,57	0	1,42	9	70	0	0	6	1	3	0	0	0	1	0	1	0	0	0	97,73
AO5268	0,22	2,59	1	1,24	0	1,20	8	66	0	0	6	2	3	0	0	0	1	0	1	0	0	0	94,50
AO5268	2,77	25,00	0	0,15	0	0,21	3	36	0	0	13	0	5	2	0	1	1	0	0	0	0	0	90,25

sample	Al ₂ O ₃	SiO ₂	SO ₂	CaO	V ₂ O ₃	FeO	PbO	UO ₂	TiO ₂	La ₂ O ₃	ThO ₂	MnO	Y ₂ O ₃	Ce ₂ O ₃	P ₂ O ₅	Nd ₂ O ₃	Dy ₂ O ₃	Nb ₂ O ₃	Gd ₂ O ₃	Yb ₂ O ₃	Ta ₂ O ₅	F	Total
AO5268	0,27	2,82	2	0,94	0	0,78	8	69	1	0	7	1	1	0	0	0	0	0	0	0	0	0	95,31
AO5268	0,27	2,18	4	0,54	0	0,34	23	55	1	0	6	1	2	0	0	0	0	1	1	0	0	0	97,35
AO5268	0,16	2,60	1	1,25	0	0,86	4	75	0	0	6	2	2	0	0	0	0	0	1	0	0	0	96,62
AO5268	0,04	0,70	1	1,27	0	1,10	10	68	0	0	5	1	3	0	0	0	1	0	0	0	0	0	93,20
AO5268	0,27	2,44	1	1,12	0	0,79	8	71	0	0	5	1	3	0	0	0	0	0	0	0	0	0	95,97
AO5268	0,21	2,08	1	0,88	0	0,68	13	70	0	0	3	1	2	0	0	0	0	0	0	0	0	0	96,96
AO5268	0,35	3,08	3	1,01	0	0,77	13	70	1	0	3	2	1	1	0	0	1	1	0	0	0	0	100,34
AO5268	0,36	3,60	1	0,76	0	0,66	8	72	1	0	3	1	2	1	0	1	0	1	1	0	0	0	96,99
AO5268	2,33	20,74	1	0,10	0	0,17	6	44	0	0	6	0	5	1	0	1	1	0	1	0	0	0	91,01
AO5268	0,59	3,75	8	0,40	0	0,47	29	51	1	0	5	1	2	1	0	1	0	1	0	0	0	0	104,38
AO5268	0,27	2,40	1	1,21	0	0,83	6	72	0	0	8	2	1	0	0	0	0	0	0	0	0	0	95,76
AO5268	0,03	0,91	3	0,86	0	0,62	20	59	0	0	7	1	2	0	0	0	1	0	0	0	0	0	96,88
AO5268	0,32	2,93	1	0,89	0	0,91	6	68	1	0	7	1	3	1	0	1	1	0	1	0	0	0	95,35
AO5268	0,46	2,92	2	0,63	0	0,58	17	58	1	0	7	1	2	1	0	1	0	0	1	0	0	0	95,39
AO5268	0,13	1,86	0	1,34	0	0,63	5	69	0	0	7	2	4	1	0	0	1	0	1	0	0	0	94,39
AO5268	0,16	1,94	0	1,70	0	0,82	4	77	0	0	4	2	2	0	0	0	1	0	0	0	0	0	95,01
AO5268	0,62	4,05	2	0,61	0	0,65	10	66	1	0	4	1	1	1	0	0	0	1	0	0	0	0	95,27
AO5268	0,26	1,34	0	1,03	0	0,68	10	69	0	0	6	1	3	0	0	0	1	0	1	0	0	0	95,72
AO5268	0,00	0,48	1	0,79	0	0,97	14	68	0	0	6	0	3	0	0	0	1	0	1	0	0	0	96,76
AO5268	0,06	2,30	0	1,70	0	0,78	3	76	0	0	6	2	1	0	0	0	0	0	0	0	0	0	96,13
AO5268	0,14	2,18	1	1,70	0	0,62	9	72	0	0	6	2	1	0	0	0	0	0	0	0	0	0	96,82
AO5268	0,21	2,81	1	1,12	0	0,90	7	71	0	0	5	2	3	0	0	0	0	0	1	0	0	0	95,14
AO5268	0,01	0,61	1	1,54	0	0,41	13	72	0	0	4	1	2	0	0	0	1	0	1	0	0	0	96,66
AO5268	0,12	0,93	3	1,37	0	0,61	19	66	0	0	3	1	1	0	0	0	0	0	0	0	0	0	97,38
AO5268	0,30	2,82	4	0,93	0	0,79	6	73	1	0	4	1	2	1	0	0	0	0	1	0	0	0	97,81
AO5268	0,31	3,92	1	0,69	0	0,62	7	70	1	0	6	1	1	1	0	1	1	1	1	0	0	0	96,04
AO5268	0,11	1,86	0	1,41	0	0,76	6	72	0	0	8	2	1	0	0	0	0	0	0	0	0	0	95,25
AO5268	0,02	0,46	28	0,07	0	13,24	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43,38
AO5268	0,04	0,07	28	0,00	0	9,01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37,43
AO5268	0,20	2,27	1	1,38	0	1,01	7	76	0	0	1	2	2	0	0	1	1	0	0	0	0	0	97,09
AO5268	0,25	2,79	1	1,08	0	0,83	9	75	0	0	1	2	2	1	0	1	0	0	0	0	0	0	97,03
AO5268	0,22	2,44	0	1,43	0	0,82	3	79	0	0	3	2	1	1	0	0	0	0	0	0	0	0	95,68
AO5268	0,02	0,79	1	1,46	0	0,85	15	74	0	0	2	1	1	0	0	0	0	0	0	0	0	0	97,19

AO5268	0,25	2,10	2	1,50	0	0,92	10	75	0	0	1	2	1	0	0	1	0	0	0	0	0	97,71
AO5268	0,75	8,84	3	0,60	0	0,53	13	57	0	0	8	1	2	0	0	0	0	0	1	0	0	97,77
AO5268	0,24	3,56	1	1,16	0	0,72	5	70	0	0	7	2	2	0	0	0	1	0	1	0	0	95,02
AO5268	0,34	4,72	1	0,86	0	0,61	5	68	0	0	7	1	2	0	0	0	1	0	0	0	0	94,82
StanDev	0.0471	0.0744	0.1199	0.144	0.1806	0.2021	0.7146	2.8834	0.0536	0.1256	0.1903	0.2019	0.1641	0.2391	0.058	0.5718	0.6023	0.1289	0.5781	0.3662	0	0

Abbreviations: StanDev = standard deviation in %ox

sample	Al ₂ O ₃	SiO ₂	SO ₂	K ₂ O	CaO	V ₂ O ₃	FeO	ZrO ₂	PbO	UO ₂	Na ₂ O	MgO	TiO ₂	MoO ₃	La ₂ O ₃	ThO ₂	MnO	Y ₂ O ₃	Ce ₂ O ₃	P ₂ O ₅	Nd ₂ O ₃	Dy ₂ O ₃	Ta ₂ O ₅	Total
AO3883	0.03	0.75	0	0.18	2.34	0	0.73	0	10	77	0	0	0	0	0	3	1	1	0	0	0	0	0	97.38
AO3883	0.08	1.15	3	0.15	1.89	0	0.98	0	15	71	0	0	0	0	0	4	1	1	0	0	0	0	0	100.54
AO3883	0.00	0.71	0	0.27	2.23	0	0.55	0	7	78	0	0	0	0	0	3	1	2	0	0	0	1	0	96.23
AO3883	0.05	1.08	1	0.26	2.03	0	0.82	0	5	81	0	0	0	0	0	2	1	1	0	0	0	0	0	96.62
AO3883	0.09	2.27	0	0.22	1.33	0	0.97	0	3	78	0	0	0	0	0	3	1	2	0	0	1	0	0	94.56
AO3883	0.41	3.93	0	0.25	0.95	0	0.99	0	3	71	0	0	0	0	0	8	1	1	0	0	0	1	0	92.87
AO3883	0.95	7.40	0	0.17	0.76	0	0.96	0	2	64	0	0	0	0	0	7	1	2	1	0	1	0	0	88.74
AO3883	0.31	2.34	0	0.22	1.45	0	0.89	0	4	74	0	0	0	0	0	8	1	1	0	0	1	0	0	96.02
AO3883	1.71	13.88	0	0.46	0.89	0	0.38	0	3	53	0	0	5	0	0	7	0	1	1	0	0	0	0	87.47
AO3883	2.22	13.52	0	0.34	1.05	0	0.58	0	1	62	0	0	0	0	0	7	0	2	1	0	0	0	0	91.68
AO3883	1.87	21.07	0	0.07	0.60	0	0.10	0	3	29	0	0	0	0	0	20	0	10	0	1	1	1	0	89.47
AO3883	2.23	22.01	0	0.13	0.72	0	0.05	0	2	34	0	0	0	0	0	18	0	8	0	1	1	1	0	90.86
AO3883	0.00	1.21	6	0.25	0.97	0	0.86	0	23	64	0	0	0	0	0	5	1	3	0	0	0	1	0	108.79
AO3883	0.01	1.50	0	0.12	1.42	0	0.70	0	3	74	0	0	0	0	0	6	2	4	0	0	1	1	0	94.05
AO3883	2.05	14.24	0	0.32	1.10	0	0.45	0	1	60	0	0	2	0	0	4	0	1	1	0	0	0	0	88.47
AO3883	0.01	1.44	2	0.23	0.98	0	0.80	0	10	66	0	0	0	0	0	7	1	4	0	0	1	1	0	95.25
AO3883	0.00	0.44	2	0.19	1.11	0	0.71	0	11	68	0	0	0	0	0	7	1	4	0	0	0	0	0	95.46
AO3883	0.00	0.43	2	0.12	1.21	0	0.79	0	10	67	0	0	0	0	0	7	1	4	0	0	0	1	0	94.57
AO3883	0.03	1.08	2	0.20	1.21	0	0.93	0	9	67	0	0	0	0	0	7	2	4	0	0	0	1	0	94.46
AO3883	0.00	0.47	1	0.15	1.19	0	0.75	0	6	72	0	0	0	0	0	7	1	4	0	0	1	1	0	95.48
AO3883	0.00	0.99	1	0.19	1.22	0	0.91	0	6	72	0	0	0	0	0	7	1	4	0	0	0	1	0	95.36
AO3883	0.00	0.86	2	0.21	1.31	0	0.83	0	9	68	0	0	0	0	0	7	1	4	0	0	1	1	0	95.68
AO3883	0.00	0.72	0	0.27	1.26	0	0.89	0	6	71	0	0	0	0	0	7	1	4	0	0	1	0	0	94.08
AO3883	1.39	8.42	2	0.23	0.72	0	0.40	0	10	51	0	0	0	0	0	5	0	2	1	0	1	0	0	83.83
AO3883	1.62	11.38	3	0.11	0.75	0	0.49	0	15	51	0	0	0	0	0	5	0	3	1	0	1	0	0	93.47
AO3883	1.91	12.29	4	0.28	0.91	0	0.52	0	14	49	0	0	0	0	0	6	0	1	1	0	1	0	0	92.22
AO3883	1.90	10.91	4	0.17	0.61	0	0.41	0	19	47	0	0	0	0	0	7	0	1	1	0	1	1	0	95.96
AO3883	1.39	8.94	1	0.18	0.96	0	1.29	0	7	26	0	0	31	0	1	2	0	3	3	0	1	0	1	88.74
AO3883	2.05	11.81	1	0.15	1.14	0	1.64	0	3	28	0	0	28	0	1	3	0	1	3	0	1	0	1	87.35
AO3883	2.81	18.62	1	0.32	1.34	0	0.69	0	5	40	0	0	4	0	0	10	0	3	1	1	0	1	1	89.95
AO3883	0.09	1.57	1	0.19	1.31	0	0.67	0	8	70	0	0	0	0	0	6	2	3	0	0	0	1	0	94.87
AO3883	0.04	1.16	4	0.17	1.12	0	0.79	0	19	62	0	0	0	0	0	5	1	3	0	0	0	1	0	98.70
AO3883	0.05	1.83	1	0.19	1.38	0	0.91	0	6	73	0	0	0	0	0	6	2	3	0	0	1	0	0	95.38

sample	Al ₂ O ₃	SiO ₂	SO ₂	K ₂ O	CaO	V ₂ O ₃	FeO	ZrO ₂	PbO	UO ₂	Na ₂ O	MgO	TiO ₂	MoO ₃	La ₂ O ₃	ThO ₂	MnO	Y ₂ O ₃	Ce ₂ O ₃	P ₂ O ₅	Nd ₂ O ₃	Dy ₂ O ₃	Ta ₂ O ₅	Total
AO3883	0.00	1.38	1	0.21	1.29	0	0.65	0	9	69	0	0	0	0	0	5	1	4	0	0	1	1	0	94.03
AO3883	0.00	1.40	1	0.22	1.35	0	0.75	0	7	70	0	0	0	0	0	6	1	3	0	0	0	0	0	93.20
AO3883	0.10	2.42	2	0.18	0.97	0	1.12	0	12	67	0	0	0	0	0	5	1	4	0	0	0	0	0	96.03
AO3883	1.78	14.38	3	0.19	0.97	0	0.50	0	13	44	0	0	0	0	0	11	0	5	0	1	1	0	0	95.60
AO3883	1.05	9.02	0	0.10	0.25	0	1.43	0	1	24	0	0	35	0	1	3	0	3	4	0	3	0	1	86.37
AO3883	0.01	1.56	0	0.25	1.39	0	0.88	0	4	76	0	0	0	0	0	4	1	3	0	0	1	0	0	93.81
AO3883	0.07	1.91	1	0.19	1.30	0	0.95	0	5	73	0	0	0	0	0	4	2	3	0	0	1	1	0	93.56
AO3883	0.08	1.86	1	0.20	1.25	0	0.94	0	6	74	0	0	0	0	0	4	2	3	0	0	1	1	0	96.38
AO3883	0.32	3.34	1	0.23	1.08	0	0.75	0	7	72	0	0	0	0	0	4	1	3	0	0	0	1	0	95.56
AO3883	0.01	1.45	1	0.24	1.36	0	0.88	0	7	73	0	0	0	0	0	3	2	4	0	0	0	1	0	93.84
AO3883	1.04	6.93	6	0.11	0.46	0	0.53	0	24	50	0	0	0	0	0	5	0	2	1	0	0	0	0	98.81
AO3883	0.00	1.94	0	0.27	1.31	0	0.98	0	3	76	0	0	0	0	0	4	2	4	0	0	1	1	0	95.44
AO3883	0.08	1.89	0	0.31	1.31	0	0.97	0	3	77	0	0	0	0	0	4	2	4	0	0	0	1	0	95.19
AO3883	0.12	2.04	1	0.23	1.30	0	0.99	0	4	75	0	0	0	0	0	4	2	3	0	0	0	1	0	94.54
AO3883	1.50	10.08	6	0.16	0.51	0	0.27	0	23	47	0	0	0	0	0	3	0	2	1	0	1	0	0	96.09
AO3883	1.76	10.61	3	0.25	0.47	0	0.26	0	13	50	0	0	0	0	0	4	0	2	1	0	1	1	0	90.10
AO3883	1.81	11.72	2	0.25	0.41	0	0.44	0	12	53	0	0	0	0	0	5	0	2	1	0	1	0	0	90.93
AO3883	1.81	11.92	1	0.17	1.16	0	1.66	0	3	25	0	0	29	0	1	3	0	1	3	0	1	0	4	87.33
AO3883	1.42	9.34	6	0.14	0.78	0	1.62	0	26	18	0	0	24	0	0	3	0	1	2	0	1	0	2	96.89
AO3883	2.84	22.23	2	0.27	0.64	0	0.05	0	14	27	0	0	0	0	0	14	0	7	0	1	0	1	0	92.81
AO3883	2.68	22.38	2	0.11	0.64	0	0.07	0	9	36	0	0	0	0	0	9	0	8	0	1	0	1	0	92.57
AO3883	2.40	20.72	3	0.07	0.69	0	0.03	0	11	24	0	0	0	0	0	16	0	8	0	1	0	1	0	87.67
AO3883	0.03	1.28	1	0.24	0.83	0	0.83	0	8	65	0	0	0	0	0	8	1	5	0	0	0	1	0	91.98
AO3883	0.00	0.87	3	0.18	0.83	0	0.63	0	15	62	0	0	0	0	0	7	1	5	0	0	1	1	0	97.12
AO3883	0.04	1.36	0	0.17	0.95	0	0.83	0	6	67	0	0	0	0	0	8	1	6	0	0	1	1	0	92.59
AO3883	0.04	1.79	0	0.22	1.03	0	0.99	0	3	68	0	0	0	0	0	7	1	6	0	0	0	1	0	92.16
AO3883	1.39	14.94	3	0.10	0.64	0	0.11	0	22	30	0	0	3	0	0	8	0	4	0	1	0	0	1	88.92
AO3883	1.24	12.08	3	0.20	0.72	0	0.18	0	19	36	0	0	4	0	0	7	0	3	0	0	1	1	1	89.73
AO3883	1.80	11.62	0	0.12	1.19	0	1.92	0	1	21	0	0	27	0	1	6	0	1	4	0	1	0	4	82.94
AO3883	1.19	7.59	2	0.14	0.84	0	1.81	0	8	10	0	0	29	0	1	5	0	5	3	0	2	0	4	81.09
AO3883	1.46	20.05	2	0.11	0.29	0	0.03	0	9	15	0	0	0	0	0	39	0	4	0	1	0	1	0	95.15
AO3883	1.42	20.02	2	0.06	0.40	0	0.13	0	9	14	0	0	0	0	0	41	0	3	0	1	0	0	0	93.58
AO3883	1.70	21.42	1	0.15	0.24	0	0.13	0	6	16	0	0	0	0	0	40	0	4	1	1	1	0	0	92.89

sample	Al ₂ O ₃	SiO ₂	SO ₂	K ₂ O	CaO	V ₂ O ₃	FeO	ZrO ₂	PbO	UO ₂	Na ₂ O	MgO	TiO ₂	MoO ₃	La ₂ O ₃	ThO ₂	MnO	Y ₂ O ₃	Ce ₂ O ₃	P ₂ O ₅	Nd ₂ O ₃	Dy ₂ O ₃	Ta ₂ O ₅	Total
AO3883	1.13	16.62	5	0.08	0.33	0	0.12	0	24	14	0	0	0	0	0	36	0	2	0	1	0	0	0	101.13
AO3883	1.49	20.45	1	0.10	0.40	0	0.06	0	6	12	0	0	0	0	0	46	0	2	0	1	1	0	0	93.46
AO3883	0.19	3.53	1	0.23	1.10	0	0.73	0	6	69	0	0	0	0	0	8	1	2	0	0	0	1	0	94.82
AO3883	0.02	1.74	2	0.14	1.31	0	0.65	0	10	69	0	0	0	0	0	6	2	3	0	0	0	0	0	95.95
AO3883	0.13	1.96	1	0.25	1.30	0	0.74	0	4	73	0	0	0	0	0	6	2	4	0	0	0	1	0	94.40
AO3883	0.06	2.36	1	0.22	1.17	0	0.83	0	4	73	0	0	0	0	0	6	1	4	0	0	0	0	0	95.02
AO3883	0.13	2.63	2	0.23	0.99	0	0.94	0	12	66	0	0	0	0	0	5	1	3	0	0	0	1	0	96.48
AO3883	0.41	3.28	0	0.20	1.08	0	1.00	0	2	73	0	0	0	0	0	5	1	4	1	0	1	0	0	93.14
AO3883	0.15	2.19	1	0.22	1.45	0	0.89	0	4	74	0	0	0	0	0	5	2	3	0	0	0	0	0	94.47
AO3883	0.12	2.65	0	0.24	1.07	0	0.78	0	3	73	0	0	0	0	0	5	1	4	0	0	1	0	0	93.11
AO3883	0.13	2.59	1	0.24	1.13	0	0.83	0	4	71	0	0	0	0	0	7	1	3	0	0	0	1	0	93.75
AO3883	0.24	3.17	1	0.25	1.14	0	0.97	0	4	71	0	0	0	0	0	7	1	3	0	0	0	1	0	94.01
AO3883	1.98	11.20	2	0.18	0.45	0	0.42	0	12	50	0	0	0	0	0	4	0	2	1	0	1	1	0	88.14
AO3883	1.99	12.66	2	0.15	0.48	0	0.48	0	9	54	0	0	0	0	0	6	0	2	1	0	1	0	0	91.78
AO3883	1.03	7.66	0	0.21	0.67	0	0.94	0	2	67	0	0	0	0	0	5	1	3	1	0	1	1	0	91.67
AO3883	1.96	13.39	1	0.28	0.43	0	0.68	0	6	59	0	0	0	0	0	3	0	3	1	0	1	1	0	92.02
AO3883	0.98	7.67	1	0.05	1.03	0	1.68	0	6	26	0	0	34	0	0	2	0	3	2	0	1	0	1	89.16
AO3883	1.41	10.28	1	0.14	0.99	0	1.84	0	4	29	0	0	31	0	1	2	0	1	3	0	1	0	1	88.55
AO3883	0.00	1.84	0	0.15	1.03	0	0.73	0	4	68	0	0	0	0	0	8	1	5	0	0	1	1	0	93.02
AO3883	0.02	1.82	0	0.22	1.03	0	0.85	0	2	68	0	0	0	0	0	8	1	5	0	0	1	0	0	90.78
AO3883	0.04	1.85	2	0.21	0.85	0	0.75	0	9	64	0	0	0	0	0	8	1	4	0	0	0	1	0	92.81
AO3883	0.10	2.29	1	0.29	0.80	0	0.87	0	8	64	0	0	0	0	0	7	1	5	0	0	1	1	0	93.50
AO3883	0.00	1.81	1	0.19	0.93	0	0.74	0	5	67	0	0	0	0	0	8	2	5	0	0	1	1	0	92.34
AO3883	0.07	1.86	1	0.18	0.86	0	0.76	0	7	65	0	0	0	0	0	8	1	5	0	0	1	1	0	93.63
AO3883	0.00	1.80	0	0.17	0.97	0	0.79	0	3	68	0	0	0	0	0	8	1	5	0	0	1	1	0	91.89
AO3883	1.42	9.28	2	0.18	0.42	0	0.66	0	11	52	0	0	0	0	0	8	0	3	1	0	1	1	0	90.19
AO3883	1.98	12.24	2	0.19	0.35	0	0.36	0	11	49	0	0	0	0	0	7	0	2	1	0	1	0	0	90.80
AO3883	2.41	13.92	1	0.14	0.39	0	0.26	0	5	50	0	0	0	0	0	10	0	2	1	0	1	0	0	86.79
AO3883	2.25	20.89	1	0.07	0.52	0	0.28	0	4	22	0	0	3	0	0	27	0	9	0	1	1	1	0	91.75
AO3883	1.06	6.78	0	0.12	0.60	0	1.51	0	2	31	0	0	38	0	1	1	0	2	3	0	1	1	1	90.28
AO3883	1.63	19.32	2	0.04	0.25	0	0.10	0	11	8	0	0	0	0	0	43	0	4	1	1	0	0	0	92.75
AO3883	1.59	18.37	3	0.13	0.28	0	0.02	0	15	8	0	0	0	0	1	41	0	3	1	1	1	0	0	93.87
AO3883	1.76	21.36	1	0.11	0.26	0	0.11	0	3	13	0	0	0	0	0	41	0	5	1	1	1	0	0	89.64

sample	Al ₂ O ₃	SiO ₂	SO ₂	K ₂ O	CaO	V ₂ O ₃	FeO	ZrO ₂	PbO	UO ₂	Na ₂ O	MgO	TiO ₂	MoO ₃	La ₂ O ₃	ThO ₂	MnO	Y ₂ O ₃	Ce ₂ O ₃	P ₂ O ₅	Nd ₂ O ₃	Dy ₂ O ₃	Ta ₂ O ₅	Total
AO3883	1.86	12.07	1	0.08	0.35	0	0.38	0	5	55	0	0	0	0	0	8	0	2	1	0	1	1	0	88.54
AO3883	1.95	11.47	1	0.13	0.35	0	0.33	0	10	46	0	0	0	0	0	7	0	2	1	0	1	0	0	82.89
AO3883	1.86	20.47	2	0.07	0.15	0	0.00	0	11	12	0	0	0	0	0	39	0	4	1	1	1	0	0	92.91
AO3883	1.73	10.52	1	0.25	0.44	0	0.42	0	4	55	0	0	0	0	0	10	0	2	1	0	1	0	0	87.98
AO3883	1.54	15.35	1	0.14	1.08	0	1.28	0	2	25	0	0	19	0	1	9	0	3	3	2	1	0	1	88.96
AO3883	1.97	11.30	1	0.12	1.03	0	2.35	0	5	21	0	0	32	0	0	4	0	1	2	0	1	1	2	87.37
AO3883	1.95	14.15	0	0.19	1.18	0	1.38	0	1	27	0	0	24	0	1	5	0	1	3	0	1	0	2	85.08
StanDev	0.06	0.13	0.16	0.10	0.10	0.13	0.20	0.16	0.31	2.56	0.09	0.03	0.14	0.10	0.06	0.27	0.21	0.22	0.26	0.05	0.47	0.55	0.16	

Abbreviations: StanDev = standard deviation in %ox

Table 3: Electron microprobe data of uraninite analyses in atomic %

sample	Al	Si	S	Ca	V	Fe	Pb	U	Ti	La	Th	Mn	Y	Ce	P	Nd	Dy	Nb	Gd	Yb	Ta	F	O	Total
DO8628	0.09	1.18	1	3.15	0	0.57	5	21	0	0	1	1	2	0	0	0	0	0	0	0	0	1	62	100.60
DO8628	0.07	2.13	1	4.77	0	0.53	2	21	0	0	1	1	2	0	0	0	0	0	0	0	0	1	62	100.45
DO8628	0.01	0.37	0	2.35	0	1.21	4	23	0	0	2	1	2	0	0	0	0	0	0	0	0	1	62	100.71
DO8628	0.14	2.82	2	2.80	0	0.52	5	15	3	0	2	1	1	0	0	0	0	1	0	0	0	1	62	100.23
DO8628	0.03	0.48	0	0.96	0	0.95	7	23	0	0	2	1	2	0	0	0	0	0	0	0	0	0	63	100.45
DO8628	0.05	1.09	1	1.72	0	0.86	5	22	1	0	2	1	2	0	0	0	0	0	0	0	0	0	63	100.52
DO8628	0.00	0.99	1	1.64	0	0.77	5	21	1	0	2	1	2	0	0	0	0	0	0	0	0	1	63	100.41
DO8628	0.00	0.44	0	1.91	0	1.06	5	22	0	0	2	1	2	0	0	0	0	0	0	0	0	1	62	100.43
DO8628	0.00	0.69	0	2.27	0	0.62	5	22	0	0	2	1	2	0	0	0	0	0	0	0	0	1	63	100.55
DO8628	0.00	0.14	0	1.26	0	0.90	5	23	0	0	2	1	2	0	0	0	0	0	0	0	0	1	63	100.64
DO8628	0.25	6.70	2	0.37	0	0.62	4	4	6	0	1	0	4	0	3	0	0	2	0	0	0	2	63	100.10
DO8628	0.31	8.99	1	0.42	0	0.18	2	4	2	0	2	0	6	0	4	0	1	1	0	0	0	2	63	100.00
DO8628	0.04	0.77	2	3.43	0	0.59	5	21	0	0	1	1	1	0	0	0	0	0	0	0	0	2	62	100.44
DO8628	0.00	0.36	4	1.53	0	0.62	11	18	0	0	1	1	1	0	0	0	0	0	0	0	0	0	62	100.64
DO8628	0.17	2.19	2	3.76	0	0.51	3	21	0	0	1	1	1	0	0	0	0	0	0	0	0	1	63	100.52
DO8628	0.01	0.42	0	3.67	0	1.09	4	24	0	0	1	1	1	0	0	0	0	0	0	0	0	1	62	100.80
DO8628	0.14	2.20	1	3.69	0	0.59	3	21	0	0	1	1	1	0	0	0	0	0	0	0	0	2	62	100.47
DO8628	0.05	1.10	3	2.17	0	0.54	8	19	0	0	1	1	1	0	0	0	0	0	0	0	0	0	62	100.59
DO8628	0.00	0.69	0	3.18	0	0.90	5	24	0	0	1	1	1	0	0	0	0	0	0	0	0	1	62	100.56
DO8628	0.01	0.33	1	1.20	0	0.63	8	23	0	0	1	1	1	0	0	0	0	0	0	0	0	0	63	100.83
DO8628	0.10	1.52	1	4.44	0	0.71	3	21	0	0	1	2	1	0	0	0	0	0	0	0	0	2	62	100.58
DO8628	0.13	1.30	5	3.56	0	0.71	6	17	0	0	1	1	0	0	0	0	0	0	0	0	0	1	62	100.32
DO8628	0.15	1.96	0	6.27	0	0.64	1	23	0	0	1	2	0	0	0	0	0	0	0	0	0	3	61	100.96
DO8628	0.01	1.90	0	5.84	0	0.78	1	22	0	0	2	2	1	0	0	0	0	0	0	0	0	2	62	100.56
DO8628	0.08	2.00	2	4.95	0	0.62	3	20	0	0	2	1	1	0	0	0	0	0	0	0	0	2	62	100.48
DO8628	0.00	0.74	0	4.21	0	0.97	3	24	0	0	2	1	1	0	0	0	0	0	0	0	0	2	62	100.77
DO8628	0.29	3.90	2	1.63	0	0.97	4	18	1	0	1	0	1	0	0	0	0	1	0	0	0	0	64	100.35
DO8628	0.00	0.52	1	2.18	0	1.44	6	23	0	0	1	1	1	0	0	0	0	0	0	0	0	0	63	100.56
DO8628	0.00	1.20	1	4.60	0	1.03	4	21	1	0	1	1	1	0	0	0	0	1	0	0	0	1	62	100.56
DO8628	0.01	1.19	1	2.05	0	1.09	6	22	1	0	1	1	1	0	0	0	0	0	0	0	0	0	63	100.65
DO8628	0.00	1.43	1	5.36	0	0.76	2	21	0	0	1	1	1	0	0	0	0	0	0	0	0	3	61	100.48
DO8628	0.04	0.46	0	1.08	0	1.45	5	25	0	0	1	0	2	0	0	0	0	0	0	0	0	0	63	100.73

sample	Al	Si	S	Ca	V	Fe	Pb	U	Ti	La	Th	Mn	Y	Ce	P	Nd	Dy	Nb	Gd	Yb	Ta	F	O	Total
DO8628	0.00	0.18	1	1.98	0	0.82	7	22	0	0	1	0	2	0	0	0	0	0	0	0	0	1	62	100.53
DO8628	0.10	1.96	1	3.43	0	0.79	4	20	0	0	1	1	2	0	0	0	0	0	0	0	0	1	62	100.43
DO8628	0.02	0.68	0	1.99	0	0.84	6	24	0	0	1	1	2	0	0	0	0	0	0	0	0	0	63	100.64
DO8628	0.06	1.72	0	3.87	0	0.54	3	21	0	0	1	1	2	0	0	0	0	0	0	0	0	2	62	100.39
DO8628	0.00	0.62	0	3.14	0	0.93	4	23	0	0	1	1	2	0	0	0	0	0	0	0	0	1	62	100.57
DO8628	0.10	1.04	1	4.27	0	0.41	5	20	0	0	1	1	1	0	0	0	0	0	0	0	0	2	61	100.45
DO8628	0.06	1.12	1	2.32	0	0.78	6	21	0	0	1	0	2	0	0	0	0	0	0	0	0	1	63	100.63
DO8628	1.11	6.81	2	0.45	0	1.45	3	3	8	0	1	0	3	0	2	0	0	2	0	0	0	0	64	100.01
DO8628	1.90	9.86	1	0.78	0	2.03	3	3	8	0	1	0	0	0	1	0	0	3	0	0	1	0	64	100.34
DO6920	0.13	8.26	1	0.94	0	0.00	2	7	0	0	2	0	5	0	7	0	0	0	1	0	0	2	64	100.12
DO6920	0.16	8.43	0	1.01	0	0.12	1	6	1	0	2	0	6	0	7	0	1	0	1	0	0	2	64	100.03
DO6920	0.19	8.21	1	0.92	0	0.17	2	7	0	0	1	0	5	0	6	0	0	0	0	0	0	2	64	100.11
DO6920	0.17	8.45	5	0.91	0	4.17	1	4	0	0	4	0	2	0	3	0	0	0	0	0	0	3	63	100.13
DO6920	0.14	9.87	1	0.72	0	0.00	1	7	0	0	4	0	4	0	4	0	0	0	1	0	0	3	64	100.18
DO6920	0.21	9.82	1	1.27	0	0.00	1	4	0	0	7	0	3	0	4	0	0	0	0	0	0	4	63	100.21
DO6920	0.06	0.52	0	1.69	0	0.11	0	0	0	8	1	0	0	15	0	3	0	0	0	0	0	25	45	100.79
DO6920	0.17	0.14	0	1.06	0	1.22	0	0	0	7	0	0	0	15	0	4	0	0	0	0	0	27	44	100.45
DO6920	0.00	0.06	0	0.78	0	0.38	0	0	0	8	0	0	0	16	0	4	0	0	0	0	0	28	43	100.63
DO6920	0.01	0.12	0	0.95	0	0.27	0	0	0	8	0	0	0	16	0	4	0	0	0	0	0	27	44	100.67
DO6920	0.42	0.47	0	2.30	0	0.54	0	0	0	7	1	0	0	14	1	3	0	0	0	0	0	24	46	100.43
DO6920	1.97	1.95	0	3.45	0	0.97	1	25	0	0	0	0	0	1	0	0	0	0	0	0	0	0	64	100.50
DO6920	0.15	1.47	0	3.54	0	1.11	1	26	0	0	0	0	0	1	0	0	0	0	0	0	0	0	64	100.53
DO6920	0.29	2.44	0	2.89	0	0.63	0	26	0	0	0	0	0	1	0	0	0	0	0	0	0	0	65	100.68
DO6920	0.74	4.15	0	2.18	0	0.96	1	24	0	0	0	0	0	1	0	1	0	0	0	0	0	0	65	100.78
DO6920	0.29	1.76	0	2.16	0	0.99	0	0	0	7	0	0	0	14	0	3	0	0	0	0	0	28	43	101.08
DO6920	0.13	8.40	1	1.12	0	0.60	0	4	0	0	7	0	4	0	6	0	0	0	0	0	0	3	64	100.18
DO6920	0.12	8.29	2	1.07	0	1.37	0	3	0	0	6	0	4	0	6	0	0	0	0	0	0	3	64	100.09
DO6920	0.00	0.06	0	0.77	0	0.36	0	0	0	7	0	0	1	15	0	5	0	0	0	0	0	28	43	100.61
DO6920	0.06	0.06	0	0.66	0	0.12	0	0	0	8	0	0	0	15	0	4	0	0	0	0	0	30	42	100.74
DO6920	0.32	11.19	1	0.52	0	0.29	0	10	0	0	1	0	4	0	4	0	0	0	0	0	0	2	65	100.24
DO6920	0.29	11.86	1	0.51	0	0.26	0	9	0	0	2	0	4	0	4	0	0	0	1	0	0	2	65	100.23
DO6920	0.50	12.15	0	0.43	0	0.00	1	9	0	0	2	0	4	0	3	0	0	0	0	0	0	2	65	100.12
DO8628	0.26	4.02	1	1.43	0	0.67	1	23	0	0	1	0	1	1	0	0	0	0	0	0	0	0	65	100.47
DO8628	0.00	1.69	2	3.28	0	0.45	5	19	1	0	2	0	0	0	0	0	0	1	0	0	0	1	63	100.33

sample	Al	Si	S	Ca	V	Fe	Pb	U	Ti	La	Th	Mn	Y	Ce	P	Nd	Dy	Nb	Gd	Yb	Ta	F	O	Total
DO8628	0.24	2.06	1	3.82	0	0.80	4	22	1	0	2	1	0	0	0	0	0	0	0	0	0	1	63	100.73
DO8628	0.02	0.53	16	0.00	0	0.05	19	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	60	100.37
DO8628	0.00	1.00	3	0.94	0	0.75	5	18	1	0	2	1	2	0	0	0	0	0	0	0	0	0	63	100.44
DO8628	0.00	0.99	0	2.35	0	1.01	5	20	1	0	2	1	3	0	0	0	0	0	0	0	0	1	62	100.40
DO8628	0.00	0.00	0	0.73	0	0.66	6	21	0	0	3	0	3	0	0	0	0	0	0	0	0	2	62	100.50
DO8628	0.00	2.66	1	0.68	0	0.86	5	16	2	0	3	0	3	0	1	0	0	1	0	0	0	1	63	100.25
DO8628	0.01	1.84	0	2.92	0	0.73	3	17	1	0	2	1	4	0	0	0	1	1	0	0	0	3	61	100.33
DO8628	0.01	1.42	0	1.38	0	1.19	5	18	1	0	3	1	3	0	0	0	0	1	0	0	0	1	63	100.21
DO8628	0.00	0.21	0	2.65	0	0.82	4	20	0	0	3	1	3	0	0	0	1	0	0	0	0	3	61	100.43
DO8628	0.00	0.57	0	2.47	0	0.68	4	20	0	0	3	1	3	0	0	1	0	0	1	0	0	2	62	100.54
DO8628	0.00	0.19	0	1.32	0	0.88	5	21	0	0	3	0	3	0	0	0	0	0	0	0	0	2	62	100.71
DO8628	0.15	4.26	1	3.01	0	0.55	3	15	3	0	1	1	2	0	1	0	0	2	0	0	0	1	63	100.07
DO8628	0.05	0.27	0	0.60	0	0.87	7	23	0	0	3	0	2	0	0	0	0	0	0	0	0	0	63	101.08
DO8628	0.00	0.51	0	1.70	0	1.53	5	22	0	0	3	1	2	0	0	0	0	0	0	0	0	1	63	100.59
DO8628	0.00	0.23	0	0.83	0	0.99	7	23	0	0	3	1	1	0	0	0	0	0	0	0	0	0	63	100.45
DO8628	0.00	0.71	0	1.34	0	0.68	6	21	1	0	3	0	2	0	0	0	0	0	1	0	0	1	63	100.59
DO8628	0.35	4.74	2	1.53	0	0.53	4	16	0	0	2	0	3	0	1	0	1	0	0	0	0	0	63	100.41
AO5268	0.20	3.57	1	2.32	0	1.04	2	21	0	0	2	2	1	0	0	0	0	0	0	0	0	0	64	100.68
AO5268	1.14	8.71	3	1.11	0	0.42	4	15	0	0	1	1	1	0	0	0	0	0	0	0	0	0	64	100.57
AO5268	0.03	1.86	4	1.10	0	0.58	6	18	1	0	1	1	1	0	0	0	0	0	0	0	0	0	64	100.71
AO5268	0.64	4.08	0	0.14	0	0.83	1	3	19	0	0	0	2	1	0	1	0	1	0	0	0	0	65	100.08
AO5268	1.91	5.39	1	0.22	0	1.67	1	3	16	0	0	0	1	1	0	1	0	1	0	0	0	0	65	100.09
AO5268	0.08	2.76	2	1.31	0	0.67	2	20	1	0	2	2	2	0	0	0	0	0	0	0	0	0	64	100.43
AO5268	0.15	2.49	1	2.05	0	0.89	2	22	0	0	2	2	2	0	0	0	1	0	0	0	0	0	64	100.67
AO5268	0.12	2.12	0	2.31	0	1.11	1	23	0	0	2	2	2	0	0	0	0	0	0	0	0	0	64	100.84
AO5268	0.12	1.91	6	1.04	0	0.41	8	15	0	0	1	1	1	0	0	0	0	0	0	0	0	0	63	100.40
AO5268	0.05	2.05	1	2.02	0	0.86	2	22	0	0	2	2	2	0	0	0	0	0	0	0	0	0	64	100.59
AO5268	0.29	3.37	2	1.65	0	0.69	4	19	0	0	2	2	2	0	0	0	0	0	0	0	0	0	64	100.58
AO5268	0.00	1.19	2	2.21	0	1.56	3	21	0	0	2	2	2	0	0	0	0	0	0	0	0	1	63	100.51
AO5268	0.33	3.32	2	1.70	0	1.29	3	19	0	0	2	2	2	0	0	0	0	0	0	0	0	0	63	100.52
AO5268	2.48	19.02	0	0.13	0	0.13	1	6	0	0	2	0	2	0	0	0	0	0	0	0	0	0	65	100.11
AO5268	0.24	3.38	1	1.75	0	0.93	2	22	0	0	2	2	1	0	0	0	0	0	0	0	0	0	64	100.62
AO5268	0.41	3.64	2	1.30	0	0.85	3	20	1	0	2	2	1	0	0	0	0	0	0	0	0	0	64	100.83
AO5268	0.40	2.73	4	0.72	0	0.36	8	15	1	0	2	1	1	0	0	0	0	1	0	0	0	0	63	100.36

sample	Al	Si	S	Ca	V	Fe	Pb	U	Ti	La	Th	Mn	Y	Ce	P	Nd	Dy	Nb	Gd	Yb	Ta	F	O	Total
AO5268	0.42	3.13	2	1.54	0	0.85	3	20	0	0	1	2	2	0	0	0	0	0	0	0	0	0	64	100.49
AO5268	0.07	1.01	1	1.94	0	1.32	4	22	0	0	2	2	2	0	0	0	0	0	0	0	0	1	63	100.44
AO5268	0.32	2.73	2	1.24	0	0.74	5	20	0	0	1	1	1	0	0	0	0	0	0	0	0	0	64	100.39
AO5268	0.48	3.58	4	1.26	0	0.75	4	18	1	0	1	2	1	0	0	0	0	0	0	0	0	0	64	100.45
AO5268	0.52	4.40	2	0.99	0	0.67	3	20	1	0	1	1	1	0	0	0	0	0	0	0	0	0	64	100.45
AO5268	2.29	17.27	1	0.09	0	0.12	1	8	0	0	1	0	2	0	0	0	0	0	0	0	0	0	65	100.46
AO5268	0.72	3.87	8	0.44	0	0.40	8	12	1	0	1	1	1	0	0	0	0	0	0	0	0	0	63	100.69
AO5268	0.43	3.19	1	1.73	0	0.92	2	21	0	0	2	2	0	0	0	0	0	0	0	0	0	0	64	100.92
AO5268	0.05	1.22	3	1.24	0	0.70	7	18	0	0	2	1	2	0	0	0	0	0	0	0	0	0	63	100.31
AO5268	0.47	3.75	1	1.22	0	0.98	2	19	1	0	2	1	2	0	0	0	0	0	0	0	0	0	64	100.79
AO5268	0.68	3.67	3	0.84	0	0.61	6	16	1	0	2	1	1	0	0	0	0	0	0	0	0	0	63	100.30
AO5268	0.21	2.49	0	1.92	0	0.70	2	21	0	0	2	2	3	0	0	0	0	0	0	0	0	0	64	100.40
AO5268	0.25	2.63	1	2.47	0	0.93	2	23	0	0	1	2	1	0	0	0	0	0	0	0	0	0	64	100.83
AO5268	0.88	4.93	2	0.79	0	0.66	3	18	1	0	1	1	1	0	0	0	0	1	0	0	0	0	64	100.84
AO5268	0.42	1.85	0	1.53	0	0.79	4	21	0	0	2	1	2	0	0	0	0	0	0	0	0	0	64	100.35
AO5268	0.00	0.69	1	1.23	0	1.19	6	22	0	0	2	0	2	0	0	0	1	0	0	0	0	0	63	100.59
AO5268	0.09	3.03	1	2.41	0	0.87	1	22	0	0	2	2	1	0	0	0	0	0	0	0	0	0	64	100.72
AO5268	0.22	2.85	2	2.38	0	0.68	3	21	0	0	2	2	1	0	0	0	0	0	0	0	0	0	64	100.97
AO5268	0.32	3.64	1	1.55	0	0.98	2	20	0	0	1	2	2	0	0	0	0	0	0	0	0	0	64	100.76
AO5268	0.01	0.87	1	2.38	0	0.50	5	23	0	0	1	1	1	0	0	0	0	0	0	0	0	0	63	100.60
AO5268	0.19	1.25	3	1.96	0	0.68	7	20	0	0	1	1	1	0	0	0	0	0	0	0	0	0	63	100.50
AO5268	0.42	3.34	4	1.18	0	0.79	2	19	1	0	1	1	1	0	0	0	0	0	0	0	0	0	65	100.92
AO5268	0.44	4.81	1	0.91	0	0.63	2	19	1	0	2	1	1	0	0	0	0	0	0	0	0	0	65	100.50
AO5268	0.18	2.58	1	2.09	0	0.88	2	22	0	0	2	2	1	0	0	0	0	0	0	0	0	0	64	101.00
AO5268	0.02	0.45	25	0.08	0	10.85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	100.26
AO5268	0.05	0.08	29	0.00	0	8.58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67	105.58
AO5268	0.30	2.92	2	1.91	0	1.09	3	22	0	0	0	2	1	0	0	0	0	0	0	0	0	0	64	100.93
AO5268	0.38	3.54	2	1.47	0	0.88	3	21	0	0	0	2	1	0	0	0	0	0	0	0	0	0	64	100.97
AO5268	0.34	3.23	0	2.03	0	0.91	1	23	0	0	1	2	1	0	0	0	0	0	0	0	0	0	65	101.00
AO5268	0.03	1.12	2	2.20	0	1.01	6	23	0	0	1	2	1	0	0	0	0	0	0	0	0	0	63	101.15
AO5268	0.38	2.69	2	2.06	0	0.99	3	21	0	0	0	2	1	0	0	0	0	0	0	0	0	0	64	101.09
AO5268	0.93	9.28	3	0.68	0	0.47	4	13	0	0	2	1	1	0	0	0	0	0	0	0	0	0	64	100.72
AO5268	0.35	4.51	1	1.57	0	0.77	2	20	0	0	2	2	2	0	0	0	0	0	0	0	0	0	64	100.44
AO5268	0.49	5.84	1	1.14	0	0.63	2	19	0	0	2	2	1	0	0	0	0	0	0	0	0	0	64	100.42

sample	Al	Si	S	Ca	V	Fe	Pb	U	Ti	La	Th	Mn	Y	Ce	P	Nd	Dy	Nb	Gd	Yb	Ta	F	O	Total
AO5268	0.20	3.57	1	2.32	0	1.04	2	21	0	0	2	2	1	0	0	0	0	0	0	0	0	0	64	100.68
LLD	0.05	0.05	0.08	0.11	0.21	0.20	0.23	0.33	0.05	0.13	0.11	0.20	0.12	0.24	0.06	0.62	0.70	0.13	0.07	0.43	0.26	0.12		

sample	Al	Si	S	K	Ca	V	Fe	Zr	Pb	U	Na	Mg	Ti	Mo	La	Th	Mn	Y	Ce	P	Nd	Dy	Ta	O	total
AO3883	0.04	1.02	1	0.31	3.42	0	0.83	0	4	23	0	0	0	0	0	1	1	1	0	0	0	0	0	63	100.23
AO3883	0.11	1.42	3	0.24	2.51	0	1.01	0	5	20	0	0	0	0	0	1	1	1	0	0	0	0	0	63	100.25
AO3883	0.00	0.98	0	0.48	3.28	0	0.63	0	2	24	0	0	0	0	0	1	1	2	0	0	0	0	0	63	100.39
AO3883	0.08	1.45	1	0.45	2.91	0	0.92	0	2	24	0	0	0	0	0	1	2	1	0	0	0	0	0	64	100.38
AO3883	0.14	3.01	0	0.37	1.90	0	1.08	0	1	23	0	0	0	0	0	1	2	1	0	0	0	0	0	64	100.35
AO3883	0.62	5.07	0	0.41	1.31	0	1.07	0	1	20	0	0	0	0	0	2	1	1	0	0	0	0	0	64	100.24
AO3883	1.35	8.90	0	0.25	0.97	0	0.97	0	1	17	0	0	0	0	0	2	1	1	0	0	0	0	0	65	100.27
AO3883	0.49	3.09	0	0.37	2.04	0	0.98	0	1	22	0	0	0	0	0	3	1	1	0	0	0	0	0	64	100.49
AO3883	1.90	13.06	0	0.55	0.90	0	0.30	0	1	11	0	0	3	0	0	1	0	1	0	0	0	0	0	65	100.19
AO3883	2.55	13.20	0	0.42	1.10	0	0.48	0	0	13	0	0	0	0	0	2	0	1	0	0	0	0	0	65	100.13
AO3883	1.79	17.13	0	0.07	0.53	0	0.07	0	1	5	0	0	0	0	0	4	0	4	0	1	0	0	0	65	100.47
AO3883	2.09	17.51	0	0.13	0.61	0	0.03	0	0	6	0	0	0	0	0	3	0	4	0	0	0	0	0	65	100.39
AO3883	0.00	1.32	6	0.35	1.14	0	0.79	0	7	16	0	0	0	0	0	1	1	2	0	0	0	0	0	63	100.30
AO3883	0.02	2.05	1	0.21	2.08	0	0.80	0	1	22	0	0	0	0	0	2	2	3	0	0	0	0	0	64	100.67
AO3883	2.32	13.66	0	0.39	1.13	0	0.36	0	0	13	0	0	2	0	0	1	0	1	0	0	0	0	0	65	100.14
AO3883	0.01	1.92	2	0.40	1.40	0	0.89	0	4	20	0	0	0	0	0	2	1	3	0	0	0	0	0	63	100.49
AO3883	0.00	0.61	2	0.34	1.64	0	0.82	0	4	21	0	0	0	0	0	2	1	3	0	0	0	0	0	63	100.64
AO3883	0.00	0.60	2	0.21	1.79	0	0.92	0	4	21	0	0	0	0	0	2	2	3	0	0	0	0	0	63	100.77
AO3883	0.04	1.46	2	0.35	1.75	0	1.05	0	3	20	0	0	0	0	0	2	2	3	0	0	0	0	0	63	100.66
AO3883	0.00	0.65	1	0.26	1.78	0	0.88	0	2	22	0	0	0	0	0	2	2	3	0	0	1	0	0	64	100.73
AO3883	0.00	1.37	1	0.34	1.80	0	1.05	0	2	22	0	0	0	0	0	2	2	3	0	0	0	0	0	64	100.67
AO3883	0.00	1.15	2	0.36	1.88	0	0.93	0	3	20	0	0	0	0	0	2	2	3	0	0	0	0	0	63	100.40
AO3883	0.00	1.01	1	0.48	1.90	0	1.05	0	2	22	0	0	0	0	0	2	1	3	0	0	0	0	0	64	100.73
AO3883	1.91	9.80	2	0.34	0.90	0	0.39	0	3	13	0	0	0	0	0	1	0	1	0	0	0	0	0	64	100.15
AO3883	1.86	11.13	3	0.14	0.79	0	0.40	0	4	11	0	0	0	0	0	1	0	1	0	0	0	0	0	64	100.15
AO3883	2.16	11.75	3	0.34	0.93	0	0.41	0	4	10	0	0	0	0	0	1	0	1	0	0	0	0	0	64	100.11
AO3883	2.16	10.54	4	0.21	0.63	0	0.33	0	5	10	0	0	0	0	0	2	0	1	0	0	0	0	0	64	100.13
AO3883	1.17	6.36	1	0.16	0.73	0	0.77	0	1	4	0	0	16	0	0	0	0	1	1	0	0	0	0	65	100.14
AO3883	1.70	8.28	0	0.13	0.85	0	0.96	0	1	4	0	0	15	0	0	0	0	1	1	0	0	0	0	65	100.10

sample	Al	Si	S	K	Ca	V	Fe	Zr	Pb	U	Na	Mg	Ti	Mo	La	Th	Mn	Y	Ce	P	Nd	Dy	Ta	O	total
AO3883	0.14	2.11	2	0.32	1.88	0	0.75	0	3	21	0	0	0	0	0	2	2	2	0	0	0	0	0	64	100.46
AO3883	0.06	1.47	4	0.28	1.51	0	0.84	0	7	17	0	0	0	0	0	2	1	2	0	0	0	0	0	63	100.55
AO3883	0.08	2.42	1	0.31	1.95	0	1.00	0	2	21	0	0	0	0	0	2	2	2	0	0	0	0	0	64	100.62
AO3883	0.00	1.88	2	0.36	1.87	0	0.74	0	3	21	0	0	0	0	0	2	2	3	0	0	0	0	0	63	100.48
AO3883	2.65	14.90	1	0.32	1.14	0	0.46	0	1	7	0	0	2	0	0	2	0	1	0	0	0	0	0	65	100.02
AO3883	0.00	1.93	1	0.38	2.01	0	0.86	0	3	22	0	0	0	0	0	2	2	2	0	0	0	0	0	64	100.40
AO3883	0.15	3.09	3	0.29	1.32	0	1.20	0	4	19	0	0	0	0	0	1	1	2	0	0	0	0	0	63	100.65
AO3883	1.86	12.74	2	0.22	0.92	0	0.37	0	3	9	0	0	0	0	0	2	0	2	0	0	0	0	0	64	100.23
AO3883	0.87	6.34	0	0.09	0.19	0	0.84	0	0	4	0	0	18	0	0	0	0	1	1	0	1	0	0	65	100.24
AO3883	0.02	2.12	1	0.43	2.03	0	1.00	0	1	23	0	0	0	0	0	1	2	2	0	0	0	0	0	64	100.35
AO3883	0.10	2.56	1	0.32	1.87	0	1.07	0	2	22	0	0	0	0	0	1	2	2	0	0	0	0	0	64	100.45
AO3883	0.13	2.42	1	0.33	1.74	0	1.02	0	2	21	0	0	0	0	0	1	2	2	0	0	0	0	0	64	100.41
AO3883	0.47	4.17	1	0.36	1.44	0	0.78	0	2	20	0	0	0	0	0	1	2	2	0	0	0	0	0	64	100.41
AO3883	0.02	1.96	1	0.41	1.97	0	1.00	0	2	22	0	0	0	0	0	1	2	3	0	0	0	0	0	63	100.37
AO3883	1.27	7.14	5	0.15	0.50	0	0.46	0	7	11	0	0	0	0	0	1	0	1	0	0	0	0	0	63	100.18
AO3883	0.01	2.57	0	0.45	1.86	0	1.08	0	1	22	0	0	0	0	0	1	2	3	0	0	0	0	0	64	100.38
AO3883	0.12	2.50	0	0.53	1.86	0	1.07	0	1	23	0	0	0	0	0	1	2	3	0	0	0	0	0	64	100.35
AO3883	0.19	2.70	1	0.39	1.85	0	1.10	0	1	22	0	0	0	0	0	1	2	2	0	0	0	0	0	64	100.36
AO3883	1.71	9.76	5	0.19	0.53	0	0.22	0	6	10	0	0	0	0	0	1	0	1	0	0	0	0	0	64	100.17
AO3883	2.13	10.90	3	0.33	0.52	0	0.22	0	4	12	0	0	0	0	0	1	0	1	1	0	0	0	0	64	100.16
AO3883	2.15	11.80	2	0.32	0.44	0	0.37	0	3	12	0	0	0	0	0	1	0	1	0	0	0	0	0	64	100.13
AO3883	1.48	8.27	0	0.15	0.86	0	0.96	0	1	4	0	0	15	0	0	0	0	0	1	0	0	0	1	65	100.14
AO3883	1.19	6.61	4	0.12	0.59	0	0.96	0	5	3	0	0	13	0	0	1	0	0	0	0	0	0	0	64	100.14
AO3883	2.55	16.98	1	0.26	0.52	0	0.03	0	3	5	1	0	0	0	0	2	0	3	0	0	0	0	0	64	100.22
AO3883	2.43	17.19	1	0.11	0.53	0	0.05	0	2	6	0	0	0	0	0	2	0	3	0	0	0	0	0	65	100.28
AO3883	2.27	16.62	2	0.07	0.59	0	0.02	0	2	4	0	0	0	0	0	3	0	3	0	0	0	0	0	65	100.24
AO3883	0.05	1.80	1	0.43	1.24	0	0.97	0	3	20	0	0	0	0	0	2	1	4	0	0	0	0	0	64	100.57
AO3883	0.00	1.14	3	0.30	1.16	0	0.69	0	5	18	0	0	0	0	0	2	1	3	0	0	0	0	0	63	100.62
AO3883	0.07	1.89	1	0.30	1.41	0	0.97	0	2	21	0	0	0	0	0	2	1	4	0	0	0	0	0	64	100.60
AO3883	0.06	2.43	0	0.38	1.49	0	1.12	0	1	20	0	0	0	0	0	2	2	5	0	0	0	1	0	64	100.70
AO3883	1.50	13.62	2	0.12	0.63	0	0.09	0	6	6	0	0	2	0	0	2	0	2	0	0	0	0	0	64	100.32
AO3883	1.39	11.54	2	0.24	0.73	0	0.14	0	5	8	0	0	3	0	0	1	0	2	0	0	0	0	0	64	100.26
AO3883	1.56	8.53	0	0.11	0.94	0	1.18	0	0	3	0	0	15	0	0	1	0	0	1	0	0	0	1	65	100.16

sample	Al	Si	S	K	Ca	V	Fe	Zr	Pb	U	Na	Mg	Ti	Mo	La	Th	Mn	Y	Ce	P	Nd	Dy	Ta	O	total
AO3883	1.40	16.29	2	0.12	0.26	0	0.02	0	2	3	0	0	0	0	0	7	0	2	0	1	0	0	0	65	100.25
AO3883	1.39	16.62	2	0.06	0.35	0	0.09	0	2	3	0	0	0	0	0	8	0	1	0	1	0	0	0	65	100.34
AO3883	1.63	17.43	1	0.15	0.21	0	0.09	0	1	3	0	0	0	0	0	7	0	2	0	1	0	0	0	65	100.21
AO3883	1.45	16.94	1	0.11	0.36	0	0.04	0	1	2	0	0	0	0	0	9	0	1	0	1	0	0	0	66	100.24
AO3883	1.11	13.81	4	0.09	0.29	0	0.08	0	5	3	0	0	0	0	0	7	0	1	0	0	0	0	0	64	100.17
AO3883	1.05	5.68	1	0.13	0.68	0	1.13	0	2	2	0	0	17	0	0	1	0	2	1	0	0	0	1	65	100.25
AO3883	0.28	4.46	1	0.37	1.49	0	0.77	0	2	19	0	0	0	0	0	2	1	2	0	0	0	0	0	64	100.29
AO3883	0.04	2.26	2	0.22	1.82	0	0.71	0	3	20	0	0	0	0	0	2	2	2	0	0	0	0	0	63	100.41
AO3883	0.20	2.60	1	0.42	1.85	0	0.82	0	1	22	0	0	0	0	0	2	2	3	0	0	0	0	0	64	100.38
AO3883	0.09	3.08	1	0.37	1.64	0	0.91	0	1	21	0	0	0	0	0	2	2	3	0	0	0	0	0	64	100.35
AO3883	0.18	3.27	3	0.37	1.32	0	0.97	0	4	18	0	0	0	0	0	2	1	2	0	0	0	0	0	64	100.34
AO3883	0.62	4.22	0	0.33	1.49	0	1.08	0	1	21	0	0	0	0	0	2	1	3	0	0	0	0	0	64	100.38
AO3883	0.24	2.89	1	0.37	2.05	0	0.98	0	1	22	0	0	0	0	0	2	2	2	0	0	0	0	0	64	100.36
AO3883	0.19	3.53	0	0.41	1.53	0	0.87	0	1	21	0	0	0	0	0	2	2	3	0	0	0	0	0	64	100.49
AO3883	0.20	3.41	1	0.40	1.59	0	0.92	0	1	21	0	0	0	0	0	2	1	2	0	0	0	0	0	64	100.38
AO3883	0.36	4.09	1	0.42	1.58	0	1.05	0	1	20	0	0	0	0	0	2	1	2	0	0	0	0	0	64	100.35
AO3883	2.43	11.67	2	0.24	0.51	0	0.36	0	3	12	0	0	0	0	0	1	0	1	0	0	0	0	0	64	100.26
AO3883	2.30	12.42	2	0.18	0.50	0	0.39	0	2	12	0	0	0	0	0	1	0	1	0	0	0	0	0	65	100.13
AO3883	1.39	8.79	0	0.30	0.82	0	0.90	0	1	17	0	0	0	0	0	1	1	2	0	0	0	0	0	65	100.38
AO3883	2.22	12.91	1	0.34	0.44	0	0.55	0	2	13	0	0	0	0	0	1	0	1	0	0	0	0	0	65	100.17
AO3883	0.81	5.38	1	0.04	0.78	0	0.98	0	1	4	0	0	18	0	0	0	0	1	0	0	0	0	0	65	100.12
AO3883	1.16	7.19	0	0.12	0.74	0	1.08	0	1	5	0	0	17	0	0	0	0	0	1	0	0	0	0	65	100.11
AO3883	0.00	2.50	1	0.26	1.50	0	0.83	0	1	21	0	0	0	0	0	3	2	3	0	0	0	0	0	64	100.51
AO3883	0.02	2.55	0	0.39	1.53	0	0.99	0	1	21	0	0	0	0	0	3	2	4	0	0	0	0	0	64	100.57
AO3883	0.06	2.47	2	0.36	1.22	0	0.84	0	3	19	0	0	0	0	0	2	1	3	0	0	0	0	0	64	100.47
AO3883	0.16	2.99	2	0.48	1.12	0	0.95	0	3	19	0	0	0	0	0	2	1	3	0	0	0	0	0	64	100.47
AO3883	0.00	2.48	1	0.33	1.37	0	0.85	0	2	20	0	0	0	0	0	3	2	4	0	0	0	0	0	64	100.72
AO3883	0.11	2.46	2	0.30	1.21	0	0.84	0	3	19	0	0	0	0	0	2	2	3	0	0	0	0	0	64	100.47
AO3883	0.00	2.50	0	0.30	1.45	0	0.92	0	1	21	0	0	0	0	0	3	2	4	0	0	0	0	0	64	100.66
AO3883	1.80	9.97	2	0.25	0.49	0	0.60	0	3	12	0	0	0	0	0	2	0	2	0	0	0	0	0	64	100.13
AO3883	2.31	12.11	2	0.24	0.37	0	0.29	0	3	11	0	0	0	0	0	2	0	1	0	0	0	0	0	65	100.23
AO3883	2.85	13.95	1	0.18	0.42	0	0.21	0	1	11	0	0	0	0	0	2	0	1	0	0	0	0	0	65	100.22
AO3883	2.04	16.08	0	0.07	0.43	0	0.18	0	1	4	0	0	1	0	0	5	0	4	0	1	0	0	0	65	100.23

sample	Al	Si	S	K	Ca	V	Fe	Zr	Pb	U	Na	Mg	Ti	Mo	La	Th	Mn	Y	Ce	P	Nd	Dy	Ta	O	total
AO3883	1.59	16.05	2	0.04	0.22	0	0.07	0	2	2	0	0	0	0	0	8	0	2	0	1	0	0	0	65	100.19
AO3883	1.57	15.44	2	0.14	0.25	0	0.01	0	3	1	0	0	0	0	0	8	0	1	0	1	0	0	0	65	100.24
AO3883	1.71	17.59	1	0.11	0.23	0	0.08	0	1	2	0	0	0	0	0	8	0	2	0	1	0	0	0	66	100.22
AO3883	1.78	16.68	2	0.07	0.13	0	0.00	0	2	2	0	0	0	0	0	7	0	2	0	1	0	0	0	65	100.33
AO3883	2.29	12.55	1	0.11	0.39	0	0.33	0	1	13	0	0	0	0	0	2	0	1	1	0	0	0	0	65	100.17
AO3883	2.51	12.51	2	0.17	0.40	0	0.30	0	3	11	0	0	0	0	0	2	0	1	0	0	0	0	0	65	100.13
AO3883	0.87	4.71	0	0.10	0.45	0	0.88	0	0	5	0	0	20	0	0	0	0	1	1	0	0	0	0	65	100.18
AO3883	2.21	11.39	1	0.35	0.51	0	0.38	0	1	13	0	0	0	0	0	2	0	1	0	0	0	0	0	65	100.19
AO3883	1.29	10.88	0	0.13	0.82	0	0.76	0	0	4	0	0	10	0	0	1	0	1	1	1	0	0	0	65	100.05
AO3883	1.56	7.61	1	0.11	0.74	0	1.33	0	1	3	0	0	16	0	0	1	0	0	1	0	0	0	0	65	100.11
AO3883	1.66	10.23	0	0.17	0.91	0	0.83	0	0	4	0	0	13	0	0	1	0	1	1	0	0	0	0	65	100.15
LLD	0.05	0.06	0.10	0.10	0.08	0.15	0.20	0.20	0.12	0.58	0.10	0.04	0.05	0.12	0.07	0.11	0.20	0.12	0.29	0.06	0.53	0.64	0.19		

Abbreviations: LLD = lowest limit of detection in ppm

Table 4: Electron microprobe analyses of monazite in weight %

sample	Al	Si	P	Ca	Ti	Mn	Fe	Y	Zr	La	Ce	Pr	Nd	Sm	Th	U	Pb	Gd	O	Total
DO6920	0.19	0.59	12.24	0.47	0	0	0.32	0	0	20	26	1	5	1	1	1	0	0	26	94.97
DO6920	0.08	4.66	3.59	1.03	0	0	0.16	8	1	0	1	0	1	1	7	36	2	1	20	87.42
DO6920	0.02	0.81	11.49	0.63	0	0	0.12	1	0	15	24	2	6	1	2	5	1	0	25	95.13
DO6920	0.00	0.19	12.64	0.06	0	0	0.00	0	0	16	29	2	8	1	1	0	0	0	26	97.21
DO6920	0.16	0.30	12.82	0.43	0	0	0.06	0	0	19	29	2	6	1	0	0	0	0	27	96.88
DO6920	1.42	5.56	1.07	0.43	21	0	5.76	2	1	0	1	0	0	0	5	6	1	0	28	79.87
DO6920	2.39	6.23	1.58	0.46	10	0	2.56	4	2	0	0	0	0	0	12	15	1	1	25	83.17
DO6920	0.18	11.77	2.40	0.70	3	0	0.57	2	1	0	1	0	1	0	13	17	2	1	24	80.24
DO8628	0.00	0.31	12.49	0.32	0	0	0.00	1	0	16	26	2	7	1	3	0	1	1	26	97.10
DO8628	0.00	0.30	12.55	0.29	0	0	0.00	1	0	16	27	2	7	1	3	0	1	0	26	97.45
DO8628	0.00	0.34	12.51	0.30	0	0	0.00	1	0	16	26	2	7	1	3	0	1	1	26	96.14
DO8628	0.01	0.32	12.44	0.35	0	0	0.00	1	0	16	26	2	7	1	3	0	1	1	26	96.39
DO8628	0.00	0.25	12.52	0.30	0	0	0.00	1	0	15	26	2	7	1	3	0	1	1	26	96.52
DO8628	0.00	0.24	12.62	0.30	0	0	0.00	1	0	15	27	2	7	1	3	0	1	1	26	97.52
DO8628	0.00	0.24	12.64	0.34	0	0	0.00	1	0	15	27	2	7	1	3	0	1	1	26	97.40
DO8628	0.00	0.22	12.63	0.27	0	0	0.00	1	0	15	27	2	7	1	2	0	0	1	26	96.23
DO8628	0.00	0.18	12.66	0.24	0	0	0.00	1	0	15	27	2	7	1	2	0	0	1	26	96.25
DO8628	0.00	0.19	12.57	0.28	0	0	0.00	1	0	15	27	2	7	1	2	0	1	1	26	95.88
DO8628	0.01	0.22	12.49	0.23	0	0	0.00	1	0	16	27	2	7	1	2	0	1	1	26	96.90
DO8628	0.00	0.34	12.59	0.23	0	0	0.00	1	0	15	26	2	7	1	3	0	1	1	26	96.73
DO8628	0.01	0.22	12.47	0.20	0	0	0.00	1	0	15	27	2	7	1	2	0	0	0	26	95.78
DO8628	0.00	0.35	12.33	0.23	0	0	0.00	1	0	15	26	2	7	1	4	0	0	1	26	96.22
DO8628	0.00	0.26	12.33	0.27	0	0	0.00	1	0	15	27	2	7	1	3	0	1	1	26	96.58
DO8628	0.00	0.24	12.40	0.22	0	0	0.00	1	0	14	26	2	7	1	3	0	1	1	26	95.90
DO8628	0.00	0.20	12.55	0.92	0	0	0.00	2	0	11	23	2	9	2	5	0	1	1	26	96.13
DO8628	0.02	0.19	12.92	0.83	0	0	0.00	2	0	11	23	2	9	2	5	0	1	1	26	96.57
DO8628	0.00	0.42	12.05	0.38	0	0	0.01	0	0	19	27	2	4	1	3	0	0	0	26	95.13
DO8628	0.00	0.11	12.84	0.16	0	0	0.00	0	0	18	30	2	5	1	1	0	0	0	26	97.00
DO8628	0.00	0.11	12.88	0.67	0	0	0.00	2	0	12	23	2	8	2	4	0	1	1	26	96.02
DO8628	0.00	0.16	13.04	0.75	0	0	0.00	2	0	12	24	2	8	2	4	0	1	1	27	96.76
DO8628	0.00	0.42	12.50	0.19	0	0	0.00	1	0	14	27	2	8	1	3	0	1	1	26	97.49
DO8628	0.00	0.42	12.40	0.18	0	0	0.00	1	0	14	27	2	8	1	3	0	1	1	26	96.71

sample	Al	Si	P	Ca	Ti	Mn	Fe	Y	Zr	La	Ce	Pr	Nd	Sm	Th	U	Pb	Gd	O	Total
DO8628	0.00	0.28	12.64	0.18	0	0	0.00	1	0	14	27	2	8	1	2	0	1	1	26	96.97
DO8628	0.01	0.31	12.66	0.16	0	0	0.00	1	0	15	27	2	8	1	2	0	0	0	26	96.74
DO8628	0.00	0.36	12.63	0.21	0	0	0.00	1	0	15	28	2	8	1	2	0	0	0	26	97.19
DO8628	0.00	0.39	12.51	0.15	0	0	0.00	1	0	14	27	2	8	2	3	0	1	1	26	97.28
DO8628	0.00	0.38	12.34	0.17	0	0	0.00	1	0	14	27	2	8	1	3	0	1	1	26	96.47
DO8628	0.00	0.22	12.62	0.15	0	0	0.00	1	0	17	29	2	7	1	2	0	0	0	26	98.27
DO8628	0.03	0.32	12.49	0.13	0	0	0.00	1	0	15	27	2	8	2	2	0	0	1	26	97.24
DO8628	0.00	0.34	12.36	0.28	0	0	0.00	1	0	15	27	2	7	1	4	0	1	0	26	96.75
DO8628	0.00	0.43	12.22	0.41	0	0	0.00	1	0	15	25	2	7	1	5	0	1	1	26	96.11
DO8628	0.00	0.29	12.50	0.24	0	0	0.00	0	0	16	28	2	7	1	3	0	0	0	26	97.56
DO8628	0.00	0.62	11.90	0.40	0	0	0.00	1	0	15	25	2	7	1	6	0	1	1	26	96.38
DO8628	0.00	0.31	12.53	0.19	0	0	0.00	1	0	14	27	2	8	1	3	0	1	1	26	97.50
DO8628	0.00	0.58	12.03	0.16	0	0	0.00	1	0	14	26	2	7	1	4	0	1	1	26	96.83
DO8628	0.15	0.34	12.57	0.16	0	0	0.00	1	0	16	27	2	7	1	2	0	1	0	26	97.39
DO8628	0.00	0.26	12.56	0.20	0	0	0.00	1	0	16	28	2	7	1	3	0	1	1	26	98.34
DO8628	0.00	0.24	12.61	0.25	0	0	0.00	1	0	15	26	2	7	1	3	0	1	1	26	96.71
DO8628	0.00	0.28	12.51	0.24	0	0	0.00	1	0	15	26	2	7	1	3	0	0	1	26	95.86
DO8628	0.00	0.71	11.60	0.38	0	0	0.00	0	0	15	25	2	7	1	6	0	1	1	25	95.93
DO8628	0.00	0.59	11.73	0.43	0	0	0.00	1	0	13	24	2	7	1	6	0	1	1	25	94.94
DO8628	0.00	0.67	11.79	0.47	0	0	0.00	1	0	13	24	2	7	1	6	0	1	1	26	96.03
DO8628	0.00	1.05	11.21	0.47	0	0	0.00	1	0	12	22	2	7	2	9	0	1	1	25	95.70
DO8628	0.00	0.57	12.32	0.32	0.00	0.00	0.00	1	0	13	26	2	8	1	5	0	1	1	26	97.23
DO8628	0.00	0.61	12.12	0.29	0.01	0.00	0.00	1	0	13	25	2	8	1	5	0	1	1	26	96.25
DO8628	0.00	0.59	12.22	0.33	0.00	0.00	0.00	1	0	13	25	2	8	2	5	0	1	1	26	96.35
DO8628	0.00	0.41	12.29	0.27	0.01	0.00	0.00	2	0	13	26	2	8	2	3	0	1	1	26	96.36
DO8628	0.00	0.39	12.36	0.30	0.02	0.00	0.00	2	0	13	26	2	8	1	4	0	1	1	26	96.34
DO8628	0.00	0.29	12.48	0.20	0.02	0.00	0.00	1	0	16	27	2	7	1	3	0	0	1	26	97.30
DO8628	0.00	0.34	12.37	0.22	0.01	0.00	0.00	1	0	16	27	2	7	1	3	0	1	1	26	97.39
DO8628	0.00	0.29	12.39	0.24	0.03	0.00	0.00	0	0	15	27	2	7	1	3	0	0	1	26	96.23
DO8628	0.00	0.66	12.03	0.47	0.00	0.00	0.01	2	0	11	23	2	8	2	6	0	1	1	26	95.99
DO8628	0.00	0.67	12.23	0.51	0.01	0.00	0.00	2	0	11	23	2	8	2	6	0	1	1	26	96.76
DO8628	0.00	0.63	12.10	0.33	0.01	0.00	0.00	2	0	11	23	2	8	2	6	0	1	1	26	96.21
DO8628	0.00	0.66	12.05	0.51	0.01	0.00	0.00	2	0	11	22	2	8	2	7	0	1	1	26	96.45

sample	Al	Si	P	Ca	Ti	Mn	Fe	Y	Zr	La	Ce	Pr	Nd	Sm	Th	U	Pb	Gd	O	Total
DO8628	0.00	0.91	11.68	0.38	0.00	0.00	0.00	1	0	15	24	2	7	1	7	0	1	1	26	97.05
DO8628	0.00	0.32	12.51	0.05	0.02	0.00	0.00	0	0	19	29	2	5	1	2	0	0	0	26	97.67
DO8628	0.00	1.15	11.22	0.45	0.01	0.00	0.00	1	0	13	22	2	7	1	10	0	1	1	25	96.34
DO8628	0.00	0.58	12.09	0.37	0.00	0.00	0.00	1	0	14	25	2	7	1	5	0	1	1	26	96.13
DO8628	0.00	1.12	11.38	0.56	0.00	0.00	0.00	1	0	12	22	2	8	2	9	0	2	1	25	95.95
DO8628	0.00	0.98	11.48	0.36	0.00	0.00	0.00	1	0	14	24	2	7	1	7	0	1	1	26	96.77
DO8628	0.00	0.63	11.52	0.70	0.02	0.00	0.03	0	0	13	24	2	7	1	6	0	1	0	25	95.08
DO8628	0.00	0.75	11.84	0.50	0.02	0.00	0.00	1	0	14	24	2	7	1	7	0	1	1	26	97.50
DO8628	0.00	0.34	12.54	0.30	0.01	0.00	0.00	2	0	14	26	2	7	1	3	0	1	1	26	96.96
DO8628	0.02	0.23	12.54	0.22	0.01	0.00	0.00	0	0	16	29	2	7	1	2	0	0	0	26	97.11
DO8628	0.00	0.35	12.47	0.32	0.00	0.00	0.00	2	0	14	26	2	7	1	3	0	1	1	26	96.56
DO8628	0.07	0.35	12.39	0.32	0.02	0.00	0.00	2	0	14	26	2	7	1	3	0	1	1	26	96.70
DO8628	0.00	0.47	12.27	0.28	0.00	0.00	0.00	1	0	14	27	2	8	1	4	0	1	0	26	97.40
DO8628	0.01	0.47	12.26	0.30	0.01	0.00	0.00	1	0	14	27	2	8	1	4	0	1	1	26	96.79
DO8628	0.00	0.16	12.91	0.30	0.01	0.00	0.00	1	0	15	28	2	7	1	2	0	0	1	26	97.36
DO8628	0.00	0.18	12.86	0.28	0.03	0.00	0.00	1	0	16	28	2	7	1	2	0	0	0	27	97.58
DO8628	0.00	0.32	12.74	0.36	0.03	0.00	0.00	1	0	17	27	2	6	1	3	0	1	0	27	98.33
DO8628	0.00	0.22	12.64	0.29	0.01	0.00	0.00	1	0	16	28	2	7	1	3	0	0	1	26	97.41
DO8628	0.00	0.45	12.35	0.22	0.02	0.00	0.00	1	0	15	27	2	7	1	2	0	1	1	26	96.50
DO8628	0.00	0.34	12.52	0.17	0.00	0.00	0.00	1	0	14	27	2	8	1	2	0	0	0	26	96.61
DO8628	0.00	0.35	12.76	0.18	0.01	0.00	0.00	1	0	15	27	2	8	1	2	0	0	1	27	98.00
DO8628	0.00	0.35	12.67	0.16	0.02	0.00	0.00	1	0	15	28	2	7	1	2	0	0	1	26	97.37
DO8628	0.00	0.36	12.50	0.18	0.05	0.00	0.00	1	0	14	27	2	8	1	3	0	0	1	26	96.69
DO8628	0.00	0.49	12.45	0.60	0.02	0.00	0.00	1	0	14	24	2	7	1	6	0	1	1	26	97.02
DO8628	0.00	0.50	12.38	0.58	0.00	0.00	0.00	0	0	14	25	2	7	1	6	0	1	1	26	97.84
DO8628	0.00	0.38	12.47	0.81	0.01	0.00	0.00	1	0	14	24	2	7	1	5	1	1	1	26	97.16
DO8628	0.00	0.36	12.70	0.81	0.01	0.00	0.00	1	0	14	24	2	7	1	5	1	1	1	26	97.35
DO8628	0.00	0.29	12.51	0.54	0.01	0.00	0.00	1	0	14	25	2	7	1	4	0	1	1	26	96.50
DO8628	0.02	1.47	10.63	0.40	0.00	0.00	0.00	0	0	12	22	2	7	1	11	0	2	0	25	96.06
DO8628	0.00	1.22	11.11	0.43	0.01	0.00	0.00	0	0	12	23	2	7	1	10	0	1	0	25	96.26
DO8628	0.00	1.26	10.99	0.42	0.00	0.00	0.00	0	0	13	23	2	7	1	10	0	2	1	25	95.93
DO8628	0.01	0.42	12.43	0.31	0.02	0.00	0.00	2	0	12	24	2	8	2	4	0	1	1	26	96.15
DO8628	0.00	0.66	11.89	0.31	0.01	0.00	0.00	2	0	12	23	2	8	2	6	0	1	1	26	96.11

sample	Al	Si	P	Ca	Ti	Mn	Fe	Y	Zr	La	Ce	Pr	Nd	Sm	Th	U	Pb	Gd	O	total
DO8628	0.01	0.40	12.33	0.30	0.00	0.00	0.00	2	0	13	24	2	8	2	4	0	1	1	26	95.54
DO8628	0.00	0.56	12.20	0.31	0.01	0.00	0.00	1	0	13	25	2	8	1	5	0	1	1	26	96.52
DO8628	0.00	0.47	12.33	0.31	0.01	0.00	0.00	2	0	12	24	2	8	2	4	0	1	1	26	95.90
DO8628	0.00	0.50	12.10	0.30	0.01	0.00	0.00	1	0	13	25	2	8	1	4	0	1	1	26	96.04
DO8628	0.03	0.37	12.30	0.24	0.00	0.00	0.00	1	0	14	27	2	7	1	4	0	1	1	26	96.45
DO8628	0.00	0.56	11.90	0.29	0.04	0.00	0.00	1	0	13	26	2	7	1	5	0	1	1	26	95.95
DO8628	0.00	0.42	12.24	0.35	0.02	0.00	0.00	1	0	13	26	2	8	1	4	0	1	1	26	96.44
DO8628	0.00	0.42	12.39	0.20	0.01	0.00	0.00	1	0	15	27	2	7	1	4	0	1	1	26	97.37
DO8628	0.00	0.31	12.38	0.25	0.01	0.00	0.00	1	0	16	27	2	7	1	3	0	1	1	26	97.61
DO8628	0.00	0.12	12.83	0.22	0.01	0.00	0.00	1	0	15	28	2	7	1	2	0	0	0	26	96.71
DO8628	0.00	0.18	12.76	0.25	0.01	0.00	0.00	2	0	14	26	2	8	1	2	0	1	1	26	96.24
DO8628	0.00	0.21	12.55	0.24	0.00	0.00	0.00	2	0	14	26	2	8	1	2	0	1	1	26	96.22
DO8628	0.00	0.85	11.49	0.39	0.02	0.00	0.00	1	0	12	23	2	8	2	7	0	1	1	25	95.41
DO8628	0.00	0.37	12.10	0.61	0.03	0.00	0.10	1	0	12	23	2	8	2	5	0	1	1	26	94.80
DO8628	0.00	1.10	11.18	0.59	0.00	0.00	0.00	1	0	11	22	2	7	2	10	0	2	1	25	95.28
DO8628	0.00	1.53	10.52	0.59	0.02	0.00	0.00	1	0	10	20	2	7	2	13	0	2	1	25	96.47
DO8628	0.00	1.07	11.31	0.62	0.00	0.00	0.00	2	0	10	20	2	8	2	10	0	2	1	25	95.71
DO8628	0.00	0.98	11.33	0.54	0.02	0.00	0.00	1	0	13	24	2	7	1	8	0	1	1	25	95.43
DO8628	0.00	0.84	11.44	0.44	0.00	0.00	0.00	1	0	14	24	2	7	1	7	0	1	1	25	96.07
DO8628	0.00	0.42	12.45	0.22	0.02	0.00	0.00	1	0	13	27	2	8	2	3	0	1	1	26	97.24
DO8628	0.00	0.36	12.25	0.26	0.00	0.00	0.00	1	0	13	27	2	8	2	3	0	1	1	26	96.52
DO8628	0.00	0.38	12.40	0.24	0.03	0.00	0.00	1	0	13	27	2	8	2	3	0	1	1	26	96.82
DO8628	0.00	0.28	12.52	0.22	0.01	0.00	0.00	1	0	14	27	2	8	2	2	0	0	1	26	96.66
DO8628	0.00	0.15	12.47	0.12	0.02	0.00	0.00	0	0	16	28	2	8	1	1	0	0	0	26	95.99
DO8628	0.00	0.17	12.81	0.25	0.00	0.00	0.00	2	0	14	27	2	8	1	2	0	0	1	26	96.88
DO8628	0.00	0.22	12.66	0.21	0.02	0.00	0.00	1	0	16	29	2	7	1	2	0	0	0	26	96.92
DO8628	0.01	0.79	11.88	0.52	0.00	0.00	0.00	1	0	14	24	2	6	1	8	0	1	1	26	97.90
DO8628	0.03	0.27	12.73	0.41	0.01	0.00	0.00	0	0	12	25	2	8	3	4	0	1	1	26	96.83
DO8628	0.00	0.53	12.17	0.27	0.00	0.00	0.00	1	0	15	26	2	7	1	5	0	1	1	26	97.04
DO8628	0.00	0.35	12.40	0.06	0.01	0.00	0.00	0	0	16	27	2	7	1	3	0	0	1	26	97.23
DO8628	0.00	0.37	12.78	0.23	0.00	0.00	0.00	1	0	14	26	2	8	1	3	0	1	1	27	97.31
DO8628	0.00	0.35	12.61	0.47	0.00	0.00	0.00	1	0	15	26	2	7	1	4	0	1	1	26	97.73
DO8628	0.02	0.31	12.69	0.15	0.02	0.00	0.00	1	0	14	26	2	8	1	3	0	1	1	26	97.62

sample	Al	Si	P	Ca	Ti	Mn	Fe	Y	Zr	La	Ce	Pr	Nd	Sm	Th	U	Pb	Gd	O	Total
DO8628	0.00	0.21	12.79	0.22	0.01	0.00	0.00	1	0	16	27	2	7	1	3	0	0	1	27	97.94
DO8628	0.00	0.49	12.40	0.28	0.01	0.00	0.00	2	0	13	26	2	7	1	4	0	1	1	26	96.71
DO8628	0.00	0.47	12.60	0.25	0.03	0.00	0.00	1	0	14	26	2	7	1	4	0	1	1	26	97.24
DO8628	0.00	0.33	12.61	0.28	0.00	0.00	0.00	1	0	16	26	2	7	1	3	0	1	1	26	97.73
DO8628	0.00	0.46	12.45	0.43	0.02	0.00	0.00	1	0	14	26	2	7	1	4	0	1	1	26	95.88
DO8628	0.00	1.25	11.37	0.72	0.00	0.00	0.00	1	0	11	21	2	8	2	11	0	2	1	26	97.65
DO8628	0.01	1.23	11.27	0.70	0.00	0.00	0.00	0	0	11	21	2	8	2	11	0	1	1	25	97.08
DO8628	0.00	0.38	12.62	0.60	0.00	0.00	0.00	1	0	13	24	2	8	2	5	0	1	1	26	96.98
DO8628	0.00	0.69	12.15	0.71	0.00	0.00	0.00	1	0	11	22	2	9	2	8	0	1	1	26	96.91
DO8628	0.00	0.85	11.54	0.49	0.01	0.00	0.01	1	0	13	25	2	7	1	7	0	1	1	26	95.42
DO8628	0.00	1.08	11.22	0.26	0.01	0.00	0.00	2	0	12	24	2	7	1	8	0	1	1	25	95.60
DO8628	0.00	0.60	12.07	0.23	0.01	0.00	0.00	2	0	13	25	2	8	1	5	0	1	1	26	96.34
DO8628	0.00	0.88	11.82	0.23	0.00	0.00	0.00	1	0	13	25	2	7	1	7	0	1	1	26	97.25
DO8628	0.00	0.35	12.15	0.28	0.03	0.00	0.03	1	0	13	26	2	8	1	4	0	1	1	26	95.80
DO8628	0.00	0.28	12.36	0.21	0.01	0.00	0.00	1	0	14	26	2	8	2	3	0	1	1	26	95.91
DO8628	0.00	0.33	12.08	0.22	0.02	0.00	0.00	1	0	13	26	2	8	1	3	0	1	1	26	95.48
DO8628	0.00	0.26	12.10	0.26	0.01	0.00	0.00	1	0	15	27	2	7	1	3	0	1	0	26	96.47
DO8628	0.00	0.28	12.53	0.31	0.01	0.00	0.00	1	0	15	27	2	7	1	3	0	1	1	26	96.38
DO8628	0.00	0.48	12.45	0.24	0.01	0.00	0.00	1	0	14	26	2	7	1	4	0	1	0	26	97.13
DO8628	0.02	0.53	12.22	0.20	0.01	0.00	0.00	1	0	14	26	2	7	1	4	0	1	1	26	97.12
DO8628	0.00	0.57	12.32	0.32	0.00	0.00	0.00	1	0	13	26	2	8	1	5	0	1	1	26	97.23
DO8628	0.00	0.61	12.12	0.29	0.01	0.00	0.00	1	0	13	25	2	8	1	5	0	1	1	26	96.25
DO8628	0.00	0.59	12.22	0.33	0.00	0.00	0.00	1	0	13	25	2	8	2	5	0	1	1	26	96.35
DO8628	0.00	0.41	12.29	0.27	0.01	0.00	0.00	2	0	13	26	2	8	2	3	0	1	1	26	96.36
DO8628	0.00	0.39	12.36	0.30	0.02	0.00	0.00	2	0	13	26	2	8	1	4	0	1	1	26	96.34
DO8628	0.00	0.29	12.48	0.20	0.02	0.00	0.00	1	0	16	27	2	7	1	3	0	0	1	26	97.30
DO8628	0.00	0.34	12.37	0.22	0.01	0.00	0.00	1	0	16	27	2	7	1	3	0	1	1	26	97.39

Table 5: Electron microprobe analyses of monazite as oxides in weight %

sample	Al ₂ O ₃	SiO ₂	P ₂ O ₅	CaO	TiO ₂	MnO	FeO	Y ₂ O ₃	ZrO ₂	La ₂ O ₃	Ce ₂ O ₃	Pr ₂ O ₃	Nd ₂ O ₃	SmO	ThO ₂	UO ₂	PbO	Gd ₂ O ₃	Total
DO6920	0.35	1.26	28.05	0.66	0	0	0.41	0	0	23	30	2	5	1	2	1	0	0	95.03
DO6920	0.15	9.97	8.22	1.44	0	0	0.21	10	2	0	1	0	1	1	8	41	2	2	87.43
DO6920	0.05	1.73	26.32	0.88	0	0	0.15	1	0	18	28	2	7	1	2	5	1	0	95.18
DO6920	0.00	0.40	28.96	0.09	0	0	0.00	0	0	19	34	3	9	1	1	0	0	0	97.32
DO6920	0.30	0.65	29.37	0.60	0	0	0.08	0	0	22	34	2	7	1	0	0	0	0	96.96
DO6920	2.69	11.90	2.44	0.60	35	0	7.40	2	1	0	2	0	1	0	5	7	1	0	79.88
DO6920	4.52	13.33	3.63	0.64	17	0	3.30	5	3	0	1	0	0	0	13	17	1	1	83.18
DO6920	0.35	25.19	5.50	0.97	4	0	0.73	3	2	0	1	0	1	0	14	20	2	1	80.25
DO8628	0.00	0.66	28.63	0.45	0	0	0.00	1	0	19	31	2	8	1	4	0	1	1	97.22
DO8628	0.00	0.64	28.76	0.41	0	0	0.00	1	0	19	32	2	8	1	4	0	1	0	97.59
DO8628	0.00	0.72	28.67	0.42	0	0	0.00	1	0	18	31	2	8	1	4	0	1	1	96.27
DO8628	0.02	0.69	28.50	0.48	0	0	0.00	1	0	19	30	2	8	1	4	0	1	1	96.50
DO8628	0.00	0.54	28.68	0.42	0	0	0.00	2	0	17	31	2	8	1	3	0	1	1	96.63
DO8628	0.00	0.51	28.91	0.42	0	0	0.00	2	0	18	31	2	8	1	3	0	1	1	97.67
DO8628	0.00	0.51	28.95	0.47	0	0	0.00	2	0	18	31	2	8	1	4	0	1	1	97.54
DO8628	0.00	0.47	28.93	0.38	0	0	0.00	1	0	18	31	2	8	1	3	0	0	1	96.38
DO8628	0.00	0.38	29.00	0.34	0	0	0.00	1	0	18	31	2	8	1	3	0	0	1	96.38
DO8628	0.00	0.41	28.80	0.39	0	0	0.00	1	0	18	31	2	8	1	3	0	1	1	96.07
DO8628	0.01	0.46	28.62	0.32	0	0	0.00	1	0	19	32	2	8	1	3	0	1	1	97.04
DO8628	0.00	0.72	28.84	0.33	0	0	0.00	2	0	17	30	2	9	2	4	0	1	1	96.94
DO8628	0.03	0.48	28.57	0.29	0	0	0.00	1	0	18	31	2	8	1	3	0	1	1	95.87
DO8628	0.00	0.74	28.26	0.32	0	0	0.00	2	0	17	30	2	9	2	4	0	0	1	96.39
DO8628	0.00	0.55	28.25	0.38	0	0	0.00	2	0	17	31	2	9	2	4	0	1	1	96.73
DO8628	0.00	0.51	28.42	0.31	0	0	0.00	2	0	16	31	2	9	2	4	0	1	1	96.04
DO8628	0.00	0.42	28.76	1.28	0	0	0.00	2	0	13	27	3	10	3	6	0	1	2	96.34
DO8628	0.03	0.42	29.61	1.16	0	0	0.00	2	0	13	27	2	10	3	6	0	1	2	96.69
DO8628	0.00	0.89	27.62	0.53	0	0	0.01	0	0	22	32	2	5	1	4	0	0	0	95.20
DO8628	0.00	0.23	29.42	0.22	0	0	0.00	0	0	22	35	2	6	1	1	0	0	0	97.12
DO8628	0.00	0.23	29.52	0.94	0	0	0.00	2	0	14	27	3	10	2	4	0	1	1	96.16
DO8628	0.00	0.34	29.88	1.05	0	0	0.00	2	0	14	28	2	10	3	5	0	1	2	96.93
DO8628	0.00	0.89	28.63	0.27	0	0	0.00	1	0	16	32	3	9	2	4	0	1	1	97.61
DO8628	0.00	0.90	28.41	0.26	0	0	0.00	1	0	17	31	3	9	2	3	0	1	1	96.87

sample	Al ₂ O ₃	SiO ₂	P ₂ O ₅	CaO	TiO ₂	MnO	FeO	Y ₂ O ₃	ZrO ₂	La ₂ O ₃	Ce ₂ O ₃	Pr ₂ O ₃	Nd ₂ O ₃	SmO	ThO ₂	UO ₂	PbO	Gd ₂ O ₃	sample
DO8628	0.00	0.60	28.97	0.26	0	0	0.00	1	0	17	32	3	9	2	2	0	1	1	97.08
DO8628	0.01	0.67	29.01	0.22	0	0	0.00	1	0	18	32	3	9	1	2	0	0	1	96.89
DO8628	0.00	0.76	28.95	0.29	0	0	0.00	1	0	17	32	3	9	2	3	0	1	1	97.35
DO8628	0.00	0.84	28.67	0.20	0	0	0.00	1	0	17	31	3	9	2	3	0	1	1	97.42
DO8628	0.00	0.81	28.27	0.24	0	0	0.00	1	0	16	31	3	9	2	4	0	1	1	96.64
DO8628	0.00	0.47	28.91	0.21	0	0	0.00	1	0	20	33	2	8	1	2	0	0	1	98.46
DO8628	0.05	0.69	28.62	0.18	0	0	0.00	1	0	17	32	3	9	2	3	0	0	1	97.34
DO8628	0.00	0.73	28.32	0.39	0	0	0.00	1	0	18	31	2	8	1	4	0	1	1	96.90
DO8628	0.00	0.92	27.99	0.57	0	0	0.00	2	0	17	29	2	8	1	5	0	1	1	96.25
DO8628	0.00	0.63	28.65	0.34	0	0	0.00	1	0	19	33	2	8	1	3	0	1	1	97.68
DO8628	0.00	1.32	27.26	0.56	0	0	0.00	1	0	17	29	2	8	1	7	0	1	1	96.49
DO8628	0.00	0.67	28.72	0.27	0	0	0.00	2	0	16	32	3	9	2	3	0	1	1	97.68
DO8628	0.00	1.25	27.57	0.22	0	0	0.00	2	0	16	31	3	9	1	5	0	1	1	97.02
DO8628	0.29	0.74	28.80	0.23	0	0	0.00	1	0	19	32	2	8	1	3	0	1	0	97.53
DO8628	0.00	0.57	28.77	0.28	0	0	0.00	1	0	19	33	3	8	1	3	0	1	1	98.44
DO8628	0.00	0.51	28.89	0.34	0	0	0.00	2	0	18	31	2	8	1	3	0	1	1	96.84
DO8628	0.00	0.60	28.67	0.33	0	0	0.00	2	0	17	30	2	8	1	3	0	0	1	95.98
DO8628	0.00	1.21	28.22	0.44	0	0	0.00	2	0	15	30	3	9	2	6	0	1	1	97.36
DO8628	0.00	1.30	27.77	0.41	0	0	0.00	2	0	15	29	3	9	2	6	0	1	1	96.42
DO8628	0.00	1.26	28.01	0.46	0	0	0.00	2	0	15	29	3	9	2	6	0	1	1	96.47
DO8628	0.00	0.87	28.15	0.37	0	0	0.00	2	0	15	31	3	9	2	4	0	1	1	96.54
DO8628	0.00	0.83	28.31	0.42	0	0	0.00	2	0	15	30	3	9	2	4	0	1	1	96.50
DO8628	0.00	0.62	28.59	0.27	0	0	0.00	1	0	18	32	2	8	1	3	0	1	1	97.40
DO8628	0.00	0.72	28.35	0.30	0	0	0.00	1	0	18	31	3	8	1	4	0	1	1	97.56
DO8628	0.00	0.62	28.38	0.33	0	0	0.00	1	0	18	32	2	9	1	3	0	0	1	96.37
DO8628	0.00	1.42	27.56	0.65	0	0	0.01	2	0	13	27	2	9	2	7	0	1	2	96.12
DO8628	0.00	1.43	28.03	0.72	0	0	0.00	2	0	13	27	3	9	3	7	0	1	2	96.91
DO8628	0.00	1.35	27.73	0.46	0	0	0.00	2	0	13	27	3	10	2	6	0	1	2	96.38
DO8628	0.00	1.41	27.61	0.72	0	0	0.00	2	0	13	26	3	10	3	8	0	1	2	96.62
DO8628	0.00	0.68	28.66	0.07	0	0	0.00	0	0	22	34	2	6	1	2	0	0	0	97.80
DO8628	0.00	1.95	26.77	0.54	0	0	0.00	1	0	17	29	2	8	2	8	0	1	1	97.17
DO8628	0.00	2.47	25.72	0.63	0	0	0.00	1	0	15	26	2	8	2	11	0	1	1	96.47
DO8628	0.00	1.24	27.70	0.52	0	0	0.00	1	0	17	29	2	8	2	6	0	1	1	96.35

sample	Al ₂ O ₃	SiO ₂	P ₂ O ₅	CaO	TiO ₂	MnO	FeO	Y ₂ O ₃	ZrO ₂	La ₂ O ₃	Ce ₂ O ₃	Pr ₂ O ₃	Nd ₂ O ₃	SmO	ThO ₂	UO ₂	PbO	Gd ₂ O ₃	sample
DO8628	0.00	2.09	26.30	0.50	0	0	0.00	1	0	16	28	2	8	2	8	0	1	1	96.91
DO8628	0.00	2.40	26.08	0.78	0	0	0.00	2	0	14	25	2	9	2	10	0	2	1	96.08
DO8628	0.00	1.36	26.39	0.98	0	0	0.04	1	0	16	28	2	9	1	7	0	1	1	95.16
DO8628	0.00	1.61	27.13	0.70	0	0	0.00	1	0	17	28	2	8	1	8	0	1	1	97.65
DO8628	0.00	0.72	28.72	0.42	0	0	0.00	2	0	17	30	2	9	2	4	0	1	1	97.13
DO8628	0.04	0.50	28.74	0.30	0	0	0.00	0	0	19	34	3	8	1	2	0	0	0	97.33
DO8628	0.00	0.74	28.57	0.45	0	0	0.00	2	0	17	30	2	9	2	4	0	1	1	96.72
DO8628	0.13	0.74	28.38	0.44	0	0	0.00	2	0	17	30	2	8	1	4	0	1	1	96.80
DO8628	0.00	1.00	28.11	0.39	0	0	0.00	1	0	17	31	3	9	1	5	0	1	0	97.52
DO8628	0.02	1.01	28.08	0.42	0	0	0.00	1	0	16	31	3	9	1	5	0	1	1	96.92
DO8628	0.00	0.34	29.58	0.42	0	0	0.00	1	0	18	32	2	8	1	3	0	0	1	97.53
DO8628	0.00	0.39	29.47	0.40	0	0	0.00	1	0	19	32	3	8	1	3	0	0	1	97.75
DO8628	0.00	0.67	29.20	0.51	0	0	0.00	1	0	20	32	2	7	1	3	0	1	1	98.44
DO8628	0.00	0.47	28.96	0.41	0	0	0.00	1	0	18	33	2	8	1	3	0	0	1	97.53
DO8628	0.00	0.96	28.31	0.31	0	0	0.00	1	0	17	32	2	8	1	3	0	1	1	96.62
DO8628	0.00	0.72	28.69	0.23	0	0	0.00	1	0	17	32	3	9	2	3	0	0	1	96.79
DO8628	0.00	0.74	29.23	0.25	0	0	0.00	1	0	17	32	3	9	1	3	0	0	1	98.15
DO8628	0.00	0.74	29.03	0.22	0	0	0.00	1	0	18	32	3	9	1	2	0	0	1	97.52
DO8628	0.00	0.77	28.63	0.25	0	0	0.00	2	0	16	32	3	9	1	3	0	1	1	96.85
DO8628	0.00	1.06	28.54	0.84	0	0	0.00	1	0	17	29	2	8	1	7	0	1	1	97.16
DO8628	0.00	1.06	28.37	0.82	0	0	0.00	1	0	17	30	2	8	1	7	0	1	1	97.96
DO8628	0.00	0.81	28.58	1.13	0	0	0.00	1	0	16	29	2	8	2	6	1	1	1	97.30
DO8628	0.00	0.76	29.11	1.13	0	0	0.00	1	0	17	29	2	8	1	5	1	1	1	97.47
DO8628	0.00	0.62	28.66	0.75	0	0	0.00	1	0	17	30	2	8	1	5	0	1	1	96.62
DO8628	0.04	3.14	24.36	0.56	0	0	0.00	1	0	14	26	2	8	1	13	0	2	1	96.18
DO8628	0.00	2.61	25.45	0.60	0	0	0.00	1	0	15	27	2	8	1	12	0	2	1	96.40
DO8628	0.00	2.69	25.19	0.59	0	0	0.00	0	0	15	27	2	8	1	12	0	2	1	96.08
DO8628	0.02	0.89	28.48	0.43	0	0	0.00	3	0	15	28	2	10	2	4	0	1	1	96.28
DO8628	0.00	1.41	27.24	0.43	0	0	0.00	2	0	15	27	2	9	2	7	0	1	1	96.25
DO8628	0.00	1.01	28.26	0.43	0	0	0.00	3	0	14	28	2	10	2	5	0	1	1	96.11
DO8628	0.01	0.86	28.26	0.42	0	0	0.00	2	0	15	28	3	10	2	4	0	1	1	95.65
DO8628	0.00	1.20	27.95	0.44	0	0	0.00	1	0	16	30	2	9	2	6	0	1	1	96.67
DO8628	0.00	1.07	27.73	0.41	0	0	0.00	1	0	16	30	3	9	2	5	0	1	1	96.20

sample	Al ₂ O ₃	SiO ₂	P ₂ O ₅	CaO	TiO ₂	MnO	FeO	Y ₂ O ₃	ZrO ₂	La ₂ O ₃	Ce ₂ O ₃	Pr ₂ O ₃	Nd ₂ O ₃	SmO	ThO ₂	UO ₂	PbO	Gd ₂ O ₃	sample
DO8628	0.00	1.20	27.26	0.41	0	0	0.00	1	0	16	30	2	9	1	6	0	1	1	96.11
DO8628	0.00	0.90	28.05	0.49	0	0	0.00	1	0	16	30	3	9	2	4	0	1	1	96.53
DO8628	0.06	0.79	28.19	0.34	0	0	0.00	1	0	16	31	3	9	1	4	0	1	1	96.55
DO8628	0.00	0.91	28.38	0.28	0	0	0.00	1	0	18	32	2	8	1	4	0	1	1	97.50
DO8628	0.00	0.66	28.37	0.35	0	0	0.00	1	0	18	32	2	8	1	4	0	1	1	97.71
DO8628	0.00	0.26	29.40	0.31	0	0	0.00	2	0	17	32	2	9	1	2	0	0	1	96.85
DO8628	0.01	0.38	29.23	0.35	0	0	0.00	2	0	17	31	2	9	2	2	0	1	1	96.41
DO8628	0.00	0.45	28.75	0.33	0	0	0.00	2	0	16	30	3	9	2	3	0	1	1	96.36
DO8628	0.00	1.82	26.32	0.55	0	0	0.00	2	0	14	27	2	9	2	9	0	1	1	95.61
DO8628	0.00	0.80	27.71	0.85	0	0	0.12	2	0	15	27	2	10	2	5	0	1	1	94.94
DO8628	0.00	2.35	25.62	0.82	0	0	0.00	1	0	13	26	2	8	2	11	0	2	1	95.41
DO8628	0.00	3.27	24.10	0.82	0	0	0.00	1	0	12	24	2	9	2	15	1	2	1	96.59
DO8628	0.00	2.28	25.90	0.87	0	0	0.00	2	0	12	24	2	10	2	11	0	2	2	95.89
DO8628	0.00	2.10	25.96	0.75	0	0	0.00	1	0	15	28	2	8	2	9	0	1	1	95.55
DO8628	0.00	1.79	26.20	0.62	0	0	0.00	1	0	16	28	2	8	2	8	0	1	1	96.20
DO8628	0.00	0.89	28.52	0.31	0	0	0.00	1	0	15	31	3	9	2	4	0	1	1	97.39
DO8628	0.00	0.78	28.06	0.37	0	0	0.00	1	0	16	31	3	9	2	4	0	1	1	96.68
DO8628	0.00	0.80	28.42	0.34	0	0	0.00	1	0	15	31	3	9	2	4	0	1	1	96.99
DO8628	0.00	0.60	28.69	0.31	0	0	0.00	1	0	16	32	3	10	2	3	0	0	1	96.82
DO8628	0.00	0.32	28.58	0.17	0	0	0.00	1	0	18	33	3	9	1	1	0	0	0	96.11
DO8628	0.00	0.35	29.35	0.35	0	0	0.00	2	0	17	32	3	9	2	2	0	0	1	97.03
DO8628	0.00	0.48	29.02	0.29	0	0	0.00	1	0	18	33	2	8	1	2	0	0	0	97.05
DO8628	0.02	1.70	27.22	0.73	0	0	0.00	1	0	16	28	2	7	1	9	0	1	1	97.99
DO8628	0.06	0.59	29.17	0.58	0	0	0.00	0	0	14	30	3	10	3	4	0	1	2	96.96
DO8628	0.00	1.14	27.89	0.37	0	0	0.00	1	0	18	30	2	8	1	6	0	1	1	97.17
DO8628	0.00	0.74	28.41	0.08	0	0	0.00	0	0	19	32	2	8	1	3	0	0	1	97.37
DO8628	0.00	0.79	29.29	0.32	0	0	0.00	2	0	17	30	3	9	2	4	0	1	1	97.42
DO8628	0.00	0.74	28.89	0.66	0	0	0.00	1	0	17	31	2	9	1	4	0	1	1	97.90
DO8628	0.03	0.66	29.08	0.20	0	0	0.00	1	0	17	31	3	9	2	4	0	1	1	97.73
DO8628	0.00	0.71	28.90	0.40	0	0	0.00	1	0	18	31	2	8	1	4	0	1	1	97.88
DO8628	0.00	0.45	29.31	0.31	0	0	0.00	1	0	19	32	2	8	1	3	0	0	1	98.08
DO8628	0.00	1.05	28.40	0.39	0	0	0.00	2	0	16	30	2	9	1	5	0	1	1	96.82
DO8628	0.00	1.00	28.86	0.36	0	0	0.00	2	0	16	31	2	8	1	5	0	1	1	97.39

sample	Al ₂ O ₃	SiO ₂	P ₂ O ₅	CaO	TiO ₂	MnO	FeO	Y ₂ O ₃	ZrO ₂	La ₂ O ₃	Ce ₂ O ₃	Pr ₂ O ₃	Nd ₂ O ₃	SmO	ThO ₂	UO ₂	PbO	Gd ₂ O ₃	sample
DO8628	0.00	2.67	26.06	1.01	0	0	0.00	1	0	13	24	2	9	2	13	0	2	1	97.83
DO8628	0.01	2.64	25.81	0.97	0	0	0.00	1	0	13	25	2	10	2	12	0	2	1	97.23
DO8628	0.00	0.80	28.92	0.84	0	0	0.00	2	0	15	28	3	9	2	5	0	1	1	97.11
DO8628	0.00	0.98	28.54	0.60	0	0	0.00	2	0	16	30	2	8	1	5	0	1	1	95.99
DO8628	0.00	1.48	27.83	1.00	0	0	0.00	1	0	13	26	2	10	2	9	0	1	1	97.09
DO8628	0.01	1.83	26.45	0.68	0	0	0.01	1	0	15	29	2	8	1	8	0	1	1	95.49
DO8628	0.00	2.32	25.72	0.36	0	0	0.00	2	0	14	28	2	8	1	9	0	1	1	95.74
DO8628	0.00	1.28	27.65	0.33	0	0	0.00	2	0	15	30	3	9	2	6	0	1	1	96.50
DO8628	0.00	1.89	27.09	0.32	0	0	0.00	2	0	15	29	3	9	2	7	0	1	1	97.39
DO8628	0.00	0.75	27.85	0.39	0	0	0.04	2	0	16	30	3	9	2	4	0	1	1	95.93
DO8628	0.00	0.59	28.31	0.29	0	0	0.00	2	0	16	30	3	10	2	3	0	1	1	96.06
DO8628	0.00	0.71	27.68	0.31	0	0	0.00	2	0	16	30	3	10	2	4	0	1	1	95.61
DO8628	0.00	0.56	27.73	0.36	0	0	0.00	1	0	18	32	2	8	1	3	0	1	1	96.62
DO8628	0.00	0.61	28.70	0.44	0	0	0.00	1	0	17	31	2	8	1	3	0	1	1	96.52
DO8628	0.00	1.02	28.53	0.33	0	0	0.00	1	0	17	31	3	9	1	4	0	1	1	97.29
DO8628	0.04	1.13	28.00	0.28	0	0	0.00	1	0	17	31	3	9	1	5	0	1	1	97.27
StanDev	0.04	0.06	0.59	0.05	0.03	0.12	0.11	0.12	0.17	0.59	0.92	0.15	0.26	0.17	0.18	0.08	0.29	0.23	

Abbreviations: StanDev = standard deviation in %ox

Table 6: Electron microprobe data of monazite analyses in atomic %

sample	Al	Si	P	Ca	Ti	Mn	Fe	Y	Zr	La	Ce	Pr	Nd	Sm	Th	U	Pb	Gd	O	Total
DO6920	0.28	0.86	16.07	0.48	0	0	0.23	0	0	6	8	0	1	0	0	0	0	0	67	100.15
DO6920	0.16	8.88	6.20	1.38	0	0	0.16	5	1	0	0	0	0	0	2	8	1	0	66	100.02
DO6920	0.04	1.20	15.50	0.65	0	0	0.09	0	0	5	7	0	2	0	0	1	0	0	67	100.15
DO6920	0.00	0.27	16.57	0.06	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.27
DO6920	0.23	0.43	16.48	0.42	0	0	0.04	0	0	5	8	1	2	0	0	0	0	0	67	100.17
DO6920	1.99	7.45	1.29	0.40	17	0	3.88	1	0	0	0	0	0	0	1	1	0	0	65	100.02
DO6920	3.74	9.37	2.16	0.48	9	0	1.94	2	1	0	0	0	0	0	2	3	0	0	65	100.01
DO6920	0.29	18.21	3.37	0.76	2	0	0.44	1	1	0	0	0	0	0	2	3	0	0	66	100.02
DO8628	0.00	0.45	16.42	0.33	0	0	0.00	0	0	5	8	1	2	0	1	0	0	0	67	100.31
DO8628	0.00	0.43	16.43	0.30	0	0	0.00	0	0	5	8	1	2	0	1	0	0	0	67	100.33
DO8628	0.00	0.49	16.53	0.30	0	0	0.00	0	0	5	8	1	2	0	1	0	0	0	67	100.33
DO8628	0.02	0.47	16.42	0.35	0	0	0.00	0	0	5	8	1	2	0	1	0	0	0	67	100.27
DO8628	0.00	0.37	16.51	0.30	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.28
DO8628	0.00	0.34	16.51	0.30	0	0	0.00	1	0	5	8	1	2	0	1	0	0	0	67	100.36
DO8628	0.00	0.34	16.52	0.34	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.32
DO8628	0.00	0.32	16.63	0.28	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.37
DO8628	0.00	0.26	16.67	0.25	0	0	0.00	1	0	5	8	1	2	0	0	0	0	0	67	100.32
DO8628	0.00	0.28	16.67	0.29	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.39
DO8628	0.01	0.32	16.47	0.23	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.37
DO8628	0.00	0.49	16.57	0.24	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.46
DO8628	0.02	0.33	16.52	0.21	0	0	0.00	1	0	4	8	1	2	0	0	0	0	0	67	100.24
DO8628	0.00	0.51	16.41	0.24	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.38
DO8628	0.00	0.38	16.37	0.28	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.34
DO8628	0.00	0.35	16.52	0.22	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.35
DO8628	0.00	0.29	16.64	0.94	0	0	0.00	1	0	3	7	1	2	1	1	0	0	0	67	100.42
DO8628	0.03	0.28	16.86	0.84	0	0	0.00	1	0	3	7	1	2	1	1	0	0	0	67	100.31
DO8628	0.00	0.62	16.15	0.40	0	0	0.00	0	0	6	8	0	1	0	1	0	0	0	67	100.17
DO8628	0.00	0.15	16.75	0.16	0	0	0.00	0	0	5	9	1	1	0	0	0	0	0	67	100.30
DO8628	0.00	0.15	16.90	0.68	0	0	0.00	1	0	3	7	1	2	1	1	0	0	0	67	100.32
DO8628	0.00	0.23	16.96	0.75	0	0	0.00	1	0	3	7	1	2	1	1	0	0	0	67	100.39
DO8628	0.00	0.60	16.36	0.19	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.30
DO8628	0.00	0.61	16.38	0.19	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.37

sample	Al	Si	P	Ca	Ti	Mn	Fe	Y	Zr	La	Ce	Pr	Nd	Sm	Th	U	Pb	Gd	O	Total
DO8628	0.00	0.41	16.54	0.19	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.25
DO8628	0.01	0.45	16.61	0.16	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.35
DO8628	0.00	0.52	16.53	0.21	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.37
DO8628	0.00	0.57	16.42	0.15	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.32
DO8628	0.00	0.56	16.39	0.18	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.43
DO8628	0.00	0.32	16.47	0.15	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.44
DO8628	0.04	0.47	16.38	0.13	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.27
DO8628	0.00	0.50	16.38	0.28	0	0	0.00	0	0	5	8	1	2	0	1	0	0	0	67	100.38
DO8628	0.00	0.63	16.27	0.42	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.34
DO8628	0.00	0.42	16.39	0.25	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.31
DO8628	0.00	0.91	15.96	0.41	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.29
DO8628	0.00	0.45	16.45	0.20	0	0	0.00	1	0	4	8	1	2	0	0	0	0	0	67	100.42
DO8628	0.00	0.86	16.04	0.16	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.44
DO8628	0.23	0.49	16.39	0.16	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.34
DO8628	0.00	0.38	16.36	0.20	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.24
DO8628	0.00	0.34	16.56	0.25	0	0	0.00	1	0	4	8	1	2	0	0	0	0	0	67	100.30
DO8628	0.00	0.41	16.55	0.24	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.31
DO8628	0.00	1.06	15.74	0.40	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.38
DO8628	0.00	0.88	15.94	0.45	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.31
DO8628	0.00	1.00	15.82	0.49	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.23
DO8628	0.00	1.59	15.36	0.49	0	0	0.00	1	0	4	7	1	2	0	2	0	0	0	67	100.38
DO8628	0.00	0.82	16.18	0.32	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.31
DO8628	0.00	0.89	16.15	0.30	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.42
DO8628	0.00	0.86	16.18	0.34	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.28
DO8628	0.00	0.59	16.31	0.27	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.39
DO8628	0.00	0.57	16.34	0.30	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.38
DO8628	0.00	0.42	16.38	0.20	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.23
DO8628	0.00	0.49	16.35	0.22	0	0	0.00	0	0	5	8	1	2	0	1	0	0	0	67	100.42
DO8628	0.00	0.43	16.46	0.24	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.36
DO8628	0.00	0.98	16.04	0.48	0	0	0.00	1	0	3	7	1	2	1	1	0	0	0	67	100.28
DO8628	0.00	0.97	16.14	0.52	0	0	0.00	1	0	3	7	1	2	1	1	0	0	0	67	100.36
DO8628	0.00	0.93	16.14	0.34	0	0	0.00	1	0	3	7	1	2	1	1	0	0	0	67	100.38
DO8628	0.00	0.97	16.07	0.53	0	0	0.00	1	0	3	7	1	2	1	1	0	0	0	67	100.42
DO8628	0.00	0.46	16.38	0.05	0	0	0.00	0	0	6	9	1	1	0	0	0	0	0	67	100.29

sample	Al	Si	P	Ca	Ti	Mn	Fe	Y	Zr	La	Ce	Pr	Nd	Sm	Th	U	Pb	Gd	O	Total
DO8628	0.00	1.73	15.25	0.47	0	0	0.00	0	0	4	7	1	2	0	2	0	0	0	67	100.32
DO8628	0.00	1.34	15.59	0.40	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.29
DO8628	0.00	0.86	16.19	0.39	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.49
DO8628	0.00	1.68	15.40	0.58	0	0	0.00	1	0	3	7	1	2	0	2	0	0	0	67	100.35
DO8628	0.00	1.45	15.46	0.37	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.34
DO8628	0.00	0.95	15.70	0.74	0	0	0.03	0	0	4	7	1	2	0	1	0	0	0	66	100.20
DO8628	0.00	1.11	15.76	0.51	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.36
DO8628	0.00	0.48	16.46	0.31	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.38
DO8628	0.03	0.34	16.53	0.22	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.58
DO8628	0.00	0.50	16.44	0.33	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.39
DO8628	0.11	0.50	16.28	0.32	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.25
DO8628	0.00	0.68	16.20	0.28	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.32
DO8628	0.01	0.69	16.23	0.31	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.33
DO8628	0.00	0.23	16.81	0.30	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.40
DO8628	0.00	0.26	16.73	0.28	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.40
DO8628	0.00	0.45	16.47	0.36	0	0	0.00	0	0	5	8	1	2	0	1	0	0	0	67	100.28
DO8628	0.00	0.32	16.54	0.29	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.30
DO8628	0.00	0.65	16.29	0.23	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.29
DO8628	0.00	0.49	16.51	0.17	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.45
DO8628	0.00	0.50	16.53	0.18	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.34
DO8628	0.00	0.50	16.51	0.16	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.35
DO8628	0.00	0.52	16.44	0.18	0	0	0.00	1	0	4	8	1	2	0	0	0	0	0	67	100.37
DO8628	0.00	0.72	16.38	0.61	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.35
DO8628	0.00	0.72	16.24	0.59	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.29
DO8628	0.00	0.55	16.38	0.82	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.36
DO8628	0.00	0.51	16.51	0.81	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.31
DO8628	0.00	0.42	16.53	0.55	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.28
DO8628	0.03	2.23	14.68	0.43	0	0	0.00	0	0	4	7	1	2	0	2	0	0	0	67	100.30
DO8628	0.00	1.84	15.18	0.45	0	0	0.00	0	0	4	7	1	2	0	2	0	0	0	67	100.33
DO8628	0.00	1.91	15.11	0.45	0	0	0.00	0	0	4	7	1	2	0	2	0	0	0	67	100.36
DO8628	0.02	0.61	16.40	0.32	0	0	0.00	1	0	4	7	1	2	1	1	0	0	0	67	100.34
DO8628	0.00	0.97	15.94	0.32	0	0	0.00	1	0	4	7	1	2	1	1	0	0	0	67	100.32
DO8628	0.00	0.69	16.40	0.32	0	0	0.00	1	0	4	7	1	2	1	1	0	0	0	67	100.49
DO8628	0.01	0.59	16.39	0.31	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.28

sample	Al	Si	P	Ca	Ti	Mn	Fe	Y	Zr	La	Ce	Pr	Nd	Sm	Th	U	Pb	Gd	O	Total
DO8628	0.00	0.74	16.18	0.30	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.40
DO8628	0.05	0.54	16.30	0.25	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.24
DO8628	0.00	0.82	16.21	0.32	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.37
DO8628	0.00	0.83	16.02	0.31	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.39
DO8628	0.00	0.62	16.23	0.36	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.23
DO8628	0.00	0.62	16.30	0.20	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.31
DO8628	0.00	0.45	16.27	0.26	0	0	0.00	0	0	5	8	1	2	0	1	0	0	0	67	100.25
DO8628	0.00	0.18	16.77	0.22	0	0	0.00	1	0	4	8	1	2	0	0	0	0	0	67	100.32
DO8628	0.00	0.26	16.76	0.25	0	0	0.00	1	0	4	8	1	2	0	0	0	0	0	67	100.43
DO8628	0.00	0.30	16.57	0.24	0	0	0.00	1	0	4	8	1	2	0	0	0	0	0	67	100.33
DO8628	0.00	1.28	15.67	0.41	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.47
DO8628	0.00	0.55	16.30	0.63	0	0	0.07	1	0	4	7	1	2	1	1	0	0	0	67	100.31
DO8628	0.00	1.66	15.34	0.62	0	0	0.00	0	0	3	7	1	2	0	2	0	0	0	67	100.35
DO8628	0.00	2.33	14.56	0.63	0	0	0.00	0	0	3	6	1	2	1	2	0	0	0	67	100.31
DO8628	0.00	1.60	15.43	0.66	0	0	0.00	1	0	3	6	1	2	1	2	0	0	0	67	100.40
DO8628	0.00	1.48	15.43	0.56	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.29
DO8628	0.00	1.25	15.52	0.46	0	0	0.00	0	0	4	7	1	2	0	1	0	0	0	67	100.32
DO8628	0.00	0.61	16.37	0.23	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.37
DO8628	0.00	0.53	16.32	0.27	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.36
DO8628	0.00	0.55	16.41	0.25	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.43
DO8628	0.00	0.41	16.52	0.23	0	0	0.00	0	0	4	8	1	2	0	0	0	0	0	67	100.40
DO8628	0.00	0.22	16.58	0.12	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.32
DO8628	0.00	0.24	16.71	0.25	0	0	0.00	1	0	4	8	1	2	0	0	0	0	0	67	100.34
DO8628	0.00	0.32	16.58	0.21	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.32
DO8628	0.02	1.16	15.70	0.53	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.25
DO8628	0.05	0.40	16.73	0.42	0	0	0.00	0	0	3	7	1	2	1	1	0	0	0	67	100.32
DO8628	0.00	0.78	16.13	0.27	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.32
DO8628	0.00	0.50	16.36	0.06	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.33
DO8628	0.00	0.53	16.60	0.23	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.27
DO8628	0.00	0.50	16.48	0.48	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.38
DO8628	0.03	0.44	16.55	0.15	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.29
DO8628	0.00	0.48	16.46	0.29	0	0	0.00	0	0	5	8	1	2	0	1	0	0	0	67	100.35
DO8628	0.00	0.30	16.60	0.22	0	0	0.00	0	0	5	8	1	2	0	0	0	0	0	67	100.34
DO8628	0.00	0.71	16.27	0.29	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.27

sample	Al	Si	P	Ca	Ti	Mn	Fe	Y	Zr	La	Ce	Pr	Nd	Sm	Th	U	Pb	Gd	O	Total
DO8628	0.00	0.66	16.41	0.44	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.26
DO8628	0.00	1.85	15.29	0.75	0	0	0.00	0	0	3	6	1	2	0	2	0	0	0	67	100.43
DO8628	0.01	1.84	15.22	0.73	0	0	0.00	0	0	3	6	1	2	0	2	0	0	0	67	100.39
DO8628	0.00	0.67	16.44	0.26	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.36
DO8628	0.00	0.54	16.49	0.61	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.30
DO8628	0.00	1.01	16.15	0.73	0	0	0.00	0	0	3	6	1	2	0	1	0	0	0	67	100.44
DO8628	0.01	1.27	15.56	0.51	0	0	0.01	1	0	4	7	1	2	0	1	0	0	0	67	100.15
DO8628	0.00	1.63	15.32	0.27	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.37
DO8628	0.00	0.88	16.08	0.24	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.36
DO8628	0.00	1.29	15.71	0.24	0	0	0.00	1	0	4	7	1	2	0	1	0	0	0	67	100.34
DO8628	0.00	0.52	16.26	0.29	0	0	0.02	1	0	4	8	1	2	0	1	0	0	0	67	100.29
DO8628	0.00	0.40	16.46	0.22	0	0	0.00	1	0	4	8	1	2	0	0	0	0	0	67	100.36
DO8628	0.00	0.49	16.26	0.23	0	0	0.00	1	0	4	8	1	2	0	1	0	0	0	67	100.31
DO8628	0.00	0.39	16.19	0.27	0	0	0.00	0	0	5	8	1	2	0	1	0	0	0	67	100.39
DO8628	0.00	0.41	16.53	0.32	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.34
DO8628	0.00	0.69	16.35	0.24	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.38
DO8628	0.03	0.77	16.17	0.21	0	0	0.00	0	0	4	8	1	2	0	1	0	0	0	67	100.36
LLD	0.05	0.05	0.06	0.05	0.04	0.16	0.14	0.11	0.20	0.24	0.29	0.14	0.17	0.15	0.09	0.09	0.31	0.25		

Abbreviations: LLD = lowest limit of detection in ppm

APPENDIX V

Table 1: Results of U-Th-Pb LA-ICP-MS analyses of various minerals from sample DO 8628 and DO 3337

Table 1: Results of U-Th-Pb LA-ICP-MS analyses of various minerals from sample DO 8628 and DO 3337

grain	L-No.	spot _x (μm)	²⁰⁷ Pb ^a (cps)	U ^b (wt %)	Pb ^b (wt%)	Th ^b U	²⁰⁶ Pb ²⁰⁴ Pb	²⁰⁶ Pb ^c ²³⁸ U	±2 σ (%)	²⁰⁷ Pb ^c ²³⁵ U	±2σ (%)	²⁰⁷ Pb ^c ²⁰⁶ Pb	±2 σ (%)	Rho ^d	Age (Ma)						conc. _d (%)
															²⁰⁶ Pb	±2σ	²⁰⁷ Pb	±2σ	²⁰⁷ Pb ^c ²⁰⁶ Pb	±2σ	
															²⁰⁶ Pb ²³⁸ U		²⁰⁷ Pb ²³⁵ U		²⁰⁷ Pb ^c ²⁰⁶ Pb		
zr1-1	a1	20	763386	0,88	0,37	0,15	768	0,2289	6,1	5,891	6,9	0,1866	3,1	0,90	1329	74	1960	61	2713	50	49
zr1-2	a2	20	770726	1,01	0,49	0,14	777	0,2950	6,0	7,633	6,4	0,1876	2,3	0,93	1667	88	2189	59	2722	37	61
zr1-3	a3	20	554000	1,07	0,29	0,09	781	0,1483	3,7	3,831	4,6	0,1873	2,7	0,81	892	31	1599	37	2719	44	33
zr1-4	a4	20	368536	0,74	0,18	0,07	262	0,1226	3,8	3,181	4,6	0,1882	2,5	0,83	745	27	1452	36	2727	42	27
zr1-5	a5	20	311912	0,54	0,19	0,05	271	0,2078	5,5	5,486	6,1	0,1915	2,5	0,91	1217	62	1898	54	2755	42	44
zr1-6	a6	20	323386	0,43	0,16	0,18	1338	0,1915	5,1	5,011	6,6	0,1898	4,2	0,77	1130	53	1821	57	2740	69	41
zr2-1	a7	20	739312	0,48	0,42	0,33	2466	0,5149	4,3	13,49	4,9	0,1901	2,5	0,86	2678	94	2715	48	2743	41	98
zr2-2	a8	20	423585	0,50	0,24	0,16	2555	0,2759	3,7	7,099	4,2	0,1866	2,0	0,87	1570	51	2124	38	2713	34	58
zr2-3	a9	20	13197	0,13	0,010	0,06	532	0,0521	8,0	1,361	9,2	0,1897	4,5	0,87	327	25	872	55	2739	75	12
zr2-4	a10	20	293651	0,67	0,15	0,08	1183	0,1156	4,6	3,055	6,4	0,1916	4,4	0,72	705	31	1422	50	2756	73	26
zr2-5	a11	20	111181	0,03	0,040	0,29	933	0,4676	7,6	12,67	8,9	0,1965	4,5	0,86	2473	159	2655	87	2797	74	88
mz1-1	a12	20	330920	0,23	0,43	3,93	2833	0,5939	3,3	19,19	3,6	0,2344	1,4	0,92	3005	81	3052	36	3082	23	97
mz1-2	a13	20	231316	0,19	2,60	97,7	8846	0,5955	2,7	19,23	3,0	0,2341	1,3	0,90	3012	65	3053	29	3081	21	98
mz1-3	a14	20	226153	0,19	2,68	102	5579	0,6199	2,7	19,75	3,0	0,2310	1,3	0,90	3110	67	3079	29	3059	21	102
mz1-4	a15	20	217537	0,18	2,77	116	3151	0,6103	2,6	19,64	3,0	0,2335	1,4	0,88	3071	64	3074	29	3076	22	100
mz1-5	a16	20	226829	0,18	2,80	110	2539	0,6092	2,7	19,60	3,0	0,2333	1,3	0,90	3067	66	3072	29	3075	21	100
mz1-6	a17	20	755421	0,33	2,70	62,2	6012	0,5526	7,3	16,00	7,7	0,2100	2,5	0,95	2836	169	2877	76	2905	40	98
mz1-7	a18	20	1068121	8,00	13,4	5,20	38289	0,6082	3,6	19,55	4,1	0,2331	2,0	0,87	3063	88	3069	41	3074	32	100
mz1-8	a19	20	585973	0,22	2,35	77,1	735	0,5352	5,6	15,68	6,0	0,2125	2,2	0,93	2764	126	2858	59	2925	35	94
mz1-9	a20	20	1182383	0,37	1,17	11,2	1152	0,5266	4,0	13,72	5,3	0,1889	3,6	0,74	2727	89	2730	52	2733	59	100
mz2-1	a21	20	231835	0,25	0,75	18,9	2567	0,6220	2,7	19,89	3,1	0,2320	1,5	0,87	3118	68	3086	30	3066	24	102
mz2-2	a22	20	241699	0,22	0,88	26,3	10916	0,6198	3,0	19,80	3,4	0,2317	1,7	0,87	3109	74	3082	34	3064	27	101
mz2-3	a25	20	201625	0,31	0,98	22,4	34222	0,6191	3,8	19,73	4,1	0,2312	1,6	0,92	3106	94	3078	41	3060	26	102
mz2-4	a26	20	321943	0,28	1,08	28,0	9659	0,6215	3,4	19,85	3,9	0,2316	1,9	0,87	3116	84	3084	38	3063	31	102
mz2-5	a27	20	31058	0,02	0,02	5,94	115	0,5088	7,7	12,46	9,9	0,1776	6,1	0,78	2652	171	2640	97	2631	102	101

mz2-6	a28	20	142343	0,11	0,36	22,4	1227	0,5972	2,9	18,93	3,3	0,2299	1,6	0,88	3019	71	3038	33	3051	26	99
zr3-1	a30	20	1455275	8,92	1,94	0,25	1833	0,1099	3,3	2,883	4,2	0,1902	2,7	0,77	672	21	1377	33	2744	45	25
zr3-2	a31	8	359207	5,28	1,66	0,33	297	0,1958	6,6	5,118	7,3	0,1896	3,1	0,91	1153	70	1839	64	2739	51	42
zr3-3	a32	16	862280	9,50	2,00	0,13	1791	0,1666	3,2	4,340	7,6	0,1890	6,9	0,42	993	30	1701	65	2733	114	36
zr3-4	a33	8	344569	11,3	1,7	0,20	1745	0,1001	2,9	2,638	4,5	0,1912	3,5	0,64	615	17	1311	34	2752	57	22
zr3-5	a34	12	1474158	14,4	3,6	0,30	2200	0,1246	4,4	3,291	6,1	0,1916	4,2	0,73	757	32	1479	48	2756	69	27
zr3-6	a35	8	74096	0,89	0,22	0,15	2023	0,1127	13	3,078	13,8	0,1980	5,2	0,93	689	84	1427	112	2810	85	25
U phase	a37	16	483376	1,53	0,60	0,36	3834	0,2649	9,0	6,750	9,7	0,1848	3,5	0,93	1515	123	2079	89	2696	58	56
U phase	a38	20	229726	0,05	0,08	0,20	418	0,3865	9,0	10,44	11,6	0,1960	7,3	0,78	2106	163	2475	113	2793	119	75
U phase	a39	20	1601975	2,73	1,01	0,30	2049	0,2110	5,5	5,282	5,9	0,1816	2,1	0,94	1234	62	1866	52	2667	35	46
U phase	a40	30	1613240	0,40	0,39	0,07	476	0,2554	7,8	6,696	11,7	0,1901	8,7	0,66	1467	103	2072	109	2743	144	53
U phase	a43	8	768757	0,96	2,52	3,04	752	0,3502	3,4	8,692	5,3	0,1800	4,0	0,65	1936	58	2306	50	2653	67	73
U phase	a45	12	174822	3,41	0,38	0,15	51	0,0718	6,5	1,885	7,6	0,1903	4,1	0,85	447	28	1076	52	2745	67	16
U phase	a46	12	1247976	2,69	5,05	0,99	651	0,4873	6,5	12,50	8,3	0,1860	5,2	0,78	2559	139	2643	82	2707	86	95
U phase	a47	8	783749	19,6	26,4	1,04	2862	0,5206	5,1	12,86	7,6	0,1792	5,6	0,67	2702	114	2670	74	2645	93	102
U phase	a48	8	275647	1,32	0,88	0,42	443	0,4030	6,2	10,16	9,1	0,1829	6,6	0,68	2183	115	2449	87	2679	110	81
U phase	a49	8	423470	0,38	0,72	1,11	394	0,3669	4,9	9,794	8,1	0,1936	6,5	0,60	2015	86	2416	78	2773	106	73
U phase	a50	8	336152	2,27	2,25	0,99	79	0,5263	5,1	13,50	8,0	0,1860	6,2	0,63	2726	114	2715	78	2707	102	101
U phase	a51	8	555526	0,30	4,14	11,0	299	0,1996	14	5,021	15,6	0,1825	6	0,91	1173	154	1823	141	2676	104	44
U phase	a53	8	643310	13,0	4,4	0,14	68	0,1656	6,8	4,265	9,5	0,1868	6,6	0,71	988	62	1687	81	2714	110	36
U phase	a55	12	430539	9,16	1,20	0,11	64	0,0625	4,0	1,586	7,1	0,1842	5,9	0,55	390	15	965	45	2691	98	15
U phase	2-a1	16	330686	4,32	0,54	0,14	57	0,0646	3,5	1,691	4,9	0,1899	3,4	0,72	404	14	1005	32	2741	57	15

U phase	2-a2	16	133036	2,04	0,20	0,18	60	0,0496	4,9	1,296	5,8	0,1896	3,2	0,83	312	15	844	34	2739	53	11
U phase	2-a3	16	154771	1,80	0,15	0,15	147	0,0497	3,3	1,264	5,5	0,1846	4,4	0,61	312	10	830	32	2695	72	12
U phase	2-a7	16	676337	2,20	0,55	0,06	54	0,1199	17	3,166	17,6	0,1914	3,6	0,98	730	120	1449	146	2754	59	27
U phase	2-a8	16	1065606	3,87	0,95	0,05	52	0,1218	5,0	3,171	5,4	0,1887	2,0	0,93	741	35	1450	42	2731	33	27
U phase	2-a9	16	1021593	2,56	2,21	0,80	133	0,5136	3,9	13,30	4,8	0,1878	2,7	0,83	2672	87	2701	46	2723	44	98
rutile	2-a10	16	746197	0,96	1,37	0,13	1065	0,5212	4,2	17,19	5,7	0,2392	3,9	0,73	2704	93	2945	57	3114	63	87
rutile	2-a11	20	57573	0,12	0,06	0,01	414	0,4758	4,7	12,79	5,8	0,1949	3,3	0,82	2509	98	2664	56	2784	55	90
U phase	2-a12	40	710179	0,20	0,11	0,17	258	0,3142	9,8	8,165	10,1	0,1885	2,1	0,98	1761	153	2250	95	2729	34	65
mon	2-a13	20	1040150	0,44	0,54	0,19	571	0,5854	4,2	19,29	4,8	0,2390	2,4	0,87	2971	100	3056	47	3113	38	95
mon	2-a18	30	1682449	1,29	2,33	9,08	1283	0,5823	5,4	17,83	6,7	0,2221	4,0	0,80	2958	129	2981	67	2996	65	99

^x Diameter of laser spot; depth of crater 8-15 µm.

^a Within run background-corrected mean ²⁰⁷Pb signal in counts per second.

^b U and Pb content and Th/U ratio were calculated relative to GJ-1 reference.

^c corrected for background, common Pb and within-run Pb/U fractionation and subsequently normalised to GJ-1 (ID-TIMS value/measured value).

²⁰⁷Pb/²³⁵U calculated using ²⁰⁷Pb/²⁰⁶Pb/(²³⁸U/²⁰⁶Pbx1/137.88). Uncertainties propagated following Gerdes & Zeh (2006, 2008)

^d Rho is the error correlation defined as $\text{err}^{206}\text{Pb}/^{238}\text{U} / \text{err}^{207}\text{Pb}/^{235}\text{U}$

^d Percent concordance = $^{206}\text{Pb}/^{238}\text{U} \text{ age} / ^{207}\text{Pb}/^{206}\text{Pb} \text{ age} \times 100$

