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Litho-geochemistry of the Phoscorite-bearing Mulligan and Lake Machattie Intrusions: Discovery of a new Alkaline Metallogenic Province in SW Queensland

Report for the Geological Survey of Queensland

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Litho-geochemistry of the Phoscorite-bearing Mulligan and Lake Machattie Intrusions: Discovery of a new Alkaline Metallogenic Province in SW Queensland

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Mineral Potential Summary

Discovery of the Diamantina Alkaline Province is a major geoscientific advance. The province (mineral belt) comprises a linear array of more than 40 large intrusions (many exceeding 10 km in diameter) that contain an extremely rare assemblage of silica-poor igneous rocks.

On airborne geophysical images, the intrusions are characterised by strong magnetic and gravity anomalies that define a northwest to southeast trending belt, extending from Cadia in N.S.W. to the Merlin kimberlite field in the Northern Territory, a distance of more than 2000 km. This is the longest mantle plume track yet discovered on any continent. Intrusions in western Queensland are a small but significant component of this plume track generated metallogenic belt.

The Diamantina Alkaline Province is an entirely new greenfield mineral province and is virtually unexplored. The metal endowment potential of Diamantina igneous rocks resembles that in identical intrusions within the economically important Kola Peninsula mineral belt of Finland and Russia.

The Diamantina intrusions are excellent exploration targets for a wide range of high-value elements that are regarded as critical for development of energy efficient technologies. These include scandium, cobalt, nickel, copper, both "heavy" and "light" rare earth elements, yttrium, niobium, hafnium, zirconium, tantalum, phosphorus, as well as gold and the platinum group elements and diamonds.

Exploration targets in the Diamantina Alkaline Province include:

- Intrusion hosted ore-bodies, where metals crystallised from the magma.
- Ore-bodies produced by fluids liberated from the intrusions that precipitate metals in the country rocks. These may extend for 1-2 km from the intrusions.
- High-grade laterite-hosted scandium, niobium and rare earth element mineralization in weathering horizons over the intrusions.
- Diamond-bearing kimberlites pipes (like the Merlin Field) which occurs along the trend of these Silurian-Devonian alkaline intrusions.

Executive Summary

This report describes the petrology, major and trace element geochemistry and isotope systematics of lithologies from the Mulligan and Lake Machattie intrusions. These intrusions are two of more than ~32 pipe-like bodies within the SW Queensland segment of the *Diamantina Alkaline Province*. A new metallogenic province containing highly differentiated plume generated intrusions that are prospective for scandium, cobalt, nickel, copper, light and heavy rare earth elements, yttrium, niobium, hafnium, zirconium, tantalum, phosphorus, uranium, thorium, silver gold and platinum group elements.

Alkaline intrusions in the province range up to ~ 12 km in diameter and display distinctive coincident magnetic and gravity anomalies.

The Mulligan and Lake Machattie intrusions are lithologically and geochemically identical to undersaturated (SiO₂-poor) alkaline intrusions which host numerous mines on the Kola Peninsula in Russia and Finland, and also in the Alto Paranaíba region of south central Brasil.

The alkaline intrusions in SW Queensland are interpreted to form part of a ~2000 km long ~ 200 km wide plume track that extended from NSW (Fifield platinum and scandium pipes) to the Northern Territory (Merlin kimberlites). This track formed when proto-Australian lithosphere drifted over the Pacific Superplume between the late Silurian (~444 Ma) and early Devonian (365 Ma).

The Diamantina Province represent an important new greenfield exploration terrane that potentially contains the following possible mineral systems; (1) orthomagmatic mineralization within the intrusions; (2) fenite-hosted carbo-fluoro-thermal mineralization with altered host lithologies and (3) if palaeo-weathering horizons are preserved below sedimentary cover sequences, then there is the potential for occurrence of secondary scandium, niobium and rare earth element mineralization. Furthermore, as kimberlites are a product of mantle plume magmatism, the presence of micro-diamonds and diamond indicator minerals in eastern Northern Territory and western Queensland also likely reflects the impact of the Pacific Superplume.

Gold-bearing shoshonites also occur in areas where an upwelling plume has penetrated and melted metasomatised mantle wedge. Thus, the Pacific Superplume may have played a role in generating the 444 Ma Cadia and Northparkes Au (PGE) and Cu deposits in the Macquarie arc. Furthermore as the plume track crosses the Thomson Orogen and its paleo-mantle wedge, there is a high potential for discovery of Cadia style alkaline porphyry style mineralisation in this part of Queensland.

Background

Exploration in areas where basement units are overlain by transported sediment is challenging as surface geochemical sampling techniques commonly yield equivocal results (Dunn, 2007). However, biogeochemical studies carried out by CRC-LEME (The Cooperative Research Centre for Landscape Environments and Mineral Exploration), have shown that spinifex (*Triodia Sp.*) biogeochemistry is a potentially useful technique for identifying gold and base metal anomalism in such environments (Reid *et al.*, 2008; 2009; Reid and Hill 2010; Reid and Hill 2013).

To encourage exploration in the Simpson Desert of southwestern Queensland, in 2014 the Queensland Department of Natural Resources and Mines funded a spinifex biogeochemical study. Objective was to evaluate the use of spinifex biogeochemistry to identify areas of possible mineralisation in sand dune country where little was known about the underlying bedrock or its mineral potential.

Areas showing distinctive elemental anomalism were interpreted to reflect three styles of possible mineralisation, namely, (1) Au, Cu and Ni in mafic and ultramafic rocks on a terrane boundary; (2) Au, Ag and Cu epithermal or mesothermal mineralisation in calc alkaline granitoids; and (3) Sc, Cu, PGE and REE in alkaline intrusions characterised by phoscorite and carbonatite pipes.

This report focuses on drill core from two alkaline intrusions (Mulligan and Lake Machattie), of the more than 40 intrusions visible on magnetic images. It covers aspects of their petrology, major and trace element geochemistry, isotope systematics and metallogenic potential. The intrusions are characterised by an abundance of highly undersaturated lithologies, including ferro-carbonatite and phoscorite. Phoscorites are an extremely rare rock-type that contain abundant apatite, magnetite, clinopyroxenite and barkevikite (Na and K-bearing iron-rich amphibole). They invariably host many types of economic mineralisation (e.g., Wall and Zaitsev, 2004; Fontana, 2006).

The alkaline intrusions are interpreted to be part of a Silurian-Devonian plume track that extends from central NSW, through SW Queensland into the Northern Territory. Intrusions along the plume track were emplaced when proto-Australian lithosphere traversed the *Pacific Superplume*, a stationary thermochemical upwelling rising 2800 km from the core mantle boundary (e.g., Maruyama *et al.*, 2007; Torsvik *et al.*, 2010). This new metallogenic province could emerge as an exciting new postcode for Greenfield exploration in Australia.

Spinifex as a Sampling Medium in Arid Environments

Spinifex (Figure 1) is widely distributed in Australia, occurring in ~ 30% of the continent (Reid and Hill, 2013). It is almost ubiquitous in regions of central and western Australia that are highly prospective for mineralisation. Root systems penetrate deeply, possibly in excess of 70 m. They serve as point of anchorage and also as a means by which water and nutrients are acquired. Nutrient uptake occurs by chemical weathering through consumption of atmospherically derived CO_2 and the conversion of silicates into bicarbonate and Si(OH)₄ (Raven and Edwards 2001).

Roots also support mycorrhizal fungi that contribute to the acquisition of mineral nutrients through increasing the surface area available for uptake and by excretion of chelating compounds that facilitate element transport (Marschne and Dell, 1994). These processes promote the



Figure 1: Spinifex a ubiquitous deeply rooted xerophytic plant, occurs over much of Australia and offers great potential as a sampling medium in biogeochemical exploration.

dissolution and transfer of elements from the basement rock/root tip interface. This occurs by the movement of carbohydrates produced by photosynthesis downward from the surface to support bacterial and fungal activity. This is balanced by an upward movement of water and chemical nutrients along root system into the growing fronds. As roots seek out deep sources of water, spinifex is an ideal sampling medium for biogeochemical exploration in arid environments.

Study Design and Analytical Details

The initial spinifex beiogeochemical study which lead to the discovery of these rare alkaline intrusions was undertaken on a tenement held by Krucible Metals Ltd., that straddles the terrane boundary between the eastern Arunta Block and the North Australian Craton and southern Mount Isa Block (Figure 2). It involved the collection and analysis of more than 3000 spinifex samples collected along NE-SW oriented traverses normal to the magnetic grain of the basement.



Figure 2: Total magnetic intensity map showing location of the study area adjacent to the Queensland – Northern Territory border. Also shown are the locations of the two GSQ/AusQuest drill holes (white vertical arrows) into magnetic highs.

Chemical analyses for this initial study were undertaken by Inductively Coupled Plasma Mass Spectrometry (ICPMS) at ACME Labs in Victoria BC, Canada. Samples were ashed prior to analysis to increase detection limits by removing volatiles. Typical concentration ranges, from ppm (μ g/g) to ppt (pg/g) measured in spinifex samples are given in Table 1. Elements concentrated in spinifex fronds include Au, Ag, PGEs, Cr, Ni, Sc, Cu, Fe, Mg, Ca, Pb, Zn, the lanthanides, Y and the actinides. Except for the low atomic number elements (e.g., Li, Na, K, Ca) no significant concentration differences were observed between fresh (green) and dry (orange to brown) spinifex samples.

Copies of the data are available through the Geological Survey of Queensland at: https://qdexguest.deedi.qld.gov.au/portal/site/qdex/search?REPORT_ID=88754&COLLECTION _ID=999A

Element	Measured Range
Lithium	0.06 to 0.86 ppm
Beryllium	0.003 to 0.05 ppm
Phosphorous	0.007 to 0.07 ppm
Sulphur	0.02 to 0.1 ppm
Scandium	0.05 to 0.28 ppm
Vanadium	0.02 to 2.49 ppm
Chromium	0.22 to 2.1 ppm
Nickel	0.02 to 1.7 ppm
Copper	0.3 to 3.7 ppm
Zinc	2.3 to 89 ppm
Arsenic	0.001 to 0.5 ppm
Selenium	0.001 to 0.565 ppm
Yttrium	0.01 to 0.435 ppm
Zirconium	0.01 to 0.559 ppm
Molybdenum	0.008 to 0.9 ppm
Silver	0.06 to 27 ppb
Cadmium	0.002 to 0.20 ppm
Antimony	0.0003 to 0.012 ppm
Tellurium	0.0003 to 0.013 ppm
Rare Earth Elements	0.2 to 2.4 ppm
Platinum-Palladium-Rhenium	0.2 to 2.3 ppb
Gold	0.003 to 0.3 ppb
Thallium	0.0003 to 0.0145 ppm
Lead	0.03 to 0.6 ppm
Bismuth	0.0003 to 0.009 ppm
Thorium	0.005 to 0.09 ppm
Uranium	0.002 to 0.012 ppm

Table 1: Concentration ranges for trace elements in Simpson Desert spinifex

Chemical Vectors for Alkaline Intrusions in the Survey Area

Figure 3 shows data for scandium, lanthanides plus yttrium, copper, platinum-palladiumrhenium, actinides (U and Th), and yttrium in more than 3000 spinifex samples. The presence of anomalous gold concentrations (up to 0.5 ppb) in spinifex throughout the survey area suggests that gold in basement rocks may be masked by the presence of particulate gold in the surficial deposits. This gold could have been dispersed by leaf litter (Lintern *et al.*, 2013).

Spinifex in the survey area exhibited considerable variation in major and trace element chemistry. This variation was interpreted to reflect the compositional variability of lithologies in the buried basement.



Figure 3: Areal variation of trace elements showing the focused locations of Sc, PGEs, U, Th feature of the and REEY

The data clearly showed that certain source-specific elements, viz., Sc, Cu, Pt, Pd Re, Th, U and REE plus Y were well correlated. As this multi-element association occured at four localities it was interpreted to reflect the presence of chemically distinctive lithologies at depth. Furthermore,

correlations between Sc with Ni and Cr suggested that these lithologies must have been mafic to ultramafic in composition. Thus the distinctive multi-element association (Sc, PGEs, REEY, Cu and actinides) indicated the presence of ultramafic to mafic alkaline igneous intrusions in the basement terrane below the study area. Importantly, this association of element vectors is similar to that reported in differentiated alkaline intrusions containing phoscorite and carbonatite (e.g., Wall and Zaitsev, 2004).

Phoscorite-carbonatite pipe complexes are multi-phase, steeply dipping, zoned pipe-like ultramafic alkaline intrusions, that are circular to elliptical in shape and have a surface diameter of between 3 and 6 km. They are commonly surrounded by fenite (metasomatic carbothermal) alteration haloes up to 2 km in width which are produced by influx of fluorine- and carbon dioxide-rich magnatic fluids derived from the intrusion. Fenite haloes are commonly highly mineralized (LeBas, 1987).

Phoscorites are petrologically spectacular phosphate-rich (apatite-bearing) medium to coarse plutonic rocks containing carbonate (calcite, dolomite or ankarite), olivine, diopside, tetraferiphlogopite, sodic amphibole (magnesio-arfvedsonite and richterite), magnetite and apatite. They are associated with calcite carbonatite (sövite) or dolomite carbonatite (beforsite). Related alkaline silicate lithologies include dunite (olivinite), pyroxenite, feldspathoid-bearing gabbro (ijolite), diorite, monzonite and syenite (Krasnova *et al.*, 2003; Wall and Zaitsev, 2004).

Discovery of phoscorites in southwest Queensland is metallogenically significant, because despite their rarity, they are invariably associated with economic mineralisation (e.g., Fontana 2006). There are fewer than 30 occurrences of phoscorite recorded globally, compared to more than 527 intrusions containing carbonatite and related mafic and ultramafic alkaline differentiates (Woolley and Kjargaard 2008 a, b). The Queensland discoveries will add considerably to this number. Other possible Australia examples include the Mordor Complex in the Northern Territory (Barnes *et al.*, 2008) and the Cummins Range carbonatite complex in the Tanami Desert (Downes *et al.*, 2014).

Confirmation of Alkaline Pipes in South West Queensland

To confirm the interpretation based on spinifex geochemistry, a search of QDEX records of previous exploration in the area indicated that AusQuest (supported by a GSQ Cooperative Drilling Initiative Grant) had drilled two coincident magnetic and gravity anomalies as IOCG targets in the Diamantina Lineament, south of the Mount Isa Block in SW Queensland. Locations of MULDDH001 – Mulligan Intrusion and LMDDH001 – Lake Machattie Intrusion, approximately 100 km SE of the study area, are shown in Figure 2. Zircons separated from "pyroxenites" and "gabbros" recovered from the cores yielded U-Pb SHRIMP ages of 386 ± 2 Ma (Carson *et al.*, 2011). However, the significance of Devonian intrusions in this part of Precambrian Australia was not appreciated.

Despite the cores showing variable alteration, IOCG lithologies were not encountered, and because concentrations of copper and gold were low, the exploration program was abandoned (Sherrington & others, 2008a, b). However, the potential importance of the AusQuest data

became immediately apparent because anomalous concentrations of Sc, PGEs, REEs, Y, Cu, U and Th in spinifex coincided with a circular dipolar magnetic anomaly in the survey area.

To explore this further, the Mulligan and Lake Machattie cores were examined at the GSQ Core Facility in Brisbane during May 2016. Visual examination of this core and a review of the chemical data reported by AusQuest (Appendix Table A1 and A2) indicated that the Mulligan and Lake Machattie intrusions contained extreme and rare lithologies, with compositions ranging from ultramafic cumulates, to pyroxenites, alkali gabbros, phoscorite, carbonatite and nepheline syenite-phonolite. Thus in view of the metallogenic potential of these intrusions, in a poorly unexplored region of Queensland, a contract was awarded to KDC Consulting to undertake the detailed litho-geochemical investigation of the two intrusions that is presented in this report.

Sample Selection

To document the lithogeochemical variability of the two intrusions, representative samples of diamond drill core were selected for detailed study at the GSQ core storage facility at Zillmere. Samples from the Mulligan intrusion are listed in Table 2, and Lake Machattie intrusion samples are given in Table 3.

KDC No.	GSQ No.	Depth (m)	From (m)	To (m)	Lithology
MUL-1		954.5			Pyroxenite
MUL-2		1104.8			Pyroxenite
MUL-3		1104.8			Lamprophyre dyke
MUL-4		1131			Nepheline Syenite
MUL-5		1132.39			Sulphide-bearing pyroxenite
MUL-6		1237.3			Barkevikite-bearing gabbro
MUL-7		1237.3			Lamprophyre dyke
MUL-8		1238			Barkevikite-bearing gabbro
MUL-9		1239.3			Barkevikite-bearing gabbro
MUL-10		1280.8			Carbonatite dyke cutting pyroxenite
MUL-11		1282.2			Syenite(?)
MUL-12		1328.67			Amphibole-bearing pyroxenite
MUL-13		1348.3			Amphibole-bearing pyroxenite
MUL-14		1397.1			Sulphide-bearing pyroxenite
MUL-15		1470.6			Amphibole-bearing pyroxenite
MUL-16		1494.6			carbonate (?) bearing pyroxenite
MUL-17		1497.68			Amphibole-bearing pyroxenite
MUL-18	2535		1138.8	1139.05	Phoscorite
MUL-19	2538		1177.16	1177.36	Phoscorite
MUL-20	2550		1480.51	1481	Olivine-amphibole-sulphide-bearing pyroxenite
MUL-21	2578		1393.14	1393.35	Amphibole-bearing pyroxenite
MUL-22	2528		1068.37	1068.59	Amphibole-bearing pyroxenite
MUL-23	2561		1280.35	1280.59	Amphibole-bearing pyroxenite
MUL-24	2547		1479.42	1479.87	Sulphide-bearing pyroxenite
MUL-25	2523		1020.75	1020.97	Amphibole-bearing micro-pyroxenite
MUL-26	2519		979.53	979.72	Sulphide-bearing pyroxenite
MUL-27	2582		1435.26	1435.54	Sulphide-bearing pyroxenite
MUL-28	2590		1353.35	1353.65	Amphibole-bearing pyroxenite
MUL-29	2505		902.2	902.4	Amphibole-bearing pyroxenite
MUL-30	2522		1010.1	1010.32	Amphibole & Carbonate -bearing pyroxenite
MUL-31	2009		1499.10	1499.37	Amph-bearing pyroxenite
MUL-32	2000		1444.40	1444.72	Amphibele bearing pyroxenite
MUL-33	2592		109.30	1092.55	Amphibole-bearing pyroxenite
	2529A		1002.3	1082.55	Amphibole-bearing pyroxenite
MUL-36	25230		1482.18	1482 32	Sulphide-bearing pyroxenite
	2576		1370 12	1370 3/	Amphibole-bearing pyroxenite
MUL-38	2521		999.4	999 59	
MUL-39	2509 A		920	920.67	Amphibole-bearing pyroxenite
MUL -40	2509 BA		920	920.67	Amphibole-bearing pyroxenite
MUI -41	2509 BR		920	920.67	Amphibole-bearing pyroxenite
MUL-42	2586		1472.72	1472.94	Amphibole-bearing pyroxenite
MUL-43	2524		1030.57	1030.76	Amphibole-bearing pyroxenite
MUL-44	2542		1201.21	1201.46	Barkevitite plag apatite titanite rock
MUL-45	2544		1215.38	1215.7	Barkevitite plag apatite titanite rock
MUL-46	2507		904.8	905	Microgabbro/diorite
MUL-47	2558		1256.08	1256.3	Diorite
MUL-48	2525		1040.58	1040.8	Microgabbro/diorite

Table 2: Samples selected for lithogeochemical study from Mulligan Intrusion

KDC Number	GSQ No.	From (m)	To (m)	Rock Type
LM-1	585408	962.05	962.22	Websterite
LM-2	585413	978.83	979.00	Lamproite?
LM-3	585403	981.85	981.99	Apatite bearing pyroxenite
LM-4	585417	999.1	999.24	Apatite bearing pyroxenite
LM-5	585419	1014.1	1014.23	Apatite-olivine-pyroxene cumulate
LM-6	585309	1033	1034.00	Phoscorite
LM-7	585427	1073.5	1073.64	Pyroxene-magnetite -apatite cumulate
LM-8	585405	1086.15	1086.29	Pyroxenite
LM-9	585435	1116.12	1116.28	Pyroxenite
LM-10	585452	1124.8	1124.95	Gabbro with apatite and carbonatite veins
LM-11	585441	1145.33	1145.49	Pyroxenite veined by carbonatite
LM-12	585453	1217.74	1217.91	Pyroxene-magnetite-apatite cumulate
LM-13	585458	1265.23	1265.39	Gabbro veined by carbonatite
LM-14	585489	1301.79	1301.95	Pyroxenite
LM-15	585468	1354.17	1355.05	Silicio carbonatite
LM-16	585476	1361.64	1362.64	Pyrochlore-bearing silicio ferrocarbonatite
LM-17	585477	1362.64	1363.66	Pyrochlore-bearing silicio ferrocarbonatite
LM-18	2572	1612.47	1612.67	Pyroxenite
LM-19	585368	1658	1659	Pyroxenite
LM-20	585376	1698	1699	Ferrocarbonatite
LM-21	585377	1701.6	1701.94	Sovite veining orthopyroxenite
LM-22	585379	1717.2	1717.63	Orthopyroxenite
LM-23	585381	1722	1723	Dunite cut by lamprophyre dyke. Dyke sampled
LM-24	585386	1733	1734	Olivine clinopyroxenite cumulate

Table 3: Samples selected for litho-geochemical study from Lake Machattie Intrusion

Selected Petrographic Images

Mulligan Intrusion

Selected photomicrographs of Mulligan Intrusion lithologies are show on Plates 1 - 9.



Plate 1: Photomicrographs under plane light and crossed polarized light of MUL 19 a phoscorite showing abundant apatite, and MUL # 2543 a carbonatebearing barkevikite-rich pyroxenite.



Plate 2: Photomicrographs under plane light and crossed polarized light of MUL #2530 a phoscorite and barkevikite showing abundant apatite, and MUL 31 a barkevikite-rich pyroxenite.



Plate 3: Photomicrographs under plane light and crossed polarized light of MUL 34 a barkevikite-rich pyroxenite cut by a narrow vein of carbonatite, and phoscorite and barkevikite showing abundant apatite, and MUL 26 a sulphide bearing barkevikite pyroxenite.



Plate 4: Photomicrographs under plane light and crossed polarized light of MUL 38 a carbonate-rich lamprophyre, and MUL #2558 a foid-bearing diorite.





Plate 5: Photomicrographs under plane light and crossed polarized light of MUL 45 and MUL 44 a coarse grained and a fine grained melilitites containing monticellite and melilite.



Plate 6: Photomicrographs under plane light and crossed polarized light of MUL 41 a pyroxenite that is cut by foid-bearing syenite and MUL 48 and a fine grained microdiorite with a trachytoid texture.



Plate 7: Photomicrographs under plane light and crossed polarized light of MUL #1070.1 carbonate ocelli in foid-bearing syenite and MUL #1104.98 intrusive relationship between amphibole-rich pyroxenite and fine grained foid-bearing syenite.



Plate 8: Photomicrographs under plane light of MUL #543.3 showing contact between phoscorite and pyroxenite, and an intrusive relationship with a foid-bearing syenite dyke.



Plate 9: Photomicrographs under plane light of MUL 19 showing abundant euhedral crystals of apatite in phoscorite, and titanite in MUL 45.

Lake Machattie Intrusion

Selected photomicrographs of Lake Machattie Intrusion lithologies are show on Plates 10 to 17.



Plate 10: Photomicrographs under plane light and crossed polarized light of LM #1202 barkevikite foid-bearing pyroxenite and LM 4 apatite-rich pyroxenite (phoscorite).



Plate 11 Photomicrographs under plane light and crossed polarized light of LM #1393.1 barkevikite-rich phoscorite and LM #1499.1 pyroxenite.



Plate 12: Photomicrographs under plane light and crossed polarized light of LM 5 apatite olivine pyroxene cumulate, and LM 7 fine grained apatite olivine pyroxene cumulate.



Plate 13: Photomicrographs under plane light and crossed polarized light of LM 13 foid-bearing gabbro cut by veins of carbonatite, and LM 13 foid-bearing gabbro cut by veins of carbonatite.



Plate 14: Photomicrographs under plane light and crossed polarized light of LM 1 websterite, and LM 22 orthopyroxenite.



Plate 15: Photomicrographs under plane light and crossed polarized light of LM 21 sövite veining orthopyroxenite, and LM 22 pyrochlore-bearing carbonatite.



Plate 16: : Photomicrographs under plane light and crossed polarized light of LM 23 dunite cut by lamprophyre dyke, and LM 1 phlogopite-bearing websterite.



Plate 17: Photomicrographs under plane light and crossed polarized light of LM 24 olivine clinopyroxene cumulate, and LM #1387.8 evidence for multiple intrusive events in Lake Machattie

Identified Ore and Accessory Phases

The following opaque phases have been identified optically in samples from Mulligan and Lake Machattie:

- Chalcopyrite.
- Pentlandite
- Sphalerite
- Co-bearing pyrite
- Pyrrhotite
- Cu Ni Fe Sulphide Violarite
- Telluride phases
- V-bearing magnetite with ulvöspinel exsolution.
- Ilmenite
- Possible PGE and VG
- Nb-bearing pyrochore
- REE-bearing apatite & xenotime,
- REE carbonates and possible fluorides
- Sc-bearing baddeleyite?

Although the identification of violarite and the tellurides have been confirmed by reconnaissance ESD, due to the complexity of these phases and their potential to form economic mineral deposits, additional work is recommended to confirm identification and to establish the paragenetic sequence of crystallisation.

Analytical Techniques

Major and trace element geochemical data in this report were analysed by Intertek Genalysis Laboratory Services Pty. Ltd, Perth, Western Australia.

Major and Trace Element Geochemistry

Only extremely fresh material was selected for analysis. This involved removing weathered material, pen marks and saw cuts by grinding. Samples were then thoroughly cleaned in Milli-Q water in an ultrasonic bath and dried on a hot plate. They were then fragmented into chips <0.5 cm in diameter using a hydraulic press. An aliquot of these chips was powdered using an agate mill in a controlled environment to produce homogeneous samples for analysis.

The following geochemical/rock standards; SARM 2 - syenite, SARM 5 – pyroxenite, SARM 6 – dunite and ECRM 676-1 – European Certified Reference Iron Ore Sinter were used to monitor analytical accuracy and precision for major element data (Table 5). Precisions (1 σ) for most major element oxides are better than 1.0% with the exception of TiO₂ (1.5%) and P₂O₅ (1.0–1.5%).

Major and trace element data were obtained using the following techniques:

Major and Minor Elements (Fusion with Li borate flux mixture and XRF analysis) FB1/XRF

Sample preparation involved weighing approximately 0.7g of sample into a platinum crucible and this was mixed with a weighed amount of low melting temperature flux comprising a mixture of lithium tetraborate and lithium metaborate. This oxidant when added to the sample was fused to produce a homogeneous melt that was cast into a platinum mold to produce a fusion disk. Dissolving the sample in glass removes physical effects (particle size and mineralogical effects) that may compromise the accuracy of X-ray powder analyses. The fusion disk was analysed on a sequential or simultaneous X-ray fluorescence spectrometer. The XRF was calibrated using glass fusion beads of known composition. Corrections were applied for the weights, instrumental drift, line overlaps and inter-element enhancement and mass absorption matrix effects.

Loss on Ignition (LOI) Determination using Thermo Gravimetric Analysis -TGA

Thermo gravimetric analysis involved weighing a mass of sample into a weighed crucible. This was then weighed again with the sample. The mass difference between the crucible and the mass of the crucible plus sample was recorded. The crucible was heated to constant mass or for a constant time at a set temperature (usually 1000°C). The crucible was once again weighed. Since the crucible was made of an inert material, any mass loss or mass gain on heating can was attributed to the sample. LOI is simple the mass loss as a percentage of the mass taken. Negative LOI indicates mass gain on heating.

LOI determination is a common component of an XRF analysis. The XRF cannot analyse light elements and these are in many cases the elements that form the LOI component of a sample. LOI is a complex oxidation-devolatilisation reaction during which volatiles are lost and reduced species (e.g. FeO) oxidised.

In addition to the LOI analysis, a moisture analysis was done using the same TGA technique, usually at 105°C.

All XRF data are reported recalculated moisture free. LOI is calculated from the dry sample.

Fluorine by Carbonate Fusion in Ni Crucibles and Fluoride Ion Analysis using a Selective Ion Electrode (SIE) - FC7/SIE

This method was used to determine fluoride rock samples. A crushed sample mass of 1.2 grams was weighed and mixed with the flux mixture in a nickel crucible and then fused in a muffle furnace at high temperature. The fusion product was leached with doubly deionised water and the fluoride in solution was determined using specific ion electrode (S.I.E.). The method was calibrated by relating the voltage on the electrode with standard fluoride calibration solutions.

Carbon or sulphur analysis by CSA

This analysis was performed in an Eltra Infrared Carbon –Sulphur Analyser. The pulped sample was weighed out and placed in a ceramic dish or boat. An accelerant is added to act as a flux and improve fluidity and oxidation of the carbon and sulphur. Heating was achieved in a high-frequency induction furnace to provide speed and accuracy. In this process sulphur and carbon are converted to SO_2 and CO_2 respectively. These gases absorb infrared radiation at specific wavelengths that is proportional to the concentration of the C or S in the sample. Any water in the sample is removed by passing the gases produced through magnesium perchlorate as water interferes with the analysis. The method was calibrated using a standard of known C and S concentration.

Trace Elements Combined digest using four Acid Dissolution, Filtration followed by Fusion an analysis by IPCOES or ICPMS – CD/MS or CD/OES

This analytical method provided a combination of low detection limits and guaranteed dissolution by fusing the residue of a four acid digest and recombining this with the acid digest solution. The method is useful for the low-level geochemical characterisation of elements that may form major components of refractory trace minerals that may not dissolve in the four acid digest. This method, for example, finds application in ultramafic and alkaline rocks where elements such as Ta and REE are found in low concentrations.

The method involved weighting ~ 0.8 gram of sample and dissolving it sequentially using 4 acid digest with precautions taken to retain sulphur. Following filtration, the filter was fused in a platinum crucible with a lithium borate flux. The fusion product was dissolved and recombined with the 4 acid solution, volumed and diluted for analysis by ICPOES or ICPMS.

Nickel Sulphide Fire Assay and ICPMS finish - NS25/MS

NiS digestion is a nickel sulphide fire assay method specially formulated for the collection of platinum group elements and gold. The method involves weighing 25 grams of crushed sample mixed the sample with flux and firing it in a furnace. When fired, the flux sample mixture forms a nickel sulphide matte and an immiscible slag which separate owing to density differences. The precious metals are collected in the nickel sulphide matte (button). The button is separated from the slag, weighed and pulverized. Portion of the pulverised button is weighed and dissolved in boiling HCl. The addition of various reagents to the boiling HCl solution and careful observation of the dissolution process ensure that the platinum group elements and gold are quantitatively recovered by filtration as insoluble residues. These residues are dissolved in aqua regia with special precautions to retain osmium. The solution is diluted and analysed by ICP mass spectrometer. The detection limit for the method is 1ppb (0.001 ppm). Corrections are applied for interferences caused by polyatomic species and internal standards are used to correct for drift and plasma fluctuations.

Stable Isotopic Data

X-ray diffraction (XRD) analysis confirmed that dolomite was the dominant carbonate phase present in the samples, which were reacted off-line at 50 °C for 3 days using the McCrea (1950) phosphoric acid digestion method.

Sample gases were analysed on an Isoprime dual inlet isotope ratio mass spectrometer (DI-IRMS) in the Stable Isotope Geochemistry Laboratory at the University of Queensland. An acid fractionation factor of 1.01066 was used for calculation of the dolomite δ^{18} O values (Rosenbaum and Sheppard 1986).

The carbonate stable isotope analyses are reported in per mil (‰) relative to V-SMOW for oxygen and V-PDB for carbon, with analytical uncertainties better than ± 0.1 ‰ (1 σ). The Isoprime DI-IRMS was calibrated and analytical precision for carbonates established through replicate analyses of standards NBS-18 and NBS-19.

QA/QC

Limits of detection for these techniques are given in Table 4. To monitor accuracy, samples were analysed with a number of certified laboratory standards. The data for the standards are given in Tables 5 - 7.

The following geochemical/rock standards; SARM 2 - syenite, SARM 5 – pyroxenite, SARM 6 – dunite and ECRM 676-1 – European Certified Reference Iron Ore Sinter were used to monitor analytical accuracy and precision for major element data (Table 5). Precisions (1 σ) for most major element oxides are better than 1.0% with the exception of TiO₂ (1.5%) and P_{2O5} (1.0–1.5%).

Accuracy of Au and PGE analyses were monitored using the following Certified Standards: PGE7E-11, MEB-1, OREAS 13b Certified PGE-Ni-Cu Ore, AMIS 0283 Certified PGE-Cu-Ni Sudbury Ore (Table 6). These data are also in excellent agreement with the certified gravimetric concentrations.

Accuracy of trace element analyses were monitored using the following Certified Standards: AMIS0341 – LCT Pegmatite, Mt Cattlin; AMIS0342 – LCT Pegmatite, Mt Cattlin; AMIS0343 – LCT Pegmatite, Mt Cattlin; AMIS0420 – Carbonatite Palabora; AMIS0170 – Platreef ore; OREAS 45e – Lateritic soil; OREAS 94 – Copper ore; OREAS 461 – Carbonatite supergene REE-Nb ore; OREAS 620 – VHMS sulphide; OREAS 13b – PGE-Cu-Ni ore; MA-1b – Canadian Certified Reference Material gold ore; SARM 2 - Syenite, SARM-4 – Norite, SARM 5 – Pyroxenite, SARM 6 – Dunite. Analytical data for these standards analysed with the Mulligan and Lake Machattie samples are given in Table 7.

KDC²

Element/Oxide	Units	Det. Limits	Element/Oxide	Units	Det. Limits
Au (FA)	ppb	0.02	Na ₂ O	%	0.01
Ag	ppm	0.01	Nb	ppm	0.1
Al_2O_3	%	0.01	Nd	ppm	0.02
As	ppm	0.5	Ni	ppm	0.5
Ba	ppm	0.25	P_2O_5	%	0.002
BaO	%	0.01	Pb	ppm	0.5
Be	ppm	0.05	Pd (FA)	ppb	0.02
Bi	ppm	0.01	Pr	ppm	0.01
С	%	0.01	Pt (FA)	ppb	0.02
CO_2	%	0.01	Rb	ppm	0.1
CaO	%	0.01	Re	ppm	0.002
Cd	ppm	0.02	Rh	ppb	1.0
Ce	ppm	0.5	Ru	ppb	1.0
Co	ppm	0.01	S	%	0.01
Cr ₂ O ₃	%	0.01	SO_3	%	0.01
Cr	ppm	20	Sb	ppm	0.05
Cs	ppm	0.1	Sc	ppm	21
Cu	ppm	0.2	Se	ppm	0.5
Dy	ppm	0.02	SiO ₂	%	0.01
Er	ppm	0.02	Sm	ppm	0.02
Eu	ppm	0.02	Sn	ppm	1.0
F	ppm	50	Sr	ppm	0.2
Fe ₂ O ₃	%	0.01	Та	ppm	0.1
Ga	ppm	0.1	Tb	ppm	0.01
Gd	ppm	0.02	Те	ppm	0.1
Ge	ppm	0.05	Th	ppm	0.1
Hf	ppm	0.1	TiO ₂	%	0.01
Но	ppm	0.02	Tl	ppm	0.02
In	ppm	0.02	Tm	ppm	0.02
Ir	ppb	1.0	Total	%	0.01
K ₂ O	%	0.01	U	ppm	0.1
LOI	%	0.01	V	ppm	10
La	ppm	0.02	W	ppm	1.0
Lu	ppm	0.01	Y	ppm	0.1
MgO	%	0.01	Yb	ppm	0.02
MnO	%	0.01	Zn	ppm	1.0
Mo	nnm	0.1	Zr	nnm	1.0

Table 4: QA/QC Detection Limits for Genalysis Analytical Procedures

		SARM#2 ¹	SARM#2	SARM#5 ²	SARM#5	SARM#6 ³	SARM#6	ECRM 676-1 ⁴	ECRM 676-1
ELEMENTS		Meas.	Cert.	Meas.	Cert.	Meas.	Cert.	Meas.	Cert.
SiO ₂	wt.%	63.61	63.63	51.17	51.1	39.08	38.96	13.77	13.70
TiO ₂	wt.%	0.05	0.04	0.19	0.2	0.02	0.02	0.32	0.32
Al ₂ O ₃	wt.%	17.25	17.34	4.3	3.5	0.26	0.42	6.46	6.42
Fe ₂ O ₃	wt.%	1.42	1.11	12.76		17.07	0.3	56.9	56.9
MnO	wt.%	0.01	0.01	0.22	12.7	0.22	17	1.09	1.07
MgO	wt.%	0.46	0.46	25.28	0.22	43.59	0.22	1.92	1.92
CaO	wt.%	0.67	0.68	2.58	25.33	0.27	43.51	18.03	17.88
Na₂O	wt.%	0.42	0.43	0.36	2.66	0.05	0.28	0.13	0.13
K₂O	wt.%	15.33	15.35	0.09	0.37		0.04	0.52	0.52
P ₂ O ₅	wt.%	0.12	0.12	0.023	0.09	0.01	0.01	1.364	1.35
SO₃	wt.%	0.01		0.03		0.02		0.28	0.29

Table 5: Compilation of Major Element Data Standards Analysed for the Diamantina Study

¹SARM 2 Certified Reference Material NIM-S Syenite

²SARM 5 Certified Reference Material Pyroxenite

³SARM 6 Certified Reference Material Dunite

⁴ ECRM 676-1 European Certified Reference Material Iron Ore Sinter

	Au	lr	Os	Pd	Pt	Rh	Ru
	ppb	ppb	ppb	ppb	ppb	ppb	ppb
PGE7E-11 ¹	9	2		73	63	7	7
Cert. Value	6.6	2.1		76.4	69.3	6.9	8.1
MEB-1 ²	94	2		48	46		
Cert. Value	100			48	48		
OREAS 13b ³	200	18	10	129	208	40	73
Cert. Value	201	17.9	12	134	204	43	78
AMIS0283 ⁴	82	10	3	504	887	43	10
Cert. Value	92			490	820		

Table 6: Data for NiS Fire Assay Standards Analysed for the Diamantina Study

¹PGE7E-11 Certified Reference Material

²MEB-1 Certified Reference Material

³OREAS 13b Certified PGE-Cu-Ni Reference Material

⁴AMIS0283 Certified PGE-Cu-Ni Reference Material Sudbury Ore

ELEMENTS	Li	F	Be	Sc	V	Cr	Со	Ni	Cu	Zn	Ga	Ge	As
UNITS	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
AMIS0341		3115											
Cert. Value		3494											
AMIS0342		1066											
Cert. Value		1074											
AMIS0343		2257											
Cert. Value		2273											
AMIS0420	3.2		0.31				87.9	132.4	5897.7	214		0.89	620.3
Cert. Value	3.8		0.3				80.3	126	5780	199		1	603
OREAS 45e				92	337	1079					15.8		
Cert. Value				91	317	1067					16		
OREAS 94													
Cert. Value													
AMIS0170	8		0.15				50.8	1132.1	708.2	51		0.92	2.5
Cert. Value	8.86		0.17				51	1071	709	51.58		0.12	1.54
OREAS 461				41	395	605					28.1		
Cert. Value					385	599							
OREAS 620													
Cert. Value													
AMIS0420				17	198	109					5		
Cert. Value				15.7	188	68.7					9		
OREAS 13b	17.5		1.8				75.9	2340.6	2369.3	134		1.1	54.3
Cert. Value							75	2247	2327	133			57
OREAS 45e	4.9		0.56				57.9	477.6	776	50		1.47	15.8
Cert. Value							52	357	709	30.6			11.4
OREAS 461	10.9		2.17				11.7	71.6	50.6	143		1.37	28.3
Cert. Value	12		2.09				12.1	71	56	139			33.6
MA-1b													
Cert. Value													
SARM2													
Cert. Value						10					4.0		
SARM4				40	223	43					16		
Cert. Value					220	30							
SARM5													
						2050							
SARM6						2959							
Cert. Value						2874							

Table 7: Compilation of Trace Element Data for Standards Analysed for the Diamantina Study

Table 7 (Continued)

ELEMENTS	Se	Rb	Sr	Zr	Nb	Мо	Cd	Sn	Те	Cs	Ba	S	SO3
UNITS	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	%
AMIS0341													
Cert. Value													
AMIS0342													
Cert. Value													
AMIS0343													
Cert. Value													
AMIS0420	4.8					1.1	0.81		8.1				
Cert. Value	5.3					1.2	0.86						
OREAS 45e		20.8	15.5	246	7.4			3		1.1	244.2		
Cert. Value		20.8	15.9	242	7.4					1.2	246		
OREAS 94												1.3	
Cert. Value												1.38	
AMIS0170	1.4					1.7	0.14		0.4				
Cert. Value	2.21					1.79	0.13		0.41				
OREAS 461		13.7	560.4	583	1339.3			26		0.7	940.7		
Cert. Value		13.5	579	603	1296			25.6		0.79	929		
OREAS 620												2.4	
Cert. Value												2.52	
AMIS0420		13.8	3110.2	864	10.3			22		0.3	489.1		
Cert. Value		14.2	3085		6.8			16.7		0.26	478		
OREAS 13b	3.5					9.1	0.09		0.4				
Cert. Value						9							
OREAS 45e	2.7					2.4			0.2			0.04	
Cert. Value												0.043	
OREAS 461	2.2					48.2	0.09		0.3				
Cert. Value						48.2			0.34				
MA-1b												1.23	
Cert. Value												1.17	
SARM2													
Cert. Value													
SARM4		4.4	264.5	13	0.5			2		0.3	81.9		<u> </u>
Cert. Value			260	23									<u> </u>
SARM5													0.03
Cert. Value													<u> </u>
SARM6		0.3	3.6	4	0.7			1		0.1			0.02
Cert. Value													

	itiliucu)														
ELEMENTS	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Но	Y	Er	Tm	Yb	Lu
UNITS	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
AMIS0341															
Cert. Value															
AMIS0342															
Cert. Value															
AMIS0343															
Cert. Value															
AMIS0420															
Cert. Value															
OREAS 45e	10.8	23.3	2.4	8.1	2.3	0.6	2	0.4	2.6	0.5	10.5	1.3	0.2	1.4	0.3
Cert. Value	11.1	23.5	2.5	9.46	2.13	0.55	2	0.36	2.28	0.46	10.6	1.41	0.22	1.48	0.23
OREAS 94															
Cert. Value															
AMIS0170															
Cert. Value															
OREAS 461	2601.5	3409.6	473.3	1572.8	194	45.8	91.8	9.1	34.3	4.5	93.5	9.2	0.9	4.5	0.5
Cert. Value	2690	3510	489	1629	220	46.7	100	9.08	34.8	4.56	91	8.8	0.89	4.39	0.52
OREAS 620															
Cert. Value															
AMIS0420	237.2	547.7	72.3	304	53.3	11.9	36.2	4	15.6	2.1	54.5	3.7	0.4	1.9	0.2
Cert. Value	231	535	67.7	290	50.9	11.9	36.9	4	15	2	50.7	3.7	0.36	1.6	0.2
OREAS 13b															
Cert. Value															
OREAS 45e															
Cert. Value															
OREAS 461															
Cert. Value															
MA-1b															
Cert. Value															
SARM2															
Cert. Value															
SARM4	2.8	5.5	0.7	3.7	0.9	0.6	1.3	0.2	1.1	0.3	6.5	0.6	0.2	0.7	0.1
Cert. Value	3	6									7			0.7	0.2
SARM5															
Cert. Value															
SARM6															
Cert. Value															

Table 7 (Continued)

FLEMENTS		Ta	14/	Dh	Th		A	A	T 1	Ch.	D:	Dal	D4	A
	ה ו	b l a	VV	PD	10	U	Au	Ag	11	50	DI	Pa	Pl	Au
	ррш	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
AIVII50341														
Alvii50342														
AIVII50343														
				03.8			0.34	1 / 2	0.28	22.92	9 55			0.34
Cort Value				93.0			0.34	1.43	0.20	22.03	0.00			0.34
	6.5	0.0	1	92.0	10.7	2.6	0.41	1.4	0.4	33.0	0.0			0.41
Cort Value	6.21	0.9	1.06		12.1	2.0								<u> </u>
OPEAS 0/	0.57	0.05	1.00		15	2.54								
Cart Value														
AMIS0170				11.2			0.08	0.29	0.17	3 73	0.37	0.82	0.65	0.08
Cert Value				11 17			0.00	0.33	0.16	3.99	0.37	0.81	0.72	0.09
ORFAS 461	13.9	23.8	4		212.4	48	0.00	0.00	0.10	0.00	0.07	0.07	0.72	0.00
Cert Value	14.1	25.1	3.88		210	4 7.9								
ORFAS 620		20.7	0.00		210									
Cert. Value														
AMIS0420	18.5	3.1	2		68.9	17.4								
Cert. Value		1.3	0.73		67.7	17								
OREAS 13b				22.2			0.2	0.92	1.05	2.11	1.63	0.12	0.12	0.2
Cert. Value							0.21	0.86						0.21
OREAS 45e				17.4			0.05	0.29	0.15	0.93	0.28	0.08	0.13	0.05
Cert. Value	-			14.3			0.05					0.075	0.11	0.05
OREAS 461				103				0.63	0.1	2.46	2.44			
Cert. Value				104					0.1	2.42	2.43			
MA-1b														
Cert. Value														
SARM2														
Cert. Value														
SARM4														
Cert. Value														
SARM5														
Cert. Value														
SARM6														
Cert. Value														

Table 7 (Continued)

\mathbf{DC}^2

Radiogenic Isotope Geochemistry

Sr, Nd, Hf and Pb isotopic data were determined in the clean room-based, low-blank Radiogenic Isotope Facility, School of Earth Sciences at the University of Queensland (RIF-UQ). Reagents

Acids used for sample dissolution and column chemistry, viz., HF, HNO₃ and HCL were reagent grade and were further purified by sub-boiling distillation in silica glass or PTFE stills. Water was purified using a Milli-Q[™] system.

Sample Digestion and Ion Exchange Chromatography

Samples were digested in an Anton Paar Multiwave PRO[™] microwave reaction system. The procedure involved weighing 200 mg of sample that was then transferred into pre-cleaned and conditioned PTFE-TFM[™] liners for ultra-high pressure digestion. An acid mixture comprising 2 ml 15.8N HNO₃, 5.4 ml 11.6 N HCl, and 1.4 ml 29 N HF was then added to the liner. The liners were placed into the rotor of the microwave. Samples were heated to 205°C and kept for 1 hour to ensure complete digestion of refractory minerals. After cooling to ~70°C or below, solutions were transferred from the liners into 20ml PFA[™] beakers. After converting the fluorides to nitrates, samples were taken up in 2ml 2N HNO₃ for separation of Sr, Nd, Pb and Hf wa s achieved by ion exchange chromatography, using a modified procedure based on Pin, *et al.* (1997), Deniel and Pin (2001) and Miková and Denkova (2007). In this procedure, Sr and Pb were separated using (Sr Spec micro-columns, Eichrom Environment[™], Bruz, France), Nd is separated using TRU Spec and LN Spec columns) and finally Hf was separated using the Ln. Spec column.

Mass Spectrometry

⁸⁷Sr/⁸⁶Sr, ¹⁴³Nd/¹⁴⁴Nd and ¹⁷⁶Hf/¹⁷⁷Hf and Pb isotopic compositions were determined by static measurement on a Nu Plasma HR MC-ICP mass spectrometer, using a modified CETAC ASX-110FR auto-sampler and a DSN-100 dissolvation nebulizing system.

Typical procedural blanks are ca. 65, 50, 60 pg <1 pg for Sr, Pb, Nd and HF respectively. Given the sample size (200 mg) these blank levels are insignificant.

Measured ⁸⁷Sr/⁸⁶Sr, ¹⁴³Nd/¹⁴⁴Nd and ¹⁷⁶Hf/¹⁷⁷Hf ratios were corrected for mass fractionation using the exponential law by normalizing to ⁸⁶Sr/⁸⁸Sr = 0.1194, ¹⁴⁶Nd/¹⁴⁴Nd = 0.7219 and ¹⁷⁹Hf/¹⁷⁷Hf = 0.7325, respectively. Instrumental drift was monitored and calibrated with standards. During sample analysis, the Sr standard NBS-987 yielded a mean ⁸⁷Sr/⁸⁶Sr = 0.710250 ± 8 (n = 8, 2SD).

For Nd analyses, instrument bias and mass fractionation were corrected by normalising raw ratios to 146 Nd/ 144 Nd = 0.7219. An in-house Nd standard, Ames Nd Metal was used as a Nd isotope drift monitor. During analysis of the Mulligan and Lake Machattie samples, 7 analyses of this internal standard yielded an average of 143 Nd/ 144 Nd = 0.511965 ± 10.

For measurement of hafnium isotope ratios, a Hf standard monitor was measured between every 5 samples. Repeat measurements gave an average 176 Hf/ 177 Hf value of 0.282145± 2 (n= 6, 2SD), corresponding to a mean value of 0.282160 ± 10 (n= 16, 2SD) for JMS-475 standard.

Pb separated by column chemistry was doped with 4-5 ppb Tl to enable fractionation correction using a 205Tl/203Tl ratio of 0.23875. During analysis of the Mulligan and Lake Machattie samples 10 analyses of NBS-981 yielded the following average ratios, with 2 standard deviations: ${}^{208}\text{Pb}/{}^{204}\text{Pb} = 36.7183 \pm 29$; ${}^{207}\text{Pb}/{}^{204}\text{Pb} = 15.4945 \pm 10$; ${}^{206}\text{Pb}/{}^{204}\text{Pb} = 16.9409 \pm 11$;
208 Pb/ 206 Pb = 2.16810 ± 15; 207 Pb/ 206 Pb = 0.91461 ± 3; using values reported by Collerson *et al.*, (2002) for additional fractionation correction.

The values of USGS reference materials BCR-2, BHVO-2 and W2 and the Japanese standard JG-3 that were analysed with the Mulligan and Lake Machattie samples are given in Table 8. They are all consistent with the reference values reported by GeoREM (http://geoem.mpch-mainz.gwdg.de/).

Isotopic data for standards analysed with the Mulligan and Lake Machattie samples are within error of the long term external precision the isotopic compositions of laboratory standards: NBS 987 (n=197), Nd Metal (n=512), Hf Lab standard (n=237) and Pb NBS 981(n=49), given in Table 8. This confirms the accuracy of the data give for the Mulligan and Lake Machattie samples in Tables 16 to 19.

	⁸⁷ Sr/ ⁸⁶ Sr	2SD	¹⁴³ Nd/ ¹⁴⁴ Nd	2SD	¹⁷⁶ Hf/ ¹⁷⁷ Hf	2SD	²⁰⁸ Pb/ ²⁰⁴ Pb	2SD	²⁰⁷ Pb/ ²⁰⁴ Pb	2SD	²⁰⁶ Pb/ ²⁰⁴ Pb	2SD	²⁰⁸ Pb/ ²⁰⁶ Pb	2SD	²⁰⁷ Pb/ ²⁰⁶ Pb	2SD
BCR-2	0.705026	0.000009	0.512633	0.000006	0.282863	0.000004	38.726680	0.003864	15.620730	0.001412	18.755990	0.002730	2.065371	0.000127	0.832832	0.000014
HVBO2			0.512982	0.000005	0.283091	0.000003										
W2	0.707032	0.000013	0.512522	0.000005	0.282723	0.000003										
JG-3	0.705396	0.000007			0.282790	0.000003	38.484180	0.000389	15.573350	0.000724	18.361610	0.001216	2.096585	0.000125	0.848157	0.000003
Nd Metal			0.511965	0.000010												
NBS987	0.710249	0.000018	(n=197)													
Nd Metal	(n=512)		0.511966	0.000010												
Hf Std.	(n=287)				0.282145	0.000008										
NBS 981	(n=490)						36.7180	0.0049	15.4945	0.0018	16.9411	0.0020	2.16759	0.00069	0.91461	0.00007

Table 8: Isotopic Compositions of Geochemical Standard Rocks

Major and Trace Element Geochemistry

Major Element Data

Major element chemistry (calculated anhydrous) and CIPW normative compositions of selected samples from Mulligan and Lake Machattie Intrusions are given in Tables 9 and 10 where Fe_2O_3 and FeO are calculated, assuming a Fe_2O_3/FeO ratio of 0.1. Data for samples of diamond drill core from these intrusions reported by AusQuest (Sherington *et al.*, 2008 a & b) are presented in Appendix 2.

Major element variations of the two data sets are shown as Harker diagrams (oxides vs. SiO₂) in Fig. 4, where Mulligan and Lake Machattie show clearly divergent fractionation trends. Major element variation during fractionation and separation of an immiscible carbonate-rich liquid are shown in Figures 4 and 5.

In the Mulligan Intrusion SiO₂ ranges between ~ 28 wt.% and 60 wt.% and exhibits smooth fractionation with increasing Al₂O₃, Na₂O and K₂O (Fig. 4 b, g & h) and decreasing TiO₂, FeO*, MnO, MgO and CaO (Fig. 4a, c, d, e f). These trends are interpreted to reflect the effect of crystal-liquid fractionation, commencing from a parent magma composition containing between 30 and 35 wt. % SiO₂. This primary melt composition is also enriched in P₂O₅, with up to 4.2 wt.% in pyroxene-rich phoscorite (Fig. 4i).

Lake Machattie Intrusion is significantly more undersaturated with SiO_2 between 10 and 41 wt.%. The majority of sample lie on the low silica end of the fractionation trends defined by Al_2O_3 , Na_2O , K_2O , TiO_2 , FeO*, MnO, MgO and CaO (Figs 4a-i). Lake Machattie lithologies, with between 25 and 35 wt. % SiO₂ range to the highest P₂O₅ contents defining a field similar to the high-P₂O₅ Mulligan samples, although the field is off-set to slightly lower SiO₂ values (Figure 4i).

A small population of carbonate-rich samples, including silicio-carbonatites, with between 10 and 30 wt.% SiO₂, exhibit divergent trends for TiO₂, FeO*, MnO, CaO, Na₂O and P₂O₅ that differ strongly from the fractionation trends in Mulligan Intrusion. Formation of this divergent trend is interpreted to reflect the role of liquid immiscibility that resulted in the separation of a carbonatitic magma. Liquid immiscibility has emerged as an important petrogenetic process during crystallisation of alkaline magmas (e.g., Carstens, 1979; Nielsen *et al.*, 1997; Kjarsgaard, 1998; Veksler *et al.*, 1998; Panina and Motorina, 2008; Kamenetsky and Kamenetsky 2010; Guzmics *et al.*, 2012; Brod *et al.*, 2013; Káldos *et al.*, 2015; Sekisova *et al.*, 2015; Weidendorfer *et al.*, 2016).

Covariation between MgO versus TiO_2 (Fig. 5a) clearly emphasises the divergent fractionation trends shown by Mulligan and Lake Machattie intrusions, with the Lake Machattie intrusion fractionating to extreme TiO_2 values of ~ 11 wt.%.

Lithologies from Mulligan and Lake Machattie Intrusions with between 30 and 40 wt.% SiO_2 are interpreted to be compositions close to those of the primary magma. Importantly these have ~ 5 wt.% TiO₂ and 15 wt. % MgO and trend close to the primary magmatic composition determined by Weidendorfer *et al.*, (2016) for the ocean island ijolite-carbonatite system on Brava Island (Fig. 5a).

Covariation between CO_2 and total alkalis is different in the two intrusions (Fig. 5b). Lake Machattie samples have significantly higher CO_2 contents ranging to ~ 28 wt. % and maximum total alkalis of ~ 6 wt. %. By contrast, samples from Mulligan intrusion are significantly less enriched in both alkalis and CO_2 . The negative correlation between CO_2 and total alkalis is similar to that reported for carbonatites on Brava Island, where it is interpreted to reflect precipitation of secondary carbonate accompanied by fluid induced loss of Na (Weidendorfer *et al.*, 2010).



Table 9: Major element chemistry and CIPW normative mineralogy of Mulligan intrusion

	MUL-1	MUL-2	MUL-2Rpt.	MUL-3	MUL-4	MUL-5	MUL-6	MUL-7	MUL-8	MUL-9
SiO ₂	35.30	41.35	41.72	41.42	56.85	37.55	47.59	40.44	49.58	53.73
TiO ₂	6.56	4.36	4.39	4.43	1.77	5.87	3.26	4.37	2.51	1.66
Al ₂ O ₃	8.97	10.77	10.94	11.69	16.68	11.16	17.22	11.02	16.79	18.79
Fe ₂ O ₃ *	2.22	1.43	1.44	1.44	0.69	1.79	1.06	1.51	1.00	0.62
FeO*	17.97	11.54	11.64	11.69	5.58	14.46	8.56	12.24	8.06	5.05
MnO	0.22	0.19	0.18	0.19	0.08	0.24	0.17	0.21	0.19	0.11
MgO	9.70	12.18	12.26	11.43	2.60	8.54	4.10	11.94	3.70	2.94
CaO	15.60	11.17	11.25	11.30	4.64	13.64	8.07	10.99	7.56	6.61
Na₂O	0.99	2.54	2.50	2.76	4.72	2.17	4.54	2.09	4.43	5.82
K ₂ O	0.45	2.19	2.19	1.93	5.46	1.29	2.81	2.89	3.63	2.59
P ₂ O ₅	0.15	0.52	0.53	0.65	0.07	0.70	1.16	0.69	1.24	0.93
CO ₂	0.78	0.82	0.00	0.37	0.44	1.04	0.45	0.67	0.26	0.33
SO₃	0.67	0.48	0.49	0.31	0.21	0.89	0.39	0.48	0.34	0.18
S	0.27	0.18	0.18	0.11	0.08	0.35	0.14	0.18	0.13	0.07
F	0.03	0.00	0.00	0.00	0.02	0.11	0.10	0.00	0.09	0.09
CI	0.02	0.06	0.06	0.07	0.04	0.08	0.19	0.06	0.20	0.26
Sr	0.01	0.05	0.06	0.05	0.03	0.05	0.14	0.06	0.24	0.17
Ва	0.02	0.03	0.03	0.03	0.01	0.01	0.00	0.03	0.00	0.00
Ni	0.03	0.10	0.10	0.09	0.01	0.03	0.00	0.07	0.00	0.01
Cr	0.02	0.03	0.03	0.04	0.02	0.04	0.04	0.04	0.05	0.02
Zr	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.02
Iotal	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	01.0	40.0	40.7	447	44.0	10.0	40.0	40.0	00.0	
Plagioclase	21.0	13.0	13.7	14.7	44.0	19.8	42.9	13.6	38.6	57.5
Orthoclase	0.0	12.8	5.8	10.4	32.5	4.6	17.6	4.9	23.2	16.5
Nepheline	2.2	9.9	9.7	11.6	1.8	0.8	0.0	7.9	0.0	4.4
Leucile	2.1	0.4	0.0	1.1	0.1	2.7	0.1	9.9	10.0	6.4
Diopside	20.1	21.4	31.3	28.2	9.1	29.9	9.1	20.1	10.0	0.4
	5.80	21.0	20.4	20.2	0.4	10.9	11.2	22.0	10.2	7.5
Na-SiO-	5.00									
Ilmenite	12.46	8 28	8 34	8 4 1	3 36	11 15	6 19	8 30	4 77	3 15
Magnetite	3.22	2.07	2.09	2.09	1.00	2.60	1 54	2.19	1.45	0.10
Anatite	0.36	1 20	1.00	1.51	0.17	1.68	2 79	1.60	2.98	2 24
Zircon	0.03	0.04	0.04	0.06	0.03	0.06	0.06	0.06	0.07	0.03
Chromite	0.04	0.15	0.15	0.13	0.01	0.04	0.00	0.00	0.01	0.01
Pvrite	0.57	0.38	0.38	0.23	0.17	0.74	0.30	0.38	0.28	0.15
Fluorite	0.04				0.03	0.12				0.02
Anhydrite										
Na ₂ SO ₄	1.19	0.85	0.87	0.55	0.37	1.58	0.69	0.85	0.60	0.32
Calcite	1.77	1.86		0.84	1.00	2.37	1.02	1.52	0.59	0.75
Na ₂ CO ₃										
Total	100.0	99.9	100.0	100.0	100.0	100.0	99.9	99.9	100.0	99.9
Mg/(Mg+Fe ²⁺)	49.0	65.3	65.2	63.5	45.4	51.3	46.1	63.5	45.0	50.9
Ca/(Ca+Na)	89.7	70.8	71.3	69.3	35.2	77.6	49.6	74.4	48.5	38.6
DI	25.3	36.1	35.1	37.7	78.3	33.9	67.1	36.3	68.4	78.4
Density, g/cc	3.4	3.1	3.2	3.1	2.8	3.2	2.9	3.1	2.9	2.8
Liquidus T., °C	1483	1372	1365	1371	1088	1442	1258	1389	1221	1145



	MUL-10	MUL-11	MUL-12	MUL-13	MUL-14	MUL-15	MUL-16	MUL-17	MUL-18	MUL-19
SiO ₂	35.44	60.09	35.42	35.29	27.76	41.21	38.74	38.11	33.17	32.07
TiO ₂	5.73	0.74	6.17	6.31	6.87	4.57	4.94	5.07	6.97	7.16
AI_2O_3	11.91	18.25	12.34	12.08	7.10	10.90	10.39	9.29	8.96	10.17
Fe ₂ O ₃ *	1.83	0.44	1.83	1.95	2.79	1.44	1.58	1.75	1.88	1.77
FeO*	14.82	3.53	14.81	15.80	22.63	11.68	12.78	14.17	15.22	14.31
MnO	0.25	0.09	0.25	0.25	0.28	0.22	0.21	0.20	0.24	0.22
MgO	7.20	0.60	7.97	7.82	8.08	9.83	9.96	10.09	9.08	9.16
CaO	13.50	1.91	12.76	12.61	11.88	13.96	13.81	15.35	16.26	15.63
Na ₂ O	2.42	6.40	2.36	2.27	0.97	2.41	2.04	1.52	1.39	1.63
K ₂ O	1.77	5.84	1.90	1.59	0.52	1.38	1.10	0.80	0.78	1.11
P ₂ O ₅	3.18	0.17	2.14	1.84	0.38	0.76	0.50	0.36	3.09	3.79
	0.71	0.96	0.78	1.08	0.38	0.74	1.02	1.51	0.81	0.77
SO ₃	0.54	0.41	0.59	0.51	7.14	0.38	1.76	1.09	1.24	1.22
א ר	0.21	0.15	0.23	0.21	2.83	0.15	0.78	0.45	0.53	0.53
	0.19	0.02	0.19	0.15	0.05	0.12	0.09	0.06	0.10	0.24
	0.13	0.05	0.13	0.12	0.04	0.09	0.06	0.03	0.09	0.12
	0.10	0.03	0.09	0.07	0.02	0.05	0.05	0.03	0.04	0.00
Da	0.00	0.00	0.00	0.00	0.15	0.02	0.05	0.02	0.01	0.00
Cr	0.01	0.00	0.01	0.00	0.03	0.03	0.10	0.04	0.02	0.01
7r	0.04	0.00	0.04	0.04	0.02	0.04	0.03	0.03	0.03	0.00
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Plagioclase	17.9	52.5	19.2	19.6	0.0	16.7	24.6	19.8	20.1	21.2
Orthoclase	9.5	34.7	2.5	5.8	1.7	8.5	6.9	2.9		0.7
Nepheline	9.2	0.8	8.7	8.6	18.1	9.3	1.6	3.1	2.0	3.1
Leucite	1.3		7.4	3.2	1.2	0.0	0.0	1.6	3.8	4.9
Diopside	19.9		21.0	20.1	0.0	35.3	29.8	36.1	29.0	22.0
Olivine	17.9	4.7	18.3	19.5	33.5	14.7	16.8	16.9	16.6	17.8
Larnite										
Na ₂ SiO ₃					4.81					
Ilmenite	10.88	1.41	11.72	11.98	13.05	8.68	9.38	9.63	13.24	13.60
Magnetite	2.65	0.64	2.65	2.83	0.00	2.09	2.29	2.54	2.73	2.57
Apatite	7.65	0.41	5.15	4.43	0.91	1.83	1.20	0.87	7.44	9.12
Zircon	0.06	0.45	0.06	0.06	0.03	0.06	0.04	0.04	0.04	0.04
Chromite	0.01		0.01		0.13	0.04	0.15	0.06	0.03	0.01
Pyrite	0.45	0.32	0.49	0.45	6.00	0.32	1.65	0.95	1.12	1.12
Fluorite		0.01			0.04	0.13	0.11	0.07		
Annyarite	0.00	0.70	1.05	0.00	27.62	0.07	2.40	1.02	2.20	0.40
Na_2SO_4	0.96	0.73	1.05	0.90	0.00	0.67	3.12	1.93	2.20	2.16
	1.01	2.10	1.77	2.40	0.00	1.00	2.32	3.43	1.04	1.75
Total	100.0	00.9	100.0	100.0	100.0	0 00	100.0	100.0	100.0	100.0
	100.0	33.0	100.0	100.0	100.0	39.9	100.0	100.0	100.0	100.0
Ma/(Ma+Fe ²⁺)	46.4	23.3	49.0	46 9	38.9	60.0	58.1	55.9	51.5	53 3
Ca/(Ca+Na)	75.5	14.2	74.9	75.4	87.1	76.2	78.9	84.8	86.6	84.1
	37.9	88.0	37.8	37.2	21.0	34.5	33.1	27.4	25.9	30.0
Density, g/cc	3.2	2.7	3.2	3.2	3.4	3.2	3.2	3.3	3.3	3.3
Liquidus T., °C	1480	1028	1481	1483	1621	1374	1420	1431	1522	1542



	MUL-20	MUL-21	MUL-22	MUL-23	MUL-24	MUL-25	MUL-26	MUL-27	MUL-28	MUL-29
SiO ₂	38.67	32.38	31.27	33.05	34.00	34.24	34.60	35.43	36.83	36.56
TiO ₂	5.29	7.39	6.86	6.79	5.64	5.99	6.50	6.49	5.62	5.79
AI_2O_3	9.83	8.72	10.35	10.79	8.60	15.50	9.19	8.71	10.59	9.45
Fe ₂ O ₃ *	1.60	2.49	2.16	1.97	2.12	1.64	2.11	2.00	1.81	1.90
FeO*	12.97	20.18	17.49	15.93	17.16	13.31	17.13	16.17	14.67	15.42
MnO	0.21	0.29	0.24	0.24	0.21	0.17	0.19	0.19	0.24	0.18
MgO	9.48	8.06	8.36	8.77	9.24	7.02	9.92	9.98	8.50	10.93
CaO	16.20	14.67	14.39	14.61	13.66	14.60	15.91	14.81	15.29	14.88
Na ₂ O	1.68	1.33	1.76	1.78	1.39	2.00	1.04	1.36	1.60	1.36
K ₂ O	0.78	0.65	1.07	1.07	0.76	1.10	0.49	0.71	0.89	0.76
P ₂ O ₅	1.09	1.78	2.98	2.69	0.34	2.29	0.35	0.35	0.66	0.18
	1.22	0.74	1.07	0.55	0.50	0.89	0.70	1.50	2.20	1.15
SO ₃	0.50	0.75	1.15	0.95	4.30	0.59	1.21	1.48	0.59	0.84
<u>א</u> ר	0.20	0.30	0.47	0.39	1.72	0.24	0.50	0.62	0.24	0.35
	0.09	0.11	0.19	0.19	0.06	0.17	0.05	0.05	0.08	0.06
	0.08	0.08	0.11	0.12	0.03	0.15	0.03	0.03	0.08	0.04
	0.04	0.03	0.00	0.07	0.03	0.05	0.02	0.02	0.04	0.02
Da	0.01	0.01	0.00	0.00	0.13	0.00	0.03	0.04	0.00	0.02
Cr	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.07
Zr Zr	0.04	0.03	0.00	0.00	0.00	0.02	0.02	0.00	0.04	0.02
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Plagioclase	18.6	18.4	21.0	21.3	2.5	31.9	23.1	20.6	21.0	20.3
Orthoclase	2.4				4.7				5.6	
Nepheline	5.9	3.4	4.0	4.8	20.2	7.1	0.5	1.0	5.2	3.3
Leucite	2.0	3.2	5.3	5.4	0.0	5.4	2.4	3.4	0.0	3.6
Diopside	38.4	22.6	17.2	20.3	0.0	15.5	23.6	32.4	30.1	28.6
Olivine	13.6	23.3	22.7	20.4	31.0	16.8	23.0	18.6	16.5	21.9
Larnite		3.42	1.13	1.74	0.00	0.44	6.27	0.42	0.00	3.01
Na₂SiO₃					12.63					
Ilmenite	10.05	14.04	13.03	12.90	10.71	11.38	12.34	12.33	10.67	11.00
Magnetite	2.32	3.61	3.13	2.86	0.00	2.38	3.06	2.90	2.62	2.75
Apatite	2.62	4.28	7.17	6.47	0.82	5.51	0.84	0.84	1.59	0.43
Zircon	0.06	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.06	0.03
Chromite	0.03	0.01	1.00	0.00	0.12	0.54	1.00	0.01	0.54	0.10
Pyrite	0.42	0.64	1.00	0.83	3.65	0.51	1.06	1.31	0.51	0.74
Fluorite					0.07		0.05	0.05	0.05	0.11
	0.90	1 2 2	2.04	1.60	32.03	1.05	0.15	2.62	1.05	1.40
Na ₂ SO ₄	0.09	1.33	2.04	1.09	0.00	2.02	2.13	2.03	5.00	1.49
	2.11	1.00	2.45	1.25	1.20	2.02	1.55	3.41	5.00	2.02
Total	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.0	99.9	99.9
	100.0	100.0	100.0	100.0	100.0	33.3	100.0	100.0	33.3	33.3
Ma/(Ma+Ee ²⁺)	56.6	41.6	46.0	49.5	49.0	48.5	50.8	52.4	50.8	55.8
Ca/(Ca+Na)	84.2	85.9	81.9	81.9	84.4	80,1	89,4	85.8	84,1	85.8
DI	28.9	25.0	30.3	31.5	27.4	44.4	25.9	25.0	31.8	27.2
Density, g/cc	3.2	3.4	3.3	3.3	3.2	3.2	3.3	3.3	3.2	3.3
Liquidus T., °C	1421	1536	1557	1524	1507	1502	1496	1481	1455	1460

Table 9 (con't)

	MUL-30	MUL-31	MUL-32	MUL-33	MUL-34	MUL-35	MUL-36	MUL-36Rpt.	MUL-37	MUL-38
SiO ₂	36.92	37.59	37.02	39.65	39.57	39.34	34.98	35.40	40.49	51.15
TiO ₂	6.21	5.55	5.89	5.12	4.86	5.04	7.13	7.24	4.52	2.67
Al ₂ O ₃	11.04	9.08	9.26	11.85	9.80	9.52	9.78	9.90	9.41	16.64
Fe ₂ O ₃ *	1.69	1.91	1.95	1.54	1.61	1.62	2.09	2.12	1.78	1.01
FeO*	13.69	15.51	15.80	12.51	13.05	13.09	16.91	17.15	14.43	8.22
MnO	0.19	0.22	0.20	0.24	0.19	0.18	0.23	0.23	0.27	0.20
MgO	9.35	9.68	9.44	8.79	11.95	12.31	9.47	9.69	8.71	2.80
CaO	14.35	15.17	14.56	14.35	13.44	13.60	13.57	13.80	15.68	7.06
Na₂O	2.18	1.55	1.68	2.24	1.70	1.65	1.63	1.65	1.77	4.50
K ₂ O	1.19	0.75	0.99	1.12	1.44	1.17	0.96	1.00	0.80	3.73
P ₂ O ₅	1.06	0.29	0.47	0.45	0.25	0.25	0.45	0.45	0.35	0.60
CO ₂	0.85	1.44	0.89	1.19	0.93	0.82	0.88	0.00	1.04	0.33
SO3	0.66	0.71	1.13	0.42	0.60	0.73	1.16	1.17	0.35	0.27
S	0.27	0.31	0.49	0.17	0.24	0.30	0.48	0.00	0.14	0.10
F	0.15	0.06	0.08	0.11	0.10	0.10	0.10	0.00	0.05	0.08
CI	0.07	0.05	0.05	0.11	0.06	0.07	0.07	0.07	0.07	0.26
Sr	0.04	0.03	0.03	0.06	0.04	0.04	0.04	0.04	0.03	0.31
Ва	0.02	0.01	0.03	0.02	0.04	0.05	0.02	0.02	0.01	0.00
Ni	0.02	0.04	0.02	0.03	0.10	0.10	0.02	0.02	0.04	0.01
Cr	0.03	0.03	0.03	0.04	0.03	0.02	0.03	0.03	0.05	0.05
Zr	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.04	0.04
lotal	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	40.0	10.0	40.0	00.0	10.0	47.5	00.4		10.5	00.0
Plagioclase	19.0	18.0	18.6	20.2	16.8	17.5	20.4	20.6	16.5	39.3
Orthoclase	77	4.0	0.7	6.8	1.4	1.4	0.4	0.4	3.4	24.3
Nepheline	1.1	4.6	3.7	8.8	5.7	5.0	3.4	3.4	6.9	6.0
Leucile	5.7 20.2	3.7	4.8	22.0	5.8 22.0	4.5	4.7	4.9	1.2	12.0
Olivino	30.2	30.7	34.Z	32.0	33.9 20.1	34.3	20.9	23.2	43.2	13.0
Unvine	0.91	0.44	0.05	14.0	20.1	20.3	20.1	5.21	13.4	1.0
	0.01	0.44	0.95				1.05	J.Z I		
Ilmenite	11 70	10.54	11 10	9.72	0.23	9.57	13.54	13 75	8 58	5.07
Magnetite	2 4 5	2 77	2.83	2.23	2 33	2 35	3.03	3.07	2.58	1.46
Anatite	2.40	0.70	1 13	1.08	0.60	0.60	1.08	1.04	0.84	1.40
Zircon	0.04	0.04	0.04	0.06	0.00	0.00	0.04	0.04	0.07	0.07
Chromite	0.03	0.06	0.03	0.04	0.15	0.15	0.03	0.03	0.06	0.01
Pvrite	0.57	0.66	1.04	0.36	0.51	0.64	1.02	0.00	0.30	0.21
Fluorite	0.14	0.08	0.09	0.17	0.19	0.19	0.15	0.00	0.05	0.07
Anhydrite										
Na₂SO₄	1.17	1.26	2.00	0.75	1.06	1.30	2.06	2.08	0.62	0.48
Calcite	1.93	3.27	2.02	2.71	2.12	1.86	2.00	0.00	2.37	0.75
Na ₂ CO ₃										
Total	99.9	100.0	100.0	99.9	100.0	100.0	100.0	99.9	100.0	99.9
Mg/(Mg+Fe ²⁺)	54.9	52.7	51.6	55.6	62.0	62.6	50.0	50.2	51.8	37.8
Ca/(Ca+Na)	78.4	84.4	82.7	78.0	81.4	82.0	82.1	82.2	83.0	46.4
DI	32.4	26.2	27.1	36.0	29.7	28.4	28.5	28.8	28.0	69.6
Density, g/cc	3.2	3.3	3.3	3.2	3.2	3.2	3.3	3.3	3.2	2.9
Liquidus T., °C	1453	1441	1451	1403	1405	1409	1489	1481	1388	1192



Table 9 (con't)

	MUL-39	MUL-40	MUL-41	MUL-42	MUL-43	MUL-44	MUL-45	MUL-46	MUL-47	MUL-48
SiO ₂	39.04	55.06	41.13	34.78	46.01	45.24	44.28	47.80	49.39	51.22
TiO ₂	5.47	1.59	4.69	6.69	3.68	3.80	3.99	3.08	2.73	2.61
AI_2O_3	10.49	17.01	10.75	10.14	16.07	16.18	15.43	17.00	18.10	17.22
Fe ₂ O ₃ *	1.41	0.83	1.35	1.91	1.23	1.25	1.33	1.16	0.98	1.02
FeO*	11.43	6.73	10.93	15.45	9.98	10.14	10.79	9.40	7.92	8.23
MnO	0.15	0.12	0.16	0.20	0.19	0.21	0.20	0.20	0.17	0.20
MgO	12.20	2.66	11.63	10.11	4.48	5.05	5.42	3.86	3.40	2.37
CaO	14.28	4.96	13.89	14.06	8.47	9.05	9.43	7.45	7.46	6.82
Na ₂ O	1.61	4.49	1.88	1.58	4.05	4.01	3.92	4.46	5.09	4.57
K ₂ O	1.10	5.15	1.33	1.02	2.94	2.52	2.29	3.11	2.51	3.66
P_2O_5	0.14	0.14	0.15	1.02	1.17	0.97	1.04	1.19	1.06	0.69
	1.44	0.62	1.07	1.15	0.59	0.52	0.52	0.41	0.30	0.33
30 ₃	0.01	0.16	0.45	1.12	0.45	0.44	0.00	0.27	0.20	0.25
о Е	0.24	0.08	0.10	0.40	0.17	0.17	0.25	0.10	0.11	0.09
	0.11	0.03	0.10	0.13	0.14	0.15	0.13	0.13	0.12	0.08
0 Gr	0.07	0.12	0.00	0.00	0.17	0.13	0.10	0.10	0.22	0.20
Ba	0.03	0.10	0.00	0.00	0.14	0.11	0.10	0.10	0.10	0.00
Ni	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.00	0.00
Cr	0.02	0.07	0.02	0.03	0.05	0.05	0.05	0.05	0.04	0.05
Zr	0.01	0.05	0.02	0.02	0.04	0.03	0.03	0.04	0.03	0.04
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Plagioclase	20.1	42.1	18.3	21.3	37.8	37.2	36.2	41.1	49.3	42.7
Orthoclase	3.0	31.7	7.9	0.0	18.4	15.7	14.3	19.5	15.8	23.8
Nepheline	5.2	3.2	7.0	3.3	6.3	7.4	6.7	6.7	6.3	5.3
Leucite			0.3	5.0						
Diopside	32.3	7.5	34.1	25.3	10.6	12.8	14.1	7.8	7.5	10.5
Olivine	18.3	8.9	17.1	20.4	12.6	13.0	13.6	12.7	10.4	8.0
Larnite				1.06						
Na₂SiO₃										
Ilmenite	10.39	3.02	8.91	12.71	6.99	7.22	7.58	5.85	5.18	4.96
Magnetite	2.04	1.20	1.96	2.77	1.78	1.81	1.93	1.68	1.42	1.48
Apatite	0.34	0.34	0.36	2.45	2.82	2.33	2.50	2.86	2.55	1.66
Zircon	0.03	0.10	0.03	0.04	0.07	0.07	0.07	0.07	0.06	0.07
Chromite	0.15	0.01	0.15	0.03	0.00	0.01	0.01	0.01	0.00	0.10
Pyrile	0.51	0.13	0.38	0.98	0.36	0.30	0.53	0.21	0.23	0.19
Anhydrita	0.24	0.04	0.21	0.10	0.09	0.11	0.09	0.06	0.06	0.05
	1.08	0.28	0.80	1 00	0.80	0.78	1 17	0.48	0.46	0.44
Calcite	3.27	1 41	2.43	2.62	1 34	1 18	1.17	0.40	0.40	0.44
NacCO	0.21	1.41	2.40	2.02	1.54	1.10	1.10	0.00	0.00	0.75
Total	100.0	99.9	100.0	100.0	99.9	99.9	99.9	99.9	99.9	99.9
		00.0	100.0	100.0	00.0	00.0	00.0	00.0	00.0	00.0
Mg/(Mg+Fe ²⁺)	65.5	41.3	65.5	53.8	44.5	47.0	47.2	42.3	43.4	33.9
Ca/(Ca+Na)	83.1	37.9	80.3	83.1	53.6	55.5	57.1	48.0	44.7	45.2
DI	31.4	77.0	33.5	29.6	62.4	60.3	57.1	67.4	71.4	71.8
Density, g/cc	3.2	2.8	3.2	3.3	3.0	3.0	3.0	2.9	2.9	2.9
Liquidus T., °C	1414	1121	1376	1493	1286	1301	1318	1254	1225	1191

	LM-1	LM-2	LM-3	LM-4	LM-5	LM-6	LM-7	LM-8	LM-9	LM-10	LM-11	LM-12	LM-13
SiO ₂	36.33	38.25	29.94	32.60	28.89	28.14	33.10	36.24	32.59	34.44	29.14	33.32	32.66
TiO ₂	6.32	3.97	10.00	8.93	9.34	7.55	7.25	4.57	6.67	6.48	9.19	7.12	7.22
Al ₂ O ₃	6.10	11.19	5.70	6.12	5.84	5.14	6.61	7.98	6.92	15.67	6.31	7.17	15.31
Fe ₂ O ₃ *	1.70	1.30	2.34	2.11	2.22	2.04	2.00	1.73	1.87	1.53	1.93	1.92	1.56
FeO*	13.80	10.54	18.96	17.11	17.99	16.52	16.19	13.99	15.17	12.39	15.62	15.56	12.61
MnO	0.16	0.19	0.20	0.19	0.20	0.17	0.21	0.26	0.22	0.21	0.26	0.23	0.18
MaO	10.70	8.75	9.58	10.49	9.40	9.04	10.05	14.65	10.02	6.17	9.50	10.11	6.34
CaO	18.11	13.05	16.33	16.92	17.91	16.78	18.64	11.08	18.12	17.26	17.55	17.96	17.19
Na ₂ O	0.74	2.36	0.54	0.45	0.46	1.66	0.45	1.52	0.64	0.85	0.72	0.41	0.72
K ₂ O	0.20	3.02	0.17	0.11	0.23	0.14	0.05	1.88	0.09	0.21	0.25	0.05	0.12
P_2O_5	0.87	1.59	1.60	0.80	2.87	2.34	1.48	2.04	1.06	1.58	2.95	0.71	1.48
CO ₂	3.50	4.45	2.34	2.07	2.52	7.41	2.26	2.87	4.78	1.65	4.59	3.63	3.59
SO3	0.89	0.56	1.43	1.37	1.35	2.01	1.07	0.65	1.20	0.86	1.20	1.16	0.54
S	0.38	0.23	0.71	0.58	0.56	0.85	0.45	0.25	0.50	0.35	0.50	0.49	0.22
F	0.05	0.16	0.08	0.05	0.13	0.13	0.06	0.00	0.06	0.07	0.15	0.04	0.06
Sr	0.03	0.13	0.03	0.02	0.04	0.03	0.03	0.10	0.03	0.24	0.07	0.03	0.16
Ва	0.01	0.17	0.01	0.00	0.01	0.01	0.00	0.07	0.00	0.01	0.02	0.00	0.00
Ni	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.04	0.02	0.00	0.02	0.02	0.00
Cr	0.06	0.05	0.00	0.03	0.01	0.00	0.05	0.05	0.03	0.01	0.02	0.04	0.00
Zr	0.02	0.04	0.03	0.02	0.03	0.02	0.03	0.05	0.02	0.02	0.03	0.03	0.02
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Plagioclase	16.22	19.02	1.63	2.67	0.31	13.99	1.97	18.04	8.29	42.48	8.92	5.84	42.62
Orthoclase	1.25	19.08	1.08	0.65	1.43	0.90	0.30	11.62	0.53	1.31	1.62	0.30	0.71
Nepheline	0.00	5.22	14.45	15.28	15.37	0.00	17.20	1.07	14.52	0.19	11.92	16.66	0.00
Leucite													
Diopside	37.48	11.43				6.60		9.99	0.00	19.81			10.82
Hypersthene	8.86					31.56							6.82
Olivine	9.15	20.21	30.04	30.54	29.41	1.82	30.82	34.99	30.02	11.77	26.61	30.18	9.85
Larnite													
Acmite			6.77	6.10	6.42		5.79		5.41		5.58	5.55	
Na ₂ SiO ₃	10.00		15.01	18.82	14.29		19.98		13.01	10.01	8.01	16.08	10 -1
Ilmenite	12.00	1.54	18.99	16.96	17.74	14.34	13.77	8.68	12.67	12.31	17.45	13.52	13./1
Magnetite	2.46	1.88				2.96		2.51		2.22			2.26
Apotito	2.00	2 02	2.95	1 0 2	6.01	5.62	2.56	4 72	2.55	2 90	7 10	1 71	2 56
Ziroon	2.09	0.06	0.04	0.02	0.91	0.03	0.04	4.73	2.00	0.02	0.04	0.04	0.02
Chromito	0.03	0.00	0.04	0.03	0.04	0.03	0.04	0.07	0.03	0.03	0.04	0.04	0.03
Shhana	0.03	0.07		0.04	0.01		0.07	0.07	0.04	0.01	0.03	0.00	0.00
Dyrito	0.81	0 / 9	1 51	1 23	1 10	1.80	0.95	0.53	1.06	0.74	1.06	1.04	0.47
Fluorite	0.01	0.43	1.01	1.20	1.15	1.00	0.35	0.00	1.00	0.74	1.00	1.04	0.47
Anhydrite	0.00	0.00	34 57	38 54	34.36	0.00	40.56	0.00	40 64	0.00	33 27	41.37	
NasSO	1.58	0.00	01.07	00.01	01.00	3 57	10.00	1 15	10.01	1 53	00.21	11.07	0.96
Calcite	7.96	10.12			0.00	16.85		6.53		3 75			8 16
NacCO	7.00	10.12	5 64	4 99	6.07	10.00	5 44	0.00	11.51	0.10	11.05	8 74	0.10
Total	100.0	100.0	100 1	100.0	100 1	100 1	100.0	100.0	100.0	100.0	100 1	100.0	100.0
Total	100.0	100.0	100.1	100.0	100.1	100.1	100.0	100.0	100.0	100.0	100.1	100.0	100.0
Ma/(Ma+Fe ²⁺)	58.0	59.7	47.4	52.2	48.2	49.4	52.5	65.1	54.1	47.0	52.0	53.7	47.3
Ca/(Ca+Na)	93.1	75.3	94.4	95.4	95.6	84.8	95.8	80.1	94.0	91.8	93.1	96.0	93.0
DI	17.5	43.3	17.2	18.6	17.1	14.9	19.5	30.7	23.3	44.0	22.5	22.8	43.3
Density, a/cc	3.3	3.0	3.3	3.3	3.3	3.3	3.2	3.2	3.2	3.2	3.3	3.2	3.2
Liquidus T., °C	1464	1429	1581	1532	1600	1614	1523	1466	1533	1499	1596	1519	1531

Table 10: Major element chemistry and CIPW normative mineralogy of Lake Machattie intrusion



Table 10 (con't)

	LM-14	LM-15	LM-15Rpt	LM-16	LM-17	LM-18	LM-19	LM-20	LM-21	LM-22	LM-23	LM-24
SiO ₂	41.15	32.86	34.05	24.38	28.42	38.34	32.80	27.75	33.04	35.09	30.29	36.12
TiO ₂	3.38	6.46	6.72	7.46	3.13	5.16	5.69	4.63	4.84	6.33	7.31	5.07
Al ₂ O ₃	9.57	14.54	15.12	8.69	7.89	8.03	6.45	5.18	6.40	6.76	6.06	5.32
Fe ₂ O ₃ *	1.44	1.59	1.65	14.62	10.98	1.43	1.73	16.35	15.86	1.96	2.29	2.05
FeO*	11.67	12.85	13.36	0.00	0.00	11.60	14.01	0.00	0.00	15.86	18.51	16.60
MnO	0.19	0.16	0.18	0.41	0.45	0.14	0.20	0.39	0.20	0.16	0.19	0.20
MgO	15.51	6.67	6.94	6.11	6.93	10.90	10.02	8.41	10.26	11.03	10.21	16.85
CaO	8.84	15.83	16.43	16.23	15.05	20.06	19.72	17.13	18.52	18.09	16.86	14.14
Na ₂ O	2.34	1.29	1.34	2.83	4.34	0.55	0.78	3.38	1.50	0.59	0.82	0.32
K ₂ O	1.79	1.40	1.46	0.06	0.21	0.17	0.04	0.30	0.52	0.08	0.23	0.03
P_2O_5	1.02	1.55	1.62	1.46	0.31	0.65	2.13	0.70	1.12	0.37	1.09	0.08
CO ₂	2.06	3.34	0.00	17.47	22.21	1.84	4.42	15.31	6.57	2.52	4.15	1.89
SO₃	0.46	0.69	0.70	0.17	0.05	0.61	1.25	0.28	0.66	0.72	1.28	0.78
S	0.18	0.28	0.00	0.07	0.02	0.25	0.53	0.12	0.30	0.29	0.54	0.32
F	0.10	0.08	0.00	0.05	0.02	0.04	0.09	0.06	0.10	0.03	0.06	0.03
Sr	0.08	0.10	0.10	0.11	0.09	0.03	0.04	0.01	0.04	0.02	0.03	0.01
Ва	0.07	0.29	0.30	0.01	0.01	0.03	0.00	0.01	0.01	0.01	0.01	0.00
Ni	0.05	0.00	0.00	0.00	0.01	0.01	0.03	0.04	0.01	0.02	0.02	0.04
Cr	0.06	0.01	0.01	0.01	0.01	0.13	0.06	0.01	0.04	0.06	0.02	0.13
Zr	0.03	0.02	0.02	0.01	0.00	0.02	0.02	0.00	0.02	0.02	0.02	0.02
Total	100.0	100.0	100.0	100.1	100.1	100.0	100.0	100.1	100.0	100.0	100.0	100.0
									10.00	10.00		4.00
Plagioclase	24.88	31.09	32.27			20.95	8.61		19.82	18.03	0.43	1.93
Orthoclase	11.09	2.67					0.24		3.15	0.00	1.43	0.18
Nepheline	1.94	3.46	3.66			0.36	13.19			0.15	15.92	13.69
Leucite	40.47	6.04	8.47			44 54			44.54	0.43		
Diopside	10.17	13.46	6.30			41.51			11.54	34.63		
Hyperstnene	04.00	45.50	10.11			40.00	00.55		14.04	10.00	04.40	40.00
Ulivine	34.89	15.59	19.41			13.28	29.55		4.30	19.90	34.18	40.23
Lamite			9.04			3.40	5.01			3.37	6.62	5.02
Acmile No2SiO2							15.01				12.07	16 70
Ilmonito	6.42	12 27	12.76			0.80	10.24			12.02	13.07	0.63
Magnotito	2.00	2 31	2 30			2.07	10.01			2.02	15.00	9.05
Hematite	2.03	2.51	2.55			2.07			15.86	2.04		
Anatite	2.45	3 73	3 75			1 56	5 13		2.69	0.89	2.62	0.19
Zircon	0.04	0.03	0.03			0.03	0.03		0.03	0.03	0.03	0.10
Chromite	0.09	0.00	0.00			0.00	0.00		0.00	0.00	0.00	0.00
Sphene	0.00	0.01	0.01			55	0.00		11.88	0.00	0.00	0.10
Pvrite	0.38	0.59	0.00			0.53	1.12		0.64	0.61	1.15	0.68
Fluorite	0.02											0.06
Anhvdrite							41.12					
Na2SO4	0.82	1.22	1.24			1.08	· · · ·		1.17	1.28		
Calcite	4.68	7.60	0.00			4.18			14.94	5.73		
Na2CO3						0.00	10.64				9.99	4.55
Total	100.0	100.1	100.0			100.0	100.1		100.1	100.0	100.0	100.0
Mg/(Mg+Fe ²⁺)	70.3	48.1	48.1			62.6	56.0		56.2	55.4	49.6	64.4
Ca/(Ca+Na)	67.6	87.1	87.1			95.3	93.3		56.3	94.4	91.9	96.1
DI	37.9	43.3	44.4			22.3	22.0		23.0	18.6	17.8	15.8
Density, g/cc	3.1	3.1	3.2			3.3	3.2		3.2	3.4	3.3	3.3
Liquidus T., °C	1376	1528	1506			1427	1529		1524	1487	1575	1468



Figure 4: SiO_2 versus oxides. The trend towards high SiO_2 reflects crystal-liquid fractionation in Mulligan Intrusion. By contrast, geochemical variations in Lake Machattie Intrusion are interpreted to be the result of separation of an immiscible carbonate-rich liquid.



Figure 5: Covariation between (a) MgO versus TiO_2 showing that Mulligan and Lake Machattie exhibit divergent fractionation trends with Lake Machattie intrusion trending to extreme TiO_2 contents at ~ 10 wt.% MgO. Image (b) also shows that covariation between CO_2 and total alkalis is different between the two intrusions. Lake Machattie samples have significantly higher CO_2 contents ranging to ~ 28 wt. % and maximum total alkalis of ~ 6 wt. %. By contrast, samples from Mulligan intrusion are significantly less enriched in both alkalis and CO_2 . The negative correlation between CO_2 and total alkalis similar to that reported in Brava Island carbonatites where it is interpreted to reflect precipitation of secondary carbonate accompanied by fluid induced loss of Na (Weidendorfer et al., 2010).

Classification of Alkaline Silicate Lithologies

In the total alkali–silica diagram (TAS) diagram (Fig. 6) of LeMaitre et al., 1989) lithologies from Mulligan Intrusion define a continuous trend of highly silica undersaturated compositions belonging to the melteigite-ijolite-urtite series (foid-bearing gabbros, diorites, monzonites and syenites). Fractionation extends from alkali pyroxenite (turjaites), though alkali gabbro and melteigite to ijolite and nepheline syenite, with SiO₂ ranging from ~30 to 62 wt.%. By contrast, lithologies from the Lake Machattie intrusion define a separate, but overlapping field with SiO₂ extending from ~40 wt% in phoscorites and alkali pyroxenites to 11wt.%. in silicio carbonatites.

The Diamantina Intrusions (Mulligan and Lake Machattie) have identical magmatic trends to lithogeochemical trends reported from Khibina, Lovozer, Kovdor, Afriknda, Lesnaya Varka, Vuoriyarvi and Turiy Massif alkaline intrusions on the Kola Peninsula (Dunworth and Bell 2001, Downes et al., 2005; Brassinnes et al., 2005; Zaistsev et al., 2015). They are also similar to geochemical variations reported in Catalão, Tapira and Salitre intrusions in Brasil (Cordeiro *et al.*, 2010; Barbosa *et al.*, 2012; Brod *et al.*, 2013) and in ocean island alkaline suites e.g., Cape Verde (Holm et al., 2006; Weidendorfer et al., 2016).



Figure 6: Total alkali versus silica plot showing the rare and extreme lithological variability in Mulligan and Lake Machattie Intrusions

Carbonatite Classification and Identification of Ferrocarbonatite

To explore the petrological affinity of the silicio carbonatites and to confirm the classification of the carbonatites major element data were assessed according to recommendations of Wooley and Kempe (1989). The CO₂-rich samples from Lake Machattie intrusion (Table 10 and Appendix 2) have CaO/(CaO+MgO+FeO*+MnO) significantly less than 0.8, confirming that they are not calciocarbonatites. With MgO<(FeO*+MnO), they are classified as silicio ferrocarbonatite, (Fig. 7).

The presence of ferrocarbonatite in the Diamantina alkaline suite is economically important, because ferrocarbonatites are reported to host and be responsible for much of the economic wealth associate with this style of magmatism (Le Bas 1987).



Figure 7: Ternary carbonatite classification diagram showing that LM-16, LM-17 and LM-20 are silicioferrocarbonatites. The blue points are Lake Machattie carbonatites that were analyses by AusQuest (data given in Appendix 2). Endmember calciocarbonatites, magnesiocarbonatites and ferrocarbonatites (Woolley and Kempe, 1989) are shown for comparison.

Ferrocarbonatites typically occur as later veins and replacement bodies within calciocarbonatite and magnesiocarbonate. They form late during fractionation, when immiscible carbonatite melt exsolves volatile-rich (CO₂ and F bearing) carbothermal mineralizing fluids. According to Le Bas (1987) this mineralization process occurs in several stages. The first stage involves REE mineralization. This is followed by fluorite deposition, deposition of barites and finally U-Th mineralization.

CIPW Normative Mineralogy

CIPW normative mineralogy of Mulligan and Lake Machattie Intrusion calculated with the Norm4 Speadsheet program (Kurt Hollocher- Union College, Written Communication 2016) are given in Table 9 and 10. The absence of normative quartz confirms the silica undersaturated nature of the intrusions. Normative nepheline ranges from 1 to 17.6 %. A small number of samples contain normative leucite (0.15 to 4.17 %) and the sample with the highest content of normative nepheline also contains kalsilite (1.75%).

Lake Machattie Intrusion is significantly more silica undersaturated than Mulligan with a high proportion of analysed samples (n=8/18) containing significant amounts of normative nepheline 14.4 to 19.5 %. Small quantities of other normative feldspathoid minerals e.g., leucite (0.4 and 0.9 %) and kalsilite 0.1 to 0.78 %) area also present in some samples.

Liquidus Temperatures of Mulligan and Lake Machattie Intrusions

Mulligan Intrusion and Lake Machattie intrusions have average SiO₂ contents and #mg numbers of 35.1 ± 2.33 wt.%; mg# = 0.55 ± 0.08 (n=27), and 34.2 ± 2.7 wt.%; mg# = 0.6 ± 0.06 (n=18) respectively, showing that both intrusions formed by crystallisation of extremely high-temperature Fe-rich magmas. The mean liquidus temperature of each intrusion was calculated from the following expression, T= (-18.33*(SiO₂)*(100/SUM))+2130°C which was developed from the relationship between liquid density and viscosity (Kurt Hollocher- Union College, Written Communication 2016).

Mulligan and Lake Machattie intrusions yield mean liquidus temperatures of 1485±48°C and 1500±53°C respectively. These high temperatures support the interpretation that the Diamantina Intrusions are of plume origin. This interpretation is also supported by the excellent agreement with temperatures calculated using the Al-in-Olivine Thermometer of Coogan *et al.*, (2014) for the Iceland Plume, 1454±47 °C (Spice *et al.*, 2016) based on data from Skye, Mull, Rum, Baffin Island, Disko Island and from Iceland, where it is still active. By contrast, the mean temperature of upper mantle-derived MORB magma ~200°C lower at 1193°C (Coogan *et al.*, 2014).

Temperatures calculated using olivine-liquid equilibria and olivine phenocrysts from Hawaii, Iceland and mid-ocean ridges (MORs) support even higher melting temperatures (mantle potential temperatures). For example, Hawaii 1688°C, Iceland 1637°C and MORs 1453-1475°C (Putirka, 2005).

Trace Elements

Trace element compositions, together with key elemental ratios of geochemical significance for samples from Mulligan and Lake Machattie intrusions are given in Tables 11 and 12, and in Appendix Tables A3 and A4. Variation in transition metal abundances with SiO₂ are shown in Figure 8. The highest transition metal abundances occur in lithologies with SiO₂ between 30 and 40 wt. %. Mulligan intrusion has the highest concentrations of Cr ~ 1300 ppm, V ~ 850 ppm, Ni ~ 1400 ppm, Sc ~ 68 ppm and Cu ~1100 ppm. However the highest Co values occur in samples from Lake Machattie intrusion ~540 ppm. The highest concentrations of transition metals occurs in cumulates from Mulligan cumulates with compositions close to those of the parental magma. In Lake Machattie intrusion the highest concentrations are seen in samples containing the smallest amount of immisible carbonate.

Variation in transition metal abundances of (a) Au, (b) Pd and Pt, (c) Zn, (d) Zr, (e) Nb and (f) REEY with SiO₂ are shown in Figure 9. Both Lake Machattie and Mulligan intrusons are enriched in Au and PGEs, with maximum values of ~11 ppb Au in both intrusions (Fig. 9a) and 33 ppb and 15 ppb Pd and Pt in Mulligan and Lake Machattie respectively (Fig. 9b) with SiO₂. These maximimum occur in lithologies from both intrusions with SiO₂ between 30 and 40 wt%. This reflects the high background levels of precious metals in these plume magmas.

Figure 9c shows that Zn, another transition metal, is significantly enriched in alkaline magmas reaching maximum values of ~450 ppm in Mulligan intrusion and 300 ppm in Lake Machattie Intrusion. In addition, Zn shows similar covariation to the transition metals discussed above in Figure 8. In addition, some Lake Machattie samples with SiO₂ concentrations of ~30 wt. % appear to continue the fraction vector defined by the Mulligan Intrusion to even lower SiO₂ contents.

High field strength element (HFSE) variation for Nb and REEs + Y are shown in Figs. 9e and 9f. Data for Mulligan Intrusion shows Nb-SiO₂ fractionation into two groups, one with SiO₂ between ~30 and 50 wt. % and a separate groups with SiO₂ between ~55 and 62 wt.%. Some of the highest Nb values (up to 500 ppm) are recorded in pyrochlore-bearing silicio carbonatites from the Lake Machattie Intrusion. Figure 9f shows REEs + Y versus SiO₂. This show that REEs + Y in Mulligan also defines two groups like that shown for Nb, one with SiO₂ between ~30 and 50 wt. % and a separate groups with SiO₂ between ~55 and 62 wt.%. EEs + Y versus SiO₂. This show that REEs + Y in Mulligan also defines two groups like that shown for Nb, one with SiO₂ between ~30 and 50 wt. % and a separate groups with SiO₂ between ~55 and 62 wt.%. Lake Machattie samples show a well defined fractioantion trend with the highest REEs+ Y (up to ~3000ppm) occurring in silicio- ferrocarbonatite compositions.

Figure 10a shows that samples from Mulligan and Lake Machattie intrusions display a steeply positive correlation between Cr and MgO with maximum Cr values of ~1350 ppm in Mulligan and 800 ppm in Lake Machattie Intrusion at ~16 wt. % MgO. This is most

	MUL-1	MUL-2	MUL-3	MUL-4	MUL-5	MUL-6	MUL-7	MUL-8	MUL-9
Li	3.3	5.7	4.5	2.3	5.1	6.0	6.6	4.1	4.1
Be	0.7	1.3	1.5	1.2	1.6	1.7	1.5	2.4	2.1
F	330			151	1043	1000		894	859
Sc	59	35	29	15	39	11	29	9	9
V	755	309	297	206	475	173	313	133	102
Cr	223	673	575	88	233	30	470	31	56
Со	81	63	62	23	56	28	62	25	17
Ni	169	246	231	52	65	14	238	9	27
Cu	190	47	28	53	71	33	47	27	10
Zn	147	102	106	50	127	108	122	105	90
Ga	23	20	21	26	22	21	18	22	22
Rb	11	56	48	122	21	114	89	92	61
Sr	202	519	609	325	657	1624	460	1698	2194
Y	19	24	27	6	31	37	28	36	21
Zr	154	244	263	179	275	276	274	329	162
Nb	20	54	65	13	55	130	66	125	60
Мо	1.7	3.0	3.6	2.1	6.3	2.4	4.9	1.8	1.9
Ag	0.07	0.04	0.04	0.05	0.04	0.07	0.06	0.06	0.04
Sn	3.9	2.7	3.2	1.0	3.2	4.0	3.7	3.8	2.1
Sb	0.1	0.1	0.1	0.1	0.1		0.1		0.1
Cs	0.2	0.9	0.7	0.5	0.3	1.0	1.0	0.8	0.6
Ва	123	485	467	281	404	1272	563	2146	1509
La	13	34	43	12	37	94	42	109	69
Ce	34	74	92	18	87	175	90	189	112
Pr	5.13	10.07	11.98	2.07	12.52	20.87	11.92	20.87	12.62
Nd	21.73	39.97	45.42	7.57	50.31	71.10	47.91	65.22	44.87
Sm	5.06	7.48	8.24	1.47	9.78	11.36	7.90	10.13	6.99
Eu	2.24	2.41	2.70	0.99	3.17	4.03	2.07	3.05	2.03
Gu Th	9.60	1 02	12.09	3.03 0.22	14.23	17.32	1 .07	10.01	0.79
	4 66	5.42	5.77	1 24	6.41	7.63	5.67	7 33	4 29
Ho	0.83	0.85	1.00	0.28	1 24	1 39	1 07	1 42	0.80
Er	2.10	2.95	2.94	0.76	3.54	3.79	2.74	3.80	2.14
Tm	0.28	0.32	0.35	0.12	0.47	0.57	0.43	0.42	0.32
Yb	1.57	1.73	1.96	0.94	2.34	3.25	2.14	3.45	1.95
Lu	0.30	0.26	0.26	0.10	0.37	0.38	0.33	0.41	0.28
Hf	6.19	6.55	6.56	4.64	8.31	6.74	6.90	8.05	3.79
Та	1.13	3.38	3.87	0.95	3.52	6.66	4.02	5.40	2.70
W	0.92	1.35	1.16	0.96	2.26	0.63	1.46	0.56	0.62
Re	0.001		0.001		0.002	0.002	0.001		
Au ppb	4.00			5.00		1.00			3.00
TI	0.03	0.12	0.08	0.12	0.04	0.13	0.12	0.11	0.07
Pb	2.00	2.68	2.97	9.86	2.97	4.93	2.29	6.78	6.32
Bi	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.01
Th	1.42	4.77	5.06	5.64	3.69	8.27	5.38	10.25	5.55
U	0.33	1.04	1.34	1.72	1.33	1.71	1.21	1.86	0.98
Y/Ho	23.4	27.7	27.4	22.8	24.8	26.5	25.9	25.4	26.2
Zr/Ht	24.9	37.2	40.1	38.6	33.1	40.9	39.7	40.9	42.9
Nb/Ta	17.4	16.0	16.8	13.9	15.7	19.6	16.3	23.3	22.4
	13.9	11.3 EQ 4	12.9	2.3	15.0	15.8	12.2	12.2	10.9
	0U. I	52.1 40.2	40.0 56.2	1.0	41.0	10.3	04.4 45.0	01.0 222 F	02.0
Ni/Sc	21.0 2.8	40.2 7 1	20.3 7 0	13.7	24.4 1 7	200.3 1 /	40.U g 1	222.3	<u>७</u> /.। २ 1
La/Yh	2.0 Q Q	10.2	21.0	12.2	1.7	28.0	10.1	31.7	25 /
Total REF	114.5	200.8	236.8	72.1	237.5	416.1	234.6	437.6	280.5
	111.5	200.0	200.0	· · ·	201.0	110.1	201.0	101.5	200.0

Table 11: Trace element data for selected lithologies from Mulligan Intrusion



	MUL_10	MLIL_11	MLIL_12	MUL_13	MLII _1/	MUL_15	MUL_16	MUL_17	MLII _18	MLII _19
Li	MOL-10 3.0	2.8	6.8	62	3.2	MOL-15	3.4	MOL-17	3.5	2.8
Ro	1.5	6.7	1.6	1.4	0.7	1.0	1 1	1.0	0.8	0.8
E	1888	244	1011	1453	550	1207	0/1	634	1820	2400
90	21	244	22	24	42	30	42	46	28	2400
V	317	2 /8	315	3/0	705	309	42	40	1/1	301
v Cr	J17	25	37	22	641	224	664	260	108	35
	50	25	56	53	170	52	76	63	61	50
Ni	18	8	23	17	1206	140	407	110	70	29
	30	7	50	34	1070	66	282	58	87	63
Zn	150	85	164	1/0	202	124	132	121	128	11/
	22	26	24	23	252	20	192	22	120	10
Dh	32	207	50	33	13	20	10	13	7	15
Sr.	1000	420	1004	976	346	713	671	13	787	1011
5i V	58	423	55	370 47	22	34	30	27	107	53
1 7r	288	21	282	310	160	205	237	27	202	185
Nh	101	166	111	02	32	295	57	40	57	71
Mo	101	5.8	27	24	1 1	23	1.0	1.6	0.6	0.7
Δα	0.09	0.12	0.09	0.06	0.21	0.08	0.07	0.04	0.07	0.05
Ay Sn	2.0	3.0	3.1	2.00	2.7	3.0	2.6	3.5	1.8	2.3
Sh	2.0	0.0	0.1	0.1	2.1	0.0	2.0	0.0	1.0	2.0
	0.3	1.8	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.0
Ba	926	230	793	630	199	476	440	264	374	509
la	125	59	94	73	22	54	36	28	78	90
Ce	257	91	209	167	55	121	85	68	182	209
Pr	33.43	8.31	27.80	22.40	7 98	15 79	11 84	10.16	26.23	29.64
Nd	120.93	23.18	107.03	91.04	33.44	59 71	49.81	37.96	105.87	115.48
Sm	21 10	3 43	18 84	16.34	7.06	12 81	9.32	9 44	18 46	21.35
Fu	6.72	0.97	6.33	4 72	2.30	3.84	3.07	2.90	5 75	6.60
Gd	28.63	4 83	26.84	21.12	10.30	17 12	14.04	12.80	25.17	28.85
Tb	2.44	0.52	2.28	1.97	0.96	1.58	1.35	1.16	2.25	2.57
Dv	12.83	3.02	11.87	9.96	4 97	7 89	6.61	5 50	10.80	12 31
Ho	2.14	0.73	2.06	1.99	0.91	1.32	1.15	1.01	2.00	2.05
Er	5.69	2.67	5.34	4.83	2.34	3.95	2.78	2.67	4.81	5.70
Tm	0.71	0.55	0.70	0.62	0.31	0.49	0.40	0.37	0.61	0.61
Yb	3.90	4.18	3.52	3.26	1.86	2.64	2.43	2.23	3.18	3.56
Lu	0.58	0.76	0.64	0.50	0.23	0.44	0.34	0.32	0.46	0.42
Hf	8.30	33.62	7.52	7.89	5.79	8.88	7.08	7.45	6.98	6.36
Та	5.27	10.00	6.11	5.40	2.29	4.24	3.71	2.80	3.80	4.12
W	0.65	2.21	1.21	1.40	0.55	0.71	0.61	0.88	0.60	0.36
Re	0.002	0.001	0.001	0.001	0.005	0.001	0.001	0.000	0.001	0.001
Au ppb	1.00		3.00	1.00	7.00		1.00	4.00	4.00	3.00
TI	0.04	0.19	0.10	0.04	0.02	0.04	0.02	0.02	0.01	0.01
Pb	3.03	22.27	2.91	2.99	1.26	2.33	1.53	1.50	0.82	0.91
Bi	0.01	0.05	0.03	0.02	0.03	0.02	0.02	0.01	0.01	0.01
Th	6.49	43.79	4.64	5.95	1.37	4.65	1.66	3.24	2.48	2.68
U	1.46	11.28	1.16	1.37	0.30	1.18	0.46	0.73	0.58	0.54
Y/Ho	26.9	29.0	26.9	23.6	24.2	25.7	25.7	26.7	24.2	25.6
Zr/Hf	34.7	66.2	37.4	39.3	29.1	33.2	33.5	30.4	28.9	29.2
Nb/Ta	19.2	16.6	18.1	16.9	14.1	17.7	15.5	14.2	14.9	17.2
Nb/Th	15.6	3.8	23.9	15.4	23.6	16.2	34.6	12.3	22.9	26.4
Nb/U	69.4	14.7	95.6	66.8	108.2	63.7	124.7	54.3	97.4	130.7
Nb/W	155.8	75.1	91.5	65.3	58.3	106.1	94.3	45.0	95.4	196.7
Ni/Sc	0.9	3.4	1.1	0.7	30.8	3.6	9.7	2.6	2.8	1.0
La/Yb	32.1	14.1	26.7	22.5	11.9	20.6	14.9	12.7	24.4	25.3
Total REE	614.6	224.4	513.4	421.0	164.0	305.4	228.4	192.1	456.1	518.6

Table 11: Continued



Table 1	I. Contin	lueu								
	MUL-20	MUL-21	MUL-22	MUL-23	MUL-24	MUL-25	MUL-26	MUL-27	MUL-28	MUL-29
Li	3.0	4.4	4.7	2.5	2.5	3.8	4.9	2.9	7.0	4.8
Be	1.1	1.0	0.8	0.9	1.0	0.6	0.6	0.9	1.2	0.8
F	901	1057	1859	1913	602	1688	509	538	829	584
Sc	37	32	25	27	48	17	64	56	28	54
V	407	524	547	398	569	402	771	611	372	650
Cr	136	59	30	28	586	23	31	77	24	494
Со	53	68	80	59	123	54	99	94	52	90
Ni	52	65	35	24	1070	13	216	295	26	176
Cu	49	76	88	49	851	30	248	209		101
7n	98	183	162	134	143	117	128	121	138	134
Ga	23	22	22	22	21	22	23	21	23	23
	23	11	12	22	17	12	10	10	15	16
RD	9	0.05	13	9	17	10	12	12	10	10
Sr	659	635	924	1050	423	1269	264	387	700	294
Ť Z.	38	40	47	52	24	30	22	23	30	22
Zr	290	256	186	232	214	138	159	186	278	172
Nb	51	57	59	79	32	41	20	32	47	27
Мо	0.7	1.4	1.5	1.0	1.3	2.9	3.1	1.3	2.0	3.3
Ag	0.05	0.04	0.06	0.06	0.21	0.04	0.08	0.07	0.04	0.06
Sn	2.7	5.6	3.1	2.5	3.0	2.4	3.6	3.3	4.4	3.3
Sb								0.1	0.1	0.1
Cs	0.1	0.2	0.3	0.1	0.3	0.2	0.3	0.2	0.2	0.3
Ва	360	270	495	603	249	460	147	204	380	201
La	46	69	77	81	24	54	18	22	35	18
Ce	111	146	174	190	57	126	45	53	90	44
Pr	16.61	19.90	24.18	26.41	9.07	17.65	7.49	8.44	12.73	6.49
Nd	67.65	76.55	95.26	107.25	35.74	73.88	32.68	34.44	54.84	27.17
Sm	12.17	14.32	16.31	19.15	8.09	13.47	6.81	7.25	10.77	6.72
Eu	4.15	4.42	5.47	5.98	2.55	4.20	2.41	2.60	3.91	2.23
Gd	18.35	19.25	24.33	27.05	11.31	18.80	11.10	11.62	16.95	10.70
Tb	1.67	1.71	2.24	2.55	1.03	1.74	1.07	1.08	1.49	1.10
Dy	8.29	8.57	10.68	11.86	5.80	8.59	5.25	4.84	8.26	4.96
Но	1.60	1.52	1.81	2.08	0.98	1.67	0.95	0.90	1.46	0.95
Er	4.27	3.85	4.65	5.29	2.57	3.47	2.33	2.49	3.89	2.29
Tm	0.53	0.45	0.57	0.61	0.40	0.48	0.34	0.33	0.46	0.24
Yb	2.88	2.79	3.51	3.67	1.66	2.68	1.64	1.40	2.65	1.64
Lu	0.40	0.41	0.40	0.52	0.26	0.28	0.20	0.26	0.40	0.19
Hf	9.17	8.17	5.76	6.99	7.13	4.40	6.06	6.31	8.65	5.79
Та	3.15	3.65	3.68	4.65	2.00	2.56	1.75	2.16	2.84	1.59
W	0.56	0.52	1.04	0.63	0.62	1.61	1.78	0.87	1.35	2.25
Re	0.001	0.001	0.001	0.001	0.004	0.000	0.002	0.002	0.001	0.001
Au ppb	1.00	1.00	1.00		4.00	3.00	1.00		-1.00	1.00
TI	0.01	0.01	0.02	0.01	0.03	0.02	0.03	0.02	0.03	0.05
Pb	1.10	1.34	1.56	1.04	1.32	1.91	2.14	1.31	1.37	1.77
Bi	0.01	0.01	0.02	0.01	0.03	0.02	0.03	0.02	0.01	0.02
Th	1.95	3.19	3.33	2.67	2.68	2.52	1.15	1.82	2.08	2.10
U	0.45	0.71	0.83	0.52	0.62	0.51	0.49	0.39	0.47	0.56
Y/Ho	23.9	26.2	26.1	25.0	24.5	21.8	23.6	25.8	24.3	22.9
Zr/Hf	31.6	31.3	32.4	33.3	30.1	31.2	26.2	29.4	32.1	29.7
Nb/Ta	16.0	15.6	16.2	17.0	16.1	15.9	11.6	14.8	16.5	17.0
Nb/Th	25.9	17.9	17.9	29.6	12.0	16.2	17.6	17.5	22.4	12.9
Nb/U	111.3	80.8	72.0	151.0	51.7	79.9	41.4	82.5	98.5	47.8
Nb/W	90.0	109.3	57.3	125.2	52.1	25.3	11.4	36.7	34.5	12.0
Ni/Sc	1.4	2.0	1.4	0.9	22.1	0.7	3.4	5.3	0.9	3.3
	15.8	24.6	21.8	22.1	14.3	20.1	10.7	15.7	13.4	10.7
Total	299.7	371.0	437.1	478.8	170.7	330.4	146.2	159.9	248.8	137.7

Table 11: Continued



	11	A 1
lable	11:	Confinued
1		Continuea

	MUL-30	MUL-31	MUL-32	MUL-33	MUL-34	MUL-35	MUL-36	MUL-37	MUL-38
Li	3.7	6.4	4.3	5.1	5.1	3.4	3.9	4.6	4.0
Be	1.2	1.0	1.1	1.6	1.0	0.7	1.1	1.6	1.6
F	1531	574	750	1062	974	955	957	540	748
Sc	36	45	49	47	45	47	40	37	8
V	492	505	545	410	433	443	560	364	93
Cr	104	280	166	176	684	698	147	286	68
Со	62	64	73	51	67	74	75	49	20
Ni	188	97	228	128	306	357	135	91	36
Cu	64	56	255	49	90	141	102	40	19
Zn	116	130	145	117	108	109	136	140	112
Ga	21	23	23	22	18	22	22	23	21
Rb	20	13	15	14	37	22	12	17	53
Sr	588	441	431	885	509	547	591	596	2222
Ŷ	31	26	24	36	24	24	29	34	45
Zr	206	235	219	316	199	160	231	356	352
Nb	44	39	40	70	40	38	51	63	221
IVIO	2.9	2.0	3.8	1.3	1.6	1.3	1.1	1.4	2.8
Ag	0.05	0.04	0.08	0.06	0.04	0.05	0.04	0.06	0.09
Sh	2.8	3.7	4.9	3.7	2.8	3.8	4.0	4.0	1.1
SD	0.1	0.1	0.1	0.1	0.6	0.6	0.1	0.1	0.2
Ra Ba	38/	250	270	566	374	373	367	283	2731
La	37	250	210		23	21	26	203	121
Ce	83	64	64	99	55	53	68	106	251
Pr	12 41	9.35	9.78	13 75	8.31	8 19	10.56	15 59	31.26
Nd	50.15	39.83	39.15	55 10	36.09	34.90	44 69	57 23	104 69
Sm	10.05	8.51	7.97	10.90	8.13	8.33	8.54	12.23	16.35
Eu	3.79	2.73	2.85	3.97	2.67	3.03	3.25	3.66	5.38
Gd	16.27	12.78	12.15	17.66	11.70	12.88	14.02	16.46	22.92
Tb	1.41	1.26	1.04	1.63	1.05	1.10	1.22	1.53	1.96
Dy	7.00	5.84	5.85	7.86	4.92	5.72	6.14	7.26	10.39
Но	1.38	1.20	1.00	1.46	1.02	1.04	1.08	1.39	1.86
Er	3.23	2.88	2.71	3.85	2.57	2.40	2.88	3.57	5.13
Tm	0.45	0.48	0.34	0.50	0.41	0.30	0.35	0.55	0.72
Yb	2.25	2.06	1.77	3.24	1.73	1.93	1.84	2.81	3.55
Lu	0.35	0.33	0.22	0.50	0.31	0.31	0.30	0.40	0.45
Hf	6.93	8.06	7.25	9.40	5.65	5.68	7.59	11.00	9.03
Та	2.78	2.62	2.64	3.94	2.61	2.22	2.97	5.02	18.03
W	1.40	1.30	1.74	0.76	1.33	0.75	0.71	1.09	0.57
Re	0.001	0.000	0.001	0.000	0.001	0.001	0.001	0.001	0.000
Au ppp	1.00	2.00	4.00	4.00	4.00	2.00	2.00	0.00	-8.00
II Dh	1.04	0.02	0.03	0.03	0.07	0.03	0.02	0.03	0.00
PU Bi	0.02	0.01	2.17	0.01	0.02	0.01	0.01	2.08	0.01
Th	3.89	2 77	2 30	2.69	3.08	1.46	1 33	3.24	6.83
	0.00	0.66	0.73	0.58	0.00	0.46	0.36	0.68	1 28
0	0.02	0.00	0.70	0.00	0.01	0.40	0.00	0.00	1.20
Y/Ho	22.7	22.0	23.8	24.9	23.4	23.3	26.7	24.8	24.4
Zr/Hf	29.7	29.1	30.2	33.6	35.2	28.2	30.4	32.4	38.9
Nb/Ta	15.8	14.7	15.3	17.7	15.1	17.1	17.1	12.6	12.2
Nb/Th	11.3	13.9	17.6	26.0	12.8	26.0	38.2	19.5	32.3
Nb/U	47.8	58.2	55.2	120.3	43.4	82.9	140.9	92.7	172.6
Nb/W	31.4	29.8	23.3	91.9	29.8	50.4	72.1	58.2	387.6
Ni/Sc	5.2	2.2	4.6	2.7	6.7	7.5	3.4	2.5	4.7
La/Yb	16.2	12.2	15.7	12.7	13.4	11.1	14.1	15.6	34.0
Total REE	233.6	185.9	187.0	264.8	163.9	163.7	196.4	278.8	574.4



Table I	I. Contin	lueu								
	MUL-39	MUL-40	MUL-41	MUL-42	MUL-43	MUL-44	MUL-45	MUL-46	MUL-47	MUL-48
Li	4.3	5.4	4.8	3.0	8.8	7.0	6.7	12.4	9.6	5.2
Be	0.7	1.7	0.9	0.8	1.9	2.4	2.3	1.9	2.6	2.0
F	1054	276	982	1249	1421	1326	1286	1233	1153	769
Sc	43	8	44	38	11	13	16	9	9	5
V	394	97	357	526	199	215	245	144	140	88
Cr	657	85	683	162	23	78	48	26	25	23
Co	64	15	59	75	30	35	40	22	23	17
NI	260	35	246	123	14	43	40	8	13	10
	200	10	240	02	22	43	44 57	12	13	10
Cu Zn	02	72	40	120	100	120	100	12	116	14
	80	73	01	120	123	130	120	130	116	120
Ga	18	21	17	21	22	23	23	24	22	21
Rb	15	103	24	10	84	105	78	11	101	60
Sr	628	1035	670	669	1429	1247	1218	1357	1849	2305
Y	24	22	25	32	40	39	36	39	37	45
Zr	144	545	182	194	373	338	346	355	324	375
Nb	35	108	45	40	144	143	119	142	157	219
Мо	1.0	1.8	2.1	0.9	2.2	3.1	2.4	2.0	2.2	2.7
Ag	0.02	0.05	0.02	0.05	0.06	0.08	0.08	0.07	0.07	0.09
Sn	3.8	3.1	3.6	3.2	4.4	3.2	2.9	3.9	3.8	2.1
Sb		0.1								
Cs	0.4	0.7	0.4	0.2	0.4	0.9	0.8	0.5	1.0	0.4
Ва	438	1566	541	409	1263	950	843	1447	1139	2646
La	16	51	24	31	103	94	80	106	109	125
Ce	44	99	59	79	198	174	152	204	193	255
Pr	7.02	11 72	8 79	12 72	23.69	20.52	17.84	24.01	21.25	31.60
Nd	31.65	38 15	36 15	54.38	79.45	69.56	63.70	84.08	67.07	103.24
Sm	8.02	5.87	7.80	11.00	13.31	12 54	12 71	13 35	11.57	16.66
Fu	2.80	2.1/	2 01	3 36	4.64	4.06	3.66	10.00	3.68	5.42
Cd	12.00	2.14	10.05	15.10	10.50	17.45	15.00	10.44	15.00	22.06
Оu Th	12.20	9.44	12.05	1 / 3	163	17.45	1 3/	10.44	1 37	1.90
	5.48	4.53	5 70	8 12	8.30	6.02	7 10	8 16	7.02	0.72
Цо	0.40	4.00	1.01	1 20	1 / 1	1.51	1.10	1 / 8	1.02	1.04
Fr.	2.65	1.00	3.12	3 30	1.41	3.82	3 77	1.40	1.40	1.04
Tm	0.37	0.38	0.34	0.41	9.10	0.57	0.47	0.54	0.51	4.51
Vh	1.61	2.20	1.04	2.05	2.05	2.59	2.10	2.22	2.25	0.57
10	0.25	2.20	0.09	2.05	3.05	0.40	3.10	0.45	3.25	4.11
LU LIF	0.25	10.37	0.20	0.32	0.49	0.49	0.42	0.45	0.50	0.51
	0.01	7.00	0.07	0.50	9.47	0.09	5.00	9.00	0.70	10.31
	2.14	7.00	2.92	2.07	0.01	7.40	0.69	0.43	0.03	0.40
	0.90	0.92	0.001	0.80	0.00	0.00	0.00	0.00	0.43	0.49
	15.00	0.000	0.001	0.001	0.000	0.000	0.001	0.001	0.000	0.000
ли рро ті	0.03	0.11	0.04	0.02	0.10	0.13	0.10	0.10	0.11	0.07
Dh	1.07	0.11	1.60	1.02	4.12	4.06	4.29	4.27	5.22	5.62
FU Di	0.01	0.00	0.01	0.01	4.13	4.00	4.20	4.27	0.01	0.03
	0.01	0.01	0.01	0.01	11.40	0.02	0.02	0.01	11.05	0.01
111	1.19	0.33	2.05	1.39	11.40	9.24	2.00	9.20	11.05	0.00
0	0.37	1.00	0.09	0.33	1.77	1.00	2.00	1.52	2.00	1.00
V/Ha	24.7	26.2	24.7	24.9	29.4	25.9	26.4	26.6	25.2	22.0
	24.7	20.2	24.7	24.0	20.4	20.0	20.4	20.0	25.3	23.0
	20.7	00.0 45 F	JZ.	29.0	39.4	30.0	40.0	39.3	31.Z	10.4
	10.4	10.0	10.4	15.0	10.7	19.1	20.4	10.9	11.0	12.0
	29.7	13.0	17.0	29.0	12.6	15.5	13.6	15.3	14.2	25.3
Nb/U	96.0	69.8	65.1	121.2	81.4	/9.4	59.6	93.9	/5.8	117.8
	39.0	117.8	44.3	50.2	222.5	210.7	1/6./	235.4	368.3	444.6
Ni/Sc	6.0	4.3	5.6	3.2	1.3	3.2	2.8	0.9	1.5	1.9
La/Yb	10.0	23.4	13.2	15.0	33.7	26.2	25.7	32.7	33.5	30.4
Total	140.1	240.8	170.1	230.5	463.9	415.2	370.3	478.8	445.8	581.3

Table 11: Continued

			LIVI-S						LIVI-9				
Li	1.8	7.7	1.3	1.9	3.8	4.1	1.0	4.4	1.6	1.5	3.2	1.0	1.0
Be	0.5	17	0.5	0.5	0.5	16	0.5	20	0.8	0.5	0.6	0.6	04
F	516	1540	813	485	1306	1284	638	2.0	558	711	1465	435	642
Sc	54	23	39	45	35	.231	37	21	35	16		40	16
V	462	20	567	522	540	504	190	227	426	333	425	457	200
V Cr	402	204	507	323	040	07	409	237	420	523	420	457	300
Cr	404	311	07	177	39	21	308	349	208	65	118	250	20
Co	68	49	97	82	82	70	60	67	59	42	70	62	39
NI	91	128	162	136	60	63	81	290	126	18	149	142	/
Cu	53	59	98	88	81	66	59	44	/8	13	122	90	9
Zn	107	101	137	131	127	106	144	134	160	118	201	173	117
Ga	19	16	19	18	19	17	18	16	19	24	19	23	22
Rb	5	84	3	2	7	3	1	40	2	3	7	1	2
Sr	246	1049	297	187	357	259	248	789	221	2074	552	222	1378
Y	22	32	26	21	33	26	32	31	29	34	44	31	30
Zr	166	272	196	166	193	152	198	363	182	151	223	205	152
Nb	16	96	24	18	20	10	8	118	7	9	26	7	10
Мо	0.2	3.1	0.2	0.2	0.4	0.2	0.1	2.7	0.1	0.1	0.6	0.1	0.1
Ag	0.02	0.06	0.03	0.05	0.03	0.00	0.02	0.07	0.01	0.03	0.06	0.03	0.02
Sn	3.4	2.4	3.8	3.2	3.9	4.8	4.7	2.8	4.4	1.9	2.7	3.8	2.3
Sb	0.1	0.1	0.0	0.0	0.1	0.4	0.0	0.1	0.1	0.0	0.3	0.0	0.0
Cs	0.2	1.5	0.2	0.1	0.1	0.5	0.1	0.6	0.3	0.2	0.2	0.1	0.2
Ва	86	1534	108	32	111	71	12	601	34	52	137	18	39
La	18	88	25	15	36	24	22	78	17	29	41	15	23
Ce	51	174	66	44	94	67	69	165	53	89	117	49	71
Pr	8.43	21.80	10.83	7.45	15.80	10.81	11.58	19.02	9.74	14.67	18.93	8.97	12.17
Nd	37.82	73.93	48.98	35.34	72.23	53.84	58.62	77.46	50.69	74.65	94.35	48.96	62.16
Sm	9.34	12.88	10.50	8.22	14.89	11.59	14.00	12.91	12.99	15.16	18.93	12.58	13.57
Eu	2.75	3.86	3.17	2.80	4.69	3.60	4.03	3.97	3.70	5.03	6.39	3.81	4.50
Gd	12.63	16.27	14.38	12.54	19.97	15.51	18.28	17.13	16.99	21.06	27.43	17.54	19.25
Tb	1.22	1.37	1.36	1.16	1.71	1.35	1.73	1.50	1.63	1.75	2.37	1.70	1.66
Dv	5.54	7.20	6.03	4.80	8.54	6.98	7.85	7.34	7.48	8.56	11.06	7.92	8.32
Ho	1.03	1.29	1.12	0.90	1.42	1.03	1.32	1.30	1.29	1.41	1.98	1.23	1.15
Er	2.26	3.09	2.47	2.14	3.10	2.08	2.69	3.20	2.68	3.17	4.45	2.52	2.93
Tm	0.29	0.37	0.35	0.25	0.36	0.29	0.33	0.42	0.33	0.42	0.47	0.32	0.32
Yb	1.83	2.16	1.74	1.27	1.97	1.66	1.97	2.50	1.64	2.18	2.68	1.95	1.77
Lu	0.21	0.37	0.21	0.21	0.30	0.21	0.24	0.31	0.22	0.30	0.36	0.23	0.19
Hf	6.07	6.62	7.59	7.54	7.00	6.56	9.06	9.05	8.03	5.91	8.39	8.86	6.36
Та	1.51	6.29	2.43	1.78	1.99	1.23	1.14	8.02	1.01	1.38	2.75	0.95	1.28
W	0.27	1.60	0.37	0.44	0.49	3.11	0.53	1.60	0.70	0.70	0.49	0.46	0.45
Re	0.001	0.001	0.001	0.001	0.001	0.001			0.001	0.001	0.001	0.001	
Au ppb	2.00		1.00	1.00	3.00	3.00	2.00		3.00	2.00	1.00	2.00	2.00
TI	0.02	0.12	0.01	0.01	0.02	0.07	0.01	0.08	0.02	0.02	0.04	0.01	0.01
Pb	0.85	4.71	0.92	1.31	1.18	2.70	0.59	4.39	0.69	0.62	4.08	1.18	0.38
Bi	0.00	0.02	0.01	0.00	0.00	0.01	0.00	0.02	0.01	0.01	0.04	0.01	0.00
Th	0.76	9 10	0.69	0.57	1 45	0.98	0.63	7 04	0.47	0.78	1 38	0.29	0.91
U	0.17	1.77	0.21	0.13	0.27	0.10	0.16	1.46	0.09	0.12	0.25	0.08	0.18
-	0		0.2.	0.10	0.2.	0.1.0	0.10		0.00	02	0.20	0.00	00
Y/Ho	21.9	24 7	23.6	23.2	23.2	25.7	23.8	24.2	22.3	24.0	22.3	25.1	25.8
Zr/Hf	27.3	41.1	25.9	22.0	27.6	23.2	21.8	40.2	22.6	25.6	26.6	23.2	23.9
Nb/Ta	10.5	15.2	9.0	10.2	9.9	8.3	67	14.8	7.3	6.2	9.4	7.6	77
Nb/Th	20.7	10.5	35.0	32.2	13.5	10.4	12.1	16.8	15.6	11.0	18.8	25.0	10.7
Nb/LL	93.9	54.0	116.4	136.7	73.6	106.1	47.1	81.1	82.6	71.0	103.5	89.7	54.7
Nb/W	58.0	59.7	65.9	41.2	40.3	3.3	14.5	74.1	10.6	12.3	53.4	15.5	21.7
Ni/Sc	17	5.5	4.2	30	17	1 9	22	13.8	3.6	12.0	4.8	3.6	0.4
	9.6	40.6	14 1	11.8	18.2	14.5	11 1	31.2	10.1	13.5	15 3	7.5	13.2
Total	149.2	402.0	187.2	133.2	268.3	194.4	208.0	384.6	173.6	259.4	330.0	165.7	216.5
REE	1.0.2	102.0	101.2	100.2	200.0	· · · · ·	200.0	004.0		200.4	000.0	100.1	2.0.0

Table 12: Trace element data for selected lithologies from Lake Machattie Intrusion



	2. (CUI	unucu)									
	LM-14	LM-15	LM-16	LM-17	LM-18	L-19	LM-20	LM-21	LM-22	LM-23	LM-24
Li	2.8	54.2	1.6	1.1	6.4	0.9	9.0	11.1	3.7	5.0	1.5
Be	1.2	0.6	0.6	0.8	0.5	0.5	2.8	3.0	0.5	0.5	0.3
F	1000	739	497	209	393	926	593	1054	303	636	252
Sc	19	16	7	6	49	43	31	40	48	39	33
V	194	366	181	77	394	415	361	398	543	576	420
Cr	387	53	53	67	853	384	443	261	390	124	899
Co	69	37	33	28	47	60	43	51	66	71	73
Ni	395	26	21	59	90	198	75	73	158	124	296
Cu	39	28	8	7	34	121	53	54	75	105	54
Zn	112	130	112	84	83	121	426	103	110	136	144
Ga	16	22	16	16	20	124	17	100	21	21	18
Da	10	17	10	5	20	13	8	13	21	5	10
NU Sr	41	907	1057	000	226	260	427	212	166	244	07
31	000	20	1057	900	230	300	437	312	100	244	97
T	24	29	51	24	23	29	22	30	20	23	10
	205	163	58	35	173	136	100	131	144	136	119
ND	66	1	484	375	5	48	214	43	4	17	2
Mo	1.6	0.1	0.1	0.3	0.1	0.1	0.7	0.4	0.1	0.2	0.1
Ag	0.04	0.01	0.03	0.03	0.02	0.01	0.03	0.02	0.01	0.03	0.00
Sn	3.2	3.5	2.7	1.3	3.7	3.5	2.8	9.9	4.4	3.6	7.5
Sb	0.1	0.3	0.1	0.0	0.0	0.0	0.2	0.2	0.0	0.3	0.0
Cs	0.7	0.5	0.1	0.1	0.0	0.0	0.5	0.9	0.1	0.4	0.1
Ва	644	2554	54	98	273	13	109	124	103	67	23
La	43	24	223	107	13	47	20	29	9	26	5
Ce	90	70	537	264	42	122	54	78	31	70	20
Pr	11.62	11.13	63.41	31.65	7.34	17.48	7.73	11.44	5.53	10.92	3.94
Nd	44.64	57.92	235.65	116.49	40.96	77.57	32.38	52.04	32.26	49.77	22.87
Sm	8.28	12.83	30.06	16.45	10.04	13.83	7.04	11.57	7.54	10.42	5.83
Eu	2.70	4.15	6.89	4.51	2.95	4.29	2.36	3.51	2.84	3.21	2.04
Gd	11.30	18.30	26.50	17.15	13.44	18.20	10.53	15.32	12.18	14.10	9.11
Tb	0.93	1.66	1.84	1.16	1.28	1.54	0.97	1.36	1.06	1.27	0.84
Dy	5.15	7.78	8.17	5.69	6.15	7.50	5.14	6.83	5.19	5.53	4.56
Но	1.05	1.11	1.31	1.06	0.99	1.25	0.80	1.16	0.82	0.96	0.81
Er	2.13	2.87	3.21	2.47	2.33	2.74	2.32	2.71	1.87	2.35	1.61
Tm	0.37	0.36	0.49	0.41	0.25	0.33	0.31	0.44	0.23	0.25	0.19
Yb	1.80	1.82	2.63	2.55	1.58	1.51	2.10	1.96	1.18	1.54	1.00
Lu	0.27	0.22	0.39	0.35	0.17	0.26	0.33	0.27	0.16	0.20	0.16
Hf	5.45	7.00	2.20	1.07	8.02	6.31	4.43	6.27	6.75	6.42	5.45
Та	4.62	1.04	1.71	1.41	0.65	0.82	0.78	0.70	0.51	0.82	0.60
W	1.07	0.46	34.89	24.63	0.52	3.29	12.24	4.46	1.04	1.85	0.41
Re		0.001			0.001	0.001			0.001	0.001	0.001
Au ppb	2.00	3.00	4.00	7.00	5.00	3.00	5.00	2.00	1.00	3.00	3.00
TI	0.07	0.09	0.01	0.01	0.01	0.00	0.10	0.19	0.01	0.06	0.01
Pb	2.88	2.45	7.23	5.88	1.02	1.14	6.78	3.75	0.32	2.19	0.29
Bi	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00
Th	4.74	0.84	13.47	8.89	0.36	2.08	6.42	11.66	0.65	1.75	0.17
U	1.01	0.16	0.11	0.13	0.08	0.12	0.16	0.11	0.07	0.09	0.04
Y/Ho	23.1	26.3	23.7	22.5	24.9	23.4	27.2	26.1	24.2	24.1	20.2
Zr/Hf	37.7	23.3	26.2	33.2	21.5	21.5	22.6	20.8	21.3	21.1	21.9
Nb/Ta	14.3	7.1	282.6	266.8	7.8	58.4	272.9	60.9	7.5	20.1	4.0
Nb/Th	13.9	8.8	35.9	42.2	13.9	22.9	33.3	3.7	6.0	9.5	14.3
Nb/U	65.7	47.7	4438.7	2839.9	60.1	410.6	1345.9	373.7	54.3	190.8	68.0
Nb/W	61.9	16.2	13.9	15.2	9.6	14.5	17.5	9.5	3.7	9.0	5.8
Ni/Sc	20.9	1.6	2.9	9.9	1.8	4.6	2.4	1.8	3.3	3.2	9.0
La/Yb	23.8	13.2	84.7	42.0	8.0	31.0	9.4	14.7	7.9	16.6	5.3
Total REE	219.5	208.0	1130.4	563.9	138.3	309.2	142.5	212.2	106.6	191.7	76.1

Table 12: (Continued)



Figure 8: Variation in transition metal abundances of (a) Cr, (b) V, (c) Co, (d) Ni, (e) Sc and (f) Cu with SiO_2



Figure 9: Variation in transition metal abundances of (a) Au, (b) Pd and Pt, (c) Zn, (d) Zr, (e) Nb and (f) REEY with SiO₂.



Figure 10: Inter-element fractionation between (a) Cr and MgO, (b) Cu and MgO, (c) TiO2 and MgO, (d) Ni and MgO, (e) P2O5 and MgO, (f) Co and FeO*, (g) V and FeO*, (h) P2O5 and Fe)* and CO2 and Total alkalis.

likely the result of olivine and Cr-rich clinopyroxene fractionation due to accumulation of cumulate phases. The contrast in behaviour of Cu with fractionation the two intrusions is very pronounced in Fig. 10b, which shows that some Mulligan lithologies reach values of \sim 1000 ppm. By contrast the highest Cu values recorded in Lake Machattie are only \sim 150 ppm.

Figure 10c shows fractionation induced covariation between MgO and TiO₂. Commencing with a parental composition containing ~ 15 wt.% MgO and ~5 wt. % TiO₂, which is similar to the parental magma composition for Si-undersaturated alkaline magma responsible for the generation of carbonatites on Brava (Cape Verde) of Weidendorfer *et al.*, (2016), the suites evolve by crystal-liquid fractionation to low TiO₂ and low MgO lithologies in Mulligan Intrusion. Whereas in Lake Machattie intrusion, separation of an immiscible liquid, generates melts with essentially constant MgO (~10 wt. %) but these range in TiO₂ content from ~ 5 to 11 wt.%. Lake Machattie samples, with MgO > ~8 wt. %, show a positive correlation with Ni reaching maximum concentrations of ~250 ppm. However, samples from Mulligan Intrusion, presumably S-rich cumulates decouple from the fractionation trend with concentrations of up to 1400 ppm at ~ 10 wt.% MgO.

The presence of phoscorite in both intrusions is shown in Fig. 10e and 10h, where P_2O_5 ranges up to ~3.5 wt % in Lake Machattie Intrusion and ~4 wt. % in Mulligan Intrusion at MgO contents of ~ 10 wt.% and FeO* contents of ~18 wt. %. Both Mulligan and Lake

Machattie show excellent fractionation control between Co (Fig. 10f) and V (Fig. 10g) with FeO*. As discussed above, the covariation between CO_2 and total alkalis (Fig10g) is interpreted to reflect separation of an immiscible CO_2 -bearing fluid, a process responsible for major and trace element fractionation in alkaline igneous systems (e.g., Weidendorfer *et al.*, 2016).

Scandium

Scandium in Mulligan and Lake Machattie Intrusions range from 2.8 to 62.8 ppm (mean 31.2 ± 15.8 ppm) and 7.3 to 56 ppm (mean 33.3 ± 13.4 ppm) respectively. These are within error of data reported by AusQuest for a larger number of analyses (Appendix 2) viz, mean Sc = 27.3 ± 16.6 (Mulligan n=89) and 27.4 ± 9.6 ppm (Lake Machattie n =204). These concentrations are similar to those reported from phoscorites in the Kovdor Intrusion on the Kola Peninsula, viz., mean Sc = 61 ± 18 ppm (Liferovich *et al.* 1998). The mean Sc content of the Mulligan and Lake Machattie intrusions are similar to the Sc content of related silicate lithologies e.g., 27 ± 30 ppm (olivinites, pyroxenites, ijolite-melteigites and melilite-bearing rocks) and 22 ± 8 ppm (carbonatite) in the intrusion. This intrusion is currently being assessed for as a source of scandium (Kalashnikov et al., 2016).

Trace element control on fractionation of Sc with (a) V, (b) Co, (c) P2O5 and (d) Zr are shown in Fig. 12. Sc is positively correlated with V (Fig. 12a) and Co (Fig. 12b). However, Sc in both Mulligan and Lake Machattie intrusions is also correlated with P_2O_5 (Fig. 12c) and Zr (Fig. 12d). Fig. 11 a and b shows that Sc concentration is positively correlated with FeO* and MgO, indicating that it largely substitutes into ferromagnesian silicates, most likely Ti-bearing clinopyroxene as shown in Fig. 11c.

This suggests that Sc may also be substituting into other phases possibly Juonnite (Ca-Mg-Sc phosphate; Liferovich *et al.* 1998) or baddeleyite (Kalashnikov *et al.*, 2016). Although the full extent of these substitutions may be masked by Sc substitution into clinopyroxene.



Figure 11: Major element control on fractionation of Sc with (a) FeO^{*}, (b) MgO and (c) TiO_2 .



Figure 12: Trace element control on fractionation of Sc with (a) V, (b) Co, (c) P_2O_5 and (d) Zr.

Geological Survey of Queensland

Spidergram Comparisons

Primitive mantle-normalized plots, with elements arranged in order of increasing compatibility are a very effective method to compare and contrast trace element data from Mulligan and Lake Machattie Intrusion. They also provide a useful visual means to contrast the geochemistry of these alkaline intrusions from different suites, such as between the Diamantina Intrusions and alkaline intrusions on the Kola Peninsula. In this report, primitive mantle values used for this normalization procedure are either from McDonough and Sun (1995) and Lyubetskaya and Korenaga (2007).

Mulligan pyroxenites in Fig. 13 and Fig. 14a exhibit broadly uniform shaped patterns, with positive spikes in Ba, Nb, Ta, Hf and Ti, with strong negative spikes in Pb and weakly negative spikes in P.



Figure 13: Primitive mantle-normalised multi-element variation diagrams for pyroxenites from Mulligan Intrusion

Mulligan phoscorites and carbonate-bearing lithologies shown in Figure 14b, exhibit pronounced positive spikes in Ba and Hf, and strong to weak negative spikes in W, Pb and Li.



Figure 14: Primitive mantle-normalised multi-element variation diagrams for pyroxenites from Mulligan Intrusion

By contrast, in Lake Machattie Intrusion, pyroxenites (Fig. 15) display significantly more varied patterns that appear to define several groups: Gp.1 (LM-8 and LM-14), Gp.2 (LM-1, LM-9, LM-18, LM-19 and Lm-22) and Gp. 3 (LM-24) an olivine clinopyroxene cumulate. Gp. 1 shows spikes in Nb, Ta and Hf and depletions in W and Pb. Patterns for Gp. 2 display positive spikes in Ba, W, Nb and Hf and negative spikes in Pb, P and Li. The olivine-clinopyroxene cumulate shows strong negative spikes for HF and Li, and a very strong positive spikes in W and Sc.



Figure 15: Primitive mantle-normalised multi-element variation diagrams for pyroxenites from Lake Machattie Intrusion.

Primitive mantle-normalized plots of apatite-bearing pyroxenite and phoscorite from Lake Machattie intrusion are shown in Figure 16a. They exhibit broadly similar shaped patterns with positive spikes in W, Hf and Ti, and negative spikes in Rb, Th, K, Pb and Li. Note the most prominent positive W and Hf spikes are displayed by phoscorite LM-6.



Figure 16: Primitive mantle-normalised multi-element variation diagrams for pyroxenites and carbonatites from Lake Machattie Intrusion.

Primitive mantle-normalized plots of silicio ferrocarbonatites from Lake Machattie intrusion are shown in Figure 16b. They show strongly positive spikes for W, Nb, Hf and Li. Like all of the Diamantina intrusions, they exhibit strongly negative spikes for Pb.

Primitive mantle-normalized plots showing more fractionated compositions from Mulligan Intrusion are presented in Figure 17. The barkevikite-bearing gabbros (Fig. 17a) exhibit remarkably similar patterns characterized by positive spikes in Ba, Sr, and Hf and negative spikes in W and Pb. The foid-bearing diorites MUL-46 to 48 form a very uniform population with positive spikes in Rb, Ta and Nb. By contrast, the foid-bearing syenites MUL-4 and MUL-11 show considerable variation in elemental abundances, although their shapes are broadly similar.



Figure 17: Primitive mantle-normalised multi-element variation diagrams for gabbros (a) and (b) foid-bearing diorites and syenites from Mulligan Intrusion.

Primitive mantle-normalized plots of lamprophyres from Mulligan Intrusion and Lake Machattie Intrusion shown in Figure 18.



Figure 18: Primitive mantle-normalised multi-element variation diagrams for lamprophyre dykes from Mulligan and Lake Machattie Intrusion. Shown for comparison are fields showing elemental variations in lamproite (from Murphy et al., 2002) and Kaaapvaal Craton kimberlites (Collerson unpublished data)

Geochemical Comparison of Mulligan and Lake Machattie Intrusions with the Geochemistry with Kola Peninsula Alkaline Intrusions

Devonian age intrusions located in northern Finland and the Russian Kola Peninsula (Fig. 18) are similar in petrology and geochemistry to the Devonian age Diamantina Intrusions in Queensland. The Kola Peninsula intrusions are:

- The very large Khibina Intrusion (>1000 km²) comprising peridotite, pyroxenite, melilitolite, melteigite, ijolite and carbonatite (Arzamastsev and Arzamastseva, 2013);
- (2) Kovdor Intrusion (~22 km²) comprising dunite, melilitolite, melteigite, ijolite, phoscorite, carbonatite and nepheline syenite (Arzamastsev and Arzamastseva, 2013);
- (3) Turiy Mys Intrusion (~50 km²) pyroxenite, olivine melteigite, ijolite, melilitolite, urtite, phoscorite and carbonatite (Dunworth and Bell, 2001);
- (4) Vuoriyarvi Intrusion (~28 km²) pyroxenite, melteigite, phoscorite and carbonatite (Arzamastsev and Arzamastseva, 2013).



Figure 19: The locations of various alkaline intrusions in the Kola Peninsula: 1 - Khibina, 2 - Lovozero, 3 - Niva, 4 - Mavraguba, 5 - Kovdor, 6 - Sokli, 7 - Sallanlatva, 8 - Vuoriyarvi, 9 - Kandaguba, , 10 - Afrikanda, 11 - Ozernaya Varaka, 12 - Lesnaya Varaka, 13 - Salmagora, 14 - Ingozero, 15 - Turiy Mys, 16 - Kurga, 17 - Kontozero, 18 - Ivanovka, 19 - Seblyavr, 20 - Pesochny. (After Arzamastsev et al., 2008).

This geochemical similarity is illustrated using primitive mantle-normalized plots in Figure 20. Khibina (Fig. 20a), Kovdor (Fig. 20b), Vuoriyarvi (Fig. 20c) and Turiy Mys (Fig. 20d) have remarkably similar primitive mantle-normalized element distribution patterns to Mulligan and Lake Machattie Intrusions.



Figure 20: Primitive mantle-normalised multi-element variation diagrams comparing elemental variation within Mulligan and Lake Machattie Intrusions, with data for Devonian alkaline intrusions on the Kola Peninsula from Zaitsev *et al.,* (2015).

Specific features of the patterns are as follows:

- (1) Khibina positive anomalies in Hf, Nb and U, and negative spikes in K, Pb Zr, Ti and Li;
- (2) Kovdor positive anomalies in U, P, Hf, and Li, and negative spikes in Pb and Ti;
- (3) Vuoriyarvi positive anomalies in U, P, Nb and Hf, and negative spikes in K, Pb and Ti;
- (4) Turiy Mys positive anomalies in W, U, Ta, P, and Hf, and negative spikes in Th, K, Zr and Ti.

The similarity of the geochemistry of these large alkaline intrusions indicates a commonality in petrogenetic process in the two areas.

Suites of lamprophyre dykes intrude the major lithologies in both areas. Data for Mulligan and Lake Machattie lithologies are compared with lamprophyres from both intrusions in Figure 21. In Fig. 21a it is clear that Lake Machattie intrusion is dominated by melilitite compositions, with a few samples (silicio carbonatites) falling into the kimberlite field. Lamprophyres from Lake Machattie intrusion (LM-2 and LM-23) also lie in the melilitite field (Fig. 21b). By contrast, Mulligan lamprophyres (MUL-3, MUL-7 and MUL-38) lie on the same silica enrichment fractionation trend displayed by the majority of lithologies from this intrusion.



Figure 21: CaO+Na₂O+K₂O wt.% versus SiO₂ + Al₂O₃ wt.% diagram of Le Bas (1989)

Lamprophyres and kimberlites from the Kola Peninsula, Beard *et al.*, (1998; 2000) and Downes *et al.*, (2005) are broadly similar in primitive mantle-normalized trace element patterns to Diamantina lamprophyres (Fig. 22). However, although Kola melilitite dykes have similar shaped patterns, they are significantly less enriched.


Figure 22: Primitive mantle-normalised multi-element variation diagrams comparing elemental variation within Diamantina lampropyres with data for lamprophyres, kimberlites and melilitites from the Kola Peninsula. Kola Peninsula data from Beard *et al.*, (1998; 2000) and Downes *et al.*, (2005).

Variation in Rare Earth Element Abundances

To better understand Diamantina intrusive suite and gain information regarding petrogenesis of the intrusions, chondrite normalised data for REE analyses in Table 11 and 12 are shown in Figures 23 and 24. Normalizing data are from Sun and McDonough (1989).

The Lake Machattie samples are light REE enriched ($La_N/Yb_N = 5.4$ to 57.5, with the greatest degree of fractionation being shown by the ferrocarbonatites (Fig. 23d), where La_N is 350x enriched. They also have significant levels of HREEs with $Yb_N \sim 10x$ chondrites. Many sample show slightly sinusoidal U-shaped patterns some with flat LREEs that are believed to reflect the influence of augite or aegirine augite.



Figure 23: Chondrite normalised REE plots for Lake Machattie lithologies (a) Pyroxenites, (b) Olivine pyroxenites (c) Phoscorites, (d) Carbonatites and (e) Lamprophyres.



Figure 24: Chondrite normalised REE plots for Mulligan lithologies (a) Amphiboliebearing pyroxenites, (b) Phoscorites (c) S-bearing pyroxenites, (d) Orthopyroxenite, (e) Gabbros, (f) Foid-bearing diorite and (g) Foid-bearing syenites (h) Mulligan and Lake Machattie lamprophyres.

Amphibole-bearing pyroxenites (Fig. 24a) and phoscotites (Fig. 24b) from Mulligan intrusion are significantly REE enriched with up to 700x enrichment in La_N and \sim 25x enrichment in Yb_N.

 La_N/Yb_N ratios, range from 6.8 to 21.7 (Fig.27a & b). Sulphide-bearing pyroxenites (Fig. 27 c) have quite uniform moderately fractionated patterns with La_N/Yb_N ranging from 7.6 to 10.3. Orthopyroxenite MUL-1 (Fig. 27d) has a flat REE pattern with La_N/Yb_N of 5.7. Alkali gabbros from Mulligan intrusion have uniformly fractionated patterns ($La_N/Yb_N = 20.6$ to 24.1) slightly positive Eu anomalies indicative of feldspar or feldspathoid accumulation (Fig. 27e). Foid-bearing diorite (Fig. 27f) has a steeply fractionated REE pattern with broadly similar degree of fractionation ($La_N/Yb_N = 22.8$) that is seen in the other major lithologies. REE patterns of the foid-bearing syenites are highly variable, MUL -11 exhibits a U-shaped pattern that likely reflects the presence of Na clinopyroxene which could explain the elevated Zr in this sample and hence high Zr/Hf ratio (66.2). Alternatively, the patterns could be the result of carbothermal alteration.

Comparison with Kola Peninsula Intrusions

REE data for Mulligan and Lake Machattie intrusions are compared with data for Khibina, Kovdor, Yuriy Mys and Vuoriyarvi intrusions on the Kola Peninsula (data from Verhulst *et al.*, 2000; Dunworth and Bell, 2001; Arzamastsev and Arzamasseva, 2013; Zaitsev *et al*, 2014) in Figure 25.



Figure 25: Chondrite normalised REE plots comparing Mulligan and Lake Machattie lithologies with Kola Peninsula alkaline intrusions: (a) Khibina intrusion, (b) Kovdor, (c) Turiy Mys and (d) Vuoriyarvi.

This shows that alkaline intrusions from both areas have remarkably similar chondrite normalized REE patterns and thus, must had similar sources and petrogenetic histories.

The Origin of Diamantina Magmatism

CHARAC Ratio Geochemistry

The CHARAC ratios Y/Ho and Zr/Hf are useful ratios to distinguish systems that preserve magmatic source characteristics, from those affected by hydrothermal processes (Bau, 1996). Y/Ho and Zr/Hf data for Mulligan and Lake Machattie intrusions are shown in Figure 26a.

The principal is as follows. If a geochemical system is characterized by CHArge and-RAdius-Controlled (CHARAC) trace element behavior, elements with similar charge and ionic radius such as the twin pairs Y-Ho and Zr-Hf should display coherent behavior during crystallization and retain their respective chondritic ratios. Mantle-derived igneous rocks, for example, have Y/Ho and Zr/Hf ratios close to the ratios recorded by chondritic meteorites, viz. 28 and 38.



Figure 26: Plot of Y/Ho *versus* Zr/Hf ratio showing data for (a) Mulligan and Lake Machattie Intrusions, (b) Carbonatites and alkaline silicate lithologies from Brasilian alkaline intrusions, (c & d) Carbonatites and alkaline silicate lithologies from Kola Peninsula alkaline ultrabasic intrusions

Carbonatites and associated alkaline intrusions display this characteristic (de Andrade et al., 2002). These ratios are within error of values exhibited by mantle plume generated ocean island basalts (OIBs) viz., $Y/Ho = 27.7\pm2.7$ and $Zr/Hf = 36.6\pm2.9$ (Bau, 1996). However,

Y/Ho ratios can be fractionated by medium-temperature F-rich aqueous fluids (Buhn, 2008) that causes fluoride complexation to yield non-chondritic Y/Ho ratios (Bau and Dulski, 1995).

Although some samples from Mulligan Intrusion have chondritic Y/Ho ratios and lie within the CHARAC field, the majority of Mulligan samples and all of the Lake Machattie samples have sub-chondritic Y/Ho. This reflects the influence of F-rich fluids, which have the ability to fractionate Y from Ho (Buhn, 2008). Both intrusions also show considerable variation in Zr/Hf ratio which has been shown to be characteristic alkaline intrusions from which carbonatite liquids have evolved (de Andrade *et al.*, 2002).

Comparative data for similar alkaline intrusions in Brasil (Cordiero *et al.*, 2010; Barbosa *et al.*, 2012; Brod *et al.*, 2013) and the Kola Peninsula (Verhulst et al., 2000; Dunworth and Bell, 2001; Arzamastsev and Arzamasseva, 2013; Zaitsev *et al.*, 2014) are shown in Figs. 26b and Figs. 26c & d respectively. Intrusions from both locations are geochemically very similar to the Diamantina intrusions, thus confirming their petrological affinity and hence their mantle plume source.

Confirmation of a Plume Origin using Primitive (Lower) Mantle Normalised Ratios

Primitive mantle normalised Ta/U and Nb/Th ratios, calculated from data in Tables 11 and 12 using primitive mantle values from McDonough and Sun (1995) and Lyubetskaya and Korenaga (2007) are shown in Figure 27. In this projection, plume-derived samples associated with lower mantle upwelling should plot close to unity. Whereas, samples contamination by crust, crustal fluids or fluids derived from subducted slabs lie in the lower left-hand quadrant, with Ta/U _{PMN} of ~0.01 and Nb/Th _{PMN} of ~0.1.

Figure 27a shows that Mulligan intrusion and Lake Machattie intrusion plot exactly in the field expected for lower mantle-derived melts. Also shown in this figure are data for Devonian kimberlites from the Merlin Field in the Northern Territory (Reddicliffe, pers comm. 2015). These are interpreted to be associated with the same plume magmatic event responsible for the Diamantina intrusions.



Figure 27: Plots of Ta/U_{PMN} versus Nb/Th_{PMN} ratio showing data for (a) Mulligan and Lake Machattie Intrusions, (b) Carbonatites and alkaline silicate lithologies from Kola Peninsula alkaline ultrabasic intrusions (c) Mean ratios for data shown in (a) and (b) as well as data for EM1 (Barling et al., 1994) and HIMU (Wembenyui, 2007), plume magmas.

Comparative data for similar alkaline intrusions in the Kola Peninsula (Verhulst *et al.*, 2000; Dunworth and Bell, 2001; Arzamastsev and Arzamasseva, 2013; Zaitsev *et al*, 2014) are shown in Fig. 27b. Although scattered the data all fall around Ta/U _{PMN} of ~1 and Nb/Th _{PMN} of ~1, the mean composition of each intrusion falls exactly over the Diamantina field (Fig. 27c). Furthermore they plot close to the ratios exhibited by the compositions of the two main lower mantle derived plume reservoirs HIMU and EM1 (Collerson *et al.*, 2010). The presence of primordial ³He/⁴He in Kola Peninsula Intrusions, which are inferred to have originated from uncontaminated regions in the lower mantle and specifically the coremantle boundary, clearly indicate that the Kola Intrusions have a mantle plume origin (Tolstikhin *et al.* 2002). Given the geochemical similarity of the Kola Penisula Intrusions with the Diamantina intrusions, they also are interpreted to have had a plume origin.

La/Yb versus Total Rare Earth Projection

The La/Yb (a proxy for LREE/HREE ratio) versus total REE diagram, devised by Loubert *et al.*, (1972), is an extremely valuable projection to show chemical variations alkaline intrusions.



Figure 28: La/Yb ratio versus total REE showing data for ultramafic and mafic rocks from from Kovdor Intrusion and the Turiy Massif. Shown are fields for different rock associations from Loubert *et al.*, (1972). Data are from Verhulst *et al.*, (2000) and Dunsworth and Bell (2001). (Dunworth and Bell, 2001; Arzamastsev and Arzamasseva, 2013; Zaitsev *et al.*, 2014).

Data Mulligan and Lake Machattie Intrusions are shown in Fig. 28a & b. Comparative data from the Kola Penisnsula show that Mulligan and Lake Machattie have similar REE behaviour to Kovdor, Khibina, Turiy Mys and Vuoriyarvi intrusions (Figure 28c).

Precious Metal -Highly Siderophile Element Data

Unlike the lithophile elements e.g., Sc, REEs, Mn, V and Cr, that have no affinity for iron, and occur at chondrite concentration level in the terrestrial mantle, the PGE, Re, and Au, are strongly siderophile "iron-loving elements," and in the terrestrial mantle are depleted by two orders-of-magnitude relative to chondritic meteorites (Mungall and Naldrett, 2008; Lorand *et al.*, 2008). By contrast, concentration of the PGEs in the silicate Earth is about 0.023 ppm (Table 13). The major terrestrial PGE and Au reservoir is the core, which contains

16,240 ppb total PGEs and 500 ppb Au (Table 13).

		Bulk		Pyrolite	Bulk Silicate
	Chondrite	Earth	Core	Mantle	Earth
0.					
(dqq)	490	900	2800	3.4	3
Ir (ppb)	455	900	2600	3.2	3
Ru					
(ppb)	710	1300	1300	5	5
Rh					
(ppb)	130	240	740	0.9	1
Pt (ppb)	1010	1900	5700	7.1	7
Pd					
(ppb)	550	1000	3100	3.9	4
Au					
(ppb)	140	1600	500	1	1
Total					
PGEs					
(ppb)	3345	6240	16240	23.5	23
Total					
PGEs					
(ppm)	3.345	6.24	16.24	0.0235	0.023

Table 13: PGE and gold abundances in terrestrial reservoirs. AfterMcDonough and Sun (1995)

PGE contents of modern mantle rocks are the result of overprinting by magmatic processes, especially melt removal and re-fertilisation (Lorand *et al.*, 2008).

For PGE ores to be economic, they must contain at least 4 ppm PGEs (Mungall and Naldrett, 2008). This represents a significant enrichment over typical crustal rock values and sulfur is believed to control the genesis of such deposits. First, the presence of sulfide as a residual phase during mantle melting limits the availability of PGE to magmas. Secondly, the formation of an ore deposit requires the saturation of magma with immiscible sulfide liquid and the collection of that liquid in structural traps within the magmatic systems.

Flowing planetary accretion, PGEs were removed from the proto-mantle during core segregation, because of their siderophile (and sometimes chalcophile) behaviour. Further depletion then occurred during subsequent extraction of continental crust from the mantle. PGE-rich magnesian magmas, like komatiite and continental flood basalt provinces (containing alkalic and tholeiitic intrusions) form via variable degrees of partial melting associated with upwelling mantle plumes. As a result, orthomagmatic PGE mineral systems

are generally hosted by plume generated alkalic and tholeiitic mafic and ultramafic intrusions

PGEs in the Diamantina Intrusions

The platinum group metals, comprising the Iridium Group (Osmium, Iridium and Ruthenium) and the Palladium Group (Rhodium, Palladium, Platinum and Gold) determined by nickel sulphide fire assay and ICPMS are given in Tables 14 and 15.

Table 14: Highly siderophile element abundances (HSE) for Mulligan and La	ake
Machattie Intrusions	

	Os Ir		Ru	Rh	Pt	Pt Pd		Au
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
MUL-1	0.222	2.173	0.760	0.546	3.089	5.418	1.000	7.570
MUL-2	0.075	0.722	0.211	0.175	0.984	1.064		2.702
MUL-2	0.075	0.722	0.211	0.175	0.984	1.064		2.702
MUL-3	0.115	0.569	0.851	0.199	1.553	1.300	1.000	2.991
MUL-7	0.121	1.457	1.702	0.554	1.884	2.570	1.000	4.358
MUL-16	0.233	0.976	0.354	0.452	2.741	2.275	1.000	4.772
MUL-17	0.078	0.641	0.588	0.206	1.244	1.247		2.295
MUL-18	0.047	0.628	0.484	0.293	1.549	1.580	1.000	3.954
MUL-19		0.273	0.529	0.149	1.629	0.799	1.000	2.944
MUL-24	0.258	1.873	1.634	0.818	5.709	6.191	4.000	9.699
MUL-26	0.188	0.655	0.476	0.316	1.895	1.796	2.000	6.331
MUL-27	0.155	0.504	0.715	0.258	2.425	1.773	2.000	4.840
MUL-29		0.241	0.076	0.156	1.070	0.760	1.000	7.391
MUL-30	0.041	0.396	0.380	0.118	1.755	0.743	1.000	3.000
MUL-32	0.152	0.562	0.993	0.224	2.058	1.484	1.000	5.706
MUL-35	0.052	0.396	0.396	0.152	1.135	0.831	1.000	3.177
MUL-36	0.026	0.402	0.767	0.258	2.262	1.427	1.000	6.676
MUL-39	0.088	0.312	0.338	0.149	1.667	0.788	1.000	2.184
MUL-41	0.084	2.039	0.843	0.218	1.749	1.167	1.000	5.714
MUL-42	0.023	0.465	0.540	0.317	1.639	1.394	1.000	9.556
LM-1	0.248	2.050	0.852	0.364	2.362	3.144	1.000	5.750
LM-3	0.060	0.502		0.298	1.968	1.450	1.000	7.666
LM-5	0.168	0.900	0.417	0.277	2.124	1.698	1.000	6.270
LM-6	0.079	0.760	0.359	0.138	1.359	0.888	1.000	2.943
LM-7	0.168	0.750	0.194	0.252	3.085	2.185		5.779
LM-8	0.045	0.274	0.216	0.145	1.285	0.626		3.317
LM-9	0.062	1.326	1.114	0.323	3.136	2.369	1.000	7.994
LM-11	0.055	0.299	0.816	0.249	2.744	1.475	1.000	8.304
LM-12	0.026	0.711	0.878	0.303	2.613	1.886	1.000	6.718
LM-14	0.049	0.258	0.344	0.129	1.145	0.906		7.035
LM-18	0.229	1.615	0.926	0.265	3.261	1.774	1.000	11.884
LM-19	0.096	0.477	0.902	0.291	3.863	3.017	1.000	7.094
LM-22	0.029	1.077	1.259	0.298	7.641	2.757	1.000	5.382
LM-23	0.150	0.638	0.999	0.562	12.222	4.405	1.000	10.837
LM-24	0.171	1.423	1.651	0.240	3.655	2.619	1.000	5.914

Total PGE abundances in Mulligan and Lake Machattie range from 2.3 ppb to 16.5 ppb and 2.59 to 19 ppb respectively. Palladium and Pt are the most abundant elements, comprising 47.8 to 73.6 % and 62.4 to 87.6 % of the total PGE abundances in Mulligan and Lake Machattie respectively. Concentrations of Ir range from 0.24 to 2.17 ppb and 0.3 to 2.05 ppb in Mulligan and Lake Machattie respectively. Ru ranges from 0.21 to 1.7 ppb and 0.22

to 1.65 ppb in Mulligan and Lake Machattie respectively. Rh ranges from 0.15 to 0.82 ppb and 0.13 to 0.56 ppb in Mulligan and Lake Machattie respectively.

PGE abundances do not correlate with MgO, which varies from 9.15 to 12.16 wt% in Mulligan and 9.11 to 16.64 wt% in Lake Machattie samples, nor are PGEs correlated with Cr, Ni, Cu, or Zr.

In order to compare PGE chemistries, chondrite normalized highly siderophile element abundances for Mulligan and Lake Machattie samples are shown in Figure 29. Comparative data are also shown for chondrite normalized highly siderophile element abundances in other plume magmas (Fig. 30). Mulligan and Lake Machattie intrusions are systematically depleted in the Iridium-Group PGEs (Os-Rh) and enriched in the Palladium-Group PGEs (Pd and Pt).



Figure 29: Highly siderophile element (HSE) abundances in samples from (a) Mulligan intrusion and (b) Lake Machattie Intrusion. Abundances are normalized to the HSEs of carbonaceous chondrites (C1 Group) from Horan *et al.,* (2003). Data for Hawaiian picrites are from Ireland *et al.,* (2009).

This fractionation pattern, of depletion in Ir-Group PGEs, is shown by other Pacific Super Plume magmas. For example, Hawaiian picrites and basalts from the Ontong Java Plateau (Fig. 30a). By contrast, Atlantic Super Plume melts, e.g., picrites from Baffin Island and kimberlites from South Africa have flatter, significantly less fractionated patterns (Fig. 30b). This indicates that HSE fractionation patterns could be a useful vector to establish the pedigree of plume generated igneous systems; allowing those derived from the Pacific Super plume to be distinguished from those of African Super plume origin. To explore this possibility, HSE normalized PGE fractionation patterns for several intrusions from the Permian age Emeishan Large Igneous Province in the Yangtze Craton of SW China are shown in Figures 30c & d.



Figure 30: Highly siderophile element (HSE) abundances normalised to the HSEs of carbonaceous chondrites (C1 Group) from Horan *et al.*, (2003). (a) Pacific Plume generated Ontong Java Basalt (Rizo *et al.*, 2016). HSE abundance patterns for the Ontong Java Plateau basalts are similar to those of Mulligan and Lake Machattie intrusions and are also broadly similar to the HSE fractionation patterns exhibited by Hawaiian and Emieshan picrites (Ireland *et al.*, 2009; Li *et al.*, (2012). (b) Baffin Island basalts (Rizo *et al.*, 2016). HSE abundance patterns for the Baffin Island basalts are significantly less fractionated than data from Mulligan and Lake Machattie intrusions and are also broadly similar to the HSE fractionation (c & d) Alkaline basalts (c) and picrites (d) from the Emeishan large igneous province (Li *et al.*, 2012). Abundances are normalised to the HSEs of carbonaceous chondrites (C1 Group) from Horan *et al.*, (2003).

In Figures 30 c & d, although some basalts have flat patterns, the majority are strongly depleted in the Ir-Group PGEs with primitive low SiO_2 melts from the Emeishan intrusions having HSE fractionation patterns that lie over the Mulligan and Lake Machattie fields, and also show similar trends to those of other Pacific Super Plume generated suites, e.g., Hawaiian picrites and Ontong Java Plateau basalt.

Mulligan and Lake Machattie intrusions have similar shaped, very distinctive primitive mantle normalized patterns with PPGE (PPGE = Rh, Pt and Pd) enrichment over the IPGEs (IPGE = Os, Ir and Ru) (Fig. 31a & b). Patterns are similar in shape to data from the Hongge, Baima (Shellnut *et al.*, 2014) and Xinjie intrusions (Zhong *et al.*, 2011) (Fig. 31c to e). However, the overall enrichment of PGEs in the Xinjie intrusion is significantly higher. In this intrusion PGE





mineralization is associated with Cu-Ni-PGE sulphide ores in the lower part of the intrusion, while Fe-Ti-V oxide mineralization occurs near the top of the intrusion. The PGE enrichment relative to chondrites in ore, compared to the host gabbro is shown in Figure 31f.

In view of the geochemical similarity between the Diamantina Intrusions Xinjie and Hongge intrusions in the Emeishan LIP, the potential for sulphide hosted Cu-Ni-PGE mineralization is quite large in Mulligan and Lake Machattie intrusions. This is discussed further in the next section. Also of importance is the fact that the Figures 30 & 31 strongly support a Pacific Super Plume origin for both the Permian Emeishan Large Igneous Province and the Silurian Devonian Diamantina Province. This conclusion is indicated by palaeomagnetic data, which show that during the Permian, the Emeishan Large Igneous Province was intruded when the Yangtze craton was located over the Pacific Super Plume (Torsvik *et al.*, 2014). Additional support is provided by the fact that during the Silurian-Devonian, Proto-Australia traversed the Pacific Superplume (Torsvik *et al.*, 2008; 2010; 2014) (see below).

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Fractional Crystallization and Sulfur Saturation

Understanding the degree of S-saturation in an intrusion and thus, the ability to determine whether segregation of sulphide might have occurred, is important for understanding the distribution of PGEs and formation of orthomagmatic ore deposits. This is because PGE and the chalcophile elements have extremely high sulphide liquid–silicate liquid partition coefficients (e.g. Barnes and Maier, 1999; Naldrett, 2010).

Although the S-contents in samples may be useful, it is commonly results in equivocal interpretations, because of the volatile and mobile nature of S, which may be lost during degassing or low- temperature alteration (Andersen, 2006; Zhong *et al.*, 2011a; Bai *et al.*, 2012; Naldrett *et al.*, 2012). Nevertheless, it is possible to establish the degree of sulphide fractionation by comparing the concentrations of PGEs and other chalcophile elements, such as Ni and Cu. For example, Ni/Ir, Cu/Pd and Cu/Zr are useful, as these element pairs have similar compatibility between silicate liquids and major rock-forming minerals if sulphides are not present, but Ir, Pd and Cu are strongly partitioned into sulphide phases, compared to Ni, Cu and Zr, respectively, under S-saturated conditions. Thus, if sulphides separate from a silicate magma during crystalisation, the magma would be chalcophile-element depleted with elevated Ni/Ir, Cu/Pd and low Cu/Zr.

Relevant data for Mulligan and Lake Machattie are given in Table 14. It is clear that Mulligan and Lake Machattie data have similar in geochemistry to PGE-bearing Xinjie and Hongge, Emeishan intrusions (Fig. 32). This is seen in covariation between Cu and Zr (Fig. 32a), total PGEs versus Ti/Y (Fig. 32b) and $(Cu/Pd)_N$ versus Pd ppb (Fig. 32c) where the subscript N indicates normalization with primitive mantle values (McDonough and Sun, 1995; Barnes and Maier, 1999 and Lyubetskaya and Korenaga 2007). Mulligan samples have $(Cu/Pd)_N$ and $(Ni/Ir)_N$ ratios of 2.62 to 24.7 and 0.13 to 1.45 are low. The same trends are shown in Lake Machattie intrusion, whereas $(Cu/Pd)_N$ and $(Ni/Ir)_N$ ratios are also low 2.42 to 11.87 and 0.07 to 2.47 respectively (Fig. 32e and f). The low $(Cu/Pd)_N$ and $(Ni/Ir)_N$ indicates that the PGE budget in these rocks is controlled by accumulation of a sulphide liquid. Given this similarity, it is inferred that Mulligan and Lake Machattie, and by association other of the Diamantina Intrusion have the potential to host orthomagmatic PGE-rich sulphide mineralisation of the type identified in the Emeishan Xinjie Intrusion in China (Zhong *et al.*, 2008, 2010, 2014).

	Cu/Pd	Pd/Ir	Ni/Cu	Ni/Pd	Cu/Ir	Pt/Pd	lr/Ru	(Cu/Pd)N	(Ni/Ir)N	Total PGE (ppb)	MgO (wt%)	TiO2 (wt%)	Zr ppm	Y ppm	Yb ppm	Th ppm	Nb ppm
MUL-1	35053	2.49	0.89	31195	87389	0.57	2.86	5.05	0.13	12.21	9.59	6.48	154	19.4	1.57	1.42	19.67
MUL-2	44274	1.47	5.23	231428	65254	0.92	3.42	6.38	0.55	3.23	12.01	4.3	244	23.6	1.73	4.77	54.16
MUL-3	21382	2.28	8.29	177361	48829	1.19	0.67	3.08	0.65	4.59	11.28	4.37	263	27.3	1.96	5.06	65.24
MUL-7	18212	1.76	5.08	92460	32126	0.73	0.86	2.62	0.26	8.29	11.68	4.27	274	27.7	2.14	5.38	65.72
MUL-16	123986	2.33	1.44	178969	288924	1.20	2.76	17.85	0.67	7.03	10	4.96	237	29.6	2.43	1.66	57.36
MUL-17	46843	1.95	2.04	95450	91153	1.00	1.09	6.75	0.30	4.00	10.01	5.03	227	27.0	2.23	3.24	39.72
MUL-18	54745	2.52	0.91	50062	137743	0.98	1.30	7.88	0.20	4.58	9.06	6.95	202	48.6	3.18	2.48	56.78
MUL-19	78564	2.92	0.47	36780	229742	2.04	0.52	11.31	0.17	3.38	9.15	7.15	185	52.6	3.56	2.68	70.82
MUL-24	137416	3.31	1.26	172825	454186	0.92	1.15	19.79	0.92	16.48	9.57	5.84	214	24.1	1.66	2.68	32.08
MUL-26	137926	2.74	0.87	120219	378070	1.06	1.38	19.86	0.53	5.33	9.91	6.49	159	22.4	1.64	1.15	20.30
MUL-27	118042	3.52	1.41	166093	415418	1.37	0.70	17.00	0.94	5.83	9.97	6.48	186	23.2	1.40	1.82	31.93
MUL-29	133463	3.15	1.73	231257	419963	1.41	3.16	19.22	1.17	2.30	10.76	5.7	172	21.6	1.64	2.10	26.95
MUL-30	86040	1.87	2.95	253407	161217	2.36	1.04	12.39	0.77	3.43	9.24	6.14	206	31.4	2.25	3.89	43.96
MUL-32	171548	2.64	0.90	153693	453194	1.39	0.57	24.70	0.65	5.47	9.33	5.82	219	23.8	1.77	2.30	40.40
MUL-35	169059	2.10	2.54	429567	354360	1.37	1.00	24.34	1.45	2.96	12.16	4.98	160	24.2	1.93	1.46	37.97
MUL-36	71616	3.55	1.32	94391	254286	1.59	0.52	10.31	0.54	5.14	9.43	7.1	231	28.8	1.84	1.33	50.87
MUL-39	78031	2.53	4.23	330267	197387	2.11	0.92	11.24	1.35	3.34	12.1	5.42	144	23.9	1.61	1.19	35.24
MUL-41	41127	0.57	5.13	211116	23538	1.50	2.42	5.92	0.19	6.10	11.52	4.65	182	25.0	1.84	2.65	44.96
MUL-42	59765	3.00	1.47	88033	179178	1.18	0.86	8.61	0.43	4.38	10.02	6.63	194	31.9	2.05	1.39	40.11
LM-1	16826	1.53	1.71	28849	25811	0.75	2.41	2.42	0.07	9.02	10.65	6.29	166	22.5	1.83	0.76	15.78
LM-3	67718	2.89	1.65	111921	195625	1.36		9.75	0.52	4.28	9.62	10.04	196	26.5	1.74	0.69	24.10
LM-5	47408	1.89	0.75	35571	89405	1.25	2.16	6.83	0.11	5.58	9.43	9.37	193	33.0	1.97	1.45	19.57
LM-6	74699	1.17	0.96	71432	87199	1.53	2.12	10.76	0.13	3.58	9.11	7.61	152	26.4	1.66	0.98	10.19
LM-7	26769	2.92	1.39	37248	78035	1.41	3.87	3.85	0.18	6.63	10.09	7.28	198	31.5	1.97	0.63	7.63
LM-8	69945	2.29	6.63	463583	159842	2.05	1.27	10.07	1./1	2.59	14.23	4.44	363	31.3	2.50	7.04	118.40
LM-9	33055	1.79	1.61	53360	59044	1.32	1.19	4.76	0.15	8.33	10.07	6.7	182	28.8	1.64	0.47	7.35
LM-11	82432	4.94	1.23	101277	407206	1.86	0.37	11.87	0.81	5.64	9.41	9.11	223	44.2	2.68	1.38	25.97
LM-12	47712	2.65	1.58	75491	126564	1.39	0.81	6.87	0.32	6.42	10.09	7.11	205	30.9	1.95	0.29	7.18
LM-14	43161	3.51	10.09	435469	151597	1.26	0.75	6.22	2.47	2.83	15.18	3.31	205	24.3	1.80	4./4	66.06
	19054	1.10	2.05	50454	20925	1.84	1.74	2.74	0.09	8.07	10.86	5.14	1/3	24.7	1.58	0.36	5.05
	40010	0.32	1.04	/ 0000	202907	1.20	0.03	5.76	10.0	0.05	10.06	5.71	130	29.2	1.01	2.08	47.03
	2/10/	2.56	2.11	5/199	09558	2.11	0.86	3.91	0.24	13.06	10.9	0.26	144	19.9	1.18	0.65	3.86
	23926	0.91	1.18	201/1	165297	2.11	0.64	3.45	0.31	18.98	10.2	7.3	136	23.1	1.54	1./5	10.60
LIVI-24	20545	1.84	5.49	112847	3/802	1.40	0.80	2.96	0.33	9.76	10.64	5.01	119	16.4	1.00	0.17	2.38

Table 15: Major and trace element compositions, transition metal ratios and PGE systematics for Mulligan and Lake Machattie Intrusions

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Figure 32: Covariation between (a) Cu and Zr, (b) total PGEs and Ti/Y and (c) $(Cu/Pd)_{Ni}$ versus Ti/Y showing that the Diamantina intrusions are chemically similar to Emeishan intrusions that host PGE mineralization, (d) $(Cu/Pd)_{Ni}$ and MgO, (e) $(Cu/Pd)_{Ni}$ and Pd, and (f) $(Cu/Pd)_{Ni}$ versus $(Ni/Ir)_{Ni}$.

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Radiogenic Isotope Data

Radiogenic isotope ratios for representative samples from Mulligan and Lake Machattie Intrusions are given in Tables 16 to 19. Initial isotopic compositions were calculated assuming a crystallization age of 385 Ma, that was established by U-Pb SHRIMP geochronology (Carson et al., 2011). These data were obtained to (1) allow comparison to be made with other undersaturated alkaline ultramafic to mafic systems, and (2) to allow conclusions to be made regarding the nature of the mantle source of the magmas.

Initial isotope ratios (calculated at 385 Ma) are shown in Figure 33. Mulligan and Lake Machattie are both characterize by radiogenic ¹⁴³Nd/¹⁴⁴Nd yielding +ive ɛNd ratios and unradiogenic ⁸⁷Sr/⁸⁶Sr isotopic compositions plotting in the upper left hand quadrant (Fig. 33a) that indicate derivation from a depleted source with low Rb/Sr and high Sm/Nd.

Covariation between (b) ϵ Hf (t=385 Ma) and 87 Sr/ 86 Sr and (c) ϵ Hf (t=385 Ma) and ϵ Nd(t) show, with the exception of one sample, that the initial isotopic compositions are tightly clustered which indicates derivation from a homogeneous source and were not affected by post crystallization processes. However, LM-17 a pyrochlore-bearing silicio ferrocarbonatite shows extreme fractionation in Lu/Hf with a ratio of 0.327. The generation of carbonatite liquids with Lu/Hf significantly greater than their sources was previously acknowledged by Bizimis et al., (2003).

From a petrogenetic perspective, Fig. 33d, which shows ²⁰⁷Pb/²⁰⁴Pb versus ²⁰⁶Pb/²⁰⁴Pb data for Mulligan and Lake Machattie, is extremely significant. The first observation is that Mulligan data define a secondary isochron that intersects the lower mantle growth curve at ~385 Ma. Second, the Lake Machattie data plot above the lower mantle growth, with higher ²⁰⁷Pb/²⁰⁴Pb ratios. This shows both Mulligan and Lake Machattie intrusion were derived from melting of an extremely ancient source. This is because ²⁰⁷Pb is the daughter product of ²³⁵U which was almost extinct in 5 half-lives (3.52 Ga). Preservation of ancient source points very strongly to a deep earth environment, most likely the base of the lower mantle, which is only accessed by plume generated magmatism.

Figure 34a and b show comparative isotopic data for Kola Peninsula alkaline intrusions. These have identical source compositions to Mulligan and Lake Machattie. By contrast and the initial Nd and Sr isotopic compositiosn of the two GPE-bearing Permian Emeishan Large Igneous Province intrusions viz., Hongge and Xinjie have more radiogenic ⁸⁷Sr/⁸⁶Sr isotopic compositions. This indicates that although Permian Emeishan Large Igneous Province is the product of plume magmatism, it had different source components. These differences are evaluated in Figure 35.



Figure 33: Isotope covariation between (a) $\epsilon Nd_{(t)}$ versus ${}^{87}Sr/{}^{86}Sr_i$, (b) $\epsilon Hf_{(t)}$ versus ${}^{87}Sr/{}^{86}Sr_i$, (c) $\epsilon Hf_{(t)}$ versus $\epsilon Nd_{(t)}$ and (d) ${}^{207}Pb/{}^{204}Pb$ versus ${}^{206}Pb/{}^{204}Pb$, in Mulligan and Lake Machattie . Also shown in (d) are the modelled Pb isotopic growth curves for the lower and upper mantle (Kramers and Tolstikhin, 1997).



intrusions											
	Rb ppm	Sr ppm	Rb/Sr	⁸⁷ Rb/ ⁸⁶ Sr	^{8′} Sr/ ⁸⁶ Sr	± 2σ	⁸⁷ Sr/ ⁸⁶ Srl				
							t=385 Ma				
Mulligan											
MUL-3	48.1	609	0.0790	0.2281	0.705654	0.000009	0.704403				
MUL-6	114.1	1624	0.0702	0.2029	0.704595	0.000009	0.703483				
MUL-8	92.1	1698	0.0542	0.1567	0.704563	0.000010	0.703704				
MUL-9	60.6	2194	0.0276	0.0798	0.704467	0.000011	0.704030				
MUL-19	9.1	1011	0.0090	0.0260	0.703645	0.000009	0.703503				
MUL-22	12.6	924	0.0136	0.0394	0.703655	0.000009	0.703439				
MUL-30	20.2	588	0.0344	0.0992	0.704559	0.000009	0.704015				
MUL-39	15	628	0.0239	0.0690	0.703999	0.000007	0.703620				
MUL-41	24	670	0.0358	0.1034	0.704258	0.000009	0.703691				
MUL-44	104.5	1247	0.0838	0.2420	0.705287	0.000010	0.703960				
MUL-46	76.9	1357	0.0567	0.1637	0.704705	0.000009	0.703808				
MUL-48	59.5	2305	0.0258	0.0745	0.703874	0.000010	0.703465				
Lake Macha	ttie										
LM-2	84.4	1049	0.0804	0.2323	0.705185	0.000009	0.703912				
LM-5	6.6	357	0.0185	0.0533	0.703528	0.000009	0.703236				
LM-6	3.1	259	0.0120	0.0346	0.703695	0.000008	0.703505				
LM-7	0.7	248	0.0028	0.0082	0.703507	0.000009	0.703463				
LM-8	39.8	789	0.0504	0.1457	0.704612	0.000010	0.703813				
LM-9	1.7	221	0.0077	0.0222	0.703472	0.000008	0.703350				
LM-11	6.7	552	0.0121	0.0351	0.703908	0.000009	0.703715				
LM-15	17.4	807	0.0216	0.0623	0.703653	0.000008	0.703312				
LM-17	5	900	0.0056	0.0873	0.704217	0.000007	0.703739				
LM-19	0.8	360	0.0022	0.0064	0.703503	0.000009	0.703468				
LM-22	1.3	166	0.0079	0.0228	0.703503	0.000009	0.703378				
LM-24	0.7	97	0.0072	0.0208	0.703454	0.000009	0.703340				

Table 16: Rb-Sr Isotopic Data for Lithologies from Mulligan and Lake Machattie Intrusions



	Sm ppm	Nd ppm	¹⁴ ′Sm/ ¹⁴⁴ Nd	Sm/Nd	¹⁴³ Nd/ ¹⁴⁴ Nd ±2σ		$\epsilon Nd_{(0)}$	εNd
								(t)=385 Ma
Mulligan								
MUL-3	8.24	45.416	0.1097	0.1814	0.512619	0.000005	-0.36	3.92
MUL-6	11.362	71.104	0.0966	0.1598	0.512538	0.000006	-1.95	2.97
MUL-8	10.126	65.22	0.0939	0.1553	0.512524	0.000006	-2.22	2.84
MUL-9	6.99	44.873	0.0942	0.1558	0.512531	0.000007	-2.09	2.95
MUL-19	21.348	115.475	0.1118	0.1849	0.512588	0.000007	-0.98	3.20
MUL-22	16.308	95.261	0.1035	0.1712	0.512591	0.000006	-0.92	3.67
MUL-30	10.046	50.146	0.1211	0.2003	0.512632	0.000006	-0.11	3.61
MUL-39	8.024	31.651	0.1533	0.2535	0.512682	0.000006	0.86	3.00
MUL-41	7.803	36.147	0.1305	0.2159	0.2159 0.512680		0.82	4.08
MUL-44	12.544	69.555	0.1090	0.1803	0.512523	0.000005	-2.24	2.07
MUL-46	13.351	84.082	0.0960	0.1588	0.512481	0.000005	-3.05	1.90
MUL-48	16.659	103.243	0.0976	0.1614	0.512518	0.000008	-2.34	2.54
Lake Mach	attie							
LM-2	12.884	73.927	0.1054	0.1743	0.512500	0.000007	-2.70	1.79
LM-5	14.889	72.226	0.1246	0.2061	0.512610	0.000006	-0.55	3.00
LM-6	11.589	53.841	0.1301	0.2152	0.512635	0.000007	-0.06	3.22
LM-7	13.996	58.617	0.1444	0.2388	0.512638	0.000007	-0.01	2.57
LM-8	12.905	77.455	0.1007	0.1666	0.512534	0.000005	-2.04	2.69
LM-9	12.987	50.687	0.1549	0.2562	0.512692	0.000005	1.05	3.11
LM-11	18.934	94.353	0.1213	0.2007	0.512652	0.000006	0.26	3.98
LM-15	12.828	57.921	0.1339	0.2215	0.512633	0.000006	-0.09	3.00
LM-17	16.446	116.492	0.0854	0.1412	0.512511	0.000007	-2.49	2.99
LM-19	13.825	77.565	0.1078	0.1782	0.512636	0.000005	-0.04	4.34
LM-22	7.535	32.259	0.1412	0.2336	0.512702	0.000006	1.24	3.97
LM-24	5.83	22.865	0.1541	0.2550	0.512723	0.000005	1.67	3.76

Table 17: Sm-Nd Isotopic Data for Lithologies from Mulligan and Lake Machattie Intrusions

KDC²

Intrasion		Hfnnm	^{1/6} Lu/ ^{1/7} Hf	Lu/Hf	^{1/6} Hf/ ^{1//} Hf	+2σ	^{1/6} Hf/ ^{1/} 7Hf	cHf(0)	cHf (t)
	20		20/ 11	Eann			t=385 Ma		t=385 Ma
Mulligan							1 000 Ma		1 000 1110
MUL-3	0.262	6.556	0.0057	0.0400	0.282719	0.000003	0.282678	-2.32	4.81
MUL-6	0.375	6.739	0.0079	0.0556	0.282712	0.000004	0.282655	-2.57	3.99
MUL-8	0.41	8.048	0.0072	0.0509	0.282703	0.000003	0.282651	-2.89	3.83
MUL-9	0.277	3.785	0.0104	0.0732	0.282700	0.000003	0.282625	-2.99	2.93
MUL-19	0.415	6.359	0.0093	0.0653	0.282733	0.000004	0.282666	-1.85	4.37
MUL-22	0.399	5.758	0.0098	0.0693	0.282754	0.000004	0.282683	-1.09	4.97
MUL-30	0.349	6.927	0.0072	0.0504	0.282720	0.000004	0.282669	-2.29	4.46
MUL-39	0.249	5.008	0.0071	0.0497	0.282719	0.000004	0.282668	-2.35	4.42
MUL-41	0.282	5.671	0.0071	0.0497	0.282721	0.000004	0.282670	-2.27	4.50
MUL-44	0.491	8.886	0.0078	0.0553	0.282701	0.000003	0.282645	-2.96	3.61
MUL-46	0.451	9.045	0.0071	0.0499	0.282658	0.000004	0.282606	-4.51	2.26
MUL-48	0.506	10.305	0.0070	0.0491	0.282683	0.000004	0.282633	-3.61	3.19
Lake Machattie									
LM-2	0.372	6.616	0.0080	0.0562	0.282653	0.000004	0.282595	-4.67	1.86
LM-5	0.297	7.004	0.0060	0.0424	0.282683	0.000003	0.282639	-3.61	3.43
LM-6	0.21	6.558	0.0045	0.0320	0.282682	0.000005	0.282649	-3.65	3.77
LM-7	0.239	9.064	0.0037	0.0264	0.282675	0.000004	0.282648	-3.89	3.73
LM-8	0.306	9.051	0.0048	0.0338	0.282644	0.000003	0.282610	-4.97	2.38
LM-9	0.221	8.03	0.0039	0.0275	0.282682	0.000004	0.282653	-3.66	3.92
LM-11	0.355	8.387	0.0060	0.0423	0.282708	0.000004	0.282664	-2.74	4.30
LM-15	0.218	7.004	0.0044	0.0311	0.282695	0.000003	0.282663	-3.19	4.26
LM-17	0.348	1.066	0.0464	0.3265	0.285134	0.000039	0.284799	83.06	79.87
LM-19	0.259	6.311	0.0058	0.0410	0.282681	0.000012	0.282639	-3.69	3.40
LM-22	0.16	6.752	0.0034	0.0237	0.282670	0.000005	0.282646	-4.06	3.65
LM-24	0.156	5.453	0.0041	0.0286	0.282659	0.000004	0.282630	-4.45	3.09

Table 18: Lu-Hf Isotopic Data for Lithologies from Mulligan and Lake Machattie Intrusions

 $\begin{aligned} & \epsilon Hf_{(0)} = 10^{4} [({}^{176} Hf/{}^{177} Hf_{sample} / {}^{176} Hf/{}^{177} Hf_{CHUR}) - 1] \text{ where } {}^{176} Hf/{}^{177} Hf_{CHUR} = 0.2827858 \\ & \epsilon Hf_{(0)} = 10^{4} [({}^{176} Hf/{}^{177} Hf_{sample} / {}^{176} Hf/{}^{177} Hf_{CHUR}) - 1] \\ & \text{where } {}^{176} Hf/{}^{177} Hf_{CHUR} = 0.282785 - 0.0336 (e^{\lambda t} - 1) \text{ where } \lambda = 1.867 * 10^{-11} \text{ year}^{-1} (\text{Söderlund}) \end{aligned}$

et al., 2004) and t = 385 Ma. CHUR values are from Bouvier et al., (2008).



Figure 34: ɛNd versus ⁸⁷Sr/⁸⁶Sr data for (a) Kovdor, Khibina, Lovozero and Turiy Mys intrusions on the Kola Peninsula, (b) Comparison between Mulligan and Lake Machattie data the initial isotopic compositions of similar plume generated Kola Peninsula Intrusions, and (c) Comparative data for PGE-bearing Permian age Hongge (Zhong *et al.*, 2003) and Xinjie Intrusions (Zhong *et al.*, 2004)

The Devonian Diamantina intrusions Mulligan and Lake Machattie and Devonian alkaline intrusions on the Kola Peninsula Intrusions have identical source characteristics (Fig. 35a and b) that lie on a mixing line between the composition of the two lower mantle end-members EM1 and HIMU (Collerson *et al.*, 2010) and EM11. By contrast, the Emeishan intrusions, Hongge and Zinjie, have distinctly more radiogenic ⁸⁷Sr/⁸⁶Sr initial isotopic compositions and plot close to EM11. This could reflect melting of this component during plume upwelling, or alternatively, as some compositions are even more radiogenic than EM11, these isotope systematics, might be the result of the plume passing through and interacting with ancient transition zone lithologies at depths of ~400 to 650 km.

-2



Figure 35: εNd versus ⁸⁷Sr/⁸⁶Sr data for (a) Mulligan and Lake Machattie (b) Kovdor, Khibina, Lovozero and Turiy Mys intrusions on the Kola Peninsula and (c) PGE-bearing Permian age Hongge (Zhong *et al.*, 2003) and Xinjie Intrusions (Zhong *et al.*, 2004). The end-member compositions are from Murphy et al., (2002) and Collerson et al., (2010).

	Pb	U	In	PD/201PD	±2σ	201 PD/201 PD	±2σ	PD/201PD	±2σ	2000/201Pb	PD	U	200°Pb/201Pb	PD/201PD	PD/201PD
	ppm	ppm	ppm										t=385 Ma	t=385 Ma	t=385 Ma
Mulligan															
MUL-3	2.97	1.34	5.06	20.071	0.001	15.671	0.001	41.057	0.002	30.25	118.11	3.90	18.210	15.570	38.786
MUL-6	4.93	1.71	8.27	20.078	0.001	15.679	0.001	41.336	0.002	23.39	116.93	5.00	18.638	15.601	39.087
MUL-8	6.78	1.86	10.25	19.042	0.001	15.620	0.001	39.851	0.002	17.88	101.84	5.69	17.942	15.560	37.893
MUL-9	6.32	0.98	5.55	20.101	0.001	15.686	0.001	41.401	0.002	10.42	61.24	5.88	19.460	15.651	40.223
MUL-19	0.91	0.54	2.68	20.506	0.001	15.706	0.001	41.727	0.003	40.85	208.75	5.11	17.991	15.569	37.712
MUL-22	1.56	0.83	3.33	19.910	0.001	15.675	0.001	40.865	0.002	35.53	147.97	4.16	17.724	15.556	38.019
MUL-30	1.84	0.92	3.89	21.456	0.001	15.756	0.001	41.762	0.003	34.48	150.73	4.37	19.334	15.641	38.864
MUL-39	1.07	0.37	1.19	20.119	0.001	15.682	0.001	40.569	0.002	22.85	76.42	3.35	18.713	15.605	39.099
MUL-41	1.69	0.69	2.65	19.398	0.001	15.643	0.001	39.828	0.003	26.78	105.99	3.96	17.750	15.554	37.790
MUL-44	4.06	1.80	9.24	20.131	0.001	15.693	0.001	41.388	0.002	29.98	158.82	5.30	18.286	15.592	38.334
MUL-46	4.27	1.52	9.28	19.538	0.001	15.659	0.001	41.306	0.002	23.75	150.27	6.33	18.076	15.580	38.416
MUL-48	5.63	1.86	8.66	19.062	0.001	15.613	0.001	40.118	0.003	21.66	104.14	4.81	17.729	15.541	38.115
Lake Machattie	9														
LM-2	4.71	1.77	9.10	19.343	0.001	15.662	0.001	40.437	0.002	24.86	131.87	5.31	17.813	15.579	37.901
LM-5	1.18	0.27	1.45	18.701	0.001	15.690	0.001	39.707	0.002	14.59	82.37	5.64	17.803	15.642	38.123
LM-6	2.70	0.10	0.98	18.279	0.001	15.639	0.001	40.032	0.002	2.31	24.22	10.50	18.137	15.631	39.566
LM-7	0.59	0.16	0.63	20.871	0.005	15.841	0.004	44.184	0.013	19.47	78.35	4.03	19.673	15.776	42.678
LM-8	4.39	1.46	7.04	19.502	0.001	15.677	0.001	40.448	0.002	22.01	109.68	4.98	18.148	15.603	38.339
LM-9	0.69	0.09	0.47	19.887	0.003	15.804	0.003	40.773	0.007	8.67	47.32	5.46	19.354	15.775	39.863
LM-11	4.08	0.25	1.38	18.311	0.001	15.640	0.001	48.561	0.003	4.44	25.30	5.69	18.037	15.625	48.074
LM-15	2.45	0.16	0.84	18.314	0.001	15.651	0.001	38.763	0.002	4.03	22.55	5.59	18.066	15.638	38.329
LM-17	5.88	0.13	8.89	18.225	0.001	15.653	0.001	39.141	0.002	1.44	99.83	69.56	18.137	15.648	37.221
LM-19	1.14	0.12	2.08	20.131	0.002	15.725	0.002	41.747	0.005	6.89	127.98	18.56	19.707	15.702	39.285
LM-22	0.32	0.07	0.65	18.979	0.002	15.738	0.002	42.740	0.008	15.00	141.45	9.43	18.056	15.688	40.020
LM-24	0.29	0.04	0.17	18.812	0.004	15.700	0.003	39.053	0.008	7.75	38.21	4.93	18.335	15.674	38.318

Table 19: Pb Isotopic Data for Lithologies from Mulligan and Lake Machattie Intrusions

Stable Isotopes

C and O isotopic data for three samples of silicio ferrocarbonatites from Lake Machattie Intrusion, presented as standard δ ‰ notation with reference to V-PDB and V-SMOW, respectively are given in Table 20. They exhibit a restricted range in δ^{13} C of -6.04 to -6.51 and δ^{18} O of 7.63 to 8.30. In Fig. 29 they are compared with data for other carbonatites and with data for limestones. The data for carbonatites from Lake Machattie intrusion plot completely within the field of δ^{13} C and δ^{18} O (– 4 to –8 ‰) and (6 to 10‰) respectively exhibited by plume generated ocean island basalts (Bell and Simonetti, 2010).

 Table 20: Carbon and Oxygen Isotope Composition of Carbonates in Lake Machattie

 Silicio Ferrocarbonatites

Sample	Lithology	$\delta^{13}C_{PDB}$	δ ¹⁸ O _V -smow
LM-16	Pyrochlore-bearing silicio ferrocarbonatite	-6.51	7.89
LM-17	Pyrochlore-bearing silicio ferrocarbonatite	-6.32	8.30
LM-17 Rept.	Pyrochlore-bearing silicio ferrocarbonatite	-6.34	8.29
LM-17 Rept.	Pyrochlore-bearing silicio ferrocarbonatite	-6.43	7.98
LM-20	Silicio ferrocarbonatite	-6.04	7.63



Figure 36: Carbon and oxygen isotopic data for silicio ferrocarbonatites (LM-16, LM-17 and LM-20) from Lake Machattie Intrusion plot within the Greenland carbonatite field as well as the very restricted field of ocean Island basalts. The fields shown for comparison are from Bell and Simonetti (2010).

Geodynamic Interpretation and Significance

The alkaline intrusions that contain phoscorite and carbonatite in southwestern Queensland exhibit pronounced coincident magnetic and gravity anomalies, up to 12 km in diameter (Figure 2). They extend along a northwest trend, into the Northern Territory and southeast, along a t trend into New South Wales.

The ages of the intrusions, decrease from the southeast, Fifield and Owendale in New South Wales (444 ± 4 Ma; Glen *et al.*, 2007), through Gilgai (442 ± 2 Ma Fraser *et al.*, 2014) the south western Queensland Diamantina intrusions (386 ± 2 Ma; Carson *et al.*, 2011) to the Merlin kimberlite field in the Northern Territory (368 ± 4 Ma; McInness *et al.*, 2009).

In view of this age progression and lithological/geochemical similarity, the Devonian alkaline intrusions in SW Queensland are interpreted to be part of a \sim 2000 km long \sim 200 km wide plume track (Figure 37) extending from NSW (Fifield platinum and scandium pipes) to the Northern Territory (Merlin kimberlite). This formed during the Silurian to Devonian when proto-Australian lithosphere (as part of Gondwana), passed over the Pacific Superplume (Torsvik *et al.*, 2010).

This is the longest plume track yet discovered in continental lithosphere. It extends for more than 2010 km magmatism lasted from the Silurian (~444 Ma) to the early Devonian (365 Ma) a period of 76 Ma. From these parameters the plate velocity during passage over the plume can be calculated at 2.6 cm/year. For comparison, the current drift of the Australian plate is 7 cm/year. Kimberlites are products of mantle plume magmatism (Collerson *et al.*, 2010), thus the occurrence of micro-diamonds and diamond indicator minerals in eastern Northern Territory (Hutchison, 2013) and western Queensland (Tompkins 2002) further supports the impact of a mantle plume along the track shown in Figure 37.

As shoshonite magmatism occurs in areas where an upwelling plume penetrates and melts metasomatised mantle wedge (Collerson *et al.*, 2015), the Pacific superplume may also have played a role in formation of the 444 Ma Cadia and Northparkes Au (PGE) and Cu deposits when it interacted with the mantle wedge below Macquarie arc, during the Silurian.





Figure 37: Distribution of alkaline intrusions that define the plume track vector extending from Fifield to the Merlin kimberlites

Mineralisation Potential of Alkaline Intrusions Containing Phoscorite-Carbonatite Pipe Complexes

The discovery of the Diamantina Alkaline Province has considerable economic significance and opens up an entirely new region of Queensland for mineral exploration. Phoscorite-carbonatite complexes similar to those discovered in the Diamantina Alkaline Province in Queensland contain both magmatic and metasomatic mineralisation (Wall and Zaitev, 2004; Fontana, 2006).

Despite their rarity, phoscorite-carbonatite intrusions have significant economic endowment in platinum group elements (PGE; including platinum, palladium, rhodium), rare earth elements (REE),

yttrium (Y), high field strength elements (HFSE; zirconium, niobium and tantalum), scandium (Sc), iron (Fe), phosphorus (P) and the actinides (U and Th). Mines with these commodities include:

- Phosphate Phalaborwa (RSA), Jacupiranga, Tapira and Catalão (Brazil), Kovdor (Russia); Sokli (Finland).
- PGEs Alaska, Urals and Aldan Shield (Russia).
- Scandium, zirconium and hafnium Kovdor (Russia).
- Copper Phalaborwa (RSA).
- Iron Kovdor (Russia).
- Niobium Araxá and Catalão (Brazil), Sokli (Finland).
- PGEs Alaska, Urals and Aldan Shield (Russia).

Significant prospectivity of the large intrusions within the Diamantina Alkaline Province is suggested by elevated concentrations of zirconium (500 ppm), P2O5 (4.5 wt. %), Nb (250 ppm), and total REE + Y (3000 ppm). The high Sc concentration recorded in the Diamantina lithologies is similar to values in Brazilian intrusions (Brod et al., 2013).

Furthermore, the cores also have elevated precious metals with Au ranging up to 11 ppb and one interval returning an assay of 33 ppb Pt plus Pd. They have virtually identical highly siderophile and chalcophile element profiles to those reported in other plume generated igneous provinces, such as the Emeishan in China which were also emplaced when the Yangtze Craton was over the Pacific Super Plume during the Permian.

Kimberlite pipes, some of which contain economic concentrations of diamond, are also associated with plume magmatism e.g., on the Kola Peninsula in Russia and northern Finland (Downes et al., 2005). As a result the Diamantina metallogenic province has significant diamond potential. This has already been confirmed with the discovery and exploitation of the Merlin Kimberlite Field in the Northern Territory. The high concentration of diamond indicator minerals and microdiamonds occurs along the trend in the eastern Northern Territory (Hutchison, 2013) also supports this interpretation.

Key Conclusions

Identification of the Diamantina alkaline province using spinifex biogeochemistry and the discovery that the province forms part of continental scale plume track is a significant advance for Australian geology. It provides a further example of the direct link between mantle plumes and alkaline magmatic provinces (Hartnady and le Roex, 1985; Heaman *et al.*, 2004).

Although phoscorite is an extremely rare lithology, occurrences are generally associated with economic mineralisation. Thus the Diamantina Province, a new metallogenic province in Australia has the potential to emerge as exciting new postcode for greenfield exploration in Queensland.

As this province was discovered using spinifex biogeochemistry, the study has demonstrated the power of biogeochemistry in mineral exploration. Spinifex is clearly an excellent sampling medium and occurs in large tracts of Australia. Given the success of this study, spinifex biogeochemistry should continue to be used as a low-cost and low-impact "grassroots" greenfield exploration technique to identify elemental anomalism, interpret lithologies under cover and contribute to expansion of the knowledge base of Australian geoscience.

Specific key findings of this litho-geochemical study are as follows:

- The chemistry of Mulligan Intrusion defines a continuous trend of highly silica undersaturated compositions belonging to the melteigite-ijolite-urtite series (foid-bearing gabbros, diorites, monzonites and syenites). Fractionation extends from alkali pyroxenite (turjaites), though alkali gabbro and melteigite to ijolite and nepheline syenite, with SiO₂ ranging from ~30 to 62 wt.%. Mulligan Intrusion and exhibits smooth fractionation with increasing SiO₂ with Al₂O₃, Na₂O and K₂O increasing and decreasing TiO₂, FeO*, MnO, MgO and CaO.
- Lithologies from the Lake Machattie intrusion define a separate, but overlapping trend with SiO₂ extending from ~40 wt% in phoscorites and alkali pyroxenites to ~11wt.%. in silicio carbonatites. Lake Machattie intrusion is dominated by melilite-bearing compositions, with a few samples (silicio carbonatites) lie in the kimberlite field. Lake Machattie Intrusion is significantly more undersaturated with SiO₂ between 10 and 41 wt.%.
- Parent magma composition varied between 30 and 35 wt. % SiO₂. This primary melt composition is also enriched in P_2O_5 , with up to 4.2 wt.% in pyroxene-rich phoscorite.
- Lake Machattie lithologies, with between 25 and 35 wt. % SiO₂ contain the highest P₂O₅ contents. Mulligan also contains high-P₂O₅ Mulligan samples, but with to slightly lower SiO₂.
- Major element variation in Mulligan and Lake Machattie intrusions reflect crystal-liquid fractionation, as well as the separation of an immiscible carbonate-rich liquid. Mulligan and Lake Machattie intrusions have divergent fractionation trends, shown by Lake Machattie sampled fractionating to extreme $\text{TiO}_2 \sim 11 \text{ wt.\%}$. This divergent trend is interpreted to reflect the role of liquid immiscibility that resulted in the separation of a carbonatitic magma.
- Diamantina Intrusions (Mulligan and Lake Machattie) have identical magmatic trends to lithogeochemical trends reported from Khibina, Lovozer, Kovdor, Afriknda, Lesnaya Varka, Vuoriyarvi and Turiy Massif alkaline intrusions on the Kola Peninsula, Catalão, Tapira and Salitre intrusions in Brasil and the Cape Verde ocean island alkaline suite.
- CO₂-rich samples from Lake Machattie intrusion are classified as silicio ferrocarbonatite. This is economically important, because ferrocarbonatites host, and are responsible for much of the economic wealth associate with this style of magmatism
- Mulligan and Lake Machattie intrusions have liquidus temperatures of 1485±48°C and 1500±53°C respectively they agree with temperatures calculated for the Iceland plume and support the interpretation that the Diamantina Intrusions are of plume origin.
- The highest transition metal abundances occur in lithologies with SiO₂ between 30 and 40 wt. %. In Mulligan the highest concentrations are Cr ~ 1300 ppm, V ~ 850 ppm, Ni ~ 1400 ppm, Sc ~ 68 ppm and Cu ~1100 ppm. The highest concentrations of transition metals are in compositions close to those of the parental magma.
- Zn is another transition metal that is enriched in alkaline magmas it reaching maximum concentrations of ~450 ppm in Mulligan intrusion and 300 ppm in Lake Machattie Intrusion
- The highest Co values occur in Lake Machattie intrusion ~540 ppm, in samples containing the smallest amount of immisible carbonate.
- The maximum Cr values are ~1350 ppm in Mulligan and 800 ppm in Lake Machattie Intrusion.

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- Cu in Mulligan lithologies reach values of ~1000 ppm. By contrast the highest Cu values recorded in Lake Machattie are only ~ 150 ppm.
- Scandium in Mulligan and Lake Machattie Intrusions range from 2.8 to 62.8 ppm (mean 31.2±15.8 ppm) and 7.3 to 56 ppm (mean 33.3±13.4 ppm) respectively. Similar occur in phoscorites in the Kovdor Intrusion on the Kola Peninsula, viz., mean Sc = 61±18 ppm.
- The mean Sc content of the Mulligan and Lake Machattie intrusions are similar to the Sc content of related silicate lithologies e.g., 27±30 ppm (olivinites, pyroxenites, ijolite-melteigites and melilite-bearing rocks) and 22±8 ppm (carbonatite) in the Kovdor intrusion, currently being assessed for as a source of Sc.
- Lake Machattie and Mulligan intrusons are both enriched in Au and PGEs, with maximum values of ~11 ppb Au in both intrusions, and 33 ppb and 15 ppb Pd and Pt in Mulligan and Lake Machattie respectively. These values reflect the high background levels of precious metals in these plume magmas.
- The highest Nb values (up to 500 ppm) are recorded in pyrochlore-bearing silicioferrocarbonatite from Lake Machattie intrusion. These also contain the highest REEs+ Y (up to ~3000 ppm).
- Lake Machattie samples are light REE enriched ($La_N/Yb_N = 5.4$ to 57.5, with the greatest degree of fractionation being shown by the ferrocarbonatites, where La_N is 350x enriched. They also have significant levels of HREEs with $Yb_N \sim 10x$ chondrites.
- Mulligan amphibole-bearing pyroxenites and phoscotites are significantly REE enriched with up to 700x enrichment in La_N and ~25x enrichment in Yb_N. These have the potential to host HREE mineralisation.
- Chondrite normalised REE plots Mulligan and Lake Machattie intrusions are very similar to data for Khibina, Kovdor, Yuriy Mys and Vuoriyarvi intrusions on the Kola Peninsula. As alkaline intrusions from both areas have remarkably similar chondrite normalized REE patterns they appear to had similar sources and petrogenetic histories.
- Mulligan and Lake Machattie Intrusions have remarkably similar primitive mantlenormalized plots to Khibina (Fig. 20a), Kovdor (Fig. 20b), Vuoriyarvi (Fig. 20c) and Turiy Mys intrusions. This geochemical similarity of these large alkaline intrusions indicates a commonality in petrogenetic process form the Diamantina and Kola Peninsula Suites.
- La/Yb (a proxy for LREE/HREE ratio) versus total REE systematics show that Mulligan and Lake Machattie Intrusions plot in virtually the same fields as Kola Penisnsula Kovdor, Khbina, Turiy Mys and Vuoriyarvi intusions, indicating commonality in source and petrogenetic processes.
- Majority of Mulligan samples and all of the Lake Machattie samples have sub-chondritic Y/Ho. This reflects the influence of F-rich fluids, which have the ability to fractionate Y from Ho.
- Both intrusions also show considerable variation in Zr/Hf ratio which has been shown to be characteristic alkaline intrusions from which carbonatite liquids have evolved. These variations in Y/Ho and Zr/Hf are identical to the behaviour of the CHARAC elements in alkaline intrusions in Brasil and also those on the Kola Peninsula.
- The plume origin of Mulligan and Lake Machattie magmas is confirmed from primitive mantle normalised Ta/U and Nb/Th which show that Mulligan intrusion and Lake Machattie intrusion plot exactly in the field expected for lower mantle-derived melts.
- Although scattered, Kola primitive mantle normalised Ta/U and Nb/Th data all fall close to a Ta/U $_{PMN}$ of ~1 and Nb/Th $_{PMN}$ of ~1, with mean compositions of each intrusion

falling exactly over the Diamantina field, and close to the ratios exhibited by the compositions of the two main lower mantle derived plume reservoirs HIMU and EM1.

- Primordial ³He/⁴He reported in Kola Peninsula Intrusions originated from uncontaminated regions in the lower mantle most likely close to the core-mantle boundary. This indicates that these intrusions have a mantle plume origin. Given the geochemical similarity between the Kola Penisula Intrusions and the Diamantina intrusions they also are interpreted to have had a plume origin.
- Total PGE abundances in Mulligan and Lake Machattie range from 2.3 ppb to 16.5 ppb and 2.59 to 19 ppb respectively. Palladium and Pt are the most abundant elements, comprising 47.8 to 73.6 % and 62.4 to 87.6 % of the total PGE abundances in Mulligan and Lake Machattie respectively.
- Chondrite normalized highly siderophile element Mulligan and Lake Machattie intrusions are systematically depleted in the Iridium-Group PGEs (Os-Rh) and enriched in the Palladium-Group PGEs (Pd and Pt). This is an important observation as this geochemical behaviour is shown by other Pacific Super Plume magmas (Hawaii, and Ontong Java Plateau). By contrast, Atlantic Super Plume melts, e.g., picrites from Baffin Island and kimberlites from South Africa have flatter, significantly less fractionated patterns. Thus HSE fractionation patterns are a useful vector to establish the pedigree of plume generated igneous systems.
- Mulligan and Lake Machattie intrusions also have similar shaped, very distinctive primitive mantle normalized patterns with PPGE (PPGE = Rh, Pt and Pd) enrichment over the IPGEs (IPGE = Os, Ir and Ru). These patterns are similar in shape to those of the PGE-bearing Hongge and Xinjie intrusions in the Emeishan Large Igneous Province, which suggests that they may have a common origin vz. Pacific Super Plume and the Yangtze craton was located over the Pacific Super Plume during the Permian.
- Mulligan and Lake Machattie intrusions have similar Cu and Zr, total PGE versus Ti/Y, (Cu/Pd)_N versus Ti/Y and (Cu/Pd)_N versus (Ni/Ir)_N systematics to PGE-bearing Emeishan LIP, Xinjie and Hongge intrusions. Given this similarity, it is inferred that Mulligan and Lake Machattie, and by association other of the Diamantina Intrusion.
- The source of Mulligan and Lake Machattie magmas have radiogenic ¹⁴³Nd/¹⁴⁴Nd yielding +ive εNd ratios and unradiogenic ⁸⁷Sr/⁸⁶Sr isotopic compositions plotting in the upper left hand quadrant, indicating derivation from a depleted source with low Rb/Sr and high Sm/Nd.
- εHf (t=385 Ma) initial isotopic compositions also indicates derivation from a homogeneous source and were not affected by post crystallization processes. The only exception to this is shown by a sample of pyrochlore-bearing silicio ferrocarbonatite which exhibits extreme fractionation in Lu/Hf resulting in a ratio of 0.327, a common feature of carbonatites.
- ²⁰⁷Pb/²⁰⁴Pb versus ²⁰⁶Pb/²⁰⁴Pb data for Mulligan and Lake Machattie, show that Mulligan data define a secondary isochron that intersects the lower mantle growth curve at ~385 Ma. Lake Machattie data plot above the lower mantle growth, with higher ²⁰⁷Pb/²⁰⁴Pb ratios. Thus both Mulligan and Lake Machattie intrusion were derived from melting of an extremely ancient source.
- Preservation of ancient source points very strongly to a deep earth environment, most likely the base of the lower mantle, which is only accessed by plume generated magmatism.
- Devonian Diamantina intrusions (Mulligan and Lake Machattie) and Devonian alkaline intrusions on the Kola Peninsula Intrusions have identical sources that lie on a mixing

lines between the composition of the lower mantle end members EM1, HIMU and EM11.

- The Emeishan intrusions Hongge and Zinjie have distinctly more radiogenic ⁸⁷Sr/⁸⁶Sr initial isotopic compositions and plot close to EM11. This could reflect melting of an EM 11 component during plume upwelling. However, as some compositions are more radiogenic than EM11, these isotope systematics, might be the result of the plume passing through, and interacting with, ancient transition zone lithologies at depths of ~400 to 650 km.
- C and O isotopic data for carbonatites from Lake Machattie intrusion plot completely within the field of δ^{13} C and δ^{18} O (-4 to -8 ‰) and (6 to 10‰) respectively, exhibited by plume generated ocean island basalts.
- Devonian alkaline intrusions in SW Queensland are part of a ~2000 km long ~ 200 km wide plume track, extending from NSW (Fifield platinum and scandium pipes) to the Northern Territory (Merlin kimberlite).
- This is the longest plume track yet discovered in continental lithosphere. Magmatism lasted from the Silurian (~444 Ma) to the early Devonian (365 Ma) a period of 76 Ma
- The track formed during the Silurian to Devonian when proto-Australian lithosphere (as part of Gondwana), passed over the Pacific Superplume.
- Discovery of the Diamantina Alkaline Province has considerable economic significance and opens up an entirely new region of Queensland for mineral exploration.
- In this regard phoscorite-carbonatite intrusions have significant economic endowment in platinum group elements (PGE; including platinum, palladium, rhodium), rare earth elements (REE), yttrium (Y), high field strength elements (HFSE; zirconium, niobium and tantalum), scandium (Sc), iron (Fe), phosphorus (P) and the actinides (U and Th).
- Kimberlites are also associated with plume magmatism and the occurrence of micro-diamonds and diamond indicator minerals in eastern Northern Territory (Hutchison, 2013) and western Queensland further highlights the diamond potential of the plume track.
- The mineralisation system associated with the alkaline intrusions could occur either in the intrusion, or in the surrounding carbo-thermally produced fenite alteration halo due to precipitation from fluids originating from the intrusions. These highly attractive target zones could exceed 1-2 km in width.
- Furthermore, as shoshonite magmatism occurs in areas where upwelling plumes have penetrated and melted metasomatised mantle wedge (Collerson *et al.*, 2015), the Pacific superplume may also have played a role in formation of the 444 Ma Cadia and Northparkes Au (PGE) and Cu deposits as it impacted the Macquarie arc during the Silurian.

Recommendations for Additional Investigations

The Diamantina alkaline intrusions represent a major new exploration opportunity in Queensland for a range of elements, including many of high-value that are in increasing demand for electronics and technology industries. These include scandium, cobalt, vanadium, the heavy rare earth elements, the platinum group metals as well as gold, copper and nickel.

To encourage commercial interest in this opportunity and stimulate further exploration in this poorly explored region of the State, it is recommended that the GSQ consider expanding this study to include the following:

- A full mineragraphic study (EDS, EPMA and Raman) to characterise the natutre and chemistry of the oxide, sulphide and telluride phases that have been noted in this report.
- Carbonatites in the Diamantina intrusions have been shown in this report to be economically valuable ferro carbonatites (Le Bas, 1987). The mineralisation system could be found in the intrusion, or in the surrounding carbo-thermally produced fenite alteration halo caused by deposition from fluids originating from the intrusions. These zones could exceed 1-2 km in width. Unfortunately, the fenite zone was not recognised nor was it sampled in the earlier CDI drilling program at Mulligan and Lake Machattie. Therefore, an additional litho geochemical investigation on new diamond drill core that specifically targeted the fenite alteration halo is recommended as a priority step to add significant value to this new greenfield opportunity.

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Appendix

	JUI) repo	rtea by <i>l</i>	Ausque	St						
Sample #	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514
From (m)	902.2	903.82	904.8	916.51	920	920.67	921.16	925.1	936.1	940.2
To (m)	902.4	904	905	916.72	920.67	921.16	922	925.3	936.3	940.41
SiO ₂	36.08	56.49	47.74	43.07	41.61	37.79	40.14	49.15	37.14	61.06
TiO2	5.90	0.67	3.04	3.66	4.61	5.32	4.59	2.92	5.25	0.78
Al ₂ O ₃	9.35	21.80	17.10	13.10	11.10	7.94	9.83	16.30	8.75	18.20
Cr ₂ O ₃	0.07	0.00	0.00	0.06	0.09	0.09	0.11	0.00	0.07	0.00
V ₂ O ₅	0.12	0.01	0.03	0.05	0.07	0.11	0.07	0.03	0.11	0.00
FeO	17.50	2.72	9.81	11.50	11.80	16.50	12.20	9.81	17.20	3.73
MnO	0.20	0.06	0.20	0.19	0.16	0.19	0.17	0.18	0.20	0.06
MgO	10.20	1.13	3.80	9.02	10.80	11.10	12.50	3.61	11.40	0.67
CaO	14.60	2.34	7.30	10.90	13.00	16.90	13.80	7.10	14.20	1.89
Na₂O	1.28	5.64	4.47	3.05	1.96	0.77	1.63	4.11	1.29	4.86
K ₂ O	0.68	5.94	3.06	1.94	1.60	0.30	1.10	3.49	0.86	7.61
P ₂ O ₅	0.17	0.09	1.24	0.72	0.10	0.08	0.11	0.98	0.09	0.14
SO ₂	0.84	0.36	0.30	0.36	0.50	1.68	0.44	0.28	0.82	0.08
CO2	1.40	0.80	-0.10	0.60	1.00	0.70	1.20	0.40	1.00	0.40
Total C	0.39	0.26	0.06	0.17	0.28	0.23	0.36	0.14	0.28	0.16
TotOrg C	0.02	0.03	0.04	0.01	0.01	0.04	0.04	0.03	0.01	0.05
LOI	1.64	2.80	0.76	1.19	1.44	0.92	1.88	1.08	1.13	0.32
Total	100.44	101.14	98.84	99.58	100.13	100.65	100.17	99.61	99.80	100.02
Na ₂ O+K ₂ O	1.96	11.58	7.53	4.99	3.56	1.07	2.73	7.60	2.15	12.47
CaO/Al ₂ O ₃	1.56	0.11	0.43	0.83	1.17	2.13	1.40	0.44	1.62	0.10
MgO/CaO	0.70	0.48	0.52	0.83	0.83	0.66	0.91	0.51	0.80	0.35
SiO ₂ /Al ₂ O ₃	3.86	2.59	2.79	3.29	3.75	4.76	4.08	3.02	4.24	3.35
Fe/Mn	87.82	45.50	49.23	60.75	74.02	87.16	72.03	54.70	86.32	62.40
CaO wt.%	39.76	37.44	34.58	34.48	36.35	37.82	35.69	34.30	33.02	29.76
MgO wt.%	23.15	18.08	18.00	28.54	30.20	24.84	32.32	17.44	26.51	10.55
FeO+MnO%	37.09	44.48	47.42	36.98	33.45	37.35	31.99	48.26	40.47	59.69

Table Appendix 1: Major element compositions of lithologies from Mulligan (MULDH001) reported by Ausquest

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Sample #	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524
From (m)	949.55	957.78	960.34	961.31	979.53	990.8	999.4	1010.1	1020.75	1030.57
To (m)	949.74	958	960.53	961.48	979.72	991	999.59	1010.32	1020.97	1030.76
SiO ₂	36.04	33.68	43.42	43.09	34.74	58.55	40.51	37.12	34.60	44.10
TiO ₂	5.86	6.64	3.71	3.66	6.52	1.22	4.46	6.10	5.96	3.98
Al ₂ O ₃	9.68	9.55	13.50	13.30	9.26	18.20	11.00	12.00	16.40	15.60
Cr ₂ O ₃	0.01	0.00	0.05	0.05	0.01	0.00	0.09	0.01	0.01	0.01
V ₂ O ₅	0.12	0.15	0.05	0.05	0.14	0.00	0.06	0.08	0.07	0.04
FeO	17.40	19.90	11.60	11.50	19.30	4.77	12.70	14.40	14.30	11.50
MnO	0.18	0.19	0.19	0.19	0.20	0.12	0.19	0.20	0.18	0.22
MgO	9.93	9.55	8.49	8.46	9.75	1.05	11.80	9.13	6.32	4.85
CaO	14.60	15.00	10.50	10.70	15.20	2.86	11.00	13.00	14.30	9.23
Na₂O	1.58	1.05	3.18	3.14	1.06	5.06	2.47	2.37	1.95	3.77
K₂O	0.87	0.53	2.15	2.07	0.57	6.41	2.00	1.76	1.00	2.70
P ₂ O ₅	0.16	0.16	0.72	0.72	0.14	0.27	0.60	0.94	2.05	1.22
SO2	1.16	1.24	0.28	0.40	1.06	0.10	0.36	0.50	0.42	0.40
CO2	1.20	0.90	0.30	0.80	0.80	0.50	0.70	0.50	1.00	0.40
Total C	0.36	0.25	0.11	0.23	0.23	0.15	0.19	0.18	0.27	0.13
TotOrg C	0.04	0.01	0.02	0.01	0.02	0.01	0.01	0.04	0.01	0.01
LOI	1.16	1.05	0.91	1.13	0.69	0.70	1.10	1.01	1.02	1.04
Total	100.35	99.86	99.18	99.50	99.69	99.97	99.24	99.35	99.86	99.20
Na ₂ O+K ₂ O	2.45	1.58	5.33	5.21	1.63	11.47	4.47	4.13	2.95	6.47
CaO/Al ₂ O ₃	1.51	1.57	0.78	0.80	1.64	0.16	1.00	1.08	0.87	0.59
MgO/CaO	0.68	0.64	0.81	0.79	0.64	0.37	1.07	0.70	0.44	0.53
SiO ₂ /Al ₂ O ₃	3.72	3.53	3.22	3.24	3.75	3.22	3.68	3.09	2.11	2.83
Fe/Mn	97.02	105.12	61.28	60.75	96.86	39.90	67.09	72.27	79.74	52.47
CaO wt.%	34.67	33.60	34.11	34.68	34.20	32.50	30.82	35.39	40.74	35.78
MgO wt.%	23.58	21.39	27.58	27.42	21.93	11.93	33.06	24.86	18.01	18.80
FeO+MnO%	41.75	45.00	38.30	37.89	43.87	55.57	36.12	39.75	41.25	45.43

Sample #	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534
From (m)	1040.58	1049.56	1059.76	1068.37	1082.3	1090.37	1096.78	1106	1116	1126.17
To (m)	1040.8	1049.75	1060	1068.59	1082.55	1090.6	1096.96	1106.25	1116.22	1126.42
SiO ₂	51.85	58.45	59.95	32.74	39.30	45.09	35.00	60.72	35.20	36.99
TiO₂	2.42	0.95	1.13	6.38	5.01	3.17	7.89	0.92	6.07	6.18
Al ₂ O ₃	17.10	18.40	18.20	11.10	10.40	14.00	11.70	18.40	12.50	10.20
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.10	0.05	0.00	0.00	0.00	0.02
V_2O_5	0.01	0.00	0.00	0.09	0.08	0.04	0.09	0.01	0.08	0.11
FeO	8.55	5.06	3.85	17.20	13.70	10.30	15.60	3.42	14.30	16.40
MnO	0.21	0.12	0.09	0.23	0.19	0.18	0.21	0.07	0.21	0.22
MgO	1.99	0.93	0.72	8.28	11.80	9.22	9.11	0.76	8.16	9.16
CaO	6.61	3.03	2.40	14.20	12.90	9.13	13.10	2.49	13.30	15.10
Na₂O	4.54	5.10	5.18	1.94	1.81	3.30	2.04	5.65	2.42	1.47
K₂O	4.04	6.26	6.94	1.24	1.42	3.07	1.29	6.20	1.78	0.76
P ₂ O ₅	0.66	0.24	0.18	3.02	0.24	0.53	0.89	0.18	2.94	0.26
SO ₂	0.16	0.18	0.08	0.84	0.46	0.14	0.98	0.08	0.72	0.76
CO2	0.60	0.50	0.60	0.80	0.80	0.20	0.90	0.40	0.60	1.20
Total C	0.21	0.18	0.16	0.23	0.21	0.06	0.24	0.12	0.16	0.33
TotOrg C	0.05	0.04	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00
LOI	0.52	0.78	0.75	1.08	1.08	0.75	1.12	0.65	0.90	1.30
Total	99.52	100.23	100.25	99.36	99.49	99.25	100.15	100.08	99.33	100.46
Na ₂ O+K ₂ O	8.58	11.36	12.12	3.18	3.23	6.37	3.33	11.85	4.20	2.23
CaO/Al ₂ O ₃	0.39	0.16	0.13	1.28	1.24	0.65	1.12	0.14	1.06	1.48
MgO/CaO	0.30	0.31	0.30	0.58	0.91	1.01	0.70	0.31	0.61	0.61
SiO ₂ /Al ₂ O ₃	3.03	3.18	3.29	2.95	3.78	3.22	2.99	3.30	2.82	3.63
Fe/Mn	40.86	42.32	42.94	75.06	72.37	57.43	74.56	49.04	68.35	74.82
CaO wt.%	38.08	33.15	33.99	35.58	33.43	31.67	34.46	36.94	36.98	36.94
MgO wt.%	11.46	10.18	10.20	20.75	30.58	31.98	23.96	11.28	22.69	22.41
FeO+MnO%	50.46	56.67	55.81	43.67	35.99	36.35	41.58	51.78	40.34	40.66

KDC ²

Sample #	2 535	253 <u>6</u>	2537	259 <u>3</u>	253 <u>8</u>	2539	2540	2541	254 <u>2</u>	254 3
From (m)	1138.8	1149.6	1157.37	1168.91	1177.16	1186.2	1188.28	1199.3	1201.21	1209.64
To (m)	1139.05	1149.82	1157.49	1169.16	1177.36	1186.57	1188.5	1199.5	1201.46	1209.89
SiO ₂	31.51	35.32	33.51	33.19	32.03	62.84	31.65	36.69	45.19	37.62
TiO ₂	7.51	5.94	6.51	6.67	6.93	0.56	7.50	5.81	3.74	5.94
Al ₂ O ₃	9.88	12.10	10.20	11.00	10.70	18.40	10.50	11.80	16.50	12.20
Cr ₂ O ₃	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01
V ₂ O ₅	0.08	0.07	0.08	0.07	0.07	0.01	0.08	0.07	0.04	0.09
FeO	17.40	16.20	18.40	14.90	15.00	2.36	16.80	16.10	11.00	14.50
MnO	0.25	0.25	0.28	0.22	0.22	0.05	0.23	0.27	0.22	0.21
MgO	8.74	7.19	8.00	8.91	8.96	0.81	8.59	8.11	4.60	8.78
CaO	15.30	13.10	14.80	14.90	15.20	2.14	14.50	13.20	8.54	12.80
Na ₂ O	1.57	2.36	1.66	1.88	1.73	6.27	1.78	2.28	4.07	2.35
K₂O	1.04	1.52	1.02	1.34	1.25	5.88	1.20	1.25	2.81	1.32
P ₂ O ₅	3.86	2.46	2.39	3.66	4.08	0.11	3.58	0.90	1.08	0.54
SO2	0.80	0.46	0.60	0.96	1.10	0.08	1.10	0.50	0.26	0.68
CO2	0.70	0.80	1.10	0.90	0.80	0.40	0.90	0.70	0.30	1.00
Total C	0.18	0.25	0.31	0.24	0.27	0.10	0.25	0.19	0.10	0.29
TotOrg C	0.00	0.02	0.02	0.00	0.04	0.00	0.00	0.01	0.02	0.01
LOI	0.84	1.02	0.88	1.13	1.44	0.49	0.93	1.28	0.78	1.61
Total	99.66	99.06	99.77	99.97	99.82	100.50	99.58	99.18	99.25	99.94
Na ₂ O+K ₂ O	2.61	3.88	2.68	3.22	2.98	12.15	2.98	3.53	6.88	3.67
CaO/Al ₂ O ₃	1.55	1.08	1.45	1.35	1.42	0.12	1.38	1.12	0.52	1.05
MgO/CaO	0.57	0.55	0.54	0.60	0.59	0.38	0.59	0.61	0.54	0.69
SiO ₂ /Al ₂ O ₃	3.19	2.92	3.29	3.02	2.99	3.42	3.01	3.11	2.74	3.08
Fe/Mn	69.86	65.04	65.96	67.98	68.43	47.37	73.31	59.85	50.18	69.30
CaO wt.%	36.70	35.66	35.68	38.27	38.60	39.93	36.14	35.03	35.06	35.27
MgO wt.%	20.96	19.57	19.29	22.89	22.75	15.11	21.41	21.52	18.88	24.19
FeO+MnO%	42.34	44.77	45.03	38.84	38.65	44.96	42.45	43.44	46.06	40.53

Sample #	2564	2565	2566	2567	2568	2569	2590	2591	2592	2576
From (m)	1303.1	1312.35	1320.62	1328.4	1335.25	1347.59	1353.35	1363.22	1369.38	1379.12
To (m)	1303.37	1312.57	1320.86	1328.67	1335.48	1347.84	1353.65	1363.5	1369.59	1379.34
SiO ₂	32.38	32.72	42.57	46.27	41.96	32.80	36.00	33.18	38.14	39.53
TiO ₂	6.85	6.83	4.41	3.55	4.67	6.79	6.11	6.47	5.37	4.79
Al ₂ O ₃	11.10	10.70	13.90	15.30	13.90	11.40	11.00	11.90	10.60	9.47
Cr ₂ O ₃	0.01	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.04	0.03
V ₂ O ₅	0.07	0.09	0.06	0.03	0.06	0.08	0.07	0.07	0.09	0.07
FeO	16.30	20.30	12.40	10.50	12.80	19.00	16.90	15.80	15.00	16.10
MnO	0.23	0.30	0.19	0.18	0.20	0.27	0.25	0.24	0.24	0.29
MgO	8.72	7.71	6.99	4.19	6.72	7.80	8.66	8.99	9.11	8.32
CaO	14.30	13.20	10.70	7.62	11.20	13.10	13.70	14.00	15.10	15.40
Na₂O	1.91	1.89	3.16	4.22	3.21	1.96	1.73	2.09	1.58	1.67
K₂O	1.30	1.10	2.28	3.89	1.96	1.28	1.07	1.38	0.84	0.70
P ₂ O ₅	3.56	2.08	0.80	1.25	0.88	1.92	0.39	2.71	0.30	0.51
SO ₂	0.88	0.76	0.44	1.42	0.46	0.72	0.66	0.72	0.44	0.52
CO2	1.00	0.80	0.40	0.70	0.70	1.20	1.60	0.40	1.30	0.80
Total C	0.32	0.21	0.10	0.21	0.20	0.34	0.44	0.13	0.35	0.24
TotOrg C	0.04	0.00	0.00	0.02	0.00	0.02	0.00	0.03	0.00	0.03
LOI	1.11	0.58	0.80	1.10	0.77	1.03	1.80	0.68	1.60	0.98
Total	100.08	99.26	99.21	100.45	99.70	99.71	100.38	98.79	100.09	99.46
Na ₂ O+K ₂ O	3.21	2.99	5.44	8.11	5.17	3.24	2.80	3.47	2.42	2.37
CaO/Al ₂ O ₃	1.29	1.23	0.77	0.50	0.81	1.15	1.25	1.18	1.42	1.63
MgO/CaO	0.61	0.58	0.65	0.55	0.60	0.60	0.63	0.64	0.60	0.54
SiO ₂ /Al ₂ O ₃	2.92	3.06	3.06	3.02	3.02	2.88	3.27	2.79	3.60	4.17
Fe/Mn	71.13	67.92	65.50	58.55	64.24	70.63	67.85	66.08	62.73	55.72
CaO wt.%	36.16	31.80	35.34	33.88	36.22	32.61	34.67	35.87	38.28	38.39
MgO wt.%	22.05	18.57	23.08	18.63	21.73	19.42	21.92	23.03	23.09	20.74
FeO+MnO%	41.80	49.63	41.58	47.49	42.04	47.97	43.41	41.10	38.63	40.86



Sample #	2594	2577	2578	2579	2580	2581	2582	2583	2584	2585
From (m)	1382.26	1389.55	1393.14	1402.17	1414.13	1423.75	1435.26	1444.48	1454	1463.57
To (m)	1382.43	1389.73	1393.35	1402.3	1414.34	1423.95	1435.54	1444.72	1454.24	1463.84
SiO ₂	43.14	59.76	32.22	36.04	44.03	60.61	35.60	37.60	37.12	36.66
TiO ₂	3.18	1.07	7.45	7.38	3.59	0.78	6.54	5.88	6.20	6.18
Al ₂ O ₃	11.20	17.40	8.51	11.50	13.90	17.90	8.83	9.56	8.97	8.14
Cr ₂ O ₃	0.07	0.01	0.01	0.01	0.03	0.01	0.01	0.02	0.06	0.03
V ₂ O ₅	0.04	0.01	0.11	0.08	0.05	0.01	0.11	0.09	0.10	0.10
FeO	12.00	4.08	22.70	15.20	11.80	3.66	18.70	17.10	16.60	17.20
MnO	0.20	0.08	0.31	0.21	0.20	0.07	0.21	0.21	0.19	0.20
MgO	12.20	1.21	8.04	9.59	7.08	1.00	9.21	9.10	9.40	9.89
CaO	9.25	3.24	14.20	12.70	9.71	2.47	14.10	14.30	15.00	15.80
Na₂O	2.83	4.83	1.21	1.93	3.20	5.29	1.54	1.80	1.82	1.52
K₂O	2.00	6.70	0.53	1.24	2.68	6.65	0.70	1.11	0.89	0.58
P ₂ O ₅	0.70	0.19	1.24	0.57	0.82	0.19	0.33	0.53	0.44	0.26
SO2	0.36	0.10	0.78	0.90	0.72	0.04	1.24	1.00	0.70	1.08
CO2	0.80	0.40	1.00	1.30	0.30	0.40	1.60	0.80	0.80	0.60
Total C	0.24	0.14	0.27	0.37	0.21	0.12	0.45	0.21	0.23	0.17
TotOrg C	0.02	0.02	0.00	0.01	0.12	0.01	0.01	0.00	0.00	0.01
LOI	1.71	0.67	0.69	1.48	1.07	0.62	1.54	1.09	0.95	0.78
Total	99.94	99.91	99.26	100.52	99.50	99.83	100.71	100.39	99.46	99.21
Na ₂ O+K ₂ O	4.83	11.53	1.74	3.17	5.88	11.94	2.24	2.91	2.71	2.10
CaO/Al ₂ O ₃	0.83	0.19	1.67	1.10	0.70	0.14	1.60	1.50	1.67	1.94
MgO/CaO	1.32	0.37	0.57	0.76	0.73	0.40	0.65	0.64	0.63	0.63
SiO ₂ /Al ₂ O ₃	3.85	3.43	3.79	3.13	3.17	3.39	4.03	3.93	4.14	4.50
Fe/Mn	60.22	51.19	73.50	72.65	59.22	52.48	89.38	81.73	87.69	86.32
CaO wt.%	27.49	37.63	31.38	33.69	33.73	34.31	33.40	35.13	36.42	36.67
MgO wt.%	36.26	14.05	17.77	25.44	24.59	13.89	21.81	22.35	22.82	22.95
FeO+MnO%	36.26	48.32	50.85	40.88	41.68	51.81	44.79	42.52	40.76	40.38



Sample # 2595 2596 2597 2598 2599 2586 2587 2545 2546 2547 From (m) 1464 1465 1465.59 1466.2 1467.19 1472.72 1477.15 1478 1479.42 1479.42 To (m) 1465 1465.59 1466.2 1467.19 1468 1472.94 1477.39 1478.72 1479.87 1479.87 SiO₂ 36.25 32.52 37.19 32.72 44.97 42.03 39.28 44.10 34.60 34.30 TiO₂ 6.41 6.96 5.67 5.48 3.40 4.20 4.82 3.94 6.92 5.85 Al₂O₃ 8.89 9.54 9.61 10.80 13.00 8.50 11.10 9.12 7.71 6.46 Cr₂O₃ 0.04 0.04 0.03 0.19 0.07 0.04 0.12 0.06 0.06 0.09 V_2O_5 0.10 0.12 0.09 0.10 0.05 0.06 0.08 0.05 0.10 0.10 FeO 18.50 22.30 20.07 16.30 22.70 10.90 12.00 13.10 11.52 21.78 0.21 0.23 0.20 0.27 0.20 0.18 0.18 0.23 0.24 MnO 0.17 10.40 9.59 16.70 8.96 8.86 9.66 MgO 10.10 7.83 11.30 9.59 CaO 13.80 11.30 14.00 8.99 13.50 11.90 15.70 13.50 13.60 14.90 Na₂O 1.44 1.59 1.69 0.98 2.38 3.09 1.57 2.41 1.14 1.51 0.83 0.83 1.72 0.92 0.52 K₂O 1.13 1.04 0.85 1.58 2.06 **P**₂**O**₅ 0.36 0.52 0.61 0.27 0.30 0.78 0.17 0.24 0.25 0.20 SO₂ 1.20 1.80 0.68 1.26 0.40 0.40 0.64 0.58 2.84 5.03 CO₂ 0.70 1.00 1.20 1.10 1.40 0.10 1.60 0.80 0.80 0.30 Total C 0.19 0.29 0.32 0.38 0.49 0.25 0.23 0.10 0.29 0.12 TotOrg C 0.01 0.01 0.00 0.00 0.00 0.09 0.05 0.02 0.02 0.02 LOI 0.57 1.05 1.05 1.42 2.27 0.94 0.81 1.43 1.14 1.17 100.70 Total 99.90 99.98 99.77 99.78 100.67 99.04 100.28 101.67 103.11 Na₂O+K₂O 2.27 2.72 2.73 1.83 3.96 5.15 2.40 4.13 2.43 1.66 1.55 1.22 1.93 CaO/Al_2O_3 1.18 1.46 1.39 1.25 0.92 1.85 1.49 MgO/CaO 0.75 0.85 0.72 0.66 0.66 0.72 0.66 0.71 0.65 1.86 SiO₂/Al₂O₃ 4.08 3.41 3.87 5.07 3.23 4.62 3.97 3.79 4.16 4.45 Fe/Mn 88.42 97.31 81.80 84.38 64.35 60.22 73.05 64.24 87.58 91.09 CaO wt.% 32.16 26.02 34.48 18.48 40.26 37.27 38.98 39.64 31.27 31.99 MgO wt.% 24.24 22.09 24.88 34.32 26.72 24.52 28.05 26.01 22.05 20.74 FeO+MnO% 43.60 51.89 40.64 47.21 33.02 38.21 32.97 34.35 46.68 47.27



Sample #	2548	2549	2550	2551	2552	2553	2554	2588	2589
From (m)	1479.86	1480.31	1480.51	1481	1481.5	1482.18	1482.32	1483.01	1499.18
To (m)	1480.31	1480.51	1481	1481.5	1482.18	1482.32	1483	1483.24	1499.37
SiO ₂	33.50	59.90	32.10	32.10	55.60	39.40	38.10	34.37	37.14
TiO₂	5.80	0.71	7.02	6.84	1.76	5.29	5.76	6.60	5.68
Al ₂ O ₃	7.91	19.30	9.48	8.77	18.30	12.40	11.60	10.40	8.55
Cr ₂ O ₃	0.08	0.00	0.07	0.08	0.01	0.02	0.01	0.01	0.04
V_2O_5	0.09	0.00	0.11	0.10	0.02	0.06	0.07	0.09	0.10
FeO	23.22	4.04	26.00	25.46	5.93	16.65	15.48	16.60	17.60
MnO	0.47	0.06	0.27	0.30	0.10	0.27	0.22	0.21	0.23
MgO	8.80	0.63	7.47	7.41	2.31	7.02	8.44	9.23	9.81
CaO	13.50	2.50	10.30	11.50	4.40	10.40	12.40	13.60	15.00
Na₂O	1.29	5.69	1.95	1.82	5.41	2.91	2.33	2.30	1.41
K ₂ O	0.66	5.55	1.11	0.90	4.20	1.97	1.52	1.20	0.71
P ₂ O ₅	0.18	0.09	0.20	0.37	0.14	0.60	0.71	1.23	0.22
SO2	5.07	0.08	6.99	6.61	0.46	1.72	0.74	0.72	0.66
CO ₂	0.50	0.30	0.60	0.60	0.60	0.80	0.80	1.40	1.20
Total C	0.16	0.10	0.15	0.16	0.16	0.24	0.22	0.40	0.33
TotOrg C	0.02	0.02	0.00	0.00	0.01	0.01	0.01	0.01	0.00
LOI	1.50	0.34	0.85	0.83	0.52	0.59	0.78	1.74	1.50
Total	102.76	99.32	104.66	103.84	99.92	100.35	99.19	100.12	100.17
Na ₂ O+K ₂ O	1.95	11.24	3.06	2.72	9.61	4.88	3.85	3.50	2.12
CaO/Al ₂ O ₃	1.71	0.13	1.09	1.31	0.24	0.84	1.07	1.31	1.75
MgO/CaO	0.65	0.25	0.73	0.64	0.53	0.68	0.68	0.68	0.65
SiO ₂ /Al ₂ O ₃	4.24	3.10	3.39	3.66	3.04	3.18	3.28	3.30	4.34
Fe/Mn	49.59	67.58	96.65	85.18	59.52	61.89	70.62	79.34	76.80
CaO wt.%	29.35	34.58	23.39	25.74	34.54	30.29	33.94	34.31	35.18
MgO wt.%	19.13	8.71	16.96	16.59	18.13	20.44	23.10	23.28	23.01
FeO+MnO%	51.51	56.71	59.65	57.67	47.33	49.27	42.97	42.41	41.82

Sample #	585410	585408	585409	585402	585411	585412	585413	585414	585403	585415	585416
From	961.82	962.05	967.85	970.58	974.87	977.53	978.83	979.14	981.85	986.1	993.11
То	961.91	962.22	967.98	970.71	974.97	977.67	979	979.27	981.99	986.24	993.26
SiO ₂	34.26	35.74	29.19	27.15	32.93	30.16	36.89	38.06	29.30	36.90	35.69
TiO ₂	7.40	6.62	8.73	9.52	3.75	8.86	3.88	4.04	10.26	5.24	6.99
Al ₂ O ₃	5.44	5.62	5.47	4.94	9.68	5.19	10.80	11.40	5.36	6.30	6.24
Cr ₂ O ₃	0.06	0.06	0.00	0.00	0.04	0.03	0.05	0.05	0.00	0.13	0.06
V ₂ O ₅	0.09	0.09	0.12	0.11	0.05	0.10	0.05	0.05	0.12	0.09	0.086
FeO	16.80	15.40	21.30	20.70	10.50	18.30	11.40	12.00	21.60	15.20	15.4
MnO	0.18	0.18	0.21	0.20	0.21	0.19	0.20	0.21	0.22	0.16	0.18
MgO	10.60	11.00	9.59	9.22	7.99	9.69	8.72	8.31	9.79	10.90	10.6
CaO	18.20	18.40	16.60	17.90	12.80	17.80	13.10	13.40	16.60	20.00	18.6
Na₂O	0.49	0.61	0.50	0.49	3.02	0.55	2.38	2.01	0.40	0.41	0.42
K ₂ O	0.01	0.09	0.02	0.04	2.11	0.05	3.04	3.08	0.02	0.02	0.062
P ₂ O ₅	1.27	1.06	1.83	3.62	1.39	2.41	1.58	1.46	1.72	1.44	0.837
WO ₃	0.02	0.02	0.02	0.02	0.00	0.02	0.03	0.02	0.04	0.01	0.02
SO ₂	0.76	0.54	1.12	1.10	1.30	0.96	0.38	0.38	1.20	0.66	0.5
CO ₂	3.50	3.90	3.70	3.50	11.40	4.40	4.90	2.50	2.60	1.60	2.9
TotC	0.96	1.06	1.04	0.97	3.1	1.2	1.33	0.69	0.73	0.43	0.79
LOI	2.48	3.02	2.91	2.57	12.10	3.70	5.62	3.74	1.28	1.51	3.21
Total	99.02	99.50	98.66	98.56	100.96	99.21	99.45	98.91	98.64	99.40	99.685
Na ₂ O+K ₂ O	0.50	0.70	0.52	0.53	5.13	0.60	5.42	5.09	0.42	0.43	0.48
CaO/Al ₂ O ₃	3.35	3.27	3.03	3.62	1.32	3.43	1.21	1.18	3.10	3.17	2.98
MgO/CaO	0.58	0.60	0.58	0.52	0.62	0.54	0.67	0.62	0.59	0.55	0.57
SiO ₂ /Al ₂ O ₃	6.30	6.36	5.34	5.50	3.40	5.81	3.42	3.34	5.47	5.86	5.72
Fe/Mn	93.68	85.87	101.80	103.88	50.18	96.67	57.21	57.35	98.54	95.35	85.87
CaO wt.%	39.76	40.91	34.80	37.28	40.63	38.71	39.20	39.50	34.43	43.23	41.54
MgO wt.%	23.15	24.46	20.10	19.20	25.37	21.07	26.09	24.50	20.31	23.56	23.67
FeO+MnO%	37.09	34.64	45.09	43.52	34.00	40.21	34.71	36.00	45.26	33.20	34.79

Table A2: Major element compositions of lithologies from Lake Machattie (LMDH001) analysed by AusQuest

Sample #	<u>585417</u>	585418 <u></u>	585419 <u></u>	585404	585420	<u>585306</u>	585307	585308	585309	585310
From	999.1	1004.84	1014.1	1020.2	1026.54	1030	1031	1032	1033	1034
То	999.24	1004.96	1014.23	1020.34	1026.7	1031	1032	1033	1034	1035
SiO ₂	31.17	32.99	29.01	32.45	27.56	27.69	28.58	26.81	27.34	28.04
TiO ₂	10.94	8.05	9.20	8.05	10.52	8.99	7.36	6.61	8.03	7.59
Al ₂ O ₃	5.87	5.74	5.53	5.75	5.24	5.37	5.44	5.36	5.06	5.64
Cr ₂ O ₃	0.03	0.02	0.00	0.02	0.01	0.01	0.00	0.01	0.00	0.01
V ₂ O ₅	0.11	0.09	0.11	0.11	0.11	0.11	0.11	0.09	0.10	0.09
FeO	20.40	16.90	20.10	19.00	21.30	21.40	20.00	16.60	19.40	17.40
MnO	0.22	0.19	0.21	0.20	0.22	0.21	0.19	0.19	0.19	0.19
MgO	10.00	10.10	9.41	10.10	9.29	9.19	9.22	7.71	8.95	8.68
CaO	15.80	17.90	17.90	18.60	17.90	16.90	16.30	18.10	16.90	16.60
Na₂O	0.36	0.39	0.42	0.41	0.40	0.77	1.33	1.93	1.25	1.63
K ₂ O	0.05	0.04	0.03	0.01	0.02	0.10	0.13	0.74	0.06	0.50
P ₂ O ₅	0.54	1.42	2.84	2.14	3.40	2.36	1.79	2.29	2.37	2.59
WO ₃	0.00	0.01	0.03	0.03	0.02	0.02	0.03	0.00	0.01	0.01
SO ₂	0.80	0.72	0.96	0.90	1.10	1.44	1.40	1.52	1.60	0.98
CO ₂	2.10	3.30	2.70	1.30	2.10	4.00	5.90	9.20	5.90	7.50
TotC	0.56	0.91	0.74	0.35	0.57	1.09	1.6	2.51	1.61	2.06
LOI	1.94	3.28	2.23	0.74	1.17	3.51	5.84	9.94	6.46	8.09
Total	98.77	98.75	98.72	98.86	98.83	99.16	99.32	100.40	99.34	100.10
Na ₂ O+K ₂ O	0.41	0.43	0.45	0.42	0.42	0.87	1.46	2.67	1.31	2.13
CaO/Al ₂ O ₃	2.69	3.12	3.24	3.23	3.42	3.15	3.00	3.38	3.34	2.94
MgO/CaO	0.63	0.56	0.53	0.54	0.52	0.54	0.57	0.43	0.53	0.52
SiO ₂ /Al ₂ O ₃	5.31	5.75	5.25	5.64	5.26	5.16	5.25	5.00	5.40	4.97
Fe/Mn	93.07	89.28	96.07	95.35	97.18	102.28	105.65	87.69	102.48	91.92
CaO wt.%	34.04	39.70	37.59	38.83	36.75	35.43	35.66	42.49	37.19	38.72
MgO wt.%	21.54	22.40	19.76	21.09	19.07	19.27	20.17	18.10	19.70	20.25
FeO+MnO%	44.42	37.90	42.65	40.08	44.18	45.30	44.17	39.41	43.11	41.03

Sample #	585421	585311	585422	585423	585424	585425	585426	585427	585428	585429
From	1035.12	1040	1045.7	1047.2	1057.17	1065.34	1070.41	1073.5	1078.18	1080.71
То	1035.24	1041	1045.87	1047.25	1057.32	1065.8	1070.54	1073.64	1078.35	1080.85
SiO ₂	30	28.75	28.57	32.64	29.34	32.06	37.10	33.31	32.10	28.35
TiO ₂	6.93	7.81	8.36	4.74	8.71	7.95	4.36	7.01	7.70	9.01
Al ₂ O ₃	5.35	5.86	7.09	9.67	5.81	6.09	12.00	6.71	7.47	6.36
Cr ₂ O ₃	0.003	0.01	0.01	0.01	0.00	0.02	0.02	0.06	0.01	0.00
V ₂ O ₅	0.095	0.12	0.11	0.06	0.12	0.10	0.06	0.09	0.10	0.10
FeO	17.9	22.00	22.00	12.00	21.90	19.30	11.30	17.80	19.50	21.10
MnO	0.18	0.19	0.22	0.25	0.23	0.23	0.21	0.22	0.23	0.25
MgO	9.4	10.10	8.95	6.93	9.43	9.89	6.57	9.84	9.67	8.97
CaO	18.3	15.50	17.40	16.40	17.90	18.30	13.10	18.70	18.40	18.10
Na ₂ O	1.08	0.69	0.53	1.98	0.35	0.41	2.77	0.44	0.39	0.45
K ₂ O	0.055	0.05	0.04	3.42	0.02	0.01	3.22	0.03	0.04	0.01
P ₂ O ₅	2.91	2.22	2.05	3.03	2.56	1.84	1.59	1.56	1.44	2.87
WO ₃	0.01	0.03	0.01	0.02	0.02	0.00	0.00	0.02	0.00	0.02
SO ₂	0.86	1.00	1.16	0.40	1.04	0.86	0.44	0.68	0.84	1.06
CO ₂	4.6	3.40	2.50	5.40	2.10	2.20	3.70	2.50	1.80	3.00
TotC	1.27	0.96	0.69	1.46	0.57	0.6	1	0.68	0.51	0.84
LOI	4.93	4.00	1.82	6.50	1.20	1.30	4.96	2.07	0.81	1.51
Total	99.273	99.29	99.01	99.51	99.20	98.95	98.69	99.22	99.20	99.01
Na ₂ O+K ₂ O	1.14	0.74	0.57	5.40	0.37	0.42	5.99	0.47	0.43	0.46
CaO/Al ₂ O ₃	3.42	2.65	2.45	1.70	3.08	3.00	1.09	2.79	2.46	2.85
MgO/CaO	0.51	0.65	0.51	0.42	0.53	0.54	0.50	0.53	0.53	0.50
SiO ₂ /Al ₂ O ₃	5.61	4.91	4.03	3.38	5.05	5.26	3.09	4.96	4.30	4.46
Fe/Mn	99.81	116.22	100.37	48.18	95.57	84.22	54.01	81.21	85.10	84.71
CaO wt.%	39.97	32.43	35.82	46.09	36.19	38.35	42.01	40.16	38.49	37.38
MgO wt.%	20.53	21.13	18.43	19.48	19.07	20.73	21.07	21.13	20.23	18.53
FeO+MnO%	39.49	46.43	45.75	34.43	44.74	40.93	36.91	38.70	41.28	44.09

Sample #	585430	585405	585432	585431	585433	585434	585435	585436	585452	585437
From	1083.7	1086.15	1091.41	1092.19	1098.42	1106.5	1116.12	1124.25	1124.8	1128.57
То	1083.84	1086.29	1091.52	1093.32	1098.57	1106.63	1116.28	1124.43	1124.95	1128.86
SiO ₂	34.89	37.06	33.52	32.69	27.39	34.41	37.87	35.13	34.37	31.95
TiO ₂	4.62	3.37	6.95	7.10	8.07	6.65	3.12	4.31	6.80	6.93
Al ₂ O ₃	8.86	8.29	7.23	7.28	7.05	7.27	23.70	9.73	16.40	14.60
Cr ₂ O ₃	0.05	0.065	0.01	0.02	0.01	0.04	0.00	0.04	0.01	0.00
V ₂ O ₅	0.05	0.036	0.09	0.10	0.13	0.09	0.04	0.05	0.06	0.07
FeO	15.20	14.2	18.80	19.90	25.90	17.40	8.75	13.70	13.50	14.00
MnO	0.28	0.27	0.26	0.26	0.34	0.29	0.13	0.24	0.23	0.21
MgO	10.50	15.6	9.79	9.69	8.78	9.89	3.04	8.93	5.87	7.00
CaO	11.90	9.23	18.10	17.90	16.40	18.60	15.40	12.80	16.90	16.70
Na ₂ O	2.19	1.69	0.45	0.46	0.32	0.52	1.69	2.40	0.91	1.16
K₂O	2.26	2.21	0.02	0.04	0.02	0.02	0.30	2.44	0.22	0.19
P ₂ O ₅	2.77	1.77	0.98	1.09	1.92	1.00	0.72	2.12	1.59	1.96
WO ₃	0.02	0.00	0.01	0.00	0.00	0.00	0.03	0.01	0.00	0.02
SO ₂	0.46	0.34	0.66	0.84	0.62	0.64	0.34	0.50	0.60	0.58
CO ₂	3.00	1.8	1.90	2.20	1.50	2.30	3.20	5.00	1.60	3.30
TotC	0.83	0.52	0.56	0.61	0.46	0.65	0.88	1.37	0.46	0.92
LOI	3.30	4.12	1.54	1.40	0.85	1.73	3.47	5.95	1.56	3.34
Total	98.17	98.761	98.97	99.37	98.25	99.17	99.48	99.72	99.47	99.63
Na ₂ O+K ₂ O	4.45	3.90	0.47	0.50	0.34	0.54	1.99	4.84	1.13	1.35
CaO/Al ₂ O ₃	1.34	1.11	2.50	2.46	2.33	2.56	0.65	1.32	1.03	1.14
MgO/CaO	0.88	1.69	0.54	0.54	0.54	0.53	0.20	0.70	0.35	0.42
SiO ₂ /Al ₂ O ₃	3.94	4.47	4.64	4.49	3.89	4.73	1.60	3.61	2.10	2.19
Fe/Mn	54.49	52.79	72.57	76.82	76.46	60.22	67.56	57.29	58.91	66.91
CaO wt.%	31.41	23.49	38.55	37.49	31.89	40.28	56.37	35.88	46.30	44.05
MgO wt.%	27.72	39.69	20.85	20.29	17.08	21.42	11.13	25.04	16.08	18.46
FeO+MnO%	40.87	36.82	40.60	42.22	51.03	38.31	32.50	39.08	37.62	37.48

Sample #	585438	585439	585441	585440	585442	585443	585444	585498	585445	585499
From	1132.3	1137.8	1145.33	1146.44	1152.1	1154.2	1155.64	1161.5	1163.69	1168.9
То	1132.48	1137.99	1145.49	1146.58	1152.1	1152.65	1155.81	1162	1163.84	1169.1
SiO ₂	22.89	28.07	26.47	34.72	27.99	31.38	28.25	27.73	31.12	24.99
TiO ₂	7.68	9.19	8.66	6.03	9.39	4.15	8.12	8.64	6.95	8.64
Al ₂ O ₃	5.94	7.48	5.68	7.55	7.31	8.65	6.69	6.86	8.34	6.41
Cr ₂ O ₃	0.00	0.00	0.01	0.07	0.01	0.02	0.01	0.00	0.01	0.00
V ₂ O ₅	0.08	0.11	0.086	0.08	0.10	0.05	0.12	0.09	0.11	0.10
FeO	13.60	19.60	17.6	13.70	20.40	14.70	23.00	17.70	19.90	19.10
MnO	0.23	0.28	0.33	0.22	0.29	0.26	0.31	0.25	0.27	0.25
MgO	6.82	9.41	8.44	9.94	8.83	9.43	9.23	8.62	9.43	8.04
CaO	16.00	18.40	18.9	19.20	17.60	14.70	16.70	18.30	18.00	16.20
Na₂O	1.29	0.33	0.83	0.91	0.56	2.28	0.43	0.40	0.40	1.32
K ₂ O	0.12	0.01	0.225	0.06	0.05	2.52	0.03	0.03	0.02	0.11
P ₂ O ₅	2.39	3.14	2.81	1.55	2.69	2.46	2.02	3.03	1.54	2.98
WO ₃	0.00	0.03	0.02	0.01	0.01	0.02	0.04	0.03	0.00	0.02
SO ₂	6.11	0.96	0.96	0.50	1.70	0.86	0.90	1.20	1.14	1.72
CO ₂	18.20	2.10	7	3.70	2.60	5.20	5.50	5.50	3.10	7.50
TotC	4.97	0.59	1.91	1.03	0.73	1.44	1.52	1.5	0.89	2.06
LOI	16.00	1.46	6.41	4.11	1.44	6.33	1.85	5.03	1.59	8.16
Total	104.11	99.07	99.341	99.67	99.09	99.25	99.22	99.42	99.71	100.09
Na ₂ O+K ₂ O	1.41	0.34	1.06	0.97	0.61	4.80	0.46	0.43	0.42	1.43
CaO/Al ₂ O ₃	2.69	2.46	3.33	2.54	2.41	1.70	2.50	2.67	2.16	2.53
MgO/CaO	0.43	0.51	0.45	0.52	0.50	0.64	0.55	0.47	0.52	0.50
SiO ₂ /Al ₂ O ₃	3.85	3.75	4.66	4.60	3.83	3.63	4.22	4.04	3.73	3.90
Fe/Mn	59.35	70.26	53.53	62.50	70.60	56.75	74.47	71.06	73.98	76.68
CaO wt.%	43.66	38.58	41.75	44.59	37.35	37.61	33.92	40.78	37.82	37.16
MgO wt.%	18.61	19.73	18.64	23.08	18.74	24.12	18.74	19.21	19.81	18.44
FeO+MnO%	37.74	41.69	39.61	32.33	43.91	38.27	47.34	40.00	42.37	44.39

Sample #	585446	585500	585302	585303	585304	585305	585447	585448	585449	585450
From	1172.46	1175	1176	1177	1178	1179	1181.76	1184.7	1193.13	1197.54
То	1172.6	1176	1177	1178	1179	1180	1181.92	1184.87	1193.27	1197.7
SiO ₂	29.67	28.72	26.88	27.7	28.92	29.14	29.99	31.14	27.58	24.15
TiO ₂	7.59	9.19	8.34	8.71	8.36	8.45	7.19	5.91	6.80	6.63
Al ₂ O ₃	7.32	6.44	6.04	6.2	6.35	6.45	6.74	6.78	6.12	5.49
Cr ₂ O ₃	0.01	0.00	0.00	0.005	0.01	0.01	0.02	0.01	0.02	0.02
V ₂ O ₅	0.11	0.11	0.11	0.105	0.11	0.11	0.11	0.09	0.08	0.08
FeO	21.00	21.10	23.70	20.3	20.10	20.20	20.00	9.99	16.30	15.00
MnO	0.28	0.30	0.31	0.28	0.28	0.29	0.27	0.25	0.24	0.25
MgO	9.24	9.33	8.70	9.03	9.29	9.36	9.43	2.08	8.34	7.36
CaO	17.70	17.80	17.00	17.1	17.50	17.80	17.70	20.60	15.40	15.90
Na₂O	0.38	0.33	0.31	0.37	0.32	0.33	0.33	3.27	0.66	2.72
K ₂ O	0.03	0.01	0.02	0.021	0.02	0.02	0.02	0.04	0.06	0.15
P ₂ O ₅	1.80	2.56	2.86	2.58	2.36	2.37	1.99	1.63	1.68	1.42
WO ₃	0.03	0.02	0.00	0.01	0.01	0.02	0.01	0.00	0.00	0.01
SO ₂	0.46	1.48	1.02	1.2	1.12	1.16	1.22	1.56	0.86	0.32
CO ₂	2.10	2.70	3.10	4.8	3.80	3.40	2.70	14.40	11.70	17.10
TotC	0.58	0.74	0.85	1.3	1.04	0.94	0.76	3.93	3.21	4.69
LOI	1.38	0.94	2.11	4.32	3.32	2.66	3.76	15.00	13.20	18.20
Total	97.59	99.07	98.24	99.231	99.11	99.31	99.53	102.26	100.53	102.39
Na ₂ O+K ₂ O	0.41	0.34	0.33	0.39	0.34	0.35	0.35	3.31	0.72	2.87
CaO/Al ₂ O ₃	2.42	2.76	2.81	2.76	2.76	2.76	2.63	3.04	2.52	2.90
MgO/CaO	0.52	0.52	0.51	0.53	0.53	0.53	0.53	0.10	0.54	0.46
SiO ₂ /Al ₂ O ₃	4.05	4.46	4.45	4.47	4.55	4.52	4.45	4.59	4.51	4.40
Fe/Mn	75.28	70.59	76.73	72.77	72.05	69.91	74.35	40.11	68.17	60.22
CaO wt.%	36.71	36.68	34.20	36.61	37.10	37.36	37.34	62.58	38.23	41.29
MgO wt.%	19.16	19.23	17.50	19.33	19.69	19.64	19.89	6.32	20.71	19.11
FeO+MnO%	44.13	44.10	48.30	44.06	43.21	43.00	42.76	31.11	41.06	39.60

Sample #	585451	585453	585454	585455	585456	585457	585312	585313	585458	585459
From	1208.14	1217.74	1227.57	1238.52	1245.45	1255.51	1256	1257	1265.23	1274.66
То	1208.3	1217.91	1227.74	1238.68	1245.57	1255.7	1257	1258	1265.39	1274.84
SiO ₂	30.85	33.61	34.78	26.47	20.41	27.21	27.48	26.20	32.60	33.33
TiO ₂	7.36	6.99	4.02	9.39	7.65	8.59	7.17	8.83	6.08	6.05
Al ₂ O ₃	7.43	7.25	10.40	6.60	5.47	7.77	7.53	7.59	15.90	16.50
Cr ₂ O ₃	0.01	0.04	0.02	0.00	0.001	0.00	0.00	0.01	0.01	0.00
V ₂ O ₅	0.12	0.09	0.04	0.11	0.083	0.11	0.10	0.10	0.07	0.08
FeO	21.30	17.00	12.30	20.20	13.5	19.70	18.50	18.80	13.60	14.80
MnO	0.29	0.25	0.26	0.28	0.23	0.22	0.20	0.21	0.18	0.19
MgO	9.59	9.89	7.80	8.62	6.5	8.33	8.30	8.29	6.03	5.91
CaO	17.00	18.00	13.50	17.60	17.5	17.50	17.70	17.40	16.80	16.50
Na₂O	0.35	0.43	2.78	0.52	2.13	0.49	0.54	0.95	0.74	0.66
K ₂ O	0.01	0.02	3.24	0.04	0.108	0.03	0.07	0.09	0.11	0.08
P ₂ O ₅	1.05	0.74	2.42	2.94	2.48	2.36	2.55	2.84	1.52	1.20
WO ₃	0.01	0.04	0.00	0.03	0.01	0.02	0.03	0.02	0.00	0.02
SO ₂	1.18	0.78	0.52	0.96	7.19	1.04	1.50	0.88	0.38	0.64
CO ₂	2.40	3.60	4.20	4.40	21.8	5.10	5.90	5.60	3.90	2.90
TotC	0.66	0.99	1.17	1.22	5.99	1.41	1.62	1.53	1.07	0.8
LOI	1.78	3.66	5.55	4.09	14.6	4.98	6.13	5.85	4.69	2.87
Total	98.99	99.79	98.80	99.07	103.852	99.76	99.42	99.59	99.77	99.62
Na ₂ O+K ₂ O	0.36	0.45	6.02	0.56	2.24	0.52	0.61	1.04	0.85	0.74
CaO/Al ₂ O ₃	2.29	2.48	1.30	2.67	3.20	2.25	2.35	2.29	1.06	1.00
MgO/CaO	0.56	0.55	0.58	0.49	0.37	0.48	0.47	0.48	0.36	0.36
SiO ₂ /Al ₂ O ₃	4.15	4.64	3.34	4.01	3.73	3.50	3.65	3.45	2.05	2.02
Fe/Mn	73.72	68.25	47.48	72.41	58.91	89.88	92.84	89.85	75.83	78.18
CaO wt.%	35.28	39.88	39.87	37.69	46.38	38.25	39.60	38.93	45.89	44.12
MgO wt.%	19.90	21.91	23.04	18.46	17.23	18.21	18.57	18.55	16.47	15.80
FeO+MnO%	44.81	38.21	37.09	43.85	36.39	43.54	41.83	42.53	37.64	40.08

Sample #	585460	585461	585489	585462	585463	585464	585465	585466	585467	585468
From	1285.4	1296.24	1301.79	1312.14	1321.54	1333.4	1340.52	1347.63	1353	1354.17
То	1285.56	1296.4	1301.95	1312.32	1321.7	1333.58	1340.68	1347.82	1354.17	1355.05
SiO ₂	29.29	27.03	40.18	27.49	28.01	27.59	26.48	25.69	27.26	26.27
TiO ₂	5.31	8.41	3.11	8.85	9.00	9.9	8.94	10.10	8.23	5.33
Al ₂ O ₃	15.00	8.06	9.38	7.51	7.50	7.58	7.27	6.89	8.59	12.10
Cr ₂ O ₃	0.00	0.00	0.06	0.00	0.00	0.002	0.00	0.00	0.01	0.00
V ₂ O ₅	0.06	0.11	0.04	0.11	0.11	0.101	0.10	0.11	0.10	0.05
FeO	11.90	19.60	12.60	19.80	19.60	19.5	19.10	20.20	17.50	11.80
MnO	0.14	0.22	0.20	0.23	0.23	0.23	0.22	0.24	0.20	0.17
MgO	5.03	8.26	15.50	8.57	8.72	8.68	8.46	8.31	7.91	4.92
CaO	15.20	18.50	8.53	18.00	18.30	17.6	17.40	17.30	17.30	13.70
Na₂O	0.79	0.33	2.35	0.52	0.34	0.67	1.03	1.07	1.52	4.62
K ₂ O	0.15	0.02	1.79	0.03	0.02	0.035	0.05	0.04	0.26	0.55
P ₂ O ₅	1.21	3.10	0.95	2.77	2.86	2.8	3.29	3.31	2.60	1.50
WO ₃	0.00	0.03	0.00	0.03	0.03	0.02	0.02	0.02	0.00	0.00
SO ₂	0.48	1.20	0.40	1.06	1.26	1.4	1.10	1.20	1.18	0.06
CO ₂	10.70	4.00	2.60	3.70	3.20	2.8	4.00	3.50	4.70	13.30
TotC	2.92	1.1	0.75	1.02	0.93	0.78	1.11	0.95	1.3	3.64
LOI	13.60	3.65	3.71	3.64	2.53	2.51	4.60	3.54	5.22	17.10
Total	101.07	99.62	99.54	99.63	99.43	99.398	99.17	98.97	99.16	101.80
Na ₂ O+K ₂ O	0.94	0.35	4.14	0.55	0.36	0.71	1.08	1.11	1.78	5.17
CaO/Al ₂ O ₃	1.01	2.30	0.91	2.40	2.44	2.32	2.39	2.51	2.01	1.13
MgO/CaO	0.33	0.45	1.82	0.48	0.48	0.49	0.49	0.48	0.46	0.36
SiO ₂ /Al ₂ O ₃	1.95	3.35	4.28	3.66	3.73	3.64	3.64	3.73	3.17	2.17
Fe/Mn	85.31	89.42	63.23	86.40	85.53	85.10	87.14	84.48	87.82	69.67
CaO wt.%	47.10	39.72	23.16	38.63	39.06	38.25	38.51	37.57	40.32	44.79
MgO wt.%	15.59	17.73	42.09	18.39	18.61	18.87	18.73	18.05	18.43	16.08
FeO+MnO%	37.31	42.55	34.75	42.98	42.33	42.88	42.76	44.39	41.25	39.13

Sample #	585469	585470	585471	585472	585473	585474	585475	585476	585477	585478
From	1355.05	1356.05	1357.05	1358.08	1359.07	1360.07	1360.73	1361.64	1362.64	1363.66
То	1356.07	1357.05	1358.08	1359.07	1360.07	1360.73	1361.64	1362.64	1363.66	1364.67
SiO ₂	25.30	11.78	24.58	22.15	21.47	21.24	15.7	25.13	20.49	19.11
TiO ₂	5.38	2.91	4.55	6.54	7.27	7.33	5.24	8.27	5.33	3.23
Al ₂ O ₃	9.31	3.48	10.70	6.54	5.89	6.23	4.53	7.19	5.87	4.83
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.001	0.01	0.00	0.01
V ₂ O ₅	0.02	0.01	0.03	0.09	0.09	0.07	0.015	0.02	0.02	0.04
FeO	13.00	27.20	12.20	16.00	16.00	16.20	19.3	10.50	17.10	22.30
MnO	0.51	1.26	0.33	0.18	0.20	0.28	0.88	0.45	0.65	0.66
MgO	5.13	7.10	4.94	6.92	6.83	6.57	6.9	5.51	6.34	7.15
CaO	13.80	10.00	14.30	14.40	14.40	14.30	14.3	14.60	14.40	10.80
Na ₂ O	4.14	1.89	4.27	4.11	4.37	4.26	2.59	4.31	3.47	3.38
K ₂ O	0.32	0.00	0.29	0.73	0.28	0.21	0.008	0.01	0.01	0.03
P ₂ O ₅	1.34	1.06	2.01	2.20	2.48	2.29	0.811	0.55	0.80	0.39
WO ₃	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
SO ₂	-0.02	0.02	0.04	0.38	0.08	0.02	-0.02	-0.02	0.10	0.20
CO ₂	17.60	27.50	15.90	15.00	15.40	16.70	26.9	20.60	22.30	25.40
TotC	4.8	8.4	4.34	4.12	4.22	4.59	7.39	5.64	6.1	6.95
LOI	19.60	28.50	19.60	17.30	17.90	18.50	26.8	21.60	22.50	24.70
Total	102.62	103.60	102.17	101.69	101.47	102.08	104.435	103.77	103.17	103.76
Na ₂ O+K ₂ O	4.46	1.89	4.56	4.84	4.65	4.47	2.60	4.32	3.48	3.41
CaO/Al ₂ O ₃	1.48	2.87	1.34	2.20	2.44	2.30	3.16	2.03	2.45	2.24
MgO/CaO	0.37	0.71	0.35	0.48	0.47	0.46	0.48	0.38	0.44	0.66
SiO ₂ /Al ₂ O ₃	2.72	3.39	2.30	3.39	3.65	3.41	3.47	3.50	3.49	3.96
Fe/Mn	25.58	21.67	37.11	89.22	80.30	58.07	22.01	23.42	26.40	33.91
CaO wt.%	42.54	21.95	45.01	38.40	38.47	38.29	34.56	47.01	37.41	26.40
MgO wt.%	15.81	15.58	15.55	18.45	18.25	17.59	16.67	17.74	16.47	17.48
FeO+MnO%	41.65	62.47	39.44	43.15	43.28	44.12	48.77	35.25	46.12	56.12

Sample #	585479	585480	585481	585482	585483	585488	585484	585485	585314	585315
From	1364.67	1365.29	1366.3	1367.3	1368.3	1378.62	1388.77	1389.79	1390	1391
То	1365.29	1366.3	1367.3	1368.3	1369.3	1378.81	1388.97	1389.95	1391	1392
SiO ₂	21.54	24.17	26.20	26.02	27.42	26.29	26.72	26.99	25.76	26.30
TiO ₂	7.39	6.30	5.88	6.15	6.41	10.08	8.96	9.59	9.29	9.26
Al ₂ O ₃	5.33	8.91	10.20	10.60	11.60	6.38	6.70	6.7	6.57	6.53
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.007	0.00	0.01
V ₂ O ₅	0.09	0.07	0.05	0.06	0.07	0.09	0.09	0.093	0.09	0.09
FeO	17.30	14.40	12.80	14.60	13.90	19.00	18.70	18.9	18.30	18.20
MnO	0.26	0.20	0.18	0.20	0.18	0.25	0.22	0.25	0.23	0.23
MgO	6.86	5.92	5.70	5.14	4.93	8.71	8.54	8.67	8.47	8.49
CaO	14.40	14.10	13.40	15.30	15.10	17.00	17.20	17.8	16.40	17.40
Na₂O	3.49	3.96	4.06	2.53	3.29	1.12	1.24	0.86	1.41	1.22
K ₂ O	0.43	0.44	0.51	0.82	0.59	0.05	0.06	0.074	0.06	0.06
P ₂ O ₅	2.23	1.80	1.52	1.86	1.84	2.93	2.92	3.1	2.99	3.19
WO ₃	0.00	0.01	0.00	0.00	0.03	0.03	0.01	0.01	0.03	0.00
SO ₂	0.38	0.84	0.64	0.58	0.80	1.56	1.46	1.38	1.28	1.08
CO ₂	16.70	15.70	14.40	10.80	9.20	4.30	4.70	4	6.20	5.60
TotC	4.55	4.32	3.96	2.96	2.5	1.18	1.33	1.09	1.68	1.53
LOI	17.50	16.40	16.60	13.70	12.10	4.63	5.56	4.04	6.81	5.83
Total	101.75	101.84	101.70	100.50	100.76	99.30	99.71	99.554	99.37	99.41
Na ₂ O+K ₂ O	3.92	4.40	4.57	3.35	3.88	1.17	1.30	0.93	1.47	1.28
CaO/Al ₂ O ₃	2.70	1.58	1.31	1.44	1.30	2.66	2.57	2.66	2.50	2.66
MgO/CaO	0.48	0.42	0.43	0.34	0.33	0.51	0.50	0.49	0.52	0.49
SiO ₂ /Al ₂ O ₃	4.04	2.71	2.57	2.45	2.36	4.12	3.99	4.03	3.92	4.03
Fe/Mn	66.78	72.27	71.37	73.27	77.51	76.28	85.31	75.88	79.86	79.42
CaO wt.%	37.09	40.73	41.77	43.42	44.27	37.81	38.51	39.02	37.79	39.26
MgO wt.%	17.67	17.10	17.77	14.59	14.45	19.37	19.12	19.00	19.52	19.16
FeO+MnO%	45.23	42. <u>1</u> 7	40.46	42.00	41.28	42.82	42.36	41.98	42.70	41.58

Sample #	585316	585317	585318	585319	585320	585321	585322	585323	585325	585324
From	1392	1393	1394	1400	1401	1402	1403	1404	1404	1405
То	1393	1394	1395	1401	1402	1403	1404	1405	1407	1406
SiO ₂	27.13	26.54	27.36	27.13	28.12	26.98	27.96	27.00	31.16	30.17
TiO ₂	9.90	9.86	9.56	9.17	9.20	9.65	8.56	7.66	7.45	7.63
Al ₂ O ₃	6.86	6.70	6.86	6.74	6.77	6.54	6.62	6.43	7.14	7.01
Cr ₂ O ₃	0.00	0.00	0.01	0.01	0.02	0.00	0.01	0.01	0.014	0.03
V ₂ O ₅	0.10	0.10	0.10	0.09	0.09	0.10	0.10	0.11	0.101	0.09
FeO	20.20	19.30	19.40	18.40	18.50	20.10	19.30	20.30	19.5	18.40
MnO	0.25	0.24	0.24	0.23	0.24	0.25	0.22	0.22	0.23	0.24
MgO	8.94	8.67	8.87	8.88	9.07	9.26	8.96	8.83	9.69	9.49
CaO	17.20	17.50	17.80	17.80	17.90	15.40	15.40	14.70	16.4	15.50
Na ₂ O	0.72	0.86	0.70	0.83	0.66	0.92	1.26	1.42	0.74	1.23
K ₂ O	0.04	0.04	0.04	0.06	0.05	0.06	0.07	0.09	0.081	0.12
P ₂ O ₅	2.86	2.99	3.07	2.73	2.84	1.96	1.04	0.89	0.484	0.47
WO ₃	0.02	0.02	0.00	0.02	0.02	0.00	0.00	0.02	0.01	0.02
SO ₂	1.08	1.12	1.08	1.02	0.98	1.12	1.06	1.60	1.24	0.86
CO ₂	3.70	4.00	3.30	4.30	3.50	4.40	6.60	7.40	3.9	5.70
TotC	1	1.09	0.9	1.18	0.96	1.2	1.79	2.02	1.05	1.56
LOI	3.31	3.88	2.87	4.56	3.34	4.88	7.11	8.05	3.37	6.20
Total	99.61	98.91	98.85	98.85	98.77	98.41	99.44	99.34	98.66	99.03
Na ₂ O+K ₂ O	0.76	0.90	0.74	0.89	0.71	0.98	1.33	1.51	0.82	1.35
CaO/Al ₂ O ₃	2.51	2.61	2.59	2.64	2.64	2.35	2.33	2.29	2.30	2.21
MgO/CaO	0.52	0.50	0.50	0.50	0.51	0.60	0.58	0.60	0.59	0.61
SiO ₂ /Al ₂ O ₃	3.95	3.96	3.99	4.03	4.15	4.13	4.22	4.20	4.36	4.30
Fe/Mn	81.10	80.71	81.13	80.30	77.37	80.70	88.05	92.61	85.10	76.95
CaO wt.%	36.92	38.28	38.44	39.28	39.16	34.21	35.10	33.37	35.79	35.53
MgO wt.%	19.19	18.97	19.15	19.60	19.84	20.57	20.42	20.05	21.15	21.75
FeO+MnO%	43.89	42.75	42.41	41.12	41.00	45.21	44.48	46.58	43.06	42.72

Sample #	585486	585487	585490	585491	585492	585493	585494	585326	585327	585328
From	1408.37	1419.12	1429.58	1439.4	1449.61	1458.65	1467.57	1470	1471	1472
То	1408.57	1419.27	1429.78	1439.62	1449.8	1458.85	1467.8	1471	1472	1473
SiO ₂	31.50	27.38	29.80	29.88	33.18	36.37	28.76	30.50	29.78	28.02
TiO ₂	6.95	9.46	7.55	8.15	6.96	3.66	8.94	8.14	8.48	7.97
Al ₂ O ₃	7.51	6.36	6.60	6.72	7.64	9.80	7.54	7.84	7.49	7.21
Cr ₂ O ₃	0.04	0.00	0.01	0.02	0.02	0.06	0.01	0.02	0.02	0.017
V ₂ O ₅	0.11	0.10	0.10	0.10	0.10	0.05	0.11	0.11	0.10	0.101
FeO	20.00	20.00	19.40	18.90	18.00	12.30	21.10	19.90	19.10	19.2
MnO	0.24	0.24	0.21	0.22	0.20	0.22	0.23	0.22	0.22	0.22
MgO	9.69	8.80	9.47	9.41	9.90	12.20	9.19	9.44	9.20	8.84
CaO	17.10	18.00	18.60	19.20	18.50	12.40	17.70	17.70	17.80	16.8
Na₂O	0.49	0.32	0.37	0.48	0.37	2.15	0.43	0.45	0.73	1.22
K ₂ O	0.02	0.03	0.04	0.03	0.01	2.84	0.05	0.02	0.13	0.305
P ₂ O ₅	0.67	3.21	2.91	3.09	1.05	1.44	2.15	1.48	1.74	1.63
WO ₃	0.04	0.02	0.01	0.02	0.02	0.02	0.02	0.00	0.03	0.00
SO ₂	1.42	1.44	1.62	1.20	0.84	0.56	1.40	0.76	0.78	0.74
CO ₂	3.40	3.60	2.70	2.20	2.50	3.60	1.90	1.80	3.30	5.8
TotC	0.95	1.01	0.74	0.63	0.73	1.02	0.53	0.49	0.9	1.57
LOI	2.49	3.04	2.04	1.32	1.92	4.44	0.95	1.45	2.55	5.27
Total	99.22	99.41	99.46	99.36	99.44	99.53	99.11	98.51	99.05	99.103
Na ₂ O+K ₂ O	0.51	0.35	0.41	0.51	0.38	4.99	0.48	0.47	0.86	1.53
CaO/Al ₂ O ₃	2.28	2.83	2.82	2.86	2.42	1.27	2.35	2.26	2.38	2.33
MgO/CaO	0.57	0.49	0.51	0.49	0.54	0.98	0.52	0.53	0.52	0.53
SiO ₂ /Al ₂ O ₃	4.19	4.31	4.52	4.45	4.34	3.71	3.81	3.89	3.98	3.89
Fe/Mn	83.64	83.64	92.72	86.23	90.33	56.12	92.08	90.79	87.14	87.60
CaO wt.%	36.36	38.27	39.01	40.23	39.70	33.41	36.71	37.45	38.43	37.28
MgO wt.%	20.60	18.71	19.86	19.72	21.24	32.87	19.06	19.97	19.86	19.62
FeO+MnO%	43.04	43.03	41.13	40.06	39.06	33.73	44.23	42.57	41.71	43.10

Sample #	585329	585330	585331	585332	585495	585496	585333	585334	585497	585335
From	1473	1474	1475	1476	1477.2	1482.7	1486	1487.7	1493.41	1500.55
То	1474	1475	1476	1477	1477.4	1482.89	1487	1488	1493.58	1501
SiO ₂	29.52	29.49	30.50	32.70	31.78	36.96	29.39	36.00	28.23	28.07
TiO ₂	8.61	9.57	9.10	6.27	6.54	4.25	4.78	3.92	9.06	7.55
Al ₂ O ₃	7.63	7.55	7.76	8.18	8.33	11.30	9.99	11.00	7.82	8.15
Cr ₂ O ₃	0.01	0.03	0.03	0.07	0.05	0.04	0.01	0.04	0.01	0.01
V ₂ O ₅	0.11	0.10	0.09	0.09	0.10	0.05	0.06	0.05	0.11	0.12
FeO	20.30	20.10	17.50	15.90	18.30	12.10	14.90	11.80	20.60	21.10
MnO	0.23	0.23	0.21	0.20	0.21	0.22	0.32	0.21	0.23	0.22
MgO	9.23	9.29	9.21	9.41	9.36	7.28	6.04	7.56	8.82	9.09
CaO	17.40	17.40	17.90	18.60	18.90	12.90	13.70	12.40	17.90	17.50
Na ₂ O	0.62	0.54	0.78	1.10	0.72	2.85	3.79	3.31	0.35	0.47
K ₂ O	0.08	0.04	0.06	0.15	0.09	2.85	0.58	2.28	0.04	0.04
P ₂ O ₅	1.56	1.59	1.51	1.00	1.71	1.67	1.64	1.67	2.32	1.75
WO ₃	0.01	0.04	0.01	0.04	0.01	0.02	0.02	0.00	0.02	0.02
SO ₂	0.96	0.76	0.68	0.90	1.16	0.56	0.32	0.32	1.46	0.90
CO ₂	2.50	2.50	3.30	4.40	2.40	4.20	10.60	5.50	2.40	3.00
TotC	0.69	0.67	0.9	1.2	0.68	1.15	2.88	1.5	0.65	0.82
LOI	1.76	1.55	2.59	3.80	1.65	5.08	12.20	7.19	1.28	3.02
Total	98.71	98.95	98.83	99.61	99.58	99.27	100.62	99.23	98.89	98.83
Na ₂ O+K ₂ O	0.70	0.58	0.84	1.25	0.81	5.70	4.37	5.59	0.39	0.51
CaO/Al ₂ O ₃	2.28	2.30	2.31	2.27	2.27	1.14	1.37	1.13	2.29	2.15
MgO/CaO	0.53	0.53	0.51	0.51	0.50	0.56	0.44	0.61	0.49	0.52
SiO ₂ /Al ₂ O ₃	3.87	3.91	3.93	4.00	3.82	3.27	2.94	3.27	3.61	3.44
Fe/Mn	88.59	87.71	83.64	79.79	87.46	55.20	46.73	56.40	89.90	96.26
CaO wt.%	36.90	37.01	39.94	42.17	40.41	39.69	39.19	38.79	37.64	36.53
MgO wt.%	19.57	19.76	20.55	21.33	20.01	22.40	17.28	23.65	18.55	18.97
FeO+MnO%	43.53	43.24	39.51	36.50	39.58	37.91	43.54	37.57	43.81	44.50

Sample #	585336	585337	585338	585339	585340	<u>585341</u>	585342	585343	585344	585345
From	1515	1523	1524	1525	1535	1536	1537	1538	1539	1539.77
То	1515.35	1524	1525	1526	1536	1537	1538	1539	1539.77	1540
SiO ₂	28.78	27.64	25.99	26.66	27.88	28.13	28.28	27.87	27.50	25.70
TiO ₂	5.78	6.33	8.45	9.16	9.54	10.08	8.76	8.65	9.35	9.30
Al ₂ O ₃	7.17	8.43	5.79	5.89	6.18	6.01	6.20	6.27	6.01	5.66
Cr ₂ O ₃	0.012	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.01
V ₂ O ₅	0.074	0.08	0.10	0.10	0.11	0.10	0.11	0.13	0.12	0.11
FeO	14.3	16.20	17.90	18.00	20.20	19.10	20.70	22.70	21.50	21.20
MnO	0.2	0.25	0.18	0.19	0.20	0.19	0.20	0.20	0.21	0.21
MgO	8.11	6.91	8.50	8.75	9.24	9.36	9.37	9.34	9.31	9.02
CaO	18	14.60	16.90	17.40	18.60	17.90	17.40	16.80	17.50	18.60
Na₂O	1.66	2.49	0.53	0.55	0.37	0.44	0.46	0.35	0.33	0.36
K ₂ O	0.822	0.40	0.09	0.07	0.02	0.03	0.03	0.02	0.02	0.02
P ₂ O ₅	2.18	2.15	2.79	3.02	3.52	2.89	2.34	2.14	2.89	3.38
WO ₃	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.02	0.00	0.00
SO ₂	0.76	0.58	0.90	0.94	1.02	0.96	1.52	1.14	1.04	1.08
CO ₂	8.2	10.20	8.80	6.80	2.20	3.00	3.60	2.80	2.60	3.20
TotC	2.24	2.77	2.41	1.85	0.67	0.89	1.02	0.81	0.76	0.94
LOI	9.59	11.60	9.33	7.14	1.13	2.21	2.14	1.94	1.77	2.77
Total	99.668	100.42	99.85	99.71	98.74	98.30	98.52	98.38	98.30	98.35
Na ₂ O+K ₂ O	2.48	2.89	0.62	0.62	0.39	0.47	0.49	0.37	0.35	0.38
CaO/Al ₂ O ₃	2.51	1.73	2.92	2.95	3.01	2.98	2.81	2.68	2.91	3.29
MgO/CaO	0.45	0.47	0.50	0.50	0.50	0.52	0.54	0.56	0.53	0.48
SiO ₂ /Al ₂ O ₃	4.01	3.28	4.49	4.53	4.51	4.68	4.56	4.44	4.58	4.54
Fe/Mn	71.76	65.04	99.81	95.09	101.37	100.90	103.88	113.92	102.76	101.33
CaO wt.%	44.32	38.46	38.87	39.24	38.56	38.45	36.50	34.26	36.07	37.94
MgO wt.%	19.97	18.20	19.55	19.73	19.15	20.11	19.66	19.05	19.19	18.40
FeO+MnO%	35.71	43.34	41. <u>5</u> 8	41.02	42.29	41.44	43.84	46.70	44.74	43.67

Sample #	585346	585347	585348	585349	2570	585350	585351	585352	585353	585354
From	1547.7	1554.78	1558.07	1559.32	1569.55	1580	1581	1582	1591.03	1591.4
То	1548	1554.98	1558.37	1559.7	1569.75	1581	1582	1583	1591.27	1591.65
SiO ₂	26.77	26.22	27.55	27.64	31.74	27.84	30.37	31.14	31.14	31.49
TiO ₂	8.16	9.48	9.82	8.17	8.27	9.72	8.90	8.36	7.11	5.41
Al ₂ O ₃	5.94	5.46	6.02	6.34	6.42	5.97	6.34	6.47	5.94	6.16
Cr ₂ O ₃	0.01	0.004	0.00	0.01	0.03	0.01	0.01	0.02	0.08	0.07
V ₂ O ₅	0.10	0.099	0.11	0.09	0.10	0.11	0.11	0.11	0.09	0.09
FeO	19.00	18.9	20.20	18.00	19.30	20.80	20.70	19.80	16.70	15.50
MnO	0.18	0.17	0.20	0.20	0.20	0.20	0.20	0.19	0.17	0.15
MgO	8.88	8.77	9.25	9.24	9.89	9.38	9.89	9.89	9.79	9.79
CaO	16.90	17.3	18.30	17.30	18.10	18.50	17.80	18.20	18.00	18.60
Na₂O	0.98	1.06	0.47	1.42	0.47	0.33	0.35	0.37	0.78	0.97
K ₂ O	0.48	0.026	0.02	0.67	0.10	0.02	0.02	0.02	0.02	0.04
P ₂ O ₅	3.05	3.08	3.28	3.21	2.11	3.49	1.98	2.01	1.91	1.65
WO ₃	-0.01	-0.01	-0.01	-0.01	-0.01	0.01	0.02	0.04	0.02	-0.01
SO ₂	1.18	1.2	1.24	1.20	1.04	1.12	1.04	1.02	0.72	0.58
CO ₂	6.10	6.1	2.80	5.40	1.60	2.70	2.00	1.90	5.40	6.70
TotC	1.7	1.68	0.8	1.48	0.49	0.73	0.54	0.53	1.47	1.83
LOI	5.77	6.24	1.63	4.86	0.80	0.53	0.66	0.90	5.14	7.96
Total	99.08	99.679	98.88	99.83	99.05	98.76	98.94	99.07	99.08	100.28
Na ₂ O+K ₂ O	1.46	1.09	0.49	2.09	0.57	0.35	0.37	0.39	0.80	1.01
CaO/Al ₂ O ₃	2.85	3.17	3.04	2.73	2.82	3.10	2.81	2.81	3.03	3.02
MgO/CaO	0.53	0.51	0.51	0.53	0.55	0.51	0.56	0.54	0.54	0.53
SiO ₂ /Al ₂ O ₃	4.51	4.80	4.58	4.36	4.94	4.66	4.79	4.81	5.24	5.11
Fe/Mn	105.95	111.59	101.37	90.33	96.86	104.38	103.88	104.60	98.60	103.71
CaO wt.%	37.59	38.33	38.16	38.67	38.11	37.85	36.63	37.85	40.30	42.23
MgO wt.%	19.75	19.43	19.29	20.65	20.83	19.19	20.35	20.57	21.92	22.23
FeO+MnO%	42.66	42.25	42.54	40.68	41.06	42.96	43.01	41.58	37.77	35.54

Sample #	2571	2572	2573	2574	585355	585356	585357	585358	585359	585360
From	1602.39	1612.47	1624.15	1637.39	1644	1645	1646	1647	1648	1649
То	1602.52	1612.67	1624.43	1637.64	1645	1646	1647	1648	1649	1650
SiO ₂	33.67	39.00	30.04	36.21	35.75	34.04	33.76	32.24	30.82	28.00
TiO ₂	6.47	5.13	7.38	5.58	6.27	7.10	6.88	7.51	8.76	9.51
Al ₂ O ₃	6.74	7.44	7.15	7.03	6.80	6.80	6.86	6.73	6.50	5.97
Cr ₂ O ₃	0.02	0.14	0.018	0.10	0.05	0.02	0.01	0.01	0.00	0.00
V ₂ O ₅	0.11	0.08	0.126	0.09	0.11	0.12	0.12	0.12	0.12	0.12
FeO	18.90	13.00	22.3	15.70	17.70	19.90	20.10	21.20	21.60	21.70
MnO	0.17	0.15	0.23	0.18	0.20	0.21	0.21	0.22	0.23	0.23
MgO	10.30	11.10	9.69	10.60	10.80	10.60	10.50	10.20	9.94	9.49
CaO	18.40	20.20	17.6	19.00	18.40	17.60	17.80	17.40	17.10	18.30
Na₂O	0.44	0.49	0.38	0.48	0.41	0.39	0.39	0.38	0.36	0.32
K ₂ O	0.04	0.06	0.044	0.07	0.02	0.02	0.02	0.02	0.02	0.01
P ₂ O ₅	1.28	0.53	1.82	0.93	0.42	0.34	0.61	0.93	1.27	3.31
WO ₃	0.03	0.04	0.00	0.00	0.04	0.03	0.02	0.02	0.03	0.01
SO ₂	1.14	0.64	1.36	0.66	0.44	0.60	0.72	0.90	1.10	1.06
CO ₂	1.60	1.50	1.5	2.40	1.90	1.70	1.50	1.60	1.70	1.80
TotC	0.46	0.42	0.45	0.72	0.52	0.47	0.46	0.44	0.45	0.49
LOI	0.81	1.08	0.49	1.86	1.05	0.80	0.55	0.65	0.63	0.37
Total	98.99	99.50	99.068	99.20	98.97	99.03	99.01	98.97	98.93	98.90
Na ₂ O+K ₂ O	0.48	0.55	0.42	0.55	0.43	0.41	0.41	0.40	0.38	0.33
CaO/Al ₂ O ₃	2.73	2.72	2.46	2.70	2.71	2.59	2.59	2.59	2.63	3.07
MgO/CaO	0.56	0.55	0.55	0.56	0.59	0.60	0.59	0.59	0.58	0.52
SiO ₂ /Al ₂ O ₃	5.00	5.24	4.20	5.15	5.26	5.01	4.92	4.79	4.74	4.69
Fe/Mn	111.59	86.99	97.31	87.54	88.83	95.11	96.07	96.72	94.26	94.70
CaO wt.%	38.52	45.44	35.33	41.78	39.07	36.43	36.62	35.50	34.99	36.81
MgO wt.%	21.56	24.97	19.45	23.31	22.93	21.94	21.60	20.81	20.34	19.09
FeO+MnO%	39.92	29.58	45.22	34.92	38.00	41.63	41.78	43.70	44.67	44.11

Sample #	585361	585362	585363	585364	585365	585366	585367	585368	585369	585370
From	1650	1651	1652	1653	1655	1656	1657	1658	1659	1662.2
То	1651	1652	1653	1654	1656	1657	1658	1659	1660	1662.55
SiO ₂	27.71	27.66	30.40	30.06	32.37	33.93	31.18	36.65	37.73	33.54
TiO ₂	9.59	9.92	9.31	8.95	8.29	8.33	10.61	5.85	5.27	6.71
Al ₂ O ₃	5.87	5.80	6.10	6.11	6.71	6.35	5.67	6.45	6.46	6.24
Cr ₂ O ₃	0.00	0.02	0.04	0.026	0.04	0.04	0.06	0.11	0.11	0.03
V ₂ O ₅	0.12	0.12	0.11	0.109	0.10	0.10	0.10	0.10	0.09	0.12
FeO	21.80	21.70	20.20	20.2	17.70	17.40	18.60	16.50	15.00	20.60
MnO	0.23	0.23	0.22	0.21	0.21	0.20	0.22	0.20	0.18	0.22
MgO	9.43	9.44	9.89	9.84	9.94	10.50	10.20	11.10	11.20	10.50
CaO	18.30	18.20	18.00	18	17.90	18.50	17.90	18.80	19.60	17.20
Na₂O	0.33	0.32	0.35	0.43	0.74	0.39	0.40	0.41	0.43	0.37
K ₂ O	0.01	0.01	0.01	0.03	0.37	0.02	0.03	0.01	0.01	0.02
P ₂ O ₅	3.46	3.48	2.16	2.32	1.61	1.22	1.94	0.59	0.77	0.49
WO ₃	0.05	0.01	0.01	0.01	0.00	0.02	0.02	0.00	0.01	0.02
SO ₂	1.08	1.14	0.94	1.04	0.66	0.60	0.82	0.46	0.74	1.02
CO ₂	1.70	2.10	1.90	1.9	2.50	2.10	1.90	2.30	1.80	1.80
TotC	0.47	0.56	0.52	0.53	0.67	0.57	0.52	0.64	0.48	0.49
LOI	0.28	0.09	0.53	0.8	1.61	0.71	0.61	1.18	1.04	1.08
Total	98.74	98.70	98.79	98.665	98.90	98.87	98.88	99.04	99.12	98.64
Na ₂ O+K ₂ O	0.34	0.33	0.36	0.46	1.11	0.41	0.43	0.42	0.44	0.39
CaO/Al ₂ O ₃	3.12	3.14	2.95	2.95	2.67	2.91	3.16	2.91	3.03	2.76
MgO/CaO	0.52	0.52	0.55	0.55	0.56	0.57	0.57	0.59	0.57	0.61
SiO ₂ /Al ₂ O ₃	4.72	4.77	4.98	4.92	4.82	5.34	5.50	5.68	5.84	5.38
Fe/Mn	95.13	94.70	92.16	96.55	84.60	87.32	84.86	82.80	83.64	93.98
CaO wt.%	36.78	36.72	37.26	37.31	39.13	39.70	38.15	40.34	42.63	35.45
MgO wt.%	18.95	19.04	20.47	20.39	21.73	22.53	21.74	23.82	24.36	21.64
FeO+MnO%	44.27	44.24	42.27	42.30	39.15	37.77	40.11	35.84	33.01	42.91

Sample #	585371	585372	585373	585374	585375	585376	585377	585378	585379	585380
From	1671.37	1681	1682	1683	1684	1698	1701.6	1704.36	1717.2	1718.65
То	1671.83	1682	1683	1684	1685	1699	1701.94	1704.61	1717.63	1718.85
SiO ₂	30.83	33.90	38.58	36.28	32.14	16.32	33.67	27.33	34.57	27.72
TiO ₂	10.02	7.00	4.61	4.49	4.59	2.14	4.91	9.43	6.50	10.39
Al ₂ O ₃	5.47	5.69	6.27	6.26	5.37	3.08	5.87	5.43	6.44	5.43
Cr ₂ O ₃	0.03	0.11	0.07	0.07	0.068	0.05	0.06	0.01	0.04	0.01
V ₂ O ₅	0.10	0.08	0.07	0.08	0.078	0.04	0.09	0.11	0.11	0.12
FeO	19.00	14.60	12.30	12.70	15.3	20.00	14.80	20.70	19.40	22.00
MnO	0.21	0.17	0.16	0.16	0.32	1.00	0.17	0.20	0.17	0.20
MgO	10.10	10.30	11.10	10.50	9.89	7.77	9.22	9.34	10.80	9.69
CaO	18.50	19.90	20.40	20.80	18.3	15.30	18.20	17.70	16.90	17.60
Na₂O	0.37	0.97	0.96	0.94	1.59	2.95	2.38	0.68	0.56	0.35
K ₂ O	0.01	0.13	0.12	0.28	0.031	0.01	0.33	0.28	0.02	0.02
P ₂ O ₅	2.54	2.53	1.10	2.83	1.01	0.40	0.92	3.16	0.64	2.97
WO ₃	0.02	0.04	0.02	0.04	0.01	0.02	0.00	0.02	0.03	0.01
SO ₂	0.94	0.66	0.38	0.60	0.48	0.70	0.38	1.02	0.76	1.16
CO ₂	1.50	3.30	3.00	2.90	8.1	27.00	6.70	2.90	1.60	1.50
TotC	0.42	0.9	0.82	0.78	2.21	7.37	1.84	0.82	0.44	0.41
LOI	0.32	2.49	2.64	2.44	8.53	26.30	6.81	2.26	1.43	1.21
Total	98.88	99.47	99.60	99.24	99.917	103.45	99.64	98.49	98.81	99.29
Na ₂ O+K ₂ O	0.38	1.10	1.08	1.22	1.62	2.96	2.71	0.96	0.58	0.37
CaO/Al ₂ O ₃	3.38	3.50	3.25	3.32	3.41	4.97	3.10	3.26	2.62	3.24
MgO/CaO	0.55	0.52	0.54	0.50	0.54	0.51	0.51	0.53	0.64	0.55
SiO ₂ /Al ₂ O ₃	5.64	5.96	6.15	5.80	5.99	5.30	5.74	5.03	5.37	5.10
Fe/Mn	90.81	86.20	77.16	79.67	47.99	20.07	87.38	103.88	114.54	110.41
CaO wt.%	38.69	44.25	46.41	47.10	41.77	34.72	42.93	36.92	35.75	35.56
MgO wt.%	21.13	22.90	25.25	23.78	22.57	17.63	21.75	19.48	22.85	19.58
FeO+MnO%	40.18	32.84	28.34	29.12	35.65	47.65	35.31	43.60	41.40	44.86

Sample #	585381	585382	585383	585384	585385	585386	585387	585388	585389	585390
From	1722	1723	1724	1725	1726	1733	1734	1745.65	1751.6	1756
То	1723	1724	1725	1726	1727	1734	1735	1746	1752	1757
SiO ₂	26.45	30.04	29.66	33.23	31.01	32.01	29.68	33.84	29.80	31.04
TiO ₂	6.91	5.31	5.94	5.61	7.28	5.67	7.32	6.01	10.13	7.82
Al ₂ O ₃	5.23	6.31	5.45	5.98	6.05	5.67	5.89	6.38	5.47	5.75
Cr ₂ O ₃	0.01	0.05	0.06	0.06	0.02	0.094	0.02	0.03	0.04	0.02
V ₂ O ₅	0.11	0.06	0.09	0.10	0.12	0.087	0.11	0.10	0.10	0.10
FeO	18.90	13.30	15.00	16.60	20.20	17.3	19.30	17.50	18.40	18.90
MnO	0.25	0.22	0.15	0.15	0.18	0.18	0.17	0.16	0.17	0.16
MgO	8.86	8.47	9.30	10.20	9.99	11.9	9.69	10.40	9.79	9.94
CaO	14.50	14.10	16.10	17.90	16.30	15.4	16.00	17.70	18.10	17.90
Na ₂ O	2.65	4.01	2.63	0.83	0.75	1.25	1.35	0.86	0.45	0.53
K ₂ O	0.69	0.89	0.25	0.03	0.03	0.059	0.07	0.10	0.03	0.03
P ₂ O ₅	0.55	0.85	1.66	1.21	0.73	0.513	1.14	0.66	2.50	2.05
WO ₃	0.00	0.01	0.03	0.02	0.00	0.00	0.01	0.01	0.01	0.01
SO ₂	1.06	0.54	0.64	0.58	0.98	0.8	0.92	0.54	0.94	1.08
CO ₂	11.00	12.40	10.70	5.40	4.10	6.3	5.90	0.30	3.00	3.50
TotC	2.99	3.39	2.94	1.48	1.14	1.72	1.62	0.1	0.84	0.96
LOI	11.00	13.30	11.40	5.06	3.44	6.6	5.89	3.95	2.23	2.59
Total	100.15	100.85	101.29	99.03	98.20	99.243	99.18	98.34	99.00	98.88
Na ₂ O+K ₂ O	3.34	4.90	2.88	0.86	0.78	1.31	1.42	0.96	0.48	0.56
CaO/Al ₂ O ₃	2.77	2.23	2.95	2.99	2.69	2.72	2.72	2.77	3.31	3.11
MgO/CaO	0.61	0.60	0.58	0.57	0.61	0.77	0.61	0.59	0.54	0.56
SiO ₂ /Al ₂ O ₃	5.06	4.76	5.44	5.56	5.13	5.65	5.04	5.30	5.45	5.40
Fe/Mn	75.88	60.68	100.37	111.08	112.64	96.47	113.95	109.78	108.63	118.56
CaO wt.%	34.11	39.07	39.70	39.91	34.93	34.39	35.43	38.68	38.96	38.17
MgO wt.%	20.84	23.47	22.93	22.74	21.41	26.57	21.46	22.73	21.07	21.19
FeO+MnO%	45.05	37.46	37.36	37.35	43.67	39.04	43.11	38.59	39.97	40.64

Sample #	585391	585392	585393	585394	585395	585396	585397	2501	2502	2503
From	1761	1762	1763	1764	1765	1766	1767	1776	1777	1778
То	1762	1763	1764	1765	1766	1767	1768	1777	1778	1779
SiO ₂	27.49	26.59	27.92	31.66	33.66	32.25	29.84	31.33	30.19	30.01
TiO ₂	9.39	9.38	10.38	7.73	6.77	6.31	9.39	7.78	8.18	9.39
Al ₂ O ₃	5.43	5.31	5.31	5.73	5.88	5.86	5.52	5.95	5.83	5.68
Cr ₂ O ₃	0.00	0.00	0.01	0.04	0.04	0.02	0.011	0.00	0.01	0.00
V ₂ O ₅	0.12	0.12	0.11	0.10	0.10	0.11	0.116	0.13	0.13	0.13
FeO	21.60	21.90	21.10	18.70	17.30	18.60	20.9	22.50	22.80	22.70
MnO	0.18	0.18	0.18	0.16	0.16	0.16	0.19	0.18	0.18	0.18
MgO	9.59	9.32	9.59	10.10	10.50	10.10	9.99	10.20	10.10	10.00
CaO	17.90	17.60	17.60	17.70	18.60	17.50	17.4	16.60	16.60	16.50
Na₂O	0.51	0.75	0.53	0.77	0.75	1.11	0.49	0.39	0.46	0.35
K ₂ O	0.08	0.22	0.05	0.10	0.14	0.27	0.036	0.03	0.03	0.02
P ₂ O ₅	3.27	3.49	3.19	1.61	1.67	1.21	2.07	1.08	1.44	1.36
WO ₃	0.03	0.01	0.00	0.02	0.00	0.05	0.05	0.00	0.00	0.03
SO ₂	1.16	1.10	1.10	0.94	0.82	0.80	1.1	1.12	1.46	1.44
CO ₂	2.60	3.50	2.20	3.30	2.60	4.10	2.4	1.80	2.10	2.20
TotC	0.74	0.95	0.63	0.9	0.73	1.11	0.66	0.52	0.6	0.62
LOI	1.54	2.18	1.39	2.53	1.67	3.39	0.93	0.81	0.85	0.42
Total	99.03	99.10	99.08	98.79	98.77	98.85	98.693	98.60	98.84	98.83
Na ₂ O+K ₂ O	0.59	0.97	0.58	0.87	0.89	1.38	0.53	0.42	0.49	0.37
CaO/Al ₂ O ₃	3.30	3.31	3.31	3.09	3.16	2.99	3.15	2.79	2.85	2.90
MgO/CaO	0.54	0.53	0.54	0.57	0.56	0.58	0.57	0.61	0.61	0.61
SiO ₂ /Al ₂ O ₃	5.06	5.01	5.26	5.53	5.72	5.50	5.41	5.27	5.18	5.28
Fe/Mn	120.44	122.12	117.66	117.31	108.52	116.68	110.41	125.46	127.13	126.58
CaO wt.%	36.33	35.92	36.31	37.93	39.95	37.75	35.89	33.55	33.41	33.41
MgO wt.%	19.46	19.02	19.79	21.65	22.55	21.79	20.61	20.61	20.33	20.25
FeO+MnO%	44.21	45.06	43.90	40.42	37.50	40.47	43.50	45.84	46.26	46.33

Sample #	2504	58 <u>5</u> 398	58 <u>5</u> 399	58 <u>5</u> 400	2575
From	1779	1783.1	1785.4	1787.25	1787.6
То	1780	1783.84	1786	1787.55	1787.89
SiO ₂	28.12	31.17	28.44	29.44	29.04
TiO ₂	10.88	7.45	7.34	9.38	9.59
Al ₂ O ₃	5.34	5.62	5.28	5.42	5.55
Cr ₂ O ₃	0.01	0.02	0.01	0.01	0.00
V ₂ O ₅	0.12	0.11	0.10	0.11	0.11
FeO	22.60	19.70	19.00	21.10	21.10
MnO	0.19	0.16	0.15	0.17	0.18
MgO	9.84	9.99	9.42	9.94	9.88
CaO	16.60	16.30	15.20	17.10	17.60
Na ₂ O	0.34	1.22	2.16	0.46	0.43
K ₂ O	0.02	0.32	0.53	0.04	0.06
P ₂ O ₅	2.13	0.89	0.93	2.15	2.56
WO ₃	0.04	0.01	0.01	0.01	0.02
SO ₂	1.50	1.06	1.32	1.22	1.30
CO ₂	1.80	4.50	8.40	2.10	2.10
TotC	0.51	1.23	2.29	0.58	0.58
LOI	0.51	3.55	8.09	1.21	1.13
Total	98.75	98.80	100.27	98.33	99.14
Na ₂ O+K ₂ O	0.36	1.54	2.69	0.50	0.49
CaO/Al ₂ O ₃	3.11	2.90	2.88	3.15	3.17
MgO/CaO	0.59	0.61	0.62	0.58	0.56
SiO ₂ /Al ₂ O ₃	5.27	5.55	5.39	5.43	5.23
Fe/Mn	119.39	123.58	127.13	124.58	117.66
CaO wt.%	33.72	35.32	34.73	35.40	36.10
MgO wt.%	19.99	21.65	21.52	20.58	20.26
FeO+MnO%	46.29	43.03	43.75	44.03	43.64

Table A3: Trace element compositions of lithologies from Mulligan (MLDH001) analysed by AusQuest

Sample	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514
From	902.	903.8	904.	916.5	920	920.6	921.1	925.	936.	940.2
To (m)	902.	904	905	916.7	920.6	921.1	922	925.	936.	940.4
Sc	55	3	10	31	45	62	50	10	52	2
V	683	39	140	286	392	588	387	168	627	22
Cr	445	27		376	595	588	746	21	499	14
Со	104	9	25	58	68	98	73	29	113	7
Ni	201	10	7	190	294	492	329	18	136	10
Cu	88	25	10	60	110	582	66	24	103	18
Zn	122	32	124	102	78	93	80	116	113	45
Rb	15	223	82	56	34	6	32	95	40	144
Sr	289	582	1330	647	588	199	477	1190	207	395
Zr	208	336	455	327	186	167	178	441	237	240
Nb	2.5	199.0	119.	59.0	8.0	4.5	27.5	143.	16.5	77.5
Ва	188	603	1420	513	504	96	334	1250	119	810
La	17.6	67.5	109.	42.6	18.5	10.6	16.9	93.3	15.6	41.0
Ce	43.6	91.8	225.	91.6	45.8	31.0	41.6	187.	38.2	80.8
Pr	6.32	6.34	25.3	11.10	6.60	5.14	6.50	20.6	5.36	8.46
Nd	29.4	16.90	91.6	46.30	30.70	24.60	29.90	71.0	24.1	29.50
Sm	7.20	2.30	15.9	9.45	7.55	6.70	7.35	13.4	6.10	4.75
Eu	2.35	0.50	5.15	3.00	2.55	2.20	2.55	4.10	1.95	1.75
Gd	6.40	2.00	11.6	8.00	6.60	7.00	7.00	9.80	6.00	3.40
Tb	1.00	0.35	1.80	1.25	1.00	1.00	1.05	1.45	0.90	0.60
Dy	5.50	2.30	9.00	6.85	5.60	5.00	5.45	7.45	4.70	3.05
Но	0.92	0.52	1.60	1.14	0.92	0.86	0.90	1.38	0.78	0.56
Y	21.7	15.40	40.6	27.20	21.60	19.90	20.70	36.0	18.5	14.70
Er	2.15	1.70	4.10	2.70	2.15	1.95	2.10	3.40	1.95	1.50
Tm	0.26	0.28	0.54	0.34	0.26	0.24	0.26	0.46	0.24	0.22
Yb	1.50	2.10	3.30	2.10	1.50	1.25	1.45	2.95	1.40	1.35
Lu	0.20	0.30	0.44	0.28	0.18	0.16	0.18	0.38	0.18	0.18
Hf	5.40	6.80	8.60	6.60	4.60	5.20	4.80	7.60	5.80	3.80
Та	0.00	4.80	5.40	2.40	0.20	0.20	0.30	4.90	0.50	3.10
Pb	2.00	37.00	4.00	4.00	2.00	2.00	2.00	7.00	3.00	11.00
Th	2.70	164.0	9.80	6.20	2.40	0.90	4.40	9.40	2.90	4.50
U	0.70	35.30	1.70	1.50	0.50	0.20	0.90	1.50	0.60	0.90
Y/Ho	23.5	29.62	25.3	23.86	23.48	23.14	23.00	26.0	23.7	26.25
Zr/Hf	38.5	49.41	52.9	49.55	40.43	32.12	37.08	58.0	40.8	63.16
Cu/Ni	0.44	2.50	1.43	0.32	0.37	1.18	0.20	1.33	0.76	1.80
Ni/Co	1.93	1.11	0.28	3.28	4.32	5.02	4.51	0.62	1.20	1.43



Sample	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524
From	949.5	957.7	960.3	961.3	979.5	990.	999.4	1010.1	1020.7	1030.5
To (m)	949.7	958	960.5	961.4	979.7	991	999.5	1010.3	1020.9	1030.7
Sc	59	61	29	29	65	2	32	32	15	14
V	695	846	286	286	795	17	330	471	403	235
Cr	89	21	335	342	68	14	629	96	34	34
Со	116	128	58	56	115	8	74	61	52	37
Ni	159	59	175	180	278	6	362	198	18	36
Cu	168	111	62	68	257	9	65	40	21	35
Zn	116	126	100	100	122	58	96	109	102	122
Rb	23	11	66	57	15	108	48	51	15	80
Sr	242	216	661	666	206	874	575	587	1270	1340
Zr	227	199	346	327	201	217	326	275	140	487
Nb	11.5	7.0	65.0	62.5	5.0	83.0	53.5	32.5	3.5	80.0
Ва	158	128	521	505	117	2150	446	456	384	1120
La	17.3	13.7	44.0	44.2	12.8	49.9	39.0	33.4	49.3	106.0
Се	39.9	35.2	94.8	93.1	34.2	96.3	86.0	76.9	115.0	206.0
Pr	5.70	5.38	11.60	11.40	5.44	10.8	10.70	10.80	15.80	23.20
Nd	25.8	24.8	44.7	44.6	26.4	39.6	42.8	47.3	65.5	79.7
Sm	6.55	6.65	9.25	9.20	6.75	6.45	9.30	11.00	14.20	14.40
Eu	2.15	2.15	3.10	3.00	2.25	2.95	2.95	3.65	4.30	4.75
Gd	6.20	6.40	7.80	8.20	6.20	4.60	7.40	10.00	11.80	11.40
Tb	0.95	0.95	1.25	1.25	0.95	0.70	1.20	1.60	1.75	1.80
Dy	4.95	4.90	6.25	6.55	4.95	3.55	5.90	7.15	7.70	9.10
Но	0.86	0.84	1.10	1.12	0.86	0.64	1.04	1.26	1.40	1.66
Y	19.8	20.0	27.5	26.6	19.5	14.7	23.8	29.7	33.0	39.2
Er	2.00	2.00	2.70	2.70	2.00	1.50	2.50	2.85	3.05	3.90
Tm	0.26	0.24	0.34	0.34	0.24	0.22	0.30	0.32	0.34	0.52
Yb	1.40	1.35	2.10	2.10	1.35	1.35	1.85	2.05	2.00	3.25
Lu	0.18	0.16	0.28	0.26	0.16	0.18	0.24	0.24	0.24	0.44
Hf	6.60	6.00	6.60	6.20	5.80	4.00	7.20	6.20	2.00	8.20
Та	0.50	0.20	1.80	2.40	0.10	2.40	1.30	0.50	-0.10	2.00
Pb	3.00	2.00	4.00	4.00	2.00	8.00	3.00	2.00	2.00	4.00
Th	4.30	1.40	6.30	5.70	1.10	3.40	4.80	6.10	2.60	10.80
U	1.50	0.40	1.60	1.50	0.30	0.50	1.20	1.70	0.50	1.60
Y/Ho	23.02	23.81	25.00	23.75	22.67	22.9	22.88	23.57	23.57	23.61
Zr/Hf	34.39	33.17	52.42	52.74	34.66	54.2	45.28	44.35	70.00	59.39
Cu/Ni	1.06	1.88	0.35	0.38	0.92	1.50	0.18	0.20	1.17	0.97
Ni/Co	1.37	0.46	3.02	3.21	2.42	0.75	4.89	3.25	0.35	0.97
KDC ²										

Sample #	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534
From (m)	1040.58	1049.56	1059.76	1068.37	1082.3	1090.37	1096.78	1106	1116	1126.17
To (m)	1040.8	1049.75	1060	1068.59	1082.55	1090.6	1096.96	1106.25	1116.22	1126.42
Sc	5	2	1	23	41	22	31	2	29	51
V	62	17	22	476	420	241	482	45	437	605
Cr		14	27	14	684	369	14		14	164
Со	18	7	5	67	72	53	64	7	61	74
Ni	12	14	2	31	354	230	38	7	21	97
Cu	9	13	4	55	91	32	71	5	55	64
Zn	112	72	58	91	92	101	100	46	102	115
Rb	59	112	128	17	29	110	15	105	34	10
Sr	2320	774	768	993	639	724	755	647	928	471
Zr	510	312	264	129	221	495	261	452	171	299
Nb	250.0	85.5	130.0	2.5	23.5	87.5	19.0	110.0	3.0	23.5
Ва	2820	1240	1770	557	484	810	537	943	671	307
La	131.0	52.1	65.0	83.1	24.1	54.8	34.1	51.9	76.3	26.8
Ce	282.0	99.0	142.0	188.0	62.8	102.0	86.3	110.0	172.0	68.4
Pr	31.90	10.90	16.90	24.30	8.94	12.00	12.20	11.80	21.20	9.66
Nd	112.0	39.1	57.8	99.0	41.9	42.6	54.1	40.3	86.6	42.3
Sm	18.40	6.30	10.00	19.50	9.30	8.10	13.10	6.75	17.90	9.40
Eu	5.85	2.45	3.15	6.25	3.15	2.45	3.95	1.95	5.55	2.95
Gd	13.80	4.60	6.80	16.60	8.20	6.60	10.60	4.80	15.00	8.60
Tb	2.15	0.75	1.20	2.45	1.25	1.00	1.70	0.80	2.25	1.30
Dy	11.20	3.95	6.25	11.60	6.50	5.25	8.50	4.45	10.80	6.75
Но	2.02	0.72	1.08	2.00	1.06	0.96	1.38	0.80	1.86	1.16
Y	49.5	17.4	25.7	47.8	26.0	23.8	32.4	20.6	41.9	27.6
Er	4.80	1.80	2.65	4.20	2.50	2.45	3.15	2.20	3.95	2.75
Tm	0.62	0.28	0.34	0.50	0.30	0.32	0.36	0.30	0.48	0.32
Yb	3.60	1.60	2.10	2.90	1.80	2.05	2.10	1.95	2.70	2.05
Lu	0.46	0.22	0.26	0.36	0.22	0.28	0.28	0.26	0.34	0.26
Hf	10.60	5.40	5.60	1.00	5.40	8.60	6.00	6.80	2.00	7.60
Та	13.40	3.70	8.50	-0.10	0.30	1.50	0.30	7.00		0.30
Pb	5.00	10.00	9.00	2.00	1.00	3.00	3.00	10.00	4.00	1.00
Th	6.50	6.10	5.50	3.70	1.80	6.70	1.30	8.10	3.90	1.30
U	1.20	1.70	1.10	0.80	0.50	1.50	0.40	1.80	1.00	0.30
Y/Ho	24.50	24.17	23.80	23.90	24.53	24.79	23.48	25.75	22.53	23.79
Zr/Hf	48.11	57.78	47.14	129.00	40.93	57.56	43.50	66.47	85.50	39.34
Cu/Ni	0.75	0.93	2.00	1.77	0.26	0.14	1.87	0.71	2.62	0.66
Ni/Co	0.67	2.00	0.40	0.46	4.92	4.34	0.59	1.00	0.34	1.31



Sample	2535	2536	2537	2593	2538	2539	2540	2541	2542	2543
From	1138.8	1149.6	1157.37	1168.91	1177.16	1186.2	1188.28	1199.3	1201.21	1209.64
Ťo`(m)	1139.05	1149.82	1157.49	1169.16	1177.36	1186.57	1188.5	1199.5	1201.46	1209.89
Sc	24	19	22	25	26	3	26	29	12	36
V	465	370	454	415	392	39	426	392	213	482
Cr	21	34	34	27		27	14	89		34
Со	61	56	57	53	54	6	60	54	35	66
Ni	33	26	20	24	22	7	24	72	35	89
Cu	50	44	36	43	48	6	45	37	26	69
Zn	120	135	124	89	97	16	101	136	131	111
Rb	10	35	11	18	12	122	17	15	126	24
Sr	945	1080	835	1050	1040	254	994	787	1270	762
Zr	162	221	198	140	102	120	139	366	472	274
Nb	1.0	0.5	0.5	0.5		38.0	1.0	56.5	119.0	54.5
Ва	484	669	522	599	541	247	535	574	1100	534
La	91.0	98.9	82.0	90.7	94.1	24.4	85.7	49.1	104.0	35.0
Се	215.0	224.0	190.0	214.0	223.0	48.6	206.0	120.0	193.0	83.5
Pr	29.60	28.10	24.70	28.50	29.30	5.38	27.40	16.60	21.30	11.20
Nd	120.0	113.0	100.0	119.0	122.0	18.2	114.0	68.7	76.1	47.4
Sm	25.30	21.00	20.70	24.70	25.60	3.20	23.10	15.40	14.00	11.00
Eu	7.05	6.40	6.10	7.15	7.05	0.85	6.70	4.65	4.45	3.60
Gd	19.60	17.40	16.00	19.60	20.00	2.60	17.40	12.60	10.60	9.20
Tb	2.95	2.60	2.40	2.85	3.05	0.45	2.75	1.95	1.75	1.55
Dy	14.00	12.60	12.90	13.70	13.70	2.25	12.80	9.05	9.25	7.85
Но	2.46	2.16	2.12	2.26	2.52	0.42	2.06	1.66	1.56	1.28
Y	51.9	50.9	48.8	52.6	52.7	10.4	47.9	38.4	38.4	28.9
Er	4.90	4.90	4.75	4.85	4.90	1.15	4.55	3.85	3.90	2.95
Tm	0.58	0.60	0.58	0.56	0.58	0.16	0.54	0.46	0.52	0.34
Yb	3.15	3.45	3.25	3.10	3.10	1.00	2.95	2.75	3.30	2.10
Lu	0.40	0.46	0.42	0.40	0.40	0.14	0.40	0.36	0.44	0.26
Hf	2.00	1.60	1.80	1.40	0.80	2.60	1.60	8.20	7.80	6.80
Та						2.40		2.50	2.00	2.00
Pb	-1.00	3.00	2.00	1.00	1.00	8.00	2.00	2.00	4.00	4.00
Th	2.90	4.90	2.70	2.60	2.30	5.90	3.40	2.60	10.10	3.70
U	0.60	1.10	0.50	0.50	0.50	1.60	0.70	0.60	2.10	0.70
Y/Ho	21.10	23.56	23.02	23.27	20.91	24.76	23.25	23.13	24.62	22.58
Zr/Hf	81.00	138.13	110.00	100.00	127.50	46.15	86.88	44.63	60.51	40.29
Cu/Ni	1.52	1.69	1.80	1.79	2.18	0.86	1.88	0.51	0.74	0.78
Ni/Co	0.54	0.46	0.35	0.45	0.41	1.17	0.40	1.33	1.00	1.35



Sample #	2544	2555	2556	2557	2558	2559	2560	2561	2562	2563
From (m)	1215.38	1225.34	1235.33	1246.23	1256.08	1266.61	1275.74	1280.35	1282	1291.3
To (m)	1215.7	1225.55	1235.33	1246.47	1256.3	1266.87	1275.97	1280.59	1282.24	1291.49
Sc	16	33	22	7	7	9	2	23	1	23
V	224	527	302	118	118	157	28	381	17	426
Cr	75	62	349		21			21		
Со	37	76	56	24	25	26	9	59	3	63
Ni	69	66	175	10	11	9	6	23	2	19
Cu	50	105	56	12	17	21	33	46	11	47
Zn	116	132	101	111	100	118	25	133	63	138
Rb	82	18	41	132	104	107	96	14	237	23
Sr	1190	538	850	1640	1950	1600	2410	1040	490	1110
Zr	462	305	407	469	412	363	140	177	413	124
Nb	113.0	37.0	35.5	193.0	164.0	23.0	47.0	1.0	138.0	1.5
Ва	1020	356	653	1580	1180	1190	3020	667	137	623
La	85.1	37.5	57.8	128.0	116.0	143.0	30.2	90.2	47.4	94.6
Се	172.0	89.8	123.0	240.0	213.0	261.0	50.5	217.0	69.3	223.0
Pr	19.30	12.40	14.90	25.00	22.40	26.70	5.16	28.20	5.32	29.40
Nd	71.10	50.60	55.90	85.70	76.00	89.60	17.60	117.00	15.00	120.00
Sm	13.80	11.90	10.80	14.80	13.40	15.60	2.70	23.90	1.95	24.70
Eu	4.25	3.75	3.45	4.90	4.55	4.70	1.75	6.90	0.60	7.50
Gd	11.20	10.00	9.40	11.20	10.00	12.60	2.00	18.40	1.60	19.20
Tb	1.75	1.55	1.40	1.75	1.65	1.95	0.30	2.90	0.30	2.95
Dy	8.90	8.00	7.05	9.90	8.80	10.10	1.85	13.50	2.00	13.80
Но	1.60	1.28	1.20	1.76	1.56	1.92	0.34	2.26	0.44	2.44
Y	36.80	30.70	29.00	43.40	39.00	46.70	9.00	53.40	13.20	53.80
Er	3.80	3.15	2.90	4.40	3.90	4.70	0.90	5.05	1.45	5.35
Tm	0.50	0.38	0.36	0.60	0.54	0.68	0.12	0.60	0.24	0.60
Yb	3.10	2.15	2.25	3.75	3.40	4.25	0.80	3.40	1.85	3.30
Lu	0.42	0.30	0.30	0.46	0.44	0.54	0.12	0.44	0.26	0.42
Hf	8.60	7.80	8.00	9.40	8.20	5.60	2.60	1.60	5.20	0.80
Та	4.50	1.70	0.80	6.70	8.30	0.30	1.70		4.00	
Pb	5.00	2.00	3.00	6.00	5.00	5.00	9.00	1.00	19.00	2.00
Th	8.00	3.10	5.30	12.00	10.00	13.80	4.40	2.90	51.10	3.00
U	1.80	0.70	1.20	2.10	1.70	2.30	0.90	0.60	14.60	0.60
Y/Ho	23.00	23.98	24.17	24.66	25.00	24.32	26.47	23.63	30.00	22.05
Zr/Hf	53.72	39.10	50.88	49.89	50.24	64.82	53.85	110.63	79.42	155.00
Cu/Ni	0.72	1.59	0.32	1.20	1.55	2.33	5.50	2.00	5.50	2.47
Ni/Co	1.86	0.87	3.13	0.42	0.44	0.35	0.67	0.39	0.67	0.30

KDC ²

Sample #	2564	2565	2566	2567	2568	2569	2590	2591	2592	2576
From (m)	1303.1	1312.35	1320.62	1328.4	1335.25	1347.59	1353.35	1363.22	1369.38	1379.12
To (m)	1303.37	1312.57	1320.86	1328.67	1335.48	1347.84	1353.65	1363.5	1369.59	1379.34
Sc	24	20	22	10	23	22	28	23	52	32
v	409	482	319	190	342	420	409	381	493	415
Cr	41	14	164		96	7	62	21	281	192
Со	61	56	50	50	51	59	58	58	57	53
Ni	22	21	80	15	72	22	41	34	149	107
Cu	56	40	56	131	62	51	53	66	63	67
Zn	106	124	98	96	104	137	128	103	119	130
Rb	15	12	63	132	37	20	17	15	16	13
Sr	1100	967	740	797	791	909	744	1080	578	617
Zr	147	201	355	336	349	139	344	182	303	427
Nb	2.5	1.5	70.0	62.0	34.5	1.0	62.5	1.0	11.0	56.5
Ва	630	571	584	894	599	521	502	736	358	300
La	94.8	77.9	48.5	93.8	49.2	67.6	34.1	82.3	30.5	48.1
Се	217.0	178.0	102.0	177.0	106.0	154.0	87.9	202.0	79.7	116.0
Pr	28.30	23.60	12.90	19.90	13.50	20.10	12.60	26.60	11.60	15.10
Nd	117.00	92.20	50.70	73.00	52.30	80.40	54.30	109.00	49.80	63.20
Sm	23.20	20.00	10.40	13.30	12.00	16.70	13.30	23.10	11.00	13.30
Eu	6.75	5.65	3.35	4.05	3.55	5.00	4.05	7.10	3.60	4.20
Gd	19.20	15.00	9.00	10.80	9.00	13.80	10.60	19.20	10.00	10.60
Tb	2.85	2.20	1.40	1.70	1.50	2.10	1.65	2.95	1.60	1.80
Dy	12.90	11.30	7.05	8.20	7.45	9.95	8.60	13.20	7.95	9.05
Но	2.16	1.98	1.20	1.44	1.24	1.78	1.52	2.30	1.36	1.72
Υ	49.90	44.20	27.90	36.40	29.80	41.10	33.40	53.20	31.50	34.20
Er	4.80	4.40	2.90	3.50	3.00	3.90	3.45	5.05	3.25	3.70
Tm	0.56	0.52	0.36	0.46	0.38	0.46	0.44	0.62	0.40	0.46
Yb	3.30	3.05	2.20	2.95	2.30	2.65	2.55	3.50	2.40	2.85
Lu	0.40	0.40	0.30	0.40	0.30	0.36	0.32	0.46	0.32	0.40
Hf	1.60	2.60	7.60	6.20	6.80	1.20	8.00	2.20	8.00	11.00
Та			1.90	1.00	0.50		2.70		0.50	3.50
Pb	4.00	2.00	3.00	11.00	3.00	2.00	2.00	2.00	2.00	
Th	3.30	2.90	4.90	30.50	4.70	4.20	2.60	1.70	2.30	2.90
U	0.60	0.60	1.20	4.90	1.20	1.00	0.50	0.40	0.50	0.50
Y/Ho	23.10	22.32	23.25	25.28	24.03	23.09	21.97	23.13	23.16	19.88
Zr/Hf	91.88	77.31	46.71	54.19	51.32	115.83	43.00	82.73	37.88	38.82
Cu/Ni	2.55	1.90	0.70	8.73	0.86	2.32	1.29	1.94	0.42	0.63
Ni/Co	0.36	0.38	1.60	0.30	1.41	0.37	0.71	0.59	2.61	2.02



Sample #	2594	2577	2578	2579	2580	2581	2582	2583	2584	2585
From (m)	1382.26	1389.55	1393.14	1402.17	1414.13	1423.75	1435.26	1444.48	1454	1463.57
To (m)	1382.43	1389.73	1393.35	1402.3	1414.34	1423.95	1435.54	1444.72	1454.24	1463.84
Sc	20	5	32	35	19	3	44	41	46	50
V	230	56	588	465	258	45	622	521	549	566
Cr	506	75	55	68	192	68	34	137	383	226
Co	61	10	80	68	46	8	90	70	69	86
Ni	278	20	97	90	124	26	235	243	142	248
Cu	36	10	96	87	97	6	164	245	147	151
Zn	98	45	177	93	111	40	119	116	106	112
Rb	59	186	9	13	92	123	14	17	14	11
Sr	756	1210	547	852	963	593	413	477	406	319
Zr	284	213	224	238	337	395	233	301	262	246
Nb	80.5	96.0	4.5	15.5	21.5	68.0	18.0	38.0	13.5	13.5
Ва	542	2120	249	583	822	702	303	315	234	171
La	50.5	44.9	50.6	34.1	64.4	44.5	26.0	29.5	26.6	21.0
Ce	106.0	85.7	115.0	88.9	133.0	83.1	63.9	72.9	63.8	54.3
Pr	13.10	8.92	15.20	12.60	15.50	8.60	8.98	10.10	8.80	7.78
Nd	50.20	30.60	61.70	56.10	60.40	28.60	38.80	42.80	40.10	35.50
Sm	9.80	4.90	13.10	13.00	12.10	4.80	8.80	10.10	9.15	8.40
Eu	3.00	1.70	3.80	4.20	3.80	1.45	2.80	3.15	2.95	2.70
Gd	7.60	3.80	11.00	11.00	9.40	3.80	8.00	9.00	7.60	8.20
Tb	1.20	0.65	1.65	1.70	1.55	0.65	1.20	1.35	1.20	1.10
Dy	6.35	3.40	8.20	8.55	7.15	3.90	5.75	6.35	6.10	6.40
Но	1.10	0.64	1.44	1.52	1.34	0.76	0.98	1.06	1.02	0.96
Y	26.40	16.70	32.80	31.50	32.10	19.80	23.50	25.10	23.30	21.40
Er	2.65	1.70	3.25	3.20	3.20	2.25	2.30	2.45	2.35	2.15
Tm	0.34	0.24	0.38	0.38	0.42	0.32	0.28	0.28	0.28	0.28
Yb	2.10	1.50	2.25	2.15	2.50	2.25	1.65	1.75	1.60	1.45
Lu	0.28	0.20	0.30	0.28	0.34	0.32	0.20	0.22	0.20	0.18
Hf	5.80	4.80	4.00	5.80	5.60	5.60	6.20	7.80	7.40	7.00
Та	3.50	4.00		0.60	0.40	2.50	0.90	1.80	0.60	0.50
Pb	3.00	11.00	1.00	1.00	5.00	10.00	1.00	2.00	1.00	
Th	7.30	4.80	1.90	1.30	5.80	10.50	2.20	2.80	3.20	1.70
U	1.80	1.00	0.40	0.30	1.60	2.90	0.50	0.70	0.80	0.40
У/Но	24.00	26 00	22.28	20 72	23.06	26.05	23.08	23 68	22 BV	22.20
Zr/Hf	<u>48</u> 97	20.00 44 38	56.00	41 NR	60 18	70 54	37 58	38 50	35 41	35 14
Cu/Ni	0.07	0.50	n aa	0 97	0.78	0.04 0.23	0 70	1 01	1 NZ	0.61
Ni/Co	4 56	2 00	1 21	1.32	2 70	3 25	2 61	3 47	2.06	2 88
Cu/Ni Ni/Co	0.13 4.56	0.50 2.00	0.99 1.21	0.97 1.32	0.78 2.70	0.23 3.25	0.70 2.61	1.01 3.47	1.04 2.06	0.61 2.88



Sample #	2595	2596	2597	2598	2599	2586	2587	2545	2546	2547
From (m)	1464	1465	1465.59	1466.2	1467.19	1472.72	1477.15	1478	1479.42	1479.42
To (m)	1465	1465.59	1466.2	1467.19	1468	1472.94	1477.39	1478.72	1479.87	1479.87
Sc	43	33	42	27	39	27	48	43	44	51
V	571	650	504	549	286	325	431	291	583	549
Cr	253	287	233	1314	458	287	787	411	424	623
Со	90	123	84	131	52	51	61	52	107	149
Ni	220	380	259	592	188	114	209	199	512	1370
Cu	113	273	191	452	117	56	69	69	309	979
Zn	107	124	109	151	76	106	84	80	124	140
Rb	15	19	12	27	31	71	17	39	19	11
Sr	438	571	572	291	685	814	401	626	396	293
Zr	251	241	313	161	234	490	223	288	253	251
Nb	33.0	48.5	53.5	26.0	52.5	27.5	23.0	29.0	27.0	15.0
Ва	256	373	397	250	482	584	242	513	248	162
La	24.2	27.5	35.9	15.4	36.9	60.2	17.5	32.3	19.9	17.5
Се	60.3	66.5	85.2	38.3	84.5	123.0	48.8	75.7	52.4	46.1
Pr	8.30	9.20	11.60	5.62	11.30	14.60	7.20	10.30	7.36	6.90
Nd	36.90	39.50	48.00	23.80	44.70	57.90	34.70	41.50	32.80	30.90
Sm	8.60	8.85	10.60	5.60	9.15	12.10	8.45	9.50	8.20	7.80
Eu	2.80	2.85	3.35	1.80	2.95	3.75	2.75	2.80	2.55	2.25
Gd	7.60	7.80	8.60	4.80	7.60	9.40	8.20	7.60	7.00	6.60
Tb	1.10	1.10	1.40	0.75	1.20	1.45	1.20	1.20	1.05	1.00
Dy	5.75	5.70	7.25	3.70	6.10	7.35	6.25	5.70	5.00	5.00
Но	0.94	0.94	1.14	0.62	1.04	1.36	1.00	1.06	0.94	0.92
Υ	22.20	21.70	27.60	14.10	24.90	30.40	22.50	25.70	22.40	22.00
Er	2.20	2.10	2.65	1.40	2.45	3.20	2.35	2.95	2.50	2.40
Tm	0.28	0.28	0.30	0.18	0.30	0.40	0.28	0.34	0.28	0.28
Yb	1.50	1.50	1.90	1.00	1.75	2.45	1.55	1.90	1.60	1.60
Lu	0.18	0.18	0.24	0.14	0.22	0.32	0.20	0.28	0.20	0.20
Hf	7.20	6.00	7.40	4.20	6.40	8.20	6.60	9.20	7.00	7.00
Та	1.40	2.20	2.50	1.20	2.90	0.50	1.00	2.30	1.90	1.10
Pb	-1.00	1.00	-1.00	1.00	3.00	3.00	4.00	3.00	-1.00	-1.00
Th	1.80	1.80	2.00	1.60	2.00	16.30	1.40	3.80	2.50	1.70
U	0.50	0.40	0.40	0.40	0.40	3.20	0.30	0.80	0.50	0.40
Y/Ho	23.62	23.09	24.21	22.74	23.94	22.35	22.50	24.25	23.83	23.91
Zr/Hf	34.86	40.17	42.30	38.33	36.56	59.76	33.79	31.30	36.14	35.86
Cu/Ni	0.51	0.72	0.74	0.76	0.62	0.49	0.33	0.35	0.60	0.71
Ni/Co	2.44	3.09	3.08	4.52	3.62	2.24	3.43	3.83	4.79	9.19



Table A4: Trace element compositions of lithologies from Lake Machattie (LMDH001)analysed by AusQuest

Sample#	585410	585408	585409	585402	585411	585412	585413	585414	585403	585415	585416
From(m)	961.82	962.05	967.85	970.58	974.87	977.53	978.83	979.14	981.85	986.1	993.11
To (m)	961.91	962.22	967.98	970.71	974.97	977.67	979	979.27	981.99	986.24	993.26
Sc	46	46	32	32	20	37	20	22	34	44	46
V	527	476	655	633	286	549	286	302	650	493	482
Cr	390	404	27	27	274	219	349	349	14	855	411
Со	74	69	84	92	44	79	47	48	92	67	60
Ni	101	102	66	70	94	94	119	99	161	88	88
Cu	57	47	69	78	36	69	74	50	87	49	39
Zn	100	96	116	133	78	115	96	109	131	100	106
Rb	0.20	2.60	0.60	1.40	64.60	1.20	88.60	84.60	0.40	0.40	1.60
Sr	208	220	227	287	936	255	1080	1350	212	222	226
Y	23	22	25	37	26	27	30	33	24	24	23
Zr	108	146	126	116	157	115	82	201	167	119	192
Nb	0.50	5.00			15.50		1.00	5.00		0.50	3.50
Ва	8	37	16	33	1090	25	1430	1820	14	13	34
La	16.4	17.6	20.6	32.2	87.2	26.4	89.6	92.6	19.9	17.4	15.7
Ce	52.8	52.3	63.2	92.8	179.0	74.4	181.0	189.0	59.7	54.7	49.4
Pr	8.60	8.42	10.00	15.20	20.90	11.70	20.90	21.70	10.10	9.04	8.18
Nd	44.2	42.9	52.3	69.6	77.1	57.9	79.1	80.7	47.7	48.1	40.2
Sm	10.7	10.1	12.2	17.2	14.1	14.5	14.1	15.1	11.8	11.9	10.4
Eu	3.25	3.10	3.70	5.00	4.00	4.10	4.20	4.40	3.35	3.80	3.20
Gd	9.20	8.60	11.20	14.00	10.00	11.80	11.00	11.40	9.80	10.20	9.40
Tb	1.35	1.30	1.55	2.15	1.40	1.65	1.60	1.70	1.40	1.45	1.35
Dy	7.30	6.45	7.35	9.85	7.15	8.00	7.85	8.10	6.75	6.90	6.40
Но	1.00	0.96	1.10	1.56	1.12	1.18	1.26	1.34	1.08	1.12	1.04
Y	22.7	22.0	24.9	36.7	26.3	26.5	30.4	32.8	24.2	24.2	23.4
Er	2.10	1.95	2.25	3.15	2.55	2.35	2.75	3.05	2.15	2.30	2.15
Tm	0.24	0.22	0.26	0.36	0.30	0.26	0.34	0.38	0.24	0.26	0.24
Yb	1.15	1.20	1.30	1.90	1.95	1.35	2.05	2.20	1.30	1.30	1.30
Lu	0.16	0.16	0.16	0.22	0.24	0.16	0.26	0.30	0.16	0.16	0.16
Hf	2.20	3.80	2.80	2.00	1.80	2.60	0.80	2.00	4.00	3.00	7.00
Та		0.20			0.30			0.20			0.20
Pb	2.0	2.0	4.0	2.0	4.0	2.0	7.0	12.0		3.0	8.0
Th	0.3	0.8	1.1	10.9	10.2	1.1	8.3	9.9	0.6	0.4	0.4
Y/Ho	22.70	22.92	22.64	23.53	23.48	22.46	24.13	24.48	22.41	21.61	22.50
Zr/Hf	49.09	38.42	45.00	58.00	87.22	44.23	102.50	100.50	41.75	39.67	27.43
Cu/Ni	0.56	0.46	1.05	1.11	0.38	0.73	0.62	0.51	0.54	0.56	0.44
Ni/Co	1.36	1.48	0.79	0.76	2.14	1.19	2.53	2.06	1.75	1.31	1.47

Sample #	585417	585418	585419	585404	585420	585306	585307	585308	585309	585310
From(m)	999.1	1004.84	1014.1	1020.2	1026.54	1030	1031	1032	1033	1034
To (m)	999.24	1004.96	1014.23	1020.34	1026.7	1031	1032	1033	1034	1035
Sc	37	40	29	36	29	29	31	26	28	27
V	588	510	599	588	622	627	605	482	566	493
Cr	171	109	21	157	41	68	21	89	21	89
Co	80	67	72	66	80	72	73	59	70	61
Ni	122	125	55	66	40	63	104	81	59	66
Cu	57	65	57	49	72	48	64	48	60	47
Zn	132	93	102	104	131	85	119	110	116	110
Rb	1.00	1.00	0.60		0.40	1.60	2.60	20.60	1.20	15.80
Sr	165	231	300	262	323	257	225	434	234	335
Y	18	25	33	30	34	29	27	46	31	34
Zr	139	136	128	154	115	101	69	59	58	87
Nb							0.50	2.50		
Ва	15	22	18	7	8	33	55	339	32	239
La	11.4	17.7	31.5	23.9	35.5	25.2	20.0	43.7	24.9	38.0
Ce	36.6	55.6	90.6	74.6	101.0	75.1	62.6	110.0	75.2	100.0
Pr	6.48	9.24	14.50	12.30	16.50	12.10	10.50	16.00	12.10	15.10
Nd	31.5	45.7	71.3	60.1	79.9	59.4	53.6	71.2	59.9	69.6
Sm	8.4	11.3	17.3	14.6	18.4	15.3	13.5	17.7	14.6	17.0
Eu	2.55	3.45	4.80	4.50	5.25	4.35	3.90	5.55	4.45	4.80
Gd	7.00	10.00	14.80	13.20	15.40	12.00	11.00	14.40	13.00	14.20
Tb	1.05	1.45	2.15	1.85	2.15	1.80	1.60	2.25	1.80	2.00
Dy	5.20	7.00	8.95	8.70	10.00	8.50	7.75	11.80	8.65	9.20
Но	0.82	1.06	1.44	1.32	1.58	1.24	1.14	1.84	1.34	1.48
Y	18.1	25.1	32.6	30.0	33.9	28.5	27.3	45.5	30.7	33.6
Er	1.75	2.20	2.85	2.65	3.05	2.50	2.40	4.00	2.70	2.95
Tm	0.20	0.24	0.30	0.28	0.32	0.28	0.28	0.48	0.30	0.34
Yb	1.05	1.20	1.65	1.55	1.70	1.50	1.50	2.70	1.70	1.80
Lu	0.14	0.14	0.20	0.18	0.20	0.16	0.16	0.32	0.20	0.22
Hf	4.80	3.00	2.60	2.60	1.80	2.20	1.60	0.80	1.00	1.20
Та										
Pb	4.0	18.0	5.0	2.0	1.0	3.0	4.0	5.0	3.0	3.0
Th	0.4	0.4	0.9	0.6	0.8	2.4	3.7	23.9	5.1	9.7
X/11.	00.07	00.00	00.04	00 70	04.40	00.00	00.05	04.70	00.04	00 70
Y/Ho	22.07	23.68	22.64	22.73	21.46	22.98	23.95	24.73	22.91	22.70
Zr/Ht	28.96	45.33	49.23	59.23	63.89	45.91	43.13	/3./5	58.00	72.50
Cu/Ni	0.47	0.52	1.04	0.74	1.80	0.76	0.62	0.59	1.02	0.71
NI/Co	1.53	1.87	0.76	1.00	0.50	0.88	1.42	1.37	0.84	1.08

Sample#	585421	585311	585422	585423	585424	585425	585426	585427	585428	585429
From(m)	1035.12	1040	1045.7	1047.2	1057.17	1065.34	1070.41	1073.5	1078.18	1080.71
To (m)	1035.24	1041	1045.87	1047.25	1057.32	1065.8	1070.54	1073.64	1078.35	1080.85
Sc	31	31	24	24	29	34	18	31	26	23
V	532	672	633	325	650	566	314	515	571	577
Cr	21	34	41	55	0	137	164	390	82	27
Со	64	72	76	37	66	57	40	55	51	63
Ni	61	43	35	32	41	115	58	69	100	45
Cu	45	40	84	48	85	85	54	45	51	61
Zn	118	125	141	132	142	123	109	129	136	141
Rb	1.00	1.00	0.60	92.60	0.40	0.20	92.80	0.60	0.60	0.40
Sr	273	267	281	1570	315	263	1630	270	234	299
Y	29	23	29	51	34	31	34	31	30	35
Zr	49	99	128	106	159	151	114	161	139	98
Nb				1.00			2.50			
Ва	24	34	12	1440	8	6	1270	12	13	8
La	30.1	21.8	22.6	179.0	29.4	23.7	100.0	23.2	20.9	31.0
Ce	89.7	65.0	68.1	373.0	89.9	75.1	199.0	72.6	65.8	92.9
Pr	13.80	10.40	11.30	43.80	14.50	12.50	22.80	12.50	11.40	15.90
Nd	69.3	48.8	58.6	157.0	69.4	62.1	86.1	60.7	59.4	76.3
Sm	15.9	12.8	14.9	28.3	16.5	15.6	15.5	15.9	14.1	18.5
Eu	4.60	3.70	4.20	7.95	4.75	4.50	4.90	4.65	4.65	5.45
Gd	13.40	10.20	13.00	19.20	14.20	13.20	11.20	13.20	12.80	15.80
Tb	1.85	1.55	1.85	2.75	2.05	1.80	1.80	1.95	1.95	2.20
Dy	8.25	7.00	8.40	13.30	9.35	8.40	8.20	9.20	9.15	9.80
Но	1.24	1.04	1.26	2.34	1.44	1.30	1.40	1.44	1.32	1.54
Y	29.4	23.0	28.9	51.1	33.8	30.5	34.3	30.7	29.8	34.7
Er	2.55	2.05	2.50	4.55	2.85	2.70	3.10	2.75	2.75	3.05
Tm	0.28	0.24	0.28	0.60	0.32	0.28	0.40	0.30	0.28	0.32
Yb	1.35	1.15	1.40	3.40	1.70	1.60	2.30	1.60	1.50	1.65
Lu	0.16	0.14	0.16	0.44	0.20	0.18	0.30	0.18	0.18	0.20
Hf	0.40	2.00	2.80		3.00	2.80	0.40	2.60	2.60	1.40
Та										
Pb	7.0	2.0	3.0	22.0	2.0	1.0	9.0	5.0	4.0	7.0
Th	0.7	1.6	1.0	15.9	1.1	0.9	11.3	1.1	0.6	1.2
Y/Ho	23.71	22.12	22.94	21.84	23.47	23.46	24.50	21.32	22.58	22.53
Zr/Hf	122.50	49.50	45.71		53.00	53.93	285.00	61.92	53.46	70.00
Cu/Ni	0.74	0.93	2.40	1.50	2.07	0.74	0.93	0.65	0.51	1.36
Ni/Co	0.95	0.60	0.46	0.86	0.62	2.02	1.45	1.25	1.96	0.71

Sample#	585421	585311	585422	585423	585424	585425	585426	585427	585428	585429
From(m)	1035.12	1040	1045.7	1047.2	1057.17	1065.34	1070.41	1073.5	1078.18	1080.71
To (m)	1035.24	1041	1045.87	1047.25	1057.32	1065.8	1070.54	1073.64	1078.35	1080.85
Sc	31	31	24	24	29	34	18	31	26	23
V	532	672	633	325	650	566	314	515	571	577
Cr	21	34	41	55	0	137	164	390	82	27
Со	64	72	76	37	66	57	40	55	51	63
Ni	61	43	35	32	41	115	58	69	100	45
Cu	45	40	84	48	85	85	54	45	51	61
Zn	118	125	141	132	142	123	109	129	136	141
Rb	1.00	1.00	0.60	92.60	0.40	0.20	92.80	0.60	0.60	0.40
Sr	273	267	281	1570	315	263	1630	270	234	299
Y	29	23	29	51	34	31	34	31	30	35
Zr	49	99	128	106	159	151	114	161	139	98
Nb				1.00			2.50			
Ва	24	34	12	1440	8	6	1270	12	13	8
La	30.1	21.8	22.6	179.0	29.4	23.7	100.0	23.2	20.9	31.0
Ce	89.7	65.0	68.1	373.0	89.9	75.1	199.0	72.6	65.8	92.9
Pr	13.80	10.40	11.30	43.80	14.50	12.50	22.80	12.50	11.40	15.90
Nd	69.3	48.8	58.6	157.0	69.4	62.1	86.1	60.7	59.4	76.3
Sm	15.9	12.8	14.9	28.3	16.5	15.6	15.5	15.9	14.1	18.5
Eu	4.60	3.70	4.20	7.95	4.75	4.50	4.90	4.65	4.65	5.45
Gd	13.40	10.20	13.00	19.20	14.20	13.20	11.20	13.20	12.80	15.80
Tb	1.85	1.55	1.85	2.75	2.05	1.80	1.80	1.95	1.95	2.20
Dy	8.25	7.00	8.40	13.30	9.35	8.40	8.20	9.20	9.15	9.80
Но	1.24	1.04	1.26	2.34	1.44	1.30	1.40	1.44	1.32	1.54
Y	29.4	23.0	28.9	51.1	33.8	30.5	34.3	30.7	29.8	34.7
Er	2.55	2.05	2.50	4.55	2.85	2.70	3.10	2.75	2.75	3.05
Tm	0.28	0.24	0.28	0.60	0.32	0.28	0.40	0.30	0.28	0.32
Yb	1.35	1.15	1.40	3.40	1.70	1.60	2.30	1.60	1.50	1.65
Lu	0.16	0.14	0.16	0.44	0.20	0.18	0.30	0.18	0.18	0.20
Hf	0.40	2.00	2.80		3.00	2.80	0.40	2.60	2.60	1.40
Та										
Pb	7.0	2.0	3.0	22.0	2.0	1.0	9.0	5.0	4.0	7.0
Th	0.7	1.6	1.0	15.9	1.1	0.9	11.3	1.1	0.6	1.2
Y/Ho	23.71	22.12	22.94	21.84	23.47	23.46	24.50	21.32	22.58	22.53
Zr/Hf	122.50	49.50	45.71		53.00	53.93	285.00	61.92	53.46	70.00
Cu/Ni	0.74	0.93	2.40	1.50	2.07	0.74	0.93	0.65	0.51	1.36
Ni/Co	0.95	0.60	0.46	0.86	0.62	2.02	1.45	1.25	1.96	0.71

Sample#	585430	585405	585432	585431	585433	585434	585435	585436	585452	585437
From(m)	1083.7	1086.15	1091.41	1092.19	1098.42	1106.5	1116.12	1124.25	1124.8	1128.57
To (m)	1083.84	1086.29	1091.52	1093.32	1098.57	1106.63	1116.28	1124.43	1124.95	1128.86
Sc	23	17	28	27	19	31	6	18	12	15
V	258	202	510	543	706	487	230	269	353	409
Cr	328	445	96	109	68	239	21	274	34	27
Со	55	64	50	54	63	46	23	48	44	47
Ni	178	334	109	132	53	139	14	134	8	8
Cu	42	33	66	53	30	43	8	43	7	20
Zn	143	128	152	154	229	153	90	118	110	122
Rb	49.20	54.80	0.20	0.40	0.40	0.20	4.00	63.00	3.20	2.20
Sr	1270	956	256	262	296	267	4180	1210	2310	1900
Υ	43	35	31	30	37	35	15	38	34	43
Zr	78	239	144	163	135	232	76	91	108	129
Nb	1.50	23.00	0.50	1.50		2.50	4.00	1.50		
Ва	799	800	4	7	6	8	101	969	54	111
La	115.0	102.0	18.3	19.0	26.5	18.1	16.2	116.0	29.7	30.5
Ce	250.0	208.0	60.1	61.7	87.0	64.9	47.0	239.0	92.6	99.0
Pr	30.30	23.80	10.90	10.80	14.50	11.80	7.68	28.50	15.10	16.90
Nd	114.0	86.8	57.9	56.7	75.9	63.9	38.1	105.0	76.3	86.2
Sm	22.3	15.9	14.4	14.8	20.1	17.2	8.2	18.7	18.2	22.3
Eu	6.40	4.95	4.35	4.25	5.25	4.90	3.20	5.75	5.80	7.00
Gd	15.80	11.80	13.00	13.00	15.80	14.80	6.40	13.60	14.60	19.00
Tb	2.40	1.85	2.00	2.00	2.25	2.25	0.90	2.05	2.25	2.50
Dy	11.40	9.10	8.80	8.85	10.50	10.40	4.10	9.80	9.95	12.20
Но	1.92	1.46	1.36	1.34	1.70	1.64	0.64	1.66	1.48	2.00
Y	42.7	34.6	30.5	29.8	37.2	35.3	14.6	37.9	34.4	42.5
Er	3.95	3.40	2.80	2.75	3.15	3.25	1.20	3.55	3.00	3.65
Tm	0.50	0.42	0.30	0.28	0.32	0.34	0.14	0.42	0.32	0.40
Yb	2.90	2.60	1.60	1.55	1.80	1.80	0.70	2.50	1.70	2.10
Lu	0.38	0.34	0.18	0.18	0.22	0.22	0.08	0.32	0.20	0.26
Hf		2.60	3.80	4.80	2.80	7.00	2.20	0.40	1.80	2.40
Та		0.50		0.10		0.20	0.30			
Pb	7.0	9.0	7.0	6.0	5.0	4.0	4.0	10.0	1.0	6.0
Th	7.8	9.1	0.3	0.4	1.1	0.8	0.4	10.5	1.1	5.4
Y/Ho	22.24	23.70	22.43	22.24	21.88	21.52	22.81	22.83	23.24	21.25
Zr/Hf		91.92	37.89	33.96	48.21	33.14	34.55	227.50	60.00	53.75
Cu/Ni	0.24	0.10	0.61	0.40	0.57	0.31	0.57	0.32	0.88	2.50
Ni/Co	3.24	5.22	2.18	2.44	0.84	3.02	0.61	2.79	0.18	0.17

Sample	585438	585439	585441	585440	585442	585443	585444	585498	585445	585499
From(m)	1132.3	1137.8	1145.33	1146.44	1152.1	1154.2	1155.64	1161.5	1163.69	1168.9
To (m)	1132.48	1137.99	1145.49	1146.58	1152.1	1152.65	1155.81	1162	1163.84	1169.1
Sc	14	23	28	37	27	18	27	26	28	23
V	431	605	482	420	566	302	667	515	622	543
Cr	7	21	68	472	34	130	41	21	82	0
Со	64	60	58	48	83	52	82	44	56	63
Ni	22	13	138	114	139	81	30	38	34	42
Cu	32	47	77	46	117	43	76	31	33	63
Zn	65	150	120	124	175	129	221	60	206	132
Rb	1.60	0.20	4.60	1.00	0.60	63.20	0.40	0.60	0.40	2.20
Sr	542	412	1890	377	503	1340	300	379	301	299
Y	25	49	93	38	41	36	38	44	40	34
Zr	28	202	127	114	176	108	162	153	200	46
Nb	1.50					2.50				
Ва	25	5	598	26	21	1130	13	17	10	16
La	26.0	38.0	156.0	23.8	34.1	129.0	30.7	34.7	22.6	30.0
Ce	83.7	121.0	309.0	78.8	103.0	273.0	96.9	108.0	77.5	95.7
Pr	14.80	20.20	38.00	13.70	17.90	32.10	16.00	17.90	13.70	15.80
Nd	73.5	105.0	164.0	74.2	90.0	118.0	80.3	89.4	70.5	82.0
Sm	19.3	27.1	48.4	19.1	23.0	18.7	19.7	22.4	19.4	20.7
Eu	5.20	7.40	17.40	5.60	6.35	6.20	5.45	7.00	5.65	5.75
Gd	15.40	22.00	46.80	17.00	17.80	15.40	16.60	19.00	16.60	17.60
Tb	2.15	3.10	6.55	2.40	2.50	2.15	2.45	2.80	2.55	2.40
Dy	8.20	14.60	28.80	11.30	11.20	10.50	10.90	11.90	12.00	10.50
Но	1.10	2.36	4.40	1.78	1.80	1.84	1.82	1.94	1.88	1.56
Y	24.6	48.6	93.4	38.3	41.4	36.2	38.0	44.2	39.5	34.1
Er	1.90	4.30	9.35	3.45	3.60	3.20	3.45	3.65	3.70	2.80
Tm	0.18	0.44	0.98	0.36	0.38	0.40	0.38	0.36	0.38	0.28
Yb	0.75	2.20	5.30	1.85	2.00	2.30	2.05	2.00	2.10	1.40
Lu	0.08	0.26	0.68	0.22	0.22	0.30	0.24	0.22	0.24	0.16
Hf	0.80	4.40	2.40	0.60	4.00	0.40	3.60	2.60	4.20	0.80
Та										
Pb	15.0	4.0	12.0	3.0	4.0	7.0	2.0		4.0	2.0
Th	0.8	0.7	97.4	1.0	1.9	17.2	0.9	0.7	0.6	0.7
Y/Ho	22.36	20.59	21.23	21.52	23.00	19.67	20.88	22.78	21.01	21.86
Zr/Hf	35.00	45.91	52.92	190.00	44.00	270.00	45.00	58.85	47.62	57.50
Cu/Ni	1.45	3.62	0.56	0.40	0.84	0.53	2.53	0.82	0.97	1.50
Ni/Co	0.34	0.22	2.38	2.38	1.67	1.56	0.37	0.86	0.61	0.67



Sample #	585446	585500	585302	585303	585304	585305	585447	585448	585449	585450
From(m)	1172.46	1175	1176	1177	1178	1179	1181.76	1184.7	1193.13	1197.54
To (m)	1172.6	1176	1177	1178	1179	1180	1181.92	1184.87	1193.27	1197.7
Sc	28	28	25	26	28	27	31	20	27	29
V	627	611	599	588	599	611	605	476	454	471
Cr	82	21	14	34	89	75	137	34	123	123
Со	74	72	72	66	56	55	69	55	53	45
Ni	72	92	94	87	87	99	75	89	80	61
Cu	74	72	76	65	50	49	72	35	27	55
Zn	205	175	188	161	118	112	197	68	132	113
Rb	0.60		0.40	0.40	0.20	0.20		0.40	1.20	4.80
Sr	392	324	327	300	297	297	292	472	242	273
Y	40	39	40	37	38	36	36	24	28	128
Zr	160	186	136	129	147	148	72	25	16	136
Nb										14.00
Ва	47	7	14	15	15	14	11	40	17	129
La	31.8	28.6	33.6	29.9	28.1	26.8	23.5	23.1	22.3	19.3
Ce	91.4	91.2	104.0	94.5	89.4	86.7	78.5	73.0	72.2	76.8
Pr	15.00	15.80	16.80	15.20	15.10	14.60	13.60	12.40	12.40	15.80
Nd	74.2	80.6	85.7	77.0	78.4	74.3	68.4	64.3	65.0	93.6
Sm	19.5	19.9	20.3	18.8	19.0	18.7	18.6	16.6	16.6	36.9
Eu	6.00	5.65	6.00	6.15	5.60	5.60	5.15	4.75	4.85	11.90
Gd	17.60	16.20	17.60	16.20	16.60	16.20	15.40	14.20	13.60	33.60
Tb	2.60	2.35	2.55	2.15	2.30	2.35	2.30	1.85	2.00	5.70
Dy	12.10	11.20	11.90	10.70	10.70	10.80	10.10	7.65	9.40	28.60
Но	1.98	1.74	1.78	1.94	1.68	1.78	1.70	1.08	1.26	5.06
Y	39.6	38.7	39.6	36.9	37.7	36.2	35.6	23.8	27.6	128.0
Er	3.70	3.40	3.50	3.25	3.35	3.35	3.10	2.00	2.30	12.50
Tm	0.40	0.34	0.38	0.34	0.34	0.36	0.32	0.22	0.22	1.56
Yb	2.10	1.90	2.00	1.75	1.85	1.85	1.65	1.05	0.95	8.75
Lu	0.24	0.22	0.22	0.20	0.22	0.22	0.18	0.12	0.12	1.12
Hf	3.00	4.00	2.20	2.40	2.80	3.00	0.80	0.80		2.60
Та										
Pb	2.0		1.0	1.0			1.0	5.0	2.0	13.0
Th	6.8	0.7	0.8	0.6	0.6	0.6	0.6	9.0	0.4	116.0
Y/Ho	20.00	22.24	22.25	19.02	22.44	20.34	20.94	22.04	21.90	25.30
Zr/Hf	53.33	46.50	61.82	53.75	52.50	49.33	90.00	31.25		52.31
Cu/Ni	1.03	0.78	0.81	0.75	0.57	0.49	0.96	0.39	0.34	0.90
Ni/Co	0.97	1.28	1.31	1.32	1.55	1.80	1.09	1.62	1.51	1.36



Sample #	585451	585453	585454	585455	585456	585457	585312	585313	585458	585459
From(m)	1208.14	1217.74	1227.57	1238.52	1245.45	1255.51	1256	1257	1265.23	1274.66
To (m)	1208.3	1217.91	1227.74	1238.68	1245.57	1255.7	1257	1258	1265.39	1274.84
Sc	29	36	19	25	16	24	23	23	14	11
V	644	504	246	599	465	605	566	571	415	426
Cr	62	281	151	14	7	21	7	82	48	7
Со	75	58	41	65	58	55	67	47	38	47
Ni	78	131	89	10	11	40	49	18	8	4
Cu	96	72	44	63	16	41	71	27	8	4
Zn	209	162	133	179	22	128	137	75	104	125
Rb	0.20	0.40	86.00	0.60	1.40	0.40	1.40	2.00	1.60	1.20
Sr	251	237	3130	342	437	291	305	343	1440	1860
Y	36	31	49	41	21	32	32	45	29	27
Zr	236	225	171	149	52	154	94	99	112	138
Nb	1.00	4.00	3.00		6.00					0.50
Ва	15	8	1230	12	23	6	23	29	37	40
La	19.1	14.9	178.0	31.4	23.4	24.9	28.4	30.4	22.6	22.0
Ce	63.5	53.0	351.0	98.1	73.4	77.7	85.4	89.9	70.0	68.8
Pr	11.50	9.86	39.20	16.80	12.60	13.40	13.90	15.30	11.90	11.50
Nd	60.6	52.0	142.0	83.8	63.8	69.8	71.2	75.7	59.4	56.0
Sm	16.3	14.9	24.3	22.3	15.0	17.4	17.5	21.2	14.9	14.9
Eu	4.60	4.40	7.45	6.35	4.65	5.25	5.15	6.05	4.65	4.45
Gd	15.00	12.60	16.80	17.80	12.40	15.00	15.40	18.60	12.40	12.00
Tb	2.05	1.85	2.60	2.70	1.65	2.20	2.20	2.60	1.85	1.70
Dy	10.50	8.85	12.10	11.70	7.15	9.60	9.85	12.60	8.90	7.95
Но	1.78	1.34	1.98	1.88	0.94	1.42	1.54	2.10	1.24	1.20
Y	36.1	30.8	49.0	40.7	20.7	31.9	31.8	44.6	28.7	26.7
Er	3.15	2.75	4.35	3.65	1.70	2.80	2.70	4.05	2.50	2.35
Tm	0.34	0.30	0.56	0.38	0.18	0.28	0.28	0.44	0.28	0.26
Yb	1.85	1.60	3.25	2.00	0.75	1.45	1.45	2.35	1.30	1.35
Lu	0.22	0.18	0.42	0.24	0.08	0.16	0.16	0.28	0.16	0.16
Hf	7.80	7.80	0.60	3.00	2.20	3.40	1.60	1.80	2.00	3.20
Та		0.40	0.10		0.40					
Pb	5.0	1.0	16.0	4.0	11.0	1.0	2.0	2.0		2.0
Th	1.7	0.4	18.7	4.2	0.7	0.9	0.9	7.9	0.9	0.8
Y/Ho	20.28	22.99	24.75	21.65	22.02	22.46	20.65	21.24	23.15	22.25
Zr/Hf	30.26	28.85	285.00	49.67	23.64	45.29	58.75	55.00	56.00	43.13
Cu/Ni	1.23	0.55	0.49	6.30	1.45	1.03	1.45	1.50	1.00	1.00
Ni/Co	1.04	2.26	2.17	0.15	0.19	0.73	0.73	0.38	0.21	0.09

Sample#	585460	585461	585489	585462	585463	585464	585465	585466	585467	585468
From(m)	1285.4	1296.24	1301.79	1312.14	1321.54	1333.4	1340.52	1347.63	1353	1354.17
To (m)	1285.56	1296.4	1301.95	1312.32	1321.7	1333.58	1340.68	1347.82	1354.17	1355.05
Sc	10	20	16	20	22	23	23	20	17	10
V	347	622	207	605	611	566	571	605	538	280
Cr	7	14	424	0	0	14	14	14	34	21
Co	35	53	69	56	59	59	52	43	48	33
Ni	4	3	396	4	2	2	9	1	2	27
Cu	5	27	32	38	46	52	40	25	29	9
Zn	103	150	100	144	138	125	141	92	131	115
Rb	2.60	0.20	49.00	0.40	0.20	0.40	0.40	0.40	3.40	7.80
Sr	1330	322	644	298	295	331	310	269	358	796
Y	23	38	23	36	37	33	36	36	33	67
Zr	89	135	237	161	187	143	100	128	100	52
Nb			61.50							11.50
Ва	33	6	641	9	6	14	18	16	463	671
La	19.6	30.5	41.2	29.9	29.1	27.4	30.9	31.4	26.8	55.6
Ce	59.9	95.3	88.3	92.5	91.3	85.0	94.3	95.0	82.3	180.0
Pr	9.68	15.80	10.80	15.70	15.30	14.00	15.40	16.10	14.40	27.30
Nd	50.9	81.4	43.3	76.2	80.5	73.6	78.9	78.5	70.8	118.0
Sm	12.7	20.5	8.7	19.8	19.8	19.4	18.5	18.5	17.6	27.3
Eu	3.95	5.65	2.70	5.65	5.75	5.35	5.75	5.75	5.10	8.20
Gd	10.80	17.60	7.00	17.00	16.60	15.60	16.80	17.20	15.80	19.80
Tb	1.55	2.55	1.05	2.35	2.35	2.25	2.30	2.30	2.40	3.10
Dy	6.60	11.20	5.35	10.90	10.70	10.10	10.30	11.40	10.20	15.30
Но	1.02	1.80	0.92	1.72	1.70	1.54	1.56	1.64	1.52	2.60
Y	22.7	37.7	22.8	36.2	36.8	33.3	35.7	35.6	33.0	66.7
Er	1.90	3.30	2.20	3.20	3.20	2.85	2.85	3.00	3.00	6.70
Tm	0.20	0.34	0.28	0.32	0.32	0.28	0.30	0.30	0.32	0.80
Yb	0.95	1.80	1.65	1.70	1.75	1.55	1.55	1.50	1.60	4.75
Lu	0.12	0.20	0.20	0.20	0.20	0.16	0.16	0.18	0.18	0.58
Hf	2.00	2.60	4.80	3.40	4.20	3.40	2.40	3.00	2.20	1.20
Та			2.20							0.20
Pb			3.0		1.0	1.0	2.0	4.0	3.0	11.0
Th	0.9	0.8	5.0	0.8	0.7	0.7	1.4	0.8	2.0	29.5
Y/Ho	22.25	20.94	24.78	21.05	21.65	21.62	22.88	21.71	21.71	25.65
Zr/Hf	44.50	51.92	49.38	47.35	44.52	42.06	41.67	42.67	45.45	43.33
Cu/Ni	1.25	9.00	0.08	9.50	23.00	26.00	4.44	25.00	14.50	0.33
Ni/Co	0.11	0.06	5.74	0.07	0.03	0.03	0.17	0.02	0.04	0.82



Sample#	585469	585470	585471	585472	585473	585474	585475	585476	585477	585478
From(m)	1355.05	1356.05	1357.05	1358.08	1359.07	1360.07	1360.73	1361.64	1362.64	1363.66
To (m)	1356.07	1357.05	1358.08	1359.07	1360.07	1360.73	1361.64	1362.64	1363.66	1364.67
Sc	5	3	6	18	22	17	5	5	5	14
V	112	56	162	521	510	409	84	123	90	218
Cr	14	0	7	7	0	0	7	55	21	55
Со	29	60	31	44	45	44	44	26	41	55
Ni	22	41	10	11	19	18	37	23	43	115
Cu	25	15	5	13	21	19	14	1	9	44
Zn	110	165	190	155	222	451	139	87	130	155
Rb	3.20		3.00	23.60	8.60	7.80				1.20
Sr	943	745	1050	300	350	457	678	894	1110	342
Y	28	22	27	108	117	70	21	29	52	27
Zr	15	4	9	34	29	19	4	4	2	20
Nb	125.00	51.50	36.00				92.50	161.00	198.00	47.00
Ва	344	54	867	689	829	472	42	40	46	41
La	181.0	669.0	165.0	33.4	44.9	63.8	378.0	282.0	423.0	19.2
Ce	457.0	1620.0	448.0	114.0	165.0	199.0	910.0	689.0	1120.0	62.0
Pr	53.90	182.00	57.70	18.70	29.40	29.60	102.00	79.30	141.00	8.62
Nd	184.0	586.0	206.0	92.3	152.0	124.0	337.0	267.0	529.0	37.6
Sm	28.0	70.9	31.5	27.7	46.3	27.8	41.7	35.0	85.1	8.9
Eu	6.80	14.60	7.45	9.35	13.90	7.85	9.40	7.75	20.10	2.80
Gd	13.60	27.20	14.80	25.80	36.00	20.20	18.60	16.00	40.60	7.00
Tb	1.65	2.45	1.80	4.45	5.40	3.10	1.95	1.80	4.30	1.20
Dy	7.50	8.50	6.25	22.60	26.30	14.60	6.55	7.85	16.80	6.15
Но	1.14	1.02	1.14	4.26	4.68	2.80	0.98	1.24	2.50	1.08
Y	28.2	21.9	26.7	108.0	117.0	70.3	21.1	29.4	52.4	26.8
Er	2.20	0.10	2.15	10.50	11.10	7.05	1.10	2.20	3.65	2.85
Tm	0.36	0.26	0.34	1.32	1.40	0.90	0.28	0.40	0.64	0.38
Yb	2.20	1.50	2.15	8.00	8.35	5.95	1.75	2.50	3.75	2.40
Lu	0.30	0.22	0.30	0.96	1.02	0.76	0.22	0.34	0.48	0.32
Hf			0.40	0.40	0.40					0.80
Та	0.10						0.20	0.20	0.30	
Pb	16.0	16.0	47.0	31.0	92.0	43.0	19.0	8.0	11.0	8.0
Th	10.4	24.7	8.9	61.6	24.2	13.6	16.9	23.7	34.2	10.4
Y/Ho	24.74	21.47	23.42	25.35	25.00	25.11	21.53	23.71	20.96	24.81
Zr/Hf			22.50	85.00	72.50					25.00
Cu/Ni	1.14	0.37	0.50	1.18	1.11	1.06	0.38	0.04	0.21	0.38
Ni/Co	0.76	0.68	0.32	0.25	0.42	0.41	0.84	0.88	1.05	2.09



Sample #	585479	585480	585481	585482	585483	585488	585484	585485	585314	585315
From(m)	1364.67	1365.29	1366.3	1367.3	1368.3	1378.62	1388.77	1389.79	1390	1391
To (m)	1365.29	1366.3	1367.3	1368.3	1369.3	1378.81	1388.97	1389.95	1391	1392
Sc	20	15	12	14	12	22	19	22	18	18
V	504	387	302	325	364	515	521	521	521	504
Cr	27	7	14	7	27	0	0	48	14	48
Со	46	40	36	39	34	43	44	35	47	41
Ni	12	10	24	12	8	42	18	18	15	12
Cu	78	23	36	14	9	30	21	12	23	25
Zn	136	111	192	247	161	67	76	42	71	68
Rb	10.60	8.00	8.60	12.60	8.60	0.20	0.60	0.60	1.20	1.60
Sr	348	733	1040	728	1030	258	288	310	274	298
Y	76	123	94	82	81	35	40	39	35	34
Zr	12	25	18	8	59	111	102	104	68	79
Nb	1.00	0.50	1.00	0.50						
Ва	65	456	583	529	518	20	31	53	30	28
La	33.9	36.5	37.7	59.7	25.2	28.2	27.9	31.0	29.1	30.7
Ce	117.0	125.0	120.0	202.0	88.4	85.9	88.1	95.5	93.4	94.5
Pr	19.40	21.30	19.90	31.50	16.50	14.70	14.70	15.80	15.80	16.30
Nd	96.2	104.0	99.0	149.0	87.6	74.6	76.2	81.8	80.1	82.9
Sm	27.0	28.5	27.0	36.5	32.1	19.0	20.6	19.8	20.0	20.6
Eu	7.85	9.60	9.05	11.20	10.40	5.35	5.75	6.15	5.60	5.80
Gd	21.80	27.00	24.20	30.40	27.20	15.40	17.40	17.40	16.40	17.40
Tb	3.55	4.65	4.10	4.50	4.35	2.25	2.50	2.45	2.50	2.45
Dy	18.30	25.10	21.10	20.90	20.20	10.00	11.40	10.90	10.10	11.20
Но	3.00	4.50	3.58	3.28	3.28	1.46	1.86	1.74	1.60	1.76
Y	76.3	123.0	93.7	82.2	80.7	34.5	39.5	39.0	35.0	34.4
Er	7.05	11.30	9.30	7.05	7.65	2.80	3.45	3.20	2.80	3.00
Tm	0.86	1.40	1.10	0.86	0.86	0.30	0.36	0.34	0.28	0.32
Yb	4.90	8.25	6.60	4.55	5.00	1.45	1.95	1.75	1.40	1.55
Lu	0.60	0.96	0.74	0.54	0.62	0.16	0.20	0.18	0.16	0.18
Hf					0.60	2.60	2.40	2.60	1.40	1.40
Та										
Pb	24.0	43.0	46.0	14.0	10.0	2.0	5.0	3.0	2.0	1.0
Th	47.1	230.0	60.5	36.4	28.7	0.8	10.2	8.9	1.9	3.3
Y/Ho	25.43	27.33	26.17	25.06	24.60	23.63	21.24	22.41	21.88	19.55
Zr/Hf					98.33	42.69	42.50	40.00	48.57	56.43
Cu/Ni	6.50	2.30	1.50	1.17	1.13	0.71	1.17	0.67	1.53	2.08
Ni/Co	0.26	0.25	0.67	0.31	0.24	0.98	0.41	0.51	0.32	0.29



Sample #	585316	585317	585318	585319	585320	585321	585322	585323	585325	585324
From(m)	1392	1393	1394	1400	1401	1402	1403	1404	1404	1405
To (m)	1393	1394	1395	1401	1402	1403	1404	1405	1407	1406
Sc	20	19	19	22	22	22	23	23	26	26
V	560	538	543	515	521	555	543	588	566	527
Cr	14	21	62	34	130	7	34	41	96	219
Со	47	53	58	57	58	65	59	66	64	59
Ni	14	20	21	40	42	47	47	53	66	74
Cu	29	35	38	32	26	47	40	41	45	38
Zn	100	127	157	130	136	151	130	163	144	149
Rb	0.40	0.40	0.40	0.40	0.40	0.60	1.20	2.60	2.00	3.40
Sr	287	279	282	239	266	206	179	186	186	208
Y	35	34	36	32	35	32	24	23	25	28
Zr	138	114	156	112	145	114	102	54	165	116
Nb							1.50		3.00	4.00
Ва	20	20	19	39	38	46	42	43	40	75
La	29.9	28.2	28.9	26.2	27.9	22.4	14.5	13.3	11.0	10.8
Ce	92.3	87.2	90.0	81.8	86.7	72.4	47.8	45.2	40.5	40.8
Pr	15.60	14.90	15.60	14.10	14.40	12.40	8.90	8.22	7.82	7.62
Nd	78.7	75.5	80.2	71.1	72.0	64.8	46.2	44.6	42.8	43.3
Sm	19.4	20.2	19.4	17.6	19.0	17.4	13.0	12.1	12.0	12.8
Eu	5.85	5.50	5.75	5.35	5.75	5.00	3.70	3.85	3.90	4.05
Gd	16.40	16.20	16.60	15.80	15.20	14.20	10.80	10.80	11.00	11.80
Tb	2.35	2.35	2.30	2.30	2.05	2.15	1.65	1.65	1.65	1.70
Dy	10.90	10.20	10.50	9.75	10.70	9.35	7.50	7.00	7.80	8.45
Но	1.68	1.62	1.66	1.52	1.72	1.54	1.10	1.06	1.18	1.26
Y	35.2	34.4	36.4	32.1	34.6	32.4	23.6	23.0	24.6	27.6
Er	3.05	2.95	3.05	2.85	2.90	2.90	2.15	2.10	2.40	2.65
Tm	0.32	0.28	0.30	0.28	0.28	0.30	0.24	0.22	0.26	0.28
Yb	1.60	1.50	1.55	1.40	1.55	1.60	1.10	1.10	1.40	1.50
Lu	0.18	0.16	0.16	0.16	0.16	0.18	0.14	0.12	0.16	0.16
Hf	3.00	2.60	3.40	2.60	3.40	3.20	4.20	2.20	6.60	4.40
Та							0.20		0.20	0.30
Pb	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0
Th	0.8	0.8	1.0	1.7	0.9	5.7	2.1	6.0	2.0	6.4
V/U	20.05	21 22	21.02	71 17	20.12	21 04		21 70	20.95	21.00
1/H0 7*/Uf	20.95	21.23 42.05	21.93	Z1.1Z	20.12	21.04	21.45	21.70	20.85	21.90
	46.00	43.85	45.88	43.08	42.65	35.63	24.29	24.55	25.00	20.30
	2.07	1.75	1.01	0.80	0.02	1.00	0.85	0.77	0.08 1 02	U.51 1 25
Dy Ho Y Er Tm Yb Lu Hf Ta Pb Th Y/Ho Zr/Hf Cu/Ni Ni/Co	10.90 1.68 35.2 3.05 0.32 1.60 0.18 3.00 1.0 0.8 20.95 46.00 2.07 0.30	10.20 1.62 34.4 2.95 0.28 1.50 0.16 2.60 1.0 0.8 21.23 43.85 1.75 0.38	$ \begin{array}{r} 10.50 \\ 1.66 \\ 36.4 \\ 3.05 \\ 0.30 \\ 1.55 \\ 0.16 \\ 3.40 \\ 1.0 \\ 1.0 \\ 1.0 \\ 21.93 \\ 45.88 \\ 1.81 \\ 0.36 \\ \end{array} $	9.75 1.52 32.1 2.85 0.28 1.40 0.16 2.60 1.0 1.7 21.12 43.08 0.80 0.70	10.70 1.72 34.6 2.90 0.28 1.55 0.16 3.40 2.0 0.9 20.12 42.65 0.62 0.72	9.35 1.54 32.4 2.90 0.30 1.60 0.18 3.20 2.0 5.7 21.04 35.63 1.00 0.72	7.50 1.10 23.6 2.15 0.24 1.10 0.14 4.20 0.20 2.0 2.1 21.45 24.29 0.85 0.80	7.00 1.06 23.0 2.10 0.22 1.10 0.12 2.20 2.0 6.0 21.70 24.55 0.77 0.80	7.80 1.18 24.6 2.40 0.26 1.40 0.16 6.60 0.20 2.0 2.0 2.0 20.85 25.00 0.68 1.03	8.45 1.26 27.6 2.65 0.28 1.50 0.16 4.40 0.30 2.0 6.4 21.90 26.36 0.51 1.25



Sample#	585486	585487	585490	585491	585492	585493	585494	585326	585327	585328
From(m)	1408.37	1419.12	1429.58	1439.4	1449.61	1458.65	1467.57	1470	1471	1472
To (m)	1408.57	1419.27	1429.78	1439.62	1449.8	1458.85	1467.8	1471	1472	1473
Sc	24	22	28	32	34	22	24	27	25	24
V	588	560	566	555	549	286	622	599	566	566
Cr	301	14	34	116	137	376	68	144	130	116
Со	63	39	73	66	53	57	52	54	52	53
Ni	68	15	123	107	55	231	100	82	76	78
Cu	42	29	68	54	36	43	31	36	35	36
Zn	165	41	141	122	132	103	90	126	133	140
Rb	0.20	0.40	0.60	0.40	0.20	81.80	1.00	0.40	3.00	9.40
Sr	199	339	320	304	216	1280	251	227	247	292
Y	26	38	34	32	26	30	30	29	31	34
Zr	184	157	81	148	231	209	165	192	184	160
Nb	2.50				1.50	7.50				
Ва	23	45	24	15	10	1090	20	10	23	83
La	12.7	32.3	30.1	27.5	14.4	81.2	22.0	18.8	20.9	21.9
Ce	44.6	98.5	90.8	82.4	48.7	168.0	66.7	59.9	64.9	71.9
Pr	8.32	16.50	14.70	14.20	8.84	19.90	11.40	10.60	11.10	12.20
Nd	45.7	83.0	73.0	68.5	47.3	73.1	58.7	56.8	58.6	60.9
Sm	13.0	20.7	18.3	16.8	11.7	14.2	15.2	15.8	15.5	16.4
Eu	3.85	5.55	5.30	4.95	4.00	4.40	4.55	4.05	4.55	4.65
Gd	11.80	17.60	15.00	13.80	11.80	10.80	13.00	12.80	13.00	14.00
Tb	1.65	2.40	2.15	2.05	1.55	1.60	1.85	1.85	2.00	2.10
Dy	8.30	10.80	9.55	9.05	7.80	7.50	8.65	8.90	8.85	9.85
Но	1.14	1.62	1.46	1.38	1.14	1.24	1.30	1.34	1.40	1.62
Y	26.0	38.0	34.1	31.5	25.5	30.3	29.5	29.3	30.5	34.3
Er	2.40	3.25	2.75	2.80	2.40	2.80	2.65	2.65	2.85	3.25
Tm	0.26	0.32	0.28	0.28	0.26	0.34	0.28	0.28	0.30	0.36
Yb	1.25	1.75	1.50	1.50	1.35	2.05	1.45	1.50	1.60	2.00
Lu	0.16	0.20	0.16	0.16	0.16	0.26	0.16	0.18	0.18	0.24
Hf	7.60	3.00	1.00	2.60	8.00	2.60	3.20	4.40	4.60	3.00
Та	0.20									
Pb	2.0			2.0		11.0	2.0		2.0	3.0
Th	0.8	1.1	1.6	0.7	0.4	8.1	2.0	3.5	2.9	6.6
×/11-	22.04	22.40	22.20	22.02	22.27		22.00	24.07	24 70	24 47
Y/HO	22.81	23.4b	23.30	22.83	22.37	24.44	22.69	21.8/	21.79	21.1/
	24.21	52.33	81.00	56.92	28.88	80.38	51.50	43.64	40.00	53.33
	0.62	1.93	0.55	0.50	0.65	0.19	1.02	0.44	0.46	0.46
NI/CO	80.L	0.38	1.68	1.62	1.04	4.05	1.92	1.52	1.46	1.4/



Sample #	585329	585330	585331	585332	585495	585496	585333	585334	585497	585335
From(m)	1473	1474	1475	1476	1477.2	1482.7	1486	1487.7	1493.41	1500.55
To (m)	1474	1475	1476	1477	1477.4	1482.89	1487	1488	1493.58	1501
Sc	23	24	26	28	27	25	12	23	22	19
V	599	571	521	487	560	274	330	263	627	655
Cr	41	192	198	458	328	239	34	239	34	62
Со	60	55	46	46	48	41	38	41	41	49
Ni	87	74	57	56	54	80	33	97	72	33
Cu	46	59	30	33	32	45	36	49	50	39
Zn	141	119	104	120	112	110	138	112	78	140
Rb	2.20	1.20	1.40	4.00	1.60	70.00	12.20	53.00	0.40	0.60
Sr	276	275	259	239	254	1340	778	954	268	240
Y	29	30	28	35	32	37	45	43	33	29
Zr	172	162	149	238	143	258	104	264	179	162
Nb				5.00		2.50	51.50	7.50		
Ва	22	18	20	58	16	1190	379	1070	10	13
La	19.5	20.2	19.7	17.9	20.0	91.1	61.2	89.0	23.7	19.9
Ce	63.9	65.2	62.6	60.6	64.4	191.0	158.0	190.0	75.7	63.7
Pr	11.00	11.20	10.50	10.80	10.90	22.20	21.00	23.80	12.60	10.80
Nd	57.2	57.6	54.5	57.6	57.6	86.4	83.1	91.6	63.0	56.6
Sm	14.4	14.9	14.0	15.9	15.6	16.7	18.3	19.4	17.6	15.1
Eu	4.45	4.30	4.60	4.95	4.40	5.05	5.70	5.95	4.95	4.45
Gd	12.40	13.00	13.40	13.60	13.40	11.80	14.20	14.80	14.20	13.20
Tb	1.80	1.85	2.00	2.05	2.05	1.85	2.25	2.30	2.15	1.85
Dy	8.60	8.65	8.70	9.80	8.90	9.10	11.10	11.20	9.60	8.90
Но	1.36	1.44	1.28	1.56	1.38	1.54	2.00	1.80	1.44	1.34
Y	29.3	30.3	28.3	35.2	31.7	36.7	45.3	43.2	32.6	29.0
Er	2.70	2.90	2.65	3.25	2.70	3.25	4.45	4.15	2.85	2.60
Tm	0.28	0.30	0.28	0.36	0.30	0.40	0.56	0.52	0.30	0.28
Yb	1.55	1.65	1.45	2.05	1.55	2.45	3.25	3.00	1.55	1.45
Lu	0.18	0.20	0.16	0.24	0.18	0.30	0.40	0.38	0.18	0.16
Hf	4.40	4.80	3.60	8.20	2.60	2.20	3.40	3.20	3.60	3.60
Та				0.30		0.10	1.20			
Pb	1.0	1.0		3.0		7.0	32.0	7.0	2.0	
Th	1.2	1.7	1.0	9.8	2.7	9.0	22.2	14.2	0.7	0.6
Y/Ho	21.54	21.04	22.11	22.56	22.97	23.83	22.65	24.00	22.64	21.64
Zr/Hf	39.09	33.75	41.39	29.02	55.00	117.27	30.59	82.50	49.72	45.00
Cu/Ni	0.53	0.80	0.53	0.59	0.59	0.56	1.09	0.51	0.69	1.18
Ni/Co	1.45	1.35	1.24	1.22	1.13	1.95	0.87	2.37	1.76	0.67



Sample #	585336	585337	585338	585339	585340	585341	585342	585343	585344	585345
From(m)	1515	1523	1524	1525	1535	1536	1537	1538	1539	1539.77
To (m)	1515.35	1524	1525	1526	1536	1537	1538	1539	1539.77	1540
Sc	19	16	24	23	26	27	26	25	24	24
V	415	426	543	538	622	566	627	706	650	633
Cr	82	41	7	7	96	82	34	14	7	34
Со	41	43	51	53	45	40	54	60	62	64
Ni	45	21	6	7	51	29	26	22	14	10
Cu	12	23	8	8	4	5	8	15	10	16
Zn	92	128	112	103	65	49	77	101	116	135
Rb	19.40	9.00	2.20	1.60	0.40	0.60	0.40	0.20	0.20	0.40
Sr	464	565	233	248	271	250	223	213	228	280
Y	28	40	26	27	31	28	25	25	27	27
Zr	87	51	83	80	129	124	114	128	114	84
Nb	0.50									
Ва	301	255	22	19	7	11	9	5	6	8
La	49.1	47.6	26.0	27.3	32.5	27.5	23.9	21.5	25.2	27.5
Ce	118.0	124.0	75.3	79.8	94.6	80.8	71.6	63.8	75.5	80.1
Pr	16.40	17.50	12.00	12.60	15.20	12.90	11.40	10.40	12.20	12.70
Nd	71.0	75.4	62.1	62.3	73.3	66.0	59.3	51.3	61.5	63.8
Sm	15.3	17.0	15.7	15.3	18.3	16.1	14.4	12.8	15.3	14.9
Eu	4.45	5.10	4.45	4.40	5.10	4.75	4.25	3.75	4.45	4.65
Gd	11.80	13.80	13.00	13.20	15.40	13.40	11.80	12.00	12.80	13.60
Tb	1.75	2.10	1.80	1.85	2.10	1.85	1.75	1.65	1.75	1.85
Dy	7.80	9.90	8.05	8.55	9.70	8.30	8.00	7.40	8.15	8.25
Но	1.24	1.70	1.18	1.18	1.54	1.24	1.18	1.10	1.20	1.22
Y	28.3	39.6	26.3	26.8	31.0	27.9	25.4	24.8	27.0	27.2
Er	2.50	3.50	2.30	2.25	2.65	2.40	2.30	2.15	2.35	2.45
Tm	0.28	0.42	0.26	0.24	0.28	0.26	0.26	0.24	0.26	0.26
Yb	1.50	2.45	1.20	1.15	1.45	1.30	1.15	1.15	1.30	1.30
Lu	0.18	0.30	0.16	0.14	0.16	0.16	0.16	0.14	0.16	0.16
Hf	0.60	0.60	1.80	1.60	2.60	3.00	2.60	3.00	2.60	1.60
Та										
Pb	3.0	23.0	2.0			1.0	3.0		1.0	
Th	4.9	14.5	2.2	1.9	0.8	0.7	0.6	0.4	0.7	0.7
Ү/Но	22.82	23.29	22.29	22.71	20.13	22.50	21.53	22.55	22.50	22.30
Zr/Hf	145.00	85.00	46.11	50.00	49.62	41.33	43.85	42.67	43.85	52.50
Cu/Ni	0.27	1.10	1.33	1.14	0.08	0.17	0.31	0.68	0.71	1.60
Ni/Co	1.10	0.49	0.12	0.13	1.13	0.73	0.48	0.37	0.23	0.16



Sample	585346	585347	585348	585349	2570	585350	585351	585 <u>352</u>	585353	585354
From(m)	1547.7	1554.78	1558.07	1559.32	1569.55	1580	1581	1582	1591.03	1591.4
To (m)	1548	1554.98	1558.37	1559.7	1569.75	1581	1582	1583	1591.27	1591.65
Sc	26	25	25	23	39	31	31	34	35	34
V	566	555	605	527	577	627	627	599	527	487
Cr	48	27	27	68	178	48	89	157	513	486
Со	64	50	44	40	66	61	79	79	69	60
Ni	19	7	3	26	88	114	87	79	45	42
Cu	21	14	8	13	45	22	39	48	48	39
Zn	118	60	58	48	112	54	97	105	98	80
Rb	12.20	0.40	0.40	17.40	2.80	0.40	0.40	0.40	0.40	1.00
Sr	329	232	246	565	280	271	223	227	191	227
Υ	35	24	28	34	29	31	26	26	22	28
Zr	89	60	126	102	146	131	145	166	85	38
Nb					0.50					
Ва	180	9	8	337	45	6	7	6	21	23
La	36.2	24.9	26.5	51.5	25.3	28.5	19.5	19.3	17.4	15.6
Се	96.2	71.6	76.8	120.0	73.5	81.4	59.1	58.8	53.8	50.4
Pr	14.90	11.90	12.80	17.00	12.00	13.20	9.76	9.96	9.20	8.74
Nd	69.2	58.6	62.2	75.9	57.8	64.3	50.8	50.2	45.4	44.2
Sm	17.5	14.0	16.1	16.6	14.4	16.5	13.4	13.1	11.8	12.5
Eu	5.35	4.30	4.50	5.00	4.20	4.75	3.85	3.85	3.30	3.70
Gd	15.80	11.80	14.00	13.40	12.60	13.60	11.20	12.20	10.80	11.80
Tb	2.30	1.60	1.75	2.00	1.70	2.00	1.70	1.70	1.40	1.60
Dy	10.00	7.70	8.60	9.35	8.30	8.75	7.25	7.50	6.65	7.90
Но	1.60	1.06	1.26	1.46	1.32	1.36	1.10	1.12	0.98	1.16
Υ	35.4	23.8	28.2	33.5	29.4	30.5	25.9	26.4	22.1	27.5
Er	3.10	2.00	2.50	3.00	2.60	2.75	2.30	2.30	2.05	2.45
Tm	0.34	0.22	0.26	0.34	0.28	0.28	0.26	0.26	0.22	0.28
Yb	1.90	1.05	1.25	1.90	1.50	1.50	1.30	1.30	1.05	1.55
Lu	0.22	0.12	0.16	0.22	0.18	0.18	0.16	0.16	0.14	0.18
Hf	1.40	1.20	2.60	1.20	2.60	2.60	3.20	4.00	1.40	
Та										
Pb	4.0	1.0	1.0	8.0				2.0	6.0	2.0
Th	10.2	1.7	0.7	10.3	0.7	0.9	0.4	0.4	1.1	3.4
Y/Ho	22.13	22.45	22.38	22.95	22.27	22.43	23.55	23.57	22.55	23.71
Zr/Hf	63.57	50.00	48.46	85.00	56.15	50.38	45.31	41.50	60.71	
Cu/Ni	1.11	2.00	2.67	0.50	0.51	0.19	0.45	0.61	1.07	0.93
Ni/Co	0.30	0.14	0.07	0.65	1.33	1.87	1.10	1.00	0.65	0.70



Sample #	2571	2572	2573	2574	585355	585356	585357	585358	585359	585360
From(m)	1602.39	1612.47	1624.15	1637.39	1644	1645	1646	1647	1648	1649
To (m)	1602.52	1612.67	1624.43	1637.64	1645	1646	1647	1648	1649	1650
Sc	41	48	29	42	43	40	37	37	33	27
V	605	443	706	493	588	650	650	683	672	661
Cr	164	944	123	657	328	116	89	48	27	21
Со	81	51	72	54	57	62	64	73	75	44
Ni	74	102	185	107	169	176	167	108	74	74
Cu	66	33	79	49	41	59	72	102	157	89
Zn	114	79	144	106	125	130	130	142	132	54
Rb	1.20	1.40	1.00	1.20	0.20	0.20	0.20	0.40	0.40	0.20
Sr	186	186	221	216	158	145	161	181	190	248
Y	22	24	29	25	21	20	22	23	24	30
Zr	131	236	168	211	198	184	208	207	125	115
Nb		3.50		4.00	1.00	2.50	2.50	2.50		
Ва	12	21	12	31	3	3	4	5	4	3
La	14.4	12.0	19.4	15.8	9.2	8.8	10.4	12.9	15.5	26.4
Ce	45.2	39.3	61.3	49.6	32.9	31.4	35.8	43.6	48.9	77.2
Pr	7.60	7.04	10.50	8.60	6.14	5.78	6.64	7.62	8.34	12.40
Nd	38.2	38.4	54.1	45.0	34.4	32.2	36.6	38.9	44.8	64.2
Sm	10.2	10.7	14.3	11.1	9.4	9.0	9.8	10.6	11.9	16.2
Eu	3.30	3.35	4.25	3.55	2.85	2.75	2.95	3.20	3.40	4.70
Gd	9.60	10.00	12.80	10.00	8.40	8.20	9.20	9.60	10.60	13.40
Tb	1.30	1.40	1.85	1.55	1.25	1.20	1.30	1.35	1.45	1.85
Dy	6.35	7.10	8.50	7.00	6.25	5.85	6.40	7.20	6.85	9.00
Но	0.96	1.06	1.30	1.12	0.96	0.94	0.96	1.04	1.04	1.28
Y	22.2	23.8	29.0	25.1	21.2	19.8	21.7	23.0	23.7	30.2
Er	2.00	2.20	2.55	2.25	1.95	1.90	2.05	2.05	2.20	2.60
Tm	0.22	0.26	0.28	0.26	0.22	0.22	0.24	0.24	0.24	0.28
Yb	1.15	1.30	1.45	1.35	1.10	1.10	1.15	1.20	1.25	1.40
Lu	0.14	0.16	0.18	0.16	0.14	0.14	0.16	0.16	0.16	0.16
Hf	2.80	8.00	3.80	7.60	7.40	7.40	7.60	7.40	3.40	2.40
Та		0.30		0.20	0.20	0.20	0.20	0.20		
Pb				1.0						2.0
Th	0.4	0.4	0.7	0.4	0.2	0.2	0.2	0.3	0.3	0.7
Y/Ho	23.13	22.45	22.31	22.41	22.08	21.06	22.60	22.12	22.79	23.59
Zr/Hf	46.79	29.50	44.21	27.76	26.76	24.86	27.37	27.97	36.76	47.92
Cu/Ni	0.89	0.32	0.43	0.46	0.24	0.34	0.43	0.94	2.12	1.20
Ni/Co	0.91	2.00	2.57	1.98	2.96	2.84	2.61	1.48	0.99	1.68



Sample #	585361	585362	585363	585364	585365	585366	585367	585368	585369	585370
From(m)	1650	1651	1652	1653	1655	1656	1657	1658	1659	1662.2
To (m)	1651	1652	1653	1654	1656	1657	1658	1659	1660	1662.55
Sc	31	29	34	33	36	41	40	45	46	42
V	672	655	622	611	549	549	549	538	482	650
Cr	21	151	246	178	253	267	431	759	753	185
Со	73	69	70	68	61	55	57	54	59	81
Ni	137	157	145	171	159	156	180	157	179	239
Cu	161	136	140	149	111	93	87	68	98	86
Zn	132	112	129	127	118	112	87	115	106	144
Rb	0.20			0.60	10.00	2.20	1.20	0.40	0.20	0.40
Sr	268	271	218	234	377	184	238	178	186	156
Y	32	32	26	26	27	23	25	22	24	20
Zr	136	142	142	98	163	149	143	165	195	173
Nb						0.50			1.50	1.00
Ва	3	3	3	6	180	4	14	5	5	8
La	28.3	28.7	21.1	23.1	31.5	14.2	20.1	10.8	11.8	9.3
Се	84.0	85.1	64.0	67.3	79.8	46.2	60.8	38.0	40.9	33.8
Pr	13.70	13.60	10.50	11.10	11.80	8.06	10.10	6.94	7.50	5.98
Nd	69.7	69.8	51.9	55.8	55.6	42.7	51.6	37.2	40.6	32.7
Sm	16.4	16.5	13.7	14.2	13.1	11.0	12.7	9.9	10.8	8.8
Eu	4.80	4.95	3.90	4.35	4.05	3.30	3.85	3.15	3.30	2.75
Gd	14.40	13.80	11.80	12.00	11.40	10.00	11.20	9.40	9.80	8.20
Tb	2.05	2.10	1.70	1.60	1.65	1.45	1.50	1.30	1.40	1.20
Dy	9.65	9.65	7.80	8.00	7.65	6.50	7.70	6.65	6.85	5.65
Но	1.38	1.44	1.18	1.18	1.14	1.00	1.10	0.98	1.06	0.88
Y	32.2	32.1	25.8	26.0	26.8	22.9	25.0	22.2	23.7	20.4
Er	2.70	2.75	2.30	2.35	2.40	2.10	2.30	2.05	2.20	1.90
Tm	0.28	0.30	0.26	0.26	0.26	0.24	0.26	0.22	0.24	0.22
Yb	1.50	1.50	1.30	1.30	1.40	1.15	1.20	1.15	1.25	1.10
Lu	0.18	0.18	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.14
Hf	2.60	2.60	3.40	1.80	3.40	4.00	3.60	6.00	7.20	6.00
Та									0.20	0.10
Pb	2.0				1.0					1.0
Th	0.8	0.7	0.4	0.6	2.1	0.3	0.4	0.2	0.2	0.2
Y/Ho	23.33	22.29	21.86	22.03	23.51	22.90	22.73	22.65	22.36	23.18
Zr/Hf	52.31	54.62	41.76	54.44	47.94	37.25	39.72	27.50	27.08	28.83
Cu/Ni	1.18	0.87	0.97	0.87	0.70	0.60	0.48	0.43	0.55	0.36
Ni/Co	1.88	2.28	2.07	2.51	2.61	2.84	3.16	2.91	3.03	2.95



Sample	585371	585372	585373	585374	585375	585376	585377	585378	585379	585380
From(m)	1671.37	1681	1682	1683	1684	1698	1701.6	1704.36	1717.2	1718.65
To (m)	1671.83	1682	1683	1684	1685	1699	1701.94	1704.61	1717.63	1718.85
Sc	37	40	44	40	39	18	46	29	42	31
V	571	459	415	420	437	235	493	633	627	672
Cr	178	718	499	472	465	335	390	68	287	82
Со	70	52	43	47	48	43	50	70	68	81
Ni	180	171	131	159	112	43	64	116	153	132
Cu	119	57	43	49	36	29	47	88	59	85
Zn	111	89	93	85	123	281	110	112	123	123
Rb	0.20	3.00	3.00	7.60	0.60		10.40	7.60	0.40	0.40
Sr	233	260	218	376	371	1030	265	221	157	243
Y	27	34	29	36	23	22	49	25	20	25
Zr	123	37	168	9	126	29	172	104	153	106
Nb			4.00		19.00	44.00	42.00	0.50	1.50	
Ва	10	132	79	140	36	121	134	44	45	52
La	22.3	30.7	16.4	39.5	61.4	417.0	41.7	23.2	10.0	24.9
Ce	67.5	90.5	54.3	108.0	151.0	917.0	126.0	68.1	34.5	71.8
Pr	11.40	14.20	9.52	16.40	18.60	97.50	18.40	11.10	6.34	11.10
Nd	56.1	68.4	49.9	75.5	71.6	308.0	83.5	53.2	32.8	55.7
Sm	14.7	16.2	12.7	18.2	12.9	36.1	21.3	14.2	8.7	14.1
Eu	4.15	5.05	3.95	5.15	3.85	7.70	6.40	4.05	2.70	4.00
Gd	12.40	15.00	12.00	15.00	10.20	15.40	16.20	11.60	8.20	12.20
Tb	1.80	2.05	1.70	2.30	1.35	1.80	2.60	1.65	1.20	1.65
Dy	8.20	10.10	8.30	10.10	6.50	6.55	12.10	7.80	5.75	7.25
Но	1.24	1.66	1.26	1.56	1.02	0.96	2.06	1.14	0.86	1.10
Y	27.4	33.8	28.7	35.7	22.8	22.2	48.5	25.3	19.7	24.8
Er	2.50	3.15	2.75	3.20	2.10	1.25	4.70	2.25	1.75	2.15
Tm	0.28	0.34	0.30	0.34	0.26	0.28	0.60	0.24	0.20	0.24
Yb	1.40	1.85	1.65	1.90	1.35	1.75	3.45	1.20	1.05	1.20
Lu	0.16	0.22	0.18	0.22	0.18	0.22	0.44	0.16	0.14	0.16
Hf	2.60		5.80		5.00	1.60	6.80	2.40	6.20	2.00
Та			0.10		0.10	0.10	0.20		0.10	
Pb		4.0	6.0	6.0	7.0	31.0	16.0	4.0	9.0	2.0
Th	0.4	5.1	2.3	3.5	2.6	13.3	17.7	0.9	0.9	0.7
Y/Ho	22.10	20.36	22.78	22.88	22.35	23.13	23.54	22.19	22.91	22.55
Zr/Hf	47.31		28.97		25.20	18.13	25.29	43.33	24.68	53.00
Cu/Ni	0.66	0.33	0.33	0.31	0.32	0.67	0.73	0.76	0.39	0.64
Ni/Co	2.57	3.29	3.05	3.38	2.33	1.00	1.28	1.66	2.25	1.63



Sample #	585381	585382	585383	585384	585385	585386	585387	585388	585389	585390
From(m)	1722	1723	1724	1725	1726	1733	1734	1745.65	1751.6	1756
To (m)	1723	1724	1725	1726	1727	1734	1735	1746	1752	1757
Sc	32	31	35	37	35	33	32	37	34	37
V	605	359	476	543	650	487	599	571	543	577
Cr	89	322	390	404	103	643	137	185	253	109
Со	65	46	53	58	73	63	61	58	69	80
Ni	107	88	99	139	187	171	110	29	66	19
Cu	67	38	52	57	78	65	68	25	44	79
Zn	128	103	128	103	130	113	120	116	93	118
Rb	19.00	23.80	5.80	0.40	0.40	1.40	1.60	2.80	0.40	0.60
Sr	332	569	239	174	146	139	151	161	216	212
Y	36	43	36	21	18	23	22	24	24	22
Zr	118	124	16	153	146	102	88	192	128	77
Nb	84.50	68.00	1.00	2.50	3.00	3.00	1.50	4.50		
Ва	215	157	131	19	19	35	33	51	26	14
La	63.4	146.0	23.5	13.9	10.5	11.2	15.2	10.9	20.3	18.4
Се	185.0	393.0	74.8	44.8	34.1	39.5	48.0	39.3	58.4	55.5
Pr	25.00	48.40	11.60	7.66	6.16	7.22	7.86	7.16	9.82	9.14
Nd	98.1	172.0	55.8	41.4	33.3	38.1	41.6	38.7	49.2	46.0
Sm	20.3	26.3	14.4	10.1	8.5	9.9	10.2	10.1	12.6	11.3
Eu	5.45	6.90	4.65	3.05	2.60	3.00	3.10	3.10	3.50	3.45
Gd	13.20	15.80	12.40	9.20	8.00	8.40	9.40	9.00	10.00	10.80
Tb	2.00	2.25	1.80	1.30	1.10	1.25	1.30	1.35	1.40	1.40
Dy	9.30	10.40	8.85	6.60	5.15	5.85	5.90	6.90	6.70	6.35
Но	1.56	1.76	1.44	0.92	0.82	1.00	0.96	1.04	1.00	0.98
Y	35.8	43.1	35.6	20.6	18.1	23.1	22.2	24.4	23.7	22.0
Er	3.35	3.45	3.30	1.90	1.65	2.10	1.95	2.25	2.00	1.90
Tm	0.42	0.48	0.38	0.20	0.18	0.26	0.24	0.26	0.22	0.22
Yb	2.60	2.80	2.15	1.00	0.95	1.25	1.20	1.45	1.10	1.10
Lu	0.34	0.36	0.26	0.12	0.12	0.16	0.16	0.16	0.14	0.14
Hf	4.40	4.00	0.40	4.40	5.20	3.60	3.20	6.00	3.20	1.40
Та	0.50	0.90		0.20	0.20	0.10		0.20		
Pb	20.0	25.0	17.0	6.0	4.0	5.0	6.0	8.0	3.0	3.0
Th	15.8	20.7	23.3	0.8	0.8	7.9	3.5	9.7	0.7	0.9
		_	_	_	_	_		_		_
Ү/Но	22.95	24.49	24.72	22.39	22.07	23.10	23.13	23.46	23.70	22.45
Zr/Hf	26.82	31.00	40.00	34.77	28.08	28.33	27.50	32.00	40.00	55.00
Cu/Ni	0.63	0.43	0.53	0.41	0.42	0.38	0.62	0.86	0.67	4.16
Ni/Co	1.65	1.91	1.87	2.40	2.56	2.71	1.80	0.50	0.96	0.24

KDC ²

Sample #	585391	585392	585393	585394	585395	585396	585397	2501	2502	2503
From(m)	1761	1762	1763	1764	1765	1766	1767	1776	1777	1778
To (m)	1762	1763	1764	1765	1766	1767	1768	1777	1778	1779
Sc	32	29	33	35	39	40	35	50	45	46
V	661	655	633	571	549	599	650	700	711	706
Cr	14	7	48	239	260	137	75	14	41	14
Со	81	72	81	80	74	79	83	108	119	118
Ni	44	116	127	97	90	102	141	93	72	90
Cu	96	79	85	75	70	73	66	85	81	76
Zn	132	123	115	93	91	116	79	124	125	111
Rb	2.00	6.20	1.20	2.20	3.20	7.60	1.00	0.60	0.60	0.40
Sr	233	240	247	208	200	201	216	178	193	175
Y	26	31	25	22	23	30	22	19	19	18
Zr	88	88	107	107	38	151	111	95	81	89
Nb						8.50		0.50		
Ва	20	45	24	41	27	348	18	14	11	8
La	22.2	23.7	23.0	16.9	15.3	13.1	18.3	12.0	14.1	12.0
Ce	65.3	70.9	67.5	52.5	48.6	45.8	54.3	36.0	42.5	37.8
Pr	10.90	10.90	11.10	9.16	8.22	8.44	9.00	6.56	7.36	6.54
Nd	52.5	55.5	55.3	45.0	41.5	45.1	43.4	32.5	36.1	32.9
Sm	12.8	13.5	13.0	11.5	10.9	12.5	10.9	8.4	9.4	8.4
Eu	3.70	4.25	3.90	3.50	3.30	4.00	3.40	2.55	2.80	2.55
Gd	11.00	12.00	11.40	9.80	9.80	11.00	9.60	7.60	8.40	7.40
Tb	1.55	1.80	1.55	1.40	1.40	1.65	1.35	1.05	1.10	1.00
Dy	7.15	8.65	7.00	7.20	6.25	8.25	6.45	5.10	5.55	4.90
Но	1.06	1.28	1.08	1.04	1.00	1.24	0.96	0.80	0.84	0.78
Y	25.7	30.5	25.4	22.3	22.7	29.7	21.8	19.1	19.0	17.8
Er	2.20	2.70	2.15	2.10	2.10	2.75	1.95	1.65	1.70	1.55
Tm	0.24	0.30	0.24	0.24	0.24	0.30	0.22	0.20	0.20	0.18
Yb	1.25	1.60	1.20	1.25	1.25	1.75	1.05	0.95	1.00	0.90
Lu	0.16	0.18	0.16	0.16	0.16	0.20	0.14	0.12	0.12	0.12
Hf	1.60	1.80	2.20	2.60	0.40	5.60	2.60	3.60	2.00	2.60
Та						0.10				
Pb	5.0	10.0	3.0	4.0	3.0	6.0	8.0			
Th	1.8	7.0	1.1	2.2	2.3	5.9	1.1	0.4	0.7	0.2
	24.25	7 2 02	75 E J	21 11	77 20	22 OF	22 21	12 00	າງເງ	<u></u>
		23.03 10 00	23.32 10 C1	∠⊥.44 /1 1⊑		23.33	42.71	23.00	22.02 40 E0	21.02
	55.00 2 1 0	40.09 0 60	40.04 0.67	41.13 0.77	95.00 0 70	20.90 0 70	42.09	20.39	40.50	54.25 0 91
	2.10	1 61	1 57	1.01	1.70	1 20	1 70	0.91	1.15	0.04
NI/Co	0.54	1.61	1.57	1.21	1.22	1.29	1.70	0.86	0.61	0.76

KDC ²	
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Sample #	2504	585398	585399	585400	2575
From(m)	1779	1783.1	1785.4	1787.25	1787.6
To (m)	1780	1783.84	1786	1787.55	1787.89
Sc	45	41	36	37	35
V	672	599	577	627	627
Cr	75	157	75	41	27
Со	120	100	96	110	101
Ni	107	88	92	91	79
Cu	66	54	44	69	42
Zn	115	120	124	117	92
Rb	0.20	7.60	13.60	0.60	1.20
Sr	190	176	176	200	223
Y	20	28	37	20	22
Zr	113	131	75	96	114
Nb		5.00	1.50		
Ва	7	172	210	14	19
La	15.6	10.5	9.9	16.3	19.7
Се	47.0	37.4	35.7	49.8	58.5
Pr	7.74	7.04	6.68	8.40	9.48
Nd	39.1	36.8	33.9	41.0	47.7
Sm	9.4	10.6	10.7	9.9	12.3
Eu	2.80	3.35	3.75	2.95	3.40
Gd	8.80	9.20	10.40	8.60	9.80
Tb	1.20	1.45	1.70	1.25	1.40
Dy	5.50	7.40	9.30	5.65	6.65
Но	0.84	1.14	1.50	0.88	1.00
Y	19.5	27.9	37.0	20.3	21.8
Er	1.70	2.55	3.55	1.80	2.00
Tm	0.20	0.30	0.44	0.22	0.22
Yb	0.90	1.85	2.55	1.00	1.15
Lu	0.12	0.20	0.32	0.14	0.14
Hf	2.80	4.60	2.00	2.00	2.60
Та		0.20			
Pb		10.0	14.0	4.0	3.0
Th	0.4	9.8	20.2	1.8	0.7
Y/Ho	23.21	24.47	24.67	23.07	21.80
Zr/Hf	40.36	28.48	37.50	48.00	43.85
Cu/Ni	0.62	0.61	0.48	0.76	0.53
Ni/Co	0.89	0.88	0.96	0.83	0.78