PETROLOGY AND GEOCHEMISTRY OF THE GRANITOIDS OF THE HALFWAY HOUSE DOME

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Abreviations

KC	Kaapvaal Craton
BML	Barberton Mountain Land
BGB	Barberton Greenstone Belt
MGB	Murchinson Greenstone Belt
GGB	Giyani Greenstone Belt
PGB	Pietersburg Greenstone Belt
KGB	Kraaipan Greenstone Belt
AGB	Amalia Greenstone Belt
MaGB	Madibe Greenstone Belt
HHD	Halfway House Dome
TTG	Tonalite-trondhjemite-granodiorite
GGM	Granodiorite-granite-granodiorite
REE	Rear Earth Elements
HREE	Heavy Rear Earth Elements
LREE	Light Rear Earth Elements
LILE	Large Ion Lithophile Elements
HFSE	High Fluid Sensitive Elements
XRF	X-ray Fluorescence
ICP-MS	Inductively Coupled Plasma Mass Spectrometer
SEM	Scanning Electron Microscope
EDS	Energy Dispersive System
GAG	Granodiorite-Adamallite Gneiss
TG	Tonalite Gneiss
GG	Granodiorite/adamellite to Granite
PC	Pilbara Craton
SC	Superior Craton
DC	Dharwar Craton

ABSTRACT

Growing support for analogies drawn between present-day plate tectonic processes and geotectonic processes active during Archaean times has led to re-evaluations of important Archaean terrains world-wide in the light of growing support for the notion that plate tectonic processes were active in the Archaean. Archaean cratons are considered to consist typically of three main rock associations, i.e. greenstone belts, tonalite-trondhjemite-granodiorite (termed “TTG suite”) and gneisses and calc-alkaline K-rich granitoids. The latter is often referred to as granodioritic-granitic-monzogranitic (GGM). Archaean TTG associations are the main components of the Archaean continental crust generated between 4000Ma and 2500Ma whereas the calc-alkaline GGM or high K-granodiorite suites dominate large parts of Archaean cratons, generally post-date the TTGs (2800 to 2500Ma) and are fed by vertical dykes cutting through the TTGs. TTG suites have a distinctly different geochemical signature when compared to GGM suites.

The Kaapvaal Craton represents one of only a few areas where pristine mid-Archaean rocks have been preserved. The Archaean Kaapvaal Craton formation took place in two distinct periods, i.e an initial shield-forming stage, which spanned from ~3700 Ma to 3100 Ma, followed by the stage of accretion of continental fragments and stabilisation spanning the period between 3100 Ma to 2600 Ma. The central Kaapvaal Craton, like most plutonic domains within Archaean cratons, is dominated by granitoid rocks of the tonalite-trondhjemite-granodiorite (TTG) series. Of the Archaean rocks in the central domain of the Kaapvaal Craton, those in the Halfway House Dome is the best exposed. Consequently this granitoid-greenstone terrane is well suited for studies of Archaean crustal evolution and the study area is therefore delineated as the window of Archaean granitoids occurring between Johannesburg and Pretoria, South Africa. The main objectives of the present work is to present an integrated field, geochemical and petrological study aimed at constraining the petrogenetic relationship between the constituent granitoids of the Halfway House Dome, to illustrate the existence of a TTG suite in the centre of Kaapvaal Craton, propose possible

tectonic setting and processes involved in the generation of these rocks, discuss the TTG models for the Archaean crustal evolution of the central Kaapvaal Craton and to draw comparisons between the Halfway House Dome and other known TTG occurrences in South Africa and elsewhere in the world. The granitoids of the Halfway House Dome represent the final product of a multitude of physical and chemical processes, which occurred in the past history of the continental crust. The chemistry and mineralogy of these rocks therefore reflects the parental magma from which they were derived as well as the physical and chemical conditions under which the magma developed and solidified. Therefore the study of the granitoids of the Halfway House Dome is very important in understanding the evolution of the continental crust and to provide information on conditions under which the central part of the Kaapvaal Craton formed.

The thesis presents a geological map, a set of new petrographical and mineral composition data, together with whole rock major, trace and rare earth element data for a suite of granitoid rocks from the 3.3-3.0Ga Halfway House Dome, central Kaapvaal Craton. A model for the formation of the Archaean TTG suites on the Halfway House Dome is presented which reconciles the most important geochemical similarities and differences between Halfway House Dome granitoids and other world occurrences of TTGs.

Based on the microscopic and geochemical investigation the Halfway House Dome granitoids could be subdivided into three main suites, ie. a Tonalite Gneiss suite (TG) around the southern boundary, a Granodiorite-to-Adamellite Gneiss suite (GAG) across the northern part, and a Granodiorite-to-granitic suite (GG) occurring between the TG and GAG suites. The Halfway House Dome is dominantly I-type, peraluminous rocks with tonalites (TG and tonalite to trondhjemite gneiss GAG suites) falling in the metaluminous field. TTGs of the HHD are high-K calc-alkaline to calc-alkaline and are dominant high silica rocks (~70wt%), aluminous (Al_2O_3 >15wt%) with low Yb (<1ppm), high La/Yb ratios (>30), high Na_2O/K_2O (>1), and have Na_2O contents of between 3wt% and 5wt%, comparable to that of the average TTG. The Halfway House Dome tonalities (TG suite) have higher Al_2O_3, Sr, Na_2O/K_2O, $Mg^{\#}$, Ni, Cr and LILE contents compared to the more calc-alkaline granitoids (GG suite and granodiorite-to-adamellite gneiss of the GAG suite), which are typically richer in HREE (lower REE fractionation), Y and show a negative Sr and Eu anomaly. Other characteristic features of the HHD TTG's include HFSE depletion and distinct enrichment of fluid sensitive elements such as Pb. The strongly fractionated REE pattern, high $(La/Yb)_N$ ratio and depletion in HREE (Yb) of the Halfway House Dome TTGs are characteristics shared with modern adakites.

The TG suite show a trend characteristic of high-Mg diorites (MgO>6 wt% with SiO_2 ~50wt%) such as those described from the Pilbara Craton, Superior Province as well as high-Mg adakites. The high MgO, Ni and Cr contents of typical high-Mg diorites are considered to favor melting of subducted oceanic slab rather than underplated basalt, in which case felsic magmas are prevented from coming into contact with mantle peridotite. High-Mg diorites are considered to be relatively scarce (<5% of all Archaean TTGs) with very few, if any, pre-3 000Ma TTG suites showing this trend. The scarcity of high-Mg diorites suggests that the conditions for formation were not met in all Archaean terranes. The recognition of high-Mg diorites on the Halfway House Dome is therefore noteworthy as it signifies that the conditions necessary for high-Mg diorites formation were met during the formation of the TG suite, which is present in a limited area along the southern edge of the Halfway House Dome. The TG suite most probably formed through melting of a subducted oceanic slab with the melt interacting with mantle peridotite during its accent through a thin mantle wedge.

The remaining HHD granitoids (GAG granodiorite-to-adamellite gneiss and GG) most probably formed through the remelting of a TTG protolith, which has a subducted slab and mantle wedge signature (similar to the TG suite). This is proven by the presence of restite phases and the geochemistry of the GAG granodiorite-to-adamellite gneiss and GG suite approximating or imaging that of the TTG protolith, most probably the TG suite. Disequilibrium textures, such as reaction rims and the presence of Ca-rich plagioclase cores in the GAG granodiorite-to-adamellite gneiss and GG suites are indicative of a restite phase. The negative Eu anomaly and the absence of a positive Sr anomaly for the GAG granodiorite-to-adamellite gneiss and GG suites furthermore reflect the presence of plagioclase in the source.

1 INTRODUCTION

1.1 General introduction

Growing support for analogies drawn between present-day plate tectonic processes and geotectonic processes active during Archaean times has led to re-evaluations of important Archaean terrains world-wide (de Wit *et al*, 1992; Moyen *et al.*, 2003; Blewett, 2002; Smithies *et al.*, 2003; Poujol *et al.*, 2003). Evidence suggests that Archaean terrains have formed through processes such as magmatic arc formation, accretion as well as tectonic amalgamation of numerous microcontinents (de Wit *et al*, 1992; Moyen *et al.*, 2001; Smithies and Champion, 2000; Bedard *et al.*, 2003).

The Kaapvaal Craton (KC), one of only a few areas where pristine mid-Archaean rocks have been preserved, occupies the south central interior of southern Africa. The KC is bound by the ca. 1.0-1.2Ga Namaqua-Natal metamorphic province to the south and and towards the west by the ca. 1.8Ga Kheis belt (Hartnady *et al.*, 1985; Cornell *et al.*, 1998) (Figure 1.1). Towards the east, the Kaapvaal craton was rifted during the breakup of Gondwanaland. Paleogeographical reconstructions suggest that the Grunehogha province of Antarctica was connected to the eastern side of the Kaapvaal craton prior to the breakup of Gondwanaland (Groenewald *et al.*, 1991).

The Kaapvaal craton is bordered towards the north by the Limpopo belt and the Archean Zimbabwe craton (Kusky, 1998). The boundary between these two cratons is not well defined and is generally taken to be the granulite-gneisses of the Central Zone of the Limpopo Belt. The Colesberg and Thabazimbi-Murchinson lineaments have been considered to represent suture zones along which younger domains were accreted, to form the KC (Eglington and Armstrong, 2004).

Archaean craton formation took place in two distinct periods, i.e an initial shield-forming stage, which spanned from ~3700 Ma to 3100 Ma, followed by the stage of accretion of continental fragments and stabilisation spanning the period between 3100 Ma to 2600 Ma (De Wit *et al.*, 1992; Anhauesser, 1999; Thomas *et al.*, 1993). Geochronological studies aimed at unravelling the evolution of the continental crust in southern Africa suggested the formation of the Archaean Kaapvaal Craton (KC) through subduction and amalgamation of crustal fragments took place over a period of 1000 Ma from 3500 to 2500 Ma (de Wit *et al*, 1992; Lowe, 1994; Poujol *et al.*, 2003; Eglington and Armstrong, 2004). These studies showed that the Archaean granite-greenstone basement rocks of the KC could be subdivided into several domains (crustal fragments), i.e. eastern, northern, central and western (Figure 1.1) (Thomas *et al.*, 1993; Poujol and Anhaeusser, 1999; Eglington and Armstrong, 2004; Brandl and de Wit, 1997). The eastern domain is regarded as the oldest known subdomain and thought to represent the early nucleus of the KC (de Wit *et al.*, 1992; de Wit and Hart, 1993; Poujol *et al.*, 2003). This domain comprises the Barberton Mountain Land (BML) which consists of the ~ 3500Ma Barberton Greenstone Belt (BGB) as well as granitoids extending south and east towards Swaziland. The northern domain is comprised of the ~3000Ma Murchison- (MGB), Giyani- (GGB) and Pietersburg Greenstone Belts (PGB) with intervening granitoid rocks. The central domain, mainly active during 3200-3000 Ma, includes smaller occurrences of granitoid domes, i.e. the Halfway House dome (HHD) (this study), Rand anticline and Vredefort dome. The western domain is considered to be the youngest of the subdomains (3000-2700Ma) and comprises the Kraaipan- (KGB), Amalia- (AGB) and Madibe (MaGB) Greenstone Belts as well as the Gabarone granite complex (Botswana) (Brandl and de Wit, 1997; Poujol *et al.*, 2003).

Earlier studies showed the accretion process through which the KC developed is marked by episodic intervals of magmatism (Poujol *et al.*, 2003; Eglington and Armstrong, 2004). The initial plutonic and volcanic activity in the eastern domain (3550-3250Ma) was followed by a period of granitoid emplacement in the northern, central and western domains around 3200Ma. Deposition in the Witwatersrand Basin, located in the central part of the KC, is considered to be closely linked to plate tectonic processes operational during the Archaean (Bickle and Eriksson, 1982; Burke *et al.*, 1986; Stanistreet *et al.*, 1986).

1.2 Delineation of the study area

For the sake of alleviating the geological account in this study, the Archaean assemblage comprising both granitoids and mafic rocks between Johannesburg and Pretoria will be referred to as the Halfway House Dome (HHD) (Figure 1.1). The main reason for using the name: Halfway House Dome is that this is the only nomenclature presently accepted by SACS (1980).

However, it should be mentioned that previous studies has made use of various other names. The first mention of the occurrence of granitoids between Johannesburg and Pretoria was by Kynaston (1907a) who referred to these rocks as the “Johannesburg-Pretoria granites”. It was later referred to as the “Halfway House granites” (van Eeden, 1972) named after the town situated between the two major cities. Although Anhauesser (1973, 1977, 1978, 1982, and 1992) has since referred back to the original name, it was later referred to as the Johannesburg Dome (Hilliard, 1994; Poujol and Anhaeusser, 2001; Barton *et al.*, 1999; Ishihara *et al*, 2001; Anhaeusser, 2001, 2004; Prevec *et al.*, 2004; Robb *et al*, 2008). The term “Johannesburg Dome” was generally used with reference to the granitoid rocks. However, Hilliard (1994) used the term to describe a structural unit comprising not only Archaean granitoids and greenstones but also supracrustals, which fringe the central granitoids.

1.3 Problem statement

Of the Archaean rocks in the central domain of the KC, those in the Halfway House Dome (HHD) is the best exposed. Consequently this granitoid-greenstone terrane is well suited for studies of Archaean crustal evolution and the study area is therefore delineated as the window of Archaean granitoids occurring between Johannesburg and Pretoria (Figure 1.1).

Granitoids represent probes into the interior of the continental crust and possibly the upper part of the mantle and are closely related to plate tectonics (e.g. Clarke, 1992). Granitoid rocks represent the final product of a multitude of physical and chemical processes, which occurred in the past. The geochemistry and mineralogy of these rocks therefore reflect the protolith from which they were derived as well as the physical and chemical conditions under which the magma has evolved and solidified. Heterogeneous protolith source and diverse processes in the formation of granitoids, however, complicate the interpretation of the mineralogical, geochemical and isotopic data.

The trend in recent years has been to re-investigate Archaean rocks in the light of growing support for the notion that plate tectonic processes were active in the Archaean (Martin, 1999; Smithies and Champion, 2000; Martin, 1999; Whalen *et al.*, 2002; Martin and Moyen, 2002; Smithies *et al.*, 2003). Earlier studies on the formation of the KC focussed mainly on the BML and MGB (Kleinhans *et al.*, 2003; Clemens *et al.*, 2006; Poujol *et al.*, 1996; Brandl *et al.*, 1996; Poujol *et al.*, 1998) with the smaller granitoid-greenstone areas in the centre of the KC (including the HHD) largely neglected.

In terms of mapping and structural investigations, it is worth noting that there is no updated geological map of the entire HHD incorporating the more detailed work from localised studies. The available mapping work, which spans the entire HHD, includes the maps by Willemse (1933) and the more recent map (1:100 000 scale) by Anhauesser (1973). However, maps concentrating mainly on the mafic to ultramafic rocks and structural aspects of the supracrustal rocks produced by Anhauesser (1977, 1978, 1992), Hendriks (1961), Stanistreet and McCarthy (1990), Roering (1984) and Hilliard (1994) have not been incorporated in a general map of the HHD. A need therefore existed to update the current (1973) map of the HHD incorporating all the new and more detailed mapping information.

In terms of petrology and geochemistry, initial studies on the HHD focussed mainly on isolated granitoid outcrops and showed very little variation in their petrography and geochemistry (Kynaston, 1907; Willemse, 1933). The investigation by Willemse (1933) presented well-documented petrographic descriptions for granitoids from merely a small number of localised outcrops. However, this study was not comprehensive enough to enable the classification of the HHD granitoids. A more comprehensive study done on the HHD granitoids was that by Anhaeusser (1973). This study included description of the various granitoids in terms of petrography but presented only limited geochemical data (major element and partial trace element data). The main focus of the latter study was, however, to identify and classify the various granitoids occurring over the entire HHD. Although, Anhauesser, (1999) undertook an even more complete geochemical investigation (major-, trace- and REE analyses) on Nooitgedacht 534JQ, this study focused mainly on a small outcrop located in the north-western quadrant of the HHD.

It is also worth noting that until date neither detailed ICP-MS trace and REE data nor any mineral chemical data for the granitoids of the entire HHD have been documented. The need therefore existed to present a complete data set, including major, trace and REE elements together with detailed petrographical, mineralogical and mineral chemical information, for the various HHD granitoid rocks that were identified during detailed field mapping that formed part of this study.

Isotopic data have been utilised previously for localised geochronological investigations on the HHD granitoids. Ages for the different granitoid rocks (Allsopp, 1961; Anhauesser and Burger, 1982; Barton *et al.*, 1999, Poujol and Anhaeusser, 1999) were derived from a variety of techniques. However, variations exist in the ages determined by these different techniques. Therefore an investigation on the mineralogical and geochemical characteristics of the various granitoids is required in order to determine possible reasons for the apparent inconsistencies in age determininations. A comprehensive overview of the geochronology and possible explanations for the variations are essential in understanding the history of formation of the HHD.

In terms of petrogenesis, the absence of trace and REE data for the granitoids of the HHD has limited the discussions on the evolution of the HHD to speculations and analogies drawn with granitoids of the BML. The only attempt at employing modern geochemical discrimination techniques to demonstrate the evolution of the HHD was that of Anhaeusser (1999). His study was the first attempt at proposing the existence of tonalite-trondhjemite-granodiorite type (TTG) granitoids on HHD granitoids. Anhaeusser's (1999) effort, however, focussed on an isolated exposure, referred to as the Nooitgedacht outcrop, which can not be taken as representative of granitoids of the entire HHD. A gap has therefore been identified in the geochemical description of the HHD granitoids and comparison thereof to typical TTG suites. In the light of increasing support for plate tectonic processes accounting for Archaean geotectonic evolution, existing petrogenetic models for the HHD are inadequate. A need clearly exists to employ modern techniques, utilizing ICP-MS trace and REE data, to model TTG and granodioritic-granitic-monzogranitic (GGM) formation for the HHD. Furthermore, since no pronounced attempt has been made to compare the granitoids of the HHD with similar Archaean rocks elsewhere on the KC and in the world, such a course of action is also in order and forms part of this thesis.

1.4 Research objectives

The main objectives of the present work is to present an integrated field, geochemical and petrological study aimed at constraining the petrogenetic relationship between the constituent granitoids of the HHD, to illustrate the existence of a TTG suite in the centre of KC and to draw comparisons between the HHD and other known TTG occurrences in South Africa and elsewhere in the world. The study will therefore provide information on conditions under which the central part of the KC formed.

This study focuses on:

a) A compilation of field data, obtained during a mapping excercise and combined with existing information from localised previous studies, on an up-to-date detailed geological map 2628 AA Johannesburg (Appendix A). The field mapping conducted by the author (some 70% of the map) has been delineated on the geological map.
b) A brief overview of previous work on the geochemistry and petrogenesis of TTGs in general, including a brief discussion of important TTG occurrences world wide and on the KC
c) A summary of the various petrogenic models proposed for TTG suites
d) A short overview of previous work done on the HHD and surrounding supracrustals
e) During the study detailed macroscopic, petrographic, modal analyses through point counting as well as mineral chemistry analyses by Electron Microprobe was conducted by the author.
f) Presentation of the more up-to-date and comprehensive description of the various granitoid suites of the HHD from work done during this study in which attention is given to:
    i. field relationship of each suite,
    ii. detailed macroscopic and microscopic descriptions,
    iii. modal mineral proportions
    iv. mineralogy and mineral chemistry
    v. whole rock major-, trace-, and REE-geochemistry
g) Interpretation and discussion of the internal variation in mineralogy, mineral chemistry and geochemistry of HHD granitoids
h) Comparison of the HHD with world TTG occurrences

i) Application of the data from this study and proposal for the petrogenesis of the HHD granitoids

j) Proposal of a model for Archaean crustal evolution of the HHD and central Kaapvaal Craton from data obtained in this study

k) An article has been prepared for submission to South African Journal of Geology (Appendix B)

1.5 Methodology

The investigation was largely field and laboratory based but a detailed literature study of all available published and unpublished work including atricles and geological maps of the area was also conducted. Regional mapping was carried out using 1:10 000 ortho-photographs as base maps and 1:50 000 scale topo-cadastral sheets for ground control. A detailed study was also made of the 1:20 000 scale aerial photographs. In selected areas enlargements of the aerial photographs to a scale of 1:5 000 were used to map complex structures. Where the outcrop of important units like the Black Reef Formation was not visible on optical aerial photographs, available thermal infrared photographs were used on a limited scale. The existing map of the HHD (last updated in 1973) is currently used not only for geological but also for geotechnical purposes as the area is earmarked for large-scale intensive urban development. For this reason the new detailed 1:50 000 scale geological map discriminates between outcrops (20-100% outcrop shown as hatchings on map) and sub-outcrops (0-20% outcrop).

The final 1:50 000-scale map for the 2628AA Johannesburg sheet (Appendix A in the pocket at the back of the thesis) was compiled by the author, from own 1:10 000-scale field mapping (some 70% of the map) and where necessary from other information (as indicated in the legend). The final map was prepared at the Council for Geoscience.

A set of polished thin sections was made from samples collected from outcrops and quarries on the HHD. Petrographic investigations were done using an optical microscope. A Leica 440 Stereoscan Scanning Electron Microscope (SEM) attached to a LINK (OXFORD) energy dispersive system (EDS), Council for Geoscience, was used to determine some of the mineralogical and textural features of the various rock types. The electron microprobe (JEOL microprobe 733) at the Council for Geoscience was used for quantitative chemical -analyses of minerals.

Modal analysis on selected granitoid samples were done according to the method described by Hutchinson (1974). In order to achieve a standard deviation of Φ2 it was necessary to use more than one thin section per sample depending on the grain size of the sample. Mineral abbreviations as recommended by Kretz (1983) are used throughout.

The geochemical investigation was performed using XRF and ICP-MS in the laboratory of the Council for Geoscience. The list of samples and sample localities is presented in Table 1.

2 REVIEW OF PREVIOUS WORK

2.1 Review of previous work on the geochemistry and petrogenesis of TTG suites

2.1.1 Introduction

Archaean cratons are considered to consist typically of three main rock associations, i.e. greenstone belts, tonalite-trondhjemite-granodiorite (termed “TTG suite” by Jahn *et al*., 1981) gneisses and calc-alkaline K-rich granitoids (Windley, 1995 and Moyen *et al*., 2003). De Wit (1998) referred to the latter as granodioritic-granitic-monzogranitic (GGM) suites based on studies of the Barberton Mountain Land. About two thirds of the rocks forming continental crust are igneous rocks ranging in composition from granite to tonalite. Archaean TTG associations are the main components of the Archaean continental crust generated between 4000Ma and 2500Ma (Jahn *et al*., 1981; Smithies *et al*., 2003). The calc-alkaline GGM or high K-granodiorite suites dominate large parts of Archaean cratons, generally post-date the TTGs (2800 to 2500Ma) and are fed by vertical dykes cutting through the TTGs. There is a general agreement that the GGM suites form at mid to lower crustal levels through partial melting of the preexisting TTG crust and sediments (De Wit, 1998 and references therein). The term “TTG” has, on the one hand theoretical distinct petrogenetic significance, but has on the other hand become a convenient bag-name for any Archarean plutonic rock with a sodic character.

TTG suites have a distinctly different geochemical signature when compared to GGM suites (see section 2.1.2). TTG suites are generally subdivided into a TTG series and a high-Mg diorite (sanukitoid) series (Smithies and Champion, 2000). The high-Mg diorite suite was first recognised by Shirey and Hanson (1984) as a Late Archaean suite of felsic instusives and volcanic rocks from the Superior Province but also later in the central Pilbara Craton (Smithies and Champion, 1999). The major element geochemistry of the high-Mg diorite suite resembled that of a Miocene high-Mg andesite (sanukite) from Japan and was therefore referred to as “Archaean sanukitoids” (Shirey and Hanson, 1984). Subsequently similar suites of rock was recognised in other TTG occurrences and are now generally regarded as a minor, widespread component of most Late Archaean terranes and post-dates the dominant TTG series (Smithies, 2000 and Smithies *et al.*, 2003; Martin *et al.*, 2005). These rocks, which resemble modern high magnesian andesites (HMA), may constitute up to 25% of Archaean plutonic rocks (Evans and Hanson, 1997). Sanukitoid suite composition ranges from dioritic to granodioritic (tonalite is subordinate).

Archaean TTG suites share characteristics with modern adakites (Martin, 1999). From an uniformatarian standpoint the mentioned analogies strongly suggest that modern-style subduction processes, including interaction between slad-derived components and the mantle wedge, occurred as far back as ~3.3 Ga. (Martin *et al.*, 2005). Condie (1981) was one of the first researchers to apply the modern plate tectonic consept to the origin of TTG. A widely accepted view is that modern adakites might represent petrogenetic analogues of Archaean TTG (Martin, 1986; Martin, 1999).

The term “adakite” was used to define silica-rich, high Sr/Y and La/Yb volcanic and plutonic rocks derived from melting of the basaltic portion of oceanic crust subducted beneath volcanic arcs (Smithies and Champion, 2000; Martin, 1999; Castillo, 2006). It was initially believed that adakites occur exclusively at convergent plate margins where young, hot oceanic slabs are being subducted and partially melted (at pressures high enough to stabilize garnet ±amphibole) beneath the volcanic arc (Defant and Drummond, 1990). However, recent studies proposed that adakites also occurs in other arc settings where non-subduction environments dominate (Smithies and Champion, 2000). Martin and Moyen (2002) showed that based on the silica content of adakites there is two compositional groups, ie. high-SiO_2 adakites (HSA; SiO_2>60wt%) and low-SiO_2 adakites (LSA; SiO_2<60wt%). Low SiO_2 adakites include rocks referred to as high-Mg andesites (HMA). HSA has lower MgO (0.5-4wt%), CaO+Na_2O (<11wt%) and Sr (<1100ppm) compared to LSA (Martin *et al.*, 2005).

More recently a rock type, which shares several characteristics with sanukitoids, the Closepet-type granite, were recognised from South India (Moyen *et al.*, 2001), China and South Africa (Limpopo) (Barton *et al.*, 1992). The Closepet-type granite, is a Late Archaean rock suite recently identified, and shares some characteristics of sanukitoids (Martin *et al.*, 2005). The Closepet-type rock suite can evolve to monzogranite compositions. Affinities between Archaean sanukitoids, the Closepet-type granites and LSA lead to the assumption that they are analogues (Martin *et al.*, 2005). These authors also suggested that close compositional similarities between HSA and mid- to late (~3.3 Ga) Archaean TTGs strongly imply petrogenetic analogy. Closepet-type granite and sanukitoids seems to be restricted to the Late Archaean (Martin *et al*., 2005).

2.1.2 Geochemistry

Compared to GGM, the typical TTG suite has higher Al_2O_3, Sr, Na_2O/K_2O, $Mg^{\#}$ (MgO/MgO+FeO), Ni and Cr contents (Kleinhans *et al.*, 2003; Martin *et al.*, 2005). GGM suites on the other hand, are typically enriched in HREE (light REE fractionation), Y and show a negative Sr and Eu anomalies although there are strong similarities such as over enrichment in fluid sensitive elements such as Pb (Martin, 1994; Kleinhans *et al.*, 2003) (Table 2 and Table 3). The negative Sr and strong negative Eu anomaly recorded in the calc-alkaline GGM suites are indicative of plagioclase fractionation whereas similarities such as depletion in Nb and Ta are considered as evidence of slab dehydration (Kleinhans *et al.*, 2003)

In general the older Archaean TTG series is silica-rich (SiO_2 ~70%), have high Al_2O_3 (>15%), La/Yb, Na_2O/K_2O (>1), Sr and Ba (>500ppm) content but are poor in ferromagnesium components (Fe_2O_3+MgO+MnO+TiO_2<5wt%), with an average Mg# of 0.43 and average Ni and Cr contents of 14 and 29ppm respectively (Martin, 1994; Smithies and Champion, 2000 and Smithies *et al.*, 2003). Archaean TTGs have been subdivided into high-Al and low-Al groups (Barker and Arth, 1976). The high-Al group is dominant and is characterised by elevated Sr and Eu and low Yb and Y contents, strongly fractionated REE patterns and high Sr/Y ratios. Characteristic features for TTG's include HFSE depletion and distinct enrichment of fluid sensitive elements such as Pb. Kleinhans et al. (2003) suggests that this signature reflects the fact that these rocks are derived from refertilised mantle above subducion zones.

Sanukitoid as originally defined by Shirey and Hanson (1984), Stern (1989), and Stern and Hanson (1991), refer to a series of plutonic rocks containing 55 to 60wt% SiO_2, has MgO >6wt%, Mg# > 0.6, Ni >100ppm, Cr >100ppm, K_2O > 1wt %, Rb/Sr < 0.1, Sr and Ba each > 500ppm, no or minor Eu anomaly, and that show enrichment in LREEs.

Closepet-type granite differs from sanukitoid in having higher K_2O/Na_2O ratios (upto 1), being richer in Ti, Nb and Zr. In contrast to TTG, sanukitoid and Closepet-type granite follow a classical calc-alkaline trend in the K-Na-Ca triangle (Martin *et al.*, 2005). Furthermore the high MgO, Mg#, Cr, Ni, and K_2O distinguish sanukitoid and Closepet-type granite from TTGs (Martin et al., 2005).

Despite abundant similarities in the geochemistry of TTG and adakites some differences do exist. TTGs are slightly poorer in Ca and have slightly higher La/Yb ratios whereas adakites show negative Nb and smaller negative Zr and Ti anomalies (Defant and Drummond, 1990 and Martin, 1999). Adakites have a typically stronger positive Sr and Eu anomaly and higher magnesium number ($Mg^{\#}$), Ni and Cr compared to TTGs (Defant and Drummond, 1990; Smithies *et al.*, 2003). The high degree of compositional-overlap between the mid- to late (~3.3 Ga) Archaean TTGs and HSA, in terms of major and trace support the widely held view that these rocks are petrogeneticaly similar (Martin, 1987, Drummond and Defant, 1990, Drummond *et al.*, 1996; Martin and Moyen, 2002; Martin *et al.*, 2005). Both these groups of rocks show negative Nb and Ti anomalies.

Martin *et al.* (2005) showed that sanukitoids and LSA have similar ranges for elements such as SiO_2, MgO, TiO_2, Sr, Cr, Ni and Nb. LSA, however, show a strong positive Sr anomaly, which is not the case with sanukitoids. Closepet-type granite, although showing similar compositional pattern to that of LSA and sanukitoid, have slightly higher compositions of these elements (Martin *et al.*, 2005). The compositional similarities between sanukitoid and Closepet-type granite and LSA lead Martin *et al.* (2005) to suggest similar petrogenesis. Compositional differences were atributed to the fact that sanukitoid and Closepet-type granite have undergone more significant fractional crystallization as well as contamination by continental crust, which resulted in differences in the LILE contents (Moyen *et al.*, 2003 Martin *et al.*, 2005).

Table 2: Major element variations in average TTG and other relevant rock types (values in wt%)

Variables	Avg TTG >3.5 Ga	Avg TTG 3 –3.5 Ga	Avg TTG <3 Ga	Modern Arc Granitoid	Avg Sanukitoid	Closepet type granite	GGM	HSA	LSA	Avg Upper Crust	Avg Lower Crust	Avg continental crust	Primitive Mantle
	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	69.59	69.65	68.36	68.10	58.76	56.39	72.06	64.80	56.25	66.0	54.4	57.3	
TiO_2	0.39	0.36	0.38		0.74	1.20	0.34	0.56	1.49	0.5	1.0	0.9	
Al_2O_3	15.29	15.35	15.52	15.07	15.80	15.79	14.59	16.64	15.29	15.2	16.1	15.9	
Fe_2O_3	3.26	3.07	3.27	4.36	5.87	7.34	-	4.75	3.26	-	-	-	
FeO	-	-	-	-	-	-	1.75	-	-	4.5	10.6	9.1	
MnO	0.04	0.06	0.05	0.09	0.09	0.13	0.02	0.08	0.09	-	-	-	
MgO	1.00	1.07	1.36	1.55	3.90	3.38	0.59	2.18	5.15	2.2	6.3	5.3	
CaO	3.03	2.96	3.23	3.06	5.57	5.45	1.68	4.63	7.69	4.2	8.5	7.4	
Na_2O	4.60	4.64	4.70	3.68	4.42	3.94	4.87	4.19	4.11	3.9	2.8	3.1	
K_2O	2.04	1.74	2.00	3.40	2.78	3.17	4.18	1.97	2.37	3.4	0.3	1.1	
P_2O_5	0.13	0.14	0.15	0.15	0.39	0.72	0.10	0.20	0.66	0.1	0.1	0.1	
Mg#	0.38	0.41	0.45	0.41	0.57	0.48	0.25	0.48	0.61	-	-	-	
Na_2O/K_2O	0.44	0.38	0.43	0.92	0.63	0.80	-	0.47	0.58	-	-	-	

1) Average of 108 TTGs (Martin et al., 2005)
2) Average of 320 TTGs (Martin et al., 2005)
3) Average of 666 TTGs (Martin et al., 2005)
4) Average of 250 arc granitoids (Martin, 1994)
5) Average of 31 sanukitoids (Martin et al., 2005)
6) Average of 31 Closepet-type granites (<62% SiO_2) (Martin et al., 2005)
7) Nelspruit pluton (Kleinhans et al., 2003)
8) Average of 267 High Silica Adakites (Martin et al., 2005)
9) Average of 77 Low Silica Adakites (Martin et al., 2005)
10) Taylor and McLennan (1985)
11) Taylor and McLennan (1985)
12) Taylor and McLennan (1985)
13) Sun and McDonough (1989)

Table 3: Trace and RE element variations in average TTG and other relevant rock types (values in ppm)

Variables	Avg TTG >3.5 Ga	Avg TTG 3 –3.5 Ga	Avg TTG <3 Ga	Modern Arc Granitoid	Avg Sanukitoid	Closepet type	GGM	HSA	LSA	Avg Upper Crust	Avg Lower Crust	Avg Continental Crust	Primitive Mantle
Ppm	1	2	3	4	5	7	8	9	10	11	12	13	14
Rb	79	59	67	110	65	93	139	19	52	110	11.00	61	0.635
Ba	449	523	847	715	1543	1441	796	1087	721	700	757	707	6.989
Nb	8	6	7	12.1	10	18	10.1	11	6	25	5	13	0.713
Sr	360	429	541	316	1170	978	291	2051	565	350	569	503	21.1
Zr	166	155	154	171	184	323	282	188	108	240	202	210	11.2
Y	12	14	11	26	18	37	18.9	13	10	22	7	14	4.55
Ni	12	15	21	10.5	72	38	7.00	103	20	20	135	105	-
Cr	34	21	50	23	128	50	10.4	157	41	35	235	185	-
V	39	43	52	76	95	129	19.4	184	95	60	-	-	-
La	35.3	31.4	30.8	31	59.9	90.9	72.9	41.1	19	30	22	28	0.687
Ce	61.7	55.1	58.5	67	126	188	144	89.8	37.7	64	44	57	1.775
Nd	25.8	19.6	23.2	27	54.8	84.9	49.3	47.1	18.2	26	18.5	23	1.354
Sm	4.2	3.3	3.5	5.3	9.8	14.5	7.64	7.8	3.4	4.5	3.3	4.1	0.444
Eu	1.0	0.8	0.9	1	2.3	3.2	1.23	2.0	0.9	0.88	1.17	1.1	0.168
Gd	3.2	2.4	2.3	5.5	6.0	9.2	5.41	4.8	2.8	3.8	3.13	3.3	0.596
Dy	1.8	1.9	1.6	5.2	3.2	5.6	3.65	2.8	1.9	3.5	3.6	3.7	0.737
Er	0.77	0.77	0.75	3.0	1.41	2.68	1.97	1.21	0.96	2.3	2.2	2.2	0.480
Yb	0.78	0.63	0.63	3.2	1.32	2.05	1.90	0.93	0.88	2.20	1.2	1.53	0.493
Lu	0.20	0.13	0.12	0.5	0.26	0.34	0.29	0.08	0.17	0.32	0.29	0.30	0.074
Sr/Y	30.45	31.44	51.1	-	63.89	26.58	-	162.21	55.65	-	-	-	-
$(La/Yb)_N$	29.85	32.86	32.52	-	29.92	29.32	-	29.32	14.44	-	-	-	-

1) Average of 108 TTGs (Martin et al., 2005)
2) Average of 320 TTGs (Martin et al., 2005)
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9) Average of 77 Low Silica Adakites (Martin et al., 2005)
10) Taylor and McLennan (1981)
11) Weaver and Tarney (1984)
12) Weaver and Tarney (1984)
13) Sun and McDonough (1989)

2.1.3 World occurrences of TTG suites

2.1.3.1 General

Well known TTG occurrences include the 3.52-2.83 Ga Pilbara Craton (Smithies and Champion, 1999) and 3.73-2.62 Ga Yilgarn Craton (Sylvester, 1994; Champion and Sheraton, 1997; Chen *et al.*, 2006) of Australia, the ~2.7 Ga Superior Province in Canada (Shirey and Hanson, 1984; Evans and Hanson 1997; Whalen *et al.*, 2002), the 2.5 Ga Closepet batolith of the Dhawar Craton, India (Moyen *et al.*, 2003; Jayananda *et al.*, 2000), and the 3.5-2.5 Ga Barberton Mountain Land, Kaapvaal Craton, South Africa (Poujol *et al.*, 2003; Robb *et al.*, 1986; de Wit *et al.*, 1987). Evidence suggestive of plate tectonic processes in both the Early Archaean (Kaapvaal and Pilbara Cratons) and Late Archaean (Superior Craton) are compelling although the style at plate boundaries has since changed (De Wit, 1998).

A summary of the most important features of some world TTG occurrences, especially those that has been considered to have close links to the Kaapvaal Craton, is presented in Table 4. Only two relatively pristine examples of Early Archaean lithosphere are preserved, ie. the Pilbara Craton of Australia and the Kaapvaal Craton in South Africa. Various models depicting the paleogeographic relation of the Kaapvaal craton to other cratonic nuclei in the early Precambrian has been presented (Piper, 1982; Rogers, 1996; Zegers *et al.*, 1998). In most reconstructions, the Zimbabwe and Kaapvaal cratons are placed next to each other since around 2.7Ga, the time of granulite facies metamorphism in the Limpopo metamorphic belt (Barton and Van Reenen, 1992). Based on paleomagnetic data Piper (1982) suggested the existence of a Paleoproterozoic supercontinent in which the Kaapvaal craton is placed next to South America, distant from the Pilbara craton of Australia. More recently Rogers (1996) proposed a continent called Ur, which existed from the Neoarchean to the Paleoproterozoic. Ur is proposed to consist of the Kaapvaal craton (De Wit *et al.*, 1992), the Western Dharwar craton (Meen *et al.*, 1992), the Bhandara craton (Sarkar *et al.*, 1993), the Singhbhum craton (Sharma *et al.*, 1994) and the Pilbara craton (Bickle *et al.*, 1993). In the Ur configuration, Antarctica is situated between the Kaapvaal and Pilbara cratons. Recent studies proposed that the Kaapvaal and the Pilbara Cratons evolved in close proximity (Thorpe *et al.*, 1992; Brandl and de Wit, 1997; Zegers *et al.*, 1998). Similar litho-stratigraphic sequences across these cratons have led to the argument that these cratons were joined and may have formed part of a large Archaean supercontinent ("Vaalbara" Craton) (Brandl and de Wit, 1997; De Wit, 1998 and references therein). Zegers *et al.* (1998) placed the Pilbara Craton immediately to the east of the Kaapvaal Craton based on structural, geochronological and paleomagnetic data. The striking resemblance between late Archean to early Paleoproterozoic sedimentary sequences of the Kaapvaal and Pilbara Cratons also lead Cheney (1996) to suggest that the Pilbarra craton were located to the south of the Kaapvaal craton. Furthermore similarities in the seismic structure of the crust of the central Kaapvaal Craton and that of the Superior Province exist (de Wit and Tinker, 2004; Ludden and Hynes, 2000).

In western Australia two Archaean cratons are recognised. These cratons are the well-exposed Pilbara- and poorly exposed Yilgarn Cratons, which show dome-and-keel and linear greenstone belt patterns respectively. These cratons developed independently until they collided during the Paleoproterozoic (Chen *et al.*, 2006) (Table 4). Granites were generally coeval with greenstones, and the early TTG-type granitoids gave way to K-rich granitoids.

As with the Kaapvaal Craton, the well-exposed Pilbara Craton can be subdivided into several smaller granite-greenstone blocks bound by structural discontinuities (van Kranedonk and Collins, 1998; de Wit., 1998 and references therein; Bagas *et al.*, 2002; Chen *et al.*, 2006). Evidence suggests that the granitoids of the Pilbara Craton becomes progressively more K-rich as it becomes younger as a result of continual recycling of early crust (Champion and Smithies 1999, 2001). Typical TTG-type granitoids (> 3.4 Ga to 2.9 Ga) are rare and present only in the eastern half of the Eastern Pilbara Terrane (EPT) and range from tonalites to monzogranites. The TTG-type granitoids of the Shaw batolith (3.3-3.5 Ga) are granodiorite with subsidiary tonalites and adamellites (Chen *et al.*, 2006; Bickle *et al.*, 1989). The younger batoliths of the EPT (eg. Mount Edgar and Corunna Downs batoliths) lack rocks of the typical Archaean TTG-type (Champion and Smithies, 2001). High-Mg diorites (sanukitoid) occur towards the center of the granite-greenstone terrane of the Mallina basin (3500-3300 Ma) (Table 4).

The Yilgarn Craton is a complex area of Archaean intrusive, volcanic and sedimentary rocks, which occupies the southern part of Western Australia. The granitoids of the late-Archaean Yilgarn Craton is dominated by monzogranite, with minor TTG, granodiorite, sanukitoid and syenite and has been assembled between ~2.94 and 2.63 Ga through the accretion of several smaller fragments of continental crust (Narryer Terrane, Youanmi Terrane and Eastern Goldfields Terrane) (Davies and Maidens, 2003). The Yilgarn Craton is dominated by K-rich granitoid rocks that are derived through remelting of older felsic (TTG) crust (Champion and Smithies 2000; Champion and Sheraton, 1997; Chen *et al.*, 2006).

The Superior Craton (more often referred to as the Superior Province) represents the largest well-preserved late-Archaean Craton (1 572 000 km^2) and forms the core of both the North American continent and the Canadian Shield (Percival *et al.*, 2005). The formation of the Superior Province is traditionally explained within the framework of 2.72-2.68 Ga accretion of smaller continental plates and trapped oceanic terranes (de Wit, 1998 and references herein). The craton is subdivided into a volcano-plutonic or greenstone belt (sialic crust and island arcs), metasedimentary, plutonic (granitoid batholiths formed by partial melting of mantle) and high-grade gneissic subprovinces separated by faults or shear zones (Stott, 1997 and references herein). The subprovinces form tectonically juxtaposed elongated belts, which are considered to be evidence of crustal stacking during convergence of two continental masses. In the Superior Province the suite of Mg-rich TTG's (sanukitoids) has been seen as evidence that at least some Archaean TTGs originate from a LILE-enriched mantle source (Stern *et al.*, 1989, Sutcliffe *et al.*, 1990)

The Dhawar Craton of South India is made-up of a Western (3300-2700 Ma) and an Eastern part (3000-2500 Ma) (Chadwick *et al.*, 2000) (Table 4). The Western part of the Dhawar Craton consists of greenstone belts overlying the TTG basement gneisses. The Eastern part of the Dhawar Craton comprises elongated greenstone belts along with older TTG gneisses intruded by late Archaean granitoids (Rollinson *et al.*, 1981). The main granite types described for this craton include TTG, sanukitoids and biotite-granites as well as a fourth type, referred to as the Closepet-type granite (Moyen *et al.*, 2003; Jayananda *et al.*, 2000 and references herein).

Radiometric ages suggest that the Kaapvaal Craton formed and stabilized between 3.7 and 3.0 Ga ago. The $1.2x10^6 km^2$ -sized Kaapvaal Craton as one of the oldest and largest ancient continental fragments (de Wit *et al.*, 1992). The mosaic of sub-domains of the Kaapvaal craton has been welded together by processes that may have been similar to those of modern day plate tectonics (de Wit et al., 1992; Lowe, 1994). De Wit *et al.* (1992) proposed that the amalgamation of the separate blocks occurred during a period of crustal shortening at 3228 Ma. Each block consists of a sequence of extension-related komatiitic volcanic rocks (representing back arc spreading centers or oceanic plateaus), which are followed by sedimentation, subduction-related felsic volcanics and TTG plutonism (Poujol *et al.*, 2003). At around 3.1 Ga, amalgamation of granite-greenstone terrains terminated and the Kaapvaal Craton stabilized (de Wit *et al.*, 1992; Brandl and de Wit, 1997), immediately prior to the deposition of the first cratonic sedimentation.

The Barberton Mountain Land forms part of the eastern domain of the Kaapvaal Craton (Figure 1.1), which comprises mafic-ultramafic and felsic meta-volcanic, plutonic as well as meta-sedimentary rocks of the Barberton Greenstone Belt (BGB) (Table 4). This sequence is intruded by several TTG plutons (Kaap Valley-, Nelshoogte and Steynsdorp plutons), which are considered to reflect magmatism around 3105 Ma (Koma and Davis, 1994) and 3236 Ma (de Ronde and Koma, 2000). The tonalitic-trondhjemitic Nelshoogte pluton is considered to have intruded the Kaap Valley pluton (Layer *et al.*, 1998; De Ronde and Koma, 2000). The Kaap Valley pluton (3229±3 Ma; Kroner *et al.*, 1991) is seen as chemically intermediate between the Nelshoogte trondhjemite and the Goedehoop tonalite/diorite (Anhaeusser, 2001). Potasic GGM batholiths (Nelspruit, Mpuluzi and Heerenveen) occurring to the north and south of the BGB represent voluminous granodiorite-adamelite bodies.

Apart from the well-known Barberton Greenstone Belt, several other granite-greenstone terrains are preserved on the Kaapvaal Craton (Brandl and de Wit, 1997). Of the known TTG occurrences on the Kaapvaal Craton, the three prominent Archaean terranes, which will be presented here, include the Barberton Mountain Land, Murchison Greenstone Belt and the Vredefort dome and Rand Anticline.

The Vredefort Dome is located 100km south of HHD and is thought to be the oldest known impact-related scar on earth. The meteorite impact (at ~2025 Ma) resulted in a circular structure consisting of an uplifted core of exposed Archaean basement rocks surrounded by Witwatersrand Supergroup sediments with an almost vertical dip (de Wit *et al.*, 1992, Gibson *et al.*, 1998). This makes the Vredefort structure a convenient locality to study Archaean granitoids of the center of the Kaapvaal Craton. The Vredefort Dome display a wide variety of granitic, gneissic and migmatitic rocks of the mid-Archaean together with greenstone remanats ranging from granulite to greenstone metamorphic grade reflecting the complex history of the area, including the meteorite impact (Minnitt *et al.*, 1994; Hart *et al.*, 1999). Most of the ages listed for the Vredefort Dome display the effect of metamorphic overprinting. Ages for the Vredefort granitoids, which range from 3425 to 2564 Ma from xenocrystic zircons, overlap with ages for granitoids from HHD and BML (Poujol *et al.*, 2003).

Although a convenient locality to study Archaean granitoids below the Witwatersrand basin, limited exposures and high metamorphic grade complicate studies over this part of the central Kaapvaal Craton Archaean. The Archaean rocks were interpreted as lower crustal rocks, which rebounded to upper crustal levels in response to the impact (Hart *et al.*, 1999). The Archaean granitoid and greenstone rocks at the center of the Vredefort structure were, however, metamorphosed.

Rocks obtained from surface and borehole intersections along the Rand Anticline (southwest of Johannesburg) were described as porphyritic adamellite to granitic rocks as well as tonalitic gneisses and migmatites similar to those of the HHD (Robb and Meyer, 1987).

Located 190km north of the BML the Murchinson Greenstone Belt (MGB) consists of an east-northeast aligned sequence of metavolcanic and metasedimentary rocks intruded in the north and south by a variety of Archaean granitoids and gneisses (Poujol and Robb, 1999). The granitoids were formed between 3.09 Ga (Harmony Granite, Poujol and Robb, 1999) and 2.97 Ga (Maranda Granite, Poujol, 1997) and was related to ~3.09 Ga volcanism. The TTG suite of the MGB belt is younger than the equivalent rocks in the BML. The MGB was interpreted as a possible ancient volcanic arc linked to a subduction zone (Vearncombe, 1991; Poujol and Robb, 1999)

2.1.4 Petrogenetic models

There is little agreement on how Earth's earliest continental crust evolved. The popular view is that continental crust formed in the Archaean in very much the same manner as today (Lowe, 1994), proposing that Archaean continental crust formed through accretion of volcanic arc material. However, the absence of features (ophiolites etc.) akin to modern convergent margins in the Archaean record suggests otherwise (Condie 1997; Smithies *et al.*, 2003). This led to the view that plate tectonic processes in the Archaean were different to the processes observed at modern plate margins. De Wit, (1998) suggested that modern-style subduction processes might have emerged late in the Archaean. Modern adakites are relatively rare and seem to be restricted to subduction settings where unusually high heat-flow occurs, e.g. subduction of young oceanic crust, ridge subduction and flat subduction (Peacock, 1990; Martin *et al.*, 2005). In contrast to modern subduction, heat-flow were 3 to 4 times higher in the Archaean, which resulted in more efficient convection and smaller plates with younger and hotter oceanic plates being subducted (de Wit and Hart, 1993; Martin and Moyen, 2002). Rapp (2000) identified at least two sources for Archaean granitoids, ie. a crustal basaltic source and an enriched mantle source.

Martin *et al*. (2005) summarised the evolution of slab-derived magmas in four stages. The first stage during Early Archaean (>3.3 Ga) involve melting of subducted basalt at shallow depth where no mantle wedge formed and thus no evidence of interaction between TTG magma and mantle wedge is seen in the chemistry of these rocks. The second stage during Middle to Late Archaean involved melting of the subducted slab at greater depth where subduction occurred at a greater angle and a mantle wedge developed. Slab melts were not totally consumed by the reaction with the mantle, which resulted in TTG emplacement into the crust (Rapp *et al.*, 1999). The third stage during Late Archaean involved declined heat production and slab melts were consumed in reaction with mantle peridotite (Rapp *et al.*, 1999). The succeeding melting of the metasomatised mantle peridotite resulted in the production of Archaean sanukitoids and Closepet-type granites. During the last stage throughout the Lower Proterozoic the heat production was too low to allow subducted slab-melting, which resulted in slab dehydration and the formation of classical calc-alkaline magma from melting of peridotite metasomatised by dehydration fluids.

The summary by Martin *et al*. (2005) is a combination of various models for the formation of TTGs, which exists in literature. A brief review of the strengths and weaknesses of the main opposing models for the formation of TTG will be presented here. The ability of each model to reconcile the observed major, trace and REE patterns of TTGs will be considered.

Partial melting of basaltic material previously underplated beneath a thickened crust

This model suggests that Archaean continental crust evolved through direct partial melting of a thickened and continuously replenished hydrated oceanic crust by a process of flat subduction or crustal stacking (Rudnick, 1995; Smithies, 2000; Smithies and Champion, 2000). Hoffman and Ranalli (1998) argued that Archaean oceanic crust was too thick, warm and buoyant to have a steep subduction angle. Gutscher *et al.* (2000) showed very low angle subduction occurs where unusually thick oceanic crust (plateau) is present. These authors suggested that the high spreading rates would push the oceanic crust horizontally, forcing one edge to be thrusted beneath or into the other, rather than being steeply subducted.

Davies, (1992, 1995, 1998) and de Wit, (1998) suggested that early crust formed through melting of a very thick mafic crust. Experimental petrology (Rapp, 1994) and modeling (Moyen *et al*., 2001) confirmed the general assumption that partial melting of Archaean hydrous basalt generated TTG magmas (Barker and Arth, 1976; Condie, 1981, 1986; Johnson and Wyllie, 1988; Rapp *et al*., 1991; Rollinson, 1997). Atherton and Petford (1993), Davies (1995, 1998) and de Wit (1998) argued that partial melting of the lower part of a thick oceanic crust could resulted in TTG magmatism, explaining the absence of evidence of mantle interaction (i.e. high Mg#, Ni, Cr, Sr/Y).

Smithies and Champion (2000) claimed that there is not enough evidence to suggest any involvement of the mantle wedge during the growth of the continental crust prior to 3.10Ga. They suggested that the process of subduction of oceanic crust was not dominant before 3.20Ga but as the oceanic crust became less buoyant towards the end of the Archaean, slab melting due to the very low angle of subduction occurred more frequently. This is seen in the increased mantle interaction evidenced by TTGs, which formed towards the end of the Archaean.

Partial melting of a subducted oceanic slab

The theory of direct melting of a subducted oceanic crust at garnet-amphibolite to eclogite facies explains the distinct REE pattern seen in TTGs and modern adakites (Martin 1986; 1999; Defant and Drummond 1990; Drummond and Defant 1990). However, enrichment of TTGs in fluid-mobile trace elements (such as Pb) is not compatible with modern adakites, which are considered to be true eclogite melts from subductional environments. Experimental petrology also showed that liquids produced by tholeiite melting under subduction conditions have in general slightly lower $Mg^{\#}$, Ni and Cr contents compared to natural adakites (Martin, 1999).

Melting in the subducted oceanic slab and interaction with mantle wedge

Evans and Hanson (1997) presented arguments in favor of direct partial melting of the LILE-enriched mantle peridotite as a possible source for the generation of some TTGs (high-Mg diorites). Experimental petrology, however, showed that high SiO_2 granitoid magma can not be generated by direct partial melting of LILE-enriched mantle peridotite (Wyllie *et al.*, 1997; Smithies and Champion, 2000). The observed compositional range between Archaean TTGs and high-Mg diorites can, however, be explained if the mantle peridotite source is contaminated with partial melt from a crustal source (slab melt). It was therefore proposed that melts derived from partial melting of a subducted slab ascends through and interact with the mantle (Sutcliffe *et al.* 1990). This allows the modification of the SiO_2, MgO, Ni and Cr contents without changing the slab-melt signature recorded by the incompatible elements (Martin and Moyen, 2002).

Martin (1999) showed that some interaction of the adakite with the overlying mantle wedge was required to result in the enrichment seen in these rocks. The high $Mg^{\#}$, Ni and Cr signatures of adakites are therefore considered to reflect interaction of felsic melts generated by melting of metabasaltic slabs with mantle peridotite during its ascent through the mantle wedge (Martin, 1999, Smithies, 2000, Martin and Moyen, 2002). Although very few, if any, pre-3.00Ga TTG suites show a geochemical trend similar to adakites, the late Archaean TTGs (high-Mg diorite series) show this evidence for mantle interaction (Smithies, 2000).

Martin and Moyen (2002) showed that there is a systematic increase in the contribution of mantle peridotite to the formation of TTGs from early to late Archaean. These authors also considered the differences to be the result of variation in the geothermal gradient over time due to the progressive cooling of the Earth. They showed these differences could be related to greater heat production during the Archaean and shallower depth of melting of the subducted slab. This resulted in the slab melt passing through a thinner mantle wedge and therefore suffered only small degrees of interaction. When the geothermal gradient is too low slab dehydration occurs before melting can take place. The result is melting and metasomatism of the mantle wedge by an aqueous fluid, which give rise to calc-alkaline (GGM) magmas.

The discovery of high MgO, Cr, Ni and LILE enrichment in Archaean TTGs of the Superior Province, Canada, suggested the involvement of both crustal and mantle-derived magma in the formation of these TTG suites (sanukitoids) (Sutcliffe *et al.*, 1990).

Dehydration melting in the suprasubdutional mantle wedge (and later fractional crystallization)

Kamber *et al.* (2002) showed TTGs have a strong signature inherited from metamorphic dehydration. They argued that more aqueous fluids were present during dehydration melting of the subducted slab in the Archaean. These authors also assumed that the HREE depletion and LREE enrichment of TTGs could have been the result of fractional crystallization. Except for the HREE depletion observed in TTGs, the composition of these rocks is similar to modern arc-generated upper crust (Kamber *et al.*, 2002; Kleinhans *et al.*, 2003). HREE depletion can be explained by three approaches i.e. the melting of garnet-amphibolite eclogite in the slab or lower crust, inherited REE pattern of the slab derived fluid, or by fractional crystallization of garnet/amphibole in hydrous mantle melts.

Kleinhans *et al.* (2003) showed that the low HREE content of adakites and TTGs reflect the presence of garnet and amphibole in the residue of partial melting of a tholeiitic source. These authors therefore proposed a very similar model to that of Kamber *et al.* (2002). Kleinhans *et al.* (2003) showed TTGs and GGMs have a typical signature for slab dehydration. The signature include 1) over-enrichment in fluid mobile elements (Pb), 2) strong LREE/HREE fractionation, 3) high compatible-element concentrations (Ni, Cr, Co), 4) preferencial depletion in Nb compared to Ta and 5) absence of a negative Eu anomaly. These authors therefore argued that the geochemical signature of slab dehydration observed in these rocks can be derived from the suprasubductional refertilised mantle wedge. The major and trace element characteristics are explained by the subsequent fractional crystallization from parental basaltic mantle melts. The theory by Kleinhans *et al.* (2003) therefore proposes that slab dehydration is followed by extensive fractional crystallization to account for the geochemical signature of TTGs. These authors argued that subduction-related slab dehydration triggered peridotite melting.

Recent studies also discussed the importance of H_2O in the crystallization sequence of the basaltic parental melt evolving from the suprasubductional peridotite melting (Barker *et al.*, 1994; Munter *et al.*, 2001). Kleinhans *et al.* (2003) showed that the differences in the TTG and GGM characteristics could be explained by the initial H_2O content of the parental melt. Kleinhans *et al.* (2003) argued that the degree of hydration decreased with time resulting in crystallization of garnet and amphibole being progressively suppressed by plagioclase during GGM formation. Towards the end of the Archaean the hydration of subducted mantle melts dropped below the point where crystallization was dominated by garnet/amphibole, explaining the REE patterns seen in post-Archaean granitoids. Kleinhans *et al.* (2003), therefore, ascribed the disappearance of TTG and simultaneous dominance of the K-rich granitoids in post-Archaean times to the decrease in water content of the mantle-derived melt.

Partial melting of a TTG protolith

Unlike other models for TTG formation, this model requirers no link to subduction. Assimilation of tonalitic gneiss crust by younger tonalite magmas is presumed (Whalen *et al.,* 2002). Experimental studies (Rutter and Wyllie, 1988; Singh and Johannes, 1996) showed that fluid absent partial melting of tonalitic material under lower- to middle-crustal conditions can produce liquids with granitic to tonalitic compositions. The heat for partial melting of a TTG protolith can be generated by either crustal thickening or, more likely, through heat transferred from mafic magma originating from the mantle wedge (Whalen *et al.,* 2002).

Whalen *et al.* (op. cit.) showed that if magmas extracted from a TTG protolith contain restite (plagioclase, quartz, pyroxene and garnet), their composition would increasingly mimic that of the protolith. As protolith or earliest TTG crust would have been generated through another process, therefore suggesting TTG petrogenesis could not be attributed to one overarching model.

2.2 Review of previous work on the HHD and supracrustals

2.2.1 General geology

The general geology of the study area (Figure 2.1) is summarised on a simplified geological map in Figure 2.1, which will be used for ease of reference in this work. A summary of the stratigraphy and available geochronological data is presented in Table 5.

The HHD is a 700 km^2-sized, oval-shaped window of Archaean rocks consisting of mafic to ultramafic units and intruded tonalite, trondhjemite and granodiorite. Supracrustals unconformably overlying the crystalline Archaean lithologies dip radially away from the central arched area (Figure 2.1). Rocks of the Witwatersrand and Ventersdorp Supergroups mark the southern boundary of the HHD. A sedimentary contact between the Witwatersrand Supergroup and the granitoids of the HHD has been established by earlier studies (Corstophine and Jorissen, 1908). Hilliard (1994) and Roering (1986) showed the contact between the HHD granitoids and greenstone and overlying Witwatersrand Supergroup is highly sheared. The northern boundary of the HHD is constituted by quartzite and shale of the Black Reef Formation, which occurs at the base of the Transvaal Supergroup (Anhaeusser, 1973). The HHD is crosscut by variously-aged rhyolitic, porphyritic rhyolite, hybridised diabase, porphyritic diabase, as well as Pilanesberg-related syenite and composite dykes.

Table 5: Simplified stratigraphic column and available geochronology for the HHD

SUPERGROUP	**GROUP**	**SUBGROUP**	**FORMATION**	**GEOCHRONOLOGY**
ALLUVIUM				Recent
KAROO	ECCA		VRYHEID	
	DWYKA			
Post Transvaal intrusive rocks: Syenite dykes Rhyolite dykes				1 302±78Ma (van Niekerk, 1962) 1 263±176Ma (Schreiner and van Niekerk, 1958) 2 150±26Ma (Furmerton, 1978)
TRANSVAAL	CHUNIESPOORT	MALMANI	OAKTREE	2 557± 49Ma (Jahn et al., 1990) 2 552±11Ma (Barton et. al., 1994) 2 550±3 Ma (Walraven and Martini, 1995) 2 521±3Ma (Sunmer and Bowring, 1996) 2 588±7Ma (Martin et.al., 1998) 2 600-2430Ma (Walraven and Martini, 1995)
			BLACK REEF	2 600-2430Ma (Walraven and Martini, 1995) ~ 2 600Ma (Jahn et.al., 1990)
Post-Ventersdorp pre-Transvaal intrusive rocks				
VENTERSDORP	PLATBERG			2 709±4Ma (Armstrong et al., 1991)
	KLIPRIVIERSBERG		ALBERTON	2 714±8Ma (Armstrong et al., 1991)
WITWATERSRAND	WEST RAND	GOVERNMENT		2 914±8Ma (Armstrong et al., 1991)
		HOSPITAL HILL	ORANGE GROVE	2 980 Ma (Barton et al., 1989)
DOMINION GROUP				3120 to 3 070 Ma (Armstrong et al., 1990)
BASIC AND ACID DYKES				
MAFIC DYKES				*c* 3120 Ma (Prevec *et al.*, 2004)
GRANITOIDS		*Granodiorite to granite*		3132±64 Ma (Alsopp, 1961) 3101±5 to 3227±21Ma (Poujol and Anhaeusser 2001)
		Tonalite gneiss		3201±5Ma (Poujol and Anhaeusser 2001)
		Granodiorite to adamellite gneiss		2997±7 to 3 340±3.3Ma (Poujol and Anhaeusser 2001)
ARCHEAN MAFIC AND ULTRAMAFIC ROCKS				2 870- 3750Ma (SACS, 1980)

Deformation in the HHD granitoids is evidenced by the gneissic foliation as well as strike-slip shear movement zones developed mainly in two prominent cross cutting directions, i.e. northwest to southeast and northeast to southwest (Hilliard, 1994). The most prominent deformation is, however, evidenced by the Northcliff Promontory, Rietfontein fault system, West Rand syncline, Bezuidenhout Valley graben, Kromdraai graben and other structural disturbance further away from the HHD (McCarthy *et al.*, 1982; Stanistreet *et al.,* 1986; Stanistreet *et al.*, 1990; McCarthy *et al.*, 1990; Charlesworth and McCarthy, 1990). McCarthy *et al.* (1986) and Brink *et al.* (2000) showed cleavage in the supracrustals in the central Witwatersrand Basin is tangential to the Vredefort structure suggesting a strong influence by the Vredefort event. The radial dip of the supracrustals away from the central granitoids (HHD) is considered to be due to late doming. Although doming dispersed structural features around the dome, evidence of an overall northwards-directed deformational event was observed in the supracrustals as well as the granitoids (Roering, 1986; Hilliard, 1994; Gibson *et al.*, 1999).

2.2.1.1 Archaean basement

The oldest recognisable rocks of the HHD are described as a variety of mafic and ultramafic rocks with komatiitic to high-magnesian basaltic and tholeiitic affinities (Anhauesser, 1973, 1977, 1978, 1999). The presence of schistose mafic to ultramafic rocks on the HHD north of Krugersdorp was recognised as early as 1906 (Hall and Humphrey, 1906; Kynaston, 1907a, b). Willemse (1933) subdivided the mafic schist occurring north of Krugersdorp into “basic” and “acidic” schists and showed the “basic” schist consists mainly of serpentinised amphibolite and hornblende schist. Hendriks (1961) correlated serpentinite, talc-, hornblende- and amphibolite schist on the HHD with the Jamestown Igneous Complex (no longer recognised by SACS). Anhaeusser (1973) later suggested these mafic and ultramafic rocks can be correlated with the Onverwacht Group in the Baberton Mountain Land and inferred to be between 3 750 and 2 870 Ma (SACS, 1980) old.

These mafic to ultramafic rocks largely occur around the western, southwestern and southeastern margins of the HHD (Muldersdrift, Roodekrans, Edenvale and Modderfontein) (Figure 2.1). Smaller isolated xenoliths (centimetre- to meter-scaled) are found scattered over the HHD, in some instances aligned parallel to gneissosity (Anhauesser, 1973, 1977, 1978).

Localised studies on the southwestern part of the HHD resulted in the recognition of remnants of three mafic to ultramafic occurrences, i.e. the Roodekrans (Roodekrans 183IQ north of Krugersdorp), Muldersdrift (Driefontein 179 IQ, Van Wyks Restant 182 IQ and Honingklip 178 IQ) and Zandspruit (Zandspruit 191 IQ, North-Riding) complexes similar to those described as ultramafic flow units in the BML (Anhaeusser, 1977, 1978, 1992) (Figure 2.1). The two larger remnants, the Roodekrans and Muldersdrift ultramafic complexes, have been recognised as formal stratigraphic units by the South African Committee for Stratigraphy (SACS, 1980). These rocks are generally described as altered layered ultramafic assemblages comprising alternating dunitic, hartzburgitic, pyroxenitic and to a lesser extent gabbroic rocks to talc schist and serpentinite contain sporadically developed thin chrysotile veins (Anhauesser, 1973, 1977, 1978, 1992). A unit of poorly exposed metavolcanics separates the Roodekrans and Muldersdrift Complexes. This unit contains amygdales, spherulites and locally developed pillow structures (Anhaeusser, 1977, 1978). Although soil cover obscures the contacts with the granitoids it is believed that the intruding granitoids assimilated and metamorphosed the mafic to ultramafic rocks. Evidence of the resulting fragmentation and hybridisation of the amphibolitic rock by the intruding granitoids can be seen at various localities on the HHD (e.g. Grand Central airport, Figure 2.3). The original textures of the mafic and ultramafic rocks have been largely destroyed by the metamorphism associated with the intrusion of the granitoids.

Small outcrops of thinly-layered or -banded to brecciated jasper- or chert-like material, considered to be banded iron stone (BIF), occur at several localities on the HHD. The largest of these exposures occurs on Van Wyks Restant 182 IQ, along the Tarlton road and on Olifantsfontein 410 JR near Tembisa (Anhauesser, 1978; van Tonder, 1999). Although, BIFs are common in Archaean terrains (Anhauesser, 1978; Viljoen and Viljoen, 1969), the possibility of these rocks representing thrusted blocks of Witwatersrand Supergroup can not be ruled out (Roering *et al.*, 1990).

The mafic to ultramafic rocks of the HHD were considered to represent remnants similar to the primitive mafic and ultramafic rocks of the BGB (Anhaeusser, 1973; 1977; 1978; 1992). The mafic to ultramafic rocks of the BGB are believed to have formed during initial emplacement in an Archaean oceanic or volcanic arc-like geotectonic setting (Viljoen and Viljoen, 1969; Anhaeusser, 1973; 1977; 1978; 1992; 1999). Recent work by Anhauesser (2004), however, suggests that these mafic-ultramafic assemblages represent a suture or oceanic crustal collisional zone between two colliding crustal blocks similar to that found in Phanerozoic ophiolite complexes. He based this assumption on the fact that the HHD mafic-ultramafic assemblages lack evidence of other lithologies akin to greenstone complexes. Through reassessment of the mafic-ultramafic assemblages Anhauesser (*op. cit.*) showed these rocks to be closely linked to upper mantle or oceanic crust.

2.2.1.2 Granitoids

The existence of “Old Granite” north of Johannesburg was recognised as early as 1906 (Hall and Humphrey, 1906; Kynaston, 1907, 1929). These authors described a uniform grey granite covering the entire HHD with a dioritic marginal variety developed only in the northwest. A widespread mapping investigation on the HHD conducted by Willemse (1933) showed the HHD granitoids are generally fine-grained homogeneous greyish granites with locally occurring porphyritic, coarse-grained pinkish-red and dioritic varieties. In addition to producing a published geological map of the HHD, Willemse (*op. cit.*) also recognised the intrusive nature of the granitoids into the basic schist.

Anhaeusser (1973) conducted a large-scale study on the granitoids of the HHD and attempted to classify and subdivide the granitoids. This author’s seven-fold subdivision was based mainly on the macroscopic appearances of the granitoids and was later used in the compilation of the 1:250 000 East and West Rand maps by the then Geological Survey of South Africa (1973). The HHD granitoids were subdivided into the following main suites:

(a) an ancient tonalitic gneiss which were described as having limited exposure around the southern periphery of the HHD. Two main varieties were described:
  (i) a hornblende-biotite tonalite and
  (ii) a biotite trondhjemite.

(b) a migmatite and gneiss, developed over much of the northern half of the HHD, consisting of strongly foliated to banded gneisses with locally developed migmatitic features

(c) a grey granodiorite suite exposed over the south central part of the HHD, subdivided into:
  (i) a medium grained granodiorite to adamellite and
  (ii) a porphyritic granodiorite

(d) a homogeneous, medium to coarse-grained, pinkish-grey granodiorite

(e) a transitional zone, developed over the central part of the HHD, representing a mixed unit consisting of rocks from both the granodiorite suite and the migmatite gneisses of the north

Although Barton *et al.* (1999) followed much the same classification as Anhaeusser (1973) they applied a more simplified three-fold classification, i.e. tonalite, granodiorite and migmatite.

Anhaeusser (1999) performed a detailed study of a small (~1km^2) granitoid exposure on Nooitgedacht 534JQ, in the northwestern sector of HHD (approximately 10km northeast of Muldersdrift) was performed (see Figure 2.1). This study focussed on the field relationship and geochemistry of the complex granitoid-greenstone outcrop. Granitoids from this exposure were subdivided into two main suites: (a) an ancient tonatite and leucocratic-trondhjemite to granodiorite gneiss (TTG) suite and (b) a homogeneous and locally porphyritic granodiorite-to-adamellite suite which intruded the former. This investigation also showed two sets of amphybolitic dykes crosscutting the foliation in the gneisses. The amphibolitic dykes were on their turn intruded by later granitoid dykes and veins of the granodiorite to adamellite suite.

The publication on the Geology of South Africa (Robb *et al,* 2008) presents the subdivisions for the Archaean granitoids on the HHD as follows:

(a) Linden Gneiss: Hornblende-biotite tonalite gneiss similar to Anhauesser’s (1973) ancient hornblende-biotite tonalite gneiss which occur on the southern perhiphery of the HHD
(b) Lanseria Gneiss: Trondhjemite and tonalite gneiss similar to Anhauesser’s (1973) migmatite gneiss occupying the northern half of the HHD
(c) Bryanstone Granodiorite: Grey, medium-grained granodiorite similar to Anhauesser’s (1973) homogeneous, medium-grained grey granodiorite suite occupying most of the southern half of the HHD
(d) Honeydew Granodiorite: Grey, porphyritic granodiorite similar to Anhauesser’s (1973) homogeneous, medium-grained, grey porphyritic granodiorite suite on the southwestern part of the HHD
(e) Victory Park Granodiorite: Pinkish grey, medium- to coarse-grained granodiorite similar to Anhauesser’s (1973) medium to coarse-grained, pinkish-grey homogeneous granodiorites occurring on the southwestern edge of the HHD

Structural features on the HHD were largely neglected in previous studies. Willemse (1933) first recognised structural features on the HHD and showed north-west and north-east striking "crush zones" along which the granitoids have been deformed. These zones, along which strike slip shear movement occurred, were later described as shear zones (Anhaeusser, 1973, Roering, 1984, Hilliard, 1994). These authors described the shear zones as consisting of a prominent massive quartz vein in the centre flanked by a zone of crushed and sheared granite cut by secondary quartz veining. Silicification caused these lineaments to be preserved as prominent ridges. Hilliard (1994) showed strike slip shear movement on the HHD occurred mainly along two prominent directions, the one being northwest to southeast and the other being northeast to southwest. The investigation by this author showed the north-east-striking shear zones have mostly a sinistral sense of movement while the north-north-west-striking zones showed a dextral sense of movement, implying that the two main shear directions form a conjugate set. Hilliard (1994) also showed the maximum principle compressional stress (σ_1) was orientated at 010°-190°, with σ_2 vertical while σ_3, representing the bulk extensional component, was directed approximately east-west. This suggests that a regional north-south compressional event occurred over the HHD.

Hilliard (1994) proposes shearing pre-dates the deposition of the Black Reef Formation. However, ductile shearing along the Kayalami shear zone (KSZ), the major shear zone which divides the HHD into an eastern and western half, cuts through the Black Reef Formation (Transvaal Supergroup) (Figure 2.1). The fact that the Transvaal Supergroup is displaced along the KSZ, lead Hilliard and McCourt, (1995) to propose that these shear zones were re-activated as brittle faults in post-Black Reef times. Displacement of the Transvaal Supergroup rocks along KSZ was also seen as evidence that shearing pre-dates doming (Hilliard and McCourt, 1995). Hilliard (1994) reported less variation in cleavage orientation in the Transvaal Supergroup rocks after the northward radial dip off the HHD has been compensated for. Timing of the structures suggested that post-Black Reef Formation deformation pre-dates the doming event but that doming occurred after the Vredefort event (McCarthy *et al.*, 1986; Hilliard, 1994).

A prominent east-striking shear zone forming an angular unconformity between the basement granitoids and the overlying Black Reef Formation were recognised by Roering *et al.* (1990). These authors referred to the ~1.5km long shear zone developed along the northwestern border of the HHD (from Rhenosterspruit 495 JQ to Doornrandje 386 JR), as the Jukskei river shear zone (JRSZ) (Figure 2.1). The schistosity in the sheared granitoids dips towards the south at angles of up to 45° and is best seen at the junction of the Jukskei and Crocodile rivers (Figure 2.4). Roering (1990) showed the presence of tectonically juxtaposed lenses of locally mylonitised granitoids and incorporated Witwatersrand quartzite and shale as well as amygdaloidal lava in this shear zone. These authors used a schematic cross-section through the HHD, from the Northcliff Promontory to the JRSZ, to demonstrate that the HHD is made-up of tectonically imbricate thrust stacks of greenstones-, granitoids- and supercrustals. These authors also showed the Black Reef Formation was not truncated by the JRSZ suggesting a pre-Transvaal age for this early south-over-north thrusting event. Hilliard (1994) showed the geometry of JRSZ points to a north-south compressional event. This author investigated planar fabric in the granitoids at several localities on the HHD and showed a north-north-east-verging thrust system. Roering (1990) proposed northwards-directed thrusting occurred between 2 709 and 2 640 Ma, which corresponds with late Archaean accretionary tectonics of the Limpopo Orogeny. However, Poujol and Anhaeusser (2001) reported that no evidence of the series of northward verging thrust faults described by Roering *(*1990) could be found and regarded the granitoids as *in situ* magmatic and not of structural origin. Poujol and Anhaeusser (2001) proposed thin-skinned thrusting which involved only the supracrustal cover rocks.

Gneissic foliation in the HHD granitoids is generally formed by preferred orientation of biotite and hornblende, leucocratic to melanocratic banding and small greenstone xenoliths orientated parallel to foliation. The foliation has an approximately east-west strike and dips to the south (Anhaeusser, 1973). The leucocratic and melanocratic banding, developed on the northern part of the HHD, has been folded suggesting more ductile deformation.

2.2.1.3 Dominion Group

The Dominion Group, considered being a locally-developed fore-runner of the Witwatersrand Supergroup, developed in response to extension over the central part of the KC (Thomas *et* *al.*, 1993). The Dominion Group accumulated between 3 120 and 3 070 Ma (Armstrong *et al.*, 1990). The Dominion Group formed over the western part of the Witwatersrand basin in a small proto-basin considered being a structural remnant of a much larger basin (Bickle and Eriksson, 1982). The depositional environment has been described as an Andean-type back-arc basin (Burke *et al.*, 1986) or an extensional failed rift basin (Bickle and Erricsson, 1982; Tankard *et al.*, 1982).

Schistose rocks, previously considered as part of the Dominion Group, occur at the foothills of the outlier of Witwatersrand Supergroup at Zwartkop 525JQ as well as in small isolated occurrences along the northern border of the HHD on Doornrandje 368JR (Figure 2.1). However, similarities between these rocks and Ventersdorp Supergroup rocks in the area as well as the known coverage limit of the Dominion basin suggest these rocks rather form part of the Ventersdorp Supergroup (Obbes, *pers. comm.*, 1995).

2.2.1.4 Witwatersrand Supergroup

The Witwatersrand and correlative Pongola Supergroups (Beukes and Cairncross, 1991) are the oldest sedimentary cover sequences preserved on the Kaapvaal craton. The deposition of the Witwatersrand Supergroup took place after the formation of the Dominion Group at 3 100Ma (Armstrong et al., 1990) and before the Klipriviersberg Group at 2 700-2 714±8 Ma (Armstrong *et al.*, 1991). The maximum age for the onset of Witwatersrand Supergroup deposition is approximately 2 980 Ma, which corresponds to the maximum age reported for the Orange Grove Formation at the base of the Witwatersrand Supergroup (Barton *et al.*, 1989).

A marked erosional surface is developed at the base of the Witwatersrand Supergroup. The Witwatersrand Supergroup displayed a sedimentary pattern indicative of cyclic sea level fluctuation, and basin subsidence typical of thermal subsidence basins (Beukes and Nelson, 1995). Detrital zircon ages for quartzites within the Witwatersrand Supergroup suggests that sediment input into the Witwatersrand basin was mostly siliciclastic material derived from source areas of middle to late Archean age (Barton et al., 1989; Robb et al., 1990), most probably the basement rocks of the Kaapvaal craton itself.

Early models showed the Witwatersrand Basin, located at the centre of the Archaean KC, forms one of several intracratonic basins, which developed during the Archaean and Proterozoic (Pretorius, 1979; Tankard *et al.*, 1982) (Figure 1.1). Recent studies indicate the geotectonic evolution of the Witwatersrand basin was largely controlled by the structural framework of the Kaapvaal Craton (Stanistreet and McCarthy, 1991). The latter authors showed that rejuvenation of fault zones, representing lineaments and sutures associated with the structural evolution of many greenstone belts on KC, controlled Witwatersrand Basin development. These lineaments, i.e. an eastnortheastly-trending (associated with the Pietersburg and Barberton greenstone belts) and a northnorthwestly-trending one (associated with the Kraaipan and Amalia greenstone belts) played a major role in the evolution of the Witwatersrand and post-Witwatersrand Basins (McCarthy *et al.*, 1990; Stanistreet and McCarthy 1990, 1991). The presence of banded iron formation, shale, quartzite, diamictites and conglomerate indicate that the Witwatersrand Supergroups were deposited in a wide spectrum of depositional environments, ranging from deep shelf to fluvial (Beukes and Nelson, 1995).

Winter (1995) showed the Witwatersrand depobasin represents a continental retro-arc foreland basin, which has been controlled by tangential contractional tectonics during deposition. As the tectonic style changed to subduction, the deformational style changed to extensional during which conditions, favouring the outpouring of the basaltic magma of the Klipriviersberg Group, occurred (Winter, 1989, 1994, 1995).

Deposition of the West Rand Group in an epicontinental marginal environment (Eriksson *et al.*, 1981; Eriksson *et al.*, 1991; Stanistreet and McCarthy, 1991) was followed by the deposition of the Central Rand Group between 2 840 and 2 710 Ma in a foreland basin, which received detritus from the northwest (Burke *et al.*, 1986; Winter, 1987). The West and Central Rand Group rocks form prominent ridges around the southern periphery of the HHD (Walter Sisulu National Botanical gardens) and in the north-west on Zwartkop 525 JQ and Rietfontein 522JQ (north of Krugersdorp) (Figure 2.1). Hilliard and McCourt, (1995) showed the sheared contact between the granitoids and the Witwatersrand Supergrpoup recognised along the southern periphery of the HHD indicates a northwards directed thrusting event.

Structural features around the southern margin of the HHD, i.e. the Rietfontein fault system and its associated structures (Langermanskop and Bezuidenhoudt Valley Graben), were studied in detail over the past century (Mellor, 1911, 1917; McCarthy *et al.*, 1982; Stanistreet and McCarthy, 1986; Stanistreet, Meyer *et al.*, 1990; McCarthy, 1990; McCarthy *et al.*, 1990; Charlesworth and McCarthy, 1990). These studies showed the Rietfontein fault forms part of a curvi-linear fault system with dominantly left lateral movement, which was reactivated during several phases.

In recent years, structural studies on the deformation around the northern boundary of the HHD recorded widespread evedence of deformation in the clastic rocks of the Witwatersrand outlier on Zwartkop 525 JQ as well as the Late Archaean- Early Proterozoic Transvaal Supergroup rocks (Hilliard and McCourt, 1995; Gibson *et al.*, 1999). The outlier of Witwatersrand Supergroup sediments on Zwartkop 525 JQ and Rietfontein 522JQ is generally described as an overturned southward dipping syncline, which has subsequently undergone thrusting from the southwest (Hendriks, 1961; Roering 1984; Hilliard and McCourt, 1995; Gibson *et al.*, 1999). This thrusting duplicated and displaced the Witwatersrand Supergroup sediments northwards.

A generally south-over-north movement sense recognised in the Witwatersrand Supergroup on Zwartkop 525 JQ (Roering, 1984, 1986), the JRSZ (Roering, 1984, 1986; Roering *et al.*, 1990; Hilliard, 1994; Hilliard and McCourt, 1995), Ventersdorp Supergroup rocks (at Kromdraai and Bezuidenhoudt Valley Grabens) (Hilliard, 1994) as well as from the East Rand Basin (Pitts, 1990), indicate a post- to mid-Ventersdorp Supergroup, pre-Transvaal Supergroup thrusting event (Hilliard, 1994).

2.2.1.5 Ventersdorp Supergroup

Deposition of the Witwatersrand Supergroup was succeeded by the deposition of mostly lava, conglomerate, quartzite and shale of the late Archaean Ventersdorp Supergroup (Winter, 1976). Radiometric ages ranging from 2 781±5Ma (Derdepoort lava, Wingate, 1998) at the base of the succession to 2 709±4Ma (Makwassie quartz porphyry, Armstrong et al., 1991) for the central part of the Ventersdorp Supergroup have been obtained.

The Ventersdorp Supergroup is preserved extensively across the Kaavaal Craton unlike the Witwatersrand Supergroup. Lavas of the Ventersdorp Supergroup were deposited in both terrestrial and sub-aqueous environments (Winter, 1976, Hall and Els, 2002), in an extensional tectonic regime (Hall and Els, 2002, Tinker et al., 2002). A prominent erosional surface is developed at the base of the Ventersdorp Supergroup.

The compressional regime, which dominated during Witwatersrand Supergroup deposition, has changed to overall relaxation and extension resulting in the formation of graben structures (Stanistreet and McCarthy, 1986; McCarthy *et al.*, 1990; Stanistreet and McCarthy, 1990; Meyers *et al.*, 1990). These authors suggested that the graben structures, which controlled the deposition of the Platberg Group, formed in response to reactivation of the pre-existing faults, which controlled sedimentation of the Witwatersrand Supergroup. This event is considered to be craton-wide as grabens filled by Platberg Group rocks are associated with fault systems across the Witwatersrand Basin (Stanistreet and MaCarthy, 1990).

The Ventersdorp Supergroup rests unconformably on the Archaean ultramafic rocks and granitoids of the HHD (Anhaeusser, 1978). The Black Reef Formation, at the base of the Transvaal Supergroup, unconformably overlies the Ventersdorp Supergroup. In the study area the Klipriviersberg Group lava and Platberg Group sediments occur mainly south of the major Witwatersrand hills around the southern periphery of the HHD. The Ventersdorp Supergroup lavas and sediments around the southern periphery of HHD occur in a pull-apart basin structure referred to as the Bezuidenhoudt Valley graben (BVG) (Stanistreet *et al.*, 1986; McCarthy *et al.*, 1990). The BVG structure resulted from left lateral movement on the Rietfontein fault (Stanistreet *et al.*, 1986). McCarthy *et al.* (1990) suggested rapid deposition in a tectonically unstable lacustrine environment for these Ventersdorp Supergroup rocks. Ventersdorp Supergroup rocks also occur west of the Swartkops outlier on Kromdraai 520JQ and Zwartkop 525 JQ in what is referred to as the Kromdraai graben (KG) (Figure 2.1).

Conglomerate ranging to diamictite on Kromdraai 520JQ and Zwartkop 525JQ have been correlated with the Kameeldoorns Formation of the Platberg Group (Stanistreet and McCarthy, 1990). These authors proposed a paleoenvironment akin to a fan-delta entering into a deep-water body, comparable to deposition in a graben-like pull-apart basin. The sediments of the Platberg Group at Kromdraai 520JQ are considerably sheared. Shearing is seen as striations on the conglomerate clasts as well as foliation in the shaly to quartzitic matrix. The foliation has a south-westerly to south-easterly dip (Hendriks, 1961). The contact between the Ventersdorp Supergroup and the Witwatersrand Supergroup rocks on Zwartkop 525 JQ have been interpreted as an eastward verging thrust fault containing both Ventersdorp volcanics and Orange Grove sedimentary rocks (Hendriks, 1961). Stanistreet and McCarthy (1984) interpreted this fault as the northern extension of the West Rand fault system. Hilliard (1994) showed the contact to be a narrow shistoze zone with east-west-striking, south-dipping foliation, which he interpreted as a zone of intense deformation developed during northwards-directed thrusting. The narrow fault bounding the KG west of Kromdraai 520JQ is considered to be sub-parallel to BVG (Stanistreet and McCarthy, 1984).

During a mapping investigation scattered outcrops of pre-Black Reef lava were encountered on Riverside Estate 497JQ along the northern rim of the HHD (Obbes *pers comm*, 1995). These rocks consist of alternating flows of amygdaloidal- and porphyritic lavas (resembling the Alberton Formation). The lavas occur as a wedge between the Transvaal Supergroup and the HHD granitoids and are discordantly overlain by the Black Reef Formation. Due to intense structural deformation of these rocks, characterised by fragmentation and pervasive cleavage, a proper lithostratigraphic subdivision of these volcanic rocks is not possible.

2.2.1.6 Transvaal Supergroup

It is commonly accepted that the Black Reef quartzite in the Transvaal area corresponds to the base of the Vryburg Formation in Griqualand West with the basal portion of the Chuniespoort Group has been correlated with the Schmidsdrift Group of the Griqualand West Basin (Beukes, 1987). Therefore ages of 2 557 ± 49Ma (Jahn *et al.*, 1990) obtained for the top of the Schmidtsdrif Group and 2 550±3Ma (Walraven and Martini, 1995) and 2 583±5Ma (Martin *et al.*, 1998) for the Oak Tree Formation (base of the Malmani Subgroup) suggest that the deposition of the Black Reef Formation in the study area commenced at around 2 590Ma just prior to the intrusion of the Bushveld Igneous Complex at around 2 060Ma (Buick *et al.*, 2001; Walraven and Hattingh, 1993; Walraven, 1997).

An erosional surface marked by conglomerate at the base of the Black Reef Formation erodes into older sequence on the Kaapvaal craton and marks the onset of deposition of the Paleoproterozoic Transvaal Supergroup. In the study area the Black Reef Formation, at the base of the Transvaal Supergroup, unconformably overlies the Ventersdorp Supergroup, HHD granitoids and associated mafic rocks. The angular unconformity between the Black Reef Formation and the underlying sheared HHD granitoids is well exposed at the junction of the Jukskei and Crocodile rivers. The contact between the Black Reef Formation and the overlying Chuniespoort Group is transitional (Eriksson and Truswell, 1974). The boundary between the Black Reef Formation and the Oaktree Formation is taken as the first extensively-developed dolomite unit above the last quartzite of the Black Reef Formation (Obbes *pers comm*, 1995). Lithologies such as carbonates, banded iron formation, conglomerate, diamictite, quartzite and shale provide evidence of significant sea level fluctuations during the deposition of the Transvaal Supergroup.

The Transvaal Supergroup was initially considered to be relatively undeformed with only minor structural features reported (Engelbrecht *et al.*, 1986). However, several studies subsequently illustrated widespread evidence of deformation in the Black Reef Formation

(Gibson *et al.*, 1999 and references therein). An investigation on the fabrics developed in the Black Reef Formation shale, Rietfontein 522JQ and Tweefontein 523JQ, showed northwards verging thrusting (McCarthy *et al.*, 1986). These authors showed cleavage, slickenside lineations, metamorphic mineral growth, thinning and development of crenulation cleavage in the Black Reef Formation. Gibson *et al.*, (1999) showed the quartzites of the Black Reef Formation, on the northern boundary of the HHD, define open to tight assymetrical, doubly plunging folds. These folds are well developed and lead to the duplication of the quartzite by thrusting and folding along east-west lines (Stanistreet *et al.*, 1986; Obbes *pers comm*, 1995). Gibson *et al.*, (1999) also showed the orientation of the fabric correspond to that seen in the West Rand Group at Swartkops and in the JRSZ. McCarthy *et al.* (1986) showed structural trends in the Black Reef Formation is tangential to the Vredefort structure, suggesting these features are genetically related.

Dolomite of the lower Chunniespoort Group displays folds and cleavage consistent with a top to the north-shearing event (Gibson *et al.*, 1999). These authors showed these features are related to similar features observed in the Black Reef Formation. Deformation in the Transvaal Supergroup, around the northern margin of the Witwatersrand Basin, post-dates metamorphism related to the 2 060Ma Bushveld Igneous complex but pre-dates the intrusion of the 1 250-1 450Ma Pilansberg Complex dykes (Gibson *et al.*, 1999).

2.2.1.7 Karoo Supergroup

Anhaeusser (1973) reported the occurrence of sedimentary rocks, interpreted to be of Karoo age, overlying the HHD in the southeast, around Kempton Park. Brink (1979), however, considered these rocks as remnants of the African erosion cycle, suggesting a very thick layer of residual granitic soil rather than Karoo strata.

2.2.1.8 Hypabyssal rocks

Intrusive dykes that crosscut the HHD include rhyolite, porphyritic rhyolite, hybrid rocks, post-Ventersdorp diabase- and porphyritic diabase, syenite as well as composite dykes.

Diabase and porphyritic diabase dykes

Diabase dykes cut the HHD in two prominent strike directions, i.e. approximately north-south and east-west. These dykes are normally about two meters thick and postdate both the granitoids and the mafic to ultramafic rocks (Braamfontein Spruit, Randburg). A porphyritic variety with large feldspar phenocrysts (up to 2 cm) also occurs. Although some appear to be post-Karoo in age (Day, 1980), most of the dykes are considered to be post-Pilanesberg but pre-Karoo in age.

Syenite and composite dykes and sills

Although some syenite and composite dykes and sills cut across the Black Reef Formation into the granitoids of the HHD, this group of dykes and sills are mostly restricted to the dolomite of the Transvaal Supergroup. The intrusion of roughly north-south-trending syenitic and composite dykes is generally linked to the intrusion of the Pilansberg Complex at ~1 193±98 Ma (Anheausser, 1973, 1990). Schreiner and van Niekerk (1958) studied the Robinson dyke along the southern periphery of the HHD and reported an age of 1 263±176 Ma. The Gemspost dyke, occurring south of the study area, yielded a Rb-Sr age of 1 302±78 Ma (van Niekerk, 1962).

Rhyolite and porphyritic rhyolite dykes

Rhyolite and porphyritic rhyolite dykes intruded the granitoid-greenstone terrain in the western part of the study area. The porphyritic variety is fine-grained with quartz phenocrysts. The rhyolite dykes are intensely jointed, giving it a blocky appearance. These dykes are narrow bodies and not very continuous along strike (some only a few meters long) and are cut by east-west striking syenite dykes as well as highly foliated granitic material along strike slip shear zones (Figure 2.1). Similar dykes intruding the Witwatersrand Supergroup rocks east of Johannesburg yielded an age of 2 150±26Ma (Furmerton, 1978). Anhaeusser (1973) suggested that the felsite dykes might represent rapidly chilled, filter pressed products of remobilised phases of the initial granite found in the area.

2.2.2 Petrography and mineralogy of the HHD granitoids

In this section a review of relevant previous work addressing aspects such as textures, mineralogy and alteration of the HHD granitoids will be presented. The initial petrographic descriptions on localised outcrops showed the HHD granitoids to be very uniform throughout (Hall, 1906; Kynaston, 1906; 1907; 1929; Wagner, 1907; Wade, 1909; Horwood, 1910). These workers recognized microcline as the most abundant constituent of the HHD granitoids together with quartz, serisitized plagioclase, orthoclase and biotite. This was later confirmed by the investigations of Willemse (1933) and Anhauesser (1973).

Local variations in texture and mineral content were recorded by Willemse (1933) and later by Anhaeusser (1973). Willemse’s (1933) account of the petrography of the HHD granitoids indicates the presence of a locally developed porphyritic granitoid variety in which the porphyritic texture is formed by microcline-microperthite. Anhaeusser (1973) suggested the porphyritic texture, locally observed in the granodiorite suite, was formed by crystalloblastic mineral growth. Large microcline megacrysts in the porphyritic granodiorite from the Zandspruit Complex have been described as a poikilitic overgrowth enclosing earlier formed quartz and feldspar (Anhauesser, 1992).

The tonalite gneiss, as observed on the southern boundary of the HHD, was described as consisting of sericitized and saussuritized plagioclase, quartz, hornblende and minor microcline with accessory quantities of sphene, apatite and magnetite (Anhaeusser 1973;

Anhaeusser and Burger, 1982; Poujol and Anhaeusser, 1999). Barton *et al.* (1999) showed similar mineral assemblages but also mentioned the presence of minor augite.

Anhauesser (1973) described biotite as the dominant ferromagnesian mineral in the trondhjemitic gneiss suite developed on the northern half of the HHD. This author showed the gneissocity in this suite is formed by the subparallel alignment of biotite and hornblende and that the latter minerals are often totally altered to chlorite-muscovite and chlorite-biotite, respectively.

The account by Anhauesser (1973) also refers to migmatite developed over the northern half of the HHD which he described as alternating tonalitic and trondhjemitic gneisses, containing large amounts of sodic plagioclase, biotite, quartz and lesser amounts of K-feldspar, muscovite, sphene, apatite and chlorite.

Willemse (1933) mentioned the local development of a dioritic granitoid variety consisting of subhedral to euhedral hornblende in a matrix of quartz, muscovite and corroded plagioclase. Diorite from the granitoid exposure at Nooitgedacht 534JQ contains variable amounts of hornblende and quartz but also biotite and chlorite along with sericitized plagioclase (Anhaeusser 1999).

Willemse (1933) observed zonation in sodic plagioclase where mineral cores are preferentially serisitized relative to the rims. Other significant observations recorded by this author include the alteration of biotite to chlorite and the presence of accessory minerals like apatite, ilmenite, zircon, allanite as well as secondary minerals such as sphene, leuxocene, calcite, muscovite and chlorite.

Only two modal analyses of the HHD granitoids were previous recorded. These analyses formed part of the study by Alsopp (1961), who described the mineral composition of the granitoid exposure located in the vicinity of Witkoppen as: feldspar 66%, quartz 30%, chlorite 3.5%, biotite 0.5%, muscovite 0.1%.

Anhaeusser and Burger (1982) showed some zircon grains in the tonalite contain inclusions or growth zones, while others show clear signs of modification as evidenced by corrosion rounding. Poujol and Anhaeusser (1999) described zircon grains with varying degrees of metamictisation among the mainly translucent to pink coloured grains of the trondhjemitic gneiss and granodiorite from the Nooitgedacht outcrop and suggested the zircons reflect the complex history of this outcrop.

2.2.3 Geochemistry of the HHD granitoids

The gechemical record of the HHD is limited to major, some trace and the occasional (Nooitgedacht outcrop) RE element analyses. The initial geochemical data (Wade, 1909; Horwood, 1910 and Willemse, 1933) showed very little variation between granitoids sampled from various localities across the HHD. The extensive investigation by Anhauesser (1973) presented several new analyses, which were used to distinguish between the various granitoids of the HHD. Subtle variations in the major element concentrations (mainly iron, magnesium and calcium) between the various granodiorite varieties were recorded (Anhauesser, 1973). This investigation for instance showed that the tonaltic gneiss (southern HHD) has a distinctive chemical composition, which is characterised by low silica, high Na_2O (~4%), low K_2O (~1.5%) and high iron, magnesium and titanium contents as well as a relatively high Sr (925ppm) and low Rb (~130ppm) concentration compared to the other granitoids.

The only REE data available for the HHD are those recorded from the Nooitgedacht outcrop (Anhauesser, 1999). The latter investigation showed the trondhjemite gneiss is characterized by a strong LREE enrichment, moderate to strong HREE and Y depletion and either negligibly negative or positive Eu anomalies. Data presented for the Nooitgedacht tonalitic to dioritic gneiss on the other hand show a moderate LREE enrichment and a very slight HREE depletion pattern. Anhauesser (1999) and Prevec *et al.* (2004) recognised two mafic dyke sets in the Nooitgedacht exposure, which showed moderate to enriched LREE abundances. The REE pattern of the mafic dyke sets is noticeably different from that of the granitoids (Prevec *et al.*, 2004).

Anhauesser (1999) employed discrimination diagrams to characterise the granitoids from Nooitgedacht. Data from this investigation display a calc-alkaline trend. On the alkali-lime diagram (after Peacock, 1931) these rocks fall within the alkalic to calcic fields and plot in the metaluminous field on the ANK versus ACNK diagram (after Maniar and Piccoli, 1989). Ishihara *et al.* (2001) also showed the majority of the HHD granitoids are I-type with M-type granitoids occurring sporadically over the centre of the study area displaying a general east-west trend at the boundary between the TTG and the calc-alkaline granitoids.

2.2.4 Geochronology of the HHD granitoids

The central domain (HHD, Rand anticline and Vredefort Dome) of the KC was mainly active between 3200-3000 Ma during the craton accretion and stabilisation period (3100 Ma to 2600 Ma) (De Wit *et al.*, 1992; Anhauesser, 1999; Thomas *et al.*, 1993). Barton *et al.* (1999) suggested that granitoid magmatism of this age was widespread as HHD granitoid magmatism is coeval with magmatism in the Barberton area. Poujol *et al.* (2003) highlighted three main magmatic events over the central part of the Kaapvaal Craton. These events occurred at 3200-3175 Ma, 3120-3075 Ma and 2730-2705 Ma. Barton *et al.* (1999) also showed that neither the ~2025Ma Vredefort event (Koma *et al.*, 1996; Gibson *et al.*, 1999) nor the ~2060 Ma Bushveld Complex intrusion (Kruger *et al.*, 1987) had a significant influence on the formation of the HHD granitoids (Barton *et al.*, 1999).

Various geochronological studies were done on the HHD granitoids (Allsopp, 1961; Burger and Walraven, 1979; Anhaeusser and Burger, 1982; Barton *et al.*, 1999; Poujol and Anhaeusser, 2001). The findings of these studies are summarized in Table 6 and presented on a simplified map of the study area (Figure 2.2). From this summary it can be discerned that two main periods of magmatism occurred across the HHD. The oldest phase (3340±3 Ma; Poujol and Anhaeusser, 2001) consists of tonalitic to adamellite and granodiorite gneiss and associated migmatites around the northern half of the HHD and related tonalitic gneiss (3201±5 Ma; (*op cit.*)) around the southern edge of the HHD.

The second period of magmatism is manifest as a medium-grained homogeneous granodiorite to adamellite (3121±5 Ma; Poujol and Anhaeusser, 2001) across the southeastern part of the HHD and a porphyritic granodiorite to adamellite and granite (3114±2 Ma (*op cit.*)), occurring generally in the southwestern part of the HHD.

Table 6: Summary of geochronological data for the HHD granitoids

Locality	Age (Ma)	Error	Rock type	Rock classification (this study)	Method	Year	Reference
North-western quadrant	2 087	±42	Leucosome of migmatitic gneiss	GAG	Rb-Sr whole rock	1999	Barton *et al.*
South-central (Witkoppen)	2 120	±10	Granite	GG	Rb-Sr biotite	1961	Allsopp
North-western quadrant	2 188	±44	Leucosome of migmatitic gneiss	GAG	Rb-Sr whole rock	1999	Barton *et al.*
South-central	2 202 2 117 2 240 2 110 2 158	±56 ±47 ±53 ±45 ±47	Granodiorite and granite	GG	Rb-Sr biotite whole rock	1999	Barton *et al.*
South-central (Waterval 5IR)	2 236	±55	Xenolith in granodiorite	GAG	^{207}Pb/^{206}Pb composite zircon	1979	Burger and Walraven
South Central	2261	±80		GG		1999	Barton *et al.*
South-central (Halfway House)	2 310	±40	Granite	GG	Rb-Sr biotite	1961	Allsopp
Southern rim	2 321	±23	Tonalite	TG	Rb-Sr biotite	1999	Barton *et al.*
Southern rim	2 385	±127	Tonalite	TG	Rb-Sr whole rock	1999	Barton *et al.*
South-central (Lone Hill)	2 585	±65	Homogeneous granodiorite	GG	^{207}Pb/^{206}Pb composite zircon	1979	Burger and Walraven
North-eastern quadrant	2 614 2 430	±53 ±50	Leucosome of migmatitic gneiss	GAG	Rb-Sr biotite whole rock	1999	Barton *et al.*
Southern rim	3 001	+132/ -146	Tonalite	TG	Pb whole rock	1999	Barton *et al.*
South-central	3 081	±33	Granodiorite and granite	GG	Average Rb-Sr whole rock	1999	Barton *et al.*
South-central	3 112	±14	Granodiorite and granite	GG	^{207}Pb/^{206}Pb whole rock	1999	Barton *et al.*
North-western quadrant	3 135	±52	Leucosome of migmatitic gneiss	GAG	Rb-Sr whole rock	1999	Barton *et al.*
Southern rim	3 170	±34	Tonalite gneiss	TG	U-Pb multiple zircon	1982	Anhauesser and Burger
South-central	3 200 3 132	±65 ±64	Granite	GG	Rb-Sr whole rock	1961 1964	Allsopp
South-central	3 158	±179	Granodiorite and granite	GG	Rb-Sr whole rock	1999	Barton *et al.*
Southern rim	2 947	±57	Medium- to coarse-grained homogeneous granodiorite	GG	^{207}Pb/^{206}Pb zircon	2001	Poujol and Anhauesser
North-western quadrant (Nooitgedacht)	2 997	±7	Trondhjemite gneiss	GAG	^{207}Pb/^{206}Pb zircon	2001	Poujol and Anhauesser
South-central	3 101	±5	Granodiorite and granite	GG	^{207}Pb/^{206}Pb zircon	2001	Poujol and Anhauesser
South central	3 121	±5	Medium-grained grey granodiorite	GG	^{207}Pb/^{206}Pb zircon	2001	Poujol and Anhauesser
South-western quadrant	3 114	±2	Porphyritic granodiorite	GG	^{207}Pb/^{206}Pb zircon	2001	Poujol and Anheasusser
Southern rim	3 199.9	±2	Tonalite gneiss	TG	^{207}Pb/^{206}Pb zircon	2001	Poujol and Anhauesser
North-western quadrant (Nooitgedacht)	3 213	±10	Trondhjemite gneiss	GAG	^{207}Pb/^{206}Pb zircon	2001	Poujol and Anhauesser
South-western quadrant	3 227	±21	Medium-grained grey granodiorite	GG	^{207}Pb/^{206}Pb zircon	2001	Poujol and Anhauesser
North-western quadrant	3 340	±3.3	Trondhjemite gneiss	GAG	^{207}Pb/^{206}Pb zircon	2001	Poujol and Anhauesser

The summary of geochronlogical data presents an apparent spread in ages for the HHD. However, since Allsopp carried out the first age determination on the granitoids of the HHD in 1961, geochronological techniques have become more precise and the apparent spread in ages for the various granitoid suites merely highlights the fact that there is a substantial difference in the ages determined by these different techniques. The most recent study by Poujol and Anhaeusser (2001), mark the improved accuracy achieved by single zircon ^{207}Pb/^{206}Pb determinations.

The summary in Table 6 shows that the most recent (post-1999) age determinations for the three main HHD suites, utilizing the ^{207}Pb/^{206} Pb single zircon technique, are distinctly different from those of older investigations (Anhaeusser and Burger, 1982; Barton *et al.*, 1999). The initial investigation by Allsopp (1961) presented ages determined from separate mineral fractions (muscovite, biotite, chlorite and apatite), which showed dates ranging from 2100 to 4540 Ma. Allsopp (1961) considered the discordance in the separate mineral fraction ages to be the result of Sr diffusion due to reheating during one of two events, i.e. the Vredefort event or the intrusion of the Bushveld Complex. Anheausser and Burger (1982) argued that corrosion rounding on some zircons is evidence of resorption. It appears that the older Rb-Sr whole rock technique somehow underestimated the ages for the HHD granitoids. Barton *et al.* (1999) considered the excess scatter in Rb-Sr data to reflect deuteric alteration in feldspars to such an extent that only approximate age correlations are possible. Poujol and Anhauesser (2001) showed variation in the ages determined on separate zircons from the same outcrop, suggesting that the variation in ages was the result of a post-crystallisation event, which lead to Pb loss and/or recrystallisation.

The oldest age ever recorded for a granitoid from the HHD is the U-Pb single zircon emplacement age of 3340±3 Ma determined for a trondhjemitic gneiss from the tonalite to adamellite and granodiorite gneiss and associated migmatites suite on the northern half of the HHD (Poujol and Anhaeusser, 2001). The 2997±7 Ma to 3213±10 Ma (^{207}Pb/^{206} Pb) ***(op cit)*** ages determined for trondhjemitic gneiss from the nearby Nooitgedacht exposure supports the consideration by these authors that the trondhjemite gneiss represents the oldest known granitoid phase on the HHD. Barton et al. (1999) presented a Rb-Sr whole rock age of 3081±33Ma for the central HHD granodiorite to granite and suggested an emplacement age of ~3090 Ma from a source between ~3300 and 3500 Ma old.

2.2.5 Petrogenesis of the HHD granitoids

A number of magmatic events were responsible for the formation of the crust in the HHD region (Anhaeusser, 1999 and Robb *et al.*, 2008). The earliest event is likely to be Palaeoarchaean in age and included the emplacement of mafic and ultramafic volcanic (greenstone) rocks and the intrusion of a suite of tonalite-trondhjemite-granodiorite (TTG) granitoids (Robb *et al.*, 2008). Analogies drawn between granitoids from the Barberton Mountain Land and those occurring on the HHD suggested that these rocks formed in a similar manner (Anhaeusser, 1973). Tonalite from the Barberton Mountain Land were shown to have formed by partial melting of a mafic precursor whereas the granodiorite supposedly formed through a low degree of partial melting of older tonalitic to trondhjemitic (TTG) source rock (Robb and Anhaeusser, 1983). As evidenced by the presence of mafic xenoliths and the basic character of these rocks (Anhausser and Burger, 1982), the HHD tonalitic gneiss is therefore believed to have experienced a high degree of assimilation of pre-existing ultramafic material. Ishihara *et al.* (2001) proposed that the HHD formed through interaction of granitic magmas with the mafic-ultramafic country rocks. These authors proposed that HHD rocks were derived from a mantle source, either through partial melting of subducted oceanic crust or through fractional crystallization of basalt.

The only attempt at describing the HHD in terms of petrogenic discrimination diagrams is the study of Anhauesser (1999), which focussed on the isolated Nooitgedacht granitoid exposure on the northern half of the HHD. Anhauesser (1999) illustrated that data from the Nooitgedacht outcrop cluster in the syn-collisional and volcanic arc granitoid fields on Nb-Y and Rb-Y+Nb diagrams after Pearce *et al.* (1984). Based on the assumption that rocks with characteristics similar to the Nooitgedacht granotoids are associated with subduction-related continental and island arc settings, Anhaeusser (*op. cit.*), suggested that plate tectonic processes were operational during the formation of the HHD.

The study of the Nooitgedacht exposure was fortuitously used to extrapolate events, which possibly occurred at this site, to the formation of the entire HHD (Anhaeusser, 1999; Poujol and Anhaeusser, 2001). These authors illustrated the sequence of events as initial deposition of the mafic and ultramafic volcanic and plutonic rocks (komatiitic to basaltic) in a volcanic arc setting followed by a period of felsic magmatism, which led to the emplacement of TTG granitoids and assimilation of the mafic and ultramafic rocks. The mixing of the amphibolitic country rock and felsic magma led to the development of a range of gabbroic-dioritic and tonalitic rocks close to the contacts with these fragments. The felsic magmatism was followed by the intrusion of late stage amphibolitic dykes, crosscutting the foliation in the trondhjemite-tonalite gneisses. A third magmatic episode is represented by the intrusion of the trondhjemite-granodiorite, which resulted in amphibolite facies metamorphism and truncated gneisses and late stage dykes.

3 RESULTS OF THE PETROLOGICAL AND GEOCHEMICAL INVESTIGATION OF THE GRANITOIDS OF THE HHD

Based on the field relationships, petrography and geochemistry three main granitoid suites could be recognised for the HHD. The extent of each of these suites is indicated on the simplified geological map (Figure 2.1). The nomenclature used in the description is based on the modal and geochemical classification of the constituents of each suite.

3.1 Field relationships and macroscopic description

The three main granitoid suites on the HHD are: 1) Tonalite Gneiss suite (TG) associated with Archaean greenstone remnants on the southern border of the HHD (Linden Gneiss, Robb *et a.l*, 2008), 2) Granodiorite-to Adamellite Gneiss suite (GAG) with local development of tonalite and trondhjemite covering most of the northern part of the HHD (Lanseria Gneiss, Robb *et a.l*, 2008), and 3) Granodiorite-to-granite suite (GG) occurring between the TG suite in the south and the GAG suite in the north (Bryanstone, Honeydew and Victory Park Granodiorite, Robb *et a.l*, 2008). Many pegmatite dykes cross cut the three main suites. The field relationships and macroscopic description for each of these suites will be presented here. No contact between the three suites was observed during the field investigation due to soil cover and poor rock exposure.

3.1.1 Tonalite Gneiss rocks (TG)

This suite of foliated, medium to coarse-grained, tonalite to granodiorite gneiss occurs as a homogeneous unit in contact with Archaean mafic and ultramafic remnants around the southern edge of the HHD (Figure 2.1). The TG rocks are essentially comparable to the Linden Gneiss (Robb *et al.*, 2008) and to Anhauesser’s (1973) ancient hornblende-biotite tonalite gneiss. Outcrops of this rock type are extremely rare and occur in streambeds in the southern part of the HHD (Emmerentia-Rooseveld Park).

The tonalite gneiss is composed of quartz, plagioclase, amphibole and biotite, ±K-feldspar and accessory minerals such as apatite, zircon and alanite. The gneissic fabric of the rock (Figures 3.1a) is defined by the preferred orientation of mainly amphibole but also biotite (Figures 3.1b). The strike of the main foliation is around 130°. Fragmented and partly assimilated xenoliths of mafic and ultramafic compositions are present. Smaller mafic to ultramafic xenoliths are aligned parallel to the foliation (Figure 3.1a arrow). Apart from the occasional mafic to ultramafic xenoliths, the rock is rather homogeneous with pegmatite and aplite veins being relatively scarce.

3.1.2 Granodiorite-to-Adamellite Gneiss rocks (GAG)

This suite, occurring across the entire northern part of the HHD, consists mostly of granodioritic to adamellitic banded gneiss with tonalite to trondhjemite gneiss "patches" (Figure 2.1). These tonalite-trondhjemite gneiss "patches" (<1m^2 sized areas) are a gradational variation of the GAG. The tonalite to trondhjemite gneiss are, however, a subordinate component and not developed throughout the GAG. These tonalite/trondhjemite "patches" might represent remnants of a partly digested protolith (similar to the tonalitic rocks seen in the southern part of the HHD (TG). The GAG rocks are essentially similar to the Lanseria Gneiss (Robb *et al.*, 2008) and Anhauesser's (1973) migmatite gneiss.

Outcrops are rare and usually form whale-back-like exposures with best exposures seen in rock quarries. This suite of rocks is strongly foliated consisting of alternating leucocratic and melanocratic bands with some mafic xenoliths (Figure 3.2a and Figures 3.2b) observed mainly on the faces of the numerous quarries found in the northern half of the HHD. The alternating gneissic bands vary in thickness from 2 to 20cm (Figures 3.2b). In many cases the foliation and banding have been intricately folded suggesting that variable stress fields have influenced the formation of these rocks. The foliation in unfolded rocks has an average strike at 120°- 130°, which corresponds to that in the TG suite.

The irregularly shaped mafic (serpentinsed dunits, harzburgite, pyroxenite and gabbro) xenoliths, ranging from centimeters to tens of meters in size, are widespread (Figure 3.3a). The intrusive nature of the granodiorite-to-adamellite gneiss into these xenoliths is best observed near the Grand Central Airport (Figure 3.3b).

The dominant mineral assemblage in the granodiorite-to-adamellite is quartz, K-feldspar, plagioclase and biotite (Figure 3.3c). These minerals are medium-grained. Late-phase pegmatitic veins cut across the banding, layering and folding of the granodiorite-to-adamellite gneiss. These late veins have very little correspondence between their strikes and dips (Figure 3.4). In most cases the pegmatite veins have sharp contacts with the surrounding granitoids. These pegmatitic veins consist mainly of very coarse-grained quartz and K-feldspar (up to 15mm in size) and small amounts of muscovite and biotite.

3.1.3 Granodiorite-to-Granite rocks (GG)

This suite extends over most of the south-central part of the HHD. Exposure of these rocks is very limited with outcrops varying from whale-back-like exposures to tors along riverbeds and valley slopes. From field observations it is possible to distinguish three main rock types, i.e.:

i. porphyritic granodiorite (Figure 3.5a and Figure 3.5b) largely comparable to the Honeydew Granodiorite (Robb et al., 2008) and Anhaeusser’s (1973) homogeneous, medium-grained, grey porphyritic granodiorite suite;
ii. medium-grained pinkish-grey granite (Figure 3.6a and Figure 3.6b) similar to the Victory Park Granodiorite (Robb et al., 2008) and Anhaeusser’s (1973) medium to coarse-grained, pinkish-grey homogeneous granodiorites; and

iii. medium-grained homogeneous adamellite/granodiorite (Figure 3.7a and Figure 3.7b) analogous to the Bryanstone Granodiorite (Robb et al., 2008) and to Anhauesser's (1973) homogeneous, medium-grained grey granodiorite suite.

Due to poor exposure, the contact relationships of these phases could not be established.

The porphyritic granodiorite occurs locally, but not exclusively, in the south-western quadrant of the HHD. This rock contains feldspar phenocrysts (up to 2 cm) set in a medium-grained grey granodiorite matrix (Figure 3.5a). The medium-grained pinkish-grey granite is developed over most of the south-western quadrant, whereas the homogeneous adamellite/granodiorite is developed across the south-eastern part of the HHD (Figure 2.1).

Pegmatite veins are common and crosscut the granodiorite to porphyritic granodiorites. These veins consist mainly of very coarse-grained (up to 15mm) quartz, K-feldspar and lesser amounts of muscovite and biotite. Aplitic veins are not very common and locally show chill contacts with the surrounding granodiorite as noted in the Braamfontein Spruit, Randburg.

3.2 Petrography

A summary of the major textural and mineralogical characteristics of the HHD suites is presented in Table 7 and the modal analyses for the different suites are presented in Table 8 and Table 9.

3.2.1 Tonalite Gneiss rocks (TG)

The texture of the rock is medium to coarse grained and is composed of plagioclase, quartz, hornblende, biotite and K-feldspar (Figure 3.8a) (D16 and D50 in Table 7). The modal proportion of these minerals is presented in Table 8a as 45-55 vol% plagioclase, 19-25 vol%

quartz, 13 vol% to 29 vol% hornblende with K-feldspar locally less than 2 vol% and biotite <1 vol% with accessory minerals such as epidote, apatite, zircon, muscovite, allanite and sphene. The modal mineralogy of the Tonalite Gneiss (TG) rocks corresponds roughly to that of a typical Archaean TTG gneiss, which consist of 40-60% plagioclase, 25-35% quartz, 5-10% biotite, and ± 0-5% hornblende (Clarke, 1992).

Plagioclase occurs as crystals ranging between 0.5 and 4.5 mm in size and is extensively serisitized and saussuritized (up to 50% of total plagioclase) (Figure 3.8a). The majority of the plagioclase cores show alteration with the rims generally free of alteration minerals.

Quartz as amoeboidal grains is typically fine-grained with grain-sizes varying between 0.2 and 1.2 mm. It shows undulose extinction and complexly sutured grain boundaries indicative of recrystallisation and deformation. Amphibole is the dominant ferromagnesian mineral in this suite. Amphibole is pale-green to dark yellow-green and subhedral (0.5 to 1.8 mm in size), commonly poikilitic and occurs as aggregates together with biotite, sphene, apatite, chlorite, epidote and zircon (Figure 3.8a). Amphibole is either uniformly scattered throughout the rock or concentrated in flow bands. Biotite occurs as fine-grained brown-green grains (0.1 to 0.2 mm in size). Minor chloritization of hornblende and biotite is not uncommon but generally makes up <1vol%. While K-feldspar is present in small quantities (1-3mol%) in the TG suite it is one of the main constituents of the GG and GAG suites. K-feldspar occurs primarily interstitially, is mainly microcline and is rarely altered to kaolinite/sericite. Primary accessory minerals, such as epidote, apatite, zircon, muscovite, allanite and sphene, are preferentially distributed in the ferromagnesian minerals. This feature is most striking in the TG rocks, where epidote is associated with biotite and amphibole. Schermerhorn (1956) proposed that the preferential distribution of primary accessory minerals in biotite points to the magmatic growth of this mineral.

Allanite is a characteristic accessory mineral in all the HHD suites and occurs as fine-grained, well-preserved anhedral to euhedral, mainly light yellow-brown grains with some dark red brown coloured grains occurring locally. Although allanite occurs in association with biotite it is not aligned to the gneissic foliation.

Titanite is one of the most abundant accessory minerals in all the HHD suites. This mineral occurs as (a) primary euhedral (diamond-shaped), (b) subhedral granules and (c) polycrystalline aggregates finely disseminated grains along cleavage planes in biotite and (d) secondary coronas around ilmenite.

Epidote is a prominent accessory mineral and occurs as faintly to conspicuously pleochroic crystals. This mineral occurs in the groundmass as separate individual crystals, as aggregates associated with biotite and hornblende or as alteration products in the interiors of plagioclase and rims on some allanites (Figure 3.8a-d). Epidote has euhedral crystal faces where it is in contact with hornblende (Figure 3.8b and c) and biotite (Figure 3.8d) and embayed (wormy) contacts with plagioclase and quartz (Figure 3.8a-e). Epidote alteration of plagioclase is considered to have formed through metasomatic processes during normal sub-solidus alteration of Ca-plagioclase in the presence of H_2O (Smith, 1974). This mineral is more prominent in the TG suite but occurs as a minor mineral in all HHD granitoids. Epidote rims occurring around allanite, as shown in the TG suite and GAG tonalite trondhjemite gneiss, is described as characteristic features of magmatic origin of epidote (Zen and Hammarstrom, 1984). Naney (1983) and Zen and Hammarstrom (1984) interpreted the euhedral relationship between epidote-biotite and epidote-hornblende, such as that described for the alanite in the TG suite, as evidence of magmatic rather than metamorphic origin. Euhedral to subhedral epidote associated with mafic minerals (hornblende and biotite) in the TG suite is therefore considered to be primary. However, epidote of metamorphic origin is present as alteration products in plagioclase.

Zircons are common accessory mineral in all HHD suites and are generally associated with ferromagnesian minerals.

3.2.2 Granodiorite-to-Adamellite Gneiss rocks (GAG)

The granodiorite-to-adamellite gneiss is composed mainly of granular plagioclase, quartz, K-feldspar and biotite with minor muscovite, sphene, apatite, chlorite and opaque minerals (Figure 3.9a). The average modal composition of the granodiorite-to-adamellite gneiss of the GAG shows 31-52 vol% plagioclase, 21-61 vol% quartz, 11-34 vol% K-feldspar) and 1-9 vol% biotite (Table 8b and Table 9). Some variations in the main mineral assemblage of the GAG rocks have been recorded. The variation is mainly due to the presence of the locally developed tonalitic to trondhjemitic gneiss. The tonalite to trondhjemite gneiss of the GAG suite have a granular texture and is composed mainly of 52-60 vol% plagioclase 23-27 vol% quartz, 4-16 vol% K-feldspar (Or_{98-90}), 4-14 vol% biotite (Figure 3.9b).

Plagioclase (up to 50%) occurs generally as 0.5 - 4.5 mm-sized grains with partially saussuritized and sericitized centres. Alteration minerals such as sericite, epidote and calcite occur in the plagioclase cores. Plagioclase shows zoning with an altered core followed by alternating alteration free and moderately altered zones as seen in Figure 3-10a. The last altered zone is followed by a distinct alteration free rim developed exclusively on the boundaries between plagioclase and K-feldspar and absent where quartz is in contact with plagioclase or K-feldspar. In most instances these rims seem to be in crystallographic continuity with the adjoining plagioclase. It is, however, important to point out that there is a clear distinction between normal oscillatory zoning (formed above the solidus), generally observed in plagioclase phenocrysts, and these rims (formed below the solidus). This is a pertinent feature observed in the GAG and GG suites.

A sharp contact exists between the main part of the plagioclase grain and these rims (Figure 3.10a to Figure 3.10b). The boundary between the rim and the adjoining plagioclase is smooth and curved whereas the interface with the K-feldspar is irregular (corroded), indicating partial resorption (Figure 3.10a to Figure 3.10c). The rims on plagioclase are furthermore in continuity with the perthite lamellae of the adjoining K-feldspar (Figure 3.10c). Where plagioclase is poikilitically enclosed in microcline the width of the secondary rim seems almost twice the normal width and is always complete (Figure 3.10d). These discontinuous rims are up to 0.03 mm wide.

Myrmekitic intergrowths of plagioclase and quartz have developed along plagioclase grain boundaries, irrespective of the bordering mineral being quartz or K-feldspar. This feature was observed in all HHD suites. These quartz intergrowths have either a rounded or worm-like form, which radiates towards the grain boundaries (Figure 3.11a). Quartz occurs as fine to medium-grain size (up to 5.8 mm in diameter) and is characterised by amoeboidal grain shapes and undulose extinction. A conspicuous feature in medium-grained quartz in all HHD suites is the presence of inclusions of fine needles of possibly rutile (Figure 3.11b).

K-feldspar is generally microcline microperthite varying in size from fine to coarse-grained (0.5 to 4 mm sized). Microcline is anhedral and occurs either interstitialy or as granular grains poikilitically enclosing smaller grains of quartz and plagioclase (Figure 3.11c). These plagioclase and quartz inclusions are randomly orientated. Microperthitic intergrowths of plagioclase in the form of stringers, flames and patches occur in the larger microcline grains. In some instances microcline grains have perthite free edges where plagioclase abuts against K-feldspar. K-feldspar is rarely altered (Table 8b and Table 9).

The granodiorite-to-adamellite gneiss contains biotite, whereas the locally developed tonalitic to trondhjemitic gneiss of this suite aditionally contains minor hornblende as a ferromagnesian phase. Both brown and green biotite occurs as ~0.5 mm-sized flakes, often containing needles possibly of rutile (Figure 3.12) as inclusions. Biotite is slightly altered to chlorite, muscovite and titanite and is often associated with epidote. Locally coronas of titanite, occur around opaque minerals (ilmenite) (Figure 3.13).

3.2.3 Granodiorite-to-granitic rocks (GG)

The rocks from this suite are generally massive medium to coarse-grained granodiorite, adamellite and granite. Modal analyses show the mineralogy of the GG rocks consists on average 34-51 vol % plagioclase, 23-32 vol% quartz, 17-29 vol% K-feldspar and 2-7 vol% biotite with minor muscovite, titanite and opaque minerals (Figure 3.14a-c). Variations in the modal mineral proportions occur between the three GG varieties as reflected in Table 8c and Table 9.

Plagioclase constitutes less than 40 vol% in the pink-grey granite and homogeneous adamellite/granodiorite varieties whereas the porphyritic granodiorite have an average plagioclase content of 51 vol% (Table 8 and Table 9). Plagioclase occurs in lath-shaped to granular (0.90 - 2.7 mm-sized) crystals, with phenocrysts often exhibiting well-developed oscillatory zoning. Although plagioclase cores are commonly sericitized and saussuritized (Figure 3.14c), the homogeneous adamellite/granodiorites appears to be less prone to alteration (Table 8c and Table 9). Most plagioclase cores have embayed or rounded margins similar to that described in the GAG rocks. Plagioclase often shows myrmekitic intergrowths with quartz where in contact with K-feldspar.

The homogeneous adamellite/granodiorite and pink-grey granite have average quartz contents of ~30 vol% whereas the porphyritic granodiorite have an average content of 23 vol%. Three habits of quartz were identified in the HHD granitoids, i.e. medium-grained (Figure 3.14a), fine-grained interstitial and rounded to vermicular drop quartz (similar to

Figure 3.11a). Sutured grain boundaries were also observed in places and undulose extinction is feebly developed in fine- and medium-grained quartz.

The average K-feldspar content of the pink-grey granite is 23 vol% which is comparable to that of the GAG suite granodiorite-to-adamellite gneiss (~21 vol%). The GG homogeneous adamellite/granodiorite has the highest average K-feldspar content of 29 vol%, whereas the porphyritic granodiorite has the lowest average modal content for K-feldspar of around 18 vol% (Table 8c and Table 9). K-feldspar is mostly microcline and is mainly medium-grained (0.90 - 5.4mm sized) although large microcline megacrysts were observed in the porphyritic granodiorite of the GG. Microcline is rarely altered and occur either interstitial or as large grains that poikilitically encloses plagioclase and quartz (Figure 3.14b). Perthitic textures are typical of the K-feldspars.

Brown and green biotite occurs as 0.4 mm-sized flakes and contains inclusions of rutile needles, such as those described for the GAG (Figure 3.12). This suite shows the highest average alteration of biotite to chlorite, muscovite and titanite of all the HHD granitoids. The SEM BSE mineral maps (Ca and Ti) show the presence of polycrystalline aggregates of finely disseminated titanite along cleavage planes in biotite (Figure 3.15). Titanite coronas, similar to that described for the GAG (Figure 3.13), are developed locally around opaque minerals (ilmenite).

Allanite occurs as fine-grained, well-preserved anhedral to euhedral light yellow-brown to dark red brown coloured grains throughout all three suites of the HHD (Figure 3.16). The variation in colour of allanite grains is indicative of the degrees of metamictization (Deer *et al.*, 1992). The dark red-brown coloured allanite grains seen in the HHD rocks is indicative of advanced destruction of the crystal by decay of radioactive elements present in the mineral itself. Some epidote rims were observed around anhedral allanite (Figure 3.17).

3.3 Mineral chemistry

To ascertain the variability in chemical compositions of plagioclase, K-feldspar, amphibole and biotite, electronmicroprobe analysis of these minerals were carried out on 12 selected rock samples from the HHD. A complete listing of the mineral chemistry data is available in Table 10 to Table 12.

3.3.1 Probe conditions

Major element compositions were determined on C-coated polished sections by using the JEOL733 electron microprobe at the Council for Geoscience, Pretoria. Operating conditions were 20 keV, 20 nA / 40 μA beam current, a counting time of 10 s and analysis spot size of 20 lm. Traverses across grains were done manually, avoiding imperfections in the polish and inhomogeneously exsolved grain parts.

3.3.2 Description

Plagioclase

A total of 373 Electron microprobe analyses of plagioclase (rim and core) for selected rocks from the HHD granitoids were done. It should be mentioned that there is a possible systematic calibration error as indicated by the fact that Ca seems to plot consistently below the theoretical line on the Ca/Na/K per 32[O] vs Al per 32[O] diagram (Figure 3.18 and Figure 3.19). Electron microprobe analyses of the TG suite proved to be challenging due to the extensive serisitisation and sausiritisation of plagioclase in this suite (Figure 3.8a).

Plagioclase is the main constituent in all three the HHD granitoid suites (Table 7). The Ca/Na/K per 32[O] vs Al per 32[O] diagram for plagioclase (cores and rims) shows the plagioclase composition of the three HHD suites is virtually indistinguishable (Figure 3.18

and Figure 3.19). This is further highlighted on the An-Ab-Or diagram, which shows overlap in the composition of plagioclase towards the low An and high Ab end –member (Figure 3.20). An-content varies from An_{16} in the plagioclase from the TG suite, An_{21} in the GAG suite to An_{20} in the GG suite. Slight variations in the plagioclase composition are observed when the plagioclase compositions for each of the HHD rock types are plotted seperatly on the An-Ab-Or diagram (Figure 3.20). Two distinct plagioclase population groups are evident for both the GAG and GG rocks represented by cores and rims. There seems to be some overlap between these two plagioclase population groups as shown on both the An-Ab-Or diagram and An-content vs frequency histograms (An_0 to $An_{22.5}$ for both core and rim data) (Figure 3.21 and b Figure 3.22). The peak frequencies for the GAG suite are at $An_{2.5}$ and An_{20}, whereas the peaks for the GG suite are at $An_{2.5}$ and An_{15} (Figure 3.21 and Figure 3.22). The TG rocks, however, show a continious overlap in composition ($An_{7.5}$ to An_{15}) for both plagioclase cores and rims as shown by the An-Ab-Or diagram and An-content vs frequency histogram for the TG suite.

The frequency histogram shows that plagioclase core compositions are consistantly more An-rich (high-Ca end-member) compared to rim compositions (Figure 3.21). The spread in An content for plagioclase cores reflects a sharp increase in frequency at An_{20}, which is mainly associated with the plagioclase cores of the tonalite to trondhjemite gneiss of the GAG suite (Figure 3.21 and Figure 3.22).

Most of the plagioclase rim data of the HHD rocks fall well within the <5% An range with a smaller number plotting between 5 and 10 % An. However, in a few cases rim data plot above 10 % An, which suggests there are possibly two different populations of rims (Figure 3.21 and Figure 3.22). The low An ($An_{<10}$) rims are mainly represented by plagioclase from the GAG and GG suites (Table 10). This low An peak is also reflected on the frequency histogram (Figure 3.22). The second populations of plagioclase rims, ie. high An rims ($An_{>10}$) are dominantly from the TG suite and the tonalite to trondhjemite gneiss of the GAG suite. However, the observed compositional spread for plagioclase from the TG suite is possibly biased due to the high degree of alteration of the cores. This suggests the high An content from the TG suite plagioclase rims is possibly an artifact of the difficulty experienced during analysis or shows a compositional difference between the TG suite and the GAG and GG suites.

The paired-An% diagram also reflects the spread in the An-content of the plagioclase cores in all the analysed HHD granitoids (An_{22-0}) (Figure 3.23). The paired-An% diagram also show instances where the rims have An% higher than the cores of the same plagioclase grain (Figure 3.23). This higher rim An-content is mainly shown by samples from the TG suite and tonalite to trondhjemite gneiss of the GAG suite.

Variation in An content between core and rim of the same plagioclase grain is generally not more than 20% (Table 10). In general, the An content of plagioclase decreases from rim to core of the same grain. In some cases where more than one rim position was analysed there is a substantial difference in the rim compositions of the same plagioclase grain. These variations are reflected where rims of plagioclase grains are in contact with K-feldspar which generally reflect lower An content ($An_{<10}$), compared to rims in contact with quartz with An or other plagioclase with An (Table 10). As described in the petrography section these rims developed on the borders between plagioclase and K-feldspar is a distinct characteristic of the GAG and GG suites. The variations are therefore attributed to the existence of clear discontinuous rims on the contacts between plagioclase and K-feldspar (Figure 3.10a and Figure 3.14b). Plagioclase rims in contact with K-feldspar present a dominant distribution towards the low An end–member of the frequency histogram (Table 10). SEM elemental maps (Ca, Na, K) of plagiocalse from a typical granodiorite gneiss (sample D18-1) from the GAG suite are used to demonstrate the compositional differences between plagioclase core and rim (Figure 3.24). The SEM elemental map image for Ca- highlight the fact that the plagioclase cores are more Ca-rich and contain altered phases like epidote, ziosite and calcite compared to the rims of the same grain (Figure 3.24). The compositional difference is best seen on the Na-elemental map where the higher Na-concentration (lighter zones) is shown towards the rims of plagioclase. The sub-subsolidus exsolution overgrowths or secondary rims at plagioclase-K-feldspar boundaries is highlighted by the SEM Na-elemental map displaying a distinctly higher Na-content (lighter grey) in a zone at the borders between plagioclase and K-feldspar. The chemical composition of the rims around the poikilitic plagioclase inclusions in K-feldspar is indistinguishable from that of the rims on the majority of the plagioclase-K-feldspar rims (Table 10).

K-Feldspar

Analyses were carried out mainly on the GG and GAG suites as K-feldspar is one of the main constituents of these suites. As expected, the K-feldspar compositions do not vary significantly between the different suites (Table 10c). K-feldspar composition varies from Or_{96} in the TG suite and Or_{98-94} in GAG and GG suites. There is no significant difference between the rim and core data of the same K-feldspar grain in any of the suites (Table 10c).

Biotite

The electron microprobe analyses of biotite of all three HHD suites show $Mg/(Mg + Fe^{2+})$ vary between 0.51 and 0.66 in the TG suite and tonalite trondhjemite gneiss of the GAG suite showing the values ranging between 0.45 and 0.66 (Table 11). The $Mg/(Mg + Fe^{2+})$ values for biotite from the GG rocks vary between the three sub-suites between 0.30 and 0.50. The TiO_2-content of biotite also varies between the three HHD suites with the TG suite showing the lowest TiO_2-content (0.8 wt%) with the GAG and GG suite the highlest values (1.52wt% to 1.27wt%). No differentiation was observed between rim and core of the same grain.

Amphibole

Amphibole occurs mainly in the TG suite and GAG tonalite trondhjemite gneiss suite. A total of 58 analyses of amphiboles, of which more than half represents the TG suite, is presented in Table 12. The Mg/(Mg+ Fe^{2+}) for both TG and GAG tonalite trondhjemite suite range from 0.52 to 0.70. Analyses showed amphiboles are calcic with compositions in the TG suite ranging from actinolite to magnesiohornblende suggesting that some amphiboles from the TG rocks are of metamorphic origin. The amphiboles from the GAG tonalite trondhjemite gneiss suite represent mostly magnesiohornblende (Figure 3.25). The amphibole end-member compositions are listed in Table 12.

The TiO_2 content of the amphiboles from the TG suite varies between 0.13 and 1.22wt%, compared to the amphiboles from the GAG suite trondhjemite to tonalite gneiss, which has TiO_2-content generally around 0.6wt%. The main difference between the amphiboles in the two suites are in the Al_2O_3 and SiO_2 content with the amphiboles in the GAG suite tonalite trondhjemite gneiss showing a more consistant Al_2O_3 (around 6 wt%), SiO_2 (47 to 49wt%), MgO (13 to 14wt%) and FeO (around 14%) composition.

Allanite

Allanite is a characteristic accessory mineral in all the HHD suites and occurs as fine-grained, well-preserved anhedral to euhedral, mainly light yellow-brown grains with some dark red brown coloured grains occurring locally. Although allanite occurs in association with biotite it is not aligned to the gneissic foliation. Compositional zoning were observed in allanite. Wood and Ricketts (2000) and suggested that zoning which outlines euhedral sectors of the allanite grain is a primary magmatic feature. Lui *et al.* (1999) also proposed that zoning in allanites, revealed by the REE and radioactive elements, reflect the variation in the chemical environment during magmatic fractional crystallization.

The dark red-brown coloured allanite grains seen in the HHD rocks is indicative of advanced destruction of the crystal by decay of radioactive elements present in the mineral itself. Due to the the stability of allanite being compormised by metamictization the result will be allanite being more susceptible to alteration, as seen in the compositional zoning of allanite (observed under high magnification on the SEM), which is widely developed throughout the HHD suites (Figure 3.26). The SEM BSE imaging and elemental maps of a typical allanite (sample D2-3) are used to demonstrate zoning (Figure 3.26). Zoning is symmetrical, consisting of a core, enriched in Ca, Ce and La, surrounded by several concentric euhedral to subhedral shells and a mantle in which the relative abundance of these elements is reversed.

3.4 Modal classification

Based on the petrography discussed above, modal mineral composition of the various granitoid rocks of the HHD dome is reported on the modal QAP classification diagram (after Streckeisen 1976; Le Maitre, 2002), where Q = quartz, A = K-feldspar and P = plagioclase (Figure 3.27). This figure shows that rocks from the TG suite of HHD are restricted to the tonalite field, whereas those from the GAG and the GG suites are more heterogeneous. The GAG granodiorite/adamellite gneiss plots mostly in the granodiorite and monzo-granite field. The locally developed GAG tonalitic and trondhjemitic gneiss plots in the same field as tonalite but also straddle the granodiorite boundary. The pink-grey granite of the GG suite clusters mainly in the monzogranite field, but some samples also falls within the granodiorite field. The GG suite porphyritic granodiorite falls within the granodiorite field. The homogeneous adamellite/granodiorite, however, overlaps with the granite fields. In addition, this diagram shows that the GG suite is slightly more enriched in K-feldspar compared to the TG and GAG suites.

3.5 Geochemical classification

The major element compositions of the HHD granitoids were utilised in classifying the main suites according to several classification schemes. Published data for the Nooitgedacht outcrop obtained by Anhauesser (1999) as well as data from across the HHD (Anhauesser (1973, 1977, 1978) was aditionally used in the classification of the HHD suites and the findings listed along side those of the present study. A summary of the classification results is presented in Table 13. From the summary, the preferred classification scheme is the QAP modal and Q-P major element-based lithological classification diagram of Debon and Le Fort (1982) as it gave results more consistant with the modal QAP classification (Figure 3.27). The rock type indicated in Table 13 therefore refers to the preferred name for the HHD suites as used in this description.

The geochemical compositions of the HHD granitoids define three broad groupings, (i) the first group is characterised by relatively high content of MgO (>1 wt%) and SiO_2 ranging between 60 and 70wt% (hereafter TG suite) and (ii) second group is characterised by much higher content of SiO_2 (>70wt%) and lower (<1wt%) content of MgO. Based on the NaO_2/K_2O content, this group can be divided into two sub-groups, which are: (i) first sub-group has generally Na_2O/K_2O >1 (here after GAG suite) whereas the second group has $Na_2O/K_2O \leq 1$ (hereafter GG suite) (Table 13).

Other classification schemes with less consistant results includes the standard alkali diagram (Na_2O versus K_2O) (Harpum, 1963) (not shown) which places the TG in the tonalite and granodiorite fields with the GAG suite showing a large variation in rock type extending from tonalite into the granite field. The three subgroups of the GG suite (defined from macro and microscopy studies) on the other hand overlaps each other and plots almost entirely in the granodiorite and adamellite fields.

CIPW norms calculated from the major element chemistry were used in the Ab-An-Or (O'Conner, 1965) triangular classification diagram. The HHD rocks define a tonalite-trondhjemite-granite association on the Ab-An-Or diagram (Figure 3.28). The TG suite straddles the tonalite and granodiorite fields with most of the GAG suite rocks falling in the granite and trondhjemite fields. The locally developed tonalitic to trondhjemitic gneiss from the GAG suite, however, falls in the trondhjemite and quartz monzonite fields. The GG suite rocks fall predominantly in the granite field (Figure 3.28). The Nooitgedacht rocks are also presented on the Ab-An-Or diagram with the trondhjemite and trondhjemite-granodiorite gneiss grouped mainly in the trondhjemite field. This diagram can, however, only be used with rocks containing more than 10% normative quartz, which is not the case for all the Nooitgedacht diorite-tonalite rocks and therefore the field where they plot most likely may not correspond to the name appropriate to their modal composition. The data for this suite were therefore omitted from the Ab-An-Or diagram.

On the Q-P (Q= Si/3-(K+Na+2Ca/3) and P= K-(Na+Ca)) major element-based lithological classification diagram of Debon and Le Fort (1982) (Figure 3.29) the TG suite tonalite gneiss falls in both the tonalite and granodiorite fields. The GAG suite plots almost exclusively in the adamellite and granodiorite field, whereas the locally developed tonalite to trondhjemite gneiss (D27 and D28) falls within the granodiorite and tonalite fields. The GG suite plots in the same field as granite, adamellite and granodiorite. The data from the Nooitgedacht exposure plot in the same field as tonalite/trondhjemite to quartz diorite and diorite on the Q-P major element-based classification diagram.

Table 13: Summary of the classification of HHD

Suite		Rock type	QAP modal	Ab-An-Or (O' Conner, 1965)	Q-P (Debon and Le Fort, 1982)
Present study	TG	Tonalite gneiss	Tonalite	Tonalite	Tonalite
	GAG	Granodiorite-to-adamellite gneiss	Granodiorite/ Monzo-granite	Granite/ trondhjemite	Granodiorite/ Monzo-granite
		Tonalite-to-trondhjemite gneiss	Granodiorite	Granodiorite/ trondhjemite	Granodiorite/ Monzo-granite
	GG	Porphyritic granodiorite	Granodiorite	Granite	Granodiorite/ adamellite
		Pink-grey granite	Granodiorite/ Monzo-granite	Granite	Granite
		Homogeneous granodiorite/ adamellite	Granodiorite/ Monzo-granite	Granite	Adamellite/ granodiorite
Nooitgedacht		Trondhjemite gneiss	-	Trondhjemite	Tonalite/trondhjemite
		Trondhjemite-granodiorite gneiss	-	Tronehjemite	Trondhjemite
		Diorite-tonalite gneiss	-	-	Tonalite/trondhjemite to diorite
Other (Anhaeusser)		Migmatite-gneiss	-	-	Adamellite to granodiorite
		Pink granodiorite	-	-	Adamellite
		Homogeneous grey granodiorite	-	-	Adamellite to granodiorite
		Porphyritic granodiorite	-	-	Granite to granodiorite
		Tonalite	-	-	Tonalite to granodiorite

3.6 Geochemical investigation

Rock samples ranging from 5-15kg were collected for the geochemical investigation using XRF and ICPMS. Where fresh samples were not available blasting, was done. Samples were washed and weathered surfaces removed in order to minimise contamination. Major element analyses were done on fusion disks by using the Philips PW1480 X-ray fluorescence (XRF) spectrometer and trace elements were determined on pressed powder pellets using a Philips PW1400 XRF spectrometer. The preparation of the fusion disks as well as the calibration method used for determination of major and trace elements are described by Cloete and Truter (2001). Selected trace elements and REE analyses were analysed by Inductively

Coupled Plasma Spectrometer (ICP-MS). The details of the calibration and sample preparation are described by Jordaan, Maritz and Lehaha, (2005). Analytical data were processed using the GRAPHER 3 software (2002). The list of samples and sample localities is presented in Table 1.

3.6.1 Major Element Composition

Major element analyses for the HHD granitoids are presented in Table 14 with corresponding sample localities shown on the map in Figure 2.1. In the interpretation of the geochemistry available published data from previous studies on the HHD granitoids are included i.e. those by Anhaeusser (1971, 1973, 1977, 1978, 1992, listed here in Table 15 and Table 16.

The majority of the HHD granitoids do not follow either a calc-alkaline (CA) or a trondhjemite (TDJ) differentiation line on the Na-K-Ca triangle diagram (Barker and Arth, 1976) (Figure 3.30). TTG suites have a sodic character when plotted on the Na-K-Ca diagram as shown by the sodic trend defined by Luais and Hawkesworth (1994) and references therein. This sodic character is well demonstrated by the bulk of the HHD rocks, which plot closer to the Na-corner on the Na-K-Ca diagram (Figure 3.30). The TG suite (and Nooitgedacht diorite-tonalite) is the most calcic and plots distinctly away from the bulk of the HHD rocks towards the Ca corner. The most sodic samples (GG and GAG suites) plot close to the “sodic”-TTG evolution line defined by Luais and Hawkesworth (1994). Samples from the Nooitgedacht outcrop follow a similar sodic trend (Figure 3.30).

On the standard K_2O-SiO_2 plot (Peccerillo and Taylor, 1976; Rickwood, 1989) (Figure 3.31) the TG suite and tonalite-trondhjemite gneiss of the GAG suite plot in the medium-K or calc-alkaline field with the majority of the HHD granitoids plotting in the high-K calc-alkaline field (Figure 3.31). The pink grey granite of the GG suite straddles the boundaries between the calc-alkaline and high-K calc-alkaline fields. A marked difference between the majority of the HHD rocks and the Nooitgedacht outcrop are seen on this diagram. Nooitgedacht trondhjemite-granodiorite and tonalite-diorite units fall dominantly in fields defined as low-K or tholeiitic (Figure 3.31).

The concept of alumina-saturation (A/CNK *vs* SiO_2) is not only used to classify rocks into peralkaline, peraluminous and metaluminous types but also to distinguish between I- and S-type granites (Chappel and White, 1974), where A/CNK <1.1 indicates I-type and A/CNK >1.1 indicates S-type granites. The alumina-saturation diagram (Figure 3.32) shows that granitoids of the HHD (excluding Nooitgedacht rocks) fall dominantly in the I-type (<1.1 A/CNK) but in the peraluminous-type granite (A/CNK>1) field. The TG suite, GAG suite tonalite trondhjemite gneiss as well as Nooitgedacht rocks fall in the I-type metaluminous (A/CNK<1) field (Figure 3.32).

The HHD granitoids are typically silica-rich containing generally more than 60wt% SiO_2, but commonly have SiO_2 content ~70wt% (Table 14). The Al_2O_3 content, range between 12wt% and 16wt% for all HHD suites implying that the Barker and Arth (1979) distinction between high (>15wt%) and low (<15wt%) Al_2O_3 content was not possible for the HHD suites (Table 14). The HHD granitoids have K_2O contents ranging from 0wt% to 6wt% with the majority having a K_2O content of ≤ 4wt%. The Na_2O content of the HHD rocks ranges between 2wt% and 5wt% with a strong inverse correlation trend between K_2O and Na_2O exhibited (Figure 3.33). The high-MgO group (TG suite and tonalite-to-trondhjemite gneiss of GAG suite) exhibits the characteristic Na_2O/K_2O >1 seen in TTG suites, whereas the majority of the low-MgO group (GG and GAG suites) has Na_2O/K_2O ≤1 (Figure 3.33). The HHD granitoids have CaO contents ranging from 0wt% to 5wt% with the majority having a CaO content of < 4wt%, which is in accordance with that of the average TTG. On the Na_2O+CaO *vs* SiO_2 (Figure 3.34) diagram, the HHD data from all three main suites shows an inverse correlation between Na_2O+CaO and SiO_2.

Except for the relatively high MgO content (upto > 9wt% in the TG suite and the GAG suite tonalite-trondhjemite gneiss) the HHD granitoids are generally charcaterised by low contents

(< 5 wt%) of Fe_2O_3+MgO+MnO+TiO_2 (Table 14). The Mg# (MgO/MgO+FeO) for the HHD rocks ranges between 0.1 and 0.5 with the highest Mg# recorded for the tonalite-trondhjemite gneiss of the GAG suite and the TG suite (Figure 3.35). A negative correlation exists between Mg# and the SiO_2 content for the HHD granitoids in general, with Mg-enriched rocks being generaly depleted SiO_2. The majority of the HHD granitoids have FeO contents below that of the average TTG suite (~3wt%).

Due to the wide range in the silica content of granitoids Harker variation diagrams are widely used for characterisation of these rocks. As it is typical for most igneous suites, most oxides are negatively correlated with SiO_2 and the rocks from the HHD show no exception in terms of Al_2O_3, MgO, TiO_2, FeO, MnO and CaO (Figure 3.36a-f). However, exceptions are observed concerning the alkalis (Na_2O and K_2O), which show scattered trends (Figures 3.36 g and h). In the case of K_2O vs SiO_2, however, there is a slight correlation for the major part of the composition.

3.6.2 Trace Element Composition

An important geochemical feature typical of Archaean crust (TTG and GGM suites) is its rare earth element (REE) pattern. Incompatible elements are more sensitive to assimilation than major elements and may serve as tracers for crustal contamination. Furthermore certain characteristics such as HREE and HFSE depletion or high concentration of strongly compatible elements would not survive large degrees of assimilation. New set of trace and REE analyses of the HHD granitoids are presented in with corresponding sample localities shown on the map in Figure 2.1. In the interpretation of the geochemistry available published data from previous studies on the HHD granitoids are also included. Although Anhaeusser's (1971, 1973, 1977, 1978, 1992) studies cover a large part of the HHD, the data did not prove to be very useful as limited trace element values (Rb and Sr only) were recorded (Table 15). An exception is the study on the Nooitgedacht outcrop (Anhauesser, 1999) (see Figure 2.1 for locality) in which a wider range of trace element data is presented (Table 16). For this reason only the trace element data from the Nooitgedacht outcrop were used in adition to the new dataset in this study.

Amongst the LILE, the concentrations of Sr and Ba in the TG suite are high (both ~500ppm). These values are comparable to the average TTG suite which has been described as having high LILE (Sr, Rb, Ba) contents with Sr and Ba both > 500ppm. Although the GG and GAG suites have high Ba concentrations (200-500ppm), the Sr values are generally lower, ranging between 100 and 300ppm (Table 16). The majority of the Nooitgedacht rocks do not reflect high Ba content but it seems to have relatively high Sr compositions. The TG suite has low Rb (<100 ppm) content with Rb/Sr ratios ranging between 0.08 and 0.12 (similar to values typical for high-Al TTG suites), whereas for the rest of the HHD the Rb/Sr ratio is >0.5. The highly compatible element (Cr and Ni) concentrations range between 10 and 70ppm, in the GG suite (minor GAG suite) and TG suite (and tonalite-trondhjemite gneiss of the GAG suite) respectively. The variation in concentrations in these elements are demonstrated on the Ni *vs* Cr and Co plots (Figure 3.37 a-c) where the high-MgO suites (TG suite, GAG suite trondhjemite-tonalite gneiss and the Nooitgedacht diorite-tonalites) plot distinctly away from the rest of the HHD rocks as they are enriched in these elements compared to the GG suite granodiorites). The correlation between Ni and MgO are well demonstrated on the Ni *vs* Mg# diagram (Figure 3.38a) where the high-MgO suites (TG and GAG suites) are grouped together at the high-Ni and high-Mg# end. The (La_N/Yb_N) *vs* Mg# diagram (Figure 3.38b) for the HHD granitoids shows that the La/Yb ratio increases with increasing Mg#.

High Sr and low Y and Yb concentrations, and correspondingly high Sr/Y ratios as shown by the TG suite, is characteritic of adakites and high-Al TTG suites (Table 14). The GAG trondhjemite-tonalite gneiss and TG suites generally show overlap in major element compositions but can be differentiated on the basis of low Sr/Y ratio demonstrated by the GAG suite and evidenced on the Sr/Y vs Y diagram (Figure 3.39a). The suites are also separated on the Sr/Y *vs* La/Yb diagram (Figure 3.39b). Unfortunately no Y values were available for the Nooitgedacht rocks. Elemental ratios such as low Rb/Sr (< 0.15), elevated Sr/Y (> 40), $(La/Yb)_N$ >1 have been suggested to be characteristic of TTG suites as is evident from the TG suite and GAG suite tonalite trondhjemite gneiss (Table 14).

The trace element patterns shown on the Harker-type plots against SiO_2 demonstrate trends that are less clearly defined compared to the major elements, although some elements do display linear distribution patterns (Figure 3.40a to o). The trace elements data from some suites, however, do exhibit weak trends. For instance the Harker diagrams show broad positive correlations with increasing SiO_2 for Rb, Pb, Y and Yb whereas Sr, Cr, Ni, Co, Zn, V and La are negatively correlated. However, as a whole the HHD rocks do not show tight trace elements trends with SiO_2 suggesting that crystal fractionation was not a dominant process in the formation of these rocks. V and Zn form a relatively “tight” negative correlation with SiO_2, which is probably related to the crystallisation of and fractionation of oxide minerals.

Plotting the REE abundances against Zr is a very reliable assessment to identify possible alteration as well as effects of metamorphism on REE geochemistry. HFSE shows good correlation with increasing Zr as demonstrated on the Harker diagrams (Figure 3.41). These plots demonstrate a systematic increase with increasing Zr for Ba, Sr, Nb, Nd, Ce and La whereas Rb, Co and Pb show a broad scattering in data. On the Sr, Rb, Co, Cr and Ni versus Zr Harker diagrams the TG suite and trondhjemite-tonalite gneiss of the GAG suite plot at a distinct distance away from the rest of the HHD rocks suggesting a difference in genesis.

In general the majority of the HHD granitoids displays a moderately fractionated REE pattern, illustrated by the slight LREE-enrichment (La) ($(La/Yb)_N$ = 1 and 25) and more or less flat HREE pattern (relative to chondritic concentrations) (Figure 3.42a-e). The LREE/HREE ratios and HREE depletion is characteristic of TTGs. Multi-element spider diagrams used show trace element variations normalised to primitive mantle values of Sun and McDonough (1989) (Figure 3.43). The distinctive features shared by most of the HHD granitoids include strong depletion in fluid-sensitive elements such as Pb as well as a consistant negative Nb anomaly and a slight positive Y anomaly (Figure 3.43).

The high-MgO suites (TG suite and GAG tonalite trondhjemite gneiss) display a stronger fractionated REE pattern, indicated by the LREE-enriched and HREE-depleted pattern, and a modest positive Eu anomaly. The TG suite shows a pattern very similar to that of the average Oceanic Island Basalt (OIB) (Figure 3.42e).

The GAG and GG suites display a moderately fractionated REE pattern and a strong negative Eu anomaly on the chondrite-normalised REE diagrams (Figure 3.42a-d). The most distinctive feature exhibited by the spider diagram of the TG suite is the negative Zr anomaly and a strong positive Sr and absence of a Eu anomaly (Figure 3.43). The negative Eu anomaly is an indication that plagioclase fractionation probably occurred during the evolution of the GAG and GG suites. The GAG and GG suites show a slight depletion in Ba relative to Rb and Th on the multi-element spider diagrams (Figure 4.43a-e). Positive anomalies for Hf and Zr and a strong negative anomaly for Sr and Eu are also displayed.

Although they have many features in common, the HHD granitoids containing > 70wt% SiO_2 (GAG and GG suites) can be separated based on their REE patterns. The GAG suite displays a steeper REE-pattern compared to the GG suite (Figure 3.42). The spider diagram of the GAG suite also exhibits a pattern which differs from the rest of the HHD rocks in that there is "fanning" at the HREE end of the diagram. The GG suite homogenous adamellite/granodiorite has two distinct REE patterns with two samples showing distinct depletion in LREE and a strong negative Eu anomaly, whereas the rest of the suite display only a slight negative Eu anomaly (Figure 3.42b). A distinct positive Nb anomaly is shown by the GG suite homogeneous granodiorite (Figure 4.43). In general Yb and Y do not show significant enrichments, which is also common for TTG suites.

Discrimination diagrams, distinguishing between and comparing various granitic rocks and their tectonic environments, have become a fundamental part of any granitoid study. According to some studies (Twist and Harmer, 1987; Arculus, 1987; Clarke, 1992; Roberts and Clemmens, 1993) caution should be taken in the use of trace element tectonic discrimination diagrams using Rb and even Y + Nb due to the influence of source rock composition and the generative processes on the chemistry. Furthermore these diagrams are considered to show the setting in which the protoliths were formed rather than the tectonic setting when the granitoid magmas were produced. Despite this concern the trace element discrimination procedures suggested by Pearce *et al.* (1984), using the elements Rb, Y and

Nb the Nb versus Y, for intrusive rocks is widely used and therefore employed in the present study to indicate the probable tectonic settings of the HHD granitoids. The majority of the HHD granotoids cluster in the VAG (Volcanic Arc Granite) + syn-COLG (Syn-Collisional Granite) field on the Nb versus Y diagram (Figure 3.44). Further discrimination between these fields is done using the Rb versus Y+ Nb diagram which points to a VAG tectonic environment for the HHD granitoids (Figure 3.45).

4 DISCUSSION AND INTERPRETATION

The basic mineral assemblage of the HHD granitoids is comparable with typical TTG suites, which are generally equigranular quartz+plagioclase+biotite and K-feldspar (in the more potassic suites) bearing plutonic rocks. Based on the petrological and geochemical investigation the HHD granitoids were subdivided into three main suites:

- The Tonalitic gneiss suite (TG) around the southern boundary
- The Granodiorite to Adamellite banded Gneiss suite (GAG) across the northern part of HHD
- The Granodiorite/adamellite to Granite suite (GG) occurreing in the central part of HHD between the TG and GAG suites and consisting of
    i. porphyritic granodiorite
    ii. medium-grained pinkish-grey granite
    iii. homogeneous adamellite-granodiorite

From the field and petrological investigation it is clear that a widespread metasomatic event affected the entire HHD, which resulted in albitization of plagioclase. The preferred orientation of the hornblende and brown-green biotite of the TG and GAG may be linked to a low grade, greenschist metamorphic event in the area. However, the ductile deformational event(s) pre-dates the formation/intrusion of the GG suite. The Rb-Sr biotite whole rock dates, representing ages of later modification, for the HHD suites range between ~2 080 and 2 614Ma. This suggests that the influence of the ~2 000Ma Vredefort event and the ~2 060Ma intrusion of the Bushveld Complex on the HHD rocks can not be excluded.

4.1 Variation in mineralogy

Disequilibrium textures, such as reaction rims, coronas, overgrowths and zonations, observed in the granitoids of the HHD suggest crystal-fluid interaction occurred at various stages during their formation. Clarke (1992) suggested the clear discontinuous rims on plagioclase/ K-feldspar contacts, similar to that described for the GAG and GG suites, are disequilibrium textures. The distinct discontinuous rims restricted to plagioclase-K-feldspar boundaries in the GAG and GG suites were shown to be clearly more Na-rich compared to the rest of the plagioclase grain. Electron Microprobe analyses of the plagioclase showed the cores are relatively enriched in anorthite compared to the rims, which are anothite-poor ($An_{2.5}$) in the GAG and the GG suites. The TG suite plagioclase (cores and rims) does not show significant variation and is mainly spread between $An_{7.5}$ to An_{15}. The theory most likely to explain these rims at the contact between K-feldspar and plagioclase is that of K and Na-unmixing due to the inversion of orthoclase to microcline (Smith, 1974). These authors suggested that K and Na-unmixing results in the formation of exsolved albite, which either migrated to grain boundaries where it settled as secondary albite rims on adjacent plagioclase or form perthite lamellae in the host crystal. The continuity between the rims on plagioclase and the perthite lamellae of K-feldspar is in agreement with this theory of subsolvus migration of exsolved albite held in solid solution in the K-feldspar.

Further evidence of disequilibrium textures in HHD granitoids is the coronas of secondary titanite developed around magnetite and ilmenite grains. This feature is similar to that described by Rao *et al.* (1973) and Jankowitz (1986) around magnetite and ilmenite grains in granitic rocks. Rao *et al.* (1973) and Hunt and Kerrick (1979) considered these secondary titanite coronas around opaque minerals to be the result of secondary metasomatic growth. These authors describe the secondary growth as a process through which available Ca combine with Ti from the ilmenite grain (possibly also decomposition of biotite) to form the titanite rim. These secondary titanite rims is therefore evidence that the HHD has gone through a pervasive metasomatic phase.

The inconsistency seen in the modal classification diagram (Figure 3.27) where rocks with field labels “tonalite” plot as granodiorite is possibly an artefact of the widespread alteration, which probably have caused alteration such as that observed in the plagioclase cores. Barton *et al.* (1999) also showed that the deuteric alteration of the feldspars affected the Rb-Sr whole rock system.

4.2 Variation in geochemistry between suites

The HHD granitoids can broadly be devided into a low-SiO_2 (50 to 60wt%) and high MgO group (TG suite, GAG suite trondhjemite-tonalite gneiss also including the Nooitgedacht outcrop diorite-tonalite) and a high-SiO_2 (>70wt%) low MgO group (remainder of the GAG suite, GG suite and Nooitgedacht trondhjemite to granodiorite gneisse). The TG suite, GAG suite trondhjemite-tonalite gneiss and Nooitgedacht diorite-tonalite differ further distinctly from the rest of the HHD (including the remaining granitoids from Nooitgedacht outcrop) rocks in that these suites have higher Al_2O_3 (>15 wt%), MgO (>2wt %), Mg# (0.41-0.49) (Table 14 and Table 15), ferromagnesian elements (Fe_2O_3, TiO_2 and MnO) (>9wt%), as well as higher Rb, Sr, Ba, Cr, Ni contents compared to the rest of the HHD rocks. These suites therefore fall in what Smithies and Champion (2000) described as a high-Mg diorite series, a rare suite of TTG rocks, which except for high-Mg values also has a distinct characteristic of low SiO_2 content (~60 wt%). At about 60 wt% SiO_2, high Mg-diorites have a high Mg# requiring a source significantly more mafic than typical Archaean basaltic crust, suggesting a mantle source. However, two of the GAG suite trondhjemite-tonalite gneiss samples (D22 and D23) do not show the high MgO composition but rather plot along with the bulk of the GAG and GG suite rocks, ie. towards the lower MgO values. Although these two samples plot along with the majority of the HHD rocks it still represents the highest MgO values in that instance (Figure 3.36 and Table 14).

The GAG (granodiorite/adamellite gneiss) and GG suites display very little differences in major element chemistry accounting for the overlap of data from these two suites (Table 14 and Figure 3.36). Furthermore, the new dataset and those of the previous studies (Anhaeusser, 1971, 1973, 1977, 1978, 1992 show distinct overlap in all the major elements. The similarities between the GAG and GG suites and the trondhjemite to granodiorite gneisses of the Nooitgedacht outcrop include characteristics such as low MgO (<1wt%) content at high Na_2O (Na_2O/K_2O >1) values (Figure 3.33).

Despite HHD suites displaying similar trends on the SiO_2 Harker diagram, there is a significant degree of scatter when the data set for the Nooitgedacht outcrop is added suggesting that care should be taken when evaluating rocks from this outcrop as they most probably represent the exception rather than the average HHD granitoid (Figure 3.36).

All HHD suites, including the Nooitgedacht outcrop, have Na_2O contents of between 3wt% and 7wt%, comparable to that of the average TTG and adakite (Table 2, Table 3 and Table 14). Based on the Na_2O/K_2O ratio two distinct groupings in the HHD granitoids were identified. The TG and GAG suites are more sodic ($Na_2O/K_2O > 1$) whereas the GG suite is more potassic ($Na_2O/K_2O \leq 1$). This distinction is also shown on the Na_2O vs SiO_2 and K_2O vs SiO_2 Harker diagrams (Figure 3.36). Although no clear trend was shown on the Na_2O vs SiO_2 Harker diagram it does show that there is a close association between the Nooitgedacht diorite-tonalite, the TG suite and the GAG suite trondhjemite-tonalite gneiss. This diagram furthermore shows that there is a clear diference between the latter rocks and the majority of the Nooitgedacht trondhjemite and granodiorite gneiss and GG suite rocks. There is an increase in K_2O in the GAG suite relative to the TG suite (Figure 3.36).

The K/Na ratio for TG suite and the tonalite-trondhjemite gneiss of the GAG (with the exception of D27 and D28) ranges between 0.25 and 0.33, which falls within the criteria (K/Na<0.4) for typical Archaean TTGs (Martin, 1994). The remainder of the HHD suites have K/Na ratios up to 1.06 and 1.85 as shown in the adamellite/granodiorite of the GG suite and GAG granodiorite/adamellite gneiss respectively (Table 14).

The GAG tonalite-trondhjemite gneiss and the TG suite have the highest CaO composition of all HHD suites in the present study as reflected in the CaO vs SiO_2 Harker diagram (Figure 3.36). The Nooitgedacht diorite-tonalite rocks is, however, even more calcic. On the Na_2O+CaO vs SiO_2 diagram the HHD data shows an inverse correlation between Na_2O+CaO and SiO_2 with an increase in Na_2O+CaO from the TG suite to the GG suite supposedly related to the plagioclase content of the suites (Figure 3.34). A clear distinction between the Nooitgedacht rocks and the rest of the HHD are shown in that these rocks have a much higher Na_2O+CaO content at lower SiO_2 values compared to the rest of the HHD rocks.

The TG and GAG suites reflect the high LILE (Sr, Rb, Ba) contents shown by TTG suites (Table 14). The high Ba content is however not reflected in the Nooitgedacht rocks, where it seems the rocks are generally enriched in Sr compared to the rest of the HHD.

The TG suite and tonalite-trondhjemite gneiss of the GAG suites (D27 and 28) as well as the diorite-tonalite of the Nooitgedacht outcrop have Cr and Ni values comparable to that recorded in the average adakite (Table 3). The enrichment in Ni, Co and Cr in these suites compared to the GG suite is reflected on the Harker diagrams of Cr, Co and Ni against SiO_2. These diagrams show a clear distinction between the TG suite, GAG suite tonalite-trondhjemite gneiss (D27 and 28) and Nooitgedacht diorite-tonalite and the rest of the HHD rocks (Figure 3.40e and f). The TG suite, tonalite-trondhjemite gneiss of the GAG suite and Nooitgedacht data show an inverse correlation for Cr and Ni with increasing silica (Figure 3.40e and f). Further distinction between the TG suite, GAG suite tonalite-trondhjemite gneiss (D27 and 28) and Nooitgedacht diorite-tonalite and the rest of the HHD is also shown on Ni vs Cr and Co plots as these suites are enriched in all these elements compared to the GG suite granodiorites (Figure 3.37). The correlation between Ni and Mg# is well demonstrated by the grouping together of the TG suite, tonalite-trondhjemite gneiss of the GAG suite and the Nooitgedacht diorite-tonalites on the Ni vs Mg# diagram. This suggests that these rocks have characteristics that would place them in the high-Mg diorite series, whereas the remainder of the HHD suites are grouped together as part of a typical TTG suite (Figure 3.37).

The HHD granitoids display a fractionated REE pattern (Figure 3.43) with relatively high LREE/HREE ratios and depleted HREE contents. The HHD fractionated REE pattern is illustrated by the high LREE (La) contents and moderately low HREE (Yb). In the GG (homogenous granodiorite) suite, however, two samples show a highly depleted LREE and relatively elevated HREE pattern (Figure 3.42). Modern adakites and TTGs share characteristics such as a strongly fractionated REE pattern (Table 2 and Table 3). The HHD granitoids generally display a steep REE pattern (higher La_N/Yb_N ratios). The La_N/Yb_N ratio for the TG and GAG suites is, on average, much higher than that for the GG suite (Table 14).

The TG suite has high Sr/Y and high La/Yb ratios, a characteristic shared by TTG suites and high-Mg diorites (Figure 3.39). However, the significantly higher Mg#, Cr and Ni concentrations of the high-Mg diorites distinguish it from typical TTG suites. Despite abundant similarities in the geochemistry of TTG and adakites some differences do exist.

TTGs have slightly higher La/Yb ratios whereas adakites show negative Nb and smaller negative Zr and Ti anomalies (Defant and Drummond, 1990 and Martin, 1999).

HFSE depletion and slightly elevated concentrations of highly compatible (fluid-sensitive) trace elements such as Pb were recorded in all three HHD suites and are characteristic features shared by TTG suites (Table 3 and Table 14).

The two groups ie. high MgO suites (TG suite and tonalite-trondhjemite gneiss of the GAG suite) versus low MgO-high SiO_2 suites (GAG granodiorite to adamellite gneiss and GG suites) display some variations on the primordial mantle normalised diagrams (Figure 3.43). The high MgO suites show a strong positive Sr and the absence of a Eu anomaly whereas the low MgO-high SiO_2 suites show a strong negative anomaly for both Sr and Eu. The consistant negative Nb anomaly shared by most of the HHD granitoids can be interpreted as to reflect the residual behavior of minerals like rutile during basalt melting. However, rutile fractionation should also result in a strong negative Ti anomaly.

Variations within individual HHD suites were recognised. The tonalite-trondhjemite gneiss of the GAG suite display internal variations in Nb and Eu as two samples displays a strong negative Nb and Eu anomaly whereas the remainder (D27 and D28) shows a general absence of a Nb and Eu anomalies. In the GAG suite Y illustrates two contrasting anomalies, ie. the granodiorite/adamellite gneiss displaying strong negative tendancies whereas the majority of the rocks from this suite show either a slight positive or no anomaly. Furthermore one sample of the tonalite-trondhjemite gneiss of the GAG suite reflects a strong positive Y anomaly, which is in contrast to the rest of the rocks from this suite.

4.3 Comparison between HHD granitoids and well-known TTG suites

Published data from several well-known TTG suites including the Superior Province, Pilbara Craton, Dhawar Craton (Closepet), and Barberton Mountain Land as well as available average compositions of the TTG's, adakites (HAS and LSA) (Martin 1999), high-Mg diorites (Martin 1999, Smithies and Champion, 2000) and sanukitoids (Martin 1999) from various localities in the world are used for comparison with the HHD granitoids (Table 2, Table 3, Table 14, Table 17).

The majority of the HHD granitoids show characteristics similar to older TTG suites, which are generally siliceous (SiO_2~70wt%), aluminous (Al_2O_3 ~15wt%), with high Na_2O (3-7wt%). These features illustrated by the HHD rocks are characteristics of typical TTG suites such as the Barberton plutons (Nelspruit, Kaap Valley and Nelshoogte), Superior Province, Pilbara Craton, Dharwar Craton and Zimbabwe Craton. There is generally very little variation between the major element composition of the average older Archaean TTG series (>3.5Ga) and the younger TTG (<3.0Ga) series (Martin *et al.*, 2005).

Compared to the HHD rocks and average for TTG suite a typical GGM suite, such as the Barberton plutons (Dalmein, Mpageni, Nelspruit), has high SiO_2 (>70wt%) and K_2O (3-5wt%) but lower Al_2O_3 contents. Compared to the GGM suites the TTG suites are predominantly Na-rich and is marked by a high Na_2O/K_2O (>1) as shown by the TG suite, GAG suite tonalite-trondhjemite gneiss as well as the Nooitgedacht rocks. The MgO and K_2O content of the TG suite, GAG suite tonalite-trondhjemite gneiss as well as the Nooitgedacht rocks would place these suites in the same category as the high Mg-diorites of the Pilbara and Superior Province (Table 2, Table 3 and Table 14). The majority of HHD suites (with the exception of the TG suite, tonalite-trondhjemite gneiss of the GAG suite and Nooitgedacht rocks) have K_2O (4-5wt%) content, which is higher than the average TTG and adakite but comparable to the typical GGM suite and Closepet-type granite. The Closepet-type granite has high K_2O (~3wt%) content, which distinguishes it from TTGs of any age. GGM suites are also K-rich (~4wt%) compared to the average TTG, presenting low Na_2O/K_2O (<1) ratios, which is similar to the ratios for the majority of the GAG and GG suites (Table 3).

Due to the high Na_2O content (~4wt%) of adakite (HAS and LSA) the K_2O/Na_2O is typically <1 whereas Closepet-type granite have higher K_2O/Na_2O ratios (upto 1).

Typical GGM suites have lower $Mg^{\#}$, Ni and Cr contents compared to TTG suites (Kleinhans *et al.* (2003). The high-Mg rocks of the HHD (TG suite, tonalite-trondhjemite gneiss of the GAG suite and Nooitgedacht outcrop diorite-tonalite gneiss) have high Mg#, MgO, Cr and Ni contents at low silica (~60 wt%), comparable with that of Pilbara high-Mg diorite and melanodiorite, Superior Province high-Mg diorite, high-Mg adakite (sanukitoid) (Piipi and Adak types in Table 3 and Table 14) as well as the monzogranite suites of the Closepet granite. The primitive mantle reflects very high Mg# at very low SiO_2 values, highlighting the difference which exists between the primitive mantle and the TTG rocks.

Older Archaean TTG series is generally poorer in ferromagnesium components (Fe_2O_3+MgO+MnO+TiO_2<5wt%), with an average Mg# of 0.38 compared to younger TTG's (Mg# =0.45). The majority of the HHD granitoids have FeO and ferromagnesian (Fe_2O_3+MgO+MnO+TiO_2<5wt%) element composition below that of the average TTG suite (~3wt%). The FeO composition of the bulk of the HHD granitoids compares well with that of the Barberton TTG and GGM suites. However, the TG suite, GAG tonalite-trondhjemite gneiss and Nooitgedacht diorite-tonalite has FeO contents comparable to the high Mg-diorites of the Pilbara Craton.

The CaO contents of the HHD granitoids is in accordance with that of the average TTG and compares well with their counterparts in Barberton, Vredefort, Pilbara and Closepet (Table 2 and Table 14). The Nooitgedacht diorite-tonalite, TG suite and tonalite-trondhjemite gneiss of the GAG suite, however, show an exceptionally high CaO compositions similar to that shown by the high Mg-diorites of the Superior Province. Despite abundant similarities in the geochemistry of TTG and adakites some differences do exist (Defant and Drummond, 1990 and Martin, 1999). TTG's are slightly poorer in Ca compared to modern adakites as shown by the HHD suites, which have a lower CaO composition when compared to the average adakite (Table 14 to Table 17).

In general TTG suites share characteristics such as high LILE (Sr, Rb, Ba) contents with Sr and Ba both >500ppm with adakites although the latter have LILE values exceeding

1000ppm in some instances (Table 14 to Table 17). The TG and GAG suites to some extent reflect the high LILE (Sr, Rb, Ba) contents typically ecpected for TTG suites. The high Ba, Sr and the slightly less elevated Rb trend exhibited by the TG and GAG suites is similar to that observed for TTG's from Vredefort, Barberton, the high Mg-diorites of the Superior Province and Pilbara Craton as well as for Closepet granite. LILE concentrations are a function of the behavior of a fluid phase. High LILE concentrations are considered an indication of crustal contamination of magmas. Compositional differences were atributed to the fact that sanukitoid and Closepet-type granite have undergone more significant fractional crystallization as well as contamination by continental crust, which resulted in differences in the LILE contents (Moyen *et al*., 2003; Martin *et al*., 2005).

Although elevated Ni and Cr content are prominent features shared by adakites and TTG suites including high Mg-diorite/sanukitoid suites (such as the Superior Province and Pilbara Craton) high Mg-diorites, adakites and Closepet-type granite have significantly higher Mg#, Cr and Ni concentrations compared to TTG suites (Table 14 and Table 17). Furthermore the high compatible element (Ni, Co and Cr) content is considered a prominent difference between TTG and GGM suites (Table 2, Table 3 and Table 14). The high Cr and Ni content of the TG suite, tonalite-trondhjemite gneiss of the GAG suite and the diorite-tonalites of the Nooitgedacht are comparable to that recorded in the average adakite, Barberton TTG suites and high-Mg diorite of the Superior Province, Pilbara Craton and Zimbabwe Craton (Table 3 and Table 17). The GG suites have low compatible element content comparable to that of the Barberton GGM suites (Table 17).

The high Ni and Cr content together with the high Mg# of TTG suites is considered to indicate interaction with the mantle wedge (Smithies and Champion, 2000). These characteristics are also shown by high-Mg diorites and LSA.

The high Ni and Cr content together with the high Mg# for TTG suites from Barberton was taken as evidence against an origin through partial melting of garnet-amphibolite or eclogite, which are both depleted in these elements. Partial melts from garnet-amphibolite and eclogite would be even more depleted in these elements and could only acquire elevated Ni, Co and Cr contents through assimilation of peridotite. This is however, not supported by the trace element characteristics of TTG suites. Partial melts of hydrated mantle were shown to contain a higher Ni, Co and Cr concentration, which can be attributed to the high concentrations of these elements in the source region combined with a high degree of melting (Kleinhans *et al.*, 2003).

The HHD granitoids display a strongly fractionated REE pattern, a characteristic shared by modern adakites and TTGs (Figure 3.42). The HHD TG and GAG suites show a steep REE patterns (higher La_N/Yb_N ratios) generally displayd by TTG suites. From the chondrite-normalised REE diagram for the HHD rocks it is clear that the majority of the suites, with the exception of the GG (homogenous granodiorite) suite, show a typical TTG strongly fractionated REE pattern (Figure 3.42a-e). The TG suite shows a pattern very similar to that of the average Oceanic Island Basalt (OIB).

TTG suites the GGM suites have strong similarities such as over enrichment in fluid sensitive elements such as Pb (Martin, 1994; Kleinhans *et al.*, 2003). The characteristic enrichment in Pb in all HHD suites is seen on the chondrite-normalised REE diagram. Kleinhans *et al.* (2003) suggests that this signature reflects the fact that these rocks are derived from refertilised mantle above subducion zones.

A more consise version of the primitive mantle normalised diagram are used for comparison of the average composition of each of the HHD suites with various other rock types due to the fact that complete data sets for some of the comparison rocks were not available (Figure 3.46a-c). On the primitive mantle normalised diagram the TG suite show a pattern similar to that of the average Closepet type granite, LSA and the average sanukitoid and falls within the field presented by the high-Mg diorites of the Pilbara craton (Table 3) (Figure 3.46a). The GAG suite presents a pattern very similar to that of the upper crust and HSA and falls across the fields presented by the Pilbara high-Mg diorite and Barberton TTG suites (Table 3) (Figure 3.46b). Although the GAG suite pattern also matches that of the average TTG, there is some incompatablities at the HREE end. The GG suite presents a pattern very similar to that of the upper crust and falls across the fields presented by the Barberton TTG and GGM suites with incompatablities mainly at the HREE end (Figure 3.46c). Compared to typical TTG suites the GGM suites are characteristically richer in HREE (light REE fractionation) and Y.

Distinctive features shared by TTG and most HHD suites, as shown on the primitive mantle normalised diagram, includes strong depletion in Nb and Y. The average mid- to late Archaean TTGs, adakites (HSA and LSA), sanukitoid/high-Mg diorite and Closepet type granite also show a negative Nb anomaly but a less well-defined negative Y anomaly.

The GAG (granodiorite to adamellite gneiss) and GG suites display a strong negative anomaly for Sr and Eu, typical of a GGM suite, whereas the TG suite shows a strong positive Sr and the absence of a Eu anomaly, typical of TTG suites, adakite, high-Mg diorite/sanukitoid (Figure 3.46). TG suite has minor Sr and Eu anomalies as is reflected by the field for high-Mg diorites from the Pilbara Craton (Figure 3.46). Adakites have a characteristically stronger positive Sr and Eu anomaly compared to TTGs as is demonstrated on the primitive mantel normalised diagram. The Closepet-type granite, although showing similar compositional pattern to that of LSA and sanukitoid show a very slight depletion in Sr compared to these rocks. A positive Sr anomaly on the normalised multi element diagram is considered to indicate the absence of plagioclase fractionation. The negative Sr anomaly recorded in the calc-alkaline GGM suites and the GAG (granodiorite to adamellite gneiss) and GG suites therefore suggests these HHD rocks did undergo some plagioclase fractionation.

The TG suite and tonalite-trondhjemite gneiss of the GAG suite have high Sr/Y and high La/Yb ratios, a characteristic shared by adakites, TTG suites and high Mg-diorites such as Barberton Mountain Land and high Mg-diorites of the Superior Province and Pilbara Craton (Table 14 to Table 17). The high La/Yb and Sr/Y ratios of TTG suites are thought to be the result of partial melting of an eclogitic basaltic crust. High Sr and low Y concentrations, with the corresponding high Sr/Y ratios are characteristics defining adakites and considered an indication of their origin as slab-melt under high pressure (Defant and Drummond, 1990).

HFS elements (Y, Hf, Zr, Ti, Nb, Ta) are less mobile and controlled by crystal/melt processes, which have taken place during the formation of the rock. Positive anomalies for Zr occur within the GG and GAG suites with the TG suite (and GAG suite tonalite-trondhjemite gneiss) displaying a negative Zr anomaly.

An important observation from Figure 3.46 is that there is a high degree of compositional overlap between the TTG field and HSA supporting the view that these rocks share many petrogenic similarities. Despite abundant similarities in the geochemistry of TTG and adakites some differences do exist.

HREE depletion can be explained by three approaches i.e. the melting of garnet-amphibolite eclogite in the slab or lower crust, inherited REE pattern of the slab derived fluid or by fractional crystallization of garnet/amphibole in hydrous mantle melts. The last two suggest TTG originate from hydrated mantle melts with LREE preferentially transferred to mantle wedge and HREE retained in garnet and amphibole as the magma becomes more Si-rich.

4.4 Petrogenesis

Studies of the processes through which granitoid rocks with diverse compositions formed have lead to the formulation of several theories for their formations. Based on the petological and geochemical results discussed above, some possible models for the formation of the HHD granitoids will be discussed in this section.

Model 1 – This model considers the melting of hydrated basaltic material at the base of a thickened crust (Atherton and Petford, 1993). It is generally accepted that most trondhjemite-tonalite liquids formed from a basaltic source and involved processes of partial melting or fractionation. The tectonic models predicting TTG generation at the base of a thickened crust include models such as underplating of oceanic crust, sequential stacking or obduction of oceanic crust (de Wit, 1998) and successive accretion of oceanic plateaux (Condie, 1997). These models are considered more appropriate for the formation of early Archaean crust.

The high MgO, Ni and Cr contents of typical TTG favors melting of a subducted oceanic slab rather than underplated basalt. This signature of elevated MgO, Ni and Cr is seen in the HHD granitoids. Furthermore the HFSE depletion and distinct enrichment of fluid sensitive elements such as Pb, observed in all three HHD granitoid suites, are generally considered to indicate an arc signature. This signature of the fluid mobile elements can not easily be reconciled with direct melting of oceanic crust. This model is not generally applicable to HHD TTG suites.

Model 2- This model considers the direct partial melt of subducted oceanic crust. There is wide acceptance that plate tectonic processes were active during the Archaean (de Wit *et al.*, 1992; de Wit, 1998). Similarities between TTG and adakites suggest that TTGs may have formed in subduction environments analogues to that of modern adakites.

This model seems to fit some of the characteristics of the HHD suites, i.e. REE pattern similar to that of adakites. The large range in Cr/Ni and high $Mg^{\#}$ at low SiO_2 values exhibited by the TG suite and diorite-tonalite gneiss of the Nooitgedacht exposure are also considered characteristic to adakites. However, some characteristics of the HHD suites (including Nooitgedacht), such as Pb enrichment and high LILE concentrations (TG suite), are incompatable with direct melting of subducted oceanic slabs.

Model 3 - This model considers the melting of subducted oceanic slab and the interaction with mantle wedge. High Mg#, Ni, Cr and LILE indicates a LILE-enriched mantle source. High LILE concentrations such as exhibited by the TG suite and Nooitgedacht diorite-tonalite can not be explained through crustal contamination. High LILE (Sr, Ba, Rb) content reflect either a subduction modified source or mantle contamination of the slab melt. The positive Sr anomaly seen in adakites suggests greater interaction between the slab melt and a thicker mantel wedge. The same would be true for the positive Sr anomaly shown by the TG suite, the adakite analogue of the HHD.

From the MgO contents of TTGs and adakites Martin and Moyen (2002) showed that these rocks formed through interaction of felsic magma and mantle material. These authors showed that the MgO, Ni and Cr contents of TTG favors melting of subducted oceanic slab rather than underplated basalt, in which case felsic magmas are prevented from coming into contact with mantle peridotite. The high $Mg^{\#}$, Ni and Cr signatures of adakites are considered to reflect interaction of felsic melts generated by melting of metabasaltic slabs with interaction with mantle peridotite during its ascend through the mantle wedge (Martin, 1999, Smithies, 2000, and Martin and Moyen, 2002). The resulting wedge-modified adakite bears strong compositional similarity to Archaean high-Mg diorites. High Mg-diorite magmatism, documented in the TG suite and the Nooitgedacht complex, is broadly similar to that observed in the Superioir Province and Pilbara Craton. High-Mg diorites are considered to be relatively scarce (<5% of all Archaean TTGs). This is also consistent in the HHD where the high-Mg series is restricted to the southern edge of the HHD and xenoliths (Nooitgedacht outcrop) occurring in the GAG suite.

The high $Mg^{\#}$, Ni and Cr signatures of the TG and GAG tonalitic suites (and diorite-tonalite gneiss of the Nooitgedacht exposure) are considered to reflect a mantle source similar to that described for high-Mg adakites and high-Mg diorites. Rocks from the Nooitgedacht outcrop was shown to exhibit typical high-Mg diorite characteristics similar to the TG suite. However, opposing trends in many of the trace element (Sr, Nb, Ni) vs SiO_2 diagrams suggest these rocks possibly evolved from a different source than the TG suite.

Smithies, (2000) pointed out that although very few, if any, pre-3 000Ma TTG suites show this high $Mg^{\#}$, Ni and Cr trend late Archaean TTGs (high-Mg diorite series) show this evidence for mantle interaction. Martin and Moyen (2002) showed that there is a systematic increase in the contribution of mantle peridotite to TTG from early to late Archaean. The TG suite (considered to be the oldest HHD suite (at 3 170±64Ma)) shows a Ni and Cr signature typical of late Archaean high Mg-diorites, which has interacted with the mantle wedge. The scarcity of high-Mg diorites suggests that the conditions for formation were not met in all

Archaean terranes. The occurrence of high-Mg diorites on the HHD therefore signifies that the conditions necessary for high-Mg diorites formation were present along the southern edge of the HHD as well as around Nooitgedacht.

The majority of the HHD granitoids (GAG and GG suites), however, have a lower LILE, $Mg^{\#}$, Cr and Ni content than is expected from a rock which has passed through the mantle wedge. This could be the result of the slab melt passing through a thinner mantle wedge and therefore suffering only small degrees of interaction. Martin and Moyen (2002) showed shallower depth of melting of the subducted slab resulted in the slab melt passing through a thinner mantle wedge and therefore suffered only small degrees of interaction.

The occurrence of more calc-alkaline (GG and GAG) granitoids can also be explained by slab dehydration. Martin and Moyen (2002) showed that when the geothermal gradient along the Benioff plane is too low slab dehydration would occur. The result is melting and metasomatism of the mantle wedge by an aqueous fluid, which give rise to calc-alkaline magmas.

Model 4- This model considers metamorphic dehydration. Kleinhans *et al.* (2003) showed the overabundance of fluid-mobile elements (Pb) reflects the process of metamorphic dehydration. Kleinhans *et al.* (2003) suggests that the signature of HFSE depletion and distinct enrichment of fluid sensitive elements such as Pb reflects the fact that these rocks are derived from refertilised mantle above subducion zones. Kleinhans *et al.* (2003) also showed that dehydration to produce a voluminous magma of this scale could only be produced by subduction of an immense quantity of hydrated rock into the mantle. They concluded that it seems unavoidable that Archaean TTG and GGM were derived from melts, which formed in the refertilised mantle wedge.

The over enrichment in Pb and HFSE depletion in all HHD suites can therefore be considered to be a typical signature of slab dehydration. Kleinhans *et al.* (2003) reported similar patterns for the TTG and GGM suites of the Barberton mountain land.

Model 5 **-** This model considers partial melting of tonalitic crust. Partial melting of a TTG protolith due to heat transferred from the mantle wedge is considered. The presence of restite phases (such as Ca-rich core of plagioclase) as well as geochemical signatures similar to that of a TTG protolith is considered evidence of this model. The presence or absence of plagioclase in the melting residue controls the behavior of Sr and to some extent ($CaO+Na_2O$). Increased ($CaO+Na_2O$) and Sr reflect the increase in the abundance of plagioclase in the melt residue. The presence of a small positive or no Eu anomaly and a strong positive Sr anomaly in the TG suite reflects melting at pressures outside the plagioclase stability field. On the other hand the negative Eu anomaly and the absence of a positive Sr anomaly for the GAG and GG suites could reflect the presence of plagioclase in the source. Furthermore the geochemistry of the GAG and GG suite approximate the characteristics of a TTG protolith, such as the TG suite.

The TG suite most probably formed through subduction and accent through a thin mantle wedge. The remaining HHD granitoids (GAG and GG) most probably formed through the remelting of a TTG protolith with a subducted slab and mantle wedge signature (similar to the TG suite).

Calc-alkaline silicic magmas with sufficient thermal energy to rise to the upper crust require extreme thermal conditions for formation (Roberts *et al.*, 2000). Post-orogenic extension in pull-apart basins or along active or passive continental margins may produce a heat source, in the form of a mantle derived magma, needed for the generation of granitic magmas capable of ascending to the upper crust (Clemens, 1990; Vielzeuf *et al.*, 1990). De Wit (1998) and speculated that high-Mg diorite magmatism occurred during late extensional collapse of an Archaean province. Smithies and Champion (2000) showed that mantle derived high-Mg diorite suites of the Pilbara Craton intruded along major extensional basin faults. Anhauesser (2004) suggested a similar scenario for the HHD TTG suites. This author argued that the Rietfontein fault zone is likely to represent a suture zone along which two TTG micro-continents (the northern GAG (3 440Ma) and a southern TTG (below Wits basin)) collided. The heat source needed for the generation of granitic magmas of the HHD, capable of ascending to the upper crust, can therefore possibly have been related to the collision zone around the southern edge of the HHD.

5 SUMMARY

Field, petrological and geochemical investigation showed the HHD consists of a mosaic of granitoids rocks. Field investigation failed to confirm the contact relationships between the various granitoids due to poor exposure. A strong east-west foliation direction observed in the TG and GAG suites pre-dates the GG suite.

The HHD granitoids are characterised by Qz+Pl±Kfs+Bt±Hb mineral assemblages observed in the TG rocks and GAG tonalite-trondhjemite gneiss, and Qz+Pl±Kfs+Bt observed in GAG and GG rocks in addition to accessory minerals Ap+Aln+Fe+Ti-oxides+Tnt.

Various classification schemes were used with the QAP modal and Q-P major element-based lithological classification diagram (after Debon and Le Fort, 1982) being the most consistant for the HHD rocks.

New geochemical data for the HHD show that two distinct groups of rocks could be identified, ie.:
(i) low SiO_2 (60-70wt%) -high MgO (TG suite, GAG suite trondhjemite-tonalite gneiss and Nooitgedacht diorite-tonalite) suites and
(ii) high SiO_2 (>70wt%) -low MgO (GG suite and GAG suite ganodiorite/adamellite gneiss) suites.

The TG suite, GAG suite trondhjemite-tonalite gneiss and Nooitgedacht diorite-tonalite differ distinctly from the rest of the HHD (including the remaining granitoids from Nooitgedacht outcrop) rocks in that these suites have higher Al_2O_3 (>15 wt%), MgO (>2wt %), Mg# (0.41-0.49), as well as Fe_2O_3, TiO_2 and MnO (>9wt%), Rb, Sr, Ba, Cr, Ni contents compared to the rest of the HHD rocks. These suites therefore fall in what Smithies and Champion (2000) described as a high-Mg diorite series, a rare suite of TTG rocks, which except for high-Mg values also has a characteristic low SiO_2 content (~60 wt%).

Crystallisation and fractionation of the HHD minerals could account for the negative trends displayed by CaO, Al_2O_3, MgO, FeOt, TiO_2 and P_2O_5. For the HHD rocks there is generally limited scatter in the major element trends but is the opposite for the Nooitgedacht rocks. There is generally more scatter in the Nooitgedacht major element trends than would be expected if crystal fractionation was the sole process responsible for the variation. The great degree of scatter on the Mg# versus SiO_2 diagram is further indication that HHD rocks probably did not form through crystal fractionation.

The scattered geochemical variation in the HHD and Nooitgedacht rocks represents an overtone that is probably due to local variations in the source of each suite. Differences between HHD and the rocks at Nooitgedacht suggest that the entire HHD was probably assembled by the aggregation of different magma batches, each with a slightly different melt composition. These variations are could be the result of variation between the starting magmas for each suite with limited mixing between the individual suites.

The TG and GAG suites reflect the high LILE (Sr, Rb, Ba) contents shown by TTG suites, which indicates crystal fractionation and confirms a mantle source component. High LILE (Sr, Ba, Rb) content reflect either a subduction modified source or mantle contamination of the slab melt. High LILE concentrations such as exhibited by the TG suite and Nooitgedacht diorite-tonalite can not be explained through crustal contamination. High Mg#, Ni, Cr and LILE indicates a LILE-enriched mantle source.

The high content of compatible elements (Ni, Co and Cr) distinguishes between the high-Mg diorite (TG suite and the GAG suite tonalite-trondhjemite gneiss as well as the diorite-tonalite of the Nooitgedacht outcrop) and the more calc-alkaline granitoids (GG suite and trondhjemites of the GAG suite) of the HHD. Elevated Ni and Cr content are prominent features in adakites and TTG suites including high Mg-diorite suites such as the Superior Province and Pilbara and together with the high Mg# favors melting of a subducted oceanic slab and is considered proof of mantel wedge interaction. High Mg-diorite magmatism, documented in the TG suite and the Nooitgedacht complex, is broadly similar to that observed in the Superioir Province and Pilbara Craton. High-Mg diorites are considered to be relatively scares (<5% of all Archaean TTGs). This is also consistent in the HHD where the high-Mg series is restricted to the southern edge of the HHD and xenoliths (Nooitgedacht outcrop) occurring in the GAG suite.

The majority of the HHD granitoids (GAG and GG suites), however, have a lower LILE, $Mg^{\#}$, Cr and Ni content than is expected from a rock which has passed through the mantle wedge. This could be the result of the slab melt passing through a thinner mantle wedge and therefore suffering only small degrees of interaction. Martin and Moyen (2002) showed shallower depth of melting of the subducted slab resulted in the slab melt passing through a thinner mantle wedge and therefore suffered only small degrees of interaction

The HHD granitoids display a strongly fractionated REE pattern, a characteristic shared by modern adakites and TTGs. The steep REE patterns (higher La_N/Yb_N ratios) TG and GAG suites generally displayd by TTG suites. Elemental ratios such as low Rb/Sr (<0.15), elevated Sr/Y (>40), $(La/Yb)_N$ >1 have been suggested to be characteristic of TTG suites. Depletion in HREE, with respect to chondritic concentrations is a source related feature due to preferential partitioning of these elements in coexisiting restitic garnet.From the chondrite-normalised REE diagram for the HHD rocks it is clear that the majority of the granitoid suites show a typical TTG strongly fractionated REE pattern with the exception of the GG (homogenous granodiorite) suite.

The REE pattern of granitoids containing SiO2 >70wt% discriminate between the two main groupings in the HHD granitoids where the first group is characterised by low LREE content, low YbN, LaN/YbN in the range of and the absence of a significant negative Eu anomaly. The second group is marked by higher LREE contents, lower LaN/YbN and the REE pattern displaying a significant negative Eu anomaly- these rocks have affinities with post-Archaean arc granitoids (GGM)

The strong arc signature of the fluid mobile elements can not easily be reconciled with the view that TTG suites are formed by direct melting of oceanic crust. The signature of the HHD granitoids seems to be the rule for Archaean granitoids. HFSE depletion and distinct enrichment of fluid sensitive elements such as Pb, observed in all three HHD granitoid suites, are generally considered to be a typical signature of slab dehydration. This signature of Pb enrichment and high LILE concentrations of the HHD suites are incompatable with direct melting of subducted oceanic slabs. Kleinhans *et al.* (2003) suggests that the signature of HFSE depletion and distinct enrichment of fluid sensitive elements such as Pb reflects the fact that these rocks are derived from refertilised mantle above subducion zones. Kleinhans *et al.* (2003) also showed that dehydration to produce a voluminous magma of this scale could only be produced by subduction of an immense quantity of hydrated rock into the mantle. They concluded that it seems unavoidable that Archaean TTG and GGM were derived from melts, which formed in the refertilised mantle wedge. The over enrichment in Pb and HFSE depletion in all HHD suites can therefore be considered to be a typical signature of slab dehydration. Kleinhans *et al.* (2003) reported similar patterns for the TTG and GGM suites of the Barberton mountain land.

The presence or absence of plagioclase in the melting residue controls the behavior of Sr and to some extent ($CaO+Na_2O$). Increased ($CaO+Na_2O$) and Sr reflect the increase in the abundance of plagioclase in the melt residue. The presence of a small positive or no Eu anomaly and a strong positive Sr anomaly in the TG suite reflects melting at pressures outside the plagioclase stability field. On the other hand the negative Eu anomaly and the absence of a positive Sr anomaly for the GAG and GG suites could reflect the presence of plagioclase in the source. The negative Eu anomaly is an indication that plagioclase fractionation probably occurred during the evolution of the GAG and GG suites. The positive Sr anomaly seen in adakites suggests greater interaction between the slab melt and a thicker mantel wedge. The same would be true for the positive Sr anomaly shown by the TG suite, the adakite analogue of the HHD.

Geochemical similarities between the high SiO_2 suites of the HHD (TG, GAG and Nooitgedacht tonalite diorite) and the High-Mg diorite series of the Pilbara Craton and Superior Province as well as the Closepet Granite are evident.

6 CONCLUDING REMARKS

- The macro and microscopic investigation of the HHD showed that this window of Archaean rock consists of a mosaic of granitoids manifest by the differences in areal extent, mineralogy, texture, composition and age.
- Due to poor exposure the contact relationships between the various granitoids could not be confirmed.
- Based on the microscopic and geochemical investigation the HHD granitoids could be subdivided into three main suites:
  - The Tonalitic Gneiss suite (TG) around the southern boundary
  - The Granodiorite to Adamellite Gneiss suite (GAG) across the northern part
  - The Granodiorite/adamellite to Granite suite (GG) occurring between the TG and GAG suites and consisting of
    - porphyritic granodiorite
    - medium-grained pinkish-grey granite
    - homogeneous adamellite/granodiorite
- The new major, trace and REE element data from across the HHD provide confirmation that the HHD granitoids represent TTG suites at the centre of the Kaapvaal Craton.
- Petrography and geochemistry is in agreement that the Archaean HHD granitoids can be subdivided into a tonalite-trondhjemite-granodiorite or GGM series (GG suite and trondhjemites of the GAG suite) and a high Mg-diorite series (tonalities TG suites and tonalite-trondhjemite gneiss of the GAG suite and Nooitgedacht diorite-tonalite).
- In this thesis, sanukitoid (high-Mg diorite) rocks are documented for the first time in the Archaean of the central Kaapvaal Craton
- The TG suite represents high-Mg diorites similar to those described for the Pilbara Craton and Superior Province.
- The high $Mg^{\#}$, Ni and Cr as well as over enrichment in Pb and HFSE depletion of TG suite suggests that it is unavoidable that these rocks were derived from melts which were in contact with the mantle wedge in a subduction environment.
- The most appropriate model for the formation of the TG suite is that of subduction of an oceanic slab and the interaction with the mantle wedge.

- The presence of restite phases (such as plagioclase cores) and approximate TTG geochemistry in the GAG and GG suites suggests that it is most likely that these rocks were derived from remelting of a TTG protolith
- The most appropriate model for the formation of the GAG and GG suites are the partial melting of a TTG protolithic with a subducted slab and mantle wedge signature (similar to the TG suite).
- The Rietfontein fault may be a possible collisional zone at the centre of the KC along which subduction of an oceanic plate occurred.
- The heat source needed for the melting of the protolithic TTG crust could also have been related to the proposed collision zone around the southern edge of the HHD.
- Post-orogenic extension in pull-apart basins or along active or passive continental margins may produce a heat source, in the form of a mantle derived magma, needed for the generation of granitic magmas capable of ascending to the upper crust

- Discrepencies in the age determinations from previous studies might be eleviated if the assumption of the presence of restite material in the GAG and GG suites is correct. If this assumption is correct then age variations can be seen as an artefact of the presence of restite zircons.
- Although not part of this investigation, previous data from rocks of the Nooitgedacht exposure were evaluated along with the current HHD data. It can be concluded that the rocks from this exposure show some differences in the geochemistry when compared to the rest of the HHD and should therefore not be used for extrapolation of a petrogenic model for the entire HHD.

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1:250 000 East- and West Rand maps by the then Geological Survey of South Africa (1973)

APPENDIX C

Table 1: Sample list

No	Rock type	Description	Position	Long	Lat
D1	Rhyolite	Fine-grained, pinkish, jointed	Road-cutting R28 before Lanseria turn-off	27° 52' 03.8"E	26° 01' 04.2" S
D2	Granodiorite	Medium-grained, dark grey	Road-cutting R28 before Lanseria turn-off	27° 52' 02.9" E	26° 01' 03.3" S
D3	Granodiorite	Medium-grained, light grey	Road-cutting R28 before Lanseria turn-off	27° 52' 07.6" E	26° 01' 04.5" S
D4	Granodiorite	Medium-grained, light grey	Road-cutting R28 before Lanseria turn-off	27° 52' 09.0" E	26° 01' 01.9" S
D5	Granodiorite	Medium-grained, dark grey	Road-cutting R28 before Lanseria turn-off	27° 52' 07.0" E	26° 01' 02.9" S
D6	Granodiorite	Medium-grained, grey	Klein Jukskei river, Sharonlea, Randburg	27° 58' 26.1" E	26° 04' 03.8" S
D7	Rhyolite	Medium-grained, porphyritic, creamy/off-white	Road-cutting R28, Muldersdrift	27° 58' 25.6" E	26° 04' 03.4" S
D8	Rhyolite	Fine-grained, pinkish, jointed	Road-cutting R28, East of Lanseria turn-off	27° 51' 06.9" E	26° 01' 07.0" S
D9	Granodiorite	Fine to medium-grained, red	Hans Srijdom rd.	27° 57' 19.8" E	26° 03' 44.5" S
D10	Granodiorite	Fine to medium-grained and porphyritic, red	Hans Srijdom rd.	27° 57' 20.0" E	26° 03' 44.0" S
D11	Granodiorite	Fine to medium-grained, grey	Hans Srijdom rd.	27° 57' 24.3" E	26° 03' 43.8" S
D12	Granodiorite	Fine to medium-grained, grey	Klein Jukskei, off Hans Srijdom rd- Amsterdam rd	27° 57' 57.9" E	26° 04' 01.3" S
D13	Granodiorite	Fine to medium-grained, light grey	Klein Jukskei	27° 58' 39.4" E	26° 03' 30.8" S
D14	Granodiorite	Medium to coarse-grained, porphyritic, grey	Braamfontein Spruit, Delta Park, Craighall Park	28° 00' 55.8" E	26° 07' 33.7" S
D15	Granodiorite	Fine to medium-grained, light pinkish-grey	Braamfontein Spruit, Watervall aven. Craighall	28° 01' 19.7" E	26° 06' 21.3" S
D16	Tonalite-gneiss	Medium-grained, grey, gneissic	Braamfontein Spruit, Emmarentia	28° 00' 12.9" E	26° 10' 3.4" S
D17	Granodiorite	Medium to coarse-grained, pinkish-grey	Braamfontein Spruit, Pankhurst	28° 00' 11.9" E	26° 08' 4.9" S
D18	Medium-grey, granodiorite	Medium-grained, medium-grey,	Jukskei Quarry, Halfway House	na	na
D19	Light-grey granodiorite	Fine to medium-grained, light grey,	Jukskei Quarry, Halfway House	na	na
D20	Very light-grey granodiorite	Medium-grained, very light grey,	Jukskei Quarry, Halfway House	na	na

No	Rock type	Description	Position	Long	Lat
D21	Porphyritic light-grey granodiorite	Medium-grained to porphyritic, very light grey,	Jukskei Quarry, Halfway House	na	na
D22	Dark-grey granodiorite	Medium-grained, dark-grey,	Jukskei Quarry, Halfway House	na	na
D23	Very dark grey granodiorite	Medium-grained, very dark grey,	Jukskei Quarry, Halfway House	na	na
D24	Dark-grey granodiorite	Fine-grained, dark grey,	Jukskei Quarry, Halfway House	na	na
D25	Extra dark grey	Medium-grained, extra dark grey,	Jukskei Quarry, Halfway House	na	na
D26	Spotted/ dark grey	Medium to coarse-grained, spotted dark grey in contact with dark grey with different foliation directions	Jukskei Quarry, Halfway House	na	na
D27	Spotted dark grey Gneiss	Medium to coarse-grained spotted dark grey	Jukskei Quarry, Halfway House	na	na
D28	Spotted medium grey Gneiss	Medium to coarse-grained, spotted medium-grey	Jukskei Quarry, Halfway House	na	na
D29	Spotted light grey Gneiss	Medium to coarse-grained, spotted light grey	Jukskei Quarry, Halfway House	na	na
D30	Spotted extra dark grey Gneiss	Medium to coarse-grained, spotted extra dark grey	Jukskei Quarry, Halfway House	na	na
D31	Banded gneiss	Light and medium grey bands, medium-grained	Jukskei Quarry, Halfway House	na	na
D32	Porphyritic medium-grey granodiorite	Medium-grained to porphyritic, medium-grey	Jukskei Quarry, Halfway House	na	na
D34	Xenoliths	Mafic xenoliths in spotted light grey material	Jukskei Quarry, Halfway House	na	na
D35	Red granite	Medium-grained, red	Jukskei Quarry, Halfway House	na	na
D36	Mafic gneiss	Mafic rock with gneissic texture	Jukskei Quarry, Halfway House	na	na
D37	Homogeneous granodiorite	Medium-grained, pinkish-grey	William Nicol drive	na	na
D38	Granodiorite gneiss	Medium-grained, pinkish-grey rock showing foliation	Witkoppen road	na	na
D39	Granodiorite gneiss	Medium-grained, pinkish-grey rock showing foliation	Witkoppen road	na	na
D40	Granodiorite gneiss	Homogeneous pink-grey rock showing folliation	Jukskei River	na	na
D41	Granodiorite gneiss	Homogeneous reddish rock showing folliation	Braamfontein Spruit at Cheetha road	na	na
D42	Granodiorite gneiss	Medium-grained grey rock showing folliation	Jukskei River at kayalami	na	na

No	Rock type	Description	Position	Long	Lat
D43	Homogeneous granodiorite	Homogeneous, medium-grained orange rock	Braamfontein Spruit, Braynston	na	na
D44	Homogeneous granodiorite	Homogeneous, medium-grained light grey rock with some pegmatite veining	c/o Acasia and Aspen, Vandia Grove	na	na
D45	Homogeneous granodiorite	Homogeneous, coarse-grained to pegmatitic rock associated with D44	c/o Acasia and Aspen, Vandia Grove	na	na
D46	Porphyritic granodiorite	Porphyritic dark grey rock	Honeydew road	na	na
D47	Porphyritic granodiorite	Porphyritic dark grey rock	Water tower at DF Malan drive	na	na
D48	Granodiorite gneiss	Medium-grained grey rock showing folliation	DF Malan drive road cutting	na	na
D 50	Tonalite gneiss	Medium-grained, grey rock with gneissic texture	Cornelis avenue	na	na
D51	Granodiorite	Homogeneous pink-grey rock showing folliation	Struben Valley hill	na	na

Table 4: Summary of world occurrences of TTG rocks

Terrane	**Country**	**Locality**	**Age (Ma)**	**Suite**	**Rock type**	**Literature**
Pilbara	Western Australia		3500-2850		Tonalites to monzo-granite and	Bagas et al., 2002; Chen et al., 2006; Champion and Smithies, 1999
Pilbara	Western Australia	Eastern part of PC	3500-3300	Shaw batolith	Granodiorite with subsidiary tonalites and adamellites	van Kranedonk *et al.*, 2007; Champion and Smithies, 2001; Bickle *et al.*, 1989; Chen *et al.*, 2006;
Pilbara	Western Australia	Eastern part of PC	3300	Mount Edgar batolith		Champion and Smithies, 2001; Bickle *et al.*, 1993; Bagas et al., 2001;
Pilbara	Western Australia	Eastern part of PC	3400-3600	Muccan batolith		van Kranedonk and Collins, 1998; van Kranedonk *et al.*, 2007
Pilbara	Western Australia	Eastern part of PC	3500-3600	Carlindie batolith		van Kranedonk and Collins, 1998; van Kranedonk *et al.*, 2007
Pilbara	Western Australia	Eastern part of PC	3400->3600	Warrawagine		van Kranedonk and Collins, 1998; van Kranedonk *et al.*, 2007
Pilbara	Western Australia	Eastern part of PC	3100-3400	Yule batolith	Monzogranite	van Kranedonk and Collins, 1998; van Kranedonk *et al.*, 2007
Pilbara	Western Australia	Eastern part of PC	3000-3500	Corunna Downs batolith	Tonalites to monzo-granite, granodiorite and syenite	Bagas et al., 2002; Bickle *et al.*, 1989; van Kranedonk *et al.*, 2007
Pilbara	Western Australia	Central part of PC, Mallina basin	2950 2955-2945	Mallina high-Mg diorite	Diorite, monzodiorite, tonalite and granodiorite Sanukitoid	Smithies and Champion, 2000; Smithies *et al.*, 2004; van Kranedonk *et al.*, 2007
Pilbara	Western Australia	Central part of PC	2950	Portree Granitoid Complex	Alkaline granite	van Kranedonk *et al.*, 2007
Pilbara	Western Australia	Western part of PC	3100-3400	Caines Well Batolith	Granodiorite, monzogranite	van Kranedonk *et al.* ,2007
Pilbara	Western Australia	Western part of PC	3100-3400	Cherratta	Tonalite, granodiorite	van Kranedonk *et al.* ,2007
Pilbara	Western Australia	Western part of PC	3300-3400	Harding		van Kranedonk *et al.*, 2007
Pilbara	Western Australia	Western part of PC	3300-3400	Dampier		van Kranedonk *et al.*, 2007
Yilgarn	Western Australia		3730-2620	Narryer Terrane	Monzogranite, TTG, granodiorite, sanukitoid, syenite	Chen *et al.*, 2006
Yilgarn	Western Australia			South-western Gneiss Terrane		Chen *et al.*, 2003

Terrane	Country	Locality	Age (Ma)	Suite	Rock type	Literature
Yilgarn	Western Australia			Murchisnon Terrane		Chen *et al.*, 2003
Yilgarn	Western Australia		3010-2620	Youanmi Terrane		Chen *et al.*, 2006
Yilgarn	Western Australia		2720-2630	Eastern Goldfields Terrane	Granite	Chen *et al.*, 2003;Chen *et al.*, 2006
Yilgarn	Western Australia			Souther Cross Terrane		Chen *et al.*, 2003
Yilgarn	Western Australia		2940-2630		Monzogranite to granodiorite, sanukitoid	Chen et al., 2006; Champion and Smithies, 2000
Superior	Canada	Northeastern SP	2775-2668	Lake Minto domain pluton	Granodiorite, sanukitoids	Percival et al., 2005; Stott, 2003; Evans and Hanson, 1997; Stern et al., 1989; Sutcliffe et al., 1990
Superior	Canada	Northeastern SP	2725	Utsalik domain pluton	Granodiorite, monzogranite, diorite	Percival et al., 2005
Dhawar	South India	Western DC	3300-2700			
Dhawar	South India	Eastern DC	3000-2500	Peninsular Gneiss	TTG, Sanukitoid (monzodiorite, granodiorite), biotite-granite	Chadwick et al., 2000; Rollinson et al., 1981; Moyen et al., 2003; Jayananda et al., 2000
Dhawar	South India	Eastern DC	2518	Closepet granite	Closepet-type granite (diorite, granodiorite, granite), Monzogranite, monzonite, migmatite	Chadwick et al., 2000; Rollinson et al., 1981; Moyen et al., 2003; Jayananda et al., 2000
Barberton	South Africa		3236-3227	Kaap Valley pluton	Tonalite, trondhjemite, granodiorite,	Koma and Davies, 1994; Kroner *et al*., 1991; Robb *et al*., 1986
Barberton	South Africa		3236-3227	Nelshoogte pluton	Trondhjemite, tonalite, diorite	De Ronde and Koma, 2000; Clemens *et al*., 2006
Barberton	South Africa			Badplaas pluton	Trondhjemite, tonalite	Clemens *et al*., 2006
Barberton	South Africa		3216	Dalmein pluton	Tonalite, trondhjemite, granodiorite	Clemens *et al*., 2006
Barberton	South Africa		3460-3443	Stolzburg pluton	Trondhjemite	Clemens *et al*., 2006
Barberton	South Africa		3460-3443	Theespruit pluton	Trondhjemite	Clemens *et al*., 2006
Barberton	South Africa		3460-3443	Doornhoek		Clemens *et al*., 2006
Barberton	South Africa			Goedehoop	Trondhjemite, tonalite, diorite	Poujol *et al*., 1996; Brandle *et al*., 1996; Poujol and Robb, 1999; Clemens *et al*., 2006

Terrane	**Country**	**Locality**	**Age (Ma)**	**Suite**	**Rock type**	**Literature**
Barberton	South Africa		3509	Steynsdorp pluton	Tonalite, tondhjemite, granodiorite	Clemens *et al*., 2006
Murchinson	South Africa		3090	Harmony Granite		Poujol and Robb, 1999
Murchinson	South Africa		2970	Maranda Granite,		Poujol, 1997
Vredefort	South Africa		3425-2564			Poujol *et al.*, 2002
Rand anticline	South Africa				Adamellite to granite	Robb and Meyer, 1987

Table 7: Mineralogical and petrological characteristics of the HHD granitoids

	Tonalite Gneiss suite (TG)	Granodiorite to Adamellite Gneiss suite (GAG)		Granodiorite/adamellite to Granite suite (GG)		
Rock type	Tonalite to granodioritic gneiss	Granodiorite to adamellite gneiss	Tonalite to trondhjemite gneiss	Pink-grey Granite	Homogeneous adamellite to granodiorite	Porphyritic Granodiorite
Overall texture	Medium-grained, granular	Medium-grained granular	Medium-grained granular	Medium to coarse-grained, granular	Medium to coarse-grained, granular	Medium to coarse-grained, granular and locally porphyritic
Constituent minerals						
Qtz	19 - 25 modal %, anhedral, interstitial, myrmecitic intergrowths	12 - 50 modal %, anhedral, interstitial, myrmecitic intergrowths, saginetic rutile needles, inclusions of pl, bi, ill	23 - 27 modal %, anhedral, interstitial, myrmecitic intergrowths, saginetic rutile needles, inclusions of pl, bi, ill	19 - 40 modal %, anhedral, saginetic rutile needles	29 - 34 modal %, anhedral, saginetic rutile needles	23 - 24 modal %, anhedral, saginetic rutile needles
Pl	45 - 55 modal %, euhedral laths to granular and interstitial, normal zoned, core altered to ep, ser*, cal Average rim An$_{9.5}$ Average core An$_{9}$	31 - 52 modal %, euhedral to anhedral, lath-shaped, corrosive, normal zoned, core altered to ep, ser*, cal, clear Ab rims twinned, Average rim An$_{5.2}$ Average core An$_{11}$	52 - 60 modal %, euhedral to anhedral, lath-shaped, corrosive, normal zoned, core altered to ep, ser*, cal, clear Ab rims twinned, Average rim An$_{12.6}$ Average core An$_{17.7}$	33 - 41 modal %, euhedral to anhedral, laths, corrosive, normal zoned, core altered to ep, ser*, cal, clear Ab rims twinned, Average rim An$_{3.3}$ Average core An$_{2.8}$	5 - 62 modal %, euhedral to anhedral, laths, corrosive, normal zoned, core altered to ep, ser*, cal, clear Ab rims twinned, zoned Average rim An$_{3.2}$ Average core An$_{10.4}$	50 - 54 modal %, euhedral to anhedral, laths, corrosive, normal zoned, core altered to ep, ser*, cal, clear Ab rims twinned, phenocrysts oscillatory zoned Average rim An$_{4.2}$ Average core An$_{8.6}$
Kfs	< 2 modal%, anhedral, interstitial Or$_{96-6}$	11 - 34 modal %, anhedral, microcline and/or orthoclase, poikilitically enclose qtz, pl, microperthite	4 - 16 modal %, anhedral, microcline and/or orthoclase, poikilitically enclose qtz, pl, microperthite Or$_{95}$	13 - 30 modal %, anhedral, microcline and/or orthoclase, poikilitically anclose qtz, pl, microperthite, graphic intergrowths Or$_{95}$	1 - 52 modal %, anhedral, microcline and/or orthoclase, poikilitically anclose qtz, pl, microperthite, graphic intergrowths Or$_{95}$	16 - 18 modal %, anhedral, microcline and/or orthoclase, poikilitically anclose qtz, pl, microperthite, graphic intergrowths Or$_{95}$

	Tonalite Gneiss suite (TG)	Granodiorite to Adamellite Gneiss suite (GAG)		Granodiorite/adamellite to Granite suite (GG)		
Rock type	Tonalite to granodioritic gneiss	Granodiorite to adamellite gneiss	Tonalite to trondhjemite gneiss	Pink-grey Granite	Homogeneous adamellite to granodiorite	Porphyritic Granodiorite
Bt	1 - 2 modal %, pleochroic green, sagenetic rutile needles, inclusions of accessory minerals, orientated, altered to ttn, ms, chl	1 - 9 modal %, pleochroic green, sagenetic rutile needles, inclusions of accessory minerals, orientated	4 - 14 modal %, pleochroic green, sagenetic rutile needles, inclusions of accessory minerals, orientated	5 - 9 modal %, pleochroic green, sagenetic rutile needles, inclusions of accessory minerals, orientated	1 - 6 modal %, pleochroic green, sagenetic rutile needles, inclusions of accessory minerals, orientated	5 - 6 modal %, pleochroic green, sagenetic rutile needles, inclusions of accessory minerals, orientated
Hb	13 - 29 modal %, euhedral to anhedral, clots, associated with bi and ep	-	<1 modal %, euhedral to anhedral, associated with bi and ep	-	-	-
Ms	1 modal %,	1 modal %	1 modal %	1 modal %	1 modal %	1 modal %
Ep	anhedral associated with pl, euhedral associated with bi, hb, zoned, aln core	anhedral associated with pl, euhedral associated with bi, zoned	anhedral associated with pl, euhedral associated with bi, zoned	anhedral associated with pl, minor euhedral associated with bi, zoned	anhedral associated with pl, minor euhedral associated with bi, zoned	anhedral associated with pl, euhedral associated with bi, zoned
Aln	anhedral to subhedral, zoned	anhedral to subhedral	anhedral to subhedral	anhedral to subhedral	anhedral to subhedral	anhedral to subhedral
Ttn	primary euhedral to subhedral, secondary anhedral rim around ill	primary euhedral to subhedral, anhedral secondary rim around ill	primary euhedral to subhedral, anhedral secondary rim around ill	primary euhedral to subhedral, anhedral secondary rim around ill	primary euhedral to subhedral, anhedral secondary rim around ill	primary euhedral to subhedral, anhedral secondary rim around ill
Other accessory minerals	Zrn, Ap, Ill	Zrn, Ap, Ill	Zrn, Ap, Ill	Zrn, Ap, Ill	Zrn, Ap, Ill	Zrn, Ap, Ill

*ser=sericite, other mineral abbreviations according to Kretz (1983)

Table 8a: Modal analysis for the GAG and TG suites

	Granodiorite to Adamellite Gneiss suite (GAG)										Tonalite Gneiss Suite (TG)				
	Granodiorite to adamellite gneiss		Tonalite gneiss												
Sample	**D24-1**	**D24-2**	**D22-1**	**D22-2**	**D23-1**	**D23-2**	**D27-1**	**D27-2**	**D28-1**	**D28-2**	**D16-1**	**D16-2**	**D-50-1**	**D-50-2**	**D-50-3**
Total points counted	**960**	**1215**	**1032**	**1281**	**1196**	**1254**	**1105**	**1190**	**1190**	**1296**	**1245**	**1233**	**895**	**983**	**1066**
Quartz	27	26	26	3	26	27	23	26	25	24	19	22	23	25	24
Plagioclase unaltered	33	22	45	48	46	47	45	43	43	36	29	25	30	31	34
Plagioclase altered	19	24	15	12	9	10	12	9	12	18	21	20	23	20	21
K-Feldspar unaltered	11	22	<1	<1	9	4	9	12	16	10	<1	<1	<1	3	1
K-Feldspar altered	<1	<1	0	0	<1	0	<1	<1	<1	<1	-	-	-	-	-
Biotite unaltered	5	3	11	13	9	10	9	7	4	9	<1	<1	1	2	1
Biotite altered to:															
Chlorite	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Muscovite	<1	1	<1	1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1
Sphene/ Titanite	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	-
Amphibole unaltered	-	-	-	-	-	-	-	-	-	-	24	25	15	14	12
Amphibole altered to:															
Chlorite	-	-	-	-	-	-	-	-	-	-	4	4	4	<1	1
Ilmenite	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Magnetite	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Apatite euh in qz, plag	<1	<1	<1		<1	<1	<1	<1	<1	<1	<1	<1		<1	<1
Apatite anh in biotite		<1		-	<1		<1	<1	<1	<1	-	-	-	-	-
Epidote anh in biotite	<1	1	1	1	<1	<1	1	1	<1	1	3	3	2	4	3
Allanite euh	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1
Allanite anh with Ep	1	<1		-	<1	<1	<1	1	<1	<1	<1	<1	1	<1	2
Sphene euh	-	-	<1	-	-	-	-	-	-	-	<1	<1	<1	<1	1
Sphene anh	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1
Sphene coronas															
Zircon	<1	-	-	<1	<1	<1	<1	<1	<1	<1	-	-	<1	<1	-
Muscovite	-	1	<1		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1
Calcite	<1	<1	-	-	-	<1	-	-	-	-	-	-	<1	<1	-

Table 8b: Modal analysis for the GAG suite

	Granodiorite to Adamellite Gneiss suite (GAG)																					
	Granodiorite to adamellite gneiss																					
Sample	**D18-1**	**D18-2**	**D19-1**	**D19-2**	**D20-1**	**D20-2**	**D21-1**	**D21-2**	**D-38-1**	**D-38-2**	**D-38-3**	**D-40-1**	**D-40-2**	**D-40-3**	**D-41-1**	**D-41-2**	**D-41-3**	**D-42-1**	**D-42-2**	**D-42-3**	**D-48-1**	**D-48-2**
Total points counted	**1309**	**1041**	**1224**	**952**	**1435**	**1305**	**1200**	**1362**	**1268**	**1155**	**886**	**1015**	**1247**	**1215**	**1321**	**1141**	**1087**	**1374**	**1177**	**1226**	**939**	**1181**
Quartz	30	34	28	22	32	29	29	24	35	32	30	33	36	32	21	32	32	31	33	31	28	34
Plagioclase unaltered	24	24	31	32	35	33	15	27	32	31	29	35	20	36	21	25	36	31	24	23	31	36
Plagioclase altered	18	15	18	20	17	16	24	15	4	11	9	18	19	7	28	21	10	3	7	11	10	7
K-Feldspar unaltered	24	21	16	18	12	20	25	27	27	24	30	19	21	19	25	17	17	32	34	32	19	11
K-Feldspar altered	<1	<1	<1	-	<1	-	2	<1	<1	-	<1	-	<1	-	1	1	<1	-	-	<1	-	<1
Biotite unaltered	2	2	5	5	3	1	9	3	1	1	1	2	1	2	1	1	2	1	1	1	1	3
Biotite altered to:																						
Chlorite	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	1
Muscovite	<1	<1	<1	1	<1		<1	1	<1	<1	<1	1	<1	<1	<1	<1		<1	<1	<1	<1	<1
Sphene/ Titanite	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	-	<1	<1	2	1
Amphibole unaltered	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphibole altered to:																						
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ilmenite	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	<1	<1	-	-
Magnetite	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	<1	<1	-	-
Apatite euh in qz, plag	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Apatite anh in biotite	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	<1	<1	-	<1	<1	<1	-	-	<1	<1	-
Epidote anh in biotite	1	<1	1	1	<1	<1	<1	<1	1	<1	<1	1	<1	<1	1	2	<1	<1	<1	1	-	2
Allanite euh	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	<1	<1	-	-	<1	2	1
Allanite anh with Ep	<1	<1	<1	<1	<1	<1	<1	<1	-	<1	-	<1	<1	<1	-	<1	-	-	<1	<1	3	<1
Sphene euh	-	-	<1	-	-	-	-	-	1	-	-	-	<1	-	<1	<1	<1	-	-		<1	<1
Sphene anh	<1	<1	<1	<1	<1	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	<1	<1	<1	<1
Sphene coronas	-	-	-	-	-	-	-	-	<1	-	-	-	<1	-	-	<1	-	-	-	-	-	-
Zircon	<1	<1	<1	<1	<1	-	-	<1	<1	-	-	<1	<1	-	<1	<1	<1	-	-	-	<1	<1
Muscovite	<1		<1	1	1	-	1	1	<1	<1	<1	2	2	2	1	1	2	<1	-	<1	1	2
Calcite	-	-	<1	-	-	-	-	-	<1	<1		<1	<1	<1	<1	<1	<1	-	-	-	<1	<1

Table 8c: Modal analysis for the GG suite

	Granodiorite/adamellite to Granite suite (GG)																		
	Homogeneous adamellite to granodiorite																		
Sample	**D06-1**	**D06-2**	**D12-1**	**D12-2**	**D13-1**	**D13-2**	**D15-1**	**D15-2**	**D-37-1**	**D-37-2**	**D43-1**	**D43-2**	**D43-3**	**D44-A1**	**D44-A2**	**D44-B1**	**D44-B2**	**D45-1**	**D45-2**
Total points counted	**1218**	**1365**	**1075**	**1025**	**1101**	**1110**	**1100**	**1255**	**1326**	**1337**	**1341**	**1340**	**1158**	**1336**	**1346**	**1340**	**1366**	**1161**	**1174**
Quartz	34	33	34	35	37	33	31	29	29	31	31	34	33	34	30	32	35	29	36
Plagioclase unaltered	31	30	12	12	11	12	34	32	34	31	17	1	32	34	33	53	40	26	61
Plagioclase altered	9	11	30	26	15	15	6	6	6	5	<1	4	<1	2	2	<1	2	1	1
K-Feldspar unaltered	21	19	17	18	32	30	26	28	27	30	49	52	33	28	34	11	22	41	1
K-Feldspar altered		<1	<1	<1	2	2	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	-
Biotite unaltered	3	3	4	3	2	2	2	2	1	2	<1	<1	1	1	1	<1	1	<1	2
Biotite altered to :																			
Chlorite	1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Muscovite	<1	<1	1	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sphene/ Titanite	<1	<1	1	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1
Amphibole unaltered	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphibole altered to:																			
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ilmenite	-	<1	<1	<1	2	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Magnetite	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Apatite euh in qz, plag	<1	<1	<1	<1	<1	<1	<1	<1	<1	-	-	<1	-	<1	<1	<1	<1	<1	<1
Apatite anh in biotite	<1	<1	<1	<1			<1	<1	<1	-	-	-	-	-	-	-	-	-	-
Epidote anh in biotite	<1	2	<1	<1	<1	<1	1	2	1	<1	-	-	-	<1	<1	<1	<1	-	-
Allanite euh	-	-	<1	-	-	-	-	<1	-	-	-	-	-	<1	<1		<1	-	-
Allanite anh with Ep	-	<1	<1	<1	-	-	-	<1	-	<1	-	-	-	<1	<1		<1	-	-
Sphene euh	<1	-	-	-	-	-	<1	-	-	-	-	-	-	-	-	-	-	-	-
Sphene anh	-	<1	<1	<1	-	-	<1	-	<1	-	-	-	-	<1	<1	<1	<1	-	-
Sphene coronas	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zircon	-	<1	<1	<1	-	-	<1	<1	<1	-	-	<1	-	-	-	<1	-	-	-
Muscovite	<1	<1	1	1	<1	<1	<1	<1	<1	<1	-	8	<1	<1	<1	1	<1	2	1
Calcite	-	-	-	-	-	-	-	-	-	<1	-	-	-	-	-	-	-	-	-

Table 8c: Modal analysis for the GG suite (*continue*)

	Granodiorite/adamellite to Granite suite (GG)																
	Pink-grey Granite													Porphyritic granodiorite			
Sample	**D02-1**	**D02-2**	**D02-3**	**D03-1**	**D03-2**	**D04-1**	**D04-2**	**D05-1**	**D05-2**	**D17-1**	**D17-2**	**D-51-1**	**D-51-2**	**D-46-1**	**D-46-2**	**D-47-1**	**D-47-2**
Total points counted	**1086**	**1056**	**1060**	**990**	**887**	**1051**	**1000**	**945**	**977**	**1190**	**1048**	**1179**	**1159**	**1165**	**1178**	**1152**	**1169**
Quartz	25	23	37	40	38	32	19	28	35	39	37	31	33	24	23	24	29
Plagioclase unaltered	6	6	5	30	2	3	4	3	3	1	4	28	26	26	25	20	17
Plagioclase altered	32	35	35	4	26	31	36	30	37	-	-	-	-	24	27	25	29
Sericite	-	-	-	-	-	-	-	-	-	32	34	5	5	-	-	-	-
Epidote	-	-	-	-	-	-	-	-	-	1	1	4	4	-	-	-	-
K-Feldspar unaltered	24	20	13	20	27	23	30	29	16	20	15	27	27	16	18	18	17
K-Feldspar altered to:																	
Kaolinite	<1	<1	<1	-	-	-	<1	-	-	<1	<1	<1	<1	<1	<1	<1	<1
Biotite unaltered	7	7	5	6	5	9	7	6	7	3	6	3	3	5	4	4	3
Biotite altered to:																	
Chlorite	-	-	<1	<1	1	<1	<1	2	<1	1	<1	<1	<1	1	1	1	1
Muscovite	-	-	<1	<1	<1	<1	<1	<1	-	1	<1	<1	<1	<1	<1	1	1
Sphene/ Titanite	-	-	-	-	-	<1	-	-	-	1	<1	<1	<1	<1	<1	<1	<1
Amphibole unaltered	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphibole altered to	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ilmenite	<1	<1	<1	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Magnetite	<1	<1	<1	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Apatite euh in qz, plag	<1	<1	<1	-	-	-	-	-	-	<1	<1	-	-	<1	<1	<1	<1
Apatite anh in biotite	-	-	-	-	-	-	-	-	-	<1	<1	-	-	<1	<1	<1	<1
Epidote anh in biotite	-	-	-	-	<1	<1	-	-	-	<1	<1	-	-	2	2	2	2
Allanite euh	-	-	-	-			-	-	-	-	-	-	-	<1	<1	<1	<1
Allanite anh with Ep	-	-	-	<1		<1	-	-	-	-	<1	-	-	<1	<1	<1	<1
Sphene euh	-	-	-	<1	<1		-	-	-	-	-	<1	<1	<1	<1	<1	1
Sphene anh	<1	<1		<1		<1		<1	<1	-	-	<1	<1	<1	<1	<1	<1
Sphene coronas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zircon	<1	<1	<1	-	-	-	-	-	-	<1	<1	-	-	<1	<1	<1	<1
Muscovite	3	3	4	1	1	2	19	<1		1	2	1	1	1	<1	1	1
Fluorite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<1	-	-
Calcite	-	-	<1	<1	2	<1	2	1	1	-	-	<1	<1	<1	<1	<1	<1

Table 9: Summary of the modal analysis of the HHD granitoids

	Granodiorite to Adamellite Gneiss suite (GAG)								**Tonalite Gneiss Suite (TG)**			
	Tonalite gneiss				Granodiorite to adamellite gneiss							
	avg	**min**	**max**	**std**	**avg**	**min**	**max**	**std**	**avg**	**min**	**max**	**std**
Total points	**1193.00**	**1032.00**	**1296.00**	**83.49**	**1176.00**	**886.00**	**1435.00**	**149.13**	**1084.40**	**895.00**	**1545.00**	**137.38**
Quartz	22.50	23.00	27.00	1.41	30.04	21.00	61.00	3.71	22.60	19.00	25.00	2.06
Plagioclase	56.25	52.00	60.00	2.63	43.21	31.00	52.00	8.64	50.80	45.00	55.00	3.37
K-Feldspar	10.00	4.00	16.00	4.84	21.79	11.00	34.00	6.55	2.00	1.00	3.00	1.00
Biotite	9.00	4.00	14.00	2.73	2.38	1.00	9.00	2.03	0.80	<1	2.00	0.75
Amphibole	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.60	13.00	29.00	6.77
Ilmenite	0.13	<1	1.00	0.33	0.00	<1	<1	0.00	0.00	<1	<1	0.00
Magnetite	0.00	<1	<1	0.00	0.00	<1	<1	0.00	0.00	<1	<1	0.00
Apatite	0.00	<1	<1	0.00	0.00	<1	<1	0.00	0.00	<1	<1	0.00
Epidote	0.63	<1	1.00	0.48	0.52	<1	2.00	0.65	3.00	2.00	4.00	0.63
Allanite	0.13	<1	1.00	0.33	0.32	<1	5.00	1.06	0.80	<1	3.00	1.17
Sphene	0.00	<1	<1	0.00	0.09	<1	1.00	0.29	0.40	<1	1.00	0.49
Zircon	0.00	<1	<1	0.00	0.00	<1	<1	0.00	0.00	<1	<1	0.00
Muscovite	0.00	<1	<1	0.00	1.38	<1	4.00	1.06	0.20	<1	1.00	0.40
Fluorite	0.00	<1	<1	0.00	0.00	<1	<1	0.00	0.00	0.00	0.00	0.00
Calcite	0.00	<1	<1	0.00	0.00	<1	<1	0.00	0.00	<1	<1	0.00

Table 9: Summary of the modal analysis of the HHD granitoids (*continue*)

	Granodiorite/adamellite to Granite suite (GG)											
	Homogeneous adamellite to granodiorite				Pink-grey Granite				Porphytitic granodiorite			
	avg	**min**	**max**	**std**	**avg**	**min**	**max**	**std**	**avg**	**min**	**max**	**std**
Total points	**1235.00**	**1100.00**	**1346.00**	**110.51**	**1048.00**	**887**	**1086**	**63.17**	**1166.00**	**1165.00**	**1178.00**	**6.50**
Quartz	32.63	29.00	34.00	2.34	32.08	19	40	7.21	25.00	23.00	24.00	0.50
Plagioclase	38.77	5.00	62.00	11.34	36.38	33	41	4.21	48.25	50.00	54.00	1.00
K-Feldspar	29.32	1.00	52.00	11.36	22.38	13	30	5.24	17.25	16.00	18.00	1.00
Biotite	9.03	<1	6.00	1.58	5.69	5	9	1.17	6.00	5.00	6.00	0.50
Amphibole	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilmenite	1.50	<1	2.00	0.54	0.00	<1	<1	0.00	<1	<1	<1	0.00
Magnetite	0.00	<1	<1	0.00	0.00	<1	<1	0.00	<1	<1	<1	0.00
Apatite	0.00	<1	<1	0.00	0.00	<1	<1	0.00	<1	<1	<1	0.00
Epidote	1.50	<1	2.00	0.78	0.00	<1	<1	0.00	2.00	2.00	2.00	0.00
Allanite	0.00	<1	<1	0.00	0.00	<1	<1	0.00	<1	<1	<1	0.00
Sphene	0.00	<1	<1	0.00	0.00	<1	<1	0.00	<1	<1	<1	0.00
Zircon	0.00	<1	<1	0.00	0.00	<1	<1	0.00	<1	<1	<1	0.00
Muscovite	2.14	<1	8.00	1.87	4.13	1	19	5.75	0.50	<1	<1	0.50
Fluorite	0.00	<1	<1	0.00	<1	<1	<1	0.00	<1	<1	<1	0.00
Calcite	0.00	<1	<1	0.00	0.83	<1	2	0.90	<1	<1	<1	0.00

Table 10a: Electron microprobe data for plagioclase cores from selected HHD granitoids

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
D18-2-1P	3	63.42	22.83	0.00	0.00	0.00	3.74	9.23	0.12	99.34	11.259	4.778	0.000	0.000	0.000	0.711	3.182	0.027	81.16	18.15	0.69
D18-2-1P	8	64.10	22.96	0.00	0.09	0.00	3.50	9.32	0.19	100.16	11.283	4.765	0.000	0.013	0.000	0.660	3.186	0.043	81.93	16.98	1.10
D18-2-1P	9	65.09	20.93	0.00	0.39	0.00	1.56	10.15	0.40	98.52	11.617	4.404	0.000	0.058	0.000	0.298	3.518	0.091	90.03	7.64	2.33
D18-3-1P	2	63.69	22.90	0.00	0.00	0.00	3.93	8.95	0.22	99.69	11.265	4.775	0.000	0.000	0.000	0.745	3.074	0.050	79.46	19.25	1.28
D18-3-1P	3	63.13	22.98	0.00	0.00	0.00	3.85	9.30	0.11	99.37	11.215	4.813	0.000	0.000	0.000	0.733	3.208	0.025	80.89	18.48	0.63
D18-3-1P	5	64.37	22.63	0.00	0.12	0.00	2.93	9.44	0.48	99.97	11.351	4.705	0.000	0.018	0.000	0.554	3.232	0.108	83.01	14.22	2.77
D18-3-1P	6	63.40	23.06	0.00	0.00	0.00	3.83	9.14	0.13	99.56	11.231	4.816	0.000	0.000	0.000	0.727	3.144	0.029	80.61	18.64	0.75
D18-3-1P	7	63.79	22.86	0.00	0.00	0.00	3.57	9.10	0.26	99.58	11.288	4.769	0.000	0.000	0.000	0.677	3.127	0.059	80.96	17.52	1.52
D18-3-1P	8	63.49	22.74	0.00	0.00	0.00	3.47	9.21	0.12	99.03	11.291	4.768	0.000	0.000	0.000	0.661	3.181	0.027	82.21	17.09	0.70
D22-1-1P	1	62.88	23.36	0.00	0.13	0.00	3.75	9.23	0.15	99.50	11.163	4.889	0.000	0.019	0.000	0.713	3.182	0.034	80.98	18.15	0.86
D22-1-1P	3	62.64	23.36	0.00	0.13	0.00	4.12	9.03	0.12	99.40	11.139	4.897	0.000	0.019	0.000	0.785	3.118	0.027	79.33	19.97	0.69
D22-1-1P	4	63.03	23.18	0.00	0.11	0.00	4.01	9.04	0.09	99.46	11.188	4.851	0.000	0.016	0.000	0.763	3.116	0.020	79.92	19.56	0.52
D22-1-1P	2	63.42	23.37	0.00	0.12	0.00	3.78	9.11	0.12	99.92	11.198	4.865	0.000	0.018	0.000	0.715	3.123	0.027	80.80	18.50	0.70
D22-1-1P	3	63.39	23.08	0.00	0.00	0.00	3.90	8.93	0.15	99.45	11.236	4.823	0.000	0.000	0.000	0.741	3.074	0.034	79.87	19.25	0.88
D22-1-3P	2	63.38	22.82	0.00	0.12	0.00	3.71	9.30	0.13	99.46	11.249	4.775	0.000	0.018	0.000	0.706	3.205	0.029	81.35	17.91	0.75
D22-1-3P	3	63.51	22.54	0.00	0.00	0.00	4.08	9.26	0.11	99.50	11.271	4.716	0.000	0.000	0.000	0.776	3.191	0.025	79.94	19.44	0.62
D22-1-4	1	62.52	22.67	0.00	0.00	0.00	3.64	9.39	0.10	98.32	11.226	4.799	0.000	0.000	0.000	0.700	3.274	0.023	81.91	17.52	0.57
D22-1-4	2	63.52	22.98	0.00	0.00	0.00	3.77	9.19	0.09	99.55	11.249	4.798	0.000	0.000	0.000	0.715	3.160	0.020	81.12	18.36	0.52
D22-1-4	3	62.77	23.53	0.00	0.00	0.00	4.20	8.80	0.10	99.40	11.143	4.925	0.000	0.000	0.000	0.799	3.034	0.023	78.69	20.72	0.59
D22-1-4	4	63.37	22.89	0.00	0.00	0.00	3.75	9.19	0.14	99.34	11.250	4.791	0.000	0.000	0.000	0.713	3.168	0.032	80.96	18.23	0.81
D22-2-1P	2	61.74	23.19	0.00	0.13	0.00	3.74	8.97	0.09	97.86	11.139	4.932	0.000	0.020	0.000	0.723	3.142	0.021	80.86	18.60	0.53
D22-2-1P	3	62.37	23.20	0.00	0.00	0.00	4.02	8.72	0.27	98.58	11.168	4.897	0.000	0.000	0.000	0.771	3.032	0.062	78.45	19.96	1.60
D22-2-1P	2	62.37	23.79	0.00	0.00	0.00	4.57	8.96	0.14	99.83	11.058	4.972	0.000	0.000	0.000	0.868	3.085	0.032	77.42	21.79	0.79
D22-2-1P	3	63.46	23.30	0.00	0.00	0.00	3.94	9.31	0.16	100.17	11.189	4.843	0.000	0.000	0.000	0.744	3.188	0.036	80.33	18.76	0.91
D22-2-3P	2	63.33	23.79	0.00	0.00	0.00	4.24	8.95	0.12	100.43	11.133	4.930	0.000	0.000	0.000	0.799	3.055	0.027	78.73	20.58	0.69
D22-2-3P	3	63.59	23.33	0.00	0.14	0.00	3.78	9.19	0.22	100.25	11.201	4.845	0.000	0.021	0.000	0.713	3.143	0.049	80.47	18.26	1.27
D22-2-4P	2	63.28	22.96	0.00	0.00	0.00	3.87	9.21	0.11	99.43	11.230	4.804	0.000	0.000	0.000	0.736	3.174	0.025	80.66	18.70	0.63
D22-2-4P	3	62.27	23.55	0.00	0.00	0.00	4.36	9.00	0.18	99.36	11.088	4.944	0.000	0.000	0.000	0.832	3.112	0.041	78.10	20.88	1.03
D22-2-5	1	62.79	22.89	0.00	0.00	0.00	4.13	9.02	0.13	98.96	11.205	4.816	0.000	0.000	0.000	0.790	3.126	0.030	79.23	20.02	0.75
D22-2-5	2	63.48	22.97	0.00	0.10	0.00	4.02	9.19	0.08	99.84	11.226	4.789	0.000	0.015	0.000	0.762	3.156	0.018	80.19	19.36	0.46
D22-2-5	3	63.58	23.11	0.00	0.16	0.00	3.92	9.25	0.15	100.17	11.214	4.805	0.000	0.024	0.000	0.741	3.168	0.034	80.35	18.79	0.86

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
D22-2-5	4	63.57	23.34	0.00	0.00	0.00	4.01	9.03	0.27	100.22	11.199	4.847	0.000	0.000	0.000	0.757	3.089	0.061	79.07	19.38	1.55
D28-1-1P	2	63.27	23.77	0.00	0.09	0.00	4.12	9.13	0.14	100.52	11.123	4.927	0.000	0.013	0.000	0.776	3.117	0.031	79.42	19.78	0.80
D28-1-1P	3	63.18	23.75	0.00	0.00	0.00	4.05	9.19	0.09	100.26	11.128	4.932	0.000	0.000	0.000	0.764	3.143	0.020	80.02	19.46	0.51
D28-1-1P	4	63.35	23.81	0.00	0.00	0.00	4.14	9.12	0.10	100.52	11.129	4.931	0.000	0.000	0.000	0.779	3.111	0.022	79.51	19.92	0.57
D28-1-1P	4	63.99	22.61	0.00	0.00	0.00	3.62	8.93	0.16	99.31	11.337	4.723	0.000	0.000	0.000	0.687	3.072	0.036	80.94	18.11	0.95
D28-1-1P	5	64.19	23.04	0.00	0.00	0.00	3.65	8.85	0.32	100.05	11.297	4.780	0.000	0.000	0.000	0.688	3.024	0.072	79.91	18.19	1.90
D28-1-1P	6	64.99	21.72	0.00	0.00	0.00	2.45	9.64	0.15	98.95	11.524	4.540	0.000	0.000	0.000	0.465	3.319	0.034	86.92	12.19	0.89
D28-1-2P	3	63.70	23.88	0.00	0.11	0.00	3.97	9.08	0.17	100.91	11.145	4.926	0.000	0.016	0.000	0.744	3.085	0.038	79.77	19.25	0.98
D28-3-1P	2	63.43	23.89	0.00	0.00	0.00	4.16	9.07	0.16	100.71	11.124	4.939	0.000	0.000	0.000	0.782	3.089	0.036	79.07	20.01	0.92
D28-3-1P	3	63.23	23.74	0.00	0.09	0.00	3.95	8.74	0.17	99.92	11.158	4.939	0.000	0.013	0.000	0.747	2.995	0.038	79.23	19.76	1.01
D28-3-1P	4	63.51	23.47	0.00	0.13	0.00	3.91	8.82	0.10	99.94	11.200	4.880	0.000	0.019	0.000	0.739	3.020	0.022	79.87	19.54	0.59
D28-3-1P	5	65.63	20.26	0.00	0.00	0.00	0.40	10.21	0.36	96.86	11.821	4.302	0.000	0.000	0.000	0.077	3.571	0.083	95.71	2.07	2.22
D28-3-2P	6	67.00	20.20	0.00	0.00	0.00	0.51	10.67	0.07	98.45	11.867	4.218	0.000	0.000	0.000	0.097	3.670	0.016	97.02	2.56	0.42
D28-3-4P	4	66.67	20.54	0.00	0.00	0.00	0.67	10.41	0.06	98.35	11.818	4.292	0.000	0.000	0.000	0.127	3.583	0.014	96.22	3.42	0.36
D38-1-2P	5	63.72	21.77	0.00	0.00	0.00	3.12	9.20	0.11	97.92	11.437	4.607	0.000	0.000	0.000	0.600	3.207	0.025	83.68	15.66	0.66
D38-1-2P	6	67.41	19.73	0.00	0.00	0.00	0.12	11.01	0.07	98.34	11.946	4.122	0.000	0.000	0.000	0.023	3.789	0.016	98.99	0.60	0.41
D38-1-3P	4	66.88	20.41	0.00	0.00	0.00	0.15	11.01	0.12	98.57	11.838	4.259	0.000	0.000	0.000	0.028	3.784	0.027	98.55	0.74	0.71
D38-1-3P	5	65.30	20.48	0.00	0.00	0.00	0.82	10.45	0.00	97.05	11.750	4.344	0.000	0.000	0.000	0.158	3.651	0.000	95.85	4.15	0.00
D38-1-5P	1	63.10	22.72	0.00	0.00	0.00	3.63	8.96	0.15	98.56	11.277	4.787	0.000	0.000	0.000	0.695	3.109	0.034	81.00	18.11	0.89
D38-1-5P	2	64.11	22.37	0.00	0.10	0.00	3.33	9.23	0.20	99.34	11.365	4.675	0.000	0.015	0.000	0.633	3.177	0.045	82.42	16.41	1.17
D38-1-5P	3	63.23	22.18	0.00	0.00	0.00	3.08	9.47	0.17	98.13	11.349	4.693	0.000	0.000	0.000	0.592	3.301	0.039	83.94	15.07	0.99
D38-1-5P	4	63.76	22.74	0.00	0.00	0.00	3.33	9.30	0.13	99.26	11.309	4.755	0.000	0.000	0.000	0.633	3.203	0.029	82.87	16.37	0.76
D38-2-1P	2	67.77	20.40	0.00	0.00	0.00	0.44	10.95	0.13	99.69	11.863	4.210	0.000	0.000	0.000	0.083	3.722	0.029	97.09	2.15	0.76
D38-2-1P	3	66.39	21.03	0.00	0.00	0.00	1.19	10.45	0.09	99.15	11.708	4.372	0.000	0.000	0.000	0.225	3.579	0.020	93.59	5.88	0.53
D38-2-1P	4	66.65	20.38	0.00	0.00	0.00	0.49	10.71	0.08	98.31	11.828	4.264	0.000	0.000	0.000	0.093	3.691	0.018	97.07	2.45	0.48
D38-2-1P	5	64.88	22.18	0.00	0.00	0.00	2.41	9.92	0.08	99.47	11.455	4.617	0.000	0.000	0.000	0.456	3.401	0.018	87.77	11.77	0.47
D38-2-1P	6	65.71	21.73	0.00	0.00	0.00	2.10	10.10	0.10	99.74	11.555	4.505	0.000	0.000	0.000	0.396	3.449	0.022	89.19	10.23	0.58
D38-2-1P	7	65.86	20.35	0.00	0.00	0.00	1.27	10.46	0.23	98.17	11.750	4.280	0.000	0.000	0.000	0.243	3.624	0.052	92.47	6.20	1.34
D38-2-1P	17	63.87	22.66	0.00	0.00	0.00	3.10	9.43	0.17	99.23	11.330	4.739	0.000	0.000	0.000	0.589	3.248	0.038	83.81	15.20	0.99
D38-2-1P	20	63.09	22.67	0.00	0.13	0.00	3.55	9.09	0.13	98.66	11.273	4.775	0.000	0.019	0.000	0.680	3.154	0.030	81.64	17.59	0.77
D38-2-2P	8	62.50	21.92	0.00	0.00	0.00	2.93	9.42	0.15	96.92	11.354	4.695	0.000	0.000	0.000	0.570	3.323	0.035	84.60	14.52	0.89
D38-2-2P	9	62.52	22.60	0.00	0.00	0.00	3.63	9.04	0.19	97.98	11.253	4.795	0.000	0.000	0.000	0.700	3.159	0.044	80.95	17.94	1.12
D41-1-2P	2	64.86	21.69	0.00	0.00	0.00	2.78	9.49	0.10	98.92	11.509	4.538	0.000	0.000	0.000	0.529	3.270	0.023	85.57	13.83	0.59

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
D41-1-2P	3	63.69	21.69	0.00	0.00	0.00	3.38	8.78	0.16	97.70	11.451	4.597	0.000	0.000	0.000	0.651	3.065	0.037	81.67	17.35	0.98
D41-2-1P	2	65.11	22.10	0.00	0.00	0.00	2.63	9.38	0.08	99.30	11.494	4.599	0.000	0.000	0.000	0.497	3.215	0.018	86.18	13.33	0.48
D41-2-1P	3	64.21	22.77	0.00	0.09	0.00	3.42	9.00	0.10	99.59	11.338	4.740	0.000	0.013	0.000	0.647	3.086	0.023	82.17	17.23	0.60
D41-2-1P	4	64.48	22.74	0.00	0.09	0.00	3.37	8.88	0.11	99.67	11.365	4.725	0.000	0.013	0.000	0.636	3.039	0.025	82.13	17.20	0.67
D41-2-4P	3	68.23	20.19	0.00	0.00	0.00	0.19	10.83	0.07	99.51	11.936	4.164	0.000	0.000	0.000	0.036	3.679	0.016	98.63	0.95	0.42
D41-1-2P	2	66.77	21.09	0.00	0.00	0.00	1.14	10.02	0.08	99.10	11.750	4.376	0.000	0.000	0.000	0.215	3.424	0.018	93.63	5.88	0.49
D41-3-1P	3	66.68	20.96	0.00	0.00	0.00	1.11	10.12	0.08	98.95	11.757	4.357	0.000	0.000	0.000	0.210	3.465	0.018	93.83	5.68	0.49
D41-3-1P	4	67.04	20.74	0.00	0.14	0.00	0.90	10.09	0.00	98.91	11.811	4.308	0.000	0.021	0.000	0.170	3.452	0.000	95.31	4.69	0.00
D41-3-2P	4	67.26	20.11	0.00	0.00	0.00	0.18	11.08	0.10	98.73	11.885	4.189	0.000	0.000	0.000	0.034	3.802	0.023	98.53	0.88	0.58
D41-3-3P	2	65.31	22.24	0.00	0.00	0.00	2.02	9.90	0.32	99.79	11.488	4.612	0.000	0.000	0.000	0.381	3.381	0.072	88.20	9.93	1.87
D41-3-4P	1	66.62	20.23	0.00	0.00	0.00	0.47	10.70	0.10	98.12	11.845	4.241	0.000	0.000	0.000	0.090	3.694	0.023	97.05	2.35	0.60
D41-3-4P	2	68.06	20.16	0.00	0.09	0.00	0.24	10.80	0.08	99.43	11.925	4.164	0.000	0.013	0.000	0.045	3.674	0.018	98.32	1.21	0.48
D41-3-4P	3	68.18	20.50	0.00	0.00	0.00	0.40	11.03	0.12	100.23	11.869	4.207	0.000	0.000	0.000	0.075	3.728	0.027	97.36	1.95	0.70
16-1-1P	1	64.84	21.86	0.00	0.00	0.00	1.90	9.70	0.30	98.60	11.528	4.582	0.000	0.000	0.000	0.362	3.349	0.068	88.62	9.58	1.80
16-1-1P	2	65.05	21.33	0.00	0.00	0.00	1.91	9.99	0.07	98.35	11.590	4.480	0.000	0.000	0.000	0.365	3.456	0.016	90.08	9.50	0.41
16-1-1P	3	63.87	21.25	0.00	0.50	0.00	2.75	9.74	0.10	98.21	11.469	4.499	0.000	0.075	0.000	0.529	3.396	0.023	86.02	13.40	0.58
16-1-1P	4	63.74	22.83	0.00	0.00	0.00	3.19	9.66	0.12	99.54	11.286	4.766	0.000	0.000	0.000	0.605	3.321	0.027	84.01	15.31	0.69
16-1-2P	2	63.95	22.00	0.00	0.00	0.00	2.47	9.88	0.13	98.43	11.424	4.633	0.000	0.000	0.000	0.473	3.427	0.030	87.21	12.03	0.75
16-1-2P	3	64.39	21.68	0.00	0.00	0.00	2.14	10.00	0.06	98.27	11.501	4.565	0.000	0.000	0.000	0.410	3.468	0.014	89.12	10.52	0.35
16-1-2P	4	64.72	21.85	0.00	0.00	0.00	2.48	9.80	0.14	98.99	11.484	4.571	0.000	0.000	0.000	0.472	3.377	0.032	87.03	12.15	0.82
16-1-3P	1	64.95	21.76	0.00	0.10	0.00	2.41	9.56	0.09	98.87	11.522	4.551	0.000	0.015	0.000	0.458	3.293	0.020	87.31	12.15	0.54
16-1-3P	3	64.33	22.15	0.00	0.00	0.00	2.82	9.43	0.07	98.80	11.433	4.641	0.000	0.000	0.000	0.537	3.254	0.016	85.48	14.11	0.42
16-1-3P	4	65.15	21.33	0.00	0.00	0.00	1.91	9.68	0.11	98.18	11.612	4.482	0.000	0.000	0.000	0.365	3.350	0.025	89.58	9.75	0.67
D16-2-1P	2	64.93	21.92	0.00	0.00	0.00	2.46	9.76	0.09	99.16	11.493	4.574	0.000	0.000	0.000	0.467	3.355	0.020	87.33	12.15	0.53
D16-2-1P	3	63.82	21.80	0.00	0.00	0.00	2.42	9.80	0.24	98.08	11.444	4.609	0.000	0.000	0.000	0.465	3.412	0.055	86.78	11.82	1.40
D16-2-2P	2	64.22	22.29	0.00	0.00	0.00	2.61	9.70	0.10	98.92	11.408	4.668	0.000	0.000	0.000	0.497	3.346	0.023	86.56	12.85	0.59
D16-2-2P	3	65.65	21.65	0.00	0.00	0.00	1.96	10.12	0.07	99.45	11.571	4.499	0.000	0.000	0.000	0.370	3.464	0.016	89.98	9.62	0.41
D16-2-3P	1	65.18	21.74	0.00	0.00	0.00	2.37	9.89	0.13	99.31	11.522	4.531	0.000	0.000	0.000	0.449	3.395	0.029	87.65	11.59	0.76
D16-2-3P	2	64.39	22.33	0.00	0.00	0.00	2.96	9.56	0.12	99.36	11.397	4.659	0.000	0.000	0.000	0.561	3.286	0.027	84.81	14.49	0.70
D16-2-3P	3	64.82	21.48	0.00	0.00	0.00	2.22	10.08	0.13	98.73	11.532	4.505	0.000	0.000	0.000	0.423	3.482	0.030	88.50	10.75	0.75
D16-3-1P	1	65.97	21.23	0.00	0.13	0.00	1.75	10.45	0.06	99.59	11.621	4.409	0.000	0.019	0.000	0.330	3.575	0.013	91.23	8.43	0.34
D16-3-1P	2	66.89	20.62	0.00	0.00	0.00	1.19	10.80	0.10	99.60	11.756	4.273	0.000	0.000	0.000	0.224	3.686	0.022	93.73	5.70	0.57
D16-3-1P	3	66.12	20.88	0.00	0.00	0.06	1.28	10.21	0.30	98.85	11.707	4.359	0.000	0.000	0.016	0.243	3.510	0.068	91.49	6.74	1.77

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
D16-3-1P	4	67.16	20.64	0.00	0.15	0.00	0.99	10.80	0.05	99.79	11.774	4.266	0.000	0.022	0.000	0.186	3.677	0.011	94.91	4.80	0.29
D16-3-2P	2	66.83	20.15	0.00	0.19	0.00	0.10	11.08	0.08	98.43	11.857	4.215	0.000	0.028	0.000	0.019	3.817	0.018	99.04	0.49	0.47
D16-3-2P	3	65.93	20.76	0.00	0.14	0.00	1.13	10.50	0.06	98.52	11.712	4.348	0.000	0.021	0.000	0.215	3.622	0.014	94.06	5.59	0.35
D16-3-3P	1	64.92	21.83	0.00	0.00	0.00	2.62	9.75	0.09	99.21	11.492	4.556	0.000	0.000	0.000	0.497	3.351	0.020	86.63	12.85	0.53
D16-3-3P	2	65.05	22.01	0.00	0.00	0.00	2.75	9.50	0.11	99.42	11.484	4.581	0.000	0.000	0.000	0.520	3.257	0.025	85.66	13.68	0.65
D16-3-3P	4	64.27	22.15	0.00	0.00	0.00	2.88	9.49	0.18	98.97	11.418	4.639	0.000	0.000	0.000	0.548	3.274	0.041	84.75	14.19	1.06
D16-3-4P	1	67.01	20.47	0.00	0.00	0.00	1.21	10.42	0.06	99.17	11.803	4.251	0.000	0.000	0.000	0.228	3.564	0.013	93.65	6.00	0.35
D16-3-4P	2	66.78	20.63	0.00	0.00	0.00	1.39	10.41	0.07	99.28	11.762	4.284	0.000	0.000	0.000	0.262	3.560	0.016	92.76	6.83	0.41
D16-3-4P	3	66.42	20.82	0.00	0.00	0.00	1.56	10.57	0.13	99.50	11.699	4.323	0.000	0.000	0.000	0.294	3.615	0.029	91.78	7.47	0.74
D16-3-5P	1	66.06	20.92	0.00	0.11	0.00	1.20	10.66	0.07	99.02	11.686	4.363	0.000	0.016	0.000	0.227	3.662	0.016	93.77	5.82	0.40
D16-3-5P	2	66.88	20.84	0.00	0.00	0.00	0.95	10.78	0.11	99.56	11.748	4.316	0.000	0.000	0.000	0.179	3.677	0.025	94.76	4.61	0.64
D16-3-5P	3	66.84	20.71	0.00	0.00	0.00	1.11	10.62	0.09	99.37	11.761	4.296	0.000	0.000	0.000	0.209	3.629	0.020	94.05	5.42	0.52
D16-3-5P	4	65.25	22.03	0.00	0.00	0.00	2.56	9.72	0.05	99.61	11.493	4.575	0.000	0.000	0.000	0.483	3.325	0.011	87.05	12.65	0.29
D50-1-1P	1	66.13	21.65	0.00	0.00	0.00	1.44	10.42	0.22	99.86	11.605	4.479	0.000	0.000	0.000	0.271	3.551	0.049	91.73	7.00	1.27
D50-1-1P	4	66.13	21.27	0.00	0.00	0.00	1.14	10.59	0.08	99.21	11.664	4.423	0.000	0.000	0.000	0.215	3.627	0.018	93.95	5.58	0.47
D50-1-2P	1	66.15	21.39	0.00	0.13	0.08	1.00	10.55	0.28	99.58	11.641	4.438	0.000	0.019	0.021	0.189	3.605	0.063	92.97	5.40	1.62
D50-1-3P	1	64.87	21.06	0.00	0.00	0.00	1.33	10.63	0.11	98.00	11.610	4.444	0.000	0.000	0.000	0.255	3.694	0.025	92.95	6.42	0.63
D50-1-3P	3	65.88	20.91	0.00	0.00	0.00	1.19	10.42	0.12	98.52	11.699	4.377	0.000	0.000	0.000	0.226	3.593	0.027	93.41	5.89	0.71
D50-2-1P	2	65.25	22.10	0.00	0.00	0.00	1.99	10.36	0.12	99.82	11.482	4.585	0.000	0.000	0.000	0.375	3.540	0.027	89.80	9.52	0.68
D50-2-1P	3	63.53	22.59	0.00	0.00	0.00	2.94	9.77	0.12	98.95	11.312	4.742	0.000	0.000	0.000	0.561	3.378	0.027	85.17	14.14	0.69
D50-2-2P	2	65.60	22.32	0.00	0.00	0.00	2.16	10.11	0.09	100.28	11.480	4.605	0.000	0.000	0.000	0.405	3.436	0.020	88.99	10.49	0.52
D50-2-2P	4	64.89	22.51	0.00	0.00	0.00	2.60	9.84	0.13	99.97	11.409	4.666	0.000	0.000	0.000	0.490	3.359	0.029	86.62	12.63	0.75
D50-3-2P	2	65.14	22.42	0.00	0.00	0.00	2.38	10.19	0.11	100.24	11.425	4.636	0.000	0.000	0.000	0.447	3.471	0.025	88.03	11.35	0.62
D50-3-3P	2	66.90	21.88	0.00	0.00	0.00	1.62	10.62	0.09	101.11	11.597	4.472	0.000	0.000	0.000	0.301	3.575	0.020	91.76	7.72	0.51
D50-3-3P	3	66.41	22.09	0.00	0.00	0.00	1.80	10.42	0.07	100.79	11.551	4.530	0.000	0.000	0.000	0.335	3.519	0.016	90.93	8.67	0.40
D50-4-1P	2	65.13	21.98	0.00	0.00	0.00	2.24	9.84	0.21	99.40	11.501	4.576	0.000	0.000	0.000	0.424	3.374	0.047	87.75	11.02	1.23
D50-4-1P	3	66.56	20.53	0.00	0.00	0.00	0.60	10.83	0.05	98.57	11.793	4.288	0.000	0.000	0.000	0.114	3.726	0.011	96.75	2.96	0.29
D50-4-2P	2	66.32	21.34	0.00	0.00	0.00	1.41	10.49	0.08	99.64	11.653	4.420	0.000	0.000	0.000	0.265	3.579	0.018	92.66	6.87	0.46
D50-4-2P	3	65.24	22.19	0.00	0.00	0.00	1.96	10.14	0.13	99.66	11.487	4.606	0.000	0.000	0.000	0.370	3.467	0.029	89.68	9.57	0.76
D50-4-2P	4	66.10	21.51	0.00	0.00	0.00	1.35	10.36	0.11	99.43	11.634	4.463	0.000	0.000	0.000	0.255	3.541	0.025	92.69	6.66	0.65
D2-2-8	3	68.24	20.89	0.00	0.00	0.00	1.14	10.58	0.10	100.95	11.805	4.260	0.000	0.000	0.000	0.211	3.554	0.022	93.84	5.58	0.58
D2-2-8	4	67.62	20.75	0.00	0.00	0.00	1.09	10.42	0.09	99.97	11.806	4.271	0.000	0.000	0.000	0.204	3.533	0.020	94.04	5.43	0.53
D2-2-9	2	68.16	19.99	0.00	0.00	0.00	0.14	10.92	0.12	99.33	11.951	4.132	0.000	0.000	0.000	0.026	3.718	0.027	98.59	0.70	0.71

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
D2-2-9	3	67.60	19.81	0.00	0.00	0.00	0.22	10.86	0.11	98.60	11.946	4.127	0.000	0.000	0.000	0.042	3.727	0.025	98.25	1.10	0.65
D2-3-2	2	66.68	20.24	0.00	0.00	0.00	0.91	10.86	0.07	98.76	11.807	4.225	0.000	0.000	0.000	0.173	3.734	0.016	95.20	4.40	0.40
D2-3-2	3	67.76	19.95	0.00	0.00	0.00	0.25	10.86	0.11	98.93	11.935	4.143	0.000	0.000	0.000	0.047	3.714	0.025	98.10	1.25	0.65
D2-3-3	2	65.80	20.49	0.00	0.16	0.00	1.08	10.60	0.25	98.38	11.725	4.305	0.000	0.024	0.000	0.206	3.668	0.057	93.31	5.25	1.45
D2-3-3	3	68.15	19.57	0.00	0.00	0.00	0.17	11.34	0.09	99.32	11.972	4.053	0.000	0.000	0.000	0.032	3.868	0.020	98.67	0.82	0.51
D2-3-4	2	66.86	19.59	0.00	0.00	0.00	0.82	10.98	0.11	98.36	11.888	4.106	0.000	0.000	0.000	0.156	3.791	0.025	95.44	3.93	0.63
D2-3-4	3	67.01	19.37	0.00	0.00	0.00	0.29	11.11	0.10	97.88	11.950	4.072	0.000	0.000	0.000	0.055	3.847	0.023	98.01	1.41	0.58
D2-4-2	2	67.19	20.32	0.00	0.00	0.00	0.61	10.65	0.07	98.84	11.856	4.227	0.000	0.000	0.000	0.115	3.649	0.016	96.53	3.05	0.42
D2-4-2	3	65.98	20.38	0.00	0.00	0.00	0.84	10.55	0.07	97.82	11.783	4.291	0.000	0.000	0.000	0.161	3.659	0.016	95.39	4.19	0.42
D2-4-4	3	67.70	19.81	0.00	0.00	0.00	0.13	10.71	0.14	98.49	11.965	4.128	0.000	0.000	0.000	0.025	3.676	0.032	98.49	0.66	0.85
D2-4-6	2	67.90	20.21	0.00	0.00	0.00	0.30	10.87	0.10	99.38	11.907	4.178	0.000	0.000	0.000	0.056	3.702	0.022	97.92	1.49	0.59
D37-1-1	2	66.87	20.39	0.00	0.00	0.00	0.79	11.09	0.11	99.25	11.791	4.239	0.000	0.000	0.000	0.149	3.797	0.025	95.62	3.76	0.62
D37-1-1P	1	65.89	20.86	0.00	0.00	0.00	0.90	10.73	0.12	98.50	11.705	4.369	0.000	0.000	0.000	0.171	3.702	0.027	94.91	4.39	0.70
D37-1-3	4	63.98	21.74	0.00	0.00	0.00	2.32	9.99	0.12	98.15	11.459	4.590	0.000	0.000	0.000	0.445	3.474	0.027	88.03	11.28	0.69
D37-1-3	5	64.50	21.95	0.00	0.00	0.00	2.64	9.99	0.14	99.22	11.439	4.589	0.000	0.000	0.000	0.502	3.440	0.032	86.58	12.62	0.80
D37-1-5P	3	64.97	21.83	0.00	0.00	0.00	2.54	9.72	0.13	99.19	11.500	4.555	0.000	0.000	0.000	0.482	3.341	0.029	86.73	12.51	0.76
D37-1-5P	4	65.01	21.34	0.00	0.00	0.00	2.50	10.16	0.16	99.17	11.532	4.463	0.000	0.000	0.000	0.475	3.500	0.036	87.25	11.85	0.90
D37-1-6P	2	65.03	21.60	0.00	0.00	0.00	2.38	9.92	0.13	99.06	11.527	4.514	0.000	0.000	0.000	0.452	3.415	0.029	87.64	11.60	0.75
D37-1-6P	3	64.80	21.58	0.00	0.00	0.00	2.39	10.01	0.16	98.94	11.511	4.519	0.000	0.000	0.000	0.455	3.453	0.036	87.55	11.53	0.92
D37-1-8P	3	67.06	19.80	0.00	0.13	0.00	0.48	11.08	0.07	98.62	11.885	4.137	0.000	0.019	0.000	0.091	3.813	0.016	97.27	2.33	0.40
D37-1-8P	4	66.25	20.22	0.00	0.00	0.00	1.13	10.78	0.06	98.44	11.780	4.239	0.000	0.000	0.000	0.215	3.722	0.014	94.21	5.45	0.34
D37-2-1	3	64.42	22.04	0.00	0.00	0.00	2.76	9.97	0.11	99.30	11.419	4.606	0.000	0.000	0.000	0.524	3.432	0.025	86.21	13.17	0.62
D37-2-1	5	63.77	21.44	0.00	0.09	0.00	2.41	9.85	0.11	97.67	11.481	4.551	0.000	0.014	0.000	0.465	3.443	0.025	87.54	11.82	0.64
D37-2-2	4	64.19	21.23	0.00	0.00	0.00	2.63	9.93	0.22	98.20	11.506	4.486	0.000	0.000	0.000	0.505	3.456	0.050	86.15	12.59	1.25
D37-2-8P	4	63.48	21.83	0.00	0.00	0.00	3.08	9.56	0.17	98.12	11.396	4.620	0.000	0.000	0.000	0.592	3.333	0.039	84.07	14.95	0.98
D37-2-8P	5	64.81	21.18	0.00	0.00	0.00	2.42	9.50	0.14	98.05	11.587	4.464	0.000	0.000	0.000	0.464	3.298	0.032	86.94	12.22	0.84
D37-2-8P	6	64.17	20.89	0.00	0.00	0.00	2.33	9.93	0.10	97.42	11.570	4.440	0.000	0.000	0.000	0.450	3.477	0.023	88.02	11.40	0.58
D44-1-1	2	65.90	22.77	0.00	0.00	0.00	2.80	9.37	0.14	100.98	11.445	4.662	0.000	0.000	0.000	0.521	3.160	0.031	85.13	14.04	0.84
D44-1-1	3	67.74	21.36	0.00	0.00	0.00	0.97	10.58	0.09	100.74	11.741	4.365	0.000	0.000	0.000	0.180	3.561	0.020	94.68	4.79	0.53
D44-1-2P	2	65.23	21.87	0.00	0.00	0.00	2.20	9.39	0.09	98.78	11.554	4.567	0.000	0.000	0.000	0.418	3.230	0.020	88.06	11.38	0.55
D44-2-1P	2	65.64	21.94	0.00	0.00	0.00	2.19	10.02	0.13	99.92	11.526	4.542	0.000	0.000	0.000	0.412	3.417	0.029	88.56	10.68	0.75
D44-2-1P	3	65.57	22.00	0.00	0.00	0.00	2.17	10.12	0.11	99.97	11.512	4.554	0.000	0.000	0.000	0.408	3.450	0.025	88.85	10.51	0.63
D44-2-2P	2	66.01	21.98	0.00	0.00	0.00	1.97	10.11	0.19	100.26	11.547	4.533	0.000	0.000	0.000	0.369	3.434	0.042	89.30	9.60	1.10

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
D44-2-2P	3	64.81	21.86	0.00	0.00	0.00	2.00	10.04	0.16	98.87	11.505	4.575	0.000	0.000	0.000	0.380	3.461	0.036	89.25	9.81	0.93
D44-2-5P	2	65.25	22.11	0.00	0.00	0.00	2.40	9.67	0.13	99.56	11.495	4.592	0.000	0.000	0.000	0.453	3.308	0.029	87.28	11.95	0.77
D44-2-5P	3	65.67	22.02	0.00	0.00	0.00	2.53	9.53	0.16	99.91	11.524	4.556	0.000	0.000	0.000	0.476	3.248	0.036	86.39	12.66	0.95
D46-1-1P	2	64.80	22.19	0.00	0.00	0.00	3.49	9.13	0.19	99.80	11.421	4.611	0.000	0.000	0.000	0.659	3.125	0.043	81.66	17.22	1.12
D46-1-2P	6	67.72	20.80	0.00	0.00	0.00	0.58	10.95	0.09	100.14	11.807	4.275	0.000	0.000	0.000	0.108	3.707	0.020	96.65	2.82	0.52
D46-1-3P	2	64.86	22.97	0.00	0.00	0.00	3.41	9.13	0.09	100.46	11.347	4.737	0.000	0.000	0.000	0.639	3.102	0.020	82.47	17.00	0.53
D46-1-3P	4	66.71	21.94	0.00	0.00	0.00	1.96	10.26	0.08	100.95	11.581	4.490	0.000	0.000	0.000	0.365	3.459	0.018	90.05	9.49	0.46
D46-1-3P	4	66.71	21.94	0.00	0.00	0.00	1.96	10.26	0.08	100.95	11.581	4.490	0.000	0.000	0.000	0.365	3.459	0.018	90.05	9.49	0.46
D46-2-1P	3	62.52	23.42	0.00	0.00	0.00	4.15	9.07	0.10	99.26	11.129	4.915	0.000	0.000	0.000	0.792	3.135	0.023	79.38	20.04	0.58
D46-2-1P	4	63.22	23.64	0.00	0.00	0.00	4.22	9.05	0.16	100.29	11.137	4.909	0.000	0.000	0.000	0.797	3.096	0.036	78.81	20.28	0.92
D46-2-1P	5	63.48	22.94	0.00	0.00	0.00	3.61	9.17	0.16	99.36	11.260	4.797	0.000	0.000	0.000	0.686	3.159	0.036	81.39	17.68	0.93
D46-2-1P	6	64.52	22.81	0.00	0.00	0.00	3.05	9.43	0.13	99.94	11.351	4.731	0.000	0.000	0.000	0.575	3.222	0.029	84.21	15.03	0.76
D46-2-2P	3	63.76	23.83	0.00	0.00	0.00	4.06	9.11	0.09	100.85	11.155	4.915	0.000	0.000	0.000	0.761	3.095	0.020	79.85	19.64	0.52
D46-2-2P	4	63.92	23.56	0.00	0.00	0.00	3.75	9.21	0.05	100.49	11.208	4.870	0.000	0.000	0.000	0.705	3.136	0.011	81.42	18.29	0.29
D46-2-2P	5	64.12	23.45	0.00	0.00	0.00	3.63	8.95	0.09	100.24	11.252	4.852	0.000	0.000	0.000	0.683	3.050	0.020	81.27	18.19	0.54
D47-1-1	2	63.65	21.51	0.00	0.00	0.00	2.85	9.32	0.12	97.45	11.474	4.571	0.000	0.000	0.000	0.550	3.262	0.028	84.95	14.33	0.72
D47-1-1	3	62.77	22.23	0.00	0.12	0.00	3.28	9.12	0.14	97.66	11.322	4.727	0.000	0.018	0.000	0.634	3.194	0.032	82.74	16.42	0.83
D47-1-3P	3	66.36	19.29	0.00	0.00	0.00	0.77	10.57	0.07	97.06	11.932	4.089	0.000	0.000	0.000	0.148	3.691	0.016	95.74	3.85	0.42
D47-1-4P	2	64.68	22.78	0.00	0.00	0.00	2.97	9.48	0.13	100.04	11.365	4.719	0.000	0.000	0.000	0.559	3.235	0.029	84.61	14.63	0.76
D47-1-4P	3	67.83	20.58	0.00	0.00	0.00	0.52	10.78	0.05	99.76	11.854	4.240	0.000	0.000	0.000	0.097	3.658	0.011	97.12	2.59	0.30
D47-1-4P	2	64.76	22.45	0.00	0.00	0.00	2.52	9.71	0.09	99.53	11.424	4.669	0.000	0.000	0.000	0.476	3.326	0.020	87.01	12.46	0.53
D47-1-4P	3	64.31	22.54	0.00	0.00	0.00	3.08	9.35	0.12	99.40	11.374	4.700	0.000	0.000	0.000	0.584	3.211	0.027	84.02	15.27	0.71
D47-2-1	2	66.88	18.94	0.00	0.00	0.00	0.16	11.49	0.00	97.47	11.984	4.001	0.000	0.000	0.000	0.031	3.998	0.000	99.24	0.76	0.00
D47-2-1	3	65.99	19.23	0.00	0.00	0.00	0.69	11.04	0.07	97.02	11.898	4.087	0.000	0.000	0.000	0.133	3.865	0.016	96.28	3.32	0.40
D47-2-1	4	66.88	18.90	0.00	0.00	0.00	0.28	11.17	0.09	97.32	11.997	3.997	0.000	0.000	0.000	0.054	3.891	0.021	98.12	1.36	0.52
D47-2-1	6	66.74	19.29	0.00	0.00	0.00	0.44	10.92	0.00	97.39	11.953	4.073	0.000	0.000	0.000	0.084	3.798	0.000	97.82	2.18	0.00
D47-2-11P	1	67.75	19.94	0.00	0.00	0.00	0.27	11.02	0.08	99.06	11.925	4.138	0.000	0.000	0.000	0.051	3.767	0.018	98.20	1.33	0.47
D47-2-11P	2	65.47	19.65	0.00	0.00	0.00	0.40	10.58	0.13	96.23	11.872	4.201	0.000	0.000	0.000	0.078	3.725	0.030	97.19	2.03	0.78
D47-2-11P	3	66.69	20.02	0.00	0.00	0.00	0.42	10.72	0.11	97.96	11.875	4.203	0.000	0.000	0.000	0.080	3.707	0.025	97.24	2.10	0.66
D47-2-11P	4	67.27	19.78	0.00	0.00	0.00	0.25	10.83	0.12	98.25	11.934	4.137	0.000	0.000	0.000	0.048	3.731	0.027	98.04	1.25	0.71
D47-2-11P	5	67.12	19.83	0.00	0.00	0.00	0.13	11.10	0.06	98.24	11.915	4.150	0.000	0.000	0.000	0.025	3.826	0.014	99.01	0.64	0.35
D47-2-4P	2	67.75	20.19	0.00	0.00	0.00	0.35	10.89	0.06	99.24	11.900	4.181	0.000	0.000	0.000	0.066	3.714	0.013	97.91	1.74	0.35
D47-2-4P	3	68.02	20.42	0.00	0.00	0.00	0.29	10.79	0.07	99.59	11.895	4.210	0.000	0.000	0.000	0.054	3.664	0.016	98.13	1.46	0.42

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
D47-2-5P	2	67.58	20.14	0.00	0.00	0.00	0.45	10.82	0.05	99.04	11.896	4.179	0.000	0.000	0.000	0.085	3.698	0.011	97.47	2.24	0.30
D47-2-5P	3	67.89	20.44	0.00	0.12	0.00	0.23	10.81	0.07	99.56	11.884	4.218	0.000	0.018	0.000	0.043	3.674	0.016	98.43	1.16	0.42
D47-2-5P	5	67.48	20.46	0.00	0.00	0.00	0.52	10.78	0.10	99.34	11.850	4.236	0.000	0.000	0.000	0.098	3.676	0.022	96.83	2.58	0.59

Table 10b: Electron microprobe data for plagioclase rims from selected HHD granitoids

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
16-1-2P	1	63.44	21.56	0.00	0.00	0.00	2.53	9.65	0.08	97.26	11.460	4.592	0.000	0.000	0.000	0.490	3.385	0.018	86.95	12.58	0.47
16-2-1P	1	66.85	20.58	0.00	0.00	0.00	1.12	10.46	0.13	99.14	11.784	4.277	0.000	0.000	0.000	0.212	3.580	0.029	93.70	5.54	0.77
16-2-1P	2	64.93	21.92	0.00	0.00	0.00	2.46	9.76	0.09	99.16	11.493	4.574	0.000	0.000	0.000	0.467	3.355	0.020	87.33	12.15	0.53
16-2-1P	3	63.82	21.80	0.00	0.00	0.00	2.42	9.80	0.24	98.08	11.444	4.609	0.000	0.000	0.000	0.465	3.412	0.055	86.78	11.82	1.40
16-2-1P	4	64.07	22.18	0.00	0.09	0.00	2.96	9.74	0.10	99.14	11.382	4.645	0.000	0.013	0.000	0.563	3.360	0.023	85.15	14.28	0.57
16-2-2P	1	62.91	22.59	0.00	0.00	0.00	3.22	9.39	0.07	98.18	11.286	4.778	0.000	0.000	0.000	0.619	3.271	0.016	83.74	15.85	0.41
16-2-2P	4	63.82	22.00	0.00	0.17	0.00	2.97	9.72	0.09	98.77	11.386	4.627	0.000	0.025	0.000	0.568	3.367	0.020	85.13	14.35	0.52
16-3-2P	4	64.63	22.04	0.00	0.00	0.00	2.32	9.93	0.08	99.00	11.463	4.609	0.000	0.000	0.000	0.441	3.420	0.018	88.17	11.37	0.47
50-2-2P	1	65.88	21.59	0.00	0.00	0.00	1.58	10.50	0.06	99.61	11.592	4.479	0.000	0.000	0.000	0.298	3.588	0.013	92.01	7.64	0.35
50-2-2P	3	64.49	23.13	0.00	0.00	0.00	3.31	9.47	0.12	100.52	11.295	4.776	0.000	0.000	0.000	0.621	3.221	0.027	83.25	16.06	0.69
50-3-2P	1	67.54	20.78	0.00	0.00	0.00	0.94	10.99	0.08	100.33	11.775	4.271	0.000	0.000	0.000	0.176	3.720	0.018	95.06	4.49	0.45
50-3-2P	4	66.40	21.61	0.00	0.00	0.00	1.55	10.70	0.24	100.50	11.597	4.450	0.000	0.000	0.000	0.290	3.629	0.053	91.35	7.30	1.35
50-3-3P	4	66.72	21.34	0.00	0.00	0.00	1.09	10.75	0.10	100.00	11.677	4.403	0.000	0.000	0.000	0.204	3.653	0.022	94.16	5.27	0.58
50-3-4P	1	67.60	21.17	0.00	0.00	0.00	1.12	10.53	0.10	100.52	11.749	4.338	0.000	0.000	0.000	0.209	3.554	0.022	93.90	5.51	0.59
50-3-4P	3	66.93	21.09	0.00	0.00	0.00	0.81	10.86	0.11	99.80	11.727	4.356	0.000	0.000	0.000	0.152	3.695	0.025	95.44	3.93	0.64
50-3-4P	4	65.64	21.82	0.00	0.18	0.00	1.92	10.31	0.11	99.98	11.531	4.519	0.000	0.026	0.000	0.361	3.517	0.025	90.11	9.26	0.63
50-4-1P	4	66.98	20.55	0.00	0.00	0.00	0.75	10.68	0.09	99.05	11.807	4.271	0.000	0.000	0.000	0.142	3.656	0.020	95.76	3.71	0.53
18-2-1P	1	67.00	20.43	0.00	0.00	0.00	0.66	10.86	0.13	99.08	11.815	4.247	0.000	0.000	0.000	0.125	3.719	0.029	96.02	3.22	0.76
18-2-1P	4	65.07	21.37	0.00	0.00	0.00	2.11	10.06	0.09	98.70	11.567	4.478	0.000	0.000	0.000	0.402	3.473	0.020	89.16	10.32	0.52
18-2-1P	5	66.95	19.96	0.00	0.00	0.00	0.50	10.96	0.10	98.47	11.873	4.173	0.000	0.000	0.000	0.095	3.774	0.023	96.98	2.44	0.58
18-2-1P	6	67.03	20.07	0.00	0.00	0.00	0.45	11.01	0.06	98.62	11.866	4.189	0.000	0.000	0.000	0.085	3.785	0.014	97.45	2.20	0.35
18-2-1P	7	63.43	22.67	0.00	0.00	0.00	3.75	9.09	0.08	99.02	11.286	4.755	0.000	0.000	0.000	0.715	3.141	0.018	81.08	18.46	0.47
18-3-1P	1	66.93	21.01	0.00	0.00	0.00	1.42	10.40	0.12	99.88	11.722	4.338	0.000	0.000	0.000	0.266	3.537	0.027	92.34	6.96	0.70
18-3-1P	4	63.62	22.73	0.00	0.19	0.00	3.58	9.20	0.15	99.47	11.281	4.752	0.000	0.028	0.000	0.680	3.168	0.034	81.60	17.52	0.87
18-3-3P	1	62.37	22.93	0.00	0.09	0.00	3.91	9.13	0.17	98.60	11.179	4.845	0.000	0.013	0.000	0.751	3.178	0.039	80.09	18.93	0.98
18-3-3P	2	68.73	19.97	0.00	0.16	0.00	0.58	10.77	0.00	100.21	11.954	4.095	0.000	0.023	0.000	0.108	3.637	0.000	97.11	2.89	0.00
22-1-2P	1	63.97	22.84	0.00	0.00	0.00	3.84	9.19	0.08	99.92	11.284	4.750	0.000	0.000	0.000	0.726	3.148	0.018	80.89	18.65	0.46
22-1-2P	4	63.61	23.14	0.00	0.00	0.00	3.85	8.96	0.15	99.71	11.242	4.821	0.000	0.000	0.000	0.729	3.075	0.034	80.12	19.00	0.88
22-1-3P	1	63.74	22.81	0.00	0.12	0.00	3.96	9.36	0.08	100.07	11.250	4.746	0.000	0.018	0.000	0.749	3.208	0.018	80.71	18.84	0.45
22-1-3P	4	62.74	22.73	0.00	0.09	0.00	4.05	8.95	0.10	98.66	11.226	4.795	0.000	0.013	0.000	0.776	3.110	0.023	79.55	19.86	0.58
22-2-1P	1	62.00	23.06	0.00	0.11	0.00	3.96	9.08	0.06	98.27	11.148	4.888	0.000	0.017	0.000	0.763	3.170	0.014	80.32	19.33	0.35
22-2-1P	4	61.62	23.32	0.00	0.23	0.00	3.98	9.09	0.13	98.37	11.087	4.947	0.000	0.035	0.000	0.767	3.176	0.030	79.94	19.31	0.75
22-2-2P	1	63.48	22.86	0.00	0.14	0.00	3.90	9.35	0.14	99.87	11.232	4.769	0.000	0.021	0.000	0.739	3.213	0.032	80.65	18.56	0.79

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
22-2-2P	4	66.68	20.14	0.00	0.14	0.00	0.54	11.30	0.05	98.85	11.810	4.205	0.000	0.021	0.000	0.102	3.886	0.011	97.16	2.56	0.28
22-2-3P	1	67.31	20.46	0.00	0.00	0.00	0.44	11.19	0.07	99.47	11.823	4.237	0.000	0.000	0.000	0.083	3.817	0.016	97.48	2.12	0.40
22-2-3P	4	62.77	23.47	0.00	0.00	0.00	4.34	8.83	0.11	99.52	11.138	4.910	0.000	0.000	0.000	0.825	3.043	0.025	78.16	21.20	0.64
22-2-4P	1	66.48	20.32	0.00	0.00	0.00	0.98	10.82	0.10	98.70	11.785	4.247	0.000	0.000	0.000	0.186	3.725	0.023	94.69	4.73	0.57
22-2-4P	4	63.11	22.96	0.00	0.09	0.00	4.02	9.15	0.17	99.50	11.207	4.807	0.000	0.013	0.000	0.765	3.155	0.039	79.70	19.32	0.97
28-1-1P	1	62.65	23.36	0.00	0.00	0.00	4.00	9.19	0.14	99.34	11.143	4.898	0.000	0.000	0.000	0.762	3.174	0.032	79.99	19.21	0.80
28-1-1P	1	67.85	20.05	0.00	0.00	0.00	0.19	10.81	0.08	98.98	11.936	4.158	0.000	0.000	0.000	0.036	3.693	0.018	98.56	0.96	0.48
28-1-1P	2	67.77	20.29	0.00	0.00	0.00	0.54	10.56	0.05	99.21	11.897	4.199	0.000	0.000	0.000	0.102	3.600	0.011	96.96	2.74	0.30
28-1-1P	3	64.04	22.82	0.00	0.09	0.00	3.47	9.07	0.08	99.57	11.317	4.754	0.000	0.013	0.000	0.657	3.112	0.018	82.18	17.35	0.48
28-1-2P	4	67.58	20.40	0.00	0.00	0.00	0.36	11.20	0.08	99.62	11.847	4.216	0.000	0.000	0.000	0.068	3.812	0.018	97.81	1.73	0.46
28-2-1P	1	67.19	20.18	0.00	0.00	0.00	0.31	10.93	0.09	98.70	11.874	4.205	0.000	0.000	0.000	0.059	3.751	0.020	97.94	1.53	0.53
28-3-1P	1	62.09	23.32	0.00	0.09	0.00	4.14	8.85	0.09	98.58	11.126	4.926	0.000	0.013	0.000	0.795	3.079	0.021	79.06	20.41	0.53
28-3-1P	6	63.01	23.53	0.00	0.00	0.00	4.17	8.90	0.10	99.71	11.152	4.910	0.000	0.000	0.000	0.791	3.059	0.023	78.99	20.42	0.58
28-3-4P	1	66.72	21.39	0.00	0.00	0.00	1.54	10.05	0.14	99.84	11.682	4.415	0.000	0.000	0.000	0.289	3.417	0.031	91.43	7.73	0.84
28-3-4P	2	64.82	22.19	0.00	0.00	0.00	2.55	9.69	0.08	99.33	11.455	4.623	0.000	0.000	0.000	0.483	3.325	0.018	86.91	12.62	0.47
28-3-4P	3	67.98	20.16	0.00	0.00	0.00	0.33	10.74	0.18	99.39	11.919	4.167	0.000	0.000	0.000	0.062	3.657	0.040	97.28	1.65	1.07
38-1-2P	1	67.30	19.90	0.00	0.00	0.00	0.25	10.61	0.13	98.19	11.935	4.161	0.000	0.000	0.000	0.048	3.654	0.029	97.94	1.27	0.79
38-1-2P	2	67.24	20.15	0.00	0.00	0.00	0.51	10.70	0.08	98.68	11.881	4.198	0.000	0.000	0.000	0.097	3.671	0.018	96.97	2.55	0.48
38-1-2P	3	65.54	20.30	0.00	0.00	0.00	0.33	11.00	0.12	97.29	11.777	4.300	0.000	0.000	0.000	0.064	3.838	0.028	97.68	1.62	0.70
38-1-2P	4	66.83	20.31	0.00	0.00	0.00	0.35	10.77	0.09	98.35	11.850	4.246	0.000	0.000	0.000	0.066	3.708	0.020	97.71	1.75	0.54
38-1-3P	1	66.00	20.42	0.00	0.00	0.00	0.56	10.70	0.13	97.81	11.787	4.299	0.000	0.000	0.000	0.107	3.711	0.030	96.44	2.79	0.77
38-1-3P	2	67.36	20.00	0.00	0.00	0.00	0.06	10.88	0.09	98.39	11.924	4.174	0.000	0.000	0.000	0.011	3.740	0.020	99.16	0.30	0.54
38-1-3P	3	66.18	20.57	0.00	0.00	0.00	0.82	10.65	0.08	98.30	11.765	4.311	0.000	0.000	0.000	0.156	3.676	0.018	95.47	4.06	0.47
38-1-3P	6	66.44	20.41	0.00	0.00	0.00	0.46	10.75	0.08	98.14	11.815	4.279	0.000	0.000	0.000	0.088	3.712	0.018	97.23	2.30	0.48
38-1-5P	5	62.59	22.57	0.00	0.09	0.00	3.51	9.21	0.13	98.10	11.255	4.785	0.000	0.014	0.000	0.676	3.216	0.030	82.00	17.24	0.76
38-1-5P	6	66.27	19.85	0.00	0.00	0.00	0.15	10.88	0.09	97.24	11.885	4.197	0.000	0.000	0.000	0.029	3.789	0.021	98.71	0.75	0.54
38-2-1P	1	65.30	19.70	0.00	0.00	0.00	0.45	10.73	0.08	96.26	11.847	4.213	0.000	0.000	0.000	0.087	3.780	0.019	97.27	2.25	0.48
38-2-1P	10	67.71	20.21	0.00	0.00	0.00	0.39	10.91	0.10	99.32	11.890	4.184	0.000	0.000	0.000	0.073	3.720	0.022	97.49	1.92	0.59
38-2-1P	11	67.01	20.07	0.00	0.00	0.00	0.36	10.62	0.12	98.18	11.894	4.200	0.000	0.000	0.000	0.068	3.660	0.027	97.45	1.82	0.72
38-2-1P	12	66.71	20.46	0.00	0.00	0.00	0.72	10.66	0.12	98.67	11.807	4.269	0.000	0.000	0.000	0.137	3.664	0.027	95.72	3.57	0.71
38-2-1P	16	66.46	20.79	0.00	0.11	0.00	1.00	10.51	0.12	98.99	11.741	4.330	0.000	0.016	0.000	0.189	3.606	0.027	94.34	4.95	0.71
38-2-1P	19	67.18	20.33	0.00	0.00	0.00	0.47	10.72	0.10	98.80	11.858	4.231	0.000	0.000	0.000	0.089	3.674	0.023	97.06	2.35	0.59
38-2-2P	1	66.19	19.83	0.00	0.00	0.00	0.52	10.63	0.10	97.27	11.873	4.194	0.000	0.000	0.000	0.100	3.703	0.023	96.79	2.61	0.60
38-2-2P	2	66.73	19.96	0.00	0.11	0.00	0.28	10.80	0.07	97.95	11.884	4.191	0.000	0.016	0.000	0.053	3.735	0.016	98.18	1.40	0.42
38-2-2P	3	65.88	20.29	0.00	0.00	0.00	0.70	10.48	0.08	97.43	11.803	4.285	0.000	0.000	0.000	0.134	3.646	0.018	95.98	3.54	0.48

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
38-2-2P	4	65.00	20.02	0.00	0.00	0.00	0.58	10.48	0.08	96.16	11.801	4.285	0.000	0.000	0.000	0.113	3.695	0.019	96.57	2.95	0.48
38-2-2P	5	66.22	19.69	0.00	0.00	0.00	0.19	10.81	0.10	97.01	11.903	4.173	0.000	0.000	0.000	0.037	3.773	0.023	98.45	0.95	0.60
38-2-2P	6	66.51	19.47	0.00	0.00	0.00	0.14	10.66	0.08	96.86	11.957	4.126	0.000	0.000	0.000	0.027	3.721	0.018	98.80	0.72	0.49
38-2-2P	7	61.35	22.30	0.00	0.00	0.00	3.50	8.91	0.25	96.31	11.238	4.816	0.000	0.000	0.000	0.687	3.169	0.058	80.96	17.55	1.49
41-1-2P	1	66.06	20.51	0.00	0.00	0.00	1.40	10.18	0.09	98.24	11.755	4.303	0.000	0.000	0.000	0.267	3.518	0.020	92.45	7.02	0.54
41-1-2P	4	68.37	19.76	0.00	0.00	0.00	0.26	10.84	0.07	99.30	11.986	4.084	0.000	0.000	0.000	0.049	3.690	0.016	98.28	1.30	0.42
41-2-1P	1	67.62	20.19	0.00	0.00	0.00	0.26	10.70	0.06	98.83	11.912	4.193	0.000	0.000	0.000	0.049	3.660	0.013	98.32	1.32	0.36
41-2-1P	5	64.12	22.78	0.00	0.00	0.00	3.21	9.15	0.07	99.33	11.343	4.751	0.000	0.000	0.000	0.608	3.143	0.016	83.43	16.15	0.42
41-2-1P	6	64.96	22.01	0.00	0.00	0.00	2.63	9.31	0.10	99.01	11.500	4.594	0.000	0.000	0.000	0.499	3.200	0.023	85.99	13.40	0.61
41-3-1P	1	67.21	20.40	0.00	0.00	0.00	0.52	10.34	0.07	98.54	11.873	4.249	0.000	0.000	0.000	0.098	3.547	0.016	96.88	2.69	0.43
41-3-1P	5	67.30	20.93	0.00	0.00	0.00	1.05	10.41	0.07	99.76	11.775	4.317	0.000	0.000	0.000	0.197	3.537	0.016	94.33	5.25	0.42
41-3-1P	6	65.59	20.72	0.00	0.00	0.00	1.43	9.99	0.14	97.87	11.716	4.363	0.000	0.000	0.000	0.274	3.465	0.032	91.90	7.26	0.85
41-3-2P	1	66.72	19.83	0.00	0.00	0.00	0.14	10.81	0.09	97.59	11.914	4.174	0.000	0.000	0.000	0.027	3.748	0.021	98.75	0.71	0.54
41-3-2P	2	66.43	20.36	0.00	0.00	0.00	0.34	10.68	0.07	97.88	11.833	4.276	0.000	0.000	0.000	0.065	3.694	0.016	97.86	1.72	0.42
41-3-2P	3	65.84	20.79	0.00	0.11	0.00	0.78	10.48	0.11	98.11	11.730	4.367	0.000	0.016	0.000	0.149	3.626	0.025	95.42	3.92	0.66
41-3-3P	1	68.54	20.56	0.00	0.00	0.00	0.40	10.67	0.07	100.24	11.902	4.209	0.000	0.000	0.000	0.074	3.598	0.016	97.56	2.02	0.42
41-3-3P	3	66.62	21.23	0.00	0.00	0.00	1.22	10.31	0.08	99.46	11.704	4.397	0.000	0.000	0.000	0.230	3.517	0.018	93.42	6.10	0.48
2-2-6P	1	64.83	22.16	0.00	0.00	0.00	3.00	9.78	0.09	99.86	11.423	4.603	0.000	0.000	0.000	0.566	3.346	0.020	85.08	14.40	0.51
2-2-6P	4	67.11	19.66	0.00	0.00	0.00	0.44	11.09	0.11	98.41	11.911	4.114	0.000	0.000	0.000	0.084	3.822	0.025	97.24	2.13	0.63
2-2-7P	1	67.69	19.99	0.00	0.00	0.00	0.62	10.79	0.11	99.20	11.905	4.145	0.000	0.000	0.000	0.117	3.685	0.025	96.30	3.05	0.65
2-2-7P	4	66.69	19.87	0.00	0.00	0.00	0.58	10.83	0.07	98.04	11.876	4.171	0.000	0.000	0.000	0.111	3.745	0.016	96.73	2.86	0.41
2-2-8	6	66.86	19.92	0.00	0.00	0.00	0.17	10.81	0.11	97.87	11.906	4.182	0.000	0.000	0.000	0.032	3.738	0.025	98.49	0.85	0.66
2-2-8P	1	68.38	19.79	0.00	0.00	0.00	0.41	11.01	0.07	99.66	11.962	4.081	0.000	0.000	0.000	0.077	3.740	0.016	97.59	2.01	0.41
2-2-9	4	67.86	20.23	0.00	0.00	0.00	0.17	11.15	0.11	99.52	11.894	4.180	0.000	0.000	0.000	0.032	3.795	0.025	98.53	0.83	0.64
2-3-2P	1	68.13	19.68	0.00	0.09	0.00	0.27	11.08	0.12	99.37	11.962	4.074	0.000	0.013	0.000	0.051	3.778	0.027	97.99	1.32	0.70
2-3-3	4	66.35	20.58	0.00	0.00	0.00	1.15	10.51	0.12	98.71	11.756	4.299	0.000	0.000	0.000	0.218	3.616	0.027	93.64	5.65	0.70
2-3-3P	1	64.79	22.40	0.00	0.00	0.00	2.92	9.44	0.13	99.68	11.419	4.654	0.000	0.000	0.000	0.551	3.231	0.029	84.77	14.47	0.77
2-3-4	4	67.50	20.36	0.00	0.10	0.00	1.07	10.65	0.10	99.78	11.827	4.206	0.000	0.015	0.000	0.201	3.623	0.022	94.20	5.22	0.58
2-3-4P	1	68.23	19.76	0.00	0.00	0.00	0.22	11.34	0.09	99.64	11.950	4.080	0.000	0.000	0.000	0.041	3.857	0.020	98.43	1.05	0.51
2-4-2	4	66.92	20.07	0.00	0.00	0.00	0.45	10.79	0.13	98.36	11.872	4.198	0.000	0.000	0.000	0.086	3.717	0.029	97.00	2.23	0.77
2-4-2P	1	67.27	20.10	0.00	0.00	0.00	0.20	11.08	0.10	98.75	11.885	4.187	0.000	0.000	0.000	0.038	3.801	0.023	98.44	0.98	0.58
2-4-4	2	68.45	19.75	0.00	0.00	0.00	0.07	10.75	0.13	99.15	12.007	4.084	0.000	0.000	0.000	0.013	3.662	0.029	98.86	0.36	0.79
2-4-4P	1	68.17	19.63	0.00	0.00	0.00	0.07	11.04	0.10	99.01	11.992	4.071	0.000	0.000	0.000	0.013	3.771	0.022	99.06	0.35	0.59
2-4-5	4	65.53	18.33	0.00	0.00	0.00	0.66	10.75	0.08	95.35	12.005	3.959	0.000	0.000	0.000	0.130	3.824	0.019	96.27	3.26	0.47
2-4-5P	1	67.85	19.15	0.00	0.09	0.00	0.25	11.06	0.13	98.53	12.014	3.997	0.000	0.013	0.000	0.047	3.803	0.029	98.02	1.22	0.76

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
2-4-6	1	67.38	19.60	0.00	0.00	0.00	0.28	11.06	0.08	98.40	11.945	4.096	0.000	0.000	0.000	0.053	3.807	0.018	98.16	1.37	0.47
37-1-1	3	67.43	20.16	0.00	0.00	0.00	0.48	11.21	0.05	99.33	11.860	4.180	0.000	0.000	0.000	0.090	3.829	0.011	97.41	2.30	0.29
37-1-3	2	67.27	20.00	0.00	0.00	0.00	0.28	11.35	0.09	98.99	11.874	4.162	0.000	0.000	0.000	0.053	3.890	0.020	98.15	1.34	0.51
37-1-3	3	67.25	20.12	0.00	0.00	0.00	0.25	10.95	0.11	98.68	11.886	4.192	0.000	0.000	0.000	0.047	3.758	0.025	98.12	1.24	0.65
37-1-3P	1	66.84	19.97	0.00	0.00	0.00	0.56	11.05	0.07	98.49	11.858	4.177	0.000	0.000	0.000	0.106	3.807	0.016	96.89	2.71	0.40
37-1-5P	1	67.46	20.26	0.00	0.00	0.00	0.62	11.02	0.09	99.45	11.850	4.196	0.000	0.000	0.000	0.117	3.759	0.020	96.49	3.00	0.52
37-1-5P	2	67.95	19.79	0.00	0.00	0.00	0.37	10.99	0.08	99.18	11.946	4.102	0.000	0.000	0.000	0.070	3.752	0.018	97.72	1.82	0.47
37-1-6P	1	67.63	19.66	0.00	0.00	0.00	0.27	11.07	0.08	98.71	11.949	4.095	0.000	0.000	0.000	0.051	3.798	0.018	98.21	1.32	0.47
37-1-6P	4	67.36	19.90	0.00	0.00	0.00	0.43	11.26	0.12	99.07	11.884	4.139	0.000	0.000	0.000	0.081	3.858	0.027	97.27	2.05	0.68
37-1-8P	1	66.53	19.66	0.00	0.00	0.00	0.71	10.98	0.07	97.95	11.874	4.137	0.000	0.000	0.000	0.136	3.805	0.016	96.17	3.43	0.40
37-1-8P	2	67.62	19.08	0.00	0.10	0.00	0.00	11.24	0.07	98.11	12.020	3.998	0.000	0.015	0.000	0.000	3.880	0.016	99.59	0.00	0.41
37-2-1	2	63.77	21.55	0.00	0.00	0.00	2.66	9.78	0.15	97.91	11.458	4.565	0.000	0.000	0.000	0.512	3.412	0.034	86.20	12.94	0.87
37-2-1	4	67.19	19.90	0.00	0.00	0.00	0.25	11.16	0.07	98.57	11.897	4.154	0.000	0.000	0.000	0.047	3.837	0.016	98.38	1.22	0.41
37-2-1P	1	68.11	19.84	0.00	0.00	0.00	0.19	11.16	0.10	99.40	11.949	4.103	0.000	0.000	0.000	0.036	3.802	0.022	98.49	0.93	0.58
37-2-2	2	66.44	20.13	0.00	0.00	0.00	0.52	11.00	0.00	98.09	11.830	4.226	0.000	0.000	0.000	0.099	3.803	0.000	97.46	2.54	0.00
37-2-2P	1	67.09	19.60	0.00	0.00	0.00	0.29	11.38	0.12	98.48	11.909	4.102	0.000	0.000	0.000	0.055	3.923	0.027	97.94	1.38	0.68
37-2-8P	1	67.74	19.57	0.00	0.00	0.00	0.45	10.89	0.12	98.77	11.962	4.074	0.000	0.000	0.000	0.085	3.734	0.027	97.08	2.21	0.70
37-2-8P	2	67.03	19.59	0.00	0.00	0.00	0.53	10.91	0.05	98.11	11.923	4.108	0.000	0.000	0.000	0.101	3.768	0.011	97.10	2.60	0.29
37-2-8P	3	67.78	19.27	0.00	0.00	0.00	0.12	11.31	0.10	98.58	11.996	4.021	0.000	0.000	0.000	0.023	3.887	0.023	98.85	0.58	0.57
44-1-2P	1	66.55	21.88	0.00	0.00	0.00	2.10	9.38	0.12	100.03	11.623	4.505	0.000	0.000	0.000	0.393	3.181	0.027	88.34	10.91	0.74
44-1-2P	3	68.25	20.40	0.00	0.00	0.00	0.22	10.39	0.12	99.38	11.936	4.206	0.000	0.000	0.000	0.041	3.528	0.027	98.11	1.15	0.74
44-2-1P	1	68.39	20.23	0.00	0.00	0.00	0.29	10.87	0.13	99.91	11.926	4.159	0.000	0.000	0.000	0.054	3.681	0.029	97.79	1.44	0.77
44-2-1P	4	66.06	21.82	0.00	0.00	0.00	2.04	10.05	0.07	100.04	11.571	4.506	0.000	0.000	0.000	0.383	3.418	0.016	89.56	10.03	0.41
44-2-2P	1	66.99	20.10	0.00	0.00	0.00	0.15	11.18	0.10	98.52	11.870	4.199	0.000	0.000	0.000	0.028	3.847	0.023	98.69	0.73	0.58
44-2-2P	4	67.72	20.43	0.00	0.00	0.00	0.35	11.09	0.09	99.68	11.857	4.217	0.000	0.000	0.000	0.066	3.770	0.020	97.78	1.70	0.52
44-2-5P	1	67.58	20.08	0.00	0.00	0.00	0.07	10.82	0.12	98.67	11.926	4.178	0.000	0.000	0.000	0.013	3.708	0.027	98.93	0.35	0.72
44-2-5P	4	66.34	21.88	0.00	0.00	0.00	2.23	9.90	0.09	100.44	11.573	4.500	0.000	0.000	0.000	0.417	3.354	0.020	88.47	11.00	0.53
44-2-7P	1	66.17	20.73	0.00	0.00	0.00	0.87	10.70	0.07	98.54	11.740	4.336	0.000	0.000	0.000	0.165	3.686	0.016	95.31	4.28	0.41
44-2-7P	2	66.12	20.56	0.00	0.00	0.00	0.75	10.53	0.11	98.07	11.775	4.316	0.000	0.000	0.000	0.143	3.641	0.025	95.59	3.76	0.66
44-2-7P	3	65.75	20.68	0.00	0.12	0.00	0.83	10.64	0.11	98.13	11.724	4.347	0.000	0.018	0.000	0.159	3.684	0.025	95.25	4.10	0.65
46-1-1P	1	67.32	20.43	0.00	0.00	0.00	0.69	10.51	0.09	99.04	11.852	4.240	0.000	0.000	0.000	0.130	3.593	0.020	95.98	3.48	0.54
46-1-1P	3	67.12	20.85	0.00	0.00	0.00	0.85	10.48	0.07	99.37	11.786	4.316	0.000	0.000	0.000	0.160	3.573	0.016	95.32	4.27	0.42
46-1-1P	4	66.99	20.24	0.00	0.00	0.00	0.49	10.59	0.08	98.39	11.868	4.227	0.000	0.000	0.000	0.093	3.643	0.018	97.04	2.48	0.48
46-1-2P	1	67.29	20.52	0.00	0.00	0.00	0.61	10.84	0.21	99.47	11.820	4.249	0.000	0.000	0.000	0.115	3.697	0.047	95.81	2.97	1.22
46-1-2P	2	67.94	20.58	0.00	0.00	0.00	0.38	11.03	0.08	100.01	11.852	4.232	0.000	0.000	0.000	0.071	3.736	0.018	97.68	1.86	0.47

SAMPLE	No.										Cations normalised to 32 oxygens								End members		
		SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	Ab	An	Or
46-1-2P	3	67.90	20.57	0.00	0.00	0.00	0.59	10.93	0.12	100.11	11.841	4.229	0.000	0.000	0.000	0.110	3.701	0.027	96.43	2.87	0.70
46-1-2P	4	67.85	20.59	0.00	0.00	0.00	0.46	10.84	0.12	99.86	11.851	4.240	0.000	0.000	0.000	0.086	3.677	0.027	97.02	2.27	0.71
46-1-3P	1	68.22	20.85	0.00	0.00	0.00	0.75	10.52	0.11	100.45	11.839	4.266	0.000	0.000	0.000	0.139	3.545	0.024	95.58	3.76	0.66
46-1-3P	3	68.29	20.38	0.00	0.00	0.00	0.23	11.08	0.09	100.07	11.897	4.186	0.000	0.000	0.000	0.043	3.748	0.020	98.35	1.13	0.52
46-1-3P	5	64.66	22.75	0.00	0.00	0.00	3.27	9.28	0.14	100.10	11.359	4.712	0.000	0.000	0.000	0.616	3.166	0.031	83.03	16.14	0.82
46-1-3P	6	67.93	20.97	0.00	0.00	0.00	0.62	10.68	0.12	100.32	11.810	4.298	0.000	0.000	0.000	0.116	3.606	0.027	96.21	3.08	0.71
46-2-1P	1	66.63	20.57	0.00	0.00	0.00	0.83	10.69	0.11	98.83	11.782	4.288	0.000	0.000	0.000	0.157	3.670	0.025	95.27	4.08	0.64
46-2-2P	1	66.60	21.19	0.00	0.00	0.00	1.37	10.40	0.08	99.64	11.691	4.385	0.000	0.000	0.000	0.258	3.545	0.018	92.79	6.74	0.47
46-2-2P	2	68.46	20.63	0.00	0.00	0.00	0.40	11.18	0.00	100.67	11.862	4.214	0.000	0.000	0.000	0.074	3.762	0.000	98.06	1.94	0.00
46-2-2P	6	67.34	21.21	0.00	0.00	0.00	1.05	10.45	0.25	100.30	11.736	4.358	0.000	0.000	0.000	0.196	3.536	0.056	93.36	5.18	1.47
46-2-4P	4	67.96	20.58	0.00	0.00	0.00	0.22	11.09	0.13	99.98	11.858	4.233	0.000	0.000	0.000	0.041	3.757	0.029	98.17	1.07	0.76
47-1-1P	1	63.75	21.73	0.00	0.00	0.00	2.77	9.40	0.16	97.81	11.453	4.602	0.000	0.000	0.000	0.533	3.279	0.037	85.19	13.85	0.95
47-1-3P	2	66.99	19.03	0.00	0.00	0.00	0.16	11.04	0.10	97.32	12.004	4.020	0.000	0.000	0.000	0.031	3.841	0.023	98.62	0.79	0.59
47-1-3P	4	66.55	19.40	0.00	0.00	0.00	0.42	10.78	0.12	97.27	11.937	4.102	0.000	0.000	0.000	0.081	3.755	0.027	97.20	2.09	0.71
47-1-4P	1	65.83	22.38	0.00	0.00	0.00	2.54	9.93	0.08	100.76	11.470	4.597	0.000	0.000	0.000	0.474	3.360	0.018	87.23	12.31	0.46
47-1-4P	4	67.08	20.28	0.00	0.00	0.00	0.40	10.62	0.10	98.48	11.871	4.231	0.000	0.000	0.000	0.076	3.649	0.023	97.37	2.02	0.60
47-1-5P	1	67.08	20.78	0.00	0.00	0.00	0.42	10.81	0.06	99.15	11.801	4.310	0.000	0.000	0.000	0.079	3.693	0.013	97.55	2.09	0.36
47-1-5P	4	63.94	22.78	0.00	0.00	0.00	2.96	9.50	0.18	99.36	11.325	4.757	0.000	0.000	0.000	0.562	3.267	0.041	84.43	14.52	1.05
47-1-6R	4	67.69	20.48	0.00	0.00	0.00	0.54	10.75	0.13	99.59	11.856	4.229	0.000	0.000	0.000	0.101	3.656	0.029	96.56	2.68	0.77
47-2-1P	1	66.44	19.72	0.00	0.00	0.00	0.82	10.78	0.00	97.76	11.871	4.154	0.000	0.000	0.000	0.157	3.740	0.000	95.97	4.03	0.00
47-2-4P	1	68.20	20.15	0.00	0.00	0.00	0.15	11.00	0.13	99.63	11.928	4.155	0.000	0.000	0.000	0.028	3.736	0.029	98.49	0.74	0.76
47-2-4P	4	67.91	20.27	0.00	0.00	0.00	0.25	10.81	0.06	99.30	11.910	4.191	0.000	0.000	0.000	0.047	3.681	0.013	98.39	1.26	0.36
47-2-5P	1	66.92	20.46	0.00	0.00	0.00	0.55	10.71	0.05	98.69	11.828	4.263	0.000	0.000	0.000	0.104	3.676	0.011	96.96	2.75	0.30
47-2-5P	4	68.05	20.39	0.00	0.00	0.00	0.23	10.94	0.05	99.66	11.896	4.202	0.000	0.000	0.000	0.043	3.714	0.011	98.56	1.14	0.30

Table 10c: Electron microprobe data for K-feldspar from selected HHD granitoids

SAMPLE	No	Centre /Rim	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	Ab	An	Or
41-2-2M	1	R	63.35	18.78	0.00	0.00	0.00	0.00	0.34	16.45	98.92	32	11.873	4.150	0.000	0.000	0.000	0.000	0.124	3.933	20.080	0.00	0.00	0.00	3.05	0.00	96.95
41-2-3M	2	R	64.27	18.94	0.00	0.00	0.00	0.00	0.41	16.76	100.38	32	11.880	4.127	0.000	0.000	0.000	0.000	0.147	3.952	20.106	0.00	0.00	0.00	3.59	0.00	96.41
41-3-8M	1	R	63.43	18.97	0.00	0.00	0.00	0.00	0.28	17.29	99.97	32	11.821	4.168	0.000	0.000	0.000	0.000	0.101	4.111	20.201	0.00	0.00	0.00	2.41	0.00	97.59
41-3-8M	3	R	64.22	18.80	0.00	0.00	0.00	0.00	0.24	17.23	100.49	32	11.885	4.102	0.000	0.000	0.000	0.000	0.086	4.068	20.141	0.00	0.00	0.00	2.08	0.00	97.92
47-1-6R	1	R	63.03	18.91	0.00	0.00	0.00	0.00	0.35	17.07	99.36	32	11.814	4.179	0.000	0.000	0.000	0.000	0.127	4.082	20.202	0.00	0.00	0.00	3.03	0.00	96.97
47-1-6R	2	R	63.46	18.65	0.00	0.00	0.00	0.00	0.32	16.89	99.32	32	11.877	4.115	0.000	0.000	0.000	0.000	0.116	4.033	20.141	0.00	0.00	0.00	2.80	0.00	97.20
47-1-6R	3	R	63.74	18.92	0.00	0.00	0.00	0.00	0.36	16.59	99.61	32	11.868	4.153	0.000	0.000	0.000	0.000	0.130	3.941	20.091	0.00	0.00	0.00	3.20	0.00	96.80
38-1-1M	1	R	62.95	18.92	0.00	0.09	0.00	0.00	0.53	17.19	99.68	32	11.786	4.176	0.000	0.014	0.000	0.000	0.193	4.106	20.275	0.00	0.00	0.00	4.48	0.00	95.52
38-1-1	9	R	63.33	18.79	0.00	0.00	0.00	0.00	0.49	16.81	99.42	32	11.845	4.143	0.000	0.000	0.000	0.000	0.178	4.011	20.178	0.00	0.00	0.00	4.25	0.00	95.75
38-1-4M	1	R	62.88	18.67	0.00	0.00	0.00	0.00	0.55	17.00	99.10	32	11.826	4.139	0.000	0.000	0.000	0.000	0.201	4.079	20.245	0.00	0.00	0.00	4.69	0.00	95.31
38-1-4M	6	R	63.27	19.02	0.00	0.00	0.00	0.00	0.24	17.62	100.15	32	11.795	4.180	0.000	0.000	0.000	0.000	0.087	4.191	20.253	0.00	0.00	0.00	2.03	0.00	97.97
2-2-9P	1	R	63.81	18.63	0.00	0.00	0.00	0.05	0.66	16.65	99.80	32	11.880	4.089	0.000	0.000	0.000	0.010	0.239	3.955	20.172	0.00	0.00	0.00	5.68	0.24	94.09
37-2-3M	1	R	63.50	18.22	0.00	0.00	0.00	0.00	0.60	16.31	98.63	32	11.938	4.038	0.000	0.000	0.000	0.000	0.219	3.912	20.108	0.00	0.00	0.00	5.30	0.00	94.70
37-2-3M	3	R	63.14	17.78	0.00	0.00	0.00	0.00	0.47	16.52	97.91	32	11.976	3.976	0.000	0.000	0.000	0.000	0.173	3.997	20.122	0.00	0.00	0.00	4.15	0.00	95.85
37-2-4M	1	R	63.64	17.98	0.00	0.00	0.00	0.00	0.67	16.00	98.29	32	11.984	3.992	0.000	0.000	0.000	0.000	0.245	3.844	20.065	0.00	0.00	0.00	5.99	0.00	94.01
37-2-4M	3	R	63.35	17.90	0.00	0.00	0.00	0.00	0.55	16.38	98.18	32	11.971	3.988	0.000	0.000	0.000	0.000	0.202	3.949	20.110	0.00	0.00	0.00	4.86	0.00	95.14
37-2-5M	1	R	63.65	18.24	0.00	0.00	0.00	0.00	0.34	16.50	98.73	32	11.952	4.038	0.000	0.000	0.000	0.000	0.124	3.953	20.067	0.00	0.00	0.00	3.04	0.00	96.96
37-2-6M	3	R	62.31	18.23	0.00	0.00	0.00	0.00	0.26	16.97	97.77	32	11.873	4.095	0.000	0.000	0.000	0.000	0.096	4.125	20.190	0.00	0.00	0.00	2.28	0.00	97.72
37-2-7M	1	R	63.94	18.39	0.00	0.00	0.00	0.00	0.57	16.30	99.20	32	11.941	4.049	0.000	0.000	0.000	0.000	0.207	3.884	20.080	0.00	0.00	0.00	5.05	0.00	94.95
37-2-7M	6	R	63.36	17.81	0.00	0.00	0.00	0.00	0.54	16.29	98.00	32	11.988	3.973	0.000	0.000	0.000	0.000	0.198	3.932	20.091	0.00	0.00	0.00	4.80	0.00	95.20
47-1-2M	1	R	63.18	18.17	0.00	0.00	0.00	0.00	0.43	16.33	98.11	32	11.940	4.048	0.000	0.000	0.000	0.000	0.158	3.937	20.083	0.00	0.00	0.00	3.85	0.00	96.15
47-1-2	4	R	62.85	17.97	0.00	0.00	0.00	0.00	0.39	16.41	97.62	32	11.948	4.028	0.000	0.000	0.000	0.000	0.144	3.980	20.100	0.00	0.00	0.00	3.49	0.00	96.51
47-1-3P	1	R	63.31	17.75	0.00	0.00	0.00	0.00	0.33	16.54	97.93	32	11.996	3.965	0.000	0.000	0.000	0.000	0.121	3.998	20.081	0.00	0.00	0.00	2.95	0.00	97.05
44-1-3M	1	R	64.16	18.98	0.00	0.00	0.00	0.00	0.42	16.90	100.46	32	11.863	4.137	0.000	0.000	0.000	0.000	0.151	3.986	20.137	0.00	0.00	0.00	3.64	0.00	96.36
44-1-3M	4	R	64.30	19.17	0.00	0.00	0.00	0.00	0.34	17.18	100.99	32	11.840	4.161	0.000	0.000	0.000	0.000	0.122	4.036	20.158	0.00	0.00	0.00	2.92	0.00	97.08
44-1-4M	1	R	63.59	18.73	0.00	0.00	0.00	0.00	0.65	16.47	99.44	32	11.869	4.122	0.000	0.000	0.000	0.000	0.236	3.922	20.149	0.00	0.00	0.00	5.67	0.00	94.33
44-1-4M	4	R	63.55	18.89	0.00	0.00	0.00	0.00	0.30	17.00	99.74	32	11.848	4.152	0.000	0.000	0.000	0.000	0.109	4.044	20.152	0.00	0.00	0.00	2.62	0.00	97.38
44-2-3M	4	R	64.07	19.15	0.00	0.00	0.00	0.00	0.36	16.76	100.34	32	11.848	4.175	0.000	0.000	0.000	0.000	0.129	3.954	20.106	0.00	0.00	0.00	3.17	0.00	96.83
44-2-4M	1	R	63.36	18.90	0.00	0.00	0.00	0.00	0.56	16.59	99.41	32	11.838	4.163	0.000	0.000	0.000	0.000	0.203	3.955	20.159	0.00	0.00	0.00	4.89	0.00	95.11
44-2-4M	4	R	63.86	18.78	0.00	0.00	0.00	0.00	0.18	17.19	100.01	32	11.876	4.117	0.000	0.000	0.000	0.000	0.065	4.078	20.137	0.00	0.00	0.00	1.57	0.00	98.43
44-2-6M	3	R	64.36	18.94	0.00	0.00	0.00	0.00	0.36	16.77	100.43	32	11.887	4.124	0.000	0.000	0.000	0.000	0.129	3.952	20.091	0.00	0.00	0.00	3.16	0.00	96.84
44-2-6M	4	R	64.31	18.89	0.00	0.00	0.00	0.00	0.32	16.64	100.16	32	11.899	4.120	0.000	0.000	0.000	0.000	0.115	3.928	20.062	0.00	0.00	0.00	2.84	0.00	97.16
46-1-4M	1	R	63.23	18.85	0.00	0.00	0.00	0.00	0.38	17.10	99.56	32	11.828	4.157	0.000	0.000	0.000	0.000	0.138	4.081	20.203	0.00	0.00	0.00	3.27	0.00	96.73

SAMPLE	No	Centre /Rim	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	Ab	An	Or
46-1-4M	2	R	64.64	19.29	0.00	0.00	0.00	0.00	0.43	16.68	101.04	32	11.857	4.172	0.000	0.000	0.000	0.000	0.153	3.904	20.085	0.00	0.00	0.00	3.78	0.00	96.22
46-1-4M	3	R	64.60	19.17	0.00	0.00	0.00	0.00	0.44	16.41	100.62	32	11.881	4.156	0.000	0.000	0.000	0.000	0.157	3.850	20.045	0.00	0.00	0.00	3.92	0.00	96.08
46-1-4M	6	R	65.22	19.16	0.00	0.00	0.00	0.00	0.38	16.78	101.54	32	11.899	4.121	0.000	0.000	0.000	0.000	0.135	3.906	20.061	0.00	0.00	0.00	3.33	0.00	96.67
46-1-5M	2	R	64.52	18.91	0.00	0.00	0.00	0.00	0.52	16.53	100.48	32	11.898	4.111	0.000	0.000	0.000	0.000	0.186	3.889	20.084	0.00	0.00	0.00	4.57	0.00	95.43
46-1-5M	6	R	63.71	18.92	0.00	0.00	0.00	0.07	0.40	16.45	99.55	32	11.864	4.154	0.000	0.000	0.000	0.014	0.145	3.908	20.085	0.00	0.00	0.00	3.56	0.34	96.10
46-2-3M	1	R	63.36	18.56	0.00	0.00	0.00	0.37	0.43	16.43	99.15	32	11.868	4.099	0.000	0.000	0.000	0.074	0.156	3.926	20.124	0.00	0.00	0.00	3.76	1.79	94.45
46-2-4M	3	R	63.62	19.09	0.00	0.00	0.00	0.00	0.53	16.55	99.79	32	11.831	4.185	0.000	0.000	0.000	0.000	0.191	3.927	20.135	0.00	0.00	0.00	4.65	0.00	95.35
50-3-6M	1	R	62.35	18.86	0.00	0.00	0.00	0.00	0.38	16.93	98.52	32	11.791	4.205	0.000	0.000	0.000	0.000	0.140	4.084	20.219	0.00	0.00	0.00	3.30	0.00	96.70
28-1-2P	1	R	62.85	18.90	0.00	0.00	0.00	0.00	0.62	16.48	98.85	32	11.814	4.188	0.000	0.000	0.000	0.000	0.226	3.952	20.181	0.00	0.00	0.00	5.42	0.00	94.58
28-1-3M	1	RP	63.07	18.80	0.00	0.00	0.00	0.00	0.63	16.48	98.98	32	11.836	4.160	0.000	0.000	0.000	0.000	0.230	3.946	20.171	0.00	0.00	0.00	5.50	0.00	94.50
28-1-3M	4	RQ	62.80	19.02	0.00	0.00	0.00	0.00	0.34	16.21	98.37	32	11.828	4.223	0.000	0.000	0.000	0.000	0.124	3.895	20.070	0.00	0.00	0.00	3.09	0.00	96.91
28-2-2M	1	RP	63.28	19.07	0.00	0.00	0.00	0.00	0.59	16.18	99.12	32	11.830	4.203	0.000	0.000	0.000	0.000	0.214	3.859	20.106	0.00	0.00	0.00	5.26	0.00	94.74
28-2-2M	4	RB	64.29	19.11	0.00	0.09	0.00	0.00	0.44	16.60	100.53	32	11.860	4.156	0.000	0.014	0.000	0.000	0.158	3.907	20.094	0.00	0.00	0.00	3.88	0.00	96.12
28-3-2M	7	RP	63.42	18.56	0.00	0.00	0.00	0.00	0.24	16.67	98.89	32	11.901	4.106	0.000	0.000	0.000	0.000	0.087	3.991	20.085	0.00	0.00	0.00	2.14	0.00	97.86
28-3-3	3	R	63.95	18.78	0.00	0.00	0.00	0.00	0.54	16.37	99.64	32	11.892	4.117	0.000	0.000	0.000	0.000	0.195	3.884	20.088	0.00	0.00	0.00	4.78	0.00	95.22
18-1-2M	1	R	62.53	18.37	0.00	0.00	0.00	0.06	0.16	17.11	98.23	32	11.862	4.109	0.000	0.000	0.000	0.012	0.059	4.141	20.183	0.00	0.00	0.00	1.40	0.29	98.31
38-2-5M	1	C	64.09	18.83	0.00	0.00	0.00	0.00	0.33	16.98	100.23	32	11.880	4.115	0.000	0.000	0.000	0.000	0.119	4.016	20.130	0.00	0.00	0.00	2.87	0.00	97.13
38-2-5	2	C	63.95	18.74	0.00	0.11	0.00	0.00	0.54	16.68	100.02	32	11.877	4.103	0.000	0.017	0.000	0.000	0.195	3.952	20.145	0.00	0.00	0.00	4.70	0.00	95.30
41-1-3M	2	C	64.06	18.39	0.00	0.00	0.00	0.00	0.61	16.68	99.74	32	11.927	4.037	0.000	0.000	0.000	0.000	0.221	3.962	20.146	0.00	0.00	0.00	5.27	0.00	94.73
41-1-3M	3	C	64.37	18.63	0.00	0.00	0.00	0.00	0.29	17.16	100.45	32	11.913	4.065	0.000	0.000	0.000	0.000	0.104	4.052	20.133	0.00	0.00	0.00	2.51	0.00	97.49
41-1-3M	4	C	64.21	18.65	0.00	0.00	0.00	0.00	0.57	16.66	100.09	32	11.906	4.077	0.000	0.000	0.000	0.000	0.205	3.941	20.129	0.00	0.00	0.00	4.95	0.00	95.05
41-1-4M	1	C	63.70	18.65	0.00	0.00	0.00	0.00	0.41	17.04	99.80	32	11.875	4.099	0.000	0.000	0.000	0.000	0.148	4.053	20.176	0.00	0.00	0.00	3.53	0.00	96.47
41-1-4M	2	C	63.96	18.85	0.00	0.00	0.00	0.00	0.66	16.49	99.96	32	11.871	4.125	0.000	0.000	0.000	0.000	0.238	3.905	20.138	0.00	0.00	0.00	5.74	0.00	94.26
41-1-4M	4	C	63.84	18.88	0.00	0.00	0.00	0.00	0.30	17.16	100.18	32	11.856	4.134	0.000	0.000	0.000	0.000	0.108	4.066	20.164	0.00	0.00	0.00	2.59	0.00	97.41
41-2-2M	2	C	64.35	18.98	0.00	0.09	0.00	0.00	0.33	16.54	100.29	32	11.888	4.134	0.000	0.014	0.000	0.000	0.118	3.898	20.053	0.00	0.00	0.00	2.95	0.00	97.05
41-2-2M	3	C	64.54	18.95	0.00	0.00	0.00	0.00	0.62	16.37	100.48	32	11.894	4.117	0.000	0.000	0.000	0.000	0.222	3.849	20.082	0.00	0.00	0.00	5.45	0.00	94.55
41-2-3M	1	C	63.58	18.85	0.00	0.00	0.00	0.00	0.33	16.75	99.51	32	11.863	4.147	0.000	0.000	0.000	0.000	0.120	3.987	20.117	0.00	0.00	0.00	2.91	0.00	97.09
41-2-3M	3	C	63.71	18.92	0.00	0.00	0.00	0.00	0.52	16.96	100.11	32	11.839	4.145	0.000	0.000	0.000	0.000	0.188	4.021	20.193	0.00	0.00	0.00	4.46	0.00	95.54
41-3-5M	1	C	64.00	18.64	0.00	0.00	0.00	0.00	0.60	16.67	99.91	32	11.895	4.084	0.000	0.000	0.000	0.000	0.217	3.953	20.148	0.00	0.00	0.00	5.19	0.00	94.81
41-3-5M	2	C	63.62	18.78	0.00	0.00	0.00	0.00	0.34	16.94	99.68	32	11.865	4.129	0.000	0.000	0.000	0.000	0.123	4.031	20.148	0.00	0.00	0.00	2.96	0.00	97.04
41-3-5M	3	C	63.63	19.05	0.00	0.00	0.00	0.00	0.46	16.69	99.83	32	11.835	4.177	0.000	0.000	0.000	0.000	0.166	3.961	20.139	0.00	0.00	0.00	4.03	0.00	95.97
41-3-6M	1	C	62.95	18.54	0.00	0.00	0.00	0.00	0.45	17.30	99.24	32	11.838	4.110	0.000	0.000	0.000	0.000	0.164	4.151	20.264	0.00	0.00	0.00	3.81	0.00	96.19
41-3-6M	2	C	64.52	18.94	0.00	0.00	0.00	0.00	0.21	17.32	100.99	32	11.880	4.112	0.000	0.000	0.000	0.000	0.075	4.069	20.136	0.00	0.00	0.00	1.81	0.00	98.19
41-3-6M	3	C	63.92	18.95	0.00	0.00	0.00	0.00	0.49	16.69	100.05	32	11.859	4.145	0.000	0.000	0.000	0.000	0.177	3.951	20.132	0.00	0.00	0.00	4.28	0.00	95.72
41-3-7M	1	C	63.81	18.98	0.00	0.00	0.00	0.00	0.59	16.84	100.22	32	11.837	4.151	0.000	0.000	0.000	0.000	0.213	3.986	20.186	0.00	0.00	0.00	5.06	0.00	94.94

SAMPLE	No	Centre /Rim	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	Ab	An	Or
41-3-7M	2	C	64.22	19.07	0.00	0.00	0.00	0.00	0.55	16.63	100.47	32	11.858	4.151	0.000	0.000	0.000	0.000	0.197	3.918	20.124	0.00	0.00	0.00	4.79	0.00	95.21
41-3-7M	3	C	64.33	18.66	0.00	0.00	0.00	0.00	0.48	16.67	100.14	32	11.916	4.075	0.000	0.000	0.000	0.000	0.173	3.939	20.103	0.00	0.00	0.00	4.20	0.00	95.80
41-3-9M	1	C	62.74	18.70	0.00	0.00	0.00	0.00	0.23	17.07	98.74	32	11.833	4.158	0.000	0.000	0.000	0.000	0.084	4.108	20.183	0.00	0.00	0.00	2.01	0.00	97.99
41-3-9M	3	C	63.67	18.66	0.00	0.09	0.00	0.00	0.65	16.31	99.38	32	11.884	4.106	0.000	0.014	0.000	0.000	0.236	3.884	20.123	0.00	0.00	0.00	5.72	0.00	94.28
47-1-6M	1	C	64.17	18.88	0.00	0.00	0.00	0.00	0.40	16.71	100.16	32	11.885	4.122	0.000	0.000	0.000	0.000	0.144	3.948	20.100	0.00	0.00	0.00	3.52	0.00	96.48
47-1-6M	2	C	64.29	18.97	0.00	0.00	0.00	0.00	0.53	16.87	100.66	32	11.864	4.127	0.000	0.000	0.000	0.000	0.190	3.972	20.153	0.00	0.00	0.00	4.56	0.00	95.44
47-1-6M	4	C	63.61	18.93	0.00	0.00	0.00	0.00	0.28	17.21	100.03	32	11.838	4.153	0.000	0.000	0.000	0.000	0.101	4.086	20.179	0.00	0.00	0.00	2.42	0.00	97.58
47-1-7	1	C	63.60	18.71	0.00	0.00	0.00	0.00	0.25	17.41	99.97	32	11.858	4.112	0.000	0.000	0.000	0.000	0.091	4.141	20.202	0.00	0.00	0.00	2.14	0.00	97.86
47-1-7	2	C	64.07	19.06	0.00	0.00	0.00	0.00	0.31	17.16	100.60	32	11.845	4.154	0.000	0.000	0.000	0.000	0.111	4.047	20.158	0.00	0.00	0.00	2.68	0.00	97.32
47-1-7	3	C	63.65	18.88	0.00	0.00	0.00	0.00	0.32	17.19	100.04	32	11.844	4.142	0.000	0.000	0.000	0.000	0.116	4.081	20.183	0.00	0.00	0.00	2.76	0.00	97.24
47-1-7	4	C	63.41	18.79	0.00	0.09	0.00	0.00	0.48	16.89	99.66	32	11.841	4.137	0.000	0.014	0.000	0.000	0.174	4.024	20.190	0.00	0.00	0.00	4.15	0.00	95.85
47-1-7	5	C	63.78	18.94	0.00	0.00	0.00	0.00	0.54	16.67	99.93	32	11.851	4.149	0.000	0.000	0.000	0.000	0.195	3.952	20.147	0.00	0.00	0.00	4.70	0.00	95.30
47-2-6M	1	C	63.42	18.56	0.00	0.11	0.00	0.00	0.30	17.16	99.55	32	11.869	4.095	0.000	0.017	0.000	0.000	0.109	4.097	20.187	0.00	0.00	0.00	2.59	0.00	97.41
47-2-6M	2	C	63.38	18.90	0.00	0.00	0.00	0.00	0.52	16.69	99.49	32	11.837	4.162	0.000	0.000	0.000	0.000	0.189	3.977	20.165	0.00	0.00	0.00	4.53	0.00	95.47
47-2-6M	3	C	64.37	18.71	0.00	0.10	0.00	0.00	0.40	16.84	100.42	32	11.904	4.079	0.000	0.015	0.000	0.000	0.144	3.973	20.115	0.00	0.00	0.00	3.49	0.00	96.51
47-2-6M	4	C	63.86	19.00	0.00	0.00	0.00	0.00	0.61	16.81	100.28	32	11.837	4.152	0.000	0.000	0.000	0.000	0.220	3.975	20.184	0.00	0.00	0.00	5.23	0.00	94.77
47-2-6M	5	C	64.23	19.10	0.00	0.00	0.00	0.00	0.49	16.87	100.69	32	11.848	4.154	0.000	0.000	0.000	0.000	0.176	3.970	20.148	0.00	0.00	0.00	4.23	0.00	95.77
47-2-7M	1	C	62.12	18.43	0.00	0.11	0.00	0.06	0.23	17.12	98.07	32	11.823	4.135	0.000	0.018	0.000	0.012	0.085	4.157	20.230	0.00	0.00	0.00	2.00	0.29	97.71
47-2-7M	3	C	62.84	18.80	0.00	0.00	0.00	0.00	0.58	16.36	98.58	32	11.834	4.174	0.000	0.000	0.000	0.000	0.212	3.931	20.150	0.00	0.00	0.00	5.12	0.00	94.88
47-2-7M	4	C	63.07	18.97	0.00	0.00	0.00	0.00	0.65	16.44	99.13	32	11.816	4.190	0.000	0.000	0.000	0.000	0.236	3.929	20.172	0.00	0.00	0.00	5.68	0.00	94.32
47-2-7M	5	C	63.41	18.95	0.00	0.00	0.00	0.00	0.48	16.68	99.52	32	11.836	4.170	0.000	0.000	0.000	0.000	0.174	3.972	20.152	0.00	0.00	0.00	4.20	0.00	95.80
47-2-8M	1	C	63.00	18.69	0.00	0.00	0.00	0.00	0.21	16.82	98.72	32	11.860	4.148	0.000	0.000	0.000	0.000	0.077	4.040	20.124	0.00	0.00	0.00	1.86	0.00	98.14
47-2-8M	2	C	63.23	18.93	0.00	0.00	0.00	0.00	0.55	16.42	99.13	32	11.836	4.178	0.000	0.000	0.000	0.000	0.200	3.921	20.135	0.00	0.00	0.00	4.85	0.00	95.15
47-2-8M	3	C	62.92	19.00	0.00	0.00	0.00	0.00	0.38	16.85	99.15	32	11.805	4.203	0.000	0.000	0.000	0.000	0.138	4.033	20.179	0.00	0.00	0.00	3.32	0.00	96.68
47-2-8M	4	C	62.96	19.04	0.00	0.00	0.00	0.00	0.50	16.66	99.16	32	11.802	4.208	0.000	0.000	0.000	0.000	0.182	3.984	20.177	0.00	0.00	0.00	4.37	0.00	95.63
47-2-8M	5	C	61.81	18.83	0.00	0.00	0.00	0.00	0.22	16.60	97.46	32	11.793	4.235	0.000	0.000	0.000	0.000	0.082	4.041	20.150	0.00	0.00	0.00	1.98	0.00	98.02
47-2-9M	1	C	63.01	18.51	0.00	0.00	0.00	0.00	0.47	16.71	98.70	32	11.870	4.111	0.000	0.000	0.000	0.000	0.172	4.016	20.169	0.00	0.00	0.00	4.11	0.00	95.89
47-2-9M	2	C	63.51	18.91	0.00	0.00	0.00	0.00	0.55	16.70	99.67	32	11.840	4.156	0.000	0.000	0.000	0.000	0.199	3.972	20.167	0.00	0.00	0.00	4.77	0.00	95.23
47-2-9M	3	C	63.65	18.98	0.00	0.00	0.00	0.00	0.44	17.05	100.12	32	11.830	4.159	0.000	0.000	0.000	0.000	0.159	4.043	20.191	0.00	0.00	0.00	3.78	0.00	96.22
47-2-9M	4	C	63.60	18.79	0.00	0.00	0.00	0.00	0.54	16.87	99.80	32	11.852	4.128	0.000	0.000	0.000	0.000	0.195	4.011	20.187	0.00	0.00	0.00	4.65	0.00	95.35
47-2-9M	5	C	64.09	18.74	0.00	0.00	0.00	0.00	0.41	16.86	100.10	32	11.891	4.099	0.000	0.000	0.000	0.000	0.148	3.991	20.129	0.00	0.00	0.00	3.57	0.00	96.43
47-2-10	1	C	62.90	18.59	0.00	0.00	0.00	0.00	0.22	17.05	98.76	32	11.856	4.131	0.000	0.000	0.000	0.000	0.081	4.100	20.168	0.00	0.00	0.00	1.93	0.00	98.07
47-2-10	2	C	63.88	18.86	0.00	0.00	0.00	0.00	0.35	16.79	99.88	32	11.873	4.133	0.000	0.000	0.000	0.000	0.126	3.981	20.114	0.00	0.00	0.00	3.08	0.00	96.92
47-2-10	3	C	63.51	18.90	0.00	0.00	0.00	0.00	0.46	16.81	99.68	32	11.843	4.155	0.000	0.000	0.000	0.000	0.167	3.999	20.163	0.00	0.00	0.00	4.00	0.00	96.00
47-2-10	4	C	63.69	18.79	0.00	0.00	0.00	0.00	0.37	16.54	99.39	32	11.883	4.133	0.000	0.000	0.000	0.000	0.134	3.937	20.086	0.00	0.00	0.00	3.29	0.00	96.71

SAMPLE	No	Centre /Rim	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	Ab	An	Or
47-2-10	5	C	63.77	18.72	0.00	0.00	0.00	0.00	0.45	16.90	99.84	32	11.874	4.109	0.000	0.000	0.000	0.000	0.163	4.015	20.160	0.00	0.00	0.00	3.89	0.00	96.11
38-1-1	2	C	63.45	18.83	0.00	0.00	0.00	0.00	0.49	17.05	99.82	32	11.836	4.141	0.000	0.000	0.000	0.000	0.177	4.058	20.212	0.00	0.00	0.00	4.19	0.00	95.81
38-1-1	3	C	63.37	18.77	0.00	0.00	0.00	0.07	0.53	16.66	99.40	32	11.848	4.137	0.000	0.000	0.000	0.014	0.192	3.974	20.166	0.00	0.00	0.00	4.60	0.34	95.06
38-1-1	7	C	63.03	18.76	0.00	0.00	0.00	0.00	0.65	16.81	99.25	32	11.823	4.149	0.000	0.000	0.000	0.000	0.237	4.023	20.232	0.00	0.00	0.00	5.56	0.00	94.44
38-1-1	8	C	63.80	18.94	0.00	0.00	0.00	0.00	0.61	16.64	99.99	32	11.849	4.147	0.000	0.000	0.000	0.000	0.220	3.943	20.159	0.00	0.00	0.00	5.28	0.00	94.72
38-1-4M	3	C	64.08	18.75	0.00	0.00	0.00	0.00	0.49	16.89	100.21	32	11.883	4.099	0.000	0.000	0.000	0.000	0.176	3.996	20.154	0.00	0.00	0.00	4.23	0.00	95.77
38-1-4M	4	C	63.25	18.76	0.00	0.00	0.00	0.00	0.16	17.29	99.46	32	11.846	4.142	0.000	0.000	0.000	0.000	0.058	4.131	20.178	0.00	0.00	0.00	1.39	0.00	98.61
38-2-1M	13	C	63.64	18.74	0.00	0.10	0.00	0.00	0.47	16.89	99.84	32	11.858	4.117	0.000	0.016	0.000	0.000	0.170	4.015	20.176	0.00	0.00	0.00	4.06	0.00	95.94
38-2-1M	14	C	63.58	18.64	0.00	0.00	0.00	0.00	0.47	17.11	99.80	32	11.864	4.100	0.000	0.000	0.000	0.000	0.170	4.073	20.208	0.00	0.00	0.00	4.01	0.00	95.99
38-2-1M	15	C	64.09	18.51	0.00	0.00	0.00	0.00	0.37	17.25	100.22	32	11.905	4.053	0.000	0.000	0.000	0.000	0.133	4.088	20.179	0.00	0.00	0.00	3.16	0.00	96.84
2-2-2M	1	C	64.59	18.69	0.00	0.00	0.00	0.00	0.42	16.38	100.08	32	11.941	4.074	0.000	0.000	0.000	0.000	0.151	3.863	20.029	0.00	0.00	0.00	3.76	0.00	96.24
2-2-3M	1	C	64.61	18.24	0.00	0.00	0.00	0.00	0.64	16.17	99.66	32	11.992	3.991	0.000	0.000	0.000	0.000	0.231	3.829	20.042	0.00	0.00	0.00	5.68	0.00	94.32
2-2-3M	2	C	64.66	17.57	0.00	0.00	0.00	0.00	0.49	16.41	99.13	32	12.077	3.869	0.000	0.000	0.000	0.000	0.178	3.910	20.033	0.00	0.00	0.00	4.35	0.00	95.65
2-2-4M	1	C	62.94	18.52	0.00	0.09	0.00	0.00	0.62	16.09	98.26	32	11.877	4.120	0.000	0.014	0.000	0.000	0.227	3.874	20.113	0.00	0.00	0.00	5.54	0.00	94.46
2-2-4M	2	C	63.71	18.80	0.00	0.00	0.00	0.00	0.40	16.45	99.36	32	11.884	4.134	0.000	0.000	0.000	0.000	0.145	3.915	20.078	0.00	0.00	0.00	3.57	0.00	96.43
2-2-5M	3	C	63.74	17.80	0.00	0.00	0.00	0.00	0.49	16.34	98.37	32	12.008	3.953	0.000	0.000	0.000	0.000	0.179	3.927	20.068	0.00	0.00	0.00	4.37	0.00	95.63
2-2-7P	2	CINCL	64.01	18.52	0.00	0.00	0.00	0.00	0.56	16.23	99.32	32	11.932	4.070	0.000	0.000	0.000	0.000	0.203	3.860	20.064	0.00	0.00	0.00	4.99	0.00	95.01
2-2-7P	3	CINCL	63.93	18.68	0.00	0.00	0.00	0.00	0.55	16.49	99.65	32	11.898	4.098	0.000	0.000	0.000	0.000	0.199	3.915	20.110	0.00	0.00	0.00	4.83	0.00	95.17
2-3-1M	1	C	64.05	18.78	0.00	0.00	0.00	0.00	0.39	16.93	100.15	32	11.883	4.107	0.000	0.000	0.000	0.000	0.140	4.007	20.138	0.00	0.00	0.00	3.39	0.00	96.61
2-3-1	2	C	64.13	18.70	0.00	0.00	0.00	0.00	0.34	16.97	100.14	32	11.898	4.090	0.000	0.000	0.000	0.000	0.122	4.017	20.127	0.00	0.00	0.00	2.96	0.00	97.04
2-3-1	3	C	63.84	18.32	0.00	0.09	0.00	0.00	0.45	16.61	99.31	32	11.934	4.037	0.000	0.014	0.000	0.000	0.163	3.961	20.110	0.00	0.00	0.00	3.96	0.00	96.04
2-4-1M	1	C	64.20	18.32	0.00	0.00	0.00	0.00	0.28	16.76	99.56	32	11.961	4.024	0.000	0.000	0.000	0.000	0.101	3.984	20.070	0.00	0.00	0.00	2.48	0.00	97.52
2-4-1	2	C	64.00	18.35	0.00	0.00	0.00	0.00	0.51	16.60	99.46	32	11.939	4.036	0.000	0.000	0.000	0.000	0.185	3.951	20.111	0.00	0.00	0.00	4.47	0.00	95.53
2-4-1	3	C	63.77	17.96	0.00	0.00	0.00	0.00	0.45	16.54	98.72	32	11.983	3.979	0.000	0.000	0.000	0.000	0.164	3.965	20.092	0.00	0.00	0.00	3.98	0.00	96.02
2-4-1	4	C	63.86	18.01	0.00	0.00	0.00	0.00	0.42	16.83	99.12	32	11.971	3.980	0.000	0.000	0.000	0.000	0.153	4.025	20.128	0.00	0.00	0.00	3.66	0.00	96.34
2-4-1	5	C	63.35	18.00	0.00	0.00	0.00	0.00	0.47	16.71	98.53	32	11.950	4.003	0.000	0.000	0.000	0.000	0.172	4.021	20.146	0.00	0.00	0.00	4.11	0.00	95.89
2-4-7	3	C	64.10	18.83	0.00	0.00	0.00	0.00	0.42	16.31	99.66	32	11.904	4.123	0.000	0.000	0.000	0.000	0.151	3.864	20.042	0.00	0.00	0.00	3.77	0.00	96.23
37-1-2M	1	C	64.16	18.53	0.00	0.00	0.00	0.00	0.80	16.35	99.84	32	11.916	4.057	0.000	0.000	0.000	0.000	0.289	3.874	20.136	0.00	0.00	0.00	6.93	0.00	93.07
37-1-2	2	C	63.71	18.90	0.00	0.00	0.00	0.00	0.33	16.62	99.56	32	11.869	4.151	0.000	0.000	0.000	0.000	0.119	3.950	20.090	0.00	0.00	0.00	2.93	0.00	97.07
37-1-2	3	C	64.40	18.49	0.00	0.00	0.00	0.00	0.61	16.48	99.98	32	11.940	4.041	0.000	0.000	0.000	0.000	0.220	3.898	20.099	0.00	0.00	0.00	5.33	0.00	94.67
37-1-2	4	C	63.90	18.49	0.00	0.00	0.00	0.00	0.59	16.61	99.59	32	11.912	4.063	0.000	0.000	0.000	0.000	0.214	3.950	20.139	0.00	0.00	0.00	5.13	0.00	94.87
37-1-2	5	C	63.88	18.43	0.00	0.00	0.00	0.00	0.52	16.38	99.21	32	11.933	4.059	0.000	0.000	0.000	0.000	0.189	3.904	20.084	0.00	0.00	0.00	4.61	0.00	95.39
37-1-4M	1	C	63.83	17.88	0.00	0.00	0.00	0.00	0.62	16.24	98.57	32	11.998	3.962	0.000	0.000	0.000	0.000	0.226	3.895	20.081	0.00	0.00	0.00	5.49	0.00	94.51
37-1-4	2	C	63.89	18.23	0.00	0.00	0.00	0.00	0.48	16.46	99.06	32	11.957	4.022	0.000	0.000	0.000	0.000	0.174	3.930	20.084	0.00	0.00	0.00	4.25	0.00	95.75
37-1-4	3	C	63.90	17.70	0.00	0.00	0.00	0.00	0.44	16.54	98.58	32	12.023	3.926	0.000	0.000	0.000	0.000	0.161	3.970	20.080	0.00	0.00	0.00	3.89	0.00	96.11

SAMPLE	No	Centre /Rim	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	Ab	An	Or
37-1-7M	1	C	63.90	18.59	0.00	0.00	0.00	0.00	0.18	17.02	99.69	32	11.909	4.084	0.000	0.000	0.000	0.000	0.065	4.047	20.105	0.00	0.00	0.00	1.58	0.00	98.42
37-1-7M	2	C	63.91	18.39	0.00	0.00	0.00	0.00	0.55	16.55	99.40	32	11.930	4.047	0.000	0.000	0.000	0.000	0.199	3.941	20.117	0.00	0.00	0.00	4.81	0.00	95.19
37-1-7M	3	C	64.48	18.44	0.00	0.00	0.00	0.07	0.56	16.58	100.13	32	11.943	4.027	0.000	0.000	0.000	0.014	0.201	3.918	20.103	0.00	0.00	0.00	4.87	0.34	94.79
37-1-7M	4	C	64.28	18.18	0.00	0.00	0.00	0.00	0.44	16.79	99.69	32	11.970	3.991	0.000	0.000	0.000	0.000	0.159	3.989	20.109	0.00	0.00	0.00	3.84	0.00	96.16
37-2-3M	2	C	63.55	18.27	0.00	0.00	0.00	0.00	0.43	16.70	98.95	32	11.929	4.043	0.000	0.000	0.000	0.000	0.157	3.999	20.128	0.00	0.00	0.00	3.77	0.00	96.23
37-2-4M	2	C	63.34	18.00	0.00	0.00	0.00	0.00	0.36	15.96	97.66	32	11.990	4.017	0.000	0.000	0.000	0.000	0.132	3.855	19.994	0.00	0.00	0.00	3.32	0.00	96.68
37-2-6M	2	C	63.08	18.16	0.00	0.00	0.00	0.00	0.60	16.34	98.18	32	11.924	4.047	0.000	0.000	0.000	0.000	0.220	3.941	20.133	0.00	0.00	0.00	5.29	0.00	94.71
37-2-7M	2	C	63.93	18.50	0.00	0.00	0.00	0.00	0.45	16.42	99.30	32	11.930	4.070	0.000	0.000	0.000	0.000	0.163	3.909	20.072	0.00	0.00	0.00	4.00	0.00	96.00
47-1-2	2	C	63.70	18.12	0.00	0.00	0.00	0.00	0.53	16.05	98.40	32	11.977	4.016	0.000	0.000	0.000	0.000	0.194	3.850	20.037	0.00	0.00	0.00	4.79	0.00	95.21
47-1-2	3	C	63.09	17.98	0.00	0.00	0.00	0.00	0.63	15.98	97.68	32	11.962	4.019	0.000	0.000	0.000	0.000	0.232	3.865	20.078	0.00	0.00	0.00	5.66	0.00	94.34
44-1-3M	2	C	64.69	19.09	0.00	0.00	0.00	0.00	0.59	16.55	100.92	32	11.879	4.133	0.000	0.000	0.000	0.000	0.210	3.877	20.099	0.00	0.00	0.00	5.15	0.00	94.85
44-1-3M	3	C	64.40	19.19	0.00	0.00	0.00	0.00	0.59	16.52	100.70	32	11.854	4.164	0.000	0.000	0.000	0.000	0.211	3.879	20.109	0.00	0.00	0.00	5.16	0.00	94.84
44-1-4M	2	C	64.39	18.98	0.00	0.00	0.00	0.00	0.54	16.56	100.47	32	11.881	4.129	0.000	0.000	0.000	0.000	0.193	3.898	20.101	0.00	0.00	0.00	4.73	0.00	95.27
44-1-4M	3	C	64.39	19.22	0.00	0.00	0.00	0.00	0.58	16.62	100.81	32	11.846	4.169	0.000	0.000	0.000	0.000	0.207	3.901	20.123	0.00	0.00	0.00	5.04	0.00	94.96
44-2-3M	2	C	64.50	18.87	0.00	0.00	0.00	0.00	0.59	16.58	100.54	32	11.895	4.103	0.000	0.000	0.000	0.000	0.211	3.901	20.110	0.00	0.00	0.00	5.14	0.00	94.86
44-2-3M	3	C	64.45	19.00	0.00	0.00	0.00	0.00	0.44	16.72	100.61	32	11.881	4.129	0.000	0.000	0.000	0.000	0.158	3.932	20.100	0.00	0.00	0.00	3.85	0.00	96.15
44-2-4M	2	C	64.06	19.11	0.00	0.00	0.00	0.00	0.41	16.43	100.01	32	11.863	4.172	0.000	0.000	0.000	0.000	0.147	3.882	20.065	0.00	0.00	0.00	3.66	0.00	96.34
44-2-4M	3	C	64.66	18.87	0.00	0.00	0.00	0.00	0.34	16.87	100.74	32	11.906	4.096	0.000	0.000	0.000	0.000	0.122	3.963	20.088	0.00	0.00	0.00	2.98	0.00	97.02
44-2-6M	1	C	63.66	18.69	0.00	0.00	0.00	0.00	0.52	16.69	99.56	32	11.877	4.111	0.000	0.000	0.000	0.000	0.188	3.973	20.148	0.00	0.00	0.00	4.53	0.00	95.47
44-2-6M	2	C	64.22	18.86	0.00	0.00	0.00	0.00	0.61	16.41	100.10	32	11.889	4.116	0.000	0.000	0.000	0.000	0.219	3.876	20.100	0.00	0.00	0.00	5.35	0.00	94.65
46-1-4M	4	C	65.00	19.14	0.00	0.00	0.00	0.00	0.50	16.53	101.17	32	11.894	4.129	0.000	0.000	0.000	0.000	0.178	3.859	20.060	0.00	0.00	0.00	4.40	0.00	95.60
46-1-4M	5	C	64.53	19.14	0.00	0.00	0.00	0.00	0.45	16.94	101.06	32	11.857	4.146	0.000	0.000	0.000	0.000	0.161	3.971	20.135	0.00	0.00	0.00	3.89	0.00	96.11
46-1-5M	1	C	64.09	19.20	0.00	0.00	0.00	0.00	0.26	17.11	100.66	32	11.834	4.180	0.000	0.000	0.000	0.000	0.093	4.031	20.138	0.00	0.00	0.00	2.26	0.00	97.74
46-1-5M	2	R	64.52	18.91	0.00	0.00	0.00	0.00	0.52	16.53	100.48	32	11.898	4.111	0.000	0.000	0.000	0.000	0.186	3.889	20.084	0.00	0.00	0.00	4.57	0.00	95.43
46-1-5M	5	C	64.59	19.04	0.00	0.00	0.00	0.00	0.45	16.93	101.01	32	11.873	4.126	0.000	0.000	0.000	0.000	0.161	3.970	20.130	0.00	0.00	0.00	3.89	0.00	96.11
46-2-3M	2	C	63.81	18.93	0.00	0.00	0.00	0.00	0.50	16.61	99.85	32	11.859	4.148	0.000	0.000	0.000	0.000	0.180	3.938	20.126	0.00	0.00	0.00	4.38	0.00	95.62
46-2-3M	4	C	63.87	18.88	0.00	0.00	0.00	0.00	0.46	16.85	100.06	32	11.861	4.133	0.000	0.000	0.000	0.000	0.166	3.992	20.152	0.00	0.00	0.00	3.99	0.00	96.01
46-2-3M	6	C	64.23	19.06	0.00	0.00	0.00	0.00	0.29	16.84	100.42	32	11.868	4.152	0.000	0.000	0.000	0.000	0.104	3.970	20.093	0.00	0.00	0.00	2.55	0.00	97.45
46-2-4M	2	C	63.44	18.85	0.00	0.00	0.00	0.00	0.34	17.17	99.80	32	11.837	4.147	0.000	0.000	0.000	0.000	0.123	4.087	20.195	0.00	0.00	0.00	2.93	0.00	97.07
46-2-4M	5	C	63.05	18.94	0.00	0.00	0.00	0.00	0.52	16.59	99.10	32	11.821	4.186	0.000	0.000	0.000	0.000	0.189	3.968	20.165	0.00	0.00	0.00	4.55	0.00	95.45
46-2-4M	6	C	63.25	18.95	0.00	0.00	0.00	0.00	0.43	16.32	98.95	32	11.847	4.185	0.000	0.000	0.000	0.000	0.156	3.900	20.088	0.00	0.00	0.00	3.86	0.00	96.14
28-1-2P	2	C	63.36	19.25	0.00	0.00	0.00	0.00	0.47	16.42	99.50	32	11.809	4.230	0.000	0.000	0.000	0.000	0.170	3.904	20.113	0.00	0.00	0.00	4.17	0.00	95.83
28-2-1P	2	C	63.52	18.92	0.00	0.09	0.00	0.00	0.49	16.55	99.57	32	11.845	4.159	0.000	0.014	0.000	0.000	0.177	3.937	20.133	0.00	0.00	0.00	4.31	0.00	95.69
28-2-1P	3	C	64.11	19.12	0.00	0.00	0.00	0.00	0.48	16.59	100.30	32	11.853	4.168	0.000	0.000	0.000	0.000	0.172	3.913	20.106	0.00	0.00	0.00	4.22	0.00	95.78
28-2-1P	4	C	63.19	18.89	0.00	0.00	0.00	0.00	0.29	16.96	99.33	32	11.833	4.170	0.000	0.000	0.000	0.000	0.105	4.052	20.161	0.00	0.00	0.00	2.54	0.00	97.46

SAMPLE	No	Centre /Rim	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	Ab	An	Or
28-3-2M	2	C	64.06	18.97	0.00	0.00	0.00	0.00	0.48	16.11	99.62	32	11.890	4.151	0.000	0.000	0.000	0.000	0.173	3.815	20.029	0.00	0.00	0.00	4.34	0.00	95.66
28-3-2M	4	C	63.82	18.74	0.00	0.00	0.00	0.00	0.60	15.98	99.14	32	11.904	4.121	0.000	0.000	0.000	0.000	0.217	3.803	20.045	0.00	0.00	0.00	5.41	0.00	94.59
28-3-2M	5	C	63.78	18.79	0.00	0.00	0.00	0.00	0.56	16.47	99.60	32	11.877	4.125	0.000	0.000	0.000	0.000	0.203	3.913	20.118	0.00	0.00	0.00	4.92	0.00	95.08
28-3-2M	8	C	62.97	19.15	0.00	0.00	0.00	0.00	0.18	16.40	98.70	32	11.823	4.239	0.000	0.000	0.000	0.000	0.066	3.928	20.055	0.00	0.00	0.00	1.64	0.00	98.36
28-3-2M	9	C	62.93	19.03	0.00	0.00	0.00	0.00	0.18	16.51	98.65	32	11.830	4.218	0.000	0.000	0.000	0.000	0.066	3.960	20.074	0.00	0.00	0.00	1.63	0.00	98.37
28-3-2M	10	C	63.92	18.90	0.00	0.00	0.00	0.00	0.44	16.19	99.45	32	11.891	4.145	0.000	0.000	0.000	0.000	0.159	3.842	20.037	0.00	0.00	0.00	3.97	0.00	96.03
28-3-3	1	C	63.92	18.84	0.00	0.00	0.00	0.00	0.64	16.60	100.00	32	11.867	4.123	0.000	0.000	0.000	0.000	0.231	3.932	20.153	0.00	0.00	0.00	5.54	0.00	94.46
28-3-3	2	C	63.87	18.87	0.00	0.00	0.00	0.00	0.59	16.49	99.82	32	11.869	4.134	0.000	0.000	0.000	0.000	0.213	3.909	20.125	0.00	0.00	0.00	5.16	0.00	94.84
18-1-2M	2	C	64.75	18.20	0.00	0.00	0.00	0.05	0.52	16.34	99.86	32	12.000	3.976	0.000	0.000	0.000	0.010	0.187	3.863	20.037	0.00	0.00	0.00	4.61	0.24	95.15
18-1-2M	3	C	64.12	18.78	0.00	0.00	0.00	0.00	0.61	16.51	100.02	32	11.890	4.105	0.000	0.000	0.000	0.000	0.220	3.906	20.120	0.00	0.00	0.00	5.32	0.00	94.68
18-1-2M	4	C	63.86	18.82	0.00	0.00	0.00	0.00	0.55	16.55	99.78	32	11.875	4.126	0.000	0.000	0.000	0.000	0.199	3.926	20.125	0.00	0.00	0.00	4.81	0.00	95.19
18-1-2M	5	C	62.99	18.87	0.00	0.00	0.00	0.00	0.47	16.88	99.21	32	11.817	4.173	0.000	0.000	0.000	0.000	0.171	4.040	20.202	0.00	0.00	0.00	4.07	0.00	95.93
18-1-2M	6	C	63.12	18.58	0.00	0.00	0.00	0.00	0.63	16.51	98.84	32	11.865	4.117	0.000	0.000	0.000	0.000	0.230	3.959	20.171	0.00	0.00	0.00	5.49	0.00	94.51
18-2-2M	1	C	62.72	18.62	0.00	0.00	0.00	0.00	0.62	16.35	98.31	32	11.848	4.147	0.000	0.000	0.000	0.000	0.227	3.940	20.163	0.00	0.00	0.00	5.46	0.00	94.54
18-2-2M	2	C	63.28	18.50	0.00	0.00	0.00	0.00	0.48	16.25	98.51	32	11.904	4.103	0.000	0.000	0.000	0.000	0.175	3.900	20.082	0.00	0.00	0.00	4.30	0.00	95.70
18-2-2M	4	C	63.81	18.67	0.00	0.00	0.00	0.00	0.48	16.54	99.50	32	11.896	4.103	0.000	0.000	0.000	0.000	0.174	3.934	20.107	0.00	0.00	0.00	4.23	0.00	95.77
18-2-2M	7	C	63.51	18.97	0.00	0.00	0.00	0.00	0.36	16.71	99.55	32	11.845	4.171	0.000	0.000	0.000	0.000	0.130	3.976	20.123	0.00	0.00	0.00	3.18	0.00	96.83
18-3-2M	1	C	61.73	18.26	0.00	0.00	0.00	0.05	0.64	16.24	96.92	32	11.844	4.130	0.000	0.000	0.000	0.010	0.238	3.975	20.198	0.00	0.00	0.00	5.65	0.24	94.11
18-3-2M	2	C	62.05	18.41	0.00	0.00	0.00	0.00	0.53	16.39	97.38	32	11.845	4.143	0.000	0.000	0.000	0.000	0.196	3.992	20.177	0.00	0.00	0.00	4.69	0.00	95.31
18-3-2M	3	C	63.00	18.66	0.00	0.00	0.00	0.00	0.58	16.56	98.80	32	11.850	4.138	0.000	0.000	0.000	0.000	0.212	3.974	20.174	0.00	0.00	0.00	5.06	0.00	94.94
18-3-2M	4	C	62.91	18.86	0.00	0.00	0.00	0.00	0.59	16.36	98.72	32	11.829	4.181	0.000	0.000	0.000	0.000	0.215	3.925	20.150	0.00	0.00	0.00	5.20	0.00	94.80
18-3-2M	5	C	62.38	18.75	0.00	0.00	0.00	0.00	0.54	16.45	98.12	32	11.816	4.187	0.000	0.000	0.000	0.000	0.199	3.975	20.177	0.00	0.00	0.00	4.76	0.00	95.24
18-3-2M	6	C	62.76	18.45	0.00	0.00	0.00	0.00	0.39	16.94	98.54	32	11.860	4.111	0.000	0.000	0.000	0.000	0.143	4.084	20.198	0.00	0.00	0.00	3.39	0.00	96.61
18-3-2M	7	C	62.31	18.76	0.00	0.00	0.00	0.00	0.60	16.40	98.07	32	11.810	4.192	0.000	0.000	0.000	0.000	0.221	3.966	20.188	0.00	0.00	0.00	5.27	0.00	94.73
18-3-2M	8	C	62.72	18.58	0.00	0.00	0.00	0.00	0.25	16.90	98.45	32	11.854	4.140	0.000	0.000	0.000	0.000	0.092	4.075	20.160	0.00	0.00	0.00	2.20	0.00	97.80

Table 11: Electron microprobe data for biotite from selected HHD granitoids

SAMPLE	No	SiO_2	TiO_2	Al_2O_3	CR_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Ti	Al	Cr	Fe2	Mn	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	CaN	MgN
50-2A	12	37.65	0.80	17.44	0.00	0.00	15.88	0.19	12.81	0.06	0.07	9.54	94.44	24	6.185	0.099	3.378	0.000	2.182	0.026	3.136	0.011	0.022	1.999	17.038	0.20	58.86	40.94	0.34	58.9
22-1A	1	37.31	1.48	16.16	0.00	0.00	21.89	0.33	10.04	0.00	0.04	9.19	96.44	24	6.181	0.184	3.156	0.000	3.033	0.046	2.479	0.000	0.013	1.942	17.034	0.00	44.97	55.03	0.00	44.9
22-1A	2	36.64	1.08	16.14	0.00	0.00	20.72	0.37	9.79	0.07	0.05	8.88	93.74	24	6.216	0.138	3.228	0.000	2.940	0.053	2.475	0.013	0.016	1.922	17.001	0.23	45.60	54.16	0.51	45.7
22-1A	3	36.91	2.15	15.78	0.00	0.00	21.91	0.42	9.91	0.16	0.12	9.42	96.78	24	6.122	0.268	3.085	0.000	3.039	0.059	2.450	0.028	0.039	1.993	17.083	0.52	44.40	55.09	1.15	44.6
22-1A	4	36.92	1.47	16.46	0.00	0.00	21.55	0.40	10.02	0.00	0.05	9.63	96.50	24	6.126	0.183	3.220	0.000	2.990	0.056	2.478	0.000	0.016	2.039	17.108	0.00	45.31	54.69	0.00	45.3
22-1A	5	36.58	1.58	16.19	0.00	0.00	21.60	0.35	9.62	0.07	0.14	8.83	94.96	24	6.152	0.200	3.210	0.000	3.038	0.050	2.411	0.013	0.046	1.895	17.013	0.23	44.15	55.62	0.52	44.2
22-1A	6	37.48	1.49	16.62	0.00	0.00	20.82	0.38	9.94	0.00	0.18	9.34	96.25	24	6.192	0.185	3.237	0.000	2.877	0.053	2.447	0.000	0.058	1.969	17.018	0.00	45.97	54.03	0.00	45.9
22-1A	7	37.17	1.70	16.39	0.00	0.00	22.16	0.37	9.78	0.00	0.05	9.60	97.22	24	6.132	0.211	3.188	0.000	3.058	0.052	2.405	0.000	0.016	2.021	17.081	0.00	44.02	55.98	0.00	44.0
22-1A	8	37.12	1.61	16.26	0.00	0.00	21.67	0.36	9.80	0.00	0.06	9.10	95.98	24	6.173	0.201	3.188	0.000	3.014	0.051	2.429	0.000	0.019	1.931	17.006	0.00	44.63	55.37	0.00	44.6
22-1A	9	37.08	1.57	16.39	0.00	0.00	21.80	0.31	9.78	0.00	0.04	9.60	96.57	24	6.148	0.196	3.204	0.000	3.023	0.044	2.417	0.000	0.013	2.031	17.076	0.00	44.43	55.57	0.00	44.4
22-1A	10	37.06	1.82	16.16	0.00	0.00	22.07	0.41	9.86	0.00	0.09	9.38	96.85	24	6.134	0.227	3.153	0.000	3.055	0.057	2.432	0.000	0.029	1.981	17.068	0.00	44.32	55.68	0.00	44.3
22-1A	11	36.53	2.30	15.76	0.00	0.00	21.93	0.39	9.55	0.00	0.07	9.56	96.09	24	6.111	0.289	3.108	0.000	3.068	0.055	2.381	0.000	0.023	2.040	17.077	0.00	43.69	56.31	0.00	43.6
22-1A	13	35.85	2.42	15.98	0.00	0.00	21.77	0.39	9.24	0.00	0.07	9.50	95.22	24	6.058	0.308	3.183	0.000	3.076	0.056	2.327	0.000	0.023	2.048	17.079	0.00	43.06	56.94	0.00	43.0
22-1A	15	36.16	1.85	16.17	0.00	0.00	21.98	0.43	9.82	0.00	0.09	9.48	95.98	24	6.060	0.233	3.195	0.000	3.081	0.061	2.453	0.000	0.029	2.027	17.138	0.00	44.33	55.67	0.00	44.3
18-2B	1	36.67	1.51	15.95	0.00	0.00	21.85	0.37	9.80	0.00	0.08	8.99	95.22	24	6.162	0.191	3.160	0.000	3.071	0.053	2.454	0.000	0.026	1.927	17.044	0.00	44.42	55.58	0.00	44.4
18-2B	2	36.78	1.23	16.33	0.00	0.00	21.43	0.38	10.00	0.00	0.12	9.31	95.58	24	6.152	0.155	3.220	0.000	2.998	0.054	2.493	0.000	0.039	1.987	17.096	0.00	45.40	54.60	0.00	45.4
18-2B	3	36.95	2.02	16.09	0.00	0.00	21.38	0.38	9.69	0.00	0.08	9.32	95.91	24	6.156	0.253	3.160	0.000	2.979	0.054	2.406	0.000	0.026	1.981	17.014	0.00	44.68	55.32	0.00	44.6
18-3B	4	37.08	1.04	16.45	0.07	0.00	19.63	0.34	10.69	0.00	0.08	9.41	94.79	24	6.197	0.131	3.241	0.009	2.744	0.048	2.662	0.000	0.026	2.006	17.064	0.00	49.25	50.75	0.00	49.2
18-3B	4	34.06	0.81	16.46	0.00	0.00	23.98	0.41	11.15	0.00	0.06	6.42	93.35	24	5.855	0.105	3.336	0.000	3.447	0.060	2.856	0.000	0.020	1.408	17.087	0.00	45.31	54.69	0.00	45.3
28-1B	3	39.64	0.65	16.21	0.00	0.00	13.78	0.28	15.98	0.00	0.04	10.01	96.59	24	6.304	0.078	3.039	0.000	1.833	0.038	3.787	0.000	0.012	2.031	17.121	0.00	67.39	32.61	0.00	67.3
28-2B	1	39.88	0.66	15.56	0.10	0.00	13.68	0.26	16.19	0.09	0.08	9.37	95.87	24	6.367	0.079	2.929	0.013	1.827	0.035	3.852	0.015	0.025	1.908	17.050	0.27	67.65	32.08	0.40	67.8

SAMPLE	No	SiO$_2$	TiO$_2$	Al$_2$O$_3$	CR$_2$O$_3$	Fe$_2$O$_3$	FeO	MnO	MgO	CaO	Na$_2$O	K$_2$O	TOTAL	OXYG	Si	Ti	Al	Cr	Fe2	Mn	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	CaN	MgN
28-2B	2	38.30	1.95	15.45	0.00	0.00	14.50	0.31	14.82	0.00	0.10	9.85	95.28	24	6.223	0.238	2.959	0.000	1.970	0.043	3.589	0.000	0.032	2.042	17.096	0.00	64.56	35.44	0.00	64.5
28-3B	2	39.39	0.89	16.03	0.05	0.00	13.32	0.29	15.61	0.00	0.08	10.15	95.81	24	6.314	0.107	3.029	0.006	1.786	0.039	3.729	0.000	0.025	2.076	17.111	0.00	67.62	32.38	0.00	67.6
28-3B	3	39.90	1.59	15.97	0.00	0.00	14.18	0.37	15.29	0.00	0.07	10.07	97.44	24	6.305	0.189	2.975	0.000	1.874	0.050	3.601	0.000	0.021	2.030	17.044	0.00	65.77	34.23	0.00	65.7
47-1B	4	36.70	0.99	17.26	0.00	0.00	21.66	0.49	8.72	0.00	0.05	9.85	95.72	24	6.148	0.125	3.409	0.000	3.035	0.070	2.177	0.000	0.016	2.105	17.084	0.00	41.77	58.23	0.00	41.7
47-2B	2	37.10	1.36	17.62	0.00	0.00	21.60	0.44	8.48	0.00	0.10	9.40	96.10	24	6.159	0.170	3.448	0.000	2.999	0.062	2.098	0.000	0.032	1.991	16.959	0.00	41.16	58.84	0.00	41.1
47-2B	3	35.71	0.90	17.39	0.00	0.00	23.94	0.45	9.93	0.00	0.06	7.28	95.66	24	5.975	0.113	3.431	0.000	3.350	0.064	2.476	0.000	0.019	1.554	16.983	0.00	42.50	57.50	0.00	42.5
47-2B	4	37.21	1.22	17.30	0.00	0.00	21.33	0.53	8.75	0.00	0.05	9.61	96.00	24	6.186	0.153	3.391	0.000	2.966	0.075	2.168	0.000	0.016	2.038	16.993	0.00	42.23	57.77	0.00	42.2
2-1B	2	38.42	1.27	17.32	0.00	0.00	16.99	0.23	9.40	0.00	0.04	9.68	93.35	24	6.403	0.159	3.403	0.000	2.368	0.032	2.335	0.000	0.013	2.058	16.772	0.00	49.65	50.35	0.00	49.6
2-1B	3	32.31	0.86	15.65	0.00	0.00	23.73	0.48	12.95	0.00	0.02	5.14	91.14	24	5.683	0.114	3.245	0.000	3.491	0.072	3.395	0.000	0.007	1.153	17.160	0.00	49.30	50.70	0.00	49.3
2-1B	4	36.95	1.58	15.48	0.00	0.00	20.51	0.37	11.24	0.00	0.06	9.60	95.79	24	6.156	0.198	3.041	0.000	2.858	0.052	2.791	0.000	0.019	2.041	17.156	0.00	49.41	50.59	0.00	49.4
2-1B	5	36.53	1.57	14.95	0.00	0.00	20.02	0.33	11.35	0.00	0.06	9.39	94.20	24	6.181	0.200	2.982	0.000	2.833	0.047	2.862	0.000	0.020	2.027	17.152	0.00	50.26	49.74	0.00	50.2
2-1B	6	36.69	1.57	14.75	0.00	0.00	19.76	0.32	11.41	0.00	0.05	9.42	93.97	24	6.215	0.200	2.946	0.000	2.799	0.046	2.880	0.000	0.016	2.036	17.138	0.00	50.71	49.29	0.00	50.7
2-2B	1	36.42	1.42	16.40	0.00	0.00	20.46	0.34	11.47	0.00	0.06	8.92	95.49	24	6.061	0.178	3.218	0.000	2.848	0.048	2.845	0.000	0.019	1.894	17.109	0.00	49.97	50.03	0.00	49.9
2-2B	4	37.53	1.52	15.91	0.00	0.00	19.86	0.32	11.33	0.00	0.06	9.40	95.93	24	6.199	0.189	3.098	0.000	2.743	0.045	2.789	0.000	0.019	1.981	17.063	0.00	50.41	49.59	0.00	50.4
2-3B	1	37.93	1.57	15.59	0.00	0.00	19.83	0.37	11.46	0.00	0.05	9.72	96.52	24	6.234	0.194	3.021	0.000	2.726	0.052	2.807	0.000	0.016	2.038	17.088	0.00	50.73	49.27	0.00	50.7
2-3B	2	37.13	1.50	15.58	0.00	0.00	20.30	0.31	11.46	0.00	0.09	9.61	95.98	24	6.162	0.187	3.048	0.000	2.818	0.044	2.835	0.000	0.029	2.035	17.158	0.00	50.15	49.85	0.00	50.1
2-3B	3	37.61	1.66	16.06	0.00	0.00	20.53	0.33	11.28	0.00	0.06	9.68	97.21	24	6.157	0.204	3.099	0.000	2.811	0.046	2.752	0.000	0.019	2.022	17.110	0.00	49.47	50.53	0.00	49.4
2-3B	4	37.09	1.59	16.21	0.00	0.00	20.40	0.35	11.20	0.00	0.09	9.99	96.92	24	6.108	0.197	3.147	0.000	2.809	0.049	2.749	0.000	0.029	2.099	17.186	0.00	49.45	50.55	0.00	49.4
2-3B	5	37.69	1.55	16.05	0.00	0.00	20.24	0.37	11.34	0.00	0.04	9.81	97.09	24	6.173	0.191	3.099	0.000	2.772	0.051	2.768	0.000	0.013	2.050	17.118	0.00	49.96	50.04	0.00	49.9
2-3B	6	37.12	1.59	16.13	0.00	0.00	20.23	0.36	11.18	0.00	0.06	9.69	96.36	24	6.132	0.198	3.141	0.000	2.795	0.050	2.752	0.000	0.019	2.042	17.130	0.00	49.62	50.38	0.00	49.6
37-1B	3	35.90	1.22	16.94	0.00	0.00	24.80	0.61	7.52	0.06	0.05	8.62	95.72	24	6.082	0.155	3.383	0.000	3.514	0.088	1.899	0.011	0.016	1.863	17.011	0.20	35.01	64.79	0.57	35.0
37-1B	5	36.69	1.60	16.75	0.00	0.00	23.72	0.61	7.59	0.00	0.08	9.29	96.33	24	6.154	0.202	3.312	0.000	3.328	0.087	1.897	0.000	0.026	1.988	16.995	0.00	36.31	63.69	0.00	36.3

SAMPLE	No	SiO_2	TiO_2	Al_2O_3	CR_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Ti	Al	Cr	Fe2	Mn	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	CaN	MgN
37-1B	6	36.37	1.27	16.56	0.00	0.00	22.13	0.53	7.20	0.14	0.14	7.75	92.09	24	6.286	0.165	3.374	0.000	3.199	0.078	1.855	0.026	0.047	1.709	16.739	0.51	36.51	62.98	1.38	36.7
38-3B	4	36.57	0.82	17.35	0.00	0.00	22.99	0.42	7.92	0.00	0.08	9.32	95.47	24	6.161	0.104	3.446	0.000	3.239	0.060	1.988	0.000	0.026	2.003	17.027	0.00	38.04	61.96	0.00	38.0
46-1B	2	37.87	1.41	17.90	0.00	0.00	19.99	0.42	8.72	0.00	0.04	10.01	96.36	24	6.225	0.174	3.469	0.000	2.748	0.058	2.136	0.000	0.013	2.099	16.922	0.00	43.74	56.26	0.00	43.7
46-1B	3	38.09	1.33	17.43	0.00	0.00	19.47	0.35	8.87	0.00	0.03	9.90	95.47	24	6.298	0.165	3.398	0.000	2.692	0.049	2.186	0.000	0.010	2.088	16.887	0.00	44.81	55.19	0.00	44.8
46-2B	1	38.01	1.32	16.87	0.00	0.00	20.38	0.44	8.92	0.00	0.07	9.89	95.90	24	6.295	0.164	3.294	0.000	2.823	0.062	2.201	0.000	0.023	2.090	16.950	0.00	43.82	56.18	0.00	43.8
46-2B	2	35.79	0.95	18.00	0.00	0.00	22.71	0.46	9.55	0.00	0.05	7.50	95.01	24	5.995	0.120	3.554	0.000	3.181	0.065	2.384	0.000	0.016	1.603	16.918	0.00	42.84	57.16	0.00	42.8
46-2B	3	38.55	1.42	17.40	0.00	0.00	18.93	0.39	9.54	0.00	0.05	9.61	95.89	24	6.313	0.175	3.359	0.000	2.592	0.054	2.328	0.000	0.016	2.008	16.845	0.00	47.31	52.69	0.00	47.3
46-2B	4	38.03	1.37	17.27	0.00	0.00	20.84	0.36	8.64	0.00	0.07	9.62	96.20	24	6.274	0.170	3.359	0.000	2.875	0.050	2.124	0.000	0.022	2.025	16.900	0.00	42.49	57.51	0.00	42.4
46-3B	1	38.29	1.38	17.26	0.00	0.00	21.46	0.43	8.48	0.00	0.11	9.65	97.06	24	6.277	0.170	3.336	0.000	2.942	0.060	2.072	0.000	0.035	2.018	16.911	0.00	41.32	58.68	0.00	41.3
46-3B	2	38.07	1.36	17.45	0.00	0.00	20.39	0.42	8.72	0.00	0.03	9.74	96.18	24	6.271	0.168	3.389	0.000	2.809	0.059	2.141	0.000	0.010	2.047	16.894	0.00	43.25	56.75	0.00	43.2
46-3B	3	37.92	1.35	17.62	0.00	0.00	20.46	0.39	8.61	0.00	0.11	9.53	95.99	24	6.255	0.167	3.427	0.000	2.823	0.054	2.117	0.000	0.035	2.006	16.884	0.00	42.85	57.15	0.00	42.8
46-4B	1	38.38	1.32	17.33	0.00	0.00	20.38	0.46	8.77	0.00	0.07	9.71	96.42	24	6.302	0.163	3.355	0.000	2.799	0.064	2.146	0.000	0.022	2.034	16.886	0.00	43.40	56.60	0.00	43.4
46-4B	3	32.15	0.57	17.14	0.00	0.00	24.71	0.46	10.46	0.00	0.04	4.79	90.32	24	5.707	0.076	3.587	0.000	3.668	0.069	2.767	0.000	0.014	1.085	16.973	0.00	43.00	57.00	0.00	43.0
46-4B	4	38.03	1.35	17.15	0.09	0.00	20.03	0.49	8.61	0.00	0.04	9.66	95.45	24	6.307	0.168	3.353	0.012	2.778	0.069	2.128	0.000	0.013	2.044	16.871	0.00	43.37	56.63	0.00	43.3
46-5B	1	37.39	1.50	17.10	0.00	0.00	21.59	0.34	8.05	0.00	0.03	9.62	95.62	24	6.241	0.188	3.365	0.000	3.014	0.048	2.003	0.000	0.010	2.049	16.917	0.00	39.92	60.08	0.00	39.9
46-5B	2	37.17	1.34	17.01	0.00	0.00	21.95	0.42	8.14	0.00	0.03	9.56	95.62	24	6.221	0.169	3.356	0.000	3.072	0.060	2.030	0.000	0.010	2.041	16.958	0.00	39.79	60.21	0.00	39.7
46-5B	3	37.13	1.35	17.05	0.00	0.00	21.65	0.38	8.19	0.00	0.06	9.59	95.40	24	6.221	0.170	3.368	0.000	3.034	0.054	2.045	0.000	0.020	2.050	16.960	0.00	40.27	59.73	0.00	40.2
46-5B	4	37.75	1.37	17.18	0.00	0.00	20.98	0.40	8.47	0.00	0.03	9.73	95.91	24	6.262	0.171	3.360	0.000	2.910	0.056	2.094	0.000	0.010	2.059	16.922	0.00	41.84	58.16	0.00	41.8
44-1B	1	36.73	1.37	17.04	0.00	0.00	23.27	0.68	6.91	0.00	0.06	9.00	95.06	24	6.217	0.174	3.400	0.000	3.294	0.097	1.743	0.000	0.020	1.944	16.890	0.00	34.60	65.40	0.00	34.6
44-1B	4	33.47	1.19	18.17	0.00	0.00	25.34	0.80	6.66	0.06	0.09	6.70	92.48	24	5.860	0.157	3.750	0.000	3.710	0.119	1.738	0.011	0.031	1.497	16.872	0.21	31.83	67.96	0.64	31.9
44-1B	1	32.62	0.95	18.09	0.00	0.00	28.57	0.91	6.47	0.00	0.06	5.41	93.08	24	5.736	0.126	3.750	0.000	4.202	0.136	1.696	0.000	0.020	1.214	16.880	0.00	28.75	71.25	0.00	28.7
44-1B	2	33.01	1.10	17.77	0.00	0.00	27.25	0.88	6.20	0.00	0.12	6.51	92.84	24	5.819	0.146	3.693	0.000	4.018	0.131	1.629	0.000	0.041	1.464	16.941	0.00	28.85	71.15	0.00	28.8

SAMPLE	No	SiO_2	TiO_2	Al_2O_3	CR_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Ti	Al	Cr	Fe2	Mn	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	CaN	MgN
44-1B	3	33.81	1.20	18.27	0.00	0.00	26.48	0.80	5.79	0.00	0.05	6.80	93.20	24	5.898	0.157	3.758	0.000	3.863	0.118	1.505	0.000	0.017	1.513	16.831	0.00	28.04	71.96	0.00	28.0
44-3B	3	30.54	0.50	18.06	0.00	0.00	28.97	0.79	7.54	0.20	0.03	2.56	89.19	24	5.562	0.068	3.878	0.000	4.412	0.122	2.047	0.039	0.011	0.595	16.733	0.60	31.49	67.91	1.87	31.6
44-4B	2	31.74	0.85	18.11	0.00	0.00	27.91	0.85	6.77	0.07	0.14	4.77	91.21	24	5.677	0.114	3.819	0.000	4.175	0.129	1.805	0.013	0.049	1.088	16.868	0.22	30.11	69.66	0.74	30.1
44-4B	4	31.61	0.76	18.51	0.00	0.00	27.66	0.80	7.01	0.00	0.05	4.22	90.62	24	5.658	0.102	3.906	0.000	4.140	0.121	1.870	0.000	0.017	0.964	16.778	0.00	31.11	68.89	0.00	31.1
44-5B	2	30.68	1.06	17.99	0.00	0.00	25.73	0.86	6.66	0.00	0.09	6.23	89.30	24	5.621	0.146	3.886	0.000	3.942	0.133	1.818	0.000	0.032	1.456	17.035	0.00	31.57	68.43	0.00	31.5

Table 12: Electron microprobe data for amphibole from selected HHD granitoids

SAMPLE	No	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Ti	Al	Cr	Fe3	Fe2	Mn	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	CaN	MgN
16-2-1A	1	50.61	0.41	4.78	0.00	0.00	13.04	0.22	14.46	12.10	0.53	0.39	96.54	24	7.753	0.047	0.863	0.000	0.000	1.671	0.029	3.301	1.986	0.158	0.076	15.885	28.54	47.45	24.01	37.56	66.40
16-2-1A	2	50.42	0.30	4.86	0.00	0.00	14.05	0.34	14.62	12.14	0.67	0.33	97.73	24	7.679	0.034	0.873	0.000	0.000	1.790	0.044	3.318	1.981	0.198	0.064	15.981	27.95	46.81	25.24	37.38	64.96
16-2-1A	3	45.70	0.67	8.43	0.05	0.00	16.74	0.28	11.93	11.93	1.06	0.69	97.48	24	7.139	0.079	1.552	0.006	0.000	2.187	0.037	2.777	1.997	0.322	0.138	16.233	28.69	39.90	31.42	41.83	55.95
16-2-1A	4	44.98	0.81	9.03	0.00	0.00	17.25	0.33	11.40	11.54	1.09	0.92	97.35	24	7.062	0.096	1.672	0.000	0.000	2.265	0.044	2.668	1.941	0.332	0.184	16.264	28.24	38.81	32.95	42.12	54.08
16-2-1A	7	45.57	0.99	8.28	0.00	0.00	16.74	0.29	11.72	11.75	0.92	0.83	97.09	24	7.148	0.117	1.531	0.000	0.000	2.196	0.039	2.740	1.975	0.280	0.166	16.192	28.58	39.65	31.78	41.89	55.51
16-2-1A	8	45.34	1.14	8.74	0.00	0.00	16.78	0.36	11.41	11.41	1.12	0.92	97.22	24	7.108	0.134	1.615	0.000	0.000	2.200	0.048	2.666	1.917	0.341	0.184	16.213	28.26	39.30	32.44	41.83	54.79
16-2-1A	10	46.99	0.44	7.93	0.18	0.00	16.19	0.36	12.46	11.72	0.99	0.62	97.88	24	7.266	0.051	1.446	0.022	0.000	2.094	0.047	2.871	1.942	0.297	0.122	16.159	28.11	41.57	30.31	40.34	57.83
16-2-1A	11	45.28	0.55	9.16	0.00	0.00	17.20	0.36	11.34	12.37	1.19	0.75	98.20	24	7.054	0.064	1.682	0.000	0.000	2.241	0.048	2.633	2.065	0.360	0.149	16.295	29.76	37.94	32.30	43.95	54.02
16-2-1A	12	48.80	0.26	6.69	0.00	0.00	15.32	0.36	13.33	12.29	0.92	0.44	98.41	24	7.453	0.030	1.205	0.000	0.000	1.957	0.047	3.034	2.011	0.273	0.086	16.094	28.72	43.33	27.95	39.86	60.79
16-2-1A	14	45.10	0.63	9.66	0.06	0.00	18.04	0.32	11.05	12.33	1.14	0.89	99.22	24	6.983	0.073	1.763	0.007	0.000	2.336	0.042	2.550	2.045	0.343	0.176	16.318	29.51	36.79	33.70	44.51	52.19
16-2-1A	15	44.58	0.87	9.63	0.00	0.00	17.81	0.31	10.91	12.11	1.13	1.10	98.45	24	6.962	0.102	1.773	0.000	0.000	2.326	0.041	2.539	2.026	0.343	0.219	16.331	29.40	36.84	33.75	44.38	52.19
50-1A	1	48.77	0.28	6.20	0.07	0.00	15.20	0.32	13.55	12.62	0.92	0.40	98.33	24	7.462	0.032	1.118	0.008	0.000	1.945	0.041	3.090	2.069	0.273	0.078	16.118	29.13	43.49	27.38	40.11	61.37
50-1A	2	47.47	0.32	7.03	0.00	0.00	15.26	0.33	13.23	12.55	0.99	0.47	97.65	24	7.335	0.037	1.281	0.000	0.000	1.972	0.043	3.047	2.078	0.297	0.093	16.182	29.28	42.93	27.79	40.55	60.71
50-1A	3	49.26	0.33	6.13	0.00	0.00	14.79	0.35	13.52	12.36	0.83	0.38	97.95	24	7.532	0.038	1.105	0.000	0.000	1.891	0.045	3.081	2.025	0.246	0.074	16.038	28.94	44.03	27.03	39.66	61.96
50-1A	4	48.06	0.36	6.34	0.00	0.00	15.29	0.30	13.51	12.46	0.85	0.38	97.55	24	7.419	0.042	1.154	0.000	0.000	1.974	0.039	3.108	2.061	0.255	0.075	16.127	28.85	43.51	27.63	39.87	61.16
50-1A	5	45.13	1.08	9.00	0.07	0.00	17.25	0.35	11.37	11.92	1.16	0.86	98.19	24	7.033	0.127	1.654	0.009	0.000	2.248	0.046	2.641	1.991	0.351	0.171	16.270	28.93	38.39	32.68	42.98	54.01
50-1A	7	45.33	1.07	8.92	0.05	0.00	17.22	0.34	11.40	11.88	1.25	0.92	98.38	24	7.050	0.125	1.636	0.006	0.000	2.240	0.045	2.642	1.980	0.378	0.183	16.284	28.85	38.51	32.64	42.83	54.12
50-1A	8	46.10	1.04	7.91	0.00	0.00	16.10	0.32	12.27	11.98	1.10	0.82	97.64	24	7.175	0.122	1.451	0.000	0.000	2.096	0.042	2.846	1.998	0.332	0.163	16.225	28.79	41.01	30.20	41.24	57.59
50-1A	9	45.11	1.22	8.42	0.00	0.00	15.95	0.36	12.29	12.03	1.20	0.84	97.42	24	7.053	0.143	1.552	0.000	0.000	2.086	0.048	2.864	2.015	0.364	0.168	16.293	28.94	41.12	29.95	41.31	57.86
50-1A	10	45.70	1.10	8.40	0.00	0.00	16.46	0.38	12.25	11.99	1.26	0.85	98.39	24	7.082	0.128	1.535	0.000	0.000	2.133	0.050	2.829	1.991	0.379	0.168	16.296	28.63	40.69	30.68	41.30	57.01
50-1A	14	46.09	0.65	8.27	0.55	0.00	17.02	0.30	11.64	12.32	1.16	0.82	98.82	24	7.131	0.076	1.508	0.067	0.000	2.202	0.039	2.684	2.042	0.349	0.162	16.261	29.48	38.74	31.79	43.21	54.93
50-1A	16	46.28	1.00	8.07	0.00	0.00	16.85	0.35	11.99	12.33	1.14	0.79	98.80	24	7.147	0.116	1.469	0.000	0.000	2.176	0.046	2.759	2.040	0.342	0.156	16.251	29.25	39.56	31.20	42.51	55.91
50-2A	1	44.66	1.19	9.70	0.00	0.00	17.43	0.31	10.96	12.34	1.29	1.12	99.00	24	6.932	0.139	1.775	0.000	0.000	2.263	0.041	2.535	2.052	0.389	0.222	16.347	29.96	37.01	33.03	44.74	52.84
50-2A	2	50.12	0.21	5.46	0.00	0.00	14.22	0.29	14.07	12.66	0.85	0.30	98.18	24	7.618	0.024	0.978	0.000	0.000	1.808	0.037	3.187	2.062	0.251	0.058	16.023	29.22	45.17	25.62	39.28	63.81
50-2A	3	51.65	0.13	4.50	0.00	0.00	13.68	0.29	14.70	12.92	0.66	0.26	98.79	24	7.762	0.015	0.797	0.000	0.000	1.719	0.037	3.292	2.081	0.193	0.050	15.946	29.33	46.42	24.24	38.72	65.69
50-2A	4	51.14	0.13	5.01	0.21	0.00	14.20	0.36	14.33	13.05	0.85	0.29	99.57	24	7.666	0.015	0.885	0.025	0.000	1.780	0.046	3.201	2.096	0.247	0.055	16.016	29.62	45.23	25.15	39.57	64.26
50-2A	5	45.52	0.82	9.01	0.00	0.00	18.00	0.39	11.00	12.40	1.32	1.00	99.46	24	7.040	0.095	1.643	0.000	0.000	2.328	0.051	2.535	2.055	0.396	0.197	16.341	29.70	36.65	33.65	44.77	52.13
50-2A	7	46.93	0.92	7.74	0.00	0.00	16.26	0.32	12.11	12.44	1.07	0.76	98.55	24	7.234	0.107	1.407	0.000	0.000	2.096	0.042	2.782	2.055	0.320	0.149	16.191	29.64	40.13	30.24	42.48	57.03
50-2A	8	52.64	0.08	3.33	0.00	0.00	12.57	0.34	15.54	12.83	0.52	0.15	98.00	24	7.916	0.009	0.590	0.000	0.000	1.581	0.043	3.483	2.067	0.152	0.029	15.870	28.99	48.84	22.17	37.25	68.78
50-2A	13	47.01	1.03	7.57	0.00	0.00	15.20	0.38	12.46	12.11	1.18	0.79	97.73	24	7.270	0.120	1.380	0.000	0.000	1.966	0.050	2.872	2.007	0.354	0.156	16.175	29.32	41.96	28.72	41.13	59.36
50-2A	14	51.09	0.21	4.85	0.00	0.00	13.49	0.31	14.69	12.79	0.66	0.24	98.33	24	7.711	0.024	0.863	0.000	0.000	1.703	0.040	3.304	2.069	0.193	0.046	15.953	29.23	46.70	24.07	38.50	65.99
50-2A	16	53.01	0.09	3.13	0.00	0.00	12.28	0.34	15.86	12.88	0.50	0.15	98.24	24	7.938	0.010	0.553	0.000	0.000	1.538	0.043	3.540	2.067	0.145	0.029	15.862	28.93	49.54	21.53	36.86	69.71
28-1B	1	47.49	0.61	6.86	0.08	0.00	14.82	0.40	13.63	12.29	1.36	0.74	98.28	24	7.300	0.071	1.243	0.010	0.000	1.905	0.052	3.122	2.024	0.406	0.145	16.279	28.71	44.28	27.02	39.33	62.11
28-1B	2	47.17	0.67	7.02	0.00	0.00	14.70	0.44	13.65	12.09	1.38	0.80	97.92	24	7.277	0.078	1.277	0.000	0.000	1.897	0.057	3.138	1.998	0.413	0.157	16.293	28.41	44.62	26.97	38.91	62.33

SAMPLE	No	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TOTAL	OXYG	Si	Ti	Al	Cr	Fe3	Fe2	Mn	Mg	Ca	Na	K	SUM	Ca1	Mg1	Fe1	CaN	MgN
28-1B	4	47.75	0.47	7.20	0.05	0.00	14.94	0.39	13.50	12.21	1.31	0.70	98.52	24	7.311	0.054	1.300	0.006	0.000	1.913	0.051	3.081	2.003	0.389	0.137	16.245	28.63	44.03	27.34	39.40	61.69
28-1A	1	48.86	0.36	5.82	0.00	0.00	14.49	0.39	13.88	11.98	1.01	0.61	97.40	24	7.522	0.042	1.056	0.000	0.000	1.866	0.051	3.185	1.976	0.302	0.120	16.119	28.13	45.32	26.55	38.29	63.06
28-1A	2	47.98	0.50	6.72	0.00	0.00	14.83	0.34	13.41	11.78	1.20	0.70	97.46	24	7.405	0.058	1.223	0.000	0.000	1.914	0.044	3.084	1.948	0.360	0.138	16.174	28.04	44.40	27.56	38.71	61.71
28-1A	3	48.46	0.45	6.58	0.00	0.00	15.04	0.41	13.72	11.88	1.16	0.69	98.39	24	7.413	0.052	1.187	0.000	0.000	1.924	0.053	3.128	1.947	0.345	0.135	16.182	27.82	44.69	27.49	38.37	61.91
28-1A	4	49.55	0.38	5.82	0.00	0.00	13.98	0.36	14.06	11.82	1.15	0.57	97.69	24	7.572	0.044	1.048	0.000	0.000	1.787	0.047	3.202	1.935	0.341	0.111	16.087	27.95	46.24	25.80	37.67	64.19
28-1A	5	47.67	0.85	7.12	0.11	0.00	15.06	0.41	13.11	12.00	1.32	0.75	98.40	24	7.313	0.098	1.288	0.013	0.000	1.932	0.053	2.997	1.973	0.393	0.147	16.208	28.58	43.43	27.99	39.69	60.80
28-1A	6	47.49	0.87	7.10	0.15	0.00	15.09	0.41	13.29	11.70	1.30	0.76	98.16	24	7.302	0.101	1.287	0.018	0.000	1.941	0.053	3.046	1.928	0.388	0.149	16.213	27.88	44.05	28.07	38.76	61.08
28-1A	7	47.77	0.45	6.75	0.10	0.00	14.86	0.44	13.43	11.78	1.16	0.71	97.45	24	7.383	0.052	1.230	0.012	0.000	1.921	0.058	3.093	1.951	0.348	0.140	16.188	28.01	44.41	27.58	38.67	61.69
28-1A	8	47.10	0.63	7.00	0.15	0.00	14.56	0.49	13.42	11.67	1.30	0.77	97.09	24	7.314	0.074	1.281	0.018	0.000	1.891	0.064	3.106	1.942	0.392	0.153	16.235	27.99	44.76	27.25	38.47	62.16
28-2B	3	48.13	0.56	7.11	0.00	0.00	15.28	0.49	13.70	11.93	1.29	0.71	99.20	24	7.321	0.064	1.275	0.000	0.000	1.944	0.063	3.106	1.944	0.381	0.138	16.237	27.80	44.41	27.79	38.50	61.50
28-2B	4	48.04	0.52	6.78	0.06	0.00	15.23	0.46	13.76	11.83	1.19	0.77	98.64	24	7.349	0.060	1.223	0.007	0.000	1.949	0.060	3.137	1.939	0.354	0.150	16.228	27.60	44.66	27.74	38.20	61.69
28-2A	1	48.00	0.59	7.00	0.07	0.00	15.44	0.38	13.33	12.43	1.15	0.71	99.10	24	7.322	0.068	1.259	0.008	0.000	1.970	0.049	3.030	2.032	0.341	0.138	16.216	28.89	43.10	28.01	40.14	60.61
28-2A	2	46.96	0.74	7.03	0.11	0.00	14.95	0.41	13.29	12.23	1.39	0.79	97.90	24	7.261	0.086	1.282	0.013	0.000	1.933	0.054	3.063	2.026	0.417	0.156	16.292	28.86	43.61	27.53	39.82	61.30
28-2A	4	47.68	0.56	6.82	0.00	0.00	14.96	0.43	13.38	12.54	1.16	0.72	98.25	24	7.331	0.065	1.236	0.000	0.000	1.924	0.056	3.066	2.066	0.346	0.141	16.230	29.28	43.45	27.26	40.26	61.45
28-2A	5	47.24	0.51	6.87	0.00	0.00	14.95	0.45	13.21	12.19	1.29	0.76	97.47	24	7.326	0.059	1.256	0.000	0.000	1.939	0.059	3.053	2.026	0.388	0.150	16.256	28.86	43.51	27.63	39.88	61.16
28-2A	6	48.39	0.44	6.48	0.00	0.00	14.82	0.47	13.56	12.73	1.10	0.66	98.65	24	7.396	0.051	1.168	0.000	0.000	1.894	0.061	3.089	2.085	0.326	0.129	16.198	29.50	43.70	26.80	40.30	61.98
28-3B	1	50.88	0.12	3.78	0.08	0.00	11.91	0.38	14.91	12.58	0.63	0.32	95.59	24	7.852	0.014	0.688	0.010	0.000	1.537	0.050	3.429	2.080	0.189	0.063	15.911	29.52	48.66	21.81	37.76	69.05
28-3B	4	48.36	0.31	6.28	0.00	0.00	13.74	0.48	13.92	12.35	1.06	0.61	97.11	24	7.460	0.036	1.142	0.000	0.000	1.773	0.063	3.200	2.041	0.318	0.120	16.152	29.10	45.62	25.27	38.95	64.35
28-3A	1	48.16	0.73	6.74	0.08	0.00	14.46	0.43	13.70	12.59	1.11	0.68	98.68	24	7.348	0.084	1.212	0.010	0.000	1.845	0.056	3.115	2.058	0.329	0.132	16.188	29.33	44.38	26.29	39.79	62.80
28-3A	2	48.58	0.51	6.63	0.08	0.00	14.44	0.37	13.91	12.49	1.22	0.69	98.92	24	7.385	0.058	1.188	0.010	0.000	1.836	0.048	3.151	2.034	0.360	0.134	16.205	28.97	44.88	26.15	39.23	63.19
28-3A	3	47.62	0.58	7.10	0.07	0.00	14.92	0.44	13.56	12.32	1.28	0.79	98.68	24	7.291	0.067	1.282	0.008	0.000	1.910	0.057	3.094	2.021	0.381	0.154	16.265	28.77	44.04	27.19	39.51	61.83
28-3A	4	47.64	0.63	6.53	0.09	0.00	14.53	0.42	13.78	12.14	1.31	0.73	97.80	24	7.345	0.073	1.187	0.011	0.000	1.873	0.055	3.166	2.005	0.392	0.144	16.251	28.47	44.94	26.59	38.78	62.83
28-3A	5	46.99	0.64	7.42	0.08	0.00	15.24	0.37	13.26	12.25	1.30	0.83	98.38	24	7.234	0.074	1.347	0.010	0.000	1.962	0.048	3.042	2.021	0.389	0.163	16.290	28.76	43.31	27.93	39.91	60.79
28-3A	6	47.94	0.49	6.80	0.12	0.00	14.85	0.40	13.76	12.35	1.13	0.71	98.55	24	7.336	0.056	1.227	0.015	0.000	1.901	0.052	3.138	2.025	0.336	0.139	16.224	28.67	44.43	26.91	39.22	62.28

Table 14: XRF and ICP-MS analyses of the HHD granitoids

	Granodiorite/adamellite to Granite Suite (GG)															
	Pink-grey Granite						Porphytitic granodiorite		Homogeneous adamellite/granodiorite							
Sample	**D02-3**	**D03-1**	**D04-1**	**D05-1**	**D17-1**	**D-51**	**D-46-1**	**D-47-1**	**D06-1**	**D12-1**	**D13-1**	**D15-1**	**D-37-1**	**D-43-1**	**D-44A-1**	**D-45-1**
SiO_2	72.00	72.64	72.14	70.80	73.22	75.13	72.71	73.61	73.44	73.42	75.39	75.18	75.49	76.62	74.58	76.81
TiO_2	0.29	0.22	0.26	0.28	0.31	0.13	0.29	0.23	0.22	0.20	0.11	0.14	0.12	0.05	0.14	0.06
Al_2O_3	13.53	13.66	13.44	14.44	13.68	13.40	13.92	13.77	14.12	14.15	13.34	13.26	13.46	12.95	13.67	12.79
Fe_2O_3T	1.98	1.87	2.03	2.57	0.00	1.46	2.24	1.91	1.73	0.00	1.18	1.41	1.23	0.95	1.28	0.86
Fe_2O_3	0.38	0.12	0.11	0.00	0.00	0.22	0.00	0.00	0.00	0.06	0.15	0.00	0.00	0.13	0.00	0.00
FeO	1.44	1.58	1.73	2.32	1.99	1.11	2.01	1.72	1.56	1.11	0.93	1.26	1.11	0.74	1.15	0.77
MnO	0.04	0.03	0.04	0.03	0.04	0.03	0.05	0.04	0.04	0.02	0.04	0.05	0.02	0.02	0.05	0.02
MgO	0.78	0.65	0.73	1.08	0.50	0.20	0.55	0.42	0.42	0.78	0.15	0.16	0.17	0.10	0.19	0.03
CaO	1.24	1.06	1.08	0.85	0.65	0.59	1.63	1.33	1.33	0.88	0.91	0.88	0.77	0.42	0.92	0.91
Na_2O	3.14	3.39	3.30	3.25	3.75	3.67	3.73	3.63	4.21	3.93	3.88	3.99	3.68	3.80	4.37	4.92
K_2O	5.04	4.79	4.70	5.22	4.11	4.14	3.33	4.17	3.54	3.76	4.26	4.13	4.76	4.08	3.79	2.52
P_2O_5	0.11	0.08	0.09	0.10	0.11	0.02	0.10	0.08	0.07	0.07	0.03	0.05	0.03	0.02	0.02	0.02
Cr_2O_3	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
H_2O+	0.63	0.57	0.59	0.57	0.69	0.55	0.54	0.47	0.54	0.68	0.27	0.26	0.31	0.34	0.33	0.16
H_2O-	0.10	0.06	0.03	0.07	0.15	0.05	0.05	0.05	0.09	0.09	0.11	0.10	0.05	0.05	0.05	0.05
CO_2	0.80	0.58	0.74	0.54	0.28	0.17	0.05	0.12	0.06	0.53	0.07	0.06	0.06	0.09	0.09	0.16
Total	101.50	101.30	101.02	102.13	99.47	100.88	101.19	101.54	101.37	99.70	100.80	100.94	101.27	101.31	100.63	100.08
LOI	1.32	1.16	1.33	1.30		0.63	0.61	0.56	0.52		0.25	0.00	0.29	0.38	0.36	0.27
As	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Ba	677	640	639	612	583	366	520	443	603	429	301	260	407	228	208	51
Co	5	7	11	8	5	9	8	5	6	5	5	9	5	6	8	5
Cr	5	5	5	5	5	5	7	7	5	5	5	5	5	5	5	5
Cu	26	16	10	6	8	5	9	8	14	10	14	7	5	5	5	5
Ga	16	17	18	18	21	15	19	18	21	21	22	23	18	18	21	20
Hf	5	5	5	5	6	5	7	5	6	5	5	5	5	5	6	5
Mo	3	3	3	3	3	2	2	2	3	3	3	3	2	2	2	2
Nb	16	12	13	16	14	13	19	17	15	19	16	41	16	14	30	58
Ni	6	5	6	8	8	5	5	5	6	5	5	5	5	5	5	5
Pb	22	18	18	13	14	33	29	28	27	19	38	42	35	41	39	42
Rb	165	166	182	197	229	223	241	238	186	240	274	299	227	179	294	202
Sc	3	4	3	3	3	3	4	4	3	3	3	3	4	3	4	3
Sr	182	181	166	128	104	117	239	191	213	146	87	98	91	93	66	36
Ta	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Th	9	9	12	8	7	31	15	15	12	9	13	18	14	14	14	13
U	3	3	4	3	3	5	6	4	4	5	9	28	7	30	8	25
V	27	24	26	25	22	13	24	21	21	18	10	11	9	9	12	5

	Granodiorite/adamellite to Granite Suite (GG)															
	Pink-grey Granite						Porphytitic granodiorite		Homogeneous adamellite/granodiorite							
Sample	**D02-3**	**D03-1**	**D04-1**	**D05-1**	**D17-1**	**D-51**	**D-46-1**	**D-47-1**	**D06-1**	**D12-1**	**D13-1**	**D15-1**	**D-37-1**	**D-43-1**	**D-44A-1**	**D-45-1**
W	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Y	17	12	14	10	14	11	26	18	14	20	54	35	31	13	44	59
Zn	31	26	29	42	34	27	44	38	33	16	30	37	32	14	43	15
Zr	140	116	132	142	175	105	157	132	146	128	90	109	101	74	106	5
Ce	83	80	74	66	87	56	76	61	57	47	36	56	60	5	48	5
La	59	51	51	40	46	41	52	41	31	29	24	34	36	7	32	6
Nd	34	24	32	27	27	20	27	19	16	16	19	22	22	5	20	5
CIPW norms																
DiWo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DiEn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DiFs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HyEn	2	2	2	3	1	0.51	1	1	1	2	0.00	0.00	0.00	0.00	0.00	0.00
HyFs	2	3	2	4	3	1.72	3	3	3	2	1	2	2	1	2	1
Mt	1	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Il	1	0.00	1	1	1	0.25	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ap	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	30	29	28	31	25	24.79	20	25	21	23	25	25	28	24	23	15
Ab	27	29	29	28	32	31.47	32	31	36	34	33	34	31	32	37	42
An	6	5	5	4	3	2.85	8	6	6	4	4	4	4	2	5	4
Q	31	31	31	27	33	36.17	33	32	31	33	34	34	33	38	32	36
A	53	54	53	56	54	53.02	43	50	49	51	54	54	56	54	54	48
P	10	9	9	7	6	6.09	17	12	14	9	9	9	7	4	11	14
Modal QAP																
Qm	37	40	32	28	39	31.00	24	24	34	34	37	32	29	31	34	29
Am	13	20	23	29	20	36.00	16	18	21	17	32	26	27	49	28	41
Pm	40	34	34	33	34	27.00	50	45	40	42	26	40	40	17	36	27
ICP-MS																
La	52	53	44	34	45	28	nd	27	30	25	nd	21	22	6	26	3
Ce	107	108	90	71	99	61	nd	58	64	52	nd	44	46	11	58	7
Pr	10	10	8	6	9	5	nd	5	6	5	nd	5	4	1	6	1
Nd	37	37	29	24	33	18	nd	21	22	19	nd	19	17	5	22	4
Sm	6	6	5	4	5	3	nd	3	4	3	nd	4	3	1	5	2
Eu	1	1	1	1	1	1	nd	1	1	0	nd	1	0	1	0	0
Gd	6	5	4	3	5	3	nd	3	3	3	nd	5	4	2	5	4
Tb	1	1	0	0	1	0	nd	0	0	0	nd	1	1	0	1	1
Dy	4	4	3	2	3	2	nd	3	3	3	nd	5	4	3	5	9
Ho	1	1	1	0	1	0	nd	1	1	1	nd	1	1	1	1	2
Er	2	2	2	1	2	1	nd	2	1	2	nd	3	3	2	4	7

	Granodiorite/adamellite to Granite Suite (GG)															
	Pink-grey Granite						Porphytitic granodiorite		Homogeneous adamellite/granodiorite							
Sample	**D02-3**	**D03-1**	**D04-1**	**D05-1**	**D17-1**	**D-51**	**D-46-1**	**D-47-1**	**D06-1**	**D12-1**	**D13-1**	**D15-1**	**D-37-1**	**D-43-1**	**D-44A-1**	**D-45-1**
Tm	0.00	0.00	0.00	0.00	0.00	0.00	nd	0.00	0.00	0.00	nd	1	0.00	0.00	1	1
Yb	2	2	2	1	2	1	nd	2	1	2	nd	4	3	2	5	8
Lu	0.00	0.00	0.00	0.00	0.00	0.00	nd	0.00	0.00	0.00	nd	1	0.00	0.00	1	1
La/Yb	26	27	26	25	27	19	nd	16	21	12	nd	6	7	3	5	0.00
Sr/Y	10.70	15.15	11.60	13.25	7.29	10.50	1.49	1.93	15.55	7.49	nd	2.81	2.93	7.12	1.50	0.00
Rb/Sr	0.91	0.92	1.10	1.54	2.21	1.91	10.12	10.15	0.87	1.64	nd	3.05	2.49	1.92	4.43	5.63
K/Na	1.06	0.93	0.94	1.06	0.72	0.74	0.59	0.76	0.55	0.63	0.72	0.68	0.85	0.71	0.57	0.34

Table 14: XRF and ICP-MS analyses of the HHD granitoids (*continue*)

	Tonalite Gneiss Suite (TG)		**Granodiorite to Adamellite Gneiss suite (GAG)**													
			Tonalite-trondhjemite gneiss				Granodiorite/adamellite gneiss									
Sample	**D16**	**D-50**	**D22-1**	**D23-1**	**D27-1**	**D28-1**	**D18-1**	**D19-1**	**D20-1**	**D21-1**	**D24-1**	**D-38-1**	**D-40-1**	**D-41-1**	**D-42-1**	**D-48**
SiO_2	61.09	64.63	68.91	67.92	65.20	64.45	74.08	70.71	74.77	74.83	71.24	75.58	74.47	73.74	75.46	73.26
TiO_2	0.53	0.49	0.65	0.61	0.45	0.44	0.19	0.41	0.16	0.19	0.37	0.12	0.18	0.22	0.08	0.23
Al_2O_3	15.87	14.89	14.48	15.18	13.66	13.17	13.85	14.44	13.60	13.40	14.68	13.31	13.69	13.48	12.99	13.74
Fe_2O_3T	-	4.71	-	-	-	-	1.58	2.85	1.30	1.78	2.61	1.20	1.50	2.01	1.18	2.07
Fe_2O_3	0.22	1.14	0.77	-	0.66	-	-	-	-	0.23	-	-	-	0.68	-	0.12
FeO	5.05	3.23	2.79	3.69	4.02	4.68	1.43	2.57	1.17	1.39	2.34	1.08	1.34	1.20	1.06	1.76
MnO	0.09	0.07	0.07	0.08	0.12	0.11	0.03	0.04	0.02	0.03	0.06	0.02	0.03	0.04	0.02	0.05
MgO	3.61	2.78	1.11	1.21	3.89	4.35	0.41	0.64	0.42	0.35	0.59	0.21	0.27	0.47	0.19	0.40
CaO	5.57	4.24	2.57	2.44	3.16	3.60	1.21	1.85	1.49	1.47	1.81	1.00	0.94	1.00	0.63	1.88
Na_2O	3.84	3.53	4.49	4.94	3.10	2.67	3.47	4.11	4.03	4.33	4.54	3.47	4.12	3.82	3.40	3.73
K_2O	1.48	2.38	2.26	2.02	3.73	4.23	4.36	3.55	3.09	2.63	3.00	4.69	3.88	3.80	4.74	3.49
P_2O_5	0.27	0.23	0.25	0.26	0.32	0.33	0.07	0.16	0.05	0.06	0.12	0.03	0.05	0.09	0.03	0.07
Cr_2O_3	0.02	0.02	0.02	0.02	0.03	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
H_2O+	1.08	0.84	0.53	0.55	0.62	0.56	0.42	0.39	0.38	0.33	0.49	0.27	0.52	0.59	0.36	0.48
H_2O-	0.11	0.05	0.14	0.04	0.06	0.03	0.17	0.13	0.22	0.15	0.06	0.05	0.05	0.05	0.05	0.05
CO_2	0.07	0.14	0.15	0.20	0.09	0.16	0.06	0.14	0.08	0.08	0.20	0.19	0.24	0.26	0.11	0.24
Total	98.87	103.34	99.16	99.14	99.06	98.83	101.33	101.98	100.78	101.26	102.10	101.22	101.28	101.44	100.29	101.56
LOI	0.27	1.21	0.65	0.72	0.00	0.00	0.49	0.53	0.43	0.37	-	0.40	0.63	0.83	0.42	0.74
As	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Ba	601	755	308	185	711	1,014	558	756	494	210	462	452	505	450	423	364
Co	22	19	11	8	18	10	5	5	9	5	5	5	5	6	5	5
Cr	87	66	13	11	191	223	5	5	5	5	5	5	5	5	5	5
Cu	46	25	21	17	97	151	5	26	7	5	7	5	6	5	5	5
Ga	20	18	20	23	20	19	19	19	19	22	21	16	18	18	16	20
Hf	9	7	11	8	6	5	6	9	6	5	8	5	5	5	5	6
Mo	3	2	3	3	3	3	3	3	3	3	3	2	2	2	2	2
Nb	5	8	35	26	16	8	7	13	6	13	24	6	13	18	8	19
Ni	54	42	15	12	54	60	6	6	7	5	6	5	5	5	5	5
Pb	13	20	19	18	19	19	26	15	21	27	23	46	27	22	25	24
Rb	61	77	165	193	199	181	173	191	143	140	184	177	166	149	185	264
Sc	14	9	3	7	12	14	3	3	3	4	6	3	3	4	3	3
Sr	748	628	283	252	242	242	219	363	273	160	232	147	175	205	142	248
Ta	5	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5
Th	6	7	7	12	8	6	7	10	6	11	11	22	15	11	12	23
U	3	3	5	10	3	3	6	3	3	8	12	11	7	4	5	25
V	95	76	46	46	76	86	18	32	16	18	28	10	14	24	7	21
W	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

	Tonalite Gneiss Suite (TG)		Granodiorite to Adamellite Gneiss suite (GAG)													
			Tonalite-trondhjemite gneiss				Granodiorite/adamellite gneiss									
Sample	**D16**	**D-50**	**D22-1**	**D23-1**	**D27-1**	**D28-1**	**D18-1**	**D19-1**	**D20-1**	**D21-1**	**D24-1**	**D-38-1**	**D-40-1**	**D-41-1**	**D-42-1**	**D-48**
Y	13	13	71	23	49	23	5	24	4	11	21	21	10	28	43	15
Zn	67	62	64	72	84	77	34	53	22	35	51	25	32	30	19	29
Zr	102	132	326	243	169	138	134	246	129	111	210	111	144	111	88	117
Ce	72	68	117	129	87	86	61	129	35	43	112	50	53	59	37	60
La	39	33	66	74	43	50	32	85	24	29	63	37	44	44	17	40
Nd	34	22	48	41	34	33	18	53	7	12	38	21	18	29	13	14
CIPW norms																
DiWo	1.88	0.85	0.00	0.00	0.64	1.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DiEn	0.95	0.50	0.00	0.00	0.37	1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DiFs	0.88	0.31	0.00	0.00	0.24	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HyEn	8.30	6.61	2.28	3.08	9.52	10.03	1.03	1.62	1.06	0.88	1.49	0.53	0.68	1.19	0.48	1.01
HyFs	7.69	4.09	3.59	6.01	6.17	7.44	2.39	4.17	1.94	2.13	3.83	1.83	2.24	1.36	1.88	2.88
Mt	0.33	1.69	1.14	0.00	0.97	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.18
Il	1.03	0.95	1.26	1.18	0.87	0.85	0.36	0.79	0.31	0.36	0.71	0.23	0.35	0.42	0.15	0.44
Ap	0.61	0.51	0.55	0.57	0.71	0.74	0.14	0.35	0.11	0.12	0.26	0.07	0.10	0.19	0.07	0.16
Or	8.97	14.39	13.59	12.15	22.44	25.52	26.02	21.32	18.50	15.73	17.97	27.83	23.22	22.82	28.45	20.91
Ab	33.25	30.59	38.59	42.45	26.65	23.02	29.59	35.27	34.47	37.00	38.86	29.49	35.23	32.77	29.16	31.93
An	22.19	18.15	11.48	10.78	12.51	11.64	5.67	8.38	7.18	7.05	8.41	4.82	4.45	4.53	2.99	9.03
Q	13.95	21.35	26.48	22.80	18.90	16.99	33.42	27.27	35.39	35.52	27.55	34.45	32.65	34.26	35.64	32.92
A	18.54	27.92	34.51	34.64	39.55	41.33	50.32	46.64	43.33	41.28	44.44	52.97	52.78	50.16	54.84	43.21
P	45.87	35.21	29.15	30.74	22.05	18.85	10.96	18.33	16.82	18.50	20.80	9.17	10.12	9.96	5.76	18.66
Modal QAP																
Qm	19	23	26.00	26.00	23.00	25.00	30.00	28.00	32.00	29.00	27.00	35.00	33.00	21.00	31.00	28.00
Am	50	53	60.00	55.00	57.00	55.00	42.00	49.00	52.00	39.00	52.00	36.00	53.00	49.00	34.00	41.00
Pm	0.00	3	1.00	9.00	9.00	16.00	24.00	16.00	12.00	25.00	11.00	27.00	19.00	25.00	32.00	19.00
ICP-MS																
La	30	26	59	73	30	41	22	60	24	21	40	30	35	30	22	24
Ce	66	69	138	151	52	92	45	130	50	46	87	65	77	69	47	51
Pr	7	6	15	13	5	9	4	13	5	4	8	6	7	7	5	5
Nd	28	25	64	48	21	40	15	47	17	17	33	24	29	27	19	18
Sm	5	5	15	7	3	7	2	7	2	3	6	4	5	5	4	3
Eu	2	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1
Gd	5	4	15	6	3	7	2	6	2	3	5	5	5	5	5	3
Tb	0.00	0.00	2	1	0.00	1	0.00	1	0.00	0.00	1	1	1	1	1	0.00
Dy	3	3	15	4	2	5	1	4	1	2	4	4	5	5	7	2
Ho	0.00	0.00	3	1	0.00	1	0.00	1	0.00	0.00	1	1	1	1	2	0.00
Er	1	1	8	2	1	2	1	2	1	1	2	2	3	3	5	1
Tm	0.00	0.00	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	0.00

	Tonalite Gneiss Suite (TG)		**Granodiorite to Adamellite Gneiss suite (GAG)**													
			Tonalite-trondhjemite gneiss				Granodiorite/adamellite gneiss									
Sample	**D16**	**D-50**	**D22-1**	**D23-1**	**D27-1**	**D28-1**	**D18-1**	**D19-1**	**D20-1**	**D21-1**	**D24-1**	**D-38-1**	**D-40-1**	**D-41-1**	**D-42-1**	**D-48**
Yb	1	1	6	2	1	2	1	2	1	1	2	2	3	3	5	2
Lu	0.00	0.00	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	0.00
La/Yb	25	24	9	32	35	18	30	32	26	15	22	14	13	11	4	15
Sr/Y	58.50	48.72	4.00	11.11	4.94	10.62	44.86	15.11	73.73	14.27	11.32	6.93	18.25	7.39	3.31	16.38
Rb/Sr	0.08	0.12	0.58	0.76	0.82	0.75	0.79	0.53	0.52	0.87	0.79	1.20	0.95	0.73	1.31	1.07
K/Na	0.25	0.44	0.33	0.27	0.79	1.04	0.83	0.57	0.50	0.40	0.44	0.89	0.62	0.65	0.92	0.62

Table 15: Published data for HHD granitoids

	Pink granodiorite				Grey granodiorite			Porphyritic granodiorite					
Sample	MD21	MD4	WP1	VP2	BR14	RK7	FD2	BL2A	FN2	LF1	MD4	NT1C	ZT4
SiO_2	71.17	72.26	74.16	73.44	74.03	74.81	74.03	68.23	74.63	72.7	72.26	72.38	71.82
TiO_2	0.31	0.23	0.16	0.27	0.16	0.12	0.18	0.81	0.16	0.24	0.23	0.24	0.28
Al_2O_3	14.58	14.42	13.77	13.91	14.41	13.81	14.17	14.41	13.45	14.24	14.42	14.38	14.75
Fe_2O_3	0.91	0.49	0.47	0.3	0.25	0.04	0.51	1.42	0.12	0.58	0.49	0.51	1.87
FeO	1.3	1.11	0.72	1.29	0.86	0.81	0.71	2.6	0.95	1.06	1.11	1.11	0
MnO	0.06	0.04	0.03	0.09	0.06	0.04	0.05	0.07	0.03	0.05	0.04	0.04	0.05
MgO	0.58	0.33	0.19	0.38	0.27	0.07	0.3	1.02	0.54	0.21	0.33	0.3	1.02
CaO	1.77	1.62	1.08	1.43	1.34	1.04	1.14	2.49	0.59	1.27	1.62	1.65	1.85
Na_2O	4.26	4.34	4	4.12	4.68	4.29	3.98	4.23	3.24	4.48	4.34	4.39	3.92
K_2O	3.97	4.02	4.58	3.97	3.5	4.3	4.3	3.86	5.35	4. 15	4.02	3.97	4.09
P_2O_5	0.11	0.06	0.05	0.05	0.05	0.02	0.05	0.3	0.04	0.06	0.06	0.07	0.06
Rb	247	292	336	196	320	415	425	214	419	na	929	328	na
Sr	240	283	150	210	179	106	163	382	201	na	283	302	na

Table 15: Published data for HHD granitoids (*continue*)

	Migmatitic gneiss				Tonalite									
Sample	WK4	LF7	HD34	HD31	PV2	LN1	RP7	RK2	SK5	LP2	SB7	SB1	HD26	C
SiO_2	68.49	74.33	71.81	73.28	62.21	62.37	60.79	66.38	66.42	67.46	70.03	73.5	69.51	66.15
TiO_2	0.78	0.13	0.34	0.24	0.52	0.53	0.58	0.4	0.41	0.38	0.29	0.19	0.38	0.62
Al_2O_3	14.29	13.95	14.32	14.23	15.89	15.93	60.79	16.03	16.43	16.81	16.54	14.4	14.76	15.56
Fe_2O_3	1.42	0.21	0.85	0.45	1.45	1.42	1.54	1.17	0.98	0.52	0.49	0.26	1.08	1.36
FeO	2.54	0.91	1.38	1.14	3.38	3.42	3.59	2.3	2.27	2.23	1.44	1.04	1.65	3.42
MnO	0.06	0.05	0.06	0.05	0.1	0.1	0.11	0.07	0.06	0.06	0.06	0.04	0.07	0.08
MgO	0.93	0.09	0.51	0.29	3.43	3.56	3.52	1.89	1.73	1.17	0.43	0.21	0.83	1.94
CaO	2.34	1.09	1.84	1.46	5.64	5.58	5.27	4.3	4.33	3.3	2.55	1.72	2.69	4.65
Na_2O	4.2	4.41	4.24	4.16	3.87	3.79	4.23	4.54	4.61	5.01	6	4.6	4.23	3.9
K_2O	3.98	4.35	3.82	4.18	1.58	1.55	2.24	1.39	1.39	1.61	1.36	3.06	3.71	1.42
P_2O_5	0.28	0.02	0.12	0.04	0.27	0.27	0.28	0.09	0.13	0.09	0.09	0.03	0.12	0.21
Rb	181	434	305	349	142	130	319	na	na	na	na	na	na	na
Sr	335	168	374	219	na	na	na	na	na	na	na	na	na	na

Table 16: Published data for Nooitgedacht exposure

	Diorite-tonalite gneiss											Trondhjemite-granodiorite gneiss					Trondhjemite gneiss			
Sample	N27	N6	N24	N5	N22	N10a	N28	N9	N17	N10b	N21	N3	N11	N13	N25	N26	N2	N14	N7	N15
SiO_2	53.43	54.27	54.47	56.28	56.77	57.1	59.92	59.51	60.26	61.95	62.95	71.92	72.82	73.26	73.59	74.74	69.38	70.61	72.69	74.41
TiO_2	0.73	0.76	0.6	0.7	0.6	0.57	0.67	0.71	0.61	0.62	0.6	0.28	0.32	0.26	0.27	0.19	0.38	0.32	0.37	0.21
Al_2O_3	15.98	15.89	16.07	16.95	16.48	13.34	15.97	16.81	15.54	16.53	16.18	14.21	14.51	14.65	14.29	13.79	15.58	15.61	14.2	13.81
Fe_2O_3	1.42	1.38	1.31	1.29	0.99	1.29	1.09	1.01	1.1	0.88	0.87	0.22	0.24	0.23	0.21	0.15	0.46	0.38	0.35	0.21
FeO	7.08	6.88	6.54	6.47	4.96	6.46	5.44	5.06	5.49	4.38	4.37	1.08	1.18	1.14	1.04	0.74	2.31	1.91	1.75	1.04
MnO	0.16	0.14	0.18	0.15	0.11	0.15	0.12	0.12	0.12	0.06	0.1	0.05	0.01	0.04	0.06	0.06	0.06	0.05	0.05	0.01
MgO	6.1	5.96	6.22	4.17	5.43	7.28	4.72	3.01	4.13	2.7	2.71	0.28	0.21	0.27	0.11	0.06	0.89	0.82	1.13	0.25
CaO	8.99	8.99	9.21	7	8.08	7.97	6.89	6.15	5.94	5.81	5.12	2.42	1.69	1.76	1.49	0.9	3.11	3.07	3.17	2.47
Na_2O	3.83	3.94	3.7	4.28	4.75	3.05	4.17	4.67	4.38	4.66	4.53	7.04	6.11	6.27	5.85	4.89	6.2	5.96	5.02	6.62
K_2O	0.71	0.49	0.44	1.16	0.48	0.84	1.24	1.15	1.23	1.1	1.31	0.5	2.27	1.99	2.78	4.19	0.94	0.96	0.87	0.41
P_2O_5	0.08	0.1	0.07	0.15	0.08	0.09	0.1	0.2	0.15	0.15	0.25	0.05	0.05	0.03	0.04	0.04	0.1	0.08	0.1	0.04
Ba	98	73	61	202	249	113	166	202	182	189	55	127	388	416	436	761	237	240	253	248
Co	23	23	30	14	16	23	14	21	23	16	23	9	9	11	9	11	12	10	14	10
Cr	126	135	139	139	67	575	135	55	122	54	83	9	13	9	14	9	20	9	20	9
Cu	37	36	2	45	3	2	2	102	2	54	64	2	2	2	2	2	na	na	na	na
Nb	11	12	15	11	14	9	10	12	11	10	9	9	12	15	12	12	8	9	9	11
Ni	43	42	48	42	36	129	43	43	84	37	51	9	9	9	9	9	9	9	9	9
Rb	26	7	3	52	66	39	60	54	70	68	6	20	73	59	91	123	34	31	37	23
Sr	234	227	202	235	425	216	330	339	333	371	265	311	263	291	246	223	432	435	344	315
V	224	214	199	260	108	182	191	146	141	130	165	na	na	na	na	na	na	na	na	na
Ce	20.4	0	0	23.9	80.3	20.9	28.1	0	33.3	40.8	26.3	na	na	na	na	na	na	41.7	42.5	30.2
La	8.65	0	0	9.81	41	9.48	11.1	0	16	22	9.48	na	na	na	na	na	na	21	22.2	17.4
Nd	10.1	0	0	12.2	31.1	10.7	17.3	0	15.4	16.4	17.7	na	na	na	na	na	na	15.7	16.8	10.9
Q	0	1.24	2.09	4.01	2.59	8.54	6.56	9.37	10.4	13.41	15.41	24.77	24.89	25.01	25.73	28.19	21.3	23.92	31.34	29.46
Or	4.26	2.93	2.63	6.95	2.87	5.04	7.45	6.91	7.35	6.58	7.82	3.01	13.49	11.77	16.47	24.82	5.59	5.69	5.16	2.44
Ab	32.9	33.74	31.68	36.73	40.71	26.19	35.88	40.15	37.45	39.89	38.72	60.75	52	53.1	49.63	41.48	52.77	50.54	42.6	56.3
An	24.66	24.5	26.23	23.93	22.5	20.51	21.54	21.84	19.29	21.16	20.13	5.79	5.48	5.94	4.52	3.3	11.96	13.02	13.67	6.78

Table 17: Published data for world occurrences of TTG suites

	Adakites				**TTG**	**Kaapvaal Craton**													
						Barberton TTG									**Barberton GGM**				
	Adak-type	Piip type	Avg Adakite1	Avg Adakite 2	Avg TTG	Nelshoogte	Theespruit	Steynsdorp	Nelspruit 1	Nelspruit 2	Stolzburg	Theespruit 2	Steynsdorp 2	Kaap Valley	Dalmein	Mpageni	Salisbury	Nelspruit 1	Nelspruit 2
SiO_2	59.7	58	67.72	63.89	69.79	70.08	69.01	65.24	66.65	68.48	69.78	63.9	65.25	64.51	69.8	74.3	72.77	71.95	72.06
TiO_2	0.89	0.67	0.36	0.61	0.34	0.27	0.31	0.48	0.34	0.45	0.28	0.27	0.58	0.51	0.35	0.37	0.32	0.26	0.34
Al_2O_3	15.43	17.19	16.44	17.4	15.56	15.4	15.45	16.29	14.59	16.36	15.92	14.13	16.63	16.11	15.06	12.34	13.87	14.39	14.59
Fe_2O_3	3.75	5.33	2.72	4.68	3.12	2.02	2.13	3.02	2.11	2.45	1.94	1.79	3.48	3.95	2.27	1.95	1.89	1.77	1.75
FeO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MnO	0.04	0.08	0.06	0.08	0.05	0.03	0.03	0.05	0.04	0.04	0.05	0.03	0.05	0.06	0.06	0.04	0.04	0.03	0.02
MgO	4.76	6.38	1.06	2.47	1.18	0.93	1.29	1.9	0.77	1.14	0.56	1.04	2.08	2.71	1.07	0.37	0.66	0.52	0.59
CaO	7.48	7.12	3.71	5.23	3.19	2.72	2.81	3.87	2.51	3	2.52	2.38	4.34	4.56	2.01	1	1.86	1.68	1.68
Na_2O	3.69	3.5	4.38	4.4	4.88	5.88	7.49	6.9	8.5	6.08	6.45	6.32	6.38	6.45	5.34	7.65	5.5	6.76	4.87
K_2O	2.08	0.96	2.27	1.52	1.76	1.25	1.63	2.22	1.53	1.49	2.41	1.81	1.48	1.47	3.52	5.6	3.59	3.5	4.18
P_2O_5	0.39	0.14	0.14	0.19	0.13	0.09	0.1	0.18	0.12	0.15	0.11	0.08	0.22	0.19	0.19	0.08	0.13	0.09	0.1
Ba	32	87	1087	485	43	141	316	326	164	133	971	396	340	237	921	1022	849	615	796
Co	na	na	na	na	na	4.84	7.02	10.5	4.25	7.28	3.09	6.18	11.6	15.5	5.05	1.43	4.09	2.56	3.01
Cr	161	262	9	54	29	7.88	31.1	57.8	5.17	22.1	3.88	20.8	46.8	74.6	10.1	2.87	7.59	3.44	10.4
Cu	na	na	na	na	na	9.71	5.67	5.43	4.43	4.12	1.7	0.58	15.1	14.9	7.29	2.41	3.9	1.23	1.31
Ga	na	na	na	na	na	15.9	18.2	18.3	21.2	18.2	19.6	18.2	18.2	17.3	17.1	14	16.4	16.4	17.6
Hf	na	na	na	na	na	3.62	3.37	4.66	7.49	4.9	3.52	3.41	6.25	2.55	4.35	9.16	4.18	5.32	7.11
Mo	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Nb	na	na	13	8.3	6.4	1.99	4.71	6.95	15.8	5.87	13.08	5.85	5.89	3.76	11.7	29.2	10.5	6.57	10.1
Ni	126	127	3	39	14	6.85	39	40	7.48	12.8	11.1	34	35.5	56.3	6.88	2.25	8.1	2.88	7
Pb	na	na	na	na	na	3.46	7.18	8.43	14.7	10.5	14.9	8.23	7.04	4.71	21.7	45.8	15	13	15.2
Rb	13	9	43	30	55	41.9	49	71.4	75.3	115	68.6	60.5	54	39.1	100	169	75.5	77.2	139
Sc	na	na	na	na	na	1.54	3.28	5.75	0.81	3.68	2.27	3.25	6.32	8.11	3.44	2.52	4.08	2.17	2.64
Sr	2366	384	1123	869	454	528	590	558	835	523	638	541	616	572	593	329	448	266	291
Ta	na	na	na	na	na	0.13	0.39	0.86	1.45	0.45	0.87	0.6	0.38	0.24	0.9	1.94	0.74	0.12	0.54
Th	2.88	0.6	6.5	3.52	6.9	2.55	2.91	2.51	15.7	4.25	3.84	3.77	2.39	1.71	13.4	27.8	7.59	8.46	11.2
U	0.97	0.28	2.5	0.99	1.6	0.51	0.96	1.47	3.24	3.96	3.83	1.04	1.25	0.47	2.28	5.08	1.65	0.39	1.49
V	na	na	na	na		22.4	22.1	42.3	20.6	36	15.2	21.3	50.4	75.7	29.1	9.71	24.3	11.8	19.4
W	na	na	na	na		0.03	0.08	0.02	0.26	0.03	0.01	0.06	0.04	0.06	0.1	0.62	0.05	0.04	0.13
Y	na	18	15	9.5	7.5	2.67	5.89	12.7	10.1	7.46	6	7.73	10.8	9	17.2	37.8	15.7	6.5	18.9
Zn	na	na	na	na		31.8	50	57.6	63.5	61.7	83.6	50.1	57.4	54.7	64.5	31.8	46.6	45.1	40.5
Zr	na	na	73	117	152	158	136	219	279	233	132	133	303	103	182	407	159	203	282
Ce	70.9	15.1	50.9	34.65		42.8	23.2	22.4	131	48.5	49	28.4	32	31.7	137	496	85.7	87.8	144
La	30.3	6.27	29.7	17.55	17.55	22.8	12.7	11	86.5	27	24.5	15.5	16.6	14.8	69.8	271	41.7	44.1	72.9
Nd	39.8		20.7	20.14	21.4	14.7	9.99	11.5	32.4	16.2	20.9	12.3	15.4	15.1	49.8	136	33.3	32.1	49.3
Sm	6.85	1.94	3.2	3.15	3.3	1.89	2.01	2.65	3.9	2.5	3.46	2.59	3.21	2.99	7.8	17.9	5.64	5.36	7.64
Eu	1.74	0.65	0.95	0.97	0.92	0.56	0.64	0.91	0.86	0.7	0.86	0.66	1.05	0.96	1.79	2.45	1.28	1.06	1.23
Yb	0.62	1.42	0.46	0.91	0.55	0.29	0.52	1.48	1.19	0.72	0.45	0.62	1	0.8	1.5	3.37	1.35	0.49	1.9
La/Yb	48.87	4.42	64.57	19.28	58.00	78.62	24.42	7.43	72.69	37.50	54.44	25.00	16.60	18.50	46.53	80.42	30.89	90.00	38.37

Table 17: Published data for world occurrences of TTG suites (continue)

	Dhawar Craton													
	Closepet type granite			Closepet Migmatite gneiss		Closepet Monzogranite			Closepet Monzonite			Closepet Pink granite		
	Avg	J15	J29	Avg Mig	Avg Gneiss	Avg	CG5	J39	Avg	CG9	CG40	Avg	J2	J57
SiO_2	70.93	67.33	74.27	74.03	73.15	64.8	62.03	67.97	55.12	50.3	60.55	73.83	70.51	76.52
TiO_2	0.4	0.52	0.26	0.35	0.25	0.7	0.8	0.69	1.4	2.87	1.02	0.2	0.26	0.08
Al_2O_3	15	16.21	13.99	13.31	14.71	15.75	16.51	14.85	16.28	13.84	15.7	14.2	15.03	13.53
Fe_2O_3	-	-	-	-	-	-	-	-	9.64	14.2	6.98	1.65	2.7	1.06
FeO	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MnO	0.04	0.03	0.02	0.04	0.07	0.07	0.1	0.06	0.13	0.14	0.14	0.02	0.02	0.01
MgO	0.54	0.81	0.16	0.42	0.64	1.51	1.92	1	3.42	4.05	3.06	0.22	0.11	0.17
CaO	1.96	2.91	1.56	1.7	2.26	3.34	3.39	2.81	5.79	7.7	4.6	1.45	1.69	1.16
Na_2O	3.93	4.76	3.65	3.5	5.02	4.2	4.16	4.24	3.99	3.08	3.97	3.54	3.72	2.8
K_2O	4.39	3.19	5.01	3.99	1.52	3.93	4.15	3.95	3.27	1.8	3.42	4.82	5.79	4.63
P_2O_5	0.11	0.13	0.07	0.09	0.21	0.36	0.47	0.26	0.97	2.01	0.56	0.07	0.17	0.04
Ba	751	1135	923	na	na	986	294	306	1485	812	884	873	1512	795
Co	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Cr	101	115	72	na	na	127		119	239			82	109	
Cu	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Ga	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Hf	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Mo	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Nb	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Ni	5	3	3	na	na	11	15	7	26	46	20	3	3	
Pb	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Rb	144	117	134	na	na	106	98	119	94	50	110	129	124	140
Sc	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Sr	355	766	391	na	na	684	882	527	1161	840	654	321	504	254
Ta	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Th	na	na	na	na	na	na	na	na	na	na	na	na	na	na
U	na	na	na	na	na	na	na	na	na	na	na	na	na	na
V	30	46	15	na	na	64	80	45	138	223	103	15	26	
W	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Y	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Zn	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Zr	263	304	127	na	na	265	294	306	na	na	na	131	145	59
Ce	na	na	na	na	na	na	na	na	na	na	na	na	na	na
La	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Nd	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Sm	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Eu	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Yb	na	na	na	na	na	na	na	na	na	na	na	na	na	na
La/Yb	na	na	na	na	na	na	na	na	na	na	na	na	na	na

Table 17: Published data for world occurrences of TTG suites (*Continue*)

	Pilbara Craton															
	High-Mg diorite															
	142260	142257	142259	142260	142262	142306	118967	141965	141966	141967	141927	141964	142346	142347	142348	142349
SiO_2	61.86	64.22	61.88	61.86	65.95	64.54	61.47	64.25	63.15	63.09	69.46	65.26	62.8	59.33	63.7	65.66
TiO_2	0.51	0.39	0.56	0.51	0.39	0.53	0.57	0.51	0.54	0.55	0.34	0.44	0.55	0.63	0.55	0.49
Al_2O_3	14.48	15.68	14.77	14.48	15.05	14.79	14.79	14.76	14.38	14.35	14.78	14.41	14.76	14.03	14.19	14.03
Fe_2O_3	6.34	4.17	6.31	6.34	4.39	5.37	6.92	5.56	6.15	5.95	2.86	5.41	6.19	8.38	6.38	5.92
FeO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MnO	0.08	0.06	0.09	0.08	0.06	0.08	0.07	0.07	0.07	0.07	0.03	0.07	0.08	0.11	0.08	0.07
MgO	4.17	3.41	3.36	4.17	2.31	2.53	3.72	3.37	2.96	3.21	1.04	2.07	3.5	5.33	3.43	2.95
CaO	4.67	4.81	4.83	4.67	3.53	3.19	4.67	3.71	4.18	4.31	2.31	3.58	4.34	5.49	3.42	3.56
Na_2O	3.91	4.12	3.94	3.91	4.32	4.19	3.67	4.05	4.05	4	4.83	4.28	4.01	3.64	3.78	3.76
K_2O	1.8	1.24	2.02	1.8	2.11	2.53	2.16	2.47	2.17	2.22	2.82	2.45	2.76	2.37	2.95	2.76
P_2O_5	0.24	0.13	0.28	0.24	0.16	0.24	0.27	0.28	0.32	0.29	0.15	0.23	0.34	0.43	0.23	0.24
Ba	695	441	808	695	700	1598	1067	1007	930	794	962	915	1194	1012	1174	1059
Co	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Cr	na	136	116	215	98	67	170	94	135	135	28	78	124	224	136	114
Cu	na	24	40	30	20	6	28	35	19	37	13	22	8	40	14	16
Ga	na	16.9	17.7	17	17.2	18	16.6	18.7	18.5	18.2	20.6	17.4	17.2	17.5	17.1	16.3
Hf	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Mo	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Nb	5.3	3.7	6.3	5.3	5.1	7	6.7	7.4	6.7	6.7	6.7	6.5	8.4	8.3	8.4	8.2
Ni	99	64	56	99	49	17	89	41	54	59	14	33	66	120	66	54
Pb	na	5	17	14.5	17	22	17	19.5	18.5	18.5	26.5	23.5	25.4	23.1	20.3	21.4
Rb	81	53	88	81	94	85	98	114	98	99	107	99	124	106	123	99
Sc	na	13	14	12	8	11	11	9.5	10	12	4	7.5	12	14	14	10
Sr	523	369	522	523	412	947	499	525	546	480	504	512	645	632	497	446
Ta	na	0.5	0.5	0.5	0.5		0.8	0.8	0.4	0.5	0.6	0.5	na	na	na	na
Th	9.3	5	11.2	9.3	10.2	13.4	8.1	12.3	9.3	11.1	13.2	11.9	15	13	13	18
U	3.3	1	2.6	3.3	2.3	2.6	1.7	3	1.9	3	3.7	3.2	2	3	2	2
V	na	85	106	98	63	71	99	78	90	88	31	61	84	104	82	68
W	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Y	215	9.4	18.5	15.2	10.9	16	15	13.3	13.8	14.6	8.3	11.8	17.4	19.8	15.5	14.6
Zn	na	46	75	73	58	66	78	76	77	81	63	67	70	79	70	61
Zr	130	98	136	130	122	141	155	166	150	151	187	158	164	145	147	139
Ce	76.7	32.3	93.3	76.7	62.4	108	90	102.9	96	91.7	87.5	89.3	119	130.2	71.2	107.2
La	39.7	17.8	47.4	39.7	34.6	53	47.1	54.5	50.8	46.7	47.7	47.4	58.6	61.6	32.8	57.2
Nd	32.7	13.1	39.9	32.7	23	33	36.8	38.6	37.7	35.2	29.8	32.7	58.4	63.7	41.1	43.4
Sm	5.4	2.4	6.9	5.4	3.7	na	5.8	5.8	6	5.8	4.4	5	na	na	na	na
Eu	1.4	0.7	1.8	1.4	1	na	1.6	1.5	1.6	1.6	1.1	1.4	na	na	na	na
Yb	0.2	0.8	1.4	1.2	0.9	na	1.3	1	1	1.1	0.6	0.9	na	na	na	na
La/Yb	33.08	22.25	33.86	33.08	38.44	na	36.23	54.50	50.80	42.45	79.50	52.67	na	na	na	na

Table 17: Published data for world occurrences of TTG suites (*continue*)

	Superior Province		**Central Kaapvaal Craton**								
	High-Mg diorite		**Vredefort Biotite-granodiorite**			**Vredefort Granodiorite**			**Vredefort Granite-gneiss**		
	Avg 1	Avg 2	KK244	KK242	KK239	KK47	KK44	KK43	KK52	KK50	KK48
SiO_2	56.07	57.36	67.48	68.42	67.26	67.38	71.55	66.85	72.16	70.73	74.06
TiO_2	0.71	0.06	0.54	0.47	0.62	0.61	0.24	0.52	0.31	0.27	0.08
Al_2O_3	14.88	16.32	15.25	15.53	15.36	16.07	14.78	16.77	14.73	15.23	14.76
Fe_2O_3	7.88	6.34	3.66	3.17	3.64	3.2	1.68	3.08	1.74	1.92	0.75
FeO	-	-	-	-	-	-	-	-	-	-	-
MnO	0.12	0.10	na	na	na	na	na	na	na	na	na
MgO	6.85	4.61	0.79	0.69	0.85	0.89	1.07	1.34	1.02	1.31	0.19
CaO	7.65	6.39	2.59	2.33	2.63	2.38	1.59	2.5	0.94	1.48	1.12
Na_2O	4.04	5.25	5.01	4.07	4.3	4.78	4.1	4.67	3.87	4.74	4.34
K_2O	2.23	2.02	2.68	3.17	2.92	3.25	4.01	2.98	4.5	3.23	4.02
P_2O_5	0.36	0.37	na	na	na	na	na	na	na	na	na
Ba	1214		887	1448	1521	1751	1153	1248	495	675	599
Co	na	na	6.68	6.29	7.17	6.9	1.6	7.69	2.74	2.85	0.95
Cr	97	150	na	na	na	na	na	na	na	na	na
Cu	na	na	na	na	na	na	na	na	na	na	na
Ga	na	na	na	na	na	na	na	na	na	na	na
Hf	na	na	5.62	7.9	5.65	6.53	3.41	6.81	3.2	3.87	1.57
Mo	na	na	na	na	na	na	na	na	na	na	na
Nb	na	na	na	na	na	na	na	na	na	na	na
Ni	154	55	na	na	na	na	na	na	na	na	na
Pb	na	na	na	na	na	na	na	na	na	na	na
Rb	60	34	59	74	67	68	64	88	161	94	70
Sc	na	na	3.48	2.76	5.65	4.65	1.6	3.57	19.66	2.46	0.61
Sr	1229	1371	569	661	783	765	431	640	323	414	217
Ta	na	na	0.13	0.08	0.19	0.26	0.13	0.25	1.22	0.55	0.01
Th	na	na	15.99	36.68	13.89	1.76	4.05	5.5	27.68	9.04	3.03
U	na	na	0.35	0.1	0.17	0.18	0.37	0.18	2.39	0.83	0.1
V	na	na	na	na	na	na	na	na	na	na	na
W	na	na	na	na	na	na	na	na	na	na	na
Y	na	11	na	na	na	na	na	na	na	na	na
Zn	na		na	na	na	na	na	na	na	na	na
Zr	111	123	233	279	226	256	125	269	146	137	53
Ce	97	98	108.4	108.8	97.3	71.3	39.1	98.2	88.3	93.1	18.2
La	na	43	78.4	98.3	82.4	46.8	26.8	71.3	65.4	73.7	20.4
Nd	na	50	47.8	43.4	42.4	33.4	14.2	44.2	32.8	38	12
Sm	na	8.55	7.52	5.57	6.74	4.89	2.59	5.76	7.82	6.39	1.34
Eu	na	2.25	1.44	1.16	1.53	1.89	0.99	1.22	0.89	1.14	0.92
Yb	1.6	0.93	0.88	0.51	0.77	0.76	0.52	0.75	2.73	1.18	0.22
La/Yb	na	46.51	89.09	192.75	107.01	61.58	51.54	95.07	23.96	62.46	92.73

Table 17: Published data for world occurrences of TTG suites (*continue*)

	Zimbabwe Craton								
	Tonalite Trondhjemite- Na granites			**High-Mg diorite**			**High K granite suite**		
	MKQ1	TS82	TS70	AR128	AR234	AR245	MK54	MK108	MK49
SiO_2	74	74.39	74.46	52.4	53.1	56.5	70.73	71.86	74.27
TiO_2	0.13	0.08	0.26	0.52	0.36	0.36	0.28	0.22	0.01
Al_2O_3	14.09	13.53	10.94	14.3	17.3	17.2	13.57	13.11	12.6
Fe_2O_3	1.37	1.36	3.96	0.98	0.59	0.58	2.25	1.84	0.45
FeO	-	-	-	7.9	4.78	4.66	-	-	-
MnO	0.02	0.04	0.06	0.17	0.08	0.08	0.04	0.02	0.01
MgO	0.27	0.2	0.12	7.39	7.74	7.74	0.55	0.47	0.05
CaO	2.01	1.28	1.11	7.76	6.66	6.66	1.66	1.71	0.44
Na_2O	4.32	4.4	4.14	3.82	2.42	2.42	3.65	4.07	2.53
K_2O	3.09	3.04	2.22	0.2	2.31	2.31	4.51	4.17	7.7
P_2O_5	0.01	0.03	0.11	0.14	0.04	0.14	0.08	0.07	0.01
Ba	570	751	984	27	490	504	966	838	1835
Co	19	9	15.5				13.5	14	26.5
Cr	5	4	5	234	188	194	8	7	6
Cu	5	5	5	16	53	53	5	5	5
Ga	-	-	-	-	-	-	-	-	-
Hf	-	-	-	-	-	-	-	-	-
Mo	-	-	-	-	-	-	-	-	-
Nb	9	5	4	3	4	5	10	12	2
Ni	3	7	3	81	340	339	2	2	1
Pb	5	15	4		16	16	18	15	6
Rb	99.2	86	48	2	115	116	149	172	202
Sc	-	-	-	-	-	-	-	-	-
Sr	168	128	75	151	251	252	180	189	280
Ta	8.5	3	6	0.1	0.76	0.75	4	5.5	8.5
Th	4	3	6	1	20	18	25	22	1
U	7	2.5	3	0.3	6	5	7.5	8	0.5
V	5	5	5	248	76	73	20	15	5
W	-	-	-	-	-	-	-	-	-
Y	9	6	35.5	19	7	6	16.5	9.5	3.5
Zn	45	40	40	51	56	56	50	55	5
Zr	94	43	292	45	108	111	222	182	25
Ce	35	24	64	7.89	46.66	44.77	142	122	15
La	21.5	13	32	3.3	24.13	23.8	76.5	69.5	9
Nd	12.5	11	27.5	5.04	19.3	18.48	47	42	5.5
Sm	2.3	2.1	5.9	1.56	3.41	3.37	7.9	6.1	1.8
Eu	0.8	0.5	1.1	0.5	0.74	0.77	0.8	0.8	0.6
Yb	0.8	0.4	4	1.68	0.75	0.75	1.4	0.7	-
La/Yb	-	-	-	-	-	-	-	-	-

APPENDIX D